ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Anticipation of future risk due to land cover change and WUI extend. Application to the Baronnies Provençales Regional Natural Parc (France)

Eric Maillé*, Christophe Bouillon

[1]*French National Research Institute for Agriculture, Alimentation and Environment (INRAE), RECOVER joined research unit, Aix-en-Provence, France {eric.maille, christophe.bouillon}@inrae.fr*

**Corresponding author*

Keywords

Land Use Land Cover Change, Wildland-Urban Interface, Dynamic Modelling, Simulation, Risk Mapping

Abstract

We propose a modelling framework aimed at representing change in fire risk level due to land cover change, and more specifically to change in the map of Wildland Urban Interface (WUI). The framework is composed of one module that simulates transitions between classes of the land cover matrix using a "state-transition" model, while a gravity-like model is used to represent discontinuous urban spread in relation to the land cover matrix dynamic. The WUI map is calculated using the WUIMap model at each step of time: this later method crosses some fuel types and classes of scattered buildings spatial distribution. A risk level is associated to each interface type based on a rules based assessment of hazard and vulnerability components.

The methodology was applied to the French sub-mediterranean Baronnies Provençales Regional Natural Parc. This area was up to now few prone to forest fire, mainly due to its elevation, but climate change scenarios let anticipate the average climate fire risk level will drastically increase in this area during the next decades. The objective was to assess the increase part of risk level originated by land cover change, and provide a spatial representation of this change. Results show that although spread of scattered buildings will remain low in terms of number of buildings, its impact on risk components, and specifically on territorial vulnerability, is considerable, as a low number of buildings may impact very large portion of the territory in terms of risk. In a further step of this research, new multicriteria models will be used to refine risk assessment.

1. Introduction

Drivers of wildfire risk change are numerous, including climate change and land cover change (FUME 2013). Because of climate change, wildfire risk will raise in both latitude (toward the North) and altitude. However, in many situations, climate change may be considered uniform at the scale of local territories. On the other hand, land cover change affects the spatial distribution of the risk within local territories, especially if the global risk, associating hazard, vulnerability and exposure components (IPCC 2014), is considered. Together with change in vegetation fuel, dynamic of wildland urban interfaces is a key factor of change in such global risk.

Anticipating future fire risk at local scale is a key element for land management and planning activities in wild fire prone areas. We propose a method of evaluation of risk change in relation to WUI dynamic. It is applied to one backside French South-Eastern supra-Mediterranean protected area: the Baronnies Provençales Regional Natural Parc area (Parc Naturel Régional des Baronnies Provençales). It gathers some 116 Eurostats Local Administrative Units (LAU, formerly NUTS 5), ie. "communes". Due to its elevation (from 300m up to 1500m), and the attenuation of the Mediterranean influences, this area was up to now relatively little prone to forest fires. Different works (Chatry et al., 2010, Galizia et al. 2021, Romero and Ganteaume, 2020) show that this situation will change in the next few decades due to climate change and land cover change.

2. Objectives

The objective is to provide an assessment of future change in risk spatial distribution related to change in WUI extend in a low mountain protected area. The risk to be assessed is the global risk, integrating hazard, vulnerability and exposure (Birkmann et al, 2014). The temporal perspective, ie. the simulation time period of the modelling exercise, is the next two to three decades (2050-2060).

3. Method

3.1. Risk assessment at WUI

WUI typologies, which characterizes the relationship between fuel areas and areas of vulnerabilities, are used as estimators of global risk level. Change in risk spatial distribution is assessed based on change in WUI map. The WUI typology used is the WUIMap (Lampin-Maillet and Bouillon, 2011) model one. A scale of risk associated to WUI types is proposed, combining a hazard component and a vulnerability component to calculate a global risk index for each WUI type (figure 3).

3.2. Future WUI change

Future WUI change are simulated based on a couple of Land Use/Land Cover Change (LULCC) change models (Maillé and Espinasse, 2012). This approach separates two main types of Land Cover Change (LULCC): i) scattered buildings diffusion-densification simulated by a gravity-like model and ii) the change in land cover "matrix" simulated by a "state-transitions" model. It also separates and articulates land cover change processes (physical) and some land uses change processes (symbolic).

