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Role of land-cover and WUI types on spatio-temporal dynamics of fires in the French Mediterranean area

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Spatio-Temporal Dynamics of Fires in the French Mediterranean according to Land Cover and Wildland-Urban Interface

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1 Spatio-Temporal Dynamics of Fires in the French Mediterranean according to Land Cover
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5 2 and Wildland-Urban Interface
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For Peer Review

4 **ABSTRACT**

5 This spatio-temporal dynamic of fires was analyzed at the community scale in one of the most
6 fire-prone areas of southeastern France. Three periods between 1993 and 2017 were compared
7 in order to highlight a temporal variation of fires, land cover, and Wildland-Urban Interface
8 (WUI). Fire density were highly variable among communities, hotspots being located mostly
9 in the South-East, close to big cities but spatially varying in time. Fire occurrence and burned
10 area did not significantly differ among periods, mostly due to high inter-annual variability. The
11 proportion of fires with unknown cause decreased over time while criminal fires were the most
12 frequent and deleterious, especially before 2009, followed by negligence during private
13 activities, mostly after 2009. WUI represents ~30% of the study area, the different types varying
14 spatially (denser clustered types mostly located in the South-East in contrast to “scattered” and
15 “isolated”). There was an increase in WUI area over time, especially for both clustered types
16 while the “isolated” decreased but this was highly heterogeneous among communities. Half of
17 the ignitions occurred in WUI, “very dense clustered” and “scattered” types being the most
18 affected, especially in 2009. Land cover classes significantly varied among periods, with a
19 decrease in “agricultural areas” during the two first periods that increased again afterwards,
20 which was reversed for “artificialized” and “natural areas”, to a lesser extent. The latter was the
21 most impacted by ignitions (60%), regardless of the period, but showed a decreasing trend over
22 time in contrast to the former.

24 **KEY-WORDS**

25 Fire ignition, WUI, land cover, fire causes, French Mediterranean area

1. INTRODUCTION

At the global scale, wildfires have become one of the main disturbances for the socio-ecosystems (1). In Europe, on average, 68,000 fires burn every year 450,000 ha of vegetation, 85% affecting the Mediterranean basin (2). Along the top five of the most affected European countries (Portugal, Spain, France, Italy, and Greece), wildfires also take a heavy toll on Turkey as well as on the coastal area of the Balkans (3). In some of these countries, megafires regularly destroy large areas entailing huge economic impacts, e.g. 47,000 ha in Portugal in 2017 or 85,000 ha in Greece in 2019 (4; 5). In France, however, the magnitude of fire events is much lesser as, for the past couple of decades, the largest fire size was 6,744 ha in 2003 and 2,600 ha in 2016 (6;7). The French Mediterranean region concentrates most fire occurrence and burned area (58% of the burned area on average, between 2010 and 2018, and up to 80% in 2003 (2)) where large fires (≥ 100 ha), representing only 1% of the occurrence, are responsible for more than 70% of the burned area (8). However, the spatial variability of the fire activity in this area is high, the southeasternmost part concentrating more than 68% of the fire occurrence and 73% of the burned area, mainly in summer (8). Several factors explain such a sensitivity to fire, among the most important being climate and weather conditions (warm, dry, and windy in summer) that are exacerbated by the climatic change leading to an increase in the drought and heat wave frequency (9; 10). There is already emerging evidence of an increasing frequency of compounded heat waves and drought episodes across Mediterranean regions in the observational record (11). Ecological factors, such as high vegetation cover resulting from the land abandonment since the mid-XXth century and by the systematic fire suppression policy, provide abundant fuel biomass for the fire (12). Human factors, such as population density, drive numerous fire ignitions ; 95% of the total number of fires are human-caused, among them, 32% being criminal (8 ;13). The forest dynamic established for a century, and more recently, the increase in coastal urbanization, industrial development, and tourist activity have resulted

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3 51 in an increase in the human pressure on the wildland area (13). This trend is continuing into the
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5 52 2000s with an intensification of the urban growth and infrastructure development adjoining
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7 53 wildland areas (14), increasing the proportions of areas called « Wildland-Urban Interfaces »
8
9 54 (WUI) (15; 16; 17; 18). In southeastern France (as in other Mediterranean regions throughout
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11 55 the world), WUIs are a serious issue in terms of land and fire management, since they often are
12
13 56 the source of a large part of fire ignitions and are the most vulnerable (high stake areas) (19).
14
15 57 The WUI rate of increase is often high, especially in tourist areas, along with that of the
16
17 58 population density (20). In the horizon 2030, the population in some parts of southeastern
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19 59 France (2,050,000 dwellers in the district Bouches du Rhône in 2020) could have a 9%-increase
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21 60 (www.insee.fr) that could raise the fire occurrence at the WUI. It is therefore of the upmost
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23 61 importance to better take into account the WUI in the current and future fire risk assessment.
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29 62 Highlighting WUI as a factor also influencing the fire activity in Mediterranean areas has
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31 63 been developed in previous studies (19; 21; 22; 23; 24; 25). In contrast, only a few tackle
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33 64 this issue, especially the spatio-temporal evolution of WUI, at a finer scale (i.e. community
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35 65 scale), but they need to be updated (e.g. 24). The information on the fire causes responsible for
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37 66 the ignitions is also something needed to improve fire prevention, which is rarely provided (8;
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43 68 The aim of the current work was to define what the spatio-temporal dynamics of fires (in
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45 69 terms of occurrence, burned area, as well as level of certainty and nature of fire causes) were at
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47 70 fine scale during the last 25 years (1993-2017) in the French Mediterranean area. This would
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49 71 allow an updated view of the current situation in this area in terms of fire activity. Moreover, a
50
51 72 better knowledge of the fire causes, coupled with a spatial analysis of the ignition points, will
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53 73 highlight the main factors and the preferential areas of these fire ignitions. Ultimately, this work
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55 74 should allow refining the fire policies in terms of awareness raising, firefighting means, and
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57 75 land management.
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77 2. MATERIAL AND METHODS

78 2.1. Study area

79 The study area, the Bouche du Rhône district (Fig. 1a), is one of the 15 administrative
80 districts of southeastern France (coordinates : North-West: 43.6558N, 5.4958E; South-East:
81 43.8328N, 5.6728E, surface area : 5087 km²). It is also one of the most fire-prone region in
82 terms of fire occurrence (i.e. number of fires) and burned area, especially in summer (6; 8; 13).
83 This high sensitivity to fire is due to specific physiographic conditions given that this area is
84 characterized by high population density (394 inhabitants km⁻²,
85 <https://www.geoportail.gouv.fr>), especially in its eastern part, and by an extensive WUI, which
86 is among the main drivers of fire density in the study area (24). The on-going urban sprawling
87 mostly occurs in watersheds and valleys adjoining the numerous forest massifs (Fig. 1a) in this
88 part of the district. The attractiveness of the study area to tourism is high, especially in summer
89 on the coast. The main fuel types, located mostly on limestone-derived soils, are *Pinus*
90 *halepensis* stands (26) and mixed pine-oak (*Quercus ilex* and *Q. pubescens*) stands (respectively
91 42% and 18% of the forest stands; database of Inventaire National Forestier), often the pre-
92 forest vegetation type before oak forests (27). Shrublands, called “garrigues”, are another
93 dominant fuel type (43% of the natural vegetation; database of Inventaire National Forestier)
94 that corresponds to the predominant successional stage after woodland degradation (28).
95 Wildfires occur frequently in the whole area, making of the landscape a mosaic of all the
96 previously mentioned types of natural vegetation and of agricultural areas. The Mediterranean
97 vegetation is very flammable, affecting fire spread and ultimately, the distribution of large fires.
98 In contrast, the southwestern part of the district Bouches du Rhône, characterized by the lowest
99 population density, is occupied by a large wetland area and by irrigated crops, such as rice
100 paddies, corresponding to the Rhône’s delta, therefore less susceptible to fire.

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3 101 The Mediterranean climate prevailing in the study area is characterized by short and wet
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5 102 winters and by prolonged hot and dry summers, with strong drying wind (called Mistral) which
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7 103 favours fire propagation (29). The mean maximum temperature ranged from 9.8°C to 13.2°C
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9 104 in winter and from 27.9°C to 30.6°C in summer. Mean annual precipitation ranged from 472
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11 105 mm to 820 mm (Météo France database). In general, topography is not very rough and the
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13 106 altitude ranges from sea level up to 1038 m in the East.
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108 **2.2. Fire data**

109 *2.2.1. Fire occurrence, burned area, level of certainty and nature of fire causes*

110 We compiled the data provided by the regional fire database Prométhée (number, burned
111 area, certainty and nature of causes), which has been recording the fires in southeastern France
112 since 1973, according to three periods (1993-1999, 2003-2009, and 2011-2017) in order to
113 highlight the temporal variation of fires in the study area (Fig. 1b).

114 The level of certainty of fire causes was divided into two classes : unknown and known (the
115 latter corresponding to the merging of the three classes “certain”, “likely”, and “supposed” used
116 to qualify the level of certainty in the Prométhée database). Among the nature of the known
117 causes given in this database, five classes of one-digit codes were taken into account, according
118 to the definitions given by the Joint Research Centre (30): (i) natural (any wildfire caused by
119 natural origin, with no human involvement in any way; only lightning in the study area), (ii)
120 accidental (wildfires unintentionally and indirectly caused by humans, without use of fire,
121 connected neither to will nor to negligence, rather to fatality, and which included fires due to
122 structures such as power lines, railways, vehicles, or garbage dumps), (iii) deliberate/criminal
123 (wildfire intentionally caused by humans with the use of fire for different motives such as
124 conflict, interest, or pyromania), (iv) negligence during professional works (wildfire

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3 125 unintentionally caused by humans using fire or glowing objects during professional activities,
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5 126 not connected to fatality), and (v) negligence during private activities (wildfire unintentionally
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7 127 caused by humans using fire or glowing objects during recreation, not connected to fatality).
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10 128 Using 3-digits codes, the fire database Prométhée allows for more accuracy regarding the nature
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12 129 of causes (e.g. 311 : deliberate with the motive of conflict regarding real estate). However, only
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14 130 the more recent period studied (2011-2017) was implemented with such an accuracy. To be
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17 131 consistent over the three periods studied, we chose to work on the one-digit code causes.
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21 22 23 133 *2.2.2. Georeferenced Ignitions*

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26 134 The ignition spatial coordinates provided by the fire database Prométhée are not accurate
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28 135 because the fire ignitions are located using a 2 km*2 km grid reference (developed by the
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30 136 firefighting services for approximating the location of the fire event). The considerable
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32 137 imprecision arising from this georeferencing method makes it difficult working at fine scale
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35 138 especially with land cover or WUI data. Therefore, we used the georeferenced ignitions
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37 139 compiled by the Office National des Forêts (ONF) and Direction Départementale des Territoires
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39 140 et de la Mer of Bouches du Rhône (DDTM13) available from 1961 to 2017, although less
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42 141 exhaustive than the Prométhée fire database (especially in the beginning of the period). Indeed,
43
44 142 the fire perimeters are defined using satellite images (implying a lack of data for the fires whose
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46 143 size is lower than 10 ha, with 22% of the fires recorded vs 37% in 2003-3009, and 91% in 2011-
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49 144 2017).

