Landscape Research
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713437121

A Wildland-Urban Interface Typology for Forest Fire Risk Management in Mediterranean Areas

Luis Galiana-Martin[a]; Gema Herrero[b]; Jesus Solana[b]
[a] Geography, Autonomous University of Madrid, Spain [b] Regional Geography and Physical Geography, Complutensian University of Madrid, Spain

Online publication date: 17 March 2011

To cite this Article Galiana-Martin, Luis , Herrero, Gema and Solana, Jesus(2011) 'A Wildland-Urban Interface Typology for Forest Fire Risk Management in Mediterranean Areas', Landscape Research, 36: 2, 151 — 171
To link to this Article: DOI: 10.1080/01426397.2010.549218
URL: http://dx.doi.org/10.1080/01426397.2010.549218

Landscape Research,
Vol. 36, No. 2, 151–171, April 2011

Routledge
Taylor & Francis Group

A Wildland–Urban Interface Typology for Forest Fire Risk Management in Mediterranean Areas

LUIS GALIANA-MARTIN*, GEMA HERRERO** & JESUS SOLANA**
*Geography, Autonomous University of Madrid, Spain **Regional Geography and Physical Geography, Complutensian University of Madrid, Spain

ABSTRACT *The transitional areas that lie between wildlands and urbanized spaces, generally defined as wildland–urban interfaces (WUI), represent an increasing risk factor in Mediterranean areas; these define a new scenario in forest fire fighting and prevention. We have developed a methodological approach in order to assess the hazard and vulnerability of WUI which is based on landscape analysis, on the use of Geographic Information Systems (GIS) techniques and remote sensing. Unlike traditional approaches which are based on local scale characterization of WUI, we propose a progressive multi-scale approach. In order to reach an operative classification of the WUI the methodology was developed in three stages: a regional urban development model, a landscape character assessment and finally, a WUI typology. The last WUI typology has been based on the identification of different urban morphologies and their context within the type of landscape in which they occur.*

KEY WORDS: Landscape analysis, wildland–urban interface, landscape character, spatial planning, fire risk, GIS, Sierra Calderona

1. Introduction

Sierra Calderona lies in the Valencia region in Spain and constitutes one of the easternmost foothills of the Iberian System, between the rivers Turia and Palancia. The social, economic and ecological situation in Sierra Calderona is similar to that found in other mountain areas along the Spanish Mediterranean coast. These mountain regions are subject to intense spatial pressures that are causing profound changes in their functions, spatial organization and landscapes (Pascual Aguilar, 2003, 2004; Burriel & Salom, 2002). These areas can be understood as transitional: there is growing suburbanization, abandonment of the traditional rural lifestyles, a reduction in traditional agrarian activities and increasing cultivation of new crops. In addition, secondary natural vegetation is advancing and a powerful impact from large forest fires can be seen. The transitional areas between urban and wildland masses are of special interest and consideration in forest fire risk management because of the high frequency

Correspondence Address: Luis Galiana-Martin, Autonomous University of Madrid, Geography, C/ Francisco Tomás y Valiente, 1, Madrid 28007, Spain. Email: luis.galiana@uam.es

ISSN 0142-6397 Print/1469-9710 Online/11/020151-21
DOI: 10.1080/01426397.2010.549218

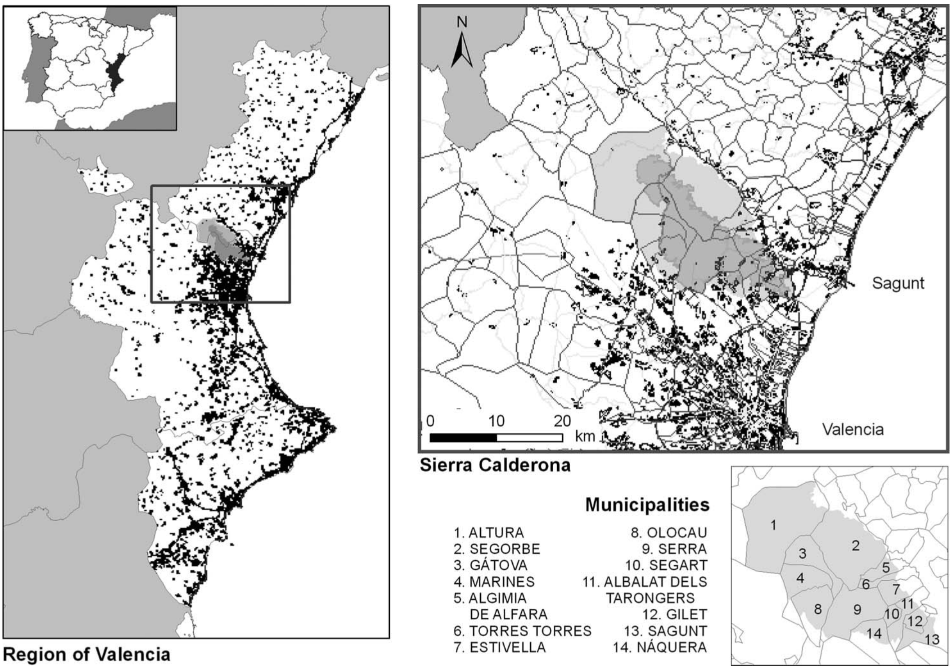


Figure 1. The location of study area.
Source: Conselleria de Medi Ambient, Aigua, Urbanisme i Habitatge (Generalitat Valenciana) (own elaboration).

of wildland fires and the high potential these have for disastrous consequences economically and in landscape terms (Urios Moliner, 2004; Vince *et al*., 2005).

In Western European countries, North America and Australia, increasing attention is being given to the wildland–urban interface (WUI), defined as a system of sites with a marked tendency towards dispersed housing development and proximity to wildland areas (Davis, 1990; Radeloff *et al*., 2005; Theobald & Romme, 2007). New conflicts arise and environmental management of these areas is affected as a result of the changes occurring in the landscapes including fragmentation of habitats, the introduction of exotic species, and water supply difficulties (Radeloff *et al*., 2005). In Mediterranean ecosystems one of the most obvious problems is the fire that threatens lives and properties at the WUI. To reduce this vulnerability, fire suppression services increase the protection provided in these areas at the expense of their capability to suppress large fires in the wildlands themselves. Moreover, as the WUI areas expand the chances of wildfires in all these areas increases.

This new scenario in forest fire management requires special training for fire suppression services (Davis, 1990), a strong campaign to raise awareness of the issues within the resident population (Beringer, 2000), and fire prevention measures based on decreasing combustible biomass (Winter & Fried, 2000). Furthermore, development of residential housing projects in high fire risk wildland areas needs to be done cautiously through responsible planning, zoning and growth management and appropriate patterns of land use that might help to mitigate potential fire-related disasters (Myszewski & Kundell, 2005). In this context, an accurate characterization of WUIs that takes into account the transversal nature of interface issues and the need for interdisciplinary approaches to understand issues such as the impact of demographic trends, changing land-use patterns, forest ecosystem management and economic development is seen as the key to managing fire-hazard situations efficiently at the WUI (Hermansen & Macie, 2005).