On a conceptual level, the model considers land cover classes, representing land cover types. However, land cover classes are endowed with attributes (similarly to computer sciences "classes") and have their own behavior (dynamic). We call legend (or nomenclature) the list of the land cover classes. Patches are spatial instances of a class (polygon, pixel, continuous set of pixels…). The model then represents two types of dynamic: semantic transitions (change of classes) and state change (change in attribute values).

The model is based on a very simple legend (nomenclature) of 4 (plus 1) land uses/land cover dynamic classes: i) F: Forest lands, ii) W: non-forest wildlands (opened and half-opened, including some pastoral lands), iii) A: agriculture (cultivated, excluding pastoral lands), and iv) U: urban and other artificialized lands (including roads and infrastructures). One last land cover class gathers land covers supposed static (water areas and some mountain mineral areas). WUI land cover classes are not part of the legend (nomenclature), but are derived from the model outputs.

The state of land cover classes is represented by attributes, depending on the LC class. 3 main state attributes are represented: fuel load (concerns the only W land cover class), potential of building density (all non-urban dynamic land cover classes) and anthropogenic pressure (only W land cover class). Attributes values are normalized between 0 and 1:

- for fuel load, 0 is the minimum load (herbaceous stratum only), 1 is the forest state ;
- for potential of building density, 0 is a non-buildable area, 1 is an area that can evolve up to continuous urban, according to the land planning document ;
- for anthropogenic pressure, 1 represents "fully" used area (no free ecological dynamic possible: urban and periurban lands, cultivated areas, high pressure pastoral area), 0 represents area with free (or quasi-free) ecological dynamics (totally abandoned areas).

Among the land use change processes represented by the model, the buildable state of land patches is a key factor of WUI dynamics, linked to land planning activity. However, our approach is purely geographic, as the only variables that drive the dynamic are than land cover and topography. The underlying anthropogenic and/or natural processes determining land cover changes are not explicitly represented. For example, change of one given land patch from not buildable (0) to fully buildable (1) (symbolic state) only depends on initial land cover class of the patch, continuity with other buildable areas, local initial building density and some other topographical variables defining an "urban potential" (average altitude, slope and aspect of the patch). A stochastic residual comes to modulate the results of the deterministic calculation, in order to propose a normal representation of the spatial distribution of the unknown information (typically, personal human decisions).

Finally, an interface map is calculated at each step of time using the WUIMap model. This one cross some specific classes of building density and classes of vegetation aggregation. This model was demonstrated to provide good indicators of the global (hazard/vulnerability) risk (Lampin-Maillet & Bouillon, 2011). The different classes of WUI stemming from the WUIMap model are provided in the legend of fig 3.

The following table proposes a synoptic view of the model and its relationship with the WUIMap risk model.

Table 1: Synoptic view of the WUI change model and its relationship with the WUIMap risk model. *Note that W->F semantic transition results from two possible dynamics: forest spread or afforestation, for which the W->F transition automatically occurs when the fuel load of a W patch reaches 1. **Also the Non-U -> U transition automatically occurs when building density overcomes the WUI very high-density threshold.