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53 54 55 146 **2.3. Land Cover Data**

56 57 58 147 *2.3.1. Main Land Cover Data*

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3 148 Data was extracted from the BD OCSOL PACA database (CRIGE PACA : Centre Régional
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5 149 d'Information Géographique Provence-Alpes- Côte d'Azur). This data (projection Lambert 93)
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7
8 150 is an improvement of the Corinne Land Cover (CLC) version, and has allowed, since 1988, an
9
10 151 updated regional land cover with good geometrical quality and maximum semantic confidence.
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12 152 The basic nomenclature of land covers remains mostly the same as for CLC (1 = artificialized,
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14 153 2 = agricultural, 3 = natural (forests and other wildland), 4 = wetland, and 5 = water bodies)
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17 154 with sub-classes increasing the accuracy of the land cover (e.g. code 111 = urban areas). In the
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19 155 current work, the two last classes have been merged into a class "Others". The CRIGE PACA
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21 156 land cover is available in 1999, 2006, and 2014 corresponding to the three periods studied
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24 157 (1993-1999, 2003-2009, and 2011-2017).

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26 158 The land cover analysis aims to identify the global evolutionary dynamic of the land cover
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28 159 classes over time in the study area. Moreover, crossing land covers and ignition points allows
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30 160 highlighting the fire ignition preferential areas in space and time.
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34 35 162 2.3.2. *Wildland-Urban Interface*

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38 163 For the three periods studied, WUI data was extracted using the software *WUImap* developed
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40 164 by IRSTEA (which has become INRAE since January 1st, 2020). WUI vectorial data was
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43 165 obtained crossing vectorial layers of « buildings » at the different periods, the study area's
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45 166 administrative boundary, and the mandatory brush-clearing area in WUI (regional regulation
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47 167 for buildings located in WUI, i.e. at least than 200 m from wildland). Contrary to the work of
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50 168 (24) who calculated a global WUI surface area corresponding to a 100 m-buffer around each
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52 169 building located in WUI, we used a more accurate WUI characterization and mapping (31)
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54 170 based on the four types of housing density (i.e. WUI types): "isolated", "scattered", "dense
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56 171 clustered", and "very dense clustered", as defined in (32). This latter analysis was only
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59 172 performed for 1999 and 2009 due to a computing problem in generating the different layers of
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3 173 housing density for 2017 (too much data compiled requiring too much computational
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5 174 resources). Data on housing came from a vector layer made by the French National
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7 175 Geographical Institute (BD TOPO®) and was updated using a Spot 5 multi-spectral 2.5-m pan-
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10 176 sharpened image. The analysis was carried out in two steps, on the one hand, studying the WUI
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12 177 surface area changes between periods, and on the other hand, determining the part of
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14 178 explanation of fire ignitions by WUI and its temporal trend. This required the crossing between
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16 179 layers of fire ignitions and WUI using geographical information systems (ArcGIS 10).
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23 181 **2.4. Data analyses**

26 182 Spatial analysis of fires at the community level (fire occurrence and density) was based on
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28 183 the total number of fires with known causes during the 1993-2017 period, using ArcGis
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30 184 software to assess the spatio-temporal variability of fires in the study area. Representing
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32 185 wildfire incidents as points on a map made it difficult to distinguish “clusters” of ignitions,
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34 186 because of the overlapping ignitions. To address this limitation, we used the Kernel density
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36 187 method to highlight the hotspots of ignitions (and of large fire ignitions) throughout the study
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38 188 area. This method is a non-parametric statistical technique that was aimed at producing a
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40 189 smooth density surface; therefore, accounting for the uncertainty regarding the accuracy of the
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42 190 original ignition location. In assigning a buffer area around each spatial fire ignition, a normal
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44 191 distribution of density surfaces (based on the number of ignitions per point) was created over
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46 192 each point. When multiple buffers overlapped, the kernel density values were combined to
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48 193 derive the ignition density surface. This provided a much clearer illustration of where the
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50 194 ignitions were the most frequent (hotspot) and allowed the use of a straightforward and
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52 195 quantitative value (number of ignitions per square kilometer). For this analysis, we used the
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54 196 Spatial Analyst Extension of ArcGIS 10.2 whose kernel function was based on Silverman’s
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3 197 quartic kernel function (as in (8)). However, spatial analyst provides a search radius algorithm
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5 198 based on the distance between ignitions giving a too smoothed result. In order to obtain sharper
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8 199 density changes, we empirically chose a shorter search radius (6000 m-radius, including 28
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10 200 possible locations) according to the initial grid of the Prométhée database. A 50m-resolution
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12 201 was chosen for the output raster. This analysis was carried out at two different periods (1999
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14 202 and 2009) in order to highlight how the fire hotspots would vary spatially in the study area over
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17 203 time.

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20 204 Afterwards, a global analysis of the fire occurrence and burned area was performed
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22 205 according to the period, followed by an interannual analysis, to determine the temporal variation
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24 206 within the same period that could not be highlighted using only the global analysis. The analysis
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26 207 of fire causes consisted of different steps. The first step studied the proportion of known vs
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28 208 unknown fire causes in the three periods in order to apprehend the improvement of the certainty
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30 209 of the causes over time and to determine when their analysis could be reliably attempted. Next,
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32 210 the fire occurrence and burned area were analyzed according to the nature of the cause in order
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34 211 to find out which were the most frequent and deleterious causes. The Chi² test was used to test
35
36 212 the difference in number of fires, burned area, certainty and nature of fire causes among periods
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38 213 and ANOVAs (Kruskal-Wallis test) were used to compare the different periods
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40 214 (Statgraphics®19-X64; Statgraphics Technologies, Inc, USA). The same analyses were carried
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42 215 out to assess the temporal variation of land cover and WUI, at the scale of the study area and of
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44 216 the community.

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52 53 54 218 **3. RESULTS**

55 56 57 219 **3.1. Spatio-temporal variation of fires**

58 59 60 220 *3.1.1. Spatial variation of fires*

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3 221 During the period 1973-2017, there was a high variability of the number of fires among
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5 222 communities (Fig. 2a), which was well defined spatially (most affected areas in the centre and
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7 223 in the East of the study area). The major cities, Marseille and Aix-en-Provence, their
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9 224 neighbouring communities, as well as those around the Etang de Berre, were the most sensitive
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11 225 to fire. Taking into account the community surface area, the community's fire density could be
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13 226 derived from the data provided by the fire database Prométhée, refining the results of the
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15 227 previous analysis, and highlighting that the communities the most at risk were located in the
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17 228 southeastern part of the study area (Fig. 2b). Using the georeferenced fire ignitions, we
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19 229 performed the analysis only for the most recent periods (2003-2009 and 2011-2017), given the
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21 230 lack of data for the period 1993-1999 in the ONF/DDTM13 database. A temporal variation of
22
23 231 the fire ignition hot-spots was highlighted between the two periods considered (Fig. 3). During
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25 232 the period 2003-2009, the fire ignition density was higher in the communities located North
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27 233 and East of Marseille (the most impacted forest massifs being around Gardanne, western
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29 234 Regagnas massif, eastern Garlaban and the eastern part of the Calanques National park close to
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31 235 Marseille). In contrast, for the period 2011-2017, the hot-spots were more concentrated in the
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33 236 communities West of Etang de Berre (Castillon and Lunard forest massifs). Overall, most
34
35 237 communities in the Bouches-du-Rhône district were impacted by wildfires, except the wetter
36
37 238 western part corresponding to the Rhône's delta. In general, the northern part of the district
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39 239 presented a lower fire density than the southeastern part, regardless of the period. This result
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41 240 agreed with the previous analysis performed using the data of the Prométhée database, although
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43 241 less accurate in terms of georeferencing.
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55 243 *3.1.2. Temporal variation of fires*

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58 244 The comparison of the fire occurrence among periods showed a maximum of fire occurrence
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60 245 during the period 2003-2009 with 1562 fire events (Fig. 4a). In contrast, the burned area

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3 246 revealed a constant decreasing trend, from 10664 to 7402.7 ha since 1993-1999 (Fig. 4b).
4
5 247 However, both variations were not significant (Kruskal Wallis test, $P_{occurrence} = 0.175$;
6
7 248 $P_{BurnedArea} = 0.443$), mostly due to a high variability within periods. The interannual analysis of
8
9 249 occurrence and burned area highlighted important discrepancies among and within periods (Fig.
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11 250 4 and Suppl. Mat. 1, 2). Regarding the fire occurrence (Fig. 4a), between 1993 and 1999, there
12
13 251 is a low scattering of data around the annual mean (158.9 ± 34.2 fires) meaning that the
14
15 252 interannual variability was low. In contrast, this variability strongly increased for the two other
16
17 253 periods (2003-2009 and 2011-2017), displaying higher standard deviations (223.1 ± 65.7 and
18
19 254 188.9 ± 97.3 , respectively). Besides the global increase in the number of fires, there was also an
20
21 255 increase in the interannual variability (e.g. the most recent period gathered the two highest
22
23 256 values among 21 values studied in the three periods : 95 fires in 2014 and 378 fires in 2016 ;
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25 257 Suppl. Mat. 1). Regarding the burned area, the internannual variability was strong for the
26
27 258 periods 1993-1999 (1523.3 ± 1637.4 ha) and 2011-2017 (1057.5 ± 1642.9 ha) as well as, to a
28
29 259 lesser extent, for 2003-2009 (1340.1 ± 1076.4), meaning that the annual burned area has been
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31 260 more homogeneous during this latter period (Fig. 4b). As previously experienced, the most
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33 261 recent period presented the two highest values (22.3 ha in 2014 and 4533.2 ha in 2016 mostly
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35 262 due to the Rognac fire that burned burned more than 2600 ha (Suppl. Mat. 2).
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264 3.1.3. Temporal variation of the level of certainty and nature of fire causes