The description and classification of WUIs commonly begins with the assessment of two main characteristics: intensity of human presence (density and number of dwellings, density of population, accessibility, infrastructures) and the vegetation present (degree and continuity of vegetation, specific composition, structure, etc.) (Radeloff *et al.*, 2005; Lampin *et al.*, 2006; Lampin-Maillet *et al.*, 2010). This information is generally obtained from large-scale maps (1:10 000 to 1:25 000) and high-resolution satellite images processed by remote sensing techniques and Geographical Information Systems (Camia *et al.*, 2004). Internationally, there have been attempts to characterize and map WUIs using a variety of data sources and criteria depending on the final objectives of the projects (e.g. geographic description, risk assessment). Although there are studies at the national level (Radeloff *et al.*, 2005), in most cases the analysis in WUI studies focuses mainly on the local level (Lampin *et al.*, 2006; Lampin-Maillet *et al.*, 2010). Indeed, much research focuses on the site/house level, and involves assessing the potential fire risk and the vulnerability to fire damage of structures (Caballero, 2004; Cohen & Saveland, 1995; Cohen, 1999) and the vegetation generally found around houses.

We believe that use of local-scale methods alone is insufficient in studies that aim to address the issues that this situation raises. The process of WUI expansion is associated with counter-urbanization and the development of second home dynamics which respond to spatial organizational models on an urban–regional scale (Antrop, 2004). In addition, the existing landscape pattern exerts an influence over land cover and land use development, and ultimately on the pattern of new residential development. Fire behaviour is largely dependent on the landscape pattern. Thus, it is appropriate to use landscape character assessment methods developed at an intermediate scale between local and regional levels (Bürgi *et al.*, 2004). We suggest that the local scale of analysis must be complemented by a more general approach. The suitable working scale for wildfire protection at the WUI should cover both the regional scale for planning and the local scale where implementation of fire prevention management and planning will take place (Caballero, 2004).

In this paper we present a method for the identification and characterization of WUIs. This method provides a WUI classification based on hazard and vulnerability standards that are considered suitable for risk management and assessment on a scale (1:5000–1:10 000) appropriate for wildfire risk mapping in spatial and sectoral planning (Fleischhauer *et al.*, 2007). It is envisaged that the results of using this analysis method will be to help fire managers develop appropriate adaptation and mitigating actions such as the demarcation of high risk perimeters in order to regulate uses and activities in the interior, and preventive treatments to reduce combustible biomass in especially sensitive areas. In addition, useful information could be obtained to help the design of fire fighting strategies and ensure more appropriate distribution of fire fighting resources to the most vulnerable areas.

2. Landscape Context and Study Methodology

The study focused on Sierra Calderona in Spain. The alignment of this mountain system is in a NW–SE direction; the range is of moderate altitude, descending progressively from 1000 m on the western side (Montmajor) until it merges with the coastal plain towards the east. The composition is mainly of calcareous and dolomite materials from the Jurassic age. However, in the central area Triassic materials are found: red sandstones that articulate the principal mountain crests and introduce a marked lithological contrast with their surroundings. The presence of these sandstones leads to the emergence of the siliculose species (corn oak) which is of special interest due to its uniqueness in the region (Crespo Villalba, 1990; García Fayos, 1991).

The WUI characterization has been developed from an analysis carried out at different scales (regional to local) and an analysis of the interactions between the scales, that is, a multiscale analysis. Given the need for hazard and vulnerability assessment at a range of scales, the methodology developed here for a classification of WUIs was developed in four stages (Table 1). These stages correspond to a regional geographical analysis on three scales, from the most general to the most detailed. The objective of the multiscale analysis was identification of the different spatial processes acting in each of the scales defined, and their influence in the WUI characterization. These scale frameworks are not rigid but can overlap with each other in such a way that the processes identified at the smaller scale are integrated into those in the frameworks at the larger scale.

2.1. Regional Urban Development Model and Land Use and Land Cover Changes in Sierra Calderona

At the regional level, the objective of the analysis was the establishment of a descriptive model of the main territorial dynamics influencing the area (suburbanization, abandonment and transformation of the rural areas, wildfires) and definition of its main spatial patterns. The model was based on the analysis of structural (distribution of land uses) and functional elements. The results from this method informed the landscape character assessment discussed in section 2.2.

An initial study identified the territorial changes in the Sierra Calderona region. The study consisted of the cartographic representation of synthetic indices relating to the demographic dynamic, the evolution of real estate, and the forced mobility of the population (commuting between place of residence and place of study/work). Results indicated the extent to which the study area has become incorporated into the dynamics of the metropolitan city of Valencia and allowed an assessment of the demographic and functional decline in rural areas.

The land cover cartography provided by the CORINE project was the basis for the landscape dynamic analysis in the study area. The land cover for 1987 and 2000[1] as well as the changes registered between these dates were mapped. Only those variations with a surface larger than 25 ha were reflected on the maps. This means that only the greatest of the surface dynamics were recorded rather than the diffuse tendencies of lesser spatial impacts. Additionally, because of the importance of

Table 1. Methodology developed to attain the WUI classification in the case study area

Step 1	Literature review: Sierra Calderona in the development and evolution process of the metropolitan area of Valencia				**STAGE 1, REGIONAL URBAN DEVELOPMENT MODEL**
Step 2	Desk study (land cover data from CORINE LAND COVER 1990–2000; statistical information: demography, commuting, building development)				
	Land cover map (1990 & 2000); Land cover dynamics map (1990–2000)	Demographic trends 1991–2005 (analysis at the municipal scale)	Housing dynamics (1991–2001) (analysis at the municipal scale)	Commuting analysis	
Step 3	Establishment of the Urban–Regional development model and definition of the principal territorial dynamics				
Step 4	Defining the scope				**STAGE 2, LANDSCAPE CHARACTER ASSESSMENT**
Step 5	Desk study (Land cover data from CORINE 2000; Topographical map 1:10 000; Geological maps 1:50 000; literature review, forest fires historic analysis, etc.)				
	Natural factors: geology, landform, river and drainage systems, land cover, etc.		Cultural/social factors: land use, settlement pattern, patterns of field enclosure, etc.		
	Production of different map overlays				
	Combining map overlays (GIS): identify draft landscape character units and types				
Step 6	Field survey (structured fieldwork, informal interviews, photographs, etc.): complement desk study, verify and amend draft landscape character units and types				
Step 7	Classification and description of landscape character				
	Map of landscape character units and types (areas of distinct common character, and grouping areas of similar character together)		Description of landscape character units and types	Identify characteristics and main forces of change	
Step 8	Classification and description of different morphologies defined by urban development processes (Ortophotographs and Topographical map 1:10 000; Field survey)				**STAGE 3, WUI CHARACTERIZATION**
Step 9	Classification linking urban morphologies and landscape character				
Step 10	Characterization of the interfaces according to the building density and the vegetation aggregation index				
Step 11	Patterns definition and vulnerability assessment				**STAGE 4, WUI TYPOLOGY**
	Internal (building density–vegetation continuity)		External (structural forest fire hazard of the landscape unit in which it is located)		
Step 12	WUI classification according vulnerability				

wildfires in the area, the spatial fire distribution in recent years was mapped to evaluate land use changes due to wildfires (Table 2).

