P5.2-8 Technical guide to map and describe wildland-urban interfaces (WUIs)

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Reference

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Abstract

This guide presents a method for wildland-urban interface mapping, applied to large areas, at a large scale. This method can be adapted easily to specific situations observed in different European countries. The guide is based on a combination of four "housing configuration" types and three types of horizontal structure of vegetation. Twelve wildland-urban interface types have been produced. It is particularly well adapted to the French environment, but the method has also been well adapted (and applied) to Spain and Greece. In tandem with a software tool – WUImap – it was developed and presented in guide-form to map WUIs automatically. Some examples of use of such WUI maps have been presented in the guide.

Keywords: wildland-urban interfaces, fire risk, housing configuration, vegetation structure, aggregation index, WUImap tool

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1. Introduction

1.1. Context of Mediterranean region

Each year, forest fires destroy about 500.000 hectares of vegetation in Europe, and more specific in the Mediterranean region. During 2007, wildfires in the five countries of southern Europe (Portugal, Spain, France, Italy and Greece) burned-over a total area of 575 531 ha (JRC, 2008; Lampin-Maillet, 2008), and scenarios of climate change indicate an increased fire risk, with as results an increased frequency of fires and extension of fire season (Rigolot, 2009).

Many large fires are linked to the dramatic land transformation that has been taking place in the Mediterranean region for some decades and that is increasing the risk of forest fire. On the one hand, agricultural fallows and orchards are slowly colonized by vegetation, while on the other hand, the forest is not sufficiently utilized, where both result in the increased accumulation of fuel loading (Lampin-Maillet *et al.*, 2009a). In addition, urbanization - coupled to the phenomenon of forest extension - is generating new spatial configurations called "wildland-urban interfaces" (WUI), where WUIs are commonly defined as "areas where urban areas meet and interact with rural lands" (Vince *et al.*, 2005) creating a new conjunction of housing and vegetation characteristics (Stewart *et al.*, 2007).

The wildland-urban interface (WUI) illustrated by the photo on the right, is also directly related to wildland fire: 90% of wildland fires are caused by human activities in Mediterranean Europe (Martin et al,, 2005) and every year a number of people living in WUIs are killed by wildland fires. Human casualties are mostly among fire fighters who loose their lives protecting woodlands or dwellings, or populations threatened by fires, often attempting to escape. According to their environment, dwellings - especially those standing in forest areas - are to some degree sensitive to fire.

Source Cemagref/Lampin-Maillet

The wildland-urban interface represents a key-area for fire risk management (Davis, 1990; Velez, 1997; Cohen, 2000), considering the fire occurrence on the one hand (hazard), and effects and damage on the other (vulnerability).

1.2. The wildland-urban interface literature

1.2.1. Wildland-urban interface definitions

In geography, "interface" is defined as "the contact plan or contact line between two different systems" (Brunet et *al.* 1993). It constitutes a privileged zone to exchange and to interact between two systems, specifically between human and wildland systems (Carroue et *al.* 2002). In the literature, definitions present WUI as the line (area), or zone where structures and other human developments meet or mix with undeveloped wildland or vegetative fuels (United States Department of the interior, 1995). The term WUI community can also be described as "the urban-wildland interface community where humans and their development meet or intermix with wildland fuel", where houses meet or mix with undeveloped wildland vegetation (USDA and USDI 2001). Nowadays (and more generally) the WUI, is more commonly described as "the area where urban areas meet and interact with rural lands" (Vince et *al.* 2005). It includes the edges of large cities and small communities, areas where homes and other structures are intermixed with forests and other land uses, and islands of undeveloped lands within urban areas (Alavalapati et *al.* 2005, McGee 2005, Caballero et *al.* 2004). In these WUI, increased human influence and land-use conversion are changing natural resource goods, services and management (Macie and Hermanser 2002).

1.2.2. Wildland-urban interface mapping

Conceptually, the WUI is a conjunction of housing and vegetation characteristics (Stewart *et al.*, 2007). On the one hand, human presence is measured by the density of houses and other infrastructures (Lampin *et al.,* 2006a, 2006b; Caballero et al., 2004; Camia *et al.*, 2003) or by the density of the population (Kamp and Sampson, 2002).

However, empirical data on the extent of WUIs and location are scarce. Some methods developed at national or regional levels allow location and mapping of WUIs providing tools for the elaboration of physical, emergency and self protection plans, but according to Dumas *et al.* (2008) and Theobald and Romme (2007), more detailed data is required for planning and management activities. So the development of an efficient method for WUI mapping would be necessary in order to be used for fire risk management.

1.3. Objectives of the technical guide

The objective of this guide is to propose and develop a methodology in order to be able to map and describe the wildland-urban interface at a large scale and over large areas, with a view of fire prevention improvement and to analyse the WUI territorial development in the landscape. It will attempt to define the wildland-urban interface precisely. The two main components of the wildland-urban interface are (i) the housing configuration and (ii) vegetation. Concerning housing configuration, houses or buildings are dedicated to dwellings organized in isolated, scattered or clustered units. Concerning vegetation, wildland vegetation is defined as the following land cover classes: (i) wildland forests (coniferous, deciduous, and mixed forest); (ii) shrubland; (iii) native grasslands/herbaceous; (iv) transitional lands (mostly clear-cuts); and (v) woody and emergent herbaceous wetlands. Excluded from wildland vegetation are low- and high-intensity residential, commercial/industrial, orchards/vineyards, pasture/ hay, arable lands (e.g., row-crops) and pasture, small wheat lands, fallow, urban/recreational grasses, bare rock/sand/clay, quarries, open water, and perennial ice/snow (Steward *et al*, 2003, Radeloff *et al*, 2005, Lampin *et al*, 2006a).

Many methodological questions remain to define a practical WUI mapping method:

- How to select criteria to characterize housing configuration precisely, whatever the scale, including large areas. Also, how to describe and classify vegetation structure in contact with these houses.
- How to set up an appropriate mapping method for WUI mapping at a large scale, for a large area.
- How to adapt this method in the context of different European countries.

This technical guide pursues 3 main objectives:

- To present a method to map WUI after defining WUI accurately and quantitative, from a study case developed in France;
- to allow adaptation of the method in another Mediterranean countries, taking into account another urban context or legacy context (e.g.in Spain);
- to present the user's notice written for the use of the tool "WUImap", developed in order to map possible WUIs on the territory automatically.

2. Materials and data

2.1. Study sites

In order to develop the previous objectives, three study cases have been defined in three European countries: namely in France, Spain and Greece. The first is located in south-eastern France in the Metropolitan area between Aix-en-Provence and Marseille. This corresponds to site 1, in Fig.1. The second is located in the western part of Madrid. This corresponds to site 2, in Fig.1, its territorial limit of the study covers grids 508 (I, II, III, IV) and 533 (I, II), approximately 70.000 hectares. The third is located in north-eastern Greece in the western section the Thessaloniki district. This corresponds to site 3, in Fig.1.

The method for mapping and describing WUIs was developed at French site 1. It was also adapted to the Spanish site 2. It was included in Product P5.1.7, developed at Greek site 3 for hazard mapping in WUIs and for total risk mapping in WUIs.

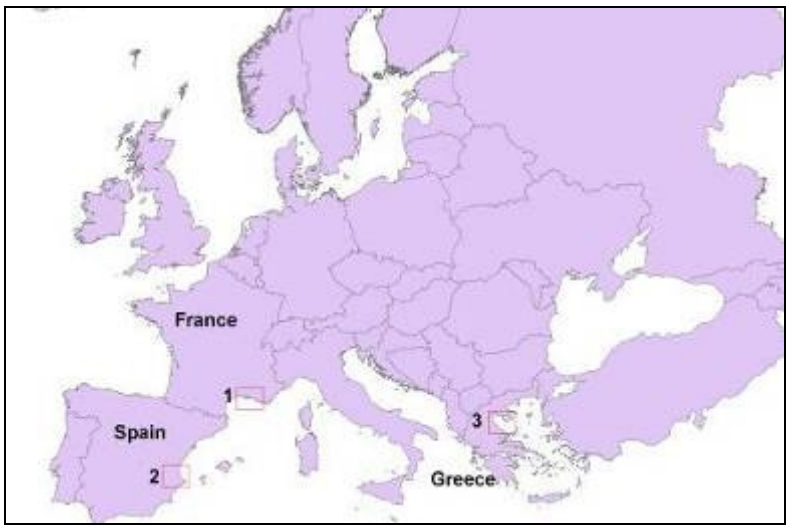


Fig.1: Location of the three European study areas

2.2. Data, softwares

At site 1, the satellite imagery SPOT 5 (with a very high resolution), acquired within the ISIS program framework by CNES (National Centre of Spatial Studies), was used. It was dated July 2002, with a 2.5 m spatial resolution resulting from pan-sharpening of multi-spectral imagery (10 m spatial resolution) with panchromatic imagery (2.5 m spatial resolution in super mode). This image has been selected because of its good and homogenous quality over the whole of the site: it covers a large area (60 km by 60 km), and its 2.5m resolution allows results at a large scale. Other databases used were (i) BD TOPO®IGN giving the house layer, and (ii) aerial photos BD ORTHO® IGN produced by the IGN (National Geographic

Institute) for updating house layer. At site 2, three kinds of data were used: (i) the national Forest Map of Spain (1:50.000), (ii) aerial photography (2006) at 0.5 meters of resolution and (iii) a map of settlements.

The main software used was:

- *ArcGIS© 9.3 software*

ArcGIS© version 9.3 software developed by ESRI (Environmental Systems Research Institute) allows to visualise, to explore, and to analyse spatial data. It is adapted to vector or raster dataset. It has been used with the extension « Spatial Analyst », to combine different layers and to map results, etc.

- *FRAGSTATS© software*

FRAGSTATS© Version3.3 (McGarigal and Marks, 1994) is a spatial analysis freeware. It quantifies spatial areas and their spatial configuration inside landscape. It allows particularly calculation of aggregation metric on vegetation.

3. Mapping methods of the wildland-urban interface

3.1. Accurate of the WUI definition in the French context

In order to map wildland urban interfaces on the territory, a precise definition of the WUI has been proposed, as follows (Lampin-Maillet et *al.* 2010a, b):

- Wildland-urban interfaces (WUIs) are composed of residential houses, which are inhabited permanently, temporarily or seasonally (agricultural, industrial, commercial and public buildings were not taken into consideration);
- Houses are located at approximately 200 meters from forests or shrublands. This distance of 200 meters refers to the French Forest Law dated the 9th July 2002, which enforces brush-clearing around buildings closer than 200 meters from forests or shrublands (Art.L.322.3 of the Forest Law code);
- WUI are delineated by a radius of 100 meters around houses. This distance takes into account the perimeter wherein fuel reduction operations are imposed on homeowners by the French Forest Law (Art.L.321.5.3). This French forest law indicates that brush-clearing has to be applied (and maintained) within a perimeter of 50 meters from the building which can be extended to 100 meters by local regulations.

The WUI definition is illustrated on Fig.2.