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48 265 The difference in the proportion of unknown causes among periods was significant (Kruskal
49
50 266 Wallis test, $p=0.012$). Indeed, the elucidation rate of fire causes considerably improved between
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52 267 1993-1999 and 2011-2017 (Fig. 4c), entailing a decrease in the proportion of unknown causes
53
54 268 from 70% down to 33%. However, for the first period, the interannual variability turned out to
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56 269 be rather high ($SD_{1993-1999} = 28\%$), meaning that the elucidation of the nature of fire causes was
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58 270 heterogeneous within the years studied. For instance, the period 1993-1999 encompassed, at
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3 271 the same time, the year with the highest proportion of unknown causes (98% in 1999) and
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5 272 among the lowest (31% in 1998). In this latter period, there was a radical change occurring
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7 273 between 1996 and 1997 regarding the proportion of unknown causes (decreasing from 72% to
8
9 274 52%) (Suppl. Mat. 3). The most recent period (2011-2017), besides the fact that it was the best
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11 275 in terms of level of certainty, was characterized by a very low interannual variability meaning
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13 276 that the elucidation rate of the fire causes was homogeneous throughout the period ($SD_{2011-2017=}$
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15 277 9.5%).
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20 278 Regarding the nature of the causes in terms of occurrence, most fires were criminal (>40%)
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22 279 showing an increasing trend from 1993-1999 to 2011-2017, followed by those due to negligence
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24 280 during private activities (>20%), the other causes being less frequent, regardless of the period
25
26 281 (Fig. 5a). Regarding the burned area, the criminal fires were the most destructive (up to 78% of
27
28 282 the total burned area, more frequently due to large fires, i.e. ≥ 100 ha, than for other causes)
29
30 283 during the two first periods. Fires due to negligence during private activities burned the most
31
32 284 during the last period (59% vs 30% for criminal fires) (Fig. 5b). This was mostly the result of
33
34 285 one fire event that occurred in 2016 and burned more than 2600 ha burned. It is also worth
35
36 286 noting that the area burned by accidental fires was exceptionally high during the first period
37
38 287 (43%) for only 11% of occurrence. Despite these contrasted trends, the statistical analyses
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40 288 revealed that neither the occurrence nor the area burned significantly varied among the periods,
41
42 289 regardless of the cause. This lack of significativity could be due to the high variability, both in
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44 290 terms of number of fires and burned area, within each period (Suppl. Mat. 4).
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50 291 The rate of change in the number of fires increased between 1993-1999 and 2003-2009,
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52 292 regardless of the cause, with the fires due to negligence during professional activities displaying
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54 293 the lowest rate (5.56%) and those due to negligence during private activities displaying the
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56 294 highest (129.8%) (Fig. 6a). Regarding these periods, a decreasing rate of change in the area
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58 295 burned by natural and accidental fires was highlighted in contrast to the other causes (increasing
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3 296 rate up to 138% for the area burned by fires due to negligence during professional activities).
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5 297 Between 2003-2009 and 2011-2017 (Fig. 6b), only the number of natural fires and of those due
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7 298 to negligence during private activities showed a decreasing rate while this trend was general for
8
9 299 the burned area except for negligence during private activities (strong increase of 753%).
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16 301 **3.2. Spatio-temporal variation of land cover and WUI**

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19 302 Regarding the land cover, the class « agricultural areas » strongly decreased from 1999 to
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21 303 2006 (except olive groves; Suppl. Mat. 5 and 6) benefiting to the classes « dense vegetation »
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23 304 (mixed forests and deciduous stands; Suppl. Mat. 5 and 6) and « artificialized areas » (except
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25 305 for discontinuous urban areas; Suppl. Mat. 5 and 6), to a lower extent (Fig. 7). Between 2006
26
27 306 and 2014, there was a general decrease in the land cover areas except for the class
28
29 307 « artificialized areas » (but with a slowing increase, from 21.1% to 1.9%). The decrease in
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31 308 « agricultural areas » was also slowed down. Overall, the evolution between 2006 and 2014
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33 309 was slight (Table 1). The statistical analyses (Khi^2) showed that the land cover classes and
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35 310 periods were not independent ($p < 0.0001$).
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40 311 Over the period studied (up to 2009), WUI represented on average 28.6% of the district
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42 312 surface area, with a 2.33%-increase between 1999 and 2009 (Table 2). The WUI types spatially
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44 313 varied throughout the territory, « very dense clustered » and « dense clustered » being mostly
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46 314 concentrated around the big cities (Marseille and Aix-en-Provence) and around the Etang de
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48 315 Berre, to a lesser extent. In contrast, the southwestern part of the study area was mostly
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50 316 characterized by the « scattered » and « isolated » types, so was the northern part, to a lesser
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52 317 extent (e.g. Fig. 8).
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57 318 The analysis of the rate of change in the surface area of the different types of WUI between
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59 319 1999 and 2009 revealed an increase in the global surface area (+ 8,5%) benefiting the « dense
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3 320 clustered » and « very dense clustered » types (+ 155% and +15%, respectively). The
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5 321 « scattered » type also increased in this time span, but to a lesser extent (+7%) in contrast to the
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7 322 « isolated » type (-3,8%) (Table 2). The statistical analyses (Khi^2) showed that the WUI classes
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9 323 and periods were not independent ($p < 0.0001$).

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13 324 This temporal variation was combined with a strong heterogeneity among communities,
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15 325 regardless of the WUI type. Regarding the « very dense clustered» type, this variability spanned
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17 326 from -3.6% in Vauvenargues to +135.9% in Saint-Marc-Jaumegarde, and the most represented
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19 327 rates of change encompassed 5% to 30% (Fig. 9a). The « dense clustered» type was
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21 328 characterized by a stronger evolution than the previous one (on average + 25.8%) but with a
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23 329 decrease in 41% of the communities (Fig. 9b). The « scattered » type also showed an increasing
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25 330 trend between 1999 and 2009, but to a lesser extent than the two previous types (on average +
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27 331 9.3%), with a variability among communities ranging from -100% in Carry-le-Rouet to +88.3%
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29 332 in Maussane-les-Alpilles. In total, 31% of the communities were characterized by a decrease in
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31 333 this type of WUI, the variation mainly ranged between -5% and +30% (Fig. 9c). The
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33 334 « isolated » WUI type was special as it was the only one characterized by a global decrease in
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35 335 the study area (- 1.6%). Indeed, 59% of the communities presented a decrease in this type of
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37 336 WUI, values ranging from -55.1% to + 107.9% (Saint Savournin and Carnoux-en-Provence,
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39 337 respectively), the most represented rates of change encompassed -15% to +10% (Fig. 9d).

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47 48 49 339 **3.3. Spatio-temporal variation of fires according to land cover and WUI**

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52 340 The land cover the most impacted by wildfires was « natural areas » (around 60% of the
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54 341 ignitions), regardless of the period, followed by « artificialized areas » (25-30%). The class
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56 342 « agricultural areas » was submitted to only 10% of ignitions, on average. Except for the class
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58 343 « natural areas », the proportion of ignitions increased from 1999 to 2006 (Table 3).

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3 344 The burned area was the highest in “natural areas” and “artificialized areas” presented a
4
5 345 smaller burned area than “agricultural areas”, regardless of the period. While the burned area
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7 346 did not change over time for the class « agricultural areas », the class « natural areas » presented
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9 347 a decreasing trend in contrast to the class « artificialized areas » (Table 3).
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13 348 Very few ignition points occurred in agricultural areas which could be explained by the small
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15 349 proportion of fires due to negligence during professional work (see fig. 5a), among which even
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17 350 a few were due to agricultural work (1.3% during the period 2011-2017 according to the
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19 351 Prométhée database). Regardless of the period, most ignitions occurring in agricultural areas
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21 352 were located in farmlands out of the irrigation perimeter (dry lands), vineyards, and orchards
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23 353 (Suppl. Mat. 5, 6, 7). On the contrary, in natural areas, the fuel amount available for fire ignition
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25 354 and propagation was high (more or less dense vegetation) and these areas represented 45% of
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27 355 the total land cover (around 2200 km²), increasing the probability of fire ignition. Most ignitions
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29 356 were located in mixed conifers-deciduous (except during the first period) as well as in conifers
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31 357 stands and in shrublands (Suppl. Mat. 5, 6, 7). These ignitions could mostly be due to arson
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33 358 given that this cause was the most frequent (50% of the total occurrence and 57% of the total
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35 359 burned area on average during the three periods studied) compared to negligence (according to
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37 360 the Prométhée database, only 1.6% of the fires were due to negligence during forestry work
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39 361 during the period 2011-2017, for instance).
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46 362 Artificialized areas represented around 1000 km² corresponding to 23% of the land cover
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48 363 and gathered between 24% and 29% of the ignitions according to the period studied (Table 3).
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50 364 Moreover, these ignitions could be due to arson or related to the cause « negligence during
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52 365 private activities» (26% of the fires and 22% of the burned area, on average, during the three
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54 366 periods studied; see Fig. 5a), especially during private work (11.8 % during the period 2011-
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56 367 2017 according to the Prométhée database). Areas corresponding to WUI in the class
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3 368 « Artificialized area » (“Discontinuous urban area” and “Scattered dwellings”) gathered most
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5 369 ignitions (Suppl. Mat. 5, 6, 7).
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8 370 Taking into account the accurately georeferenced ignitions from the DDTM13/ONF
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10 371 database, we found that WUI were impacted by 49.3% of the ignitions and those occurring in
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12 372 « natural areas » were mainly located very close to the « artificialized areas » (Fig. 10). In
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14 373 contrast, the number of fires occurring within the forest area (i.e. far from human settlements)
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16 374 was low.
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20 375 Regarding the temporal variation of the fire ignitions according to the WUI types, we found
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22 376 that half of the ignitions occurred within WUI area during the period 1993-2009 and that the
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24 377 WUI « very dense clustered» and « scattered » types were the most affected (32% and 29%,
25
26 378 respectively) (Table 4). When the analysis was carried out at the level of each period, the trend
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28 379 previously highlighted changed. In 1999, 248 ignitions occurred in the Bouches-du-Rhône
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30 380 district. Almost 39% (96 ignitions) of these ignitions were located within WUI area despite this
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32 381 area represented only 27.5% of the district’s total area (1 ignition for 1456 ha). In contrast, the
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34 382 ignitions located outside WUI area (152 representing 62% of the total number of ignitions)
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36 383 were distributed over a larger surface area (1 ignition for 2427 ha, therefore less than those in
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38 384 WUI). The most affected WUI types were « isolated » and « scattered » (35% and 28%,
39
40 385 respectively) (Table 4). In 2009, the number of ignitions increased up to 576 (more than twice
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42 386 the number of the previous period) with more than 50% within WUI area (1 ignition for 525
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44 387 ha while there was 1 ignition for 1244 ha outside WUI area, therefore less than two times). The
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46 388 most affected WUI types partially changed compared to the previous period (« very dense
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48 389 clustered » : 36% and « scattered » : 29%), showing the same pattern as during the global
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50 390 period (Table 4).
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392 4. DISCUSSION