	Buildings overlay	**Land use/land cover "matrix"**							
		Physical land cover				**Symbolic land use**			
Class of spatial dynamic	Diffusion	Semantic transitions (change in LULC class)			Attribute change	Semantic transitions		Attribute change	
Dynamic	Scattered buildings diffusion/densification	Forest advance (W -> F)*	Afforestation (W->F)*	Urbanization** (NonU→U)	Natural fuel load increase of W FL ∈ [0-1]	Not buildable -> buildable	Land abandonment (A->W)	Potential of building density pBD ∈ [0, 1]	Antropogenic pressure AP ∈ [0, 1]
Concerned classes	A,F,W	W	W	A,F,W	W	A,F,W	A	A,F,W	W
Spatial representation	Point	Pixel	Polygon	Polygon	Polygon	Polygon	Polygon	Polygon	Polygon
Main dynamic factors of the change	- Local building density - Potential building density	Anthropogenic pressure (AP) -Forest neighborhood	-Fuel load (FL=1)	-local building density (lBD)	-Anthro-pogenic pressure (AP)	-Urban neighborhood -Local building density lBD -Urban potential	-Urban neighborhood -Local building density lBD -Agriculture potential	-Urban neighborhood (UNB) -Local building density lBD	-Building density (lBD) -urban neighborhood
Main static factors of the dynamic	- Urban potential	-Forest potential			-Forest potential			-Urban potential	-Pastoral potential
Derived outputs	Local building density lBD ∈ [0,1]	Forest land and neighborhood		Urban neighborhood (UNB)	Fuel load and structural index			Wildlands state and neighborhood	
WUIMap inputs	Buildings density (low-high)	High fuel aggregation WUI types		Very high building density WUI type	Intermediate fuel aggregation WUI types		Low fuel aggregation WUI types		

3.3. Data for calibration (diachronic mapping), validation and scenarios

Parameters of the model are calibrated based on diachronic mapping. Three main data sources are used:

- French cadastral database ("DGI Majic 3") allowed assessing the "scattered building dynamic", for each of the commune. This database contains the buildings, georeferenced, with their date of construction, unless for ancient one (before 1930). It is so possible to assess an historical rate of spread of scattered buildings for each commune.
- Land cover database, including Corine Land Cover 1988/1990, 2000, 2006, 2012, 2018, and *Crige* regional land cover database 2006, 2014, 2018. These database are jointly used:
- Satellite images for date older than 1988 as well as downscaling the oldest land cover database, CLC1988 notably, in order to improve inter-date consistency.

These data allowed calculating different parameters for different contexts (for each of the communes (LAU) – for instance) of the model including notably:

- rate of spread of scattered building, in relation to topography and urban environment (urban potential)
- rate of spread of forest land on opened and semi-opened wildlands, in relation to topography (forest potential)
- speed of closure of wildlands in relation to the forest potential
- etc.

More complex "atomic models", ie elementary models that are not modules of other higher lever models, are also calculated. Typically, an atomic model is specified, based on GLM analysis of past data, for assessing the rate of land use transitions such as land abandonment probability, in relation to agriculture potential (topography, shape of the patch, urban neighborhood…). A GLM model of change from not buildable to buildable classes (potential of building density different from 0) in relation to the contextual building density and urban neighborhood is also specified. To do so, sample of patches are drawn at random and transition model are calculated by logistic modelling. Sub-samples of the patches are kept for validation.

Based on these parameters assessments, different scenarios are defined, which are specified by tuning the values of some of the parameters: protection of the environment, conservation of agriculture and forest, economic development, and one projective scenario (simple projection of the current dynamics):

- ***Scenario "protection of the environment":*** Preservation of natural spaces is favored without strong demographic impetus, which retains its trends (lower rate of discontinuous urban spread than measured in the past). On the other hand, the scenario promotes livestock farming to maintain open natural spaces (low rate of wildland closure).
- **Scenario "*conservation of agriculture and forest*"**: it promotes the maintenance of agricultural activity and production (low rate of agriculture land abandonment), as well as livestock farming to maintain open relict natural spaces (low rate of wildland closure). It also promotes logging.
- ***Scenario "*economic development*"***: it promotes "urban" economic activities as well as tourism that may have an impact on space: this is reflected in particular by a possible extension, even local, of high-stakes areas within or in contact with little artificialized areas (high rate of spread of discontinuous urban areas).

3.4. Periods and step of time

The past period for model calibration is 1974-2018. The step of time of simulations is annual.

4. Results

Examples of results showing the map of scattered urban spread and land cover matrix change simulations using the projected scenario are proposed in the following figures.