2.2. Landscape Character Assessment and Spatial Context at the Intermediate Scale

The purpose is to correlate urbanization processes with the type of landscape in which they occur and with the evolution of foreseeable risk in these areas. An exercise was carried out consisting of the description, mapping and taxonomic classification of the landscapes defined (units and types of landscape). Each unit was defined by its internal homogeneity (distinct, recognizable and consistent common character), and its differences with respect to the adjoining landscapes. Each type derives from grouping areas of similar character together. The types therefore provide a synthetic reading of the large landscape configurations and of the principal dynamics.

This exercise was conducted in accordance with the principles of the methodology developed by the Countryside Agency and Scottish Natural Heritage (2002) and takes into account the elements of the natural and cultural patterns of the landscapes, and their organization and dynamics.

2.3. Characterization of Wildland–Urban Interface Classes for Management at the Local Scale

The characterization of WUI classes was performed by defining the urban developments in the area and describing these developments in relation to the landscape types/units within which they are located. This characterization is related to the building density and the vegetation aggregation within the interface.

Table 2. Fires and surface burnt at landscape types and units in Sierra Calderona (1993–2006)

Landscape type	Landscape units	Area (ha)	No. fires	Surface burnt (ha)	% Landscape unit area
I	1	4929.78	7	573.92	11.64
	2	3390.31	12	2113.90	62.35
II	3	1454.77	9	4.48	0.31
	4	225.53	1	0.00	0.00
	5	343.95	3	0.03	0.01
III	6	8484.34	22	1787.10	21.06
	7	6004.23	33	231.08	3.85
	8	5508.73	43	601.59	10.92
IV	9	8745.43	21	2266.47	25.92
	10	1677.36	7	8.72	0.52
	11	859.39	3	2.20	0.26
V	12	2217.06	5	14.51	0.65
	13	945.67	3	22.20	2.35
Total		44 786.56	169	7626.21	17.03

Source: Official Spanish wildfires database and cartography of forest fires (Ministry of Environment, Rural and Maritime affairs).

To accomplish the characterization the types of settlement were determined according to their morphology. Therefore, to systematize their identification and cartography, the variables relating to the distance between the houses and area of the settlement were associated with a particular type of settlement through aggregation of single houses. The settlements were then mapped. A relation matrix was established between the two factors, type of landscape and morphology of settlement resulting in 12 possible combinations (Table 4a).

These 12 combinations were further characterized by combining the spatial aggregation of vegetation and housing density (Lampin-Maillet *et al.*, 2010) (Table 4b). Housing density was estimated from house cartography developed in the previous step (Table 4a). A landscape metrics calculation was used to assess the aggregation of vegetation. The aggregation index (AI) of the vegetation is used as a metric to characterize the horizontal structure of vegetation; AI allows the quantification of the landscape configuration which is related to fire behaviour. In order to do this a vegetation layer was extracted from a detailed land cover map. A 2.5 m resolution SPOT 5 image was processed and the aggregation index was calculated on the vegetation layer using the FragStat software[2].

2.4. Wildland–Urban Interface Typology Associated with Forest Fire Vulnerability

The additional characterization of the 12 possible combinations by vegetation and housing density resulted in a reduction in possible combinations from 12 to nine WUI classes. The final WUI type classification was achieved by relating the nine classes with a value based on vulnerability to forest fires. This value resulted from the combination of an *internal vulnerability* defined by the characteristics of the interface itself, and an *external vulnerability* defined by the characteristics of the landscape unit location. In this context, vulnerability was understood as a characteristic or territorial attribute, that is, the propensity to damage as a result of the occurrence of a certain phenomenon. It has an intrinsic component associated with the effects of fire on the affected property value, the potential for repair (fragility), and an external component linked to fire characteristics.

The internal vulnerability was calculated by assigning values of vulnerability to the nine WUI classes described in the WUI characterization (Table 4b). The calculation was processed for each interface, defining the WUI boundary as a 100 m buffer surrounding the corresponding mapped settlement. The external vulnerability calculation is based on the 'forest fire structural hazard' (Junta de Andalucía, 2003), which correlates to fire fuel and terrain slope (Table 4c). This parameter resulted from processing fuel models and topographic maps for each landscape unit.

3. Results and Discussion

The multiscale geographical analysis developed for the characterization of WUIs enabled the establishment of the main territorial dynamics within which these transition areas are framed and which impact directly on their spatial diffusion processes. Using the regional urban models the main processes of land use changes detected (increased urbanization, farm abandonment and progression of natural vegetation, increase in certain crops) were contextualized allowing for predictions regarding their evolution to be made. This method was also used to characterize the distribution of recent forest fires (Figure 2). The subsequent landscape characterization highlighted the dynamic aspects of the WUIs in a more detailed way, giving special attention to the different rural areas with respect to observed land use change processes. This led to a WUI characterization that reflected more closely the final objective of risk mapping.

3.1. Regional Urban Development Model and Land Use Changes in Sierra Calderona

In contrast with the adjacent landscapes that consist of agricultural plains and their intensive citrus plantations, Sierra Calderona is predominantly a wildland environment that is now suffering a progressive reduction in its cultivated surface area (almond and carob trees). The Sierra's proximity to the Valencia metropolitan area (to which functionally it now belongs) means that there are strong urbanizing pressures on the southern and eastern sectors of the area. It should be noted that the main thrust behind the declaration of the Sierra as a Natural Park in 2002 was to

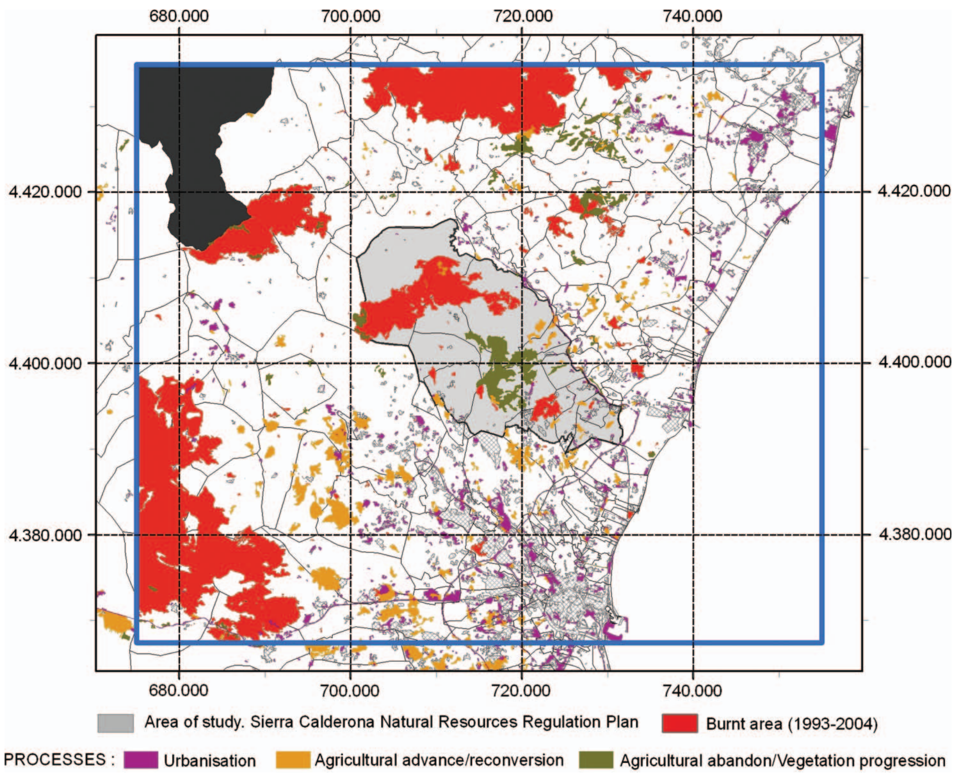


Figure 2. Land use changes between 1990 and 2000 and area burnt between 1993 and 2004. *Source*: Conselleria de Medi Ambient, Aigua, Urbanisme i Habitatge (Generalitat Valenciana) and CORINE Land Cover Project (own elaboration).

preserve its natural values against the growing presence of residential urban development.