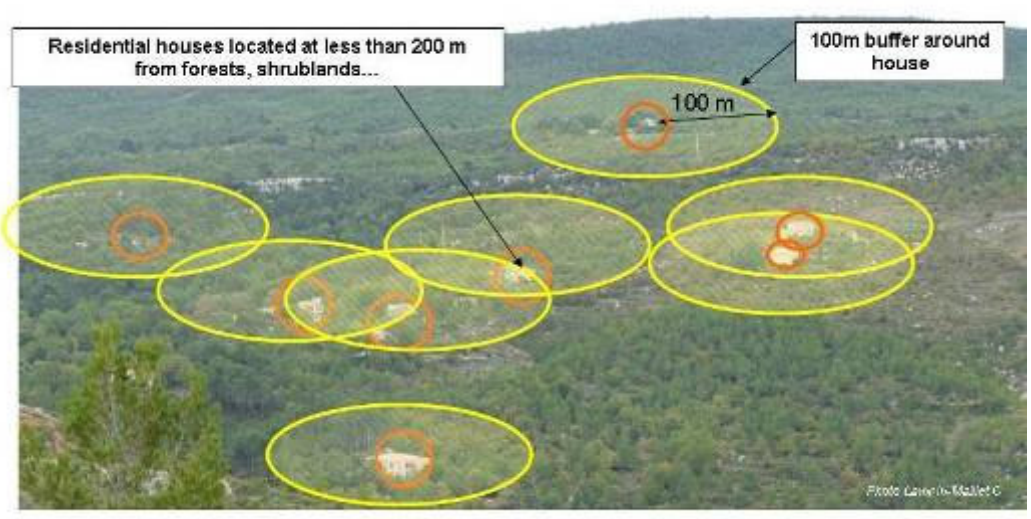


Fig 2: WUI definition

Nota: This buffer size used, includes the zone exposed to flame contact and also the zone affected by flame radiation-convection *(*Cohen, 2002, 2003; Nowicki, 2002; Caballero *et al.,* 2004; Caballero & Beltran, 2003; Southern Forest Alliance, 2003; Randall, 2003). This buffer

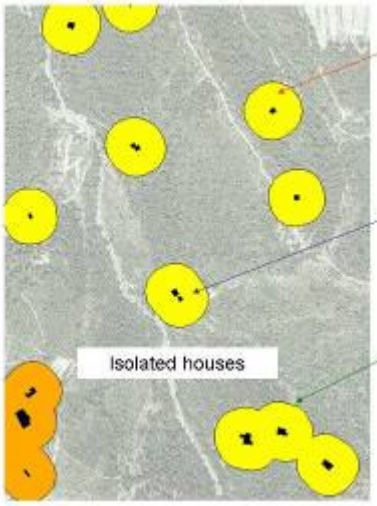
size allows including an area that is significantly exposed to firebrands from vegetation in case of fire. “228 meters distance”, is the average distance that firebrands can be carried from a wildland fire in Mediterranean Europe (results of European Saltus program, Colin *et al.,* 2002). The area considered in WUI is located up to 300 meters from massifs (200m +100m) (in the same way Radeloff *et al*., 2005 considers a buffer distance of 2.4 km corresponding to the distance that firebrands can be carried from a wildland fire to the roof of a house in USA).

3.2. Criteria to describe and map WUIs

.We considered WUI as consisting of two intermixed elements: the first concerned the spatial organization of residential houses, and the second concerned the structure of fuel vegetation. Spatial criteria were developed to specify the structure of dwellings in contact with the different vegetation structures. With regard to the structure of dwellings, after first approaches developed with housing density calculation (Lampin *et al*. 2007a,b,c), we proposed a real and quantitative definition of terms corresponding to (a) isolated, (b) scattered, (c) dense and (d) very dense clustered dwelling types, usually used by land managers and geographers. This classification is based on quantitative criteria described in Lampin-Maillet *et al.* (2010a, b) such as housing density. Concerning the structure of vegetation, the only horizontal structure of vegetation that can be recognized spatially, has also been classified ((a) no vegetation, (b) sparse vegetation and (c) continuous vegetation). Then the combination of different types of dwellings and different classes of horizontal structures of vegetation produced a wildland-urban interface typology, was considered. The method used to described/classify and map WUIs is based on three steps that are described in order below.

3.2.1. Classifying and mapping housing configuration

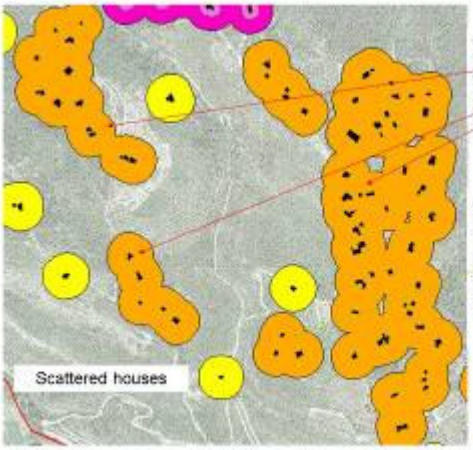
The *first step* is to classify and map the housing configuration. The houses considered as being located within the wildland-urban interface are selected (step (a) Fig.5). Then according to the definition of the dwelling types established in Lampin-Maillet et *al.* (2010a, b) and through the process of buffering and house counting described in the same paper, each house was classified as belonging to one of the four configurations of houses (Fig.3) : isolated, scattered, dense clustered, and very dense clustered housings (step (b) Fig.5). Then for each house belonging to the same housing class which takes into account the distance between houses and the number of houses, a buffer process with a 100-m radius around houses (step (c) Fig.5).



1 house (*) or clusters of 2 (**) or 3 houses (***) located more than 100 metres apart

and,

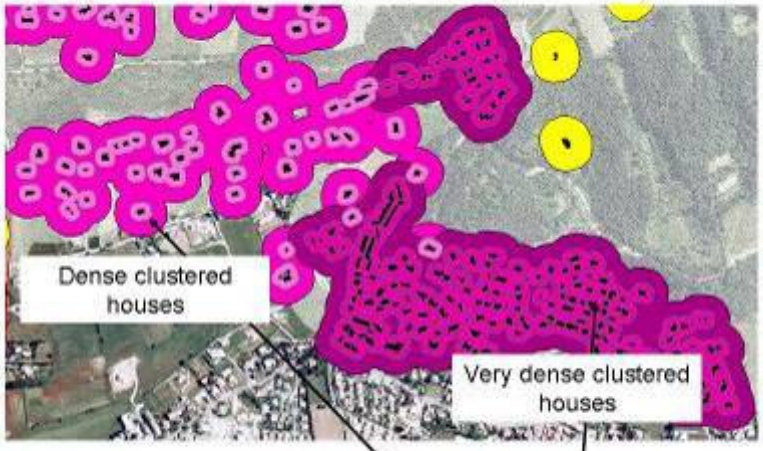
distance between the 3 houses, two by two, is superior to 100 m



clusters of 4 to 50 (*) houses located less than 100 metres apart

and,

cluster of 3 houses (**), located less than 100 metres apart with distance between the 3 houses, two by two, is inferior to 100 m



Clusters of more than 50 houses located less than 100 metres apart.
In this last category, two sub-classes have been determined:
a first one identifies dense clustered dwellings corresponding to clusters of less than 10 houses located less than 30 metres apart
and a second one identifies very dense clustered dwellings corresponding to clusters of more than 10 houses located less than 30 metres apart that being equivalent to well urbanized areas

Fig.3: Quantitative criteria for discriminating the 4 types of housing

3.2.2. Classification and mapping of horizontal structure of vegetation

The *second step* is to classify and map the structure of the vegetation. The structure of vegetation reveals its horizontal continuity, which is designed for the measurement of aggregation levels of spatial patterns within the vegetation class, in a land-cover map. Among the different existing metrics in landscape ecology (McGarigal, 2002), the most appropriate index to measure aggregation of spatial patterns is the (AI) aggregation index (Lampin-Maillet et *al.* 2010a). This aggregation index has a spatial representation.

A vegetation map in raster format is necessary for the calculation of the aggregation index. It can be provided through the selection of the vegetation class pointed out in a land cover map performed with a classification of satellite imagery for example (step (e) Fig.5). Two classes are considered: vegetation class and no vegetation class (step (f) Fig.5). Calculated on vegetation class, the aggregation index enhances spatial organization of forests and scrublands. Aggregation metrics calculations were made within a moving window with a radius of 20 metres and a map of aggregation index values was also drawn up including three classes of AI values (step (g) Fig.5). The first class concerned values equal to zero, and the two other classes were determined by sharing the numbers of value equally into two groups or by setting a threshold value equal to 95 %: the first distribution of numbers were considered as low values of aggregation, the second one as high values (step (h) Fig.5).

Note: If the vegetation map is only available in vector format, AI calculation is not relevant. Thus the structure of the vegetation can be qualitatively assessed according to its vegetation cover. In other words:

- Continuous horizontal structure of vegetation corresponding to high AI in place

  It corresponds to vegetation classes with dense vegetation covering: ground is completely covered by vegetation (resinous stands, hardwood stands, mixed stands, un-cleared vegetation, garrigues, maquis, etc.).

- Discontinuous, sparse, horizontal structure of vegetation corresponding to low AI

  It corresponds to vegetation classes with sparse vegetation covering: ground is not completely covered by vegetation, (managed areas, cleared areas, ornamental garden, plantations, hedges, etc.).

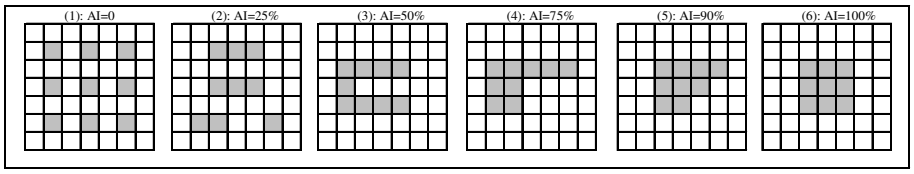
- No vegetation corresponding to AI equal to zero

  It corresponds to bare ground, built areas, agricultural areas, etc., which are not necessary non-combustible.

The spatial Aggregation Index AI is defined on the spatial arrangement and agglomeration of objects on the image. It provides information about frequency of connections between pixels of a same class of landscape (Robbez-Masson *et al.* 1999). It formula is defined by:

$$AI = \left[\frac{g_{ii}}{\max g_{ii}} \right] (100) \quad \text{with} \begin{cases} g_{ii} = \text{Number of contacts between the pixels of a class i} \\ \max - g_{ii} = \text{Maximal number of contacts between the pixels of a class i} \end{cases}$$

The calculation was made within a moving window with a radius of 20 meters. The AI values increase with the continuity and compactness of the pixels as illustrated Fig.4.



Lampin & al, 2006a

Fig.4: Evolution of aggregation index from the arrangement of 9 grey pixels

Its calculation produces a raster map with values from 0 to 100% which are classified according thresholds below:

- Aggregation = 0 corresponds to land covers different from vegetation;
- 0 < Aggregation ≤ 95% correspond to discontinuous, sparse vegetation or edges;
- Aggregation > 95% which correspond to dense and continuous vegetation.

3.2.3. Combination of the two previous criteria

The *third step* is combining the two previous criteria through a geographical information system (GIS). After the conversion of the housing configuration type layer to raster layer and its codification (step (d) Fig.5), this housing configuration type layer has been added to the aggregation layer (step (h) Fig.5). Result of the calculation allowed mapping of the wildland-urban interfaces according to 12 types (step (i) Fig.5) by crossing four classes of dwelling types and three classes of vegetation aggregation indexes in a raster format.