393 4.1. Fire metric temporal variation

394 Overall, most communities in the Bouches-du-Rhône district were impacted by wildfires,
395 except the wetter and less populated part corresponding to the Rhône's delta. The northern part
396 of the district was also less fire prone than the South-East, mainly due to lower population
397 density (24). There was a large variability in both occurrence and burned area among
398 communities, the most impacted ones being close to big cities. This agreed with the work of
399 (24) that showed that housing density, as a proxy of population density, was one of the main
400 drivers of fire density. However, the temporal variations of occurrence and burned area were
401 not significant, mostly due to the high variability within periods. There was also a temporal
402 variation of the fire hotspots, which is an additional result to the work of (24) who tackled the
403 fire issue in the study area at the spatial scale only. Indeed, during the period 2003-2009, the
404 fire ignition density was higher in the communities located North and East of Marseille while
405 for the period 2011-2017, the hot-spots were concentrated in the communities West of Etang
406 de Berre. This temporal variation of fire hotspots has also been highlighted in other regions in
407 the world, such as in California (33). This result is important in terms of fire management
408 strategy showing the the fire hotspots can change over time.

409 Among human practices known to alter the fire regime, fire suppression has been suggested
410 to be one of the the most explicative factors in the reduction of the total burned area during the
411 XX century (34). The decreasing trend of burned area in the Bouches-du-Rhône has been
412 highlighted in the end of the 80s (Fig. 1b), when a new fire policy brought new fire suppression
413 and prevention practices in southeastern France. In this new strategy, anticipation and massive
414 attack on the fire within 10 minutes after ignition could act in decreasing the probability that a
415 fire would burn large areas (34). In our work, the decreasing trend of the burned area shows the
416 efficiency of such a policy. However, the persistence of large fire events during extreme

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3 417 weather conditions (e.g. 2003, 2016) reveals that these events can outweigh by far terrestrial
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5 418 and aerial fire-fighting strategies (7; 25). For instance, this was the case during the fire in
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7 419 Rognac (August 2016) that burned more than 2600 ha, out of which 2000 ha were located at
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9 420 the WUI and in urban areas. These areas are as yet among the best defended due to their high
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11 421 stake (35). Despites favourable fire statistics in the French Mediterranean region, the burned
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13 422 area could be tripled considering on the horizon 2100 for the worst climatic scenario (36), at a
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15 423 rate between +15% and +25% per decade (37). Some even stated that the « success » of a fire
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17 424 management policy based on systematic fire suppression is doomed in the long term since the
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19 425 large or mega-fires will only be delayed (7). Indeed, the massive accumulation of fuel will lead
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21 426 to unstoppable fires due to the massive intensity released once ignited. Although the context
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23 427 differs, this situation is also on-going in South Africa or Australia (7; 25).

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29 428 Regarding the fire occurrence, the situation was less clear-cut in the Bouches-du-Rhône
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31 429 district for the past 25 years but showed a trend differing from that of the entire region (38).
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33 430 Indeed, the socio-environmental characteristics of the district make it more vulnerable to fire
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35 431 ignitions than other parts of southeastern France (8). Even though 2003 remains the most
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37 432 catastrophic year in terms of fire occurrence and burned area in most European countries, it was
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39 433 not the same in our study area ; indeed 2016 was more destructive (378 fires and 4533.2 ha
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41 434 burned vs 350 fires and 2308.1 ha burned in 2003; www.prométhée.com). It is worth noting
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43 435 that the impact of 2003 differed spatially in this region, with the neighbouring district (Var)
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45 436 among the most impacted by the 2003 fires (6). In other countries of southern Europe, such as
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47 437 Portugal, the situation differed with a regular increase in fire occurrence since the 80s,
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49 438 especially that of large fires (39; 40).

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55 439 We highlighted an improvement of the level of certainty of fire causes from 1993-1999 to
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57 440 2011-2017 but with a rather high variability, especially in 1993-1999. This heterogeneity (i.e.
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59 441 high interannual variability of fire causes) during this first period was mostly due to the creation

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3 442 of official teams (one team for each district of southeastern France, composed of a firefighter,
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5 443 a forest manager and a police officer) in 1997. These teams have to investigate, if possible, the
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7 444 cause of each fire occurring in this region, therefore increasing the proportion of known causes
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9 445 since then (8). The same trend has been observed in Portugal since 1988 (74% of unknown
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11 446 cause to 47-53% in 2015-2017 (41 ; 42)).
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15 447 The nature of the fire cause is quite diverse and the fire ignition is generally not a random
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17 448 phenomenon (43; 44) because most fires result from motivated human actions (42). The fire
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19 449 cause analysis revealed that, in the study area, most fires were criminal and were more and more
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21 450 frequent between 1993 and 2017, followed by those due to negligence from private activities,
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23 451 natural fires being the least frequent, regardless of the period. Regarding the burned area, the
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25 452 strongest temporal variation was displayed by accidental causes (only during the first period
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27 453 despite a low occurrence), criminal causes (the most destructive, especially during the two first
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29 454 periods), and negligence during private activities (especially during the last period). It is worth
30
31 455 noting that except for this latter cause, the burned area showed a decrease between 2003-2009
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33 456 and 2011-2017, while both occurrence and burned area mostly increased between 1993-1999
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35 457 and 2003-2009, due to the general increase in these fire metrics. When comparing accidental
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37 458 and natural fires, the former were more destructive in the study area, which is not the case in
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39 459 other districts of the region (8). It is worth noting that the relatively large areas burned by
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41 460 accidental fires for each period (>10%) as well as by fires due to negligence during private
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43 461 activities during the last period were due to only one destructive event (for instance, during the
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45 462 last period, an accidental fire due to a vehicle burned 711 ha in 1997). Between 1993-1999 and
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47 463 2003-2009, despite an increasing rate of the fire occurrence, regardless of the cause, the
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49 464 opposite trend was found for the area burned by the natural and accidental causes. This showed
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51 465 that the size of these fires decreased between the two periods. The increase in the rate of change
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53 466 in occurrence between the two last periods was slowing down for most causes, even decreasing
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3 467 for the natural cause and the negligence during private activities, which entailed a decreasing
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5 468 rate for the burned area, except for the latter (due to one large fire event in 2016 and in 2017).
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8 469 In the study area, natural fires were mostly small fires (< 1 ha) and the highest proportion of
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10 470 large fires were criminal. Indeed, generally, the criminal fires are set when the weather
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12 471 conditions are favourable to the fire propagation (i.e. when the wind is strong and the relative
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14 472 humidity low). It would be also interesting to check if the ignitions located in the forest areas
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16 473 would be really related to the criminal causes that represents almost half of the ignitions in the
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18 474 study area. Indeed, the motives of the criminals are to deliberately set a fire, which is favoured
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20 475 in natural areas due to the high amount of fuels available for the fire. Several studies also
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22 476 showed that, in southeastern France, when the population density is higher in summer, fires due
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24 477 to negligence (especially due to private activities close to housing or infrastructures) are smaller
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26 478 but more frequent than criminal fires but with a high spatial variability (8; 45). The situation in
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28 479 the study area is comparable to Spain (55% of criminal fires burning 59% of the total area
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30 480 between 2001 and 2010) (46).
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38 482 **4.2 Land Cover and WUI Temporal Variation**

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41 483 Land cover significantly varied over time, with a decrease in “agricultural areas” during the two
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43 484 first periods benefiting to “natural areas” and “artificialized areas”, however the trend reversed
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45 485 between 2006 and 2014. Previous studies also revealed a clear trend of forest expansion and
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47 486 the reduction of croplands and grasslands in some regions of Italy (Calabria (47), the Appenines
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49 487 (48), and Sicily (49)), often due to the intensification of silvicultural activities and to a gradual
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51 488 agricultural abandonment (47). The same occurred in Greece (50), Spain (51), but also in the
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53 489 French Pyrenean region (52). The Mediterranean area is one of the most significantly altered
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55 490 hotspots on Earth (53); indeed, agricultural lands, evergreen woodlands and shrublands, so
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57 491 widespread in the whole Mediterranean basin, are the result of anthropogenic disturbances that
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3 492 have been occurring over centuries or even millennia (54). However, over the past decades, the
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5 493 most significant land cover/land use changes have occurred as a consequence of a series of
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7 494 widespread and often connected phenomena: urban sprawling, agricultural intensification in the
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9 495 most suitable areas and agricultural abandonment in marginal areas, more frequent and more
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11 496 intense summer wildfires, and the rapid expansion of tourist activities and infrastructures, above
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14 497 all, along the coasts (20; 55 ; 56).