It should be highlighted that there is an important risk factor for residential uses associated with the growing frequency and destructiveness of forest fires in this environment as measured by the number of fires and the surface area burned (Figure 2). The hazard of its vegetative cover is related to climatic factors, together with its floristic composition and the vegetation structure. However, the hazard is especially related to an increase in biomass and its spatial continuity. This continuity is caused by the abandonment of agricultural areas recolonized by natural vegetation, a reduction in traditional wildland area exploitation (firewood, pastures, charcoal), and a change in wildland management from wood/timber production to recreational activities that do not allow for effective control of the dangerous accumulation of fuels (Urios Moliner, 2004). The expansion of residential houses in forested areas increases their already high vulnerability to wildfires.

The two areas presently most affected by forest fires are the Western *Muelas* (Landscape Type I) and the forested slopes (Landscape Type III). In the first area, there is an important incidence of large fires caused by the high probability of fire propagation on the eastern slopes when westerly winds blow. In the more urbanized second area, there is a high incidence of fires starting (Table 2).

Municipal statistics show that many of the municipalities in Sierra Calderona are fully linked to the Valencia metropolitan area. The area's high population growth rates can possibly only be explained by intra-metropolitan residential migration. The area has also experienced a steep rise in the number of dwellings built over the last few years, and the growing importance of daily back-and-forth movements.

The cartographic and statistical analysis shows that three major territorial processes explain the most recent land cover dynamics:

a) The suburbanization of environments most directly influenced by the city of Valencia. The initial urbanization process in the Sierra is related to the growth of the second home market, especially in the municipalities of Náquera and Serra. This trend accelerated during the 1970s and 1980s with large developments in the municipalities of Albalat dels Tarongers, Segart and Gilet (Miranda Montero, 1985; Pascual Aguilar, 2004). Between 1990 and 2000 throughout much of Spain the urban encroachment slowed. However, in this area it intensified along the new dual carriageway to Segorbe (Figure 1). The increase of 12% in the urbanized area (15 483 ha) pales in comparison with the 50% increase experienced by the Comunidad Valenciana during the same period (Observatorio, 2006). The area most affected by the urbanization process is the easternmost part of the study area, which is the closest and best connected to the central part of the Valencia Metropolitan Area, close to the cultivated slopes of the mountainous area (Landscape type III) and the agricultural plains (Landscape type II) (Table 3).

   A significant change in the urbanization process took place in the area in the 1990s that has continued up to the present day. For the first time the municipalities of Sierra Calderona started to build housing developments for permanent residents rather than for the second homes market. This was in part caused by the expansion of the metropolitan area of Valencia. The highest demographic growth rates were seen in the second metropolitan ring, which includes the municipalities

Table 3. Land use changes at landscape types and units in Sierra Calderona (1987–2000)

Landscape types	Landscape units	Area (ha)	Progression of natural vegetation		Agriculture reconversion		Cultivation advance		Urbanization		Agriculture abandonment		Other changes	
			ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
I	1	4929.78	–	–	–	–	–	–	0.69	0.01	–	–	–	–
	2	3390.31	85.15	2.51	–	–	–	–	–	–	–	–	–	–
II	3	1454.77	–	–	63.20	4.34	–	–	11.59	0.80	–	–	–	–
	4	225.53	–	–	–	–	10.65	4.72	9.92	4.40	–	–	3.92	1.74
	5	343.95	–	–	13.04	3.79	37.13	10.79	0.59	0.17	–	–	–	–
III	6	8484.34	377.41	4.45	–	–	6.83	0.08	–	–	–	–	20.38	0.24
	7	6004.23	2022.13	33.68	1.66	0.03	51.87	0.86	33.22	0.55	–	–	–	–
	8	5508.73	53.81	0.98	58.62	1.06	43.86	0.80	52.55	0.95	–	–	–	–
IV	9	8745.43	324	3.70	177.02	2.02	104.92	1.20	23.89	0.27	4.42	0.05	8.86	0.10
	10	1677.36	219.29	13.07	74.46	4.44	31.55	1.88	18.28	1.09	7.75	0.46	–	–
	11	859.39	–	–	38.47	4.48	9.21	1.07	1.55	0.18	–	–	–	–
V	12	2217.06	–	–	–	–	–	–	2.55	0.12	–	–	–	–
	13	945.67	–	–	1.01	0.11	–	–	–	–	–	–	–	–
Total		44 786.56	3081.79	6.88	427.48	0.95	296.02	0.66	154.83	0.35	7.75	0.02	3.92	0.01

Source: CORINE Land Cover Project, 1987 and 2000.

of Náquera, Serra and Bétera; and even extended to areas farther from the lower Palancia Valley (Gilet, Albalat dels Tarongers) and from *Camp del Turia* (Olocau, Marines). The new dual highway connecting to Segorbe and Ademuz accelerated the urban expansion. The improvement in accessibility made it possible for people to live at a greater distance into the Sierra in municipalities which have a lower integration with Valencia. This type of development points to a progressively more diffuse regional urbanization model (Burriel & Salom, 2002).

b) The abandonment of traditional un-irrigated crops and the progress of citrus and olive groves. As in many other places in the Mediterranean mountain area, the abandonment of the cultivation of un-irrigated crops has been the major land use change in recent decades. In some cases, crops have been replaced by residential developments. This has led in many places to the regeneration of the natural vegetation (*Pinus halepensis* pine groves), which is spreading rapidly over the abandoned formerly cultivated plots.