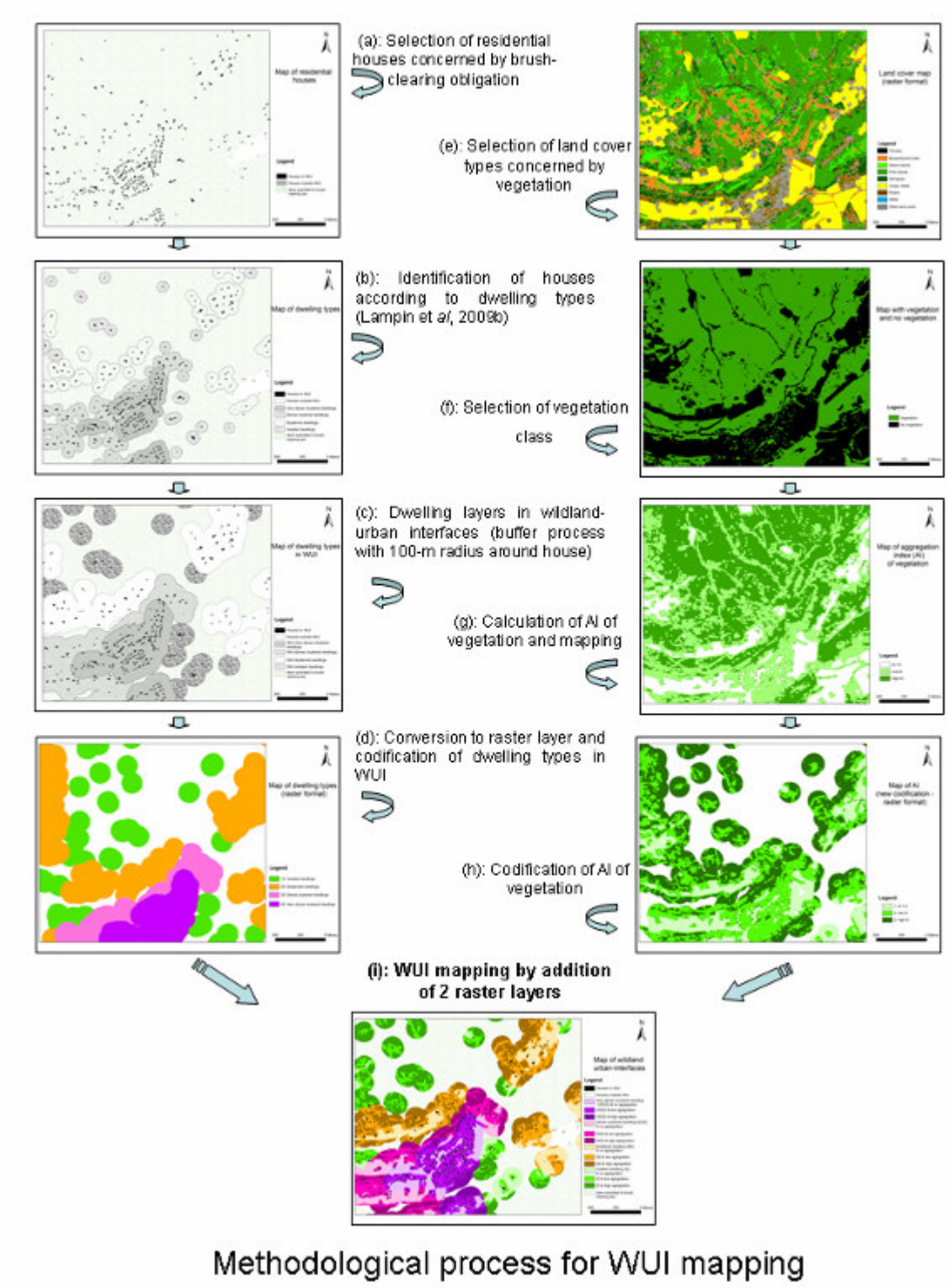
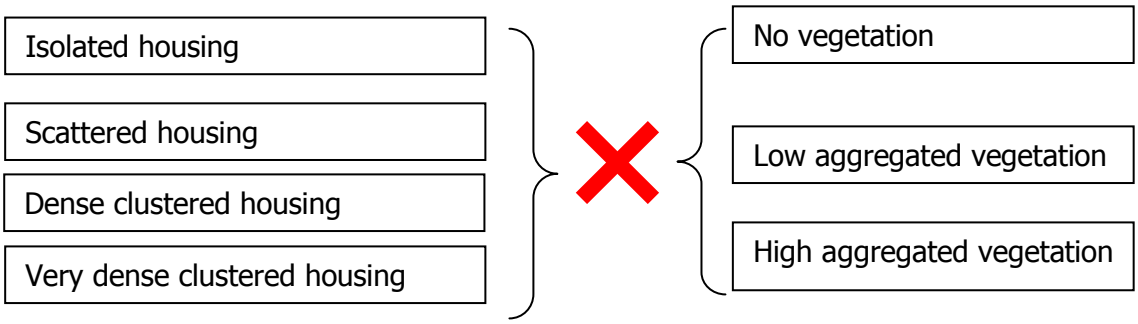


Fig.5: methodological process for WUI mapping

4. Types of Wildland-urban interfaces and mapping

4.1. Examples

Twelve types of wildland-urban interfaces have been produced by combining the three vegetation aggregation classes (no aggregation, low and high aggregation) and the four housing configuration types.



The 12 wildland urban interface types are summarized in the table 1 below, and are illustrated in Fig.6.

Type 1	Isolated housing & no aggregation	Isolated housing in contact with crops, urban areas without vegetation
Type 2	Isolated housing & low aggregation	Isolated housing in contact with discontinuous, sparse vegetation
Type 3	Isolated housing & high aggregation	Isolated housing in contact with continuous, compact vegetation
Type 4	Scattered housing & no aggregation	Scattered housing in contact with crops, urban areas without vegetation
Type 5	Scattered housing & low aggregation	Scattered housing in contact with discontinuous, sparse vegetation
Type 6	Scattered housing & high aggregation	Scattered housing with continuous, compact vegetation
Type 7	Dense clustered housing & no aggregation	Dense clustered housing in contact with crops, urban areas without vegetation
Type 8	Dense clustered housing & low aggregation	Dense clustered housing in contact with discontinuous, sparse vegetation
Type 9	Dense clustered housing & high aggregation	Dense clustered housing with continuous, compact vegetation
Type 10	Very dense clustered housing & no aggregation	Very dense clustered housing in contact with crops, urban areas without vegetation
Type 11	Very dense clustered housing & low aggregation	Very dense clustered housing in contact with discontinuous, sparse vegetation
Type 12	Very dense clustered housing & high aggregation	Very dense clustered housing with continuous, compact vegetation

Table 1: WUI typology

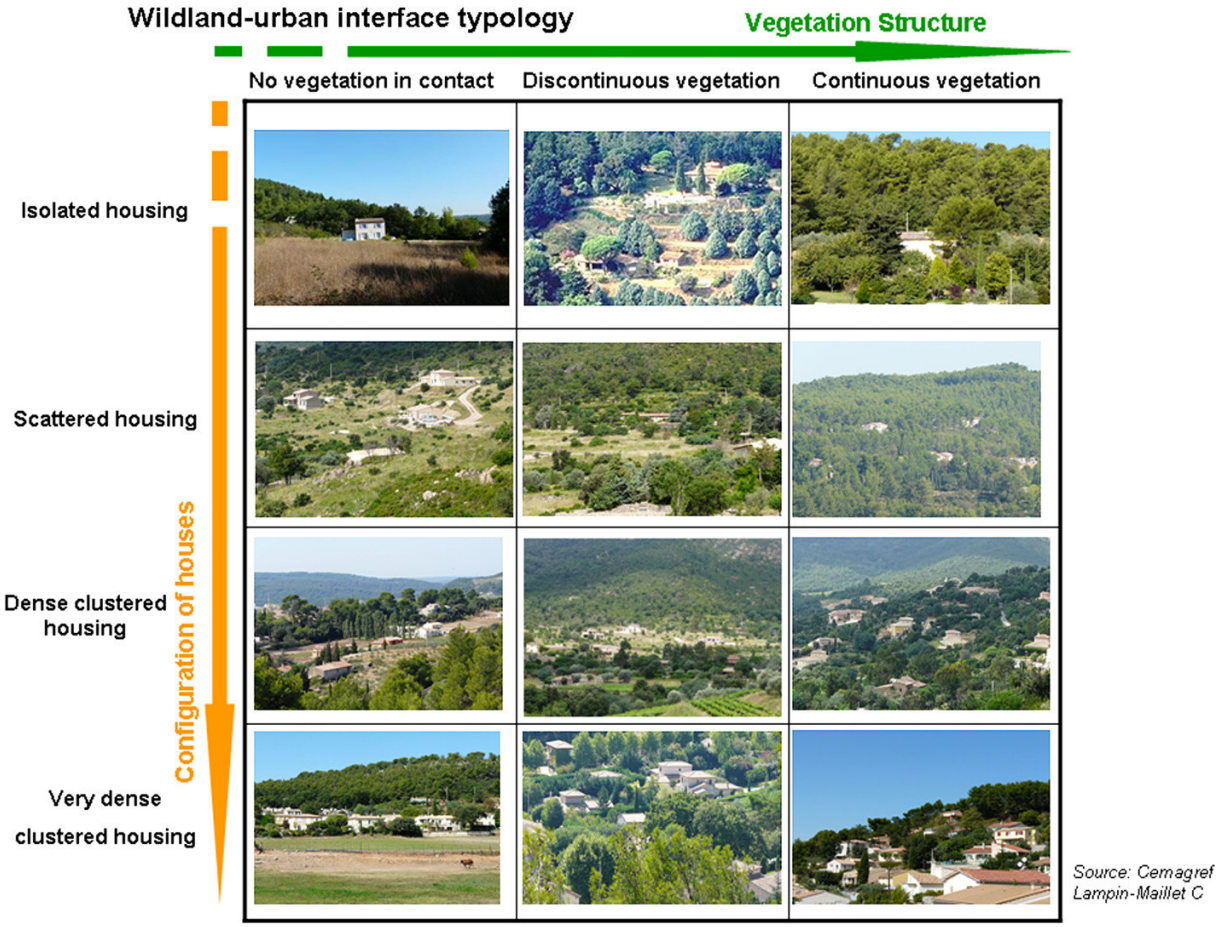


Fig.6: Illustrated wildland urban interface typology

4.2. WUI mapping

The WUI method has been applied on different areas in France: Sections of municipalities, whole municipalities, department (613,000 ha) by different people, agencies. Fig.7 illustrates a wildland-urban interface map at the scale of a municipality.

A specific tool was developed in order to map wildland-urban interfaces and housing configuration automatically. Its name is **WUImap**© Cemagref 2009. The user's notice is presented in the next paragraph whose references are:

Lampin-Maillet, C and Bouillon, C. (2010). **WUImap**© Cemagref 2010: Tool for mapping wildland-urban interfaces. User's notice. 17p.