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17 498 As for land cover, WUI can also be easily mapped everywhere in the world using land cover
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19 499 and housing data when available so that their extent and dynamic can be quantified (57). For
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21 500 instance, WUI covered 9.5% of the conterminous United States in 2010 and had a 41% growth
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23 501 in the number of houses since 1990 (58). Similar trends have been reported across southern
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25 502 Europe (59). For instance in Sardinia, the temporal trend of WUIs clearly showed the shift from
26
27 503 a prevailing agro-pastoral economy to an economy based mainly on tourism, with an
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29 504 intensification of WUI clustered interface, mainly represented by tourist villages and resorts on
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31 505 the coast, increasing at a faster rate than the scattered and isolated types (20). In the study area,
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33 506 over the period 1993-2017, WUI represented on average 28.6% of the district surface area, with
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35 507 a 2.3%-increase between 1999 and 2009. There was a well-marked spatial distribution of the
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37 508 different WUI types within the study area : the « very dense clustered » and « dense clustered»
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39 509 types were mostly concentrated around cities and around the Etang de Berre while « scattered »
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41 510 and « isolated » types were mostly located in the southwestern and northern parts of the study
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43 511 area. There was also a temporal variation of these types between 1999 and 2009. According to
44
45 512 an increase in the global WUI surface area (+ 8,5%), the « dense clustered» and « very
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47 513 dense clustered» types mostly increased as well as the « scattered » type, to a lesser extent, in
48
49 514 contrast to the « isolated » type that decreased between 1999 and 2009. This temporal variation
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51 515 was also characterized by a strong heterogeneity among communities, regardless of the WUI
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3 516 type. In the continental USA, results also showed that the extent and rate of expansion differed
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5 517 between WUI types (58).

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10 11 519 **4.3 Fires according to Land Cover and WUI**

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14 520 « Natural areas » were the most affected by fire ignitions (mainly located very close from
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16 521 the « artificialized areas », mostly urban areas) in the study area during the periods studied in
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18 522 contrast to « agricultural areas ». However, this trend was decreasing over time (fire ignitions
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20 523 dropping from 66% to 58%), which could also be related to a decrease in the surface area of the
21
22 524 land cover classes related to wildland. In contrast, ignitions were increasing in “artificialized
23
24 525 areas”, which could be correlated with the increase in this land cover’s surface area (+234.1
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26 526 km²) between 2006 and 2014, therefore resulting in more human-caused ignitions. In California,
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28 527 the distribution of fires was also found to be related to the vegetation cover and land use, and
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30 528 therefore, varied spatially throughout the territory, with more large fires where the forests are
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32 529 dense and less developed by human habitats and where the population density is relatively low.
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34 530 In contrast, frequent fires with greater social and economic impact on human lives and society
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36 531 were concentrated in areas where shrubland was the dominant land cover, associated with a
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38 532 higher level of human activity (33).

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44 533 WUI was impacted by, on average, 49.3% of the ignitions while located in a smaller surface
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46 534 area than “natural areas” (only 28.6% of the study area). In Spain, (60) found that WUI
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48 535 corresponding to dispersed housing in a forested area, characterizing people moving from cities
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50 536 to natural areas, had more fire risk than WUI corresponding to settlements in an agro-forest
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52 537 mosaic, typical in farming areas. WUI types’ susceptibility to fire also varied over time. Indeed,
53
54 538 the « isolated» and «scattered » types were the most affected (as highlighted by (17)) during
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56 539 the first period (1999), with 39% of ignitions within WUI, while it was « very dense clustered »
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3 540 and « scattered » that were the types (representing the highest proportion of WUI in 2009)
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5 541 mainly targeted in the second period (2009), with 50% of ignitions within WUI.
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8 542 It is now well-known that the fire risk is higher in WUI in the northern part of the
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10 543 Mediterranean basin (14; 61; 62). As shown in a previous work, the pattern of ignition risk
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12 544 among land covers differed between WUI and non-WUI areas in Galicia (Spain), forestry
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14 545 plantation showing the highest increase in ignition risk in WUI compared to non-WUI areas in
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16 546 contrast to native forests and agricultural areas (62). Another study (63), carried out in Catalonia
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18 547 (Spain), determined how WUI's vulnerability to wildfires spatially varied among three major
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20 548 WUI types (metropolitan, agroforest, and mountain agrosilvopastoral), each showing
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22 549 significant temporal changes in Land Use and Land Cover but with vulnerability depending on
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24 550 their own fire dynamics (63). These authors showed that the abandonment of traditional
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26 551 activities negatively affected WUI vulnerability, regardless of the type (63).
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32 552 A more in-depth analysis of the WUI areas (spatio-temporal evolution) should allow a better
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34 553 characterization of these areas for a better territorial fire risk management. Indeed, fire risk has
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36 554 been exacerbated by the rapid increase in the WUI area. This trend is supposed to worsen as
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38 555 simulations project a continued expansion in the future due to demographic trend, the attraction
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40 556 to areas with natural amenities, recreational activities, retirement to rural areas, and economic
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42 557 reasons (44; 64; 65). The current study showed that, between 2003-2009 and 2011-2017, mostly
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44 558 50% of the fires were located at WUI, even if these areas represent less than 25% of the district
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46 559 area, which is a trend also observed in other Mediterranean areas (56; 66; 67; 68; 69). However,
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48 560 if the change in the firefighting strategy in the late 80s is taken into account, the increase in fire
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50 561 risk due to climatic (increasing summer temperature and drought period) and land use
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52 562 (increasing WUI areas) changes does not necessarily lead to more fires (70).
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564 5. CONCLUSIONS

565 Most communities of the Bouche du Rhône district were impacted by fires (according to
566 their occurrence, density, and burned area) with a high spatial (the most impacted communities
567 being located close to big cities) but also temporal variability. The level of certainty of the fire
568 causes has strongly improved since 1997, showing a decreasing interannual variability,
569 especially in 2011-2017. The study area was also characterized by a high occurrence of criminal
570 fires, regardless of the period. These fires were the most destructive, except in 2011-2017, when
571 fires due to negligence during private activities burned the largest area, mostly as a result of
572 one large fire event.

573 The surface area of the main land cover classes varied among periods, with a decrease in
574 “agricultural areas” between 1999 and 2006 benefiting to the other classes but the trend reversed
575 between 2006 and 2014. The class “natural areas” was the most impacted by ignitions and
576 underwent the largest burned area, regardless of the period, in contrast to the class “agricultural
577 areas”. However, this trend was decreasing over time in contrast to that of “artificialized areas”.
578 The proportion of WUI increased over time, especially the “dense clustered” and “very dense
579 clustered” types (in contrast to the “isolated” type), and represent on average ~29% of the
580 district’s area. There was a spatial variation of the WUI types, “dense clustered” and “very
581 dense clustered” types being located mostly around urban areas in the East while the other types
582 were more frequent in the southwestern and the northern parts of the study area. The “very
583 dense clustered” and “scattered” types were the most affected by fires in 2009 while it was
584 “isolated” and “scattered” in 1999. There was a strong heterogeneity among communities in
585 this temporal variation, regardless of the WUI type.

586 Housing development is one of the most important causes of landscape change throughout
587 the world. The current work provided results at a fine scale (community) that are important to
588 take into account, as we need to better plan the WUI to develop resilient communities along

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3 589 with fire-resilient landscapes. Land use planning and landscape management, through urban
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5 590 planning policies, have to be considered to regulate existing WUI and their surrounding (71,
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7 591 72) and better plan their extension taking into account the current fire risk (22) in order to reduce
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9 592 it in the future (73). There is more and more evidence that policy makers should focus more on
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11 593 land use patterns in wildfire protection plans. For instance, (74) showed that as the spatial
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13 594 configuration of development patterns in WUI (infill, radial, and outlying) influenced wildfire
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15 595 ignition, this should be used to direct land use planning to reduce fire risk in densifying area,
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17 596 which could also reduce overall suppression costs.
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3 608 FIGURE CAPTIONS
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6 609 Figure 1 : Map of the study area (BDTOPO IGN version 2 Lambert 93). Forested systems in
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8 610 green were extracted from the “BD Forêt 2014” of the National Geographic Institute
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10 611 (<https://www.geoportail.gouv.fr>) and 1:25 000 digital terrain model from the National
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13 612 Geographic Institute (IGN).
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19 614 Figure 2 : Fire number (a) and density (b) according to communities of the Bouches-du-
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21 615 Rhône district during the period 1973-2017 (Source - www.prométhée.com).
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27 617 Figure 3 : Fire hot-spots in 2003-2009 and 2011-2017 in the Bouches-du-Rhône district (Source
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29 618 - ONF/DDTM13)
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35 620 Figure 4 : Variation of fire occurrence (a), burned area (b), and proportion of unknown causes
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37 621 (c) according to the time period (Source – www.prométhée.com).
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43 623 Figure 5 : Fire occurrence and area burned according to the fire cause during the three periods
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45 624 studied in the Bouches-du-Rhône district (Source – www.prométhée.com).
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51 626 Figure 6 : Variation of fire occurrence and burned area according to the fire cause from 1993-
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53 627 1999 to 2003-2009 and from 2003-2009 to 2011-2017 in the Bouches-du-Rhône district (Source
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55 628 – www.prométhée.com).
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3 630 Figure 7 : Proportions of the different classes of land cover according to the different periods
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5 631 studied in the Bouches-du-Rhône district (Source – CRIGE PACA).
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11 633 Figure 8 : Spatial distribution of the different types of WUI (based on housing density) in the
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13 634 Bouches-du-Rhône district in 2009.
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19 636 Figure 9 : Evolution of the WUI « clustered very dense » (a), « clustered dense » (b),
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21 « scattered » (c), and « isolated » (d) types according to the community in the Bouches-du-
22 637 Rhône district between 1999 and 2009.
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30 640 Figure 10 : Distribution of fire ignitions according to WUI in the Bouches-du-Rhône district
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32 641 (Source – ONF/DDTM13).
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642 TABLES

643 Table 1 Temporal evolution of the main land cover classes (ha) among the periods studied

644 (Source: CRIGE PACA).

	1999	2006	Rate of change	2006	2014	Rate of change
Artificialized areas	63329.82	106391.31	68.00%	106391.31	87163.17	-18.07%
Natural areas	150796.70	183383.75	21.61%	183383.75	191748,19	4,56%
Agricultural areas	218261.75	151129.22	-30.76%	151129.22	190342.99	25.95%
Others	9224.49	16270.39	76.38%	16270.39	11723.26	-27.95%

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646 Table 2 Rate of change of the WUI type surface areas (ha) between 1999 and 2009 in the
 647 Bouches-du-Rhône district. WUI types are based on the housing density (WUIMap).