During the 1987–2000 period considered in this work the abandonment of agricultural lands virtually stopped (Table 3). In contrast, recent years have witnessed an increase in the surface area occupied by the olive tree plantations, particularly in the interior valleys and mountain gullies. The main reason for this is the favourable treatment given to oil production by the European Union's Common Agricultural Policy. Equally noteworthy is the progression of citrus crop cultivation, which affects the eastern part of the study area. This area is lower in

Table 4. WUI characterization
a) Results from the combination between the morphology of the settlements and the type of landscape

Type of landscape/ morphology of settlements	Towns	Urbanizations	Scattered rural settlements
Western muelas	I, Compact towns	III, Spontaneous urbanizations (not planned) on wildland terrain	IX, Scattered settlements on terraced slopes
Wildland mountain with Lower Bunter sandstones and cultivated gullies	II, Compact towns with extensions	IV, Urbanizations planned on wildland terrain	X, Scattered settlements on wildland terrain
Agroforestal slopes	–	V, Spontaneous urbanizations (not planned)	XI, Scattered settlements on cultivated slopes
Small agricultural valleys		VI, Urbanizations planned on wildland terrain	
Agricultural foothill plains	–	VII, Spontaneous urbanizations (not planned) VIII, Urbanizations planned	XII, Scattered rural settlements

b) Different situations combining vegetation aggregation index and building density and matrix of calculation of the internal vulnerability

		Vegetation aggregation index (%)		
		0 (Zero)	0–90 (Medium)	>90 (High)
Building density (m²/ha)	0–300 (Low)	Class 1	Class 4	Class 5
	300–1500 (Medium)	Class 2	Class 8	Class 10
	>1500 (High)	Class 3	Class 12	Class 15

Internal vulnerability: Low ▢ ▢ ▢ ▢ ▢ High

Source: Lampin *et al.* (2007) and own elaboration.

c) Matrix of calculation of the forest fire structural hazard

		Fuel model (Rothermel, 1983)			
Slope (%)	Not flammable	5	1 | 3	2 | 6	4
0–10	1	2	3	3	4
10–20	1	2	3	4	5
20–30	1	3	4	4	5
30–50	1	3	4	5	5
>50	2	3	4	5	5

Structural hazard: Low ▢ ▢ ▢ ▢ ▢ High

Source: Plan against forest fires in Andalusia (INFOCA) (2003).

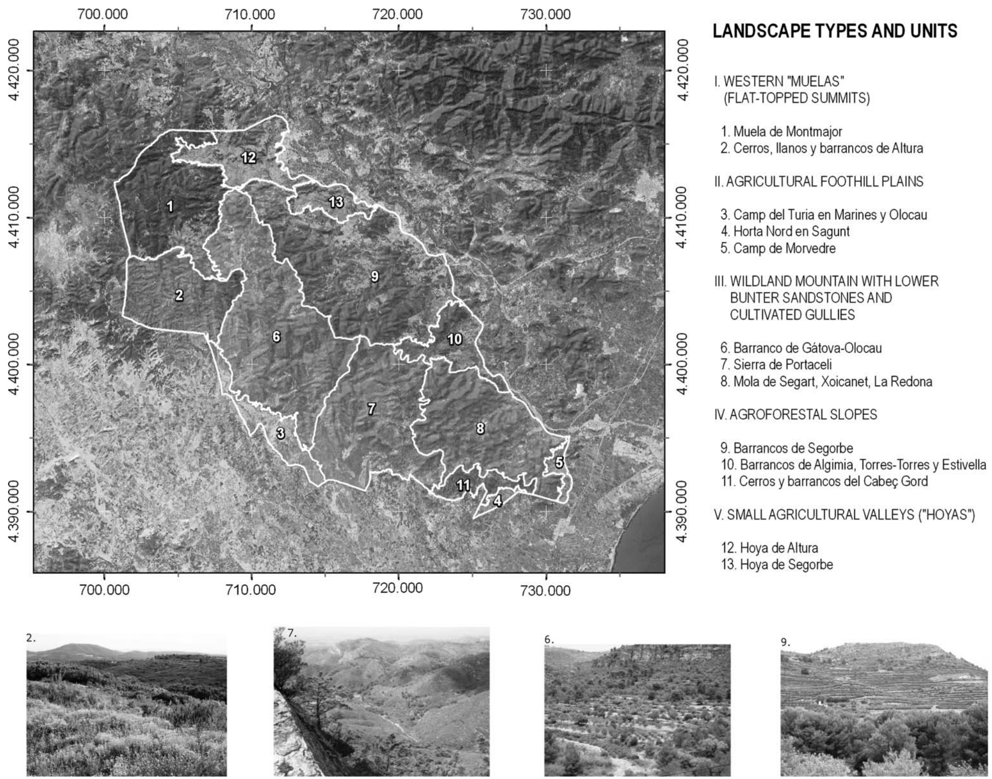
altitude, and the cultivation is progressing along the slopes formerly occupied by un-irrigated species. These new patterns highlight the complexity and the contradictory character of the landscape dynamics analysed at a local scale.

c) Progression of brushwood and the impact of large forest fires. The large areas affected by the abandonment of agricultural lands provide a scenario of intense encroachment of spatially continuous natural vegetation and a general increase in combustible biomass. This is one of the main causes for the growing problem of large forest fires in the Mediterranean basin as already outlined. The abandonment of agricultural lands has changed the character of the area from an agro-wildland mosaic landscape to a terrain that is progressively wildland but lacking in management (Badia *et al.*, 2002). Once the process of agricultural abandonment halted in Sierra Calderona, vegetation growth was essentially due to the processes of post-fire regeneration (Table 3). Combined with the recurrence of forest fires this process led to the homogenization of the vegetal cover, in which brushwood formations are predominantly associations of a pyrophyte and heliophyte character. The destruction of the arboreal stratum is the principal physiognomical result of the successive waves of fires in the area (Urios Moliner, 2004).

3.2. Landscape Character Assessment

The next step in the multiscale analysis was the landscape character assessment, based on the natural and cultural features present in the landscape and on evaluation of functional dynamics and uses (3.1). Landscape description in this phase of the study established a hierarchical typology composed of two levels: landscape units and types (Countryside Agency and Scottish Natural Heritage, 2002). Sierra Calderona landscape diversity and the surrounding area was expressed in *landscape units*. As Figure 3 shows, a total of 13 units were identified and mapped. A total of five *landscape types* were identified for the area as described below.

a) Western *muelas* (flat topped summits). This type consists essentially of a north-moderately high, partially rugged mountainous landscape that defines the western part of the study area. Unlike the rest of the Sierra, this sector is characterized by the presence of flat-topped peaks (large areas ascending to a summit with gentle slopes), composed of limestone and dolomites. The gentle gradients of this mountain range have permitted widespread agrarian activity in the territory, with extensive terraces on the slopes occupied mainly by almond trees. The human presence in this area is limited to dispersed rural small farms. Presently, agricultural activity in the area is nonexistent; there are only a few surviving agricultural enclaves of any importance. Abandoned agricultural lands are colonized by pine groves (*Pinus halepensis*) frequently in mixed expanses with holm oak (*Quercus rotundifolia*) and kermes oak (*Q. coccifera*). This is the sector of the Sierra which is most intensely affected by fires: in 1993, a 6717.96 ha fire destroyed the tree cover in a large part of the southern sector. Because of extensive reforestation projects in the northernmost area large areas of arboreal wildland still exist.
b) Agricultural foothill plains. The Sierra Calderona is surrounded on the south and east by a vast agricultural plain, which is intensely urbanized and where citrus growing is the main activity and homogenizing element. Two distinct areas can be identified. One is the *camps* (*Camp del Turia*, *Camp de Morvedre*), which are detritic glacis of cenozoic materials traditionally occupied by Mediterranean trees (almond trees, carob trees), and where recently citrus fields and new irrigated crops are making inroads. The other area is the *planas*, quaternary flood plains where traditional vegetable gardens have likewise been replaced by orange tree fields (*Horta Nord*).
c) Wildland mountains with lower bunter sandstones and cultivated gullies. The central part of the Sierra is characterized by Triassic-age materials consisting of argillites and reddish sandstones (Lower Bunter) atop the mountains that are surrounded by carbonated cores affected by deep gullies. The lithologies present make this a predominantly siliculose environment with species like cork oak (*Quercus suber*). In the lower parts of the gullies on the outskirts of towns, extensive terraced slopes are maintained and are occupied by olive and almond trees. However, crops occupy a much smaller area than they once did and have given way