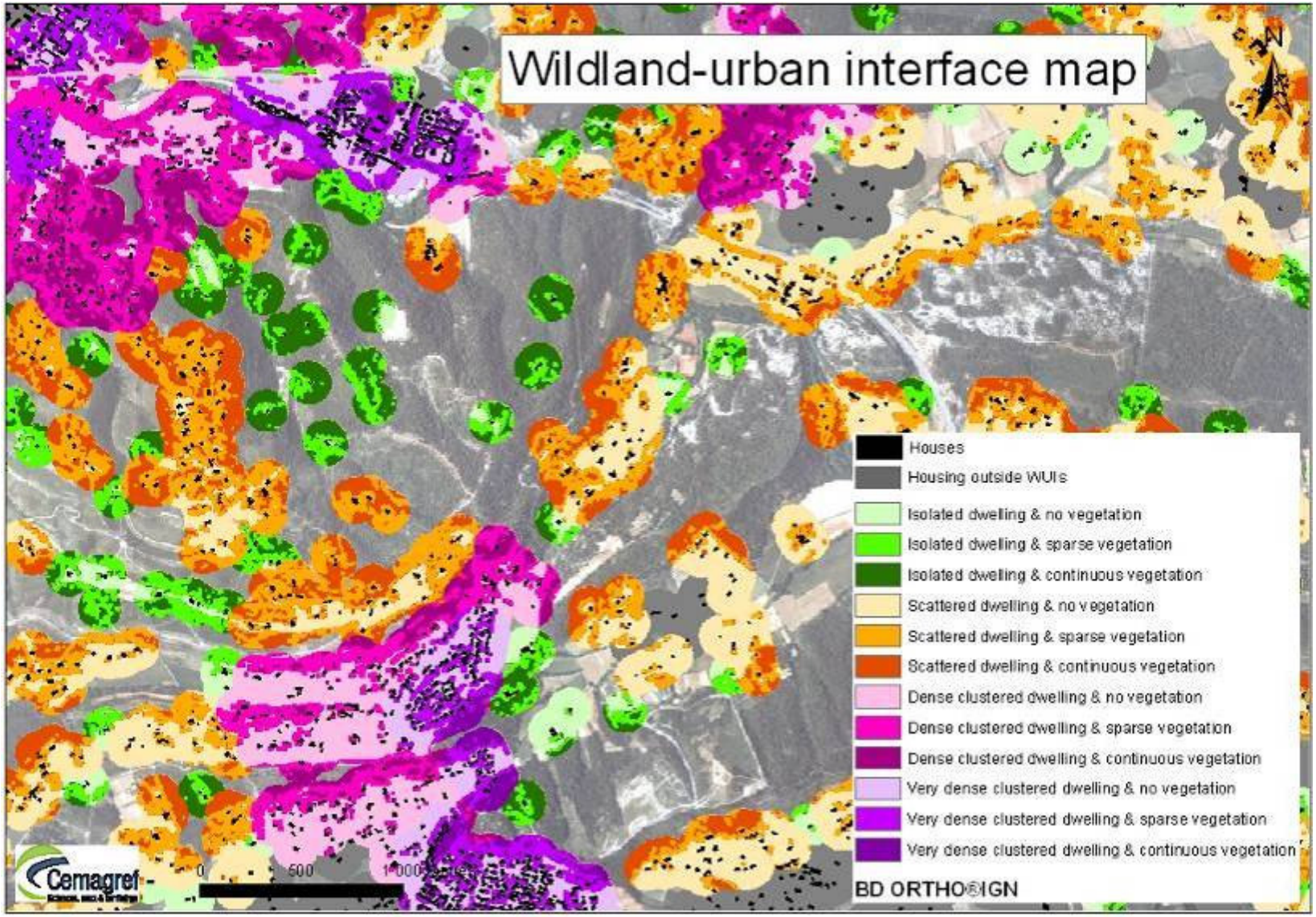


Fig.7: Wildland urban interface map in South of France (site1)

5. A tool for WUI mapping: user's notice

WUImap© Cemagref 2010
TOOL FOR MAPPING WILDLAND-URBAN INTERFACES

User's Notice

[Including in the tool's directory]

We have used © ESRI ArcGis 9.3 software as the programming platform for the development of the tool WUImap© Cemagref 2010.

The program developed in the tool WUImap allows calculation and mapping of wildland-urban interfaces defined in Lampin-Maillet *et al.* (2010a, b). It can also map different configurations of housing referring to the definitions in Lampin-Maillet *et al.* (2009a).

5.1. Requirements

The material used for computing is a PC with specifications such as:

- type of processor : © Intel Xeon - 1.6Ghz
- 3 GB RAM
- hard disk capacity : 1Go minimum

The software requirements are:

- © Microsoft Windows Xp professionnel SP3
- © ESRI ArcGis 9.3
- Python 2.5.1 software (included in ArcGis)

5.2. License

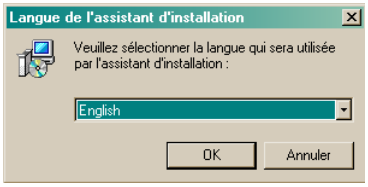
The developed tool WUImap is running with a valid licence ArcGIS 9.3 type « ArcInfo » and for the raster calculations, it used the functions provided by the Spatial Analyst extension.

The program used Python as computer language to write the necessary code for the implementation of the algorithms. Installator used Inno Setup Compiler.

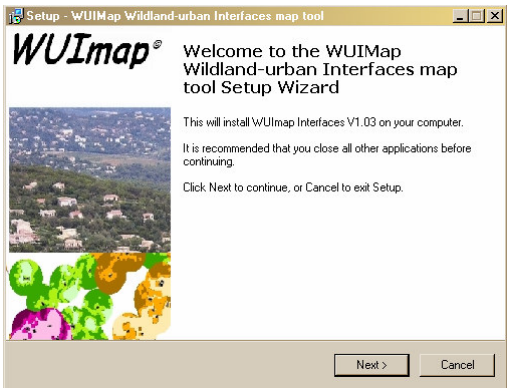
5.3. Installation

Copy installation file [Setup Interfaces Cemagref.exe] on the desk of your PC

Execute this file for installation by a click on the icon:



Follow the process in order to create repertories and icons necessary for the application:



A data set is delivered for tests. It was located in the repertory **C:\WUImap_datatest**

5.4. Data requirements

5.4.1. Types of datafiles

The required datafiles have obligatory the following format:

- geotiff (.tif) for raster formats
- shapefiles (.shp) for vector formats

5.4.2. Other requirements for a performed use of the tool WUImap

5.4.2.1. Geo-referencing

All the files are defined in the same coordinate system (Lambert 93, Lambert 2 Etendu…).

In some conditions if the geo-referencing and coordinate system assigned to any geographic data is missing or not one, errors can appear in the program and can stop the process.

5.4.2.2. Datafile preparation

It is necessary to prepare the different data layers. They have to correspond to the same study area.

So it is recommended to consider a mask corresponding to the study area and to split the different layers according to this mask. The limits of the mask correspond to the study perimeter.

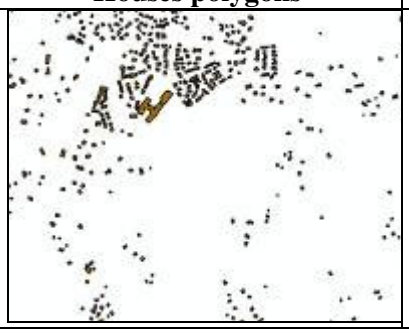
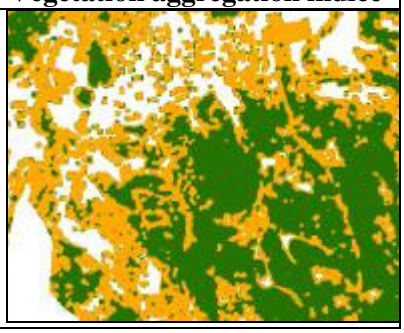
In order to map WUIs, three types of layers have to be taken into account:

- residential house layer,
- layer defining the area where brush-clearing is obligatory,
- layer of the index of vegetation.

For house layer: only houses whose centroid is included in the mask have to be considered.

For brush-clearing layer and index of vegetation: the layers have to be split by the masked area.

INPUTS

Study area	Houses polygons	Vegetation aggregation indice
		

This preparation allows for avoiding calculation errors due to missing data in raster layers.

In the case of house layer, select houses according protocol, that is to say house considered as residential house and whose area is larger than 30m².

It is useful to be sure those polygons of the layer are correct with the command « repair geometry ». It avoids stopping the program.

5.4.2.3. Raster layer resolution

A 2.5 m resolution has been considered in the method. Calculations with WUImap have been carried out automatically with this resolution. But the tool can accept files of aggregation index with a resolution varying from 0.5 m to 10m.

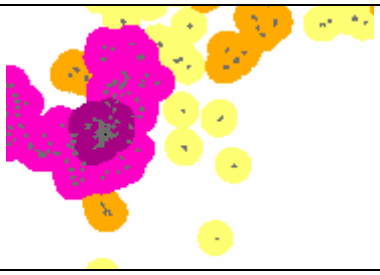
5.5. Results coming from the WUImap tool

Two types of map can be produced using the WUImap tool. Their format is raster format « .tif » (GEOTIFF) compatible with many softwares.

Data are recoded according different classes detailed in following paragraph.

5.5.1. Map of housing configuration

The produced map [housing_configuration.tif] presents the 4 types of housing:

- isolated housing, - scattered housing, - dense clustered housing - very dense clustered housing	

Calculation is carried out on the chosen study area. It distinguishes houses according their belonging or not to the brush-clearing area.

Legend and codes of the map of housing types

Color / code	Types of housing	Zones
0	No housing	**Within the area where brush-clearing is obligatory (corresponding to WUI)**
10	Isolated housing	
20	Scattered housing	
30	Dense clustered housing	
40	Very dense clustered housing	
50	Isolated housing	**Outside the area where brush-clearing is obligatory (OWUI)**
60	Scattered housing	
70	Dense clustered housing	
80	Very dense clustered housing	

This map is carried out with a fixed 2.5 m resolution.

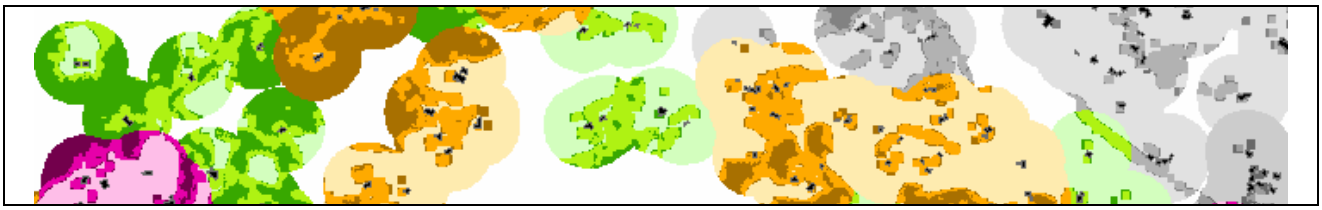
5.5.2. Map of wildland-urban interfaces

The map of wildland-urban interfaces [wui_types.tif] is produced by combination of the map of housing types and the map of vegetation aggregation index (AI).

This map cannot be produced if the layer of vegetation aggregation index is not available

Calculation is carried out on the chosen study area. It distinguishes houses according their belonging or not to the brush-clearing area.

Example of a map corresponding to the legend below



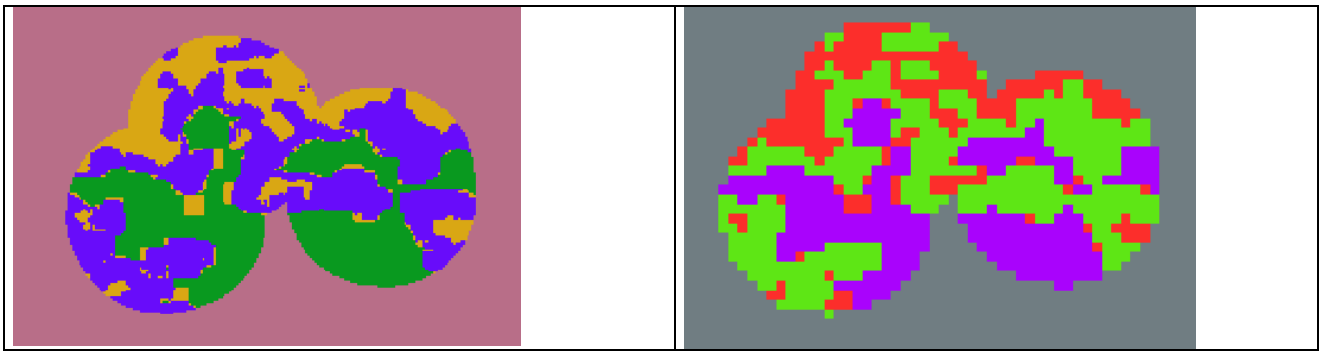
Legend and codes of the map of wildland-urban interface types

Couleur / code	Types of wildland-urban interface		Zones
0	No housing		**Within the area where brush-clearing is obligatory (corresponding to WUI)**
11	Isolated housing	AI nul	
12	Isolated housing	low AI	
13	Isolated housing	high AI	
21	Scattered housing	AI nul	
22	Scattered housing	low AI	
23	Scattered housing	high AI	
31	Dense clustered housing	AI nul	
32	Dense clustered housing	low AI	
33	Dense clustered housing	high AI	
41	Very dense clustered housing	AI nul	
42	Very dense clustered housing	low AI	
43	Very dense clustered housing	high AI	
51	Isolated housing	AI nul	**Outside the area where brush-clearing is obligatory (OWUI)**
52	Isolated housing	low AI	
53	Isolated housing	high AI	
61	Scattered housing	AI nul	
62	Scattered housing	low AI	
63	Scattered housing	high AI	
71	Dense clustered housing	AI nul	
72	Dense clustered housing	low AI	
73	Dense clustered housing	high AI	
81	Very dense clustered housing	AI nul	
82	Very dense clustered housing	low AI	
83	Very dense clustered housing	high AI	

To notice: the resolution of output data of this map is equal to resolution of input data of the map of aggregation index of vegetation (AI):

Examples:

2.5 m resolution	10 m resolution



5.6. Database management

The software installed automatically repertory of data on **C:\WUImap_datatest.**

The repertory for output data is selected by the user and will be used for creation of sub-sets of the database called « Interfaces Results » containing files created in .tif format.