Type of WUI	Surface area		Rate of change (%)
	1999	2009	
Very dense	42877	49506	+15.5
Dense	24736	28448	+15.0
Scattered	38440	41126	+7.0
Isolated	33743	32469	-3.8
Total WUI Surface Area	139796	151639	+8.5
Proportion of the study area occupied by WUI	27.48%	29.81%	+2.33

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649 Table 3 Proportion of fire occurrence and burned area in the main land covers in 2006 and
 650 2014 in the Bouches-du-Rhône district (No results for the period 1993-1999 due to the
 651 inaccuracy of the data records during this period).

	2006		2014	
	Occurrence	Burned area	Occurrence	Burned area
Artificialized areas	24.39%	17.91%	28.82%	23.74%
Agricultural areas	9.23%	31.13%	12.21%	31.61%
Natural areas	66.38%	50.95%	58.97%	44.65%

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653 Table 4 Temporal variation of the distribution of ignitions according to the WUI type (Source:
654 ONF/DDTM13, WuiMap)

Type of WUI	Number of ignitions		Number of ignitions		Number of ignitions	
	1993-2009	%	1993-1999	%	2003-2009	%
Very dense clustered	124	32.2	19	19.8	105	36.3
Dense clustered	74	19.2	16	16.7	58	20.1
Scattered	110	28.6	27	28.1	83	28.7
Isolated	77	20.0	34	35.4	43	14.9
Total within WUI	385	50.2	96	38.7	289	50.2
Total outside WUI	439	49.8	152	61.3	287	49.8
Total	824	100	248	100	576	100

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FIGURES

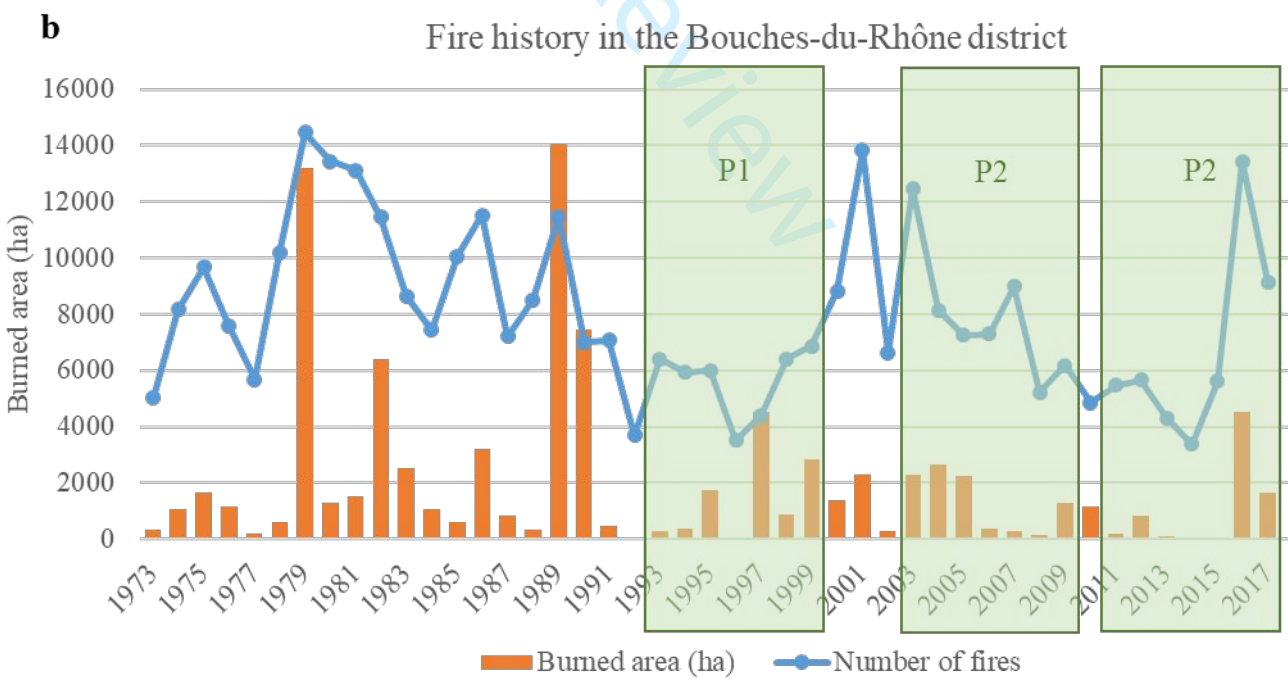
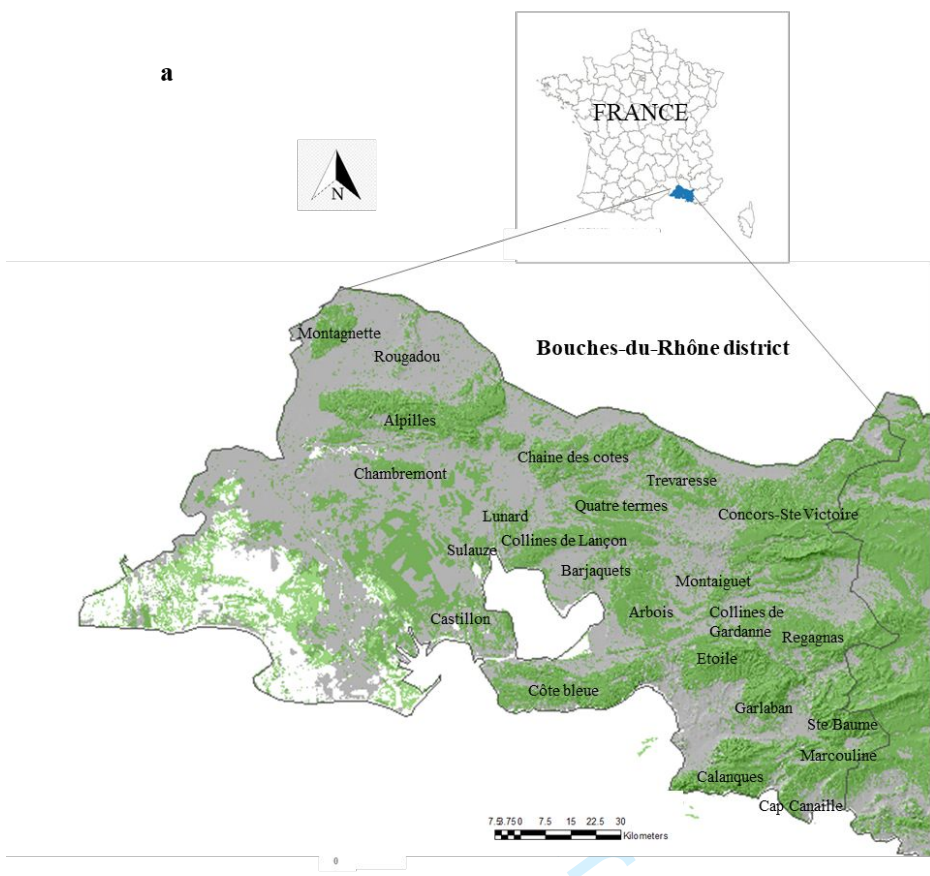