(2) Western flat-topped summits. Progression of brushwood and pine over terraced sides.
(7) Gully carved out of limestone rocks, with pinaster at the top. The vegetal cover is brushwood of heliophyte and pyrophyte species, the result of the successive forest fires, with scant presence of the arboreal stratum.
(6) Gully bottom occupied by oleanders, with terraces of olive and almond trees on either side. In the areas with steeper slopes, abandonment of crop cultivation and encroachment of natural vegetation.
(9) Terraced slope in lowest areas of the Sierra. The traditional dry-farmed crops (almond, olive, carob trees) have been replaced by plantations of irrigated orange trees

Figure 3. Landscape types and units.

to natural reforestation of *Pinus halepensis* after land abandonment. The present vegetative cover is the result of the series of large fires that have affected the area, creating a limited presence of the arboreal stratum and rich and diverse brushwood.

d) Agroforestal slopes. The mountain range relief gradually decreases in continuity and height towards the north and south of the area being replaced by hills, the alignment of which is divided by ever wider gullies. These contain tertiary and quaternary detritic materials. The vegetative cover forms an agroforestry mosaic, with *Pinus halepensis* groves covering the hills and Mediterranean mixed crops over a very fragmented cadastral pattern at the bottom of the gullies. Orange groves are gaining prominence at lower altitudes, with frequent recent plantings on slopes. Advances of citrus groves combined with diffuse urbanization processes leads to intense landscape dynamism.

e) Small agricultural valleys (*hoyas*). On the northern slope of the Sierra towards the Palancia river valley, depressed sectors topographically framed by mountain alignments are in evidence. These wider and flatter areas located on innumerable terraced slopes, are now mostly agrarian environments devoted to dry-land Mediterranean arboriculture of mainly almond trees and, in recent years, olive trees. These are sparsely populated areas which are favourable to the expansion of large hog farms scattered among crop fields.

3.3. *Wildland–Urban Interfaces Characterization*

The WUI characterization process consisted of identifying the different morphologies defined by urbanization processes, examining them in the context of the landscape type of the area in which they occur and characterizing them according to fire behaviour.

There are two reasons that justify the relation of urban morphologies to landscape character and dynamics:

- The urban morphologies present in the area are closely linked to certain elements of pre-existing landscape patterns, especially to agrarian land uses and the layout of the former rural divisions.
- The characteristics of the vegetative cover, and, therefore, fire behaviour, are directly related to the dynamic associated with each type of landscape.

Three broad types of residential settlement patterns were defined (Figure 4):

a) Towns. These are the traditional core of settlements which display a concentrated layout and high building density. There is a clear differentiation between the towns and the surrounding agrarian space. Towns may have recent extensions with a recognizable urban morphology.

b) Urbanizations. These are groupings of residential developments removed from agrarian use. These may be organized around a single housing development or a complex development (planned urbanizations) or may emerge spontaneously supported by the existing structures of agricultural use (plot, terraces, paths).

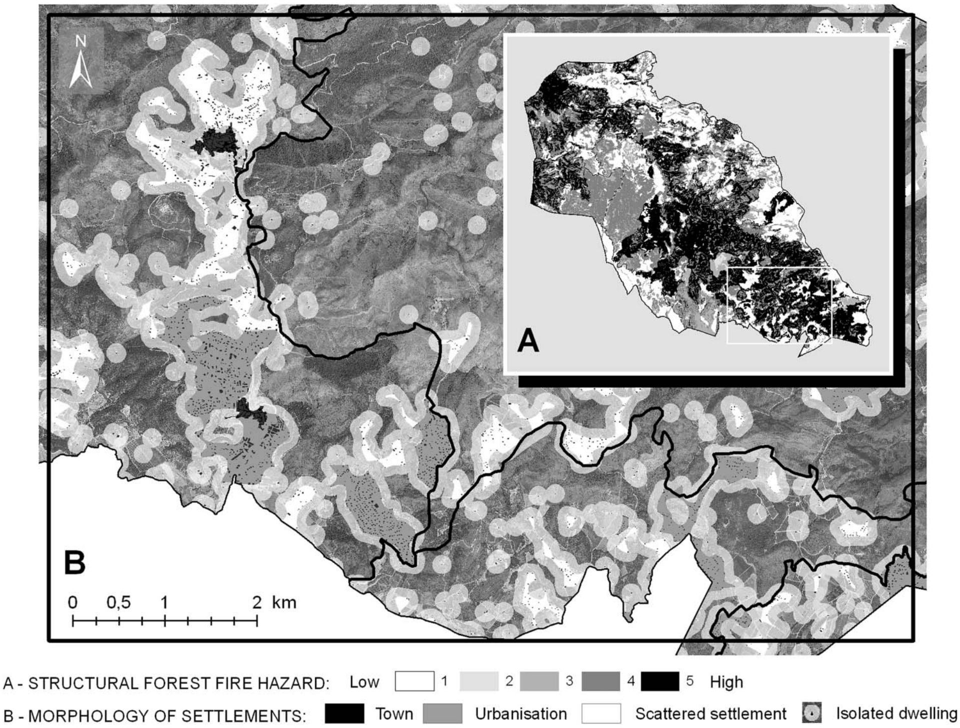


Figure 4. Structural forest fire hazard and morphologies of settlements.

c) Scattered rural settlements. These consist of sets of residential buildings, not necessarily linked to agrarian use, of low density which do not form an urban structure.

3.4. Wildland–Urban Interfaces Typology Associated with Wildfire Behaviour

A classification of nine types was established based on patterns in the distribution of density and aggregation levels (Figure 5).

The classification of the WUIs based on landscape characterization and the morphological analysis of the population settlements correlates with quantitative parameters such as building density and the vegetation aggregation index. These parameters permit an evaluation of WUIs' propensity to suffer damage because of the characteristics of the interface (Table 4b). The final classification can be applied directly to assess fire vulnerability of areas which are especially sensitive to fire risk and to arrange a hierarchical set of actions to address problems.

Knowledge of the characteristics of the landscape units provides an indication of the potential impacts of fires in the WUI. Application of the forest fire structural hazard index (Table 4c) to the landscape units indicates that the external vulnerability of the interfaces is directly related to the landscape character in which they are inserted (Table 5a).

The product of both indices (external vulnerability x internal vulnerability) results in a point-scale of WUI overall vulnerability (Table 5b).