A temporary info-file, TempW, is also created by the program itself and deleted by this program at the end of the process.

It is important to delete the following files before to execute new process if program doesn't do it itself automatically:

- WUImap Results
- TempWUImap

5.7. Functioning

5.7.1. Setting up

Click on the icon on the desk Windows

or on :

Program appears in a unique window with the whole of functionalities:

5.7.2. Input files

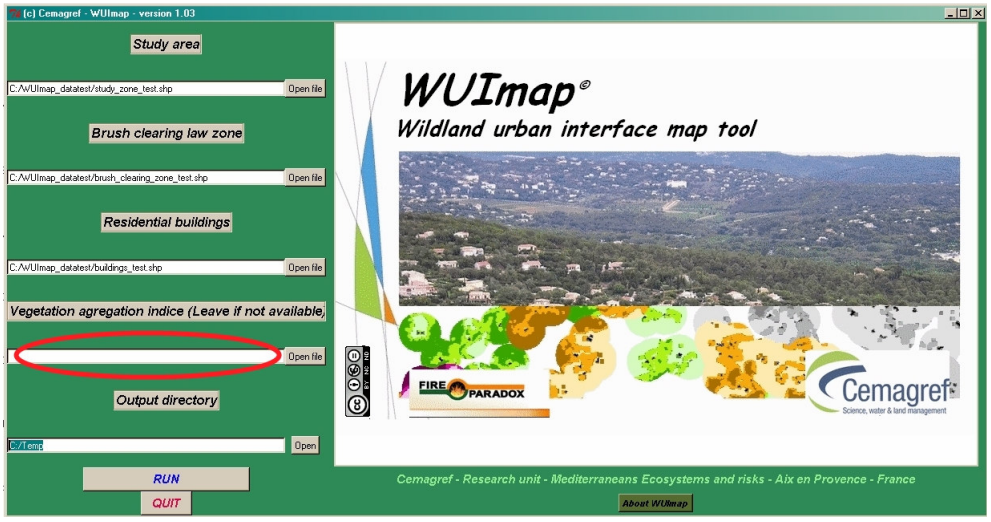
The three following files are necessary to execute the program

- **Perimeter of the study area** (file type: shapefile .shp - polygone): this file presents limits of the study area. For example it corresponds to the area of a municipality. This file corresponds to a geographical mask within calculations are carried out on the other data.
- **Area where brush-clearing is obligatory** (file type:shapefile .shp - polygone): this file corresponds to the area where brush-clearing is obligatory (forested area surrounded with a 200 m buffer)
- **Residential houses** (file type:shapefile .shp - polygone): this file is composed of polygones corresponding to residential houses whose surface is larger than 30m².

Important Remark: the referenced method used polygones (and not points) to represent houses

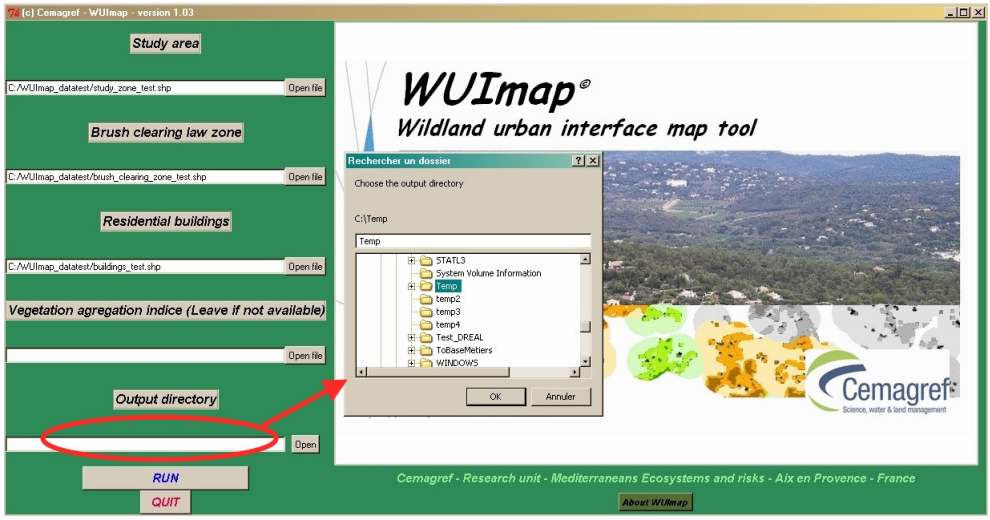
Choose files corresponding to the previous different categories:

If the file corresponding to vegetation aggregation index is missing :
Leave out the box **Aggregation Index of vegetation AI**



5.7.3. Choice of directory for output data files

This directory will be created according to the requirements of the user, but its name has not yet been specified in terms of characters or spaces. Produced maps will be stored in this directory "map of housing types" and/or "map of wildland-urban interfaces" in geo-referenced format TIF.



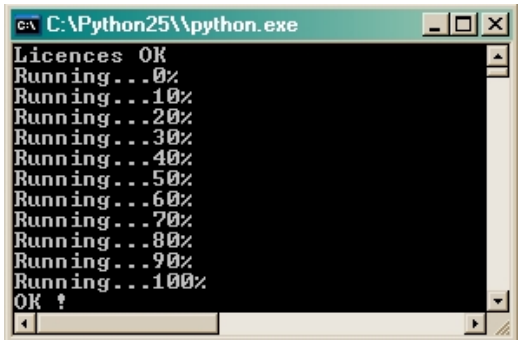
It is always possible to modify selected files and the directory for output data files with a new selection.

5.7.4. Calculation process

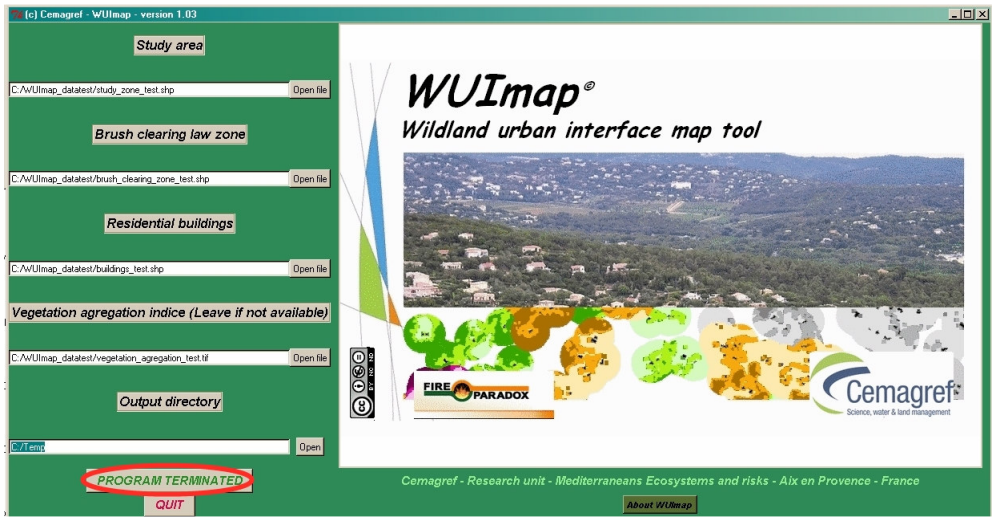
Click on « **RUN** »

The program is running… wait some times…

A command windows Dos appears. The program which is in progress can be followed.



The end of calculation can be observed with the following message « **PROGRAM TERMINATED** »



5.7.5. End of program

Click on « **QUIT** ». The program is shutting-down.

Important remark: To execute the program again, a new output datafile repertory has to be created or the previous output datafile repertory has to be deleted !

5.8. Program test

A dataset is provided in order to test the program.

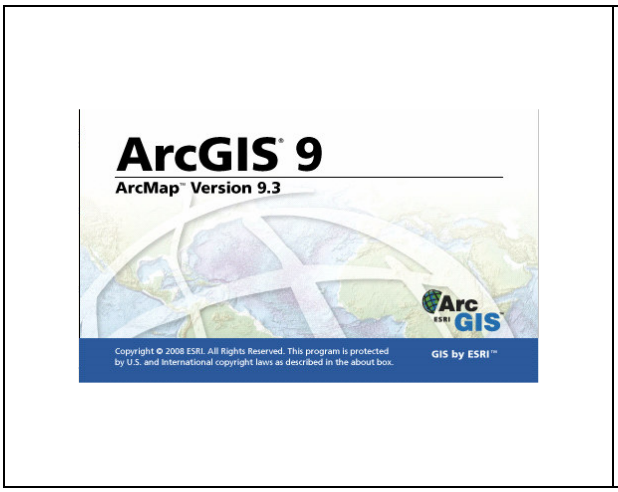
To set up the program with the present files on the repertory **C:\WUImap_datase**

5.9. Display and results checking

To display results click on 

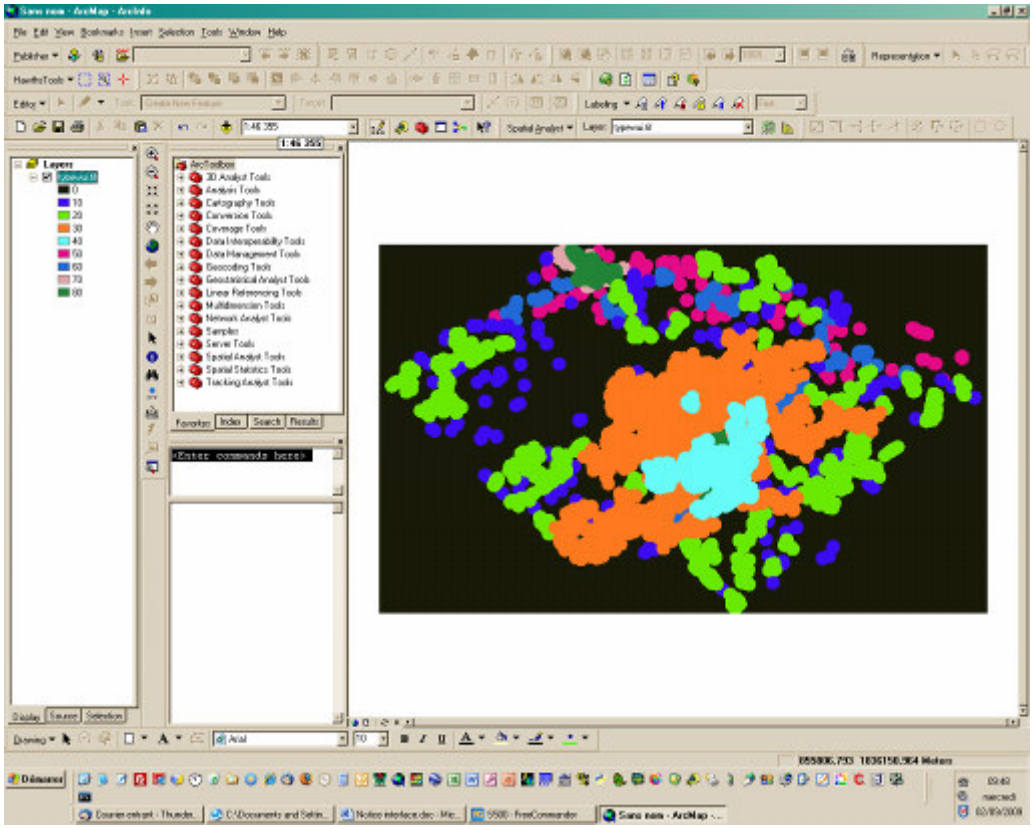
Execute Arcgis and load created images in :