Fig. 1

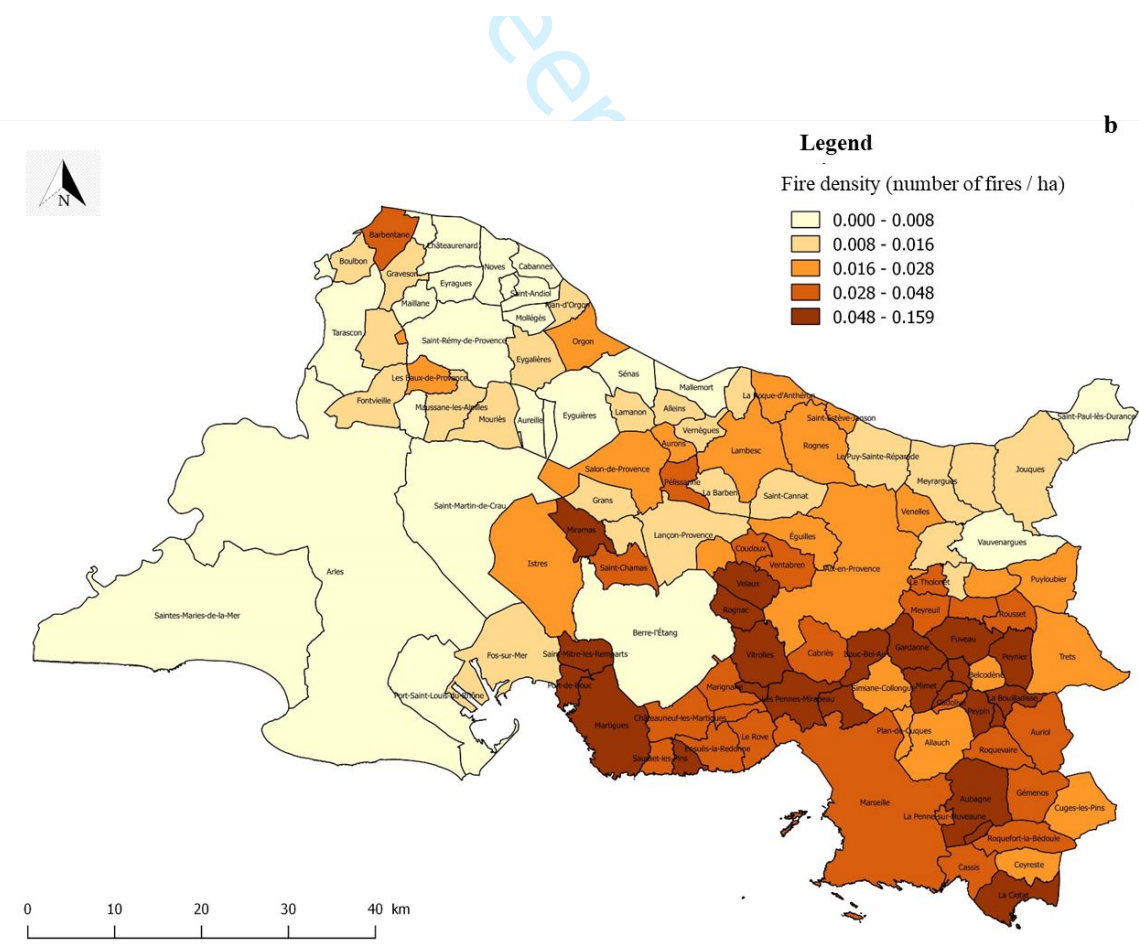
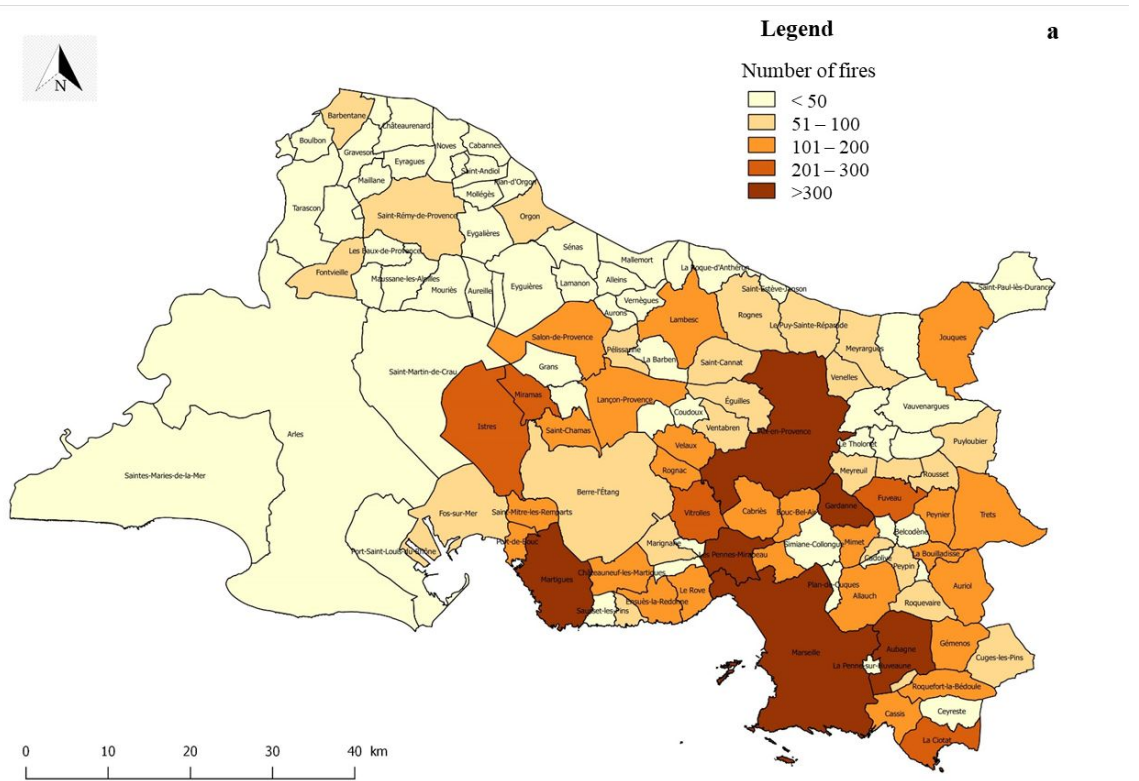


Fig. 2

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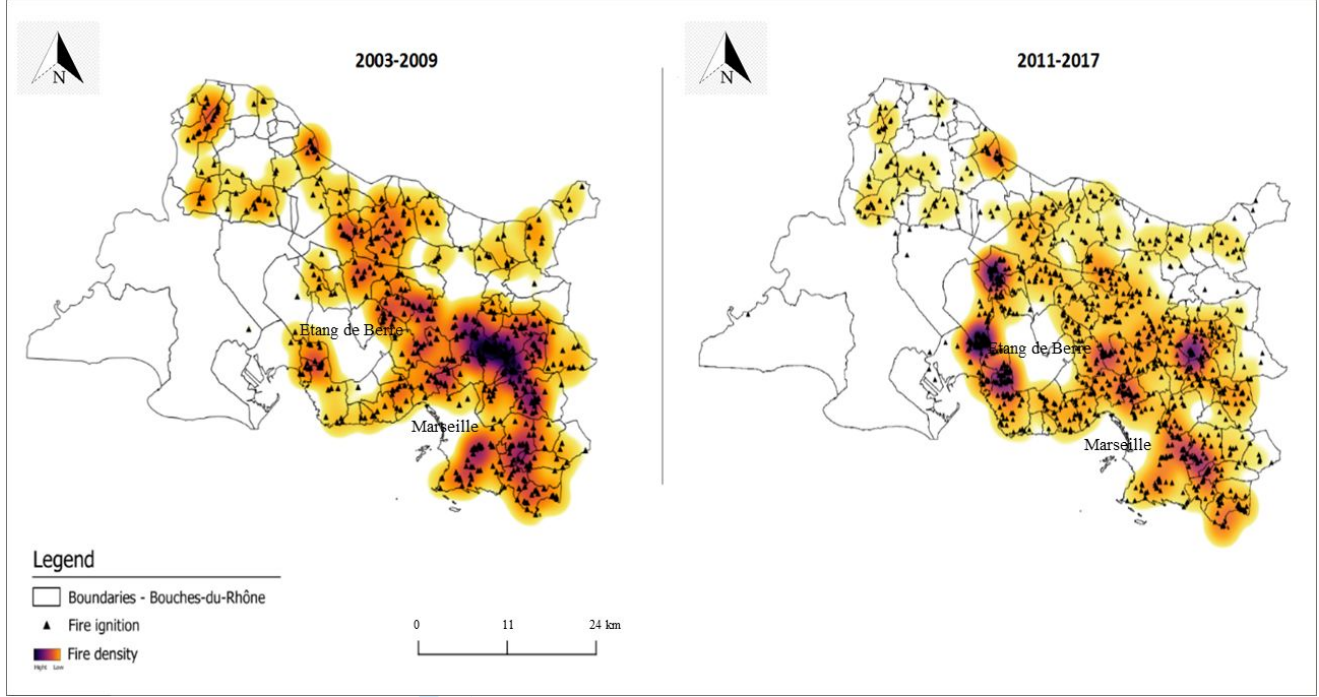
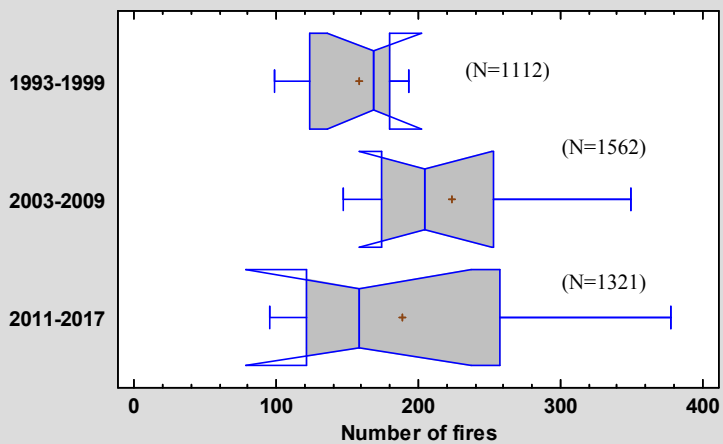


Fig. 3

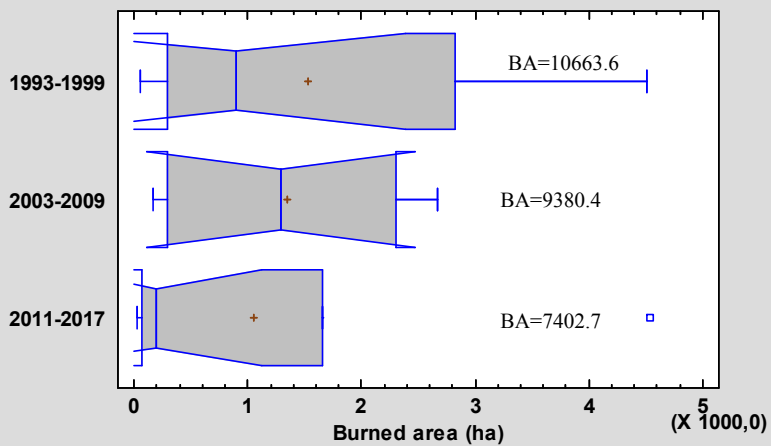
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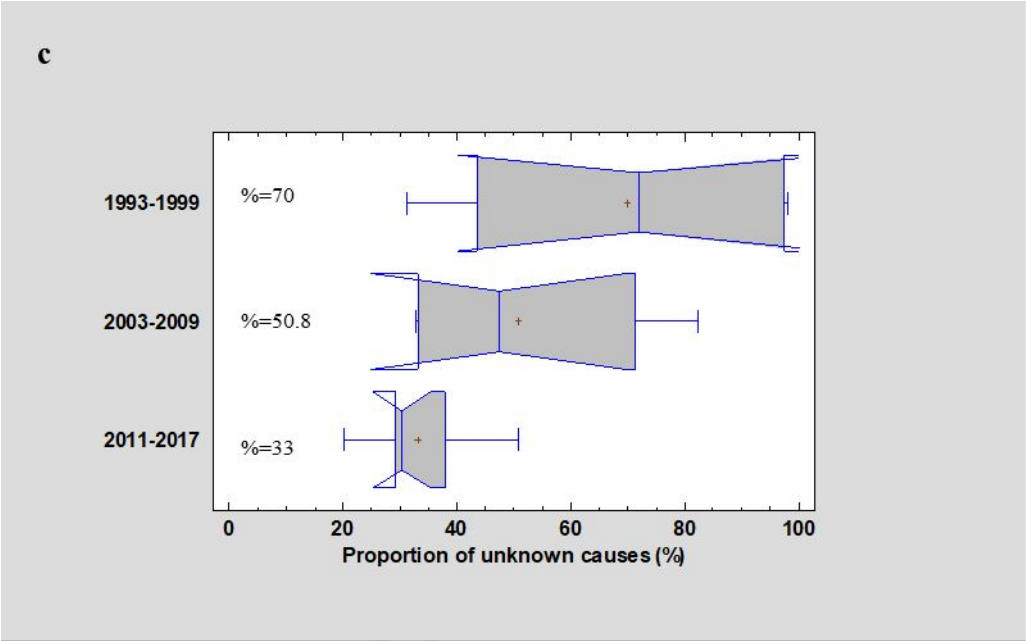