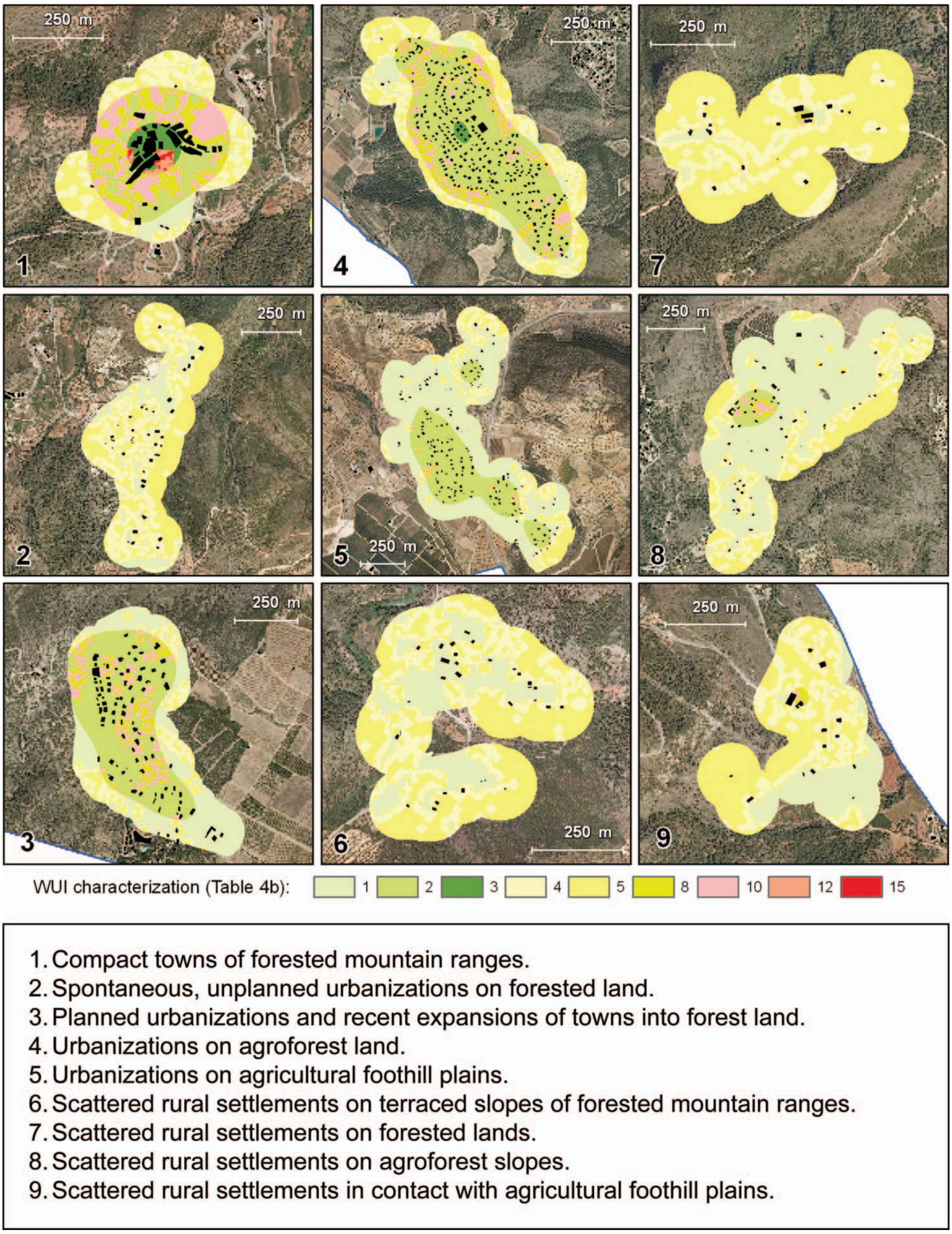


Figure 5. Typology of urban–wildland interfaces in Sierra Calderona associated with forest fire vulnerability.

WUI characterization thus obtained is based on analysis at a local scale in order to integrate it at the regional scale. The regional scale is the most efficient in terms of planning for forest fire risk management.

Assessment of fire vulnerability in the interface (through the application of the usual techniques of a quantitative approach to the levels of fragmentation, continuity or

Table 5. Vulnerability calculation
a) External vulnerability

(Figure 3)	Landscape type / Landscape unit	(1)	I		II			III			IV			V	
			1	2	3	4	5	6	7	8	9	10	11	12	13
External vulnerability		(2)	3.87	3.98	1.49	1.37	1.37	3.77	3.80	4.11	3.33	2.76	3.41	1.99	2.00

b) Vulnerability calculation of WUI types

WUI type (Figure 5)	Landscape unit (1)	External vulnerability (2)	Morphology of settlement (Figure 4)	Internal vulnerability (3)	WUI vulnerability (2) × (3)
1	8	4.11	Town	2.78	11.43
2	8	4.11	Scattered settlement	2.36	9.69
3	8	4.11	Urbanization	2.05	8.41
4	7	3.80	Urbanization	2.39	9.08
5	3	1.49	Urbanization	1.58	2.36
6	6	3.77	Scattered settlement	2.22	8.35
7	8	4.11	Scattered settlement	2.68	11.04
8	8	4.11	Scattered settlement	1.66	6.83
9	10	3.33	Scattered settlement	2.17	7.22

heterogeneity) is aided by the information drawn from the landscape description. In accordance with the patterns defined, relevant information on expected dynamics, such as information related to land uses and the evolution of natural vegetation, facilitates a more accurate fire risk forecast by providing a major dynamic factor to its mapping. This approach allows forecast criteria regarding the future evolution of forest fire risk to be included, thus enabling better potential for land use regulation.

4. Conclusions

Wildland–urban interfaces are becoming increasingly important in the Western world. In the Mediterranean environment the WUI process takes on special significance because of its interrelation with the phenomenon of large forest fires. Good management of large wildfire risk must take into account the existence of WUIs because of the effect these have on the planning of suppression and prevention efforts to reduce the often disastrous consequences of fires.

Implementation of an effective prevention system depends on a thorough and reliable knowledge of the factors affecting fire behaviour in these WUI areas and on accurate maps. The information resulting from the methodology developed in this work will help define better zoning, both from the perspective of regulating the territory in relation to land use planning and the prevention of residential developments in sensitive areas, but also that of wildland fire management to reduce combustible biomass.

Zoning of the WUI based solely on the intensity and characteristics of human development and vegetation cover represent a static approach to a much more dynamic reality. It is necessary to define this dynamism, beginning with the model of urban-regional development in a given area; this information will help predict future major territorial change tendencies.

The wildland–urban interface typologies developed in this research allow for a zoning of the fire risk at appropriate scales in the study area. The WUI types thus defined reflect the widespread territorial dynamics (suburbanization, farm abandonment, brushwood progression) and comprise landscapes that are characteristic of many other parts of the European Mediterranean coastline. Therefore, the conclusions from the study are potentially transferable, both spatially and temporally. Moreover, the methodology is reproducible and depends on sources of information easily attainable.

The first step in determining the forest fire hazard in WUIs is a characterization and mapping of the area. Next, the typology must be related to other hazard-characterizing parameters such as fuels, the probability of fire ignition or risk exposure of the population to wildfires. These parameters have a direct relationship to the type of settlement and the landscape (regional scale) and between the houses and the vegetation surrounding them (local scale).