« your chosen repertory **+\WUImap_Results »**

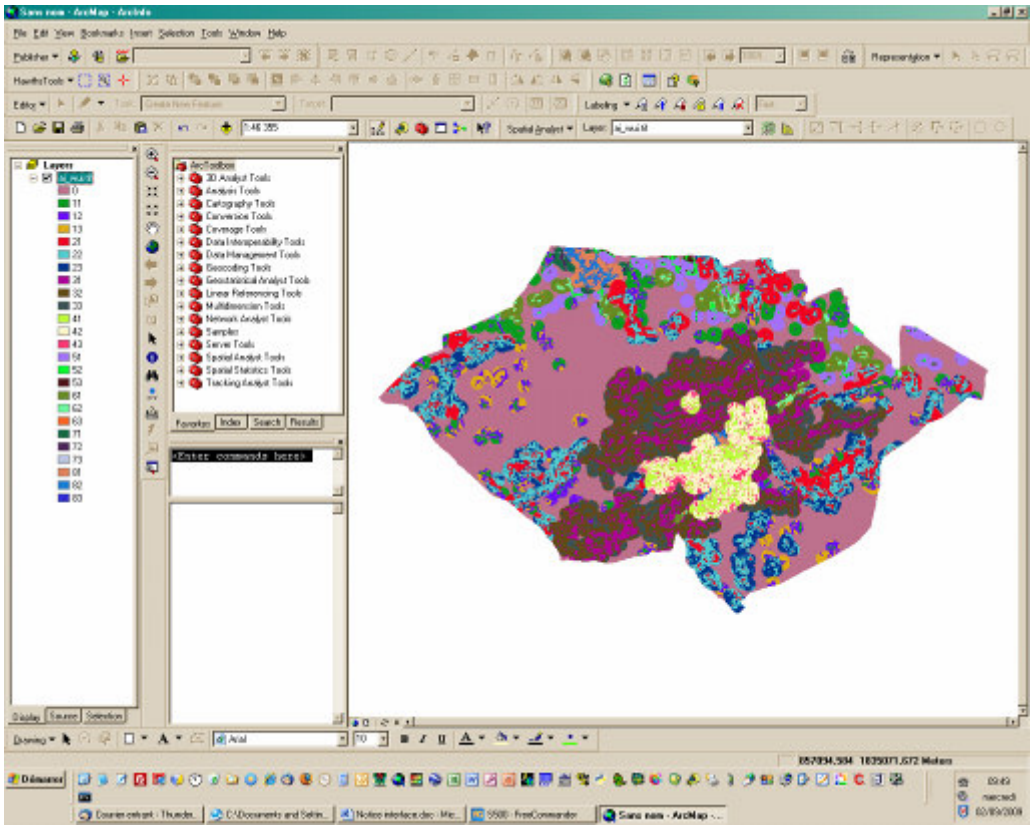


Display images: The resulting images of the test have to be similar as the images below:

Types of housing : [housing_configuration.tif]

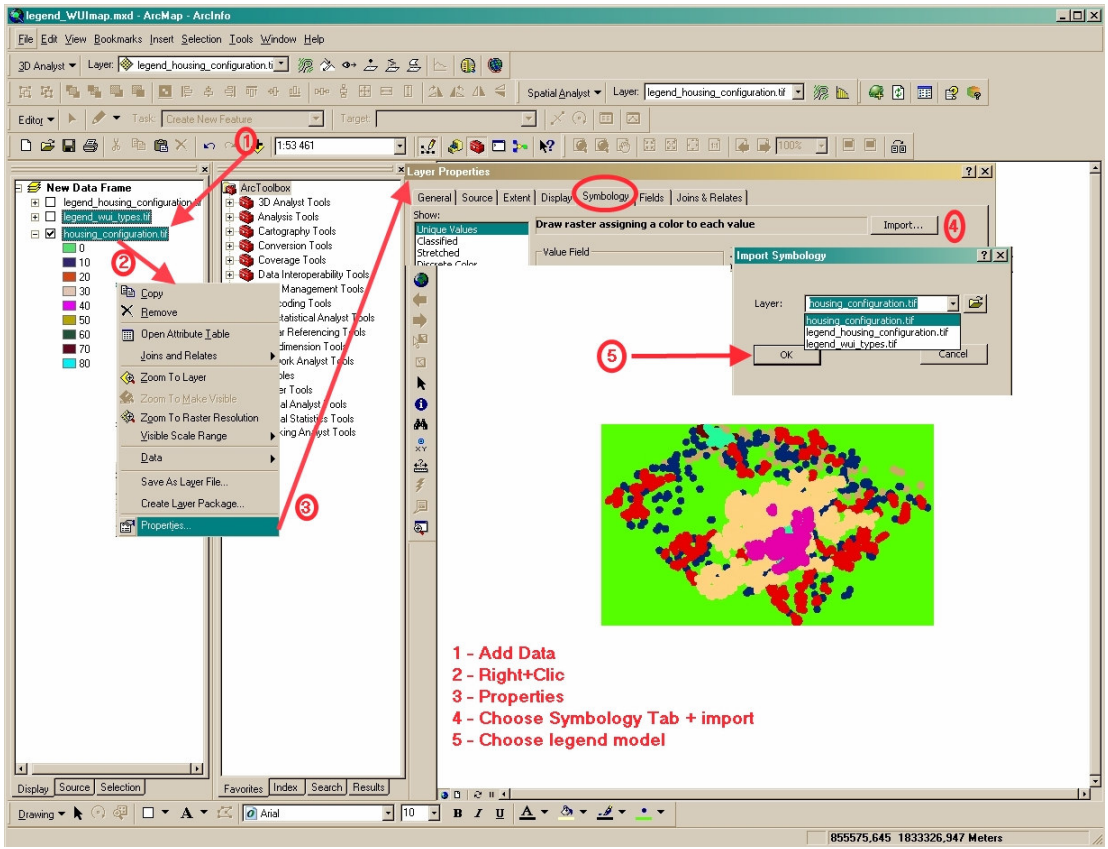


Wildland-urban Interfaces: [wui_types.tif]

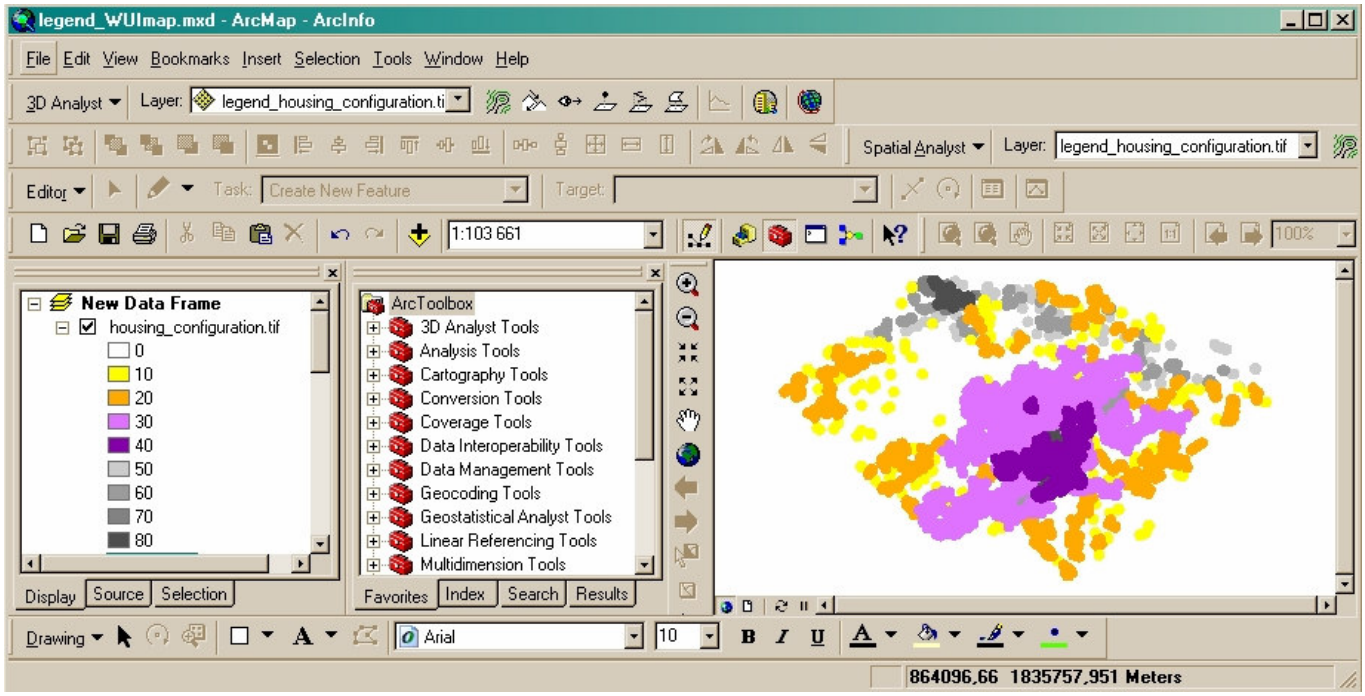


Remark: The program can manage a missing class of housing because if no house existing in this class. Mapping process takes into account this singular case without disfunctioning.

Apply the legend and predefined colours to obtain final result.



Legend results



5.10. Dis-installation

In order to delete the program on the computer click on the menu of programs

(It is necessary to have administrator rights)

5.11.Sofware restrictions

This program has been tested with a range of material configuration described earlier. Some limits can be exposed:

- Maximum size of raster as input data is 11000 x 14000 pixels, according 2.5 m resolution, around 100.000 ha.

- Maximum number of entities (polygones corresponding to houses) around 40 000 – (corresponding to a municipality of 80.000 inhabitants).

6. Adaptation in other European countries: Example of Spain

The WUI method is particularly well adapted to the French context but it can be adapted according context of different European countries.

- Criteria of distances and number of houses that were taken into account to determine housing configuration types could be changed according a specific local context of the urban organization in the country ;
- Houses considered in wildland urban interface are located at 200 meters from forests or shrubland in French context because of vegetation clearance regulation, this distance could be changed according other regulations observed in other countries or because of spot fire distance.
- The radius of 100 m is relevant for France because considering the WUI definition, the WUI area is located up to 300 metres from massifs (200 m + 100 m) so it is also significantly exposed to firebrands from vegetation in the case of fire. Therefore, in France, WUIs are included in the French Forest Orientation Law of July 9, 2002. This Law makes provision for brush clearing being obligatory within a 50-metre perimeter around each house located at a distance of less than 200 metres from forests or shrublands. In other European countries, the effective fuel treatments occur only with a 10-30 meter radius by specific regulation.

6.1. Example of the western of Madrid in Spain

The methodology developed in the French context - to map and characterize wildland-urban interfaces (WUIs) - was adapted for the local case of study selected within the framework of the doctoral thesis “Wildland-urban interfaces as new fire prone areas in Spain” (Herrero, 2010). The sources of information used in the WUI calculation process were National Forest Map of Spain for vegetation, aerial photography and layer of houses.

- Calculation of the aggregation index (AI) from the vegetation raster layer using the FRAGSTATS software have been carried out. The classification of the AI in three classes was realised according to the statistical results of the vegetation patterns in the study area, with as result a modification of thresholds.