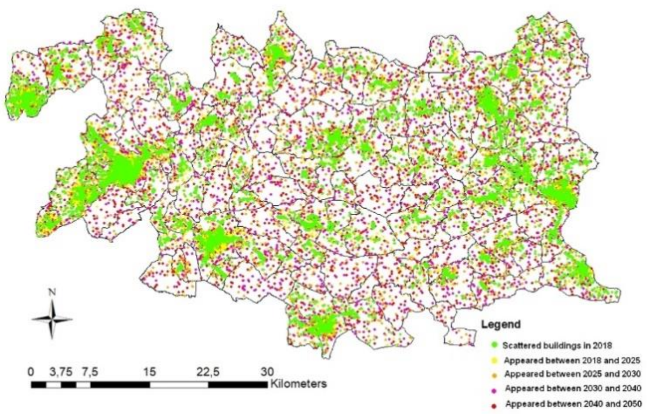

Fig 1. simulation of future scattered urban spread between 2018 and 2050 (projective scenario)

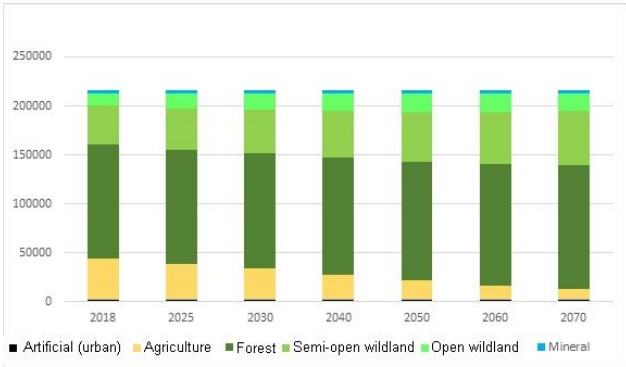

Fig 2. Quantitative change of the land cover matrix 2018 and 2050 (projective scenario)

A WUI maps are calculated based on these land cover map simulations. These maps are indicators of the global risk at local scale.

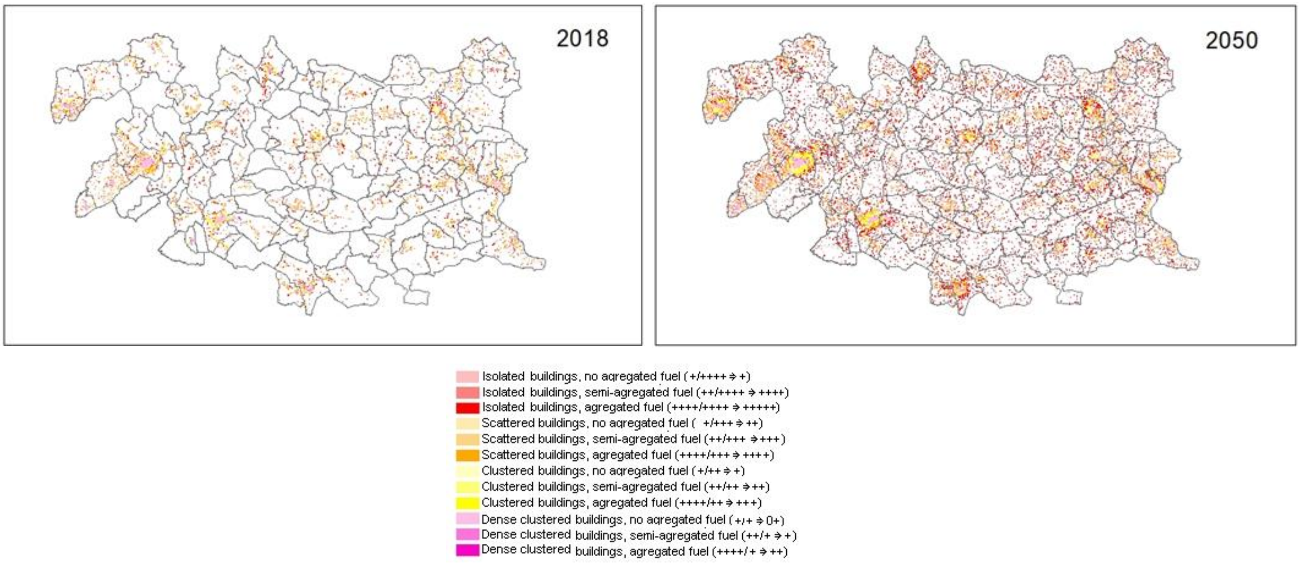

Fig 3. Simulated change in WUIMap interface types spatial distribution between 2018 and 2050, as indicator of risk. The legend mention the risk indicator associated to each WUI type in the form of:

hazard indicator / vulnerability indicator => global risk indicator

The vulnerability here considered is an "intensive" vulnerability, assessing the vulnerability of each building related to the type of interface it belongs to. The extensive vulnerability has also to be calculated, taking into account the number of buildings within the interface patches.

5. Conclusion

Anticipation of future wildfire risk in areas up to now little prone to that risk, is a key decision support for land management and planning. We propose a model for WUI spread simulation as the result of several land cover change, including scattered buildings and urban spread, as well as fuel spread on abandoned agriculture and pastoral areas. The objective of the model is not to preview the future risk absolute value, but rather to assess the possible effect of different land management scenarios on the future spatial distribution of wildfire risk. It is a support for today decisions. The risk model is simply based on WUI types. Results shows spectacular future increase of risk levels on most of the territories, while land cover change remain relatively modest: the spread of low density scattered built area results in some large areas risk increase, as low density built areas have the highest risk as soon as a significant fuel biomass is present. As a perspective, one other more complex analytical risk model (Chai-Allah & Maillé, 2020) is also used allowing better assessing the different components of the risk, including hazard, vulnerability and exposure. This later model is an expert-opinion based multicriteria one, where the interface type is one of the criteria for some of the components calculation. A panel of experts assessed the weight of this criterion for each of the relevant components. Up to now purely static, such a multicriteria risk model will be used in the future to assess change in risk level because of land cover change at territorial scale.

6. References

Birkmann, J., Kienberger, S., Alexander, D. (Eds.), 2014. Assessment of vulnerability to natural hazards. A European Perspective. Elsevier, UK.

Chai-Allah, A. & Maillé, E., 2020. « Mapping Forest Fire Risk in the Mediterranean forests—A Case Study of Provence-Alpes-Côte d'Azur region (France) ». In , 3:8107. https://doi.org/10.3390/IECF2020-08107.

Chatry, C., Le Gallou, J. , Le Quentrec, M. , Lafitte, J. , Laurens, D. , Creuchet, D. & Grelu. J., 2010. « Rapport de la mission interministérielle 'Changements climatiques et extension des zones sensibles aux feux de forêts' ». Rapport Min. Alimentation Agriculture Pêche, no 1796.

Galizia, L. F., Curt, T., Barbero, R., Rodrigues, M., 2021. Understanding Fire Regimes in Europe. International Journal of Wildland Fire 31 (1): 56-66. https://doi.org/10.1071/WF21081.

IPCC, 2014. Climate change 2014. Impact, Adaptation and Vulnerability, Summary for Policymakers, Working Group II (WGII) Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, WMO, UNEP,

https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf.

Lampin-Maillet, C., Bouillon, C., 2011. WUImap: A Software Tool for Mapping Wildland-Urban Interfaces in Mediterranean European Context. Indian journal of environmental health, 2011, 5 (5), pp.631-642. ⟨hal-02595104⟩

Maillé, E. & Espinasse, B. 2012. Pyroxene: A Territorial Decision Support System Based on Spatial Simulators Intergration for Forest Fire Risk Management, in. Petraq, Papajorgji. 2012. New Technologies for Constructing Complex Agricultural and Environmental Systems. IGI Global

Maillé, E. & Espinasse, B., 2009. Spatial Agents for scale integration of spatial dynamics models. European Journal of Geomatics and Spatial Analysis, 19(4), 523-549.

Romero, B. & Ganteaume, A., 2020. « Does Recent Fire Activity Impact Fire-Related Traits of Pinus Halepensis Mill. and Pinus Sylvestris L. in the French Mediterranean Area? » Annals of Forest Science 77 (4): 1-19. https://doi.org/10.1007/s13595-020-01016-1.