The establishment of a WUI typology and the classification produced in this work offer results that are directly applicable in the mapping of forest fire risk mapping for spatial and sectoral planning. One of the most interesting applications of this method is in the study of the vulnerability of especially sensitive areas (WUIs) at a local scale. However, smaller areas should be contextualized within wider territories (the landscape units) as large areas constitute more appropriate spatial units for the analysis of future fire scenarios.

Notes

1. Corine Land Cover 1987 and 2000 in the Comunidad Valenciana. Land Cover on a 1:100 000 scale for the years 1987 and 2000. European Project Corine Land Cover, directed by the European Environmental Agency.
2. FragStat Internet Home Page, available at: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

References

Antrop, M. (2004) Landscape change and the urbanization process in Europe, *Landscape and Urban Planning*, 67, pp. 9–26.

Badia, A., Saurí, D., Cerdan, R. & Llurdés, J. C. (2002) Causality and management of forest fires in Mediterranean environments: an example from Catalonia, *Environmental Hazards*, 4, pp. 23–32.

Beringer, J. (2000) Community fire safety at the urban/rural interface: the bushfire risk, *Fire Safety Journal*, 35, pp. 1–23.

Bürgi, M., Hersperger, A. M. & Schneeberger, N. (2004) Driving forces of landscape change—current and new directions, *Landscape Ecology*, 19, pp. 857–868.

Burriel, E. & Salom, J. (2002) La distribución de la población y el sistema urbano, in: J. Romero *et al.* (Eds) *Comunidad Valenciana*, pp. 59–70 (Valencia: Ariel).

Caballero, D. (2004) Gestión de los riesgos de incendios en la interfase forestal—urbana: proyecto WARM, in: *Proceedings of the II International Symposium on Fire Economics, Planning and Policy: A Global View*, 19–22 April, Córdoba, Spain (Córdoba: US Forest Service/Universidad de Córdoba).

Camia, A., Varela, V., Marzano, R. & Eftichidis, G. (2004) Spatial analysis in European Wildland-Urban Interface environments using GIS, in: G. Xanthopoulos (Ed.) *Proceedings of the II International Workshop: Forest Fire in the Wildland–Urban Interface and Rural Areas in Europe: An Integral Planning and Management Challenge*, 15–16 May 2003, Athens, Greece, pp. 185–196 (Chania: Mediterranean Agronomic Institute of Chania, Graphic Art and Publishing Unit).

Cohen, J. & Saveland, J. (1995) Structure ignition assessment model (SIAM), in: D. R. Weise & R. E. Martin (Coord.) *Proceedings of the Biswell Symposium: Fire Issues and Solutions in Urban Interface and Wildland Ecosystems*, 15–17 February 1994, Walnut Creek, CA (Gen. Tech. Rep. PSW-GTR-158), pp. 85–92 (Albany, CA: Pacific Southwest Research Station, Forest Service, US Department of Agriculture).

Cohen, J. D. (1999) Reducing the Wildland Fire Threat to Homes: Where and How Much?, Fire Economics Symposium, San Diego, CA.

Countryside Agency and Scottish Natural Heritage (2002) *Landscape Character Assessment: Guidance for England and Scotland* (Wetherby: Countryside Agency and Scottish Natural Heritage).

Crespo Villalba, M. B. (1990) *Contribución al estudio florístico, fitosociológico y fitogeográfico de la Sierra Calderona, Valencia-Castellón* (València: Universitat Servicio de Publicaciones).

Davis, J. B. (1990) The wildland–urban interface: paradise or battleground?, *Journal of Forestry*, 88(1), pp. 26–31.

Fleischhauer, M., Greiving, S. & Waczura, S. (2007) Planificación territorial para la gestión de riesgos en Europa, *Boletín de la AGE*, 45, pp. 49–78.

García Fayos, P. (1991) La vegetación silicícola de la Sierra Calderona (Comunidad Valenciana), *Lazaroa*, 12, pp. 317–332.

Hermansen, L. A. & Macie, E. A. (2005) An Assessment of the Southern Wildland-Urban Interface, in: S. W. Vince, M. L. Duryea, E. A. Macie & L. A. Hermansen (Eds) *Forest at the Wildland-Urban Interface: Conservation and Management*, pp. 25–41 (Boca Raton, FL: CRC Press).

Junta de Andalucía (2003) Plan de Emergencia por Incendios Forestales de Andalucía (Plan INFOCA) Sevilla.

Lampin, C., Jappiot, M., Long, M., Mansuy, N. & Borgniet, L. (2006) WUI and road networks/vegetation interfaces characterizing and mapping for forest fire risk assessment, *Forest Ecology and Management*, 234S, pp. S137–S140.

Lampin-Maillet, C., Jappiot, M., Long, M., Bouillon, C., Morge, D. & Ferrier, J.-P. (2010) Mapping wildland–urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the South of France, *Journal of Environmental Management*, 91(3), pp. 732–741.

Miranda Montero, M. J. (1985) La segunda residencia en la provincia de Valencia. Facultad de Geografía e Historia, Departamento de Geografía, Valencia.

Myszewski, M. & Kundell, J. (2005) Land-use planning and zoning at the wildland–urban interface, in: S. W. Vince, M. L. Duryea, E. A. Macie & L. A. Hermansen (Eds) *Forests at the Wildland–Urban Interface: Conservation and Management*, pp. 77–94 (Boca Raton, FL: CRC Press).

Observatorio de la sostenibilidad en España (2006) *Cambios de ocupación del suelo en España: implicaciones para la sostenibilidad* (Madrid: Mundi-Prensa).

Pascual Aguilar, J. A. (2003) *Cambios de usos del suelo y régimen hídrico en la rambla del Poyo y el barranc de Carraixet* (València: Universitat de València. Servei de Publicacions).

Pascual Aguilar, J. A. (2004) Dinámica reciente de usos del suelo en el continuo metropolitano de Valencia, *Cuadernos de Geografía*, 76, pp. 183–202.

Radeloff, V. C., Hammer, R. B, Stewart, S. I., Fried, J. F., Holcomb, S. S. & Mckeefry, J. F. (2005) The wildland–urban interface in the United States, *Ecological Applications*, 15(3), pp. 799–805.

Rothermel, R. C. (1983) How to predict the Spreads and intensity of forest and range forest fires, USDA Forest Service.

Theobald, D. M. & Romme, W. H. (2007) Expansion of the US wildland–urban interface, *Landscape and Urban Planning*, 88, pp. 340–354.

Urios Moliner, J. I. (2004) Análisis del régimen de incendios forestales en los montes de Portaceli durante el siglo XX (Serra, Valencia), *Cuadernos de Geografía*, 76, pp. 219–238.

Vince, S. W., Duryea, M. L., Macie, E. A. & Hermansen, L. A. (Eds) (2005) *Forests at the Wildland–Urban Interface: Conservation and Management* (Boca Raton, FL: CRC Press).

Winter, G. & Fried, J. S. (2000) Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland–urban interface, *Society and Natural Resources*, 13(1), pp. 33–49.