- The following four types of habitat were identified: isolated, group of buildings, urbanization and urban center with distances and number of houses considered differently.

- Delimitation of the WUI surface: a buffer of 100m around all the buildings located at a distance less of 400 m from the forest.

Thus the method can be transferred to other countries with local parameters for drawing maps adapted to others contexts. The maps are also done for the western of Madrid in Spain (Fig.8 and Fig.9).

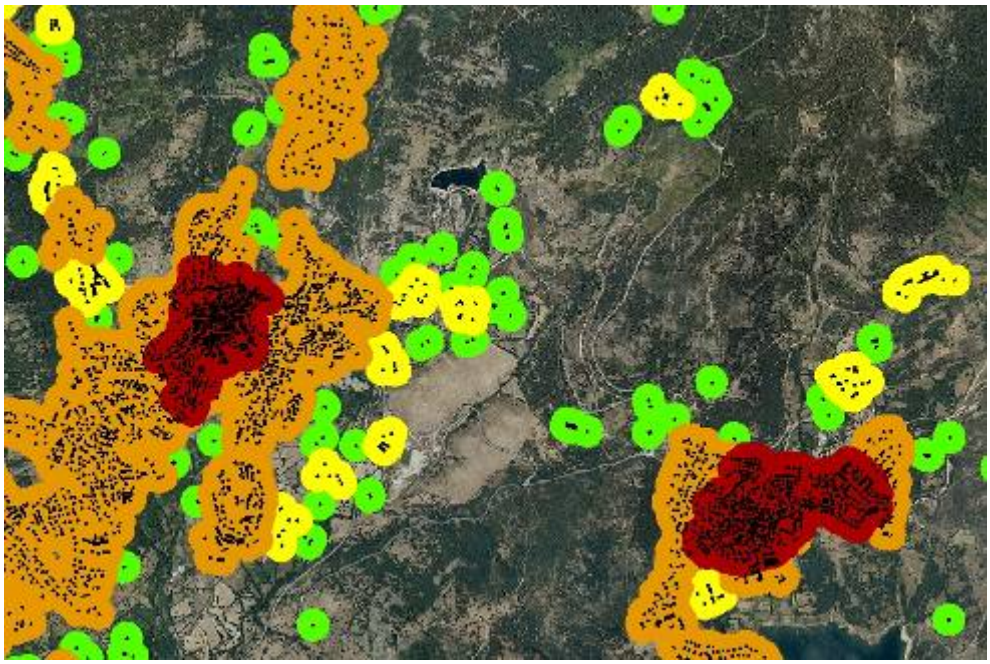


Fig.8: Map of Housing configuration in the western of Madrid in Spain (site2)

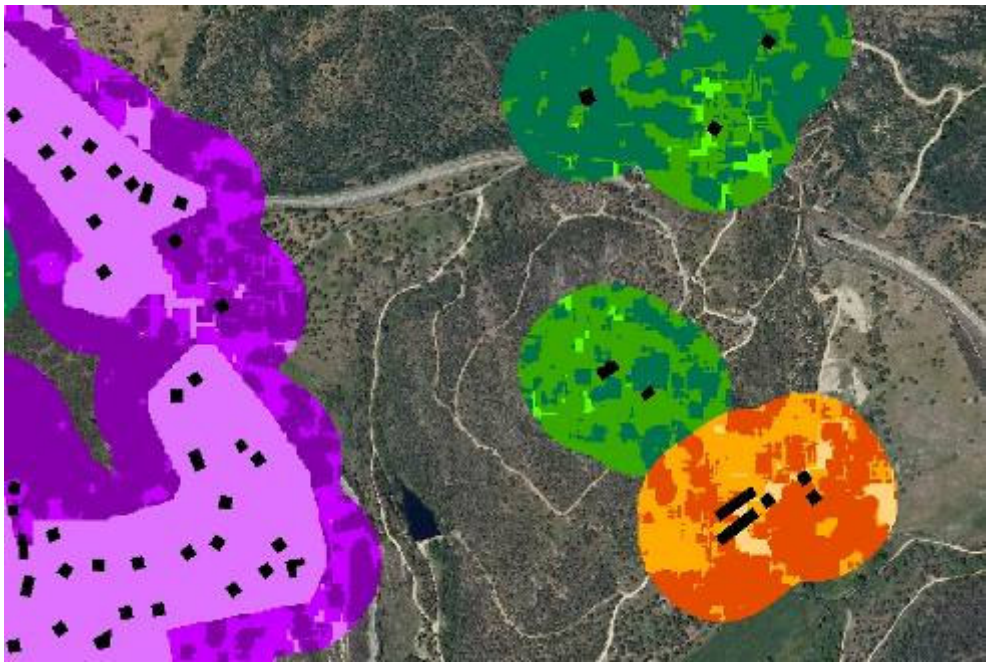


Fig.9: Map of wildland-urban interfaces in the western of Madrid in Spain (site2)

6.2. WUImap© Cemagref 2009 - Spanish adaptation

A Spanish version of **WUImap** tool was under development adapting parameters relative to housing and vegetation to the Spanish context.

A beta version was already developed and was able to calculate WUI from an area around Madrid. The interface software is represented below Fig.10.

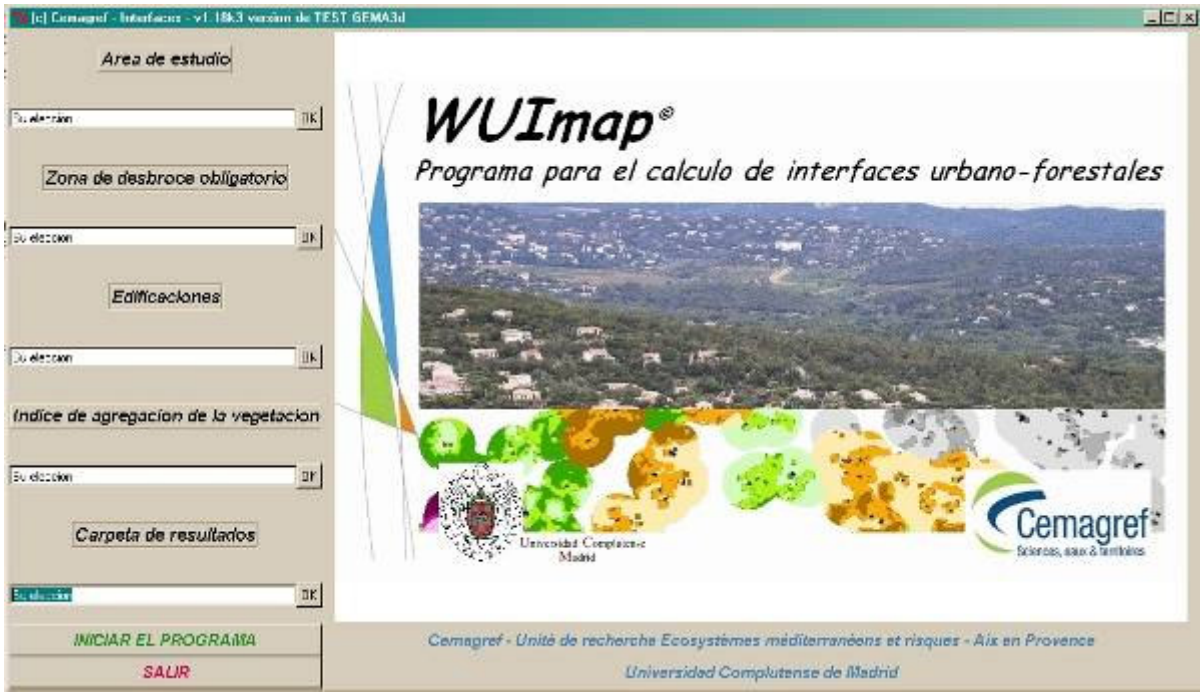


Fig.10: Interface software of the Spanish adaptation of the WUI map tool

Lampin-Maillet, C., Bouillon, C., Herrero, G. (2009). **WUImap**© Cemagref 2009-Spanish adaptation: Tool for mapping wildland-urban interfaces. User's notice. 19p.

7. Specific use of WUI map

7.1. Calculation of the Fire Hazard in WUI

Within a part of the study area on Greek site 3, WUI were delineated. The location of the WUI total area is shown in Fig.11 below:

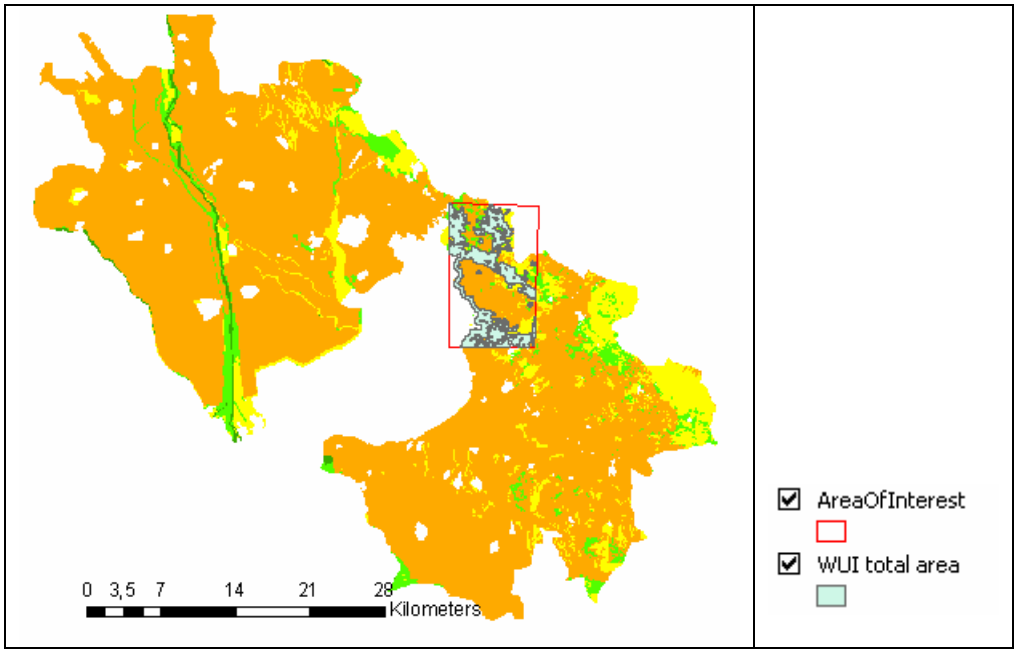


Fig. 11: Location of WUI delineation and WUI total area (site 3)

Fire Hazard assessment within the WUI was obtained by means of combining WUI total area with Hazard Index (HI) calculated in the internal report IR5.1.4 (Lampin-Maillet *et al.*, 2009b) and mapped by means of the tool presented in P5.1.7 (Mantzavelas *et al.,* 2009).

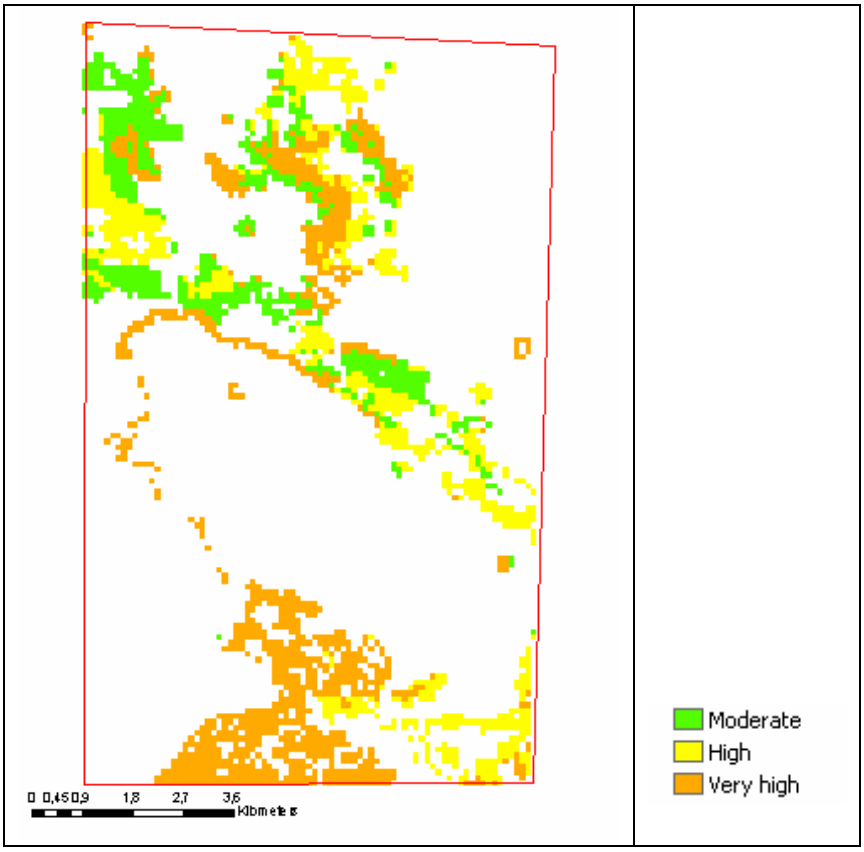


Fig. 12: Distribution of Hazard Levels in WUIs (site 3)

Results of Fig.12 showed that from 2625 Ha of the total WUI area, Hazard Index was "Moderate" for 649 Ha (24.72%), "High" for 849 Ha (32.34%) and "Very high" for 1127 Ha (42.93%).

7.2. A specific approach of fire risk assessment in WUIs by means of a total risk index

The work presented hereafter is aiming at the definition of a process for obtaining a fire risk map through the calculation of a total fire risk index based on a WUI map elaborated according the process referenced to Lampin-Maillet *et al.* (2010a, b) presented in the previous paragraphs.

Considering the WUI map, a new perception of the territory is possible: WUI area, and outside WUI area. Because of their high vulnerability, ignition probability and combustibility, it is important and efficient to focus risk assessment in the WUIs. The method developed so allows assessment and mapping of fire risk levels.

7.2.1. Spatial analysis based on WUI map

A spatial analysis on the studied territory was performed in order to establish relationships between the distribution of fire ignition points and burned area as and different land cover data, WUI types, environmental data. For that:

- A digitized database of fire ignition points created by the French National Forest Institute (ONF) was used. It comprised fire ignition points during the 1997–2007 period corresponding to a fire area of more than one hectare. Around 565 fire ignition points were located in the study area.
- A digitized database of burned area produced by the Administration of Agriculture and Forest of Bouches-du-Rhône was used. It comprised 109 wildland fires recorded study area between 1990 and 2007.
- At last, a thematic land cover layer obtained from the Spot Thema database elaborated in 2004 by CNES, Provence-Alpes-Côte-d'Azur Region and a Spot Image from Spot 5 satellite imagery on the study area were used. The detailed level describes the territory (urban, agricultural and natural components) at the 1: 10 000 scale.

Thanks to relationships established between WUIs and fire indicators calculated with past fire data (fire ignition density and burned area ratio), it is possible to point out specific WUIs which present a high level of fire risk. Fig.13 shows that WUIs corresponding to isolated dwellings present a high level of fire risk due to high levels of ignition density and burned area ratio. WUIs corresponding to very dense clustered dwellings present also a high level of ignition density linked with human activities but a low burned area ratio (high urban component and low vegetation component) (Lampin-Maillet et *al.* 2010a).

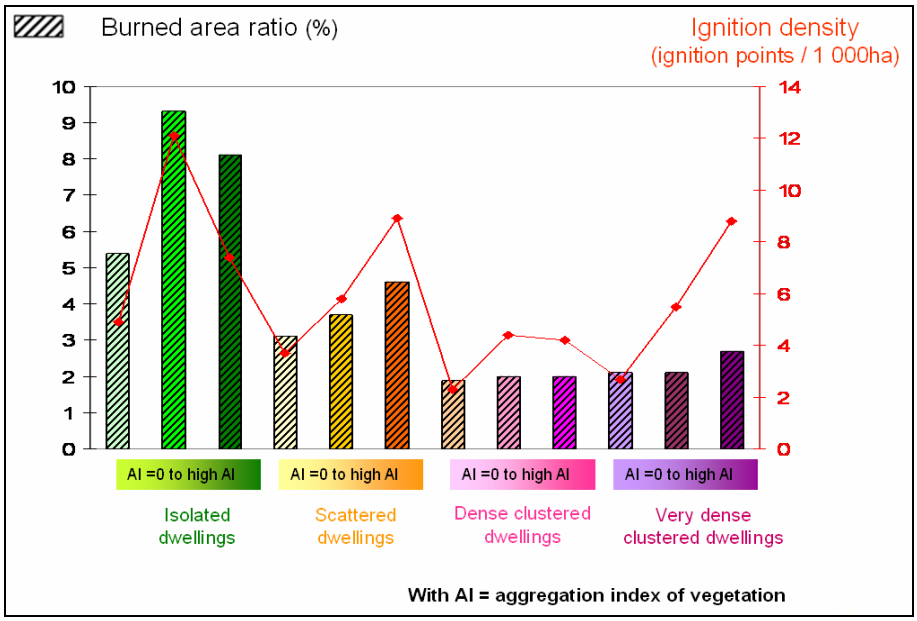


Fig.13: Fire ignition density and burned area ratio according to WUI types

7.2.2. Total Fire risk models

The spatial analysis also allowed revealing a set of conditions that may fire risk exist in WUI: housing density, road density, vegetation more or less continuous…Results of this analysis are expressed through three main functions (or fire risk indicators) based on statistical multiple regressions with R^2 more or less high:

- **Fire Ignition Density FID** = Exponential function (territory type, land cover type, housing density) *with R^2 = 51 %* ;
- **Wildfire Density WD** = Exponential function (territory type, land cover type, housing density, resinous stands, very warm exposure) *with R^2 = 57 %* ;
- **Burnt Area Ratio BAR** = Polynomial function (territory type, land cover type, housing density, road density, country road density, garrigues, altitude, low aggregation of vegetation) *with R^2 = 36 %.*

A total index of wildfire risk was performed combining the three previous indicators (Lampin-Maillet, 2009). In reference to fire risk definition, each of the three indicators is bearer of information of hazard and/or vulnerability: Fire Ignition Density **FID** and Wildfire Density **WD** are particularly concerned by fire occurrence (ignition probability and wildfire probability) and Burnt Area Ratio **BAR** is related to hazard and vulnerability through the intensity element. Their combination can contribute to a pertinent and efficient assessment of fire risk. So a **Fire risk total index RI** has been built corresponding to a linear combination of the three indicators having the same weight but corrected by their explanation level (R^2 value).

In the case of the study area the equation is:

Fire risk total index RI = 0.89 FID + WD + 0.63 BAR

With respectively a correction of 0.89 corresponding to the ratio 51% / 57% for FID, a value of 1 (the best R^2 value) corresponding to the ratio 51% / 57% for WD and a correction of 0.63 corresponding to the ratio 36% / 57% for BAR.

7.2.3. Fire risk mapping in WUIs and analysis

A map of this fire risk total index can be produced as illustrated at Fig.14 in the South of France.

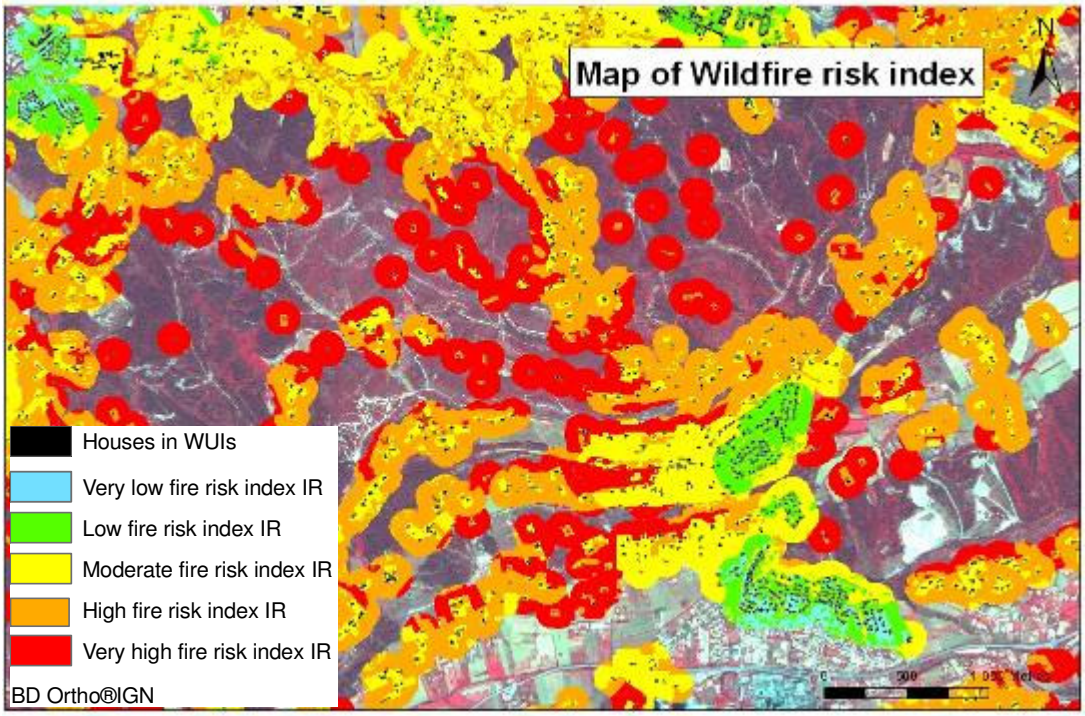


Fig.14:Map of wildfire risk global index in WUIs in South of France

Certain types of WUIs represent a high level of fire risk in terms of fire ignition density, wildfire density and burned area ratio. Regarding fire ignition density and burned area ratio, isolated WUIs with low and high aggregation indices of vegetation presented the highest values. Scattered WUIs with both low and high aggregation indices of vegetation also represented a high level of fire ignition density and burned area ratio even if these values were lower than those for isolated WUIs. Results also highlighted the fact that the burned area ratio generally decreased from isolated WUIs to dense and very dense clustered WUIs, and also decreased from a high aggregation index to a zero aggregation index (Lampin-Maillet *et al.* 2010a).

A tool has been carried out in the **Product P5.1.7 Development of a gis tool to produce fire hazard maps User's manual** (Mantzavelas *et al.,* 2009) in order to map the IR Index which is a combination between the Ignition Density Index (DE), the Wildfire Density Index (DI) and the Burned Area Index (SB). The function uses as input WUI typology, ecological, topographical and socioeconomic data. Data are processed according to the methodologies described in the internal report IR5.1.4 of Fire Paradox (Lampin-Maillet *et al.,* 2009b). The output is an IR map.

8. References

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Caballero, D., Giroud, F., Picard, C, Xanthopoulos, G. 2004. EUFIRELAB/ Euro-Mediterranean Wildland Fire Laboratory, a "wall-less" laboratory for wildland fire Sciences and technologies in the Euro-Mediterranean Region - Deliverable D-10-01-Wildland-Urban Interface Management: A state of the art. http://www.eufirelab.org/deliverable.php?unit=10. 28p.

Caballero, D., Beltran, I. 2003. Concepts and ideas of assessing settlement fire vulnerability in the W-UI zone. In Proceedings (Eds Xanthopoulos, G.) of the international workshop WARM, Forest fires in the wildland-urban interface and rural areas in Europe: an integral planning and management challenge. Athens, Greece. pp 47-54.

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QUALITY EVALUATION REPORT (QER)

General comments

Specific comments

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