Fig. 4

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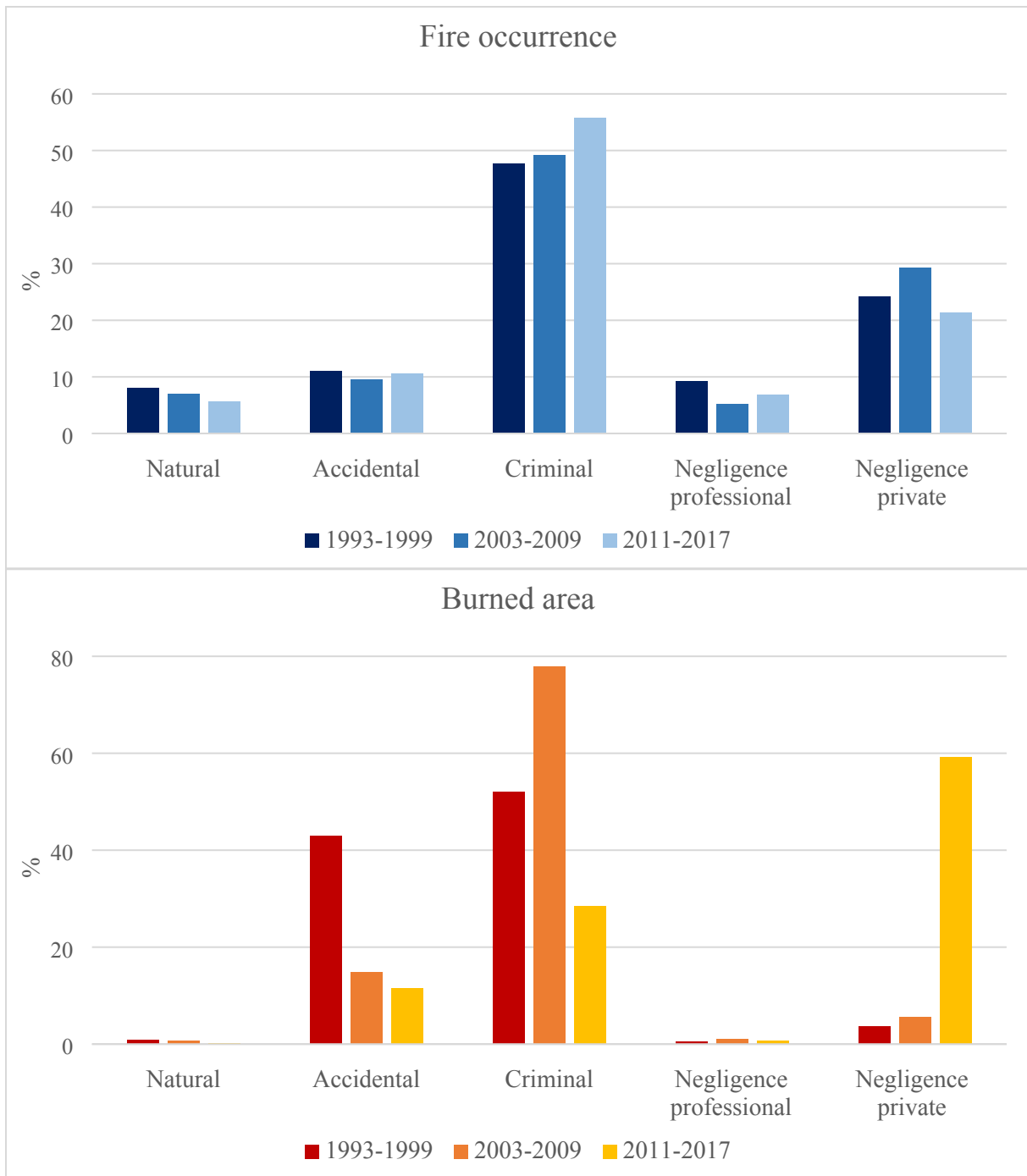
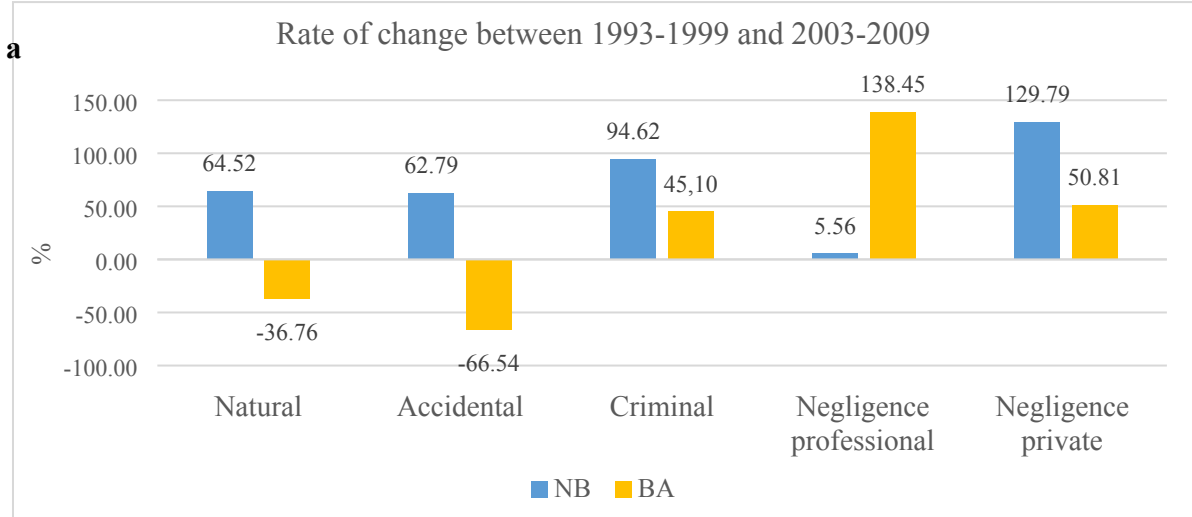


Fig. 5

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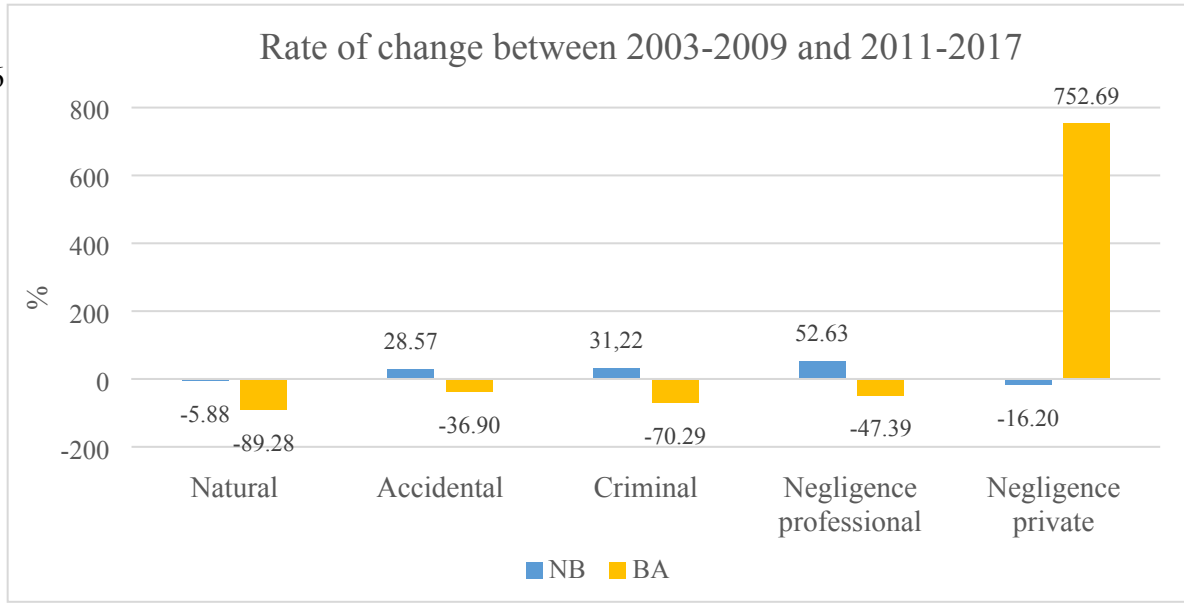


Fig. 6

For Peer Review

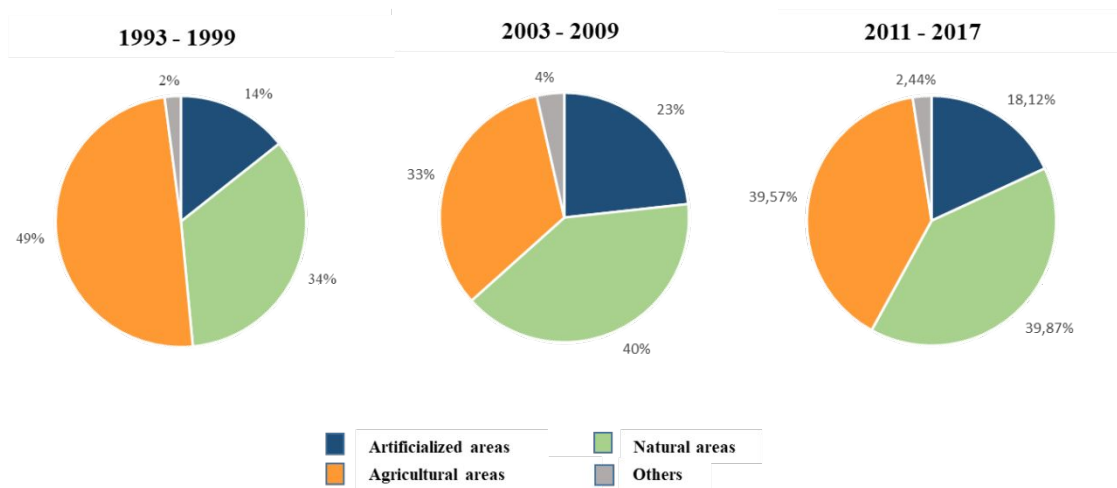


Fig. 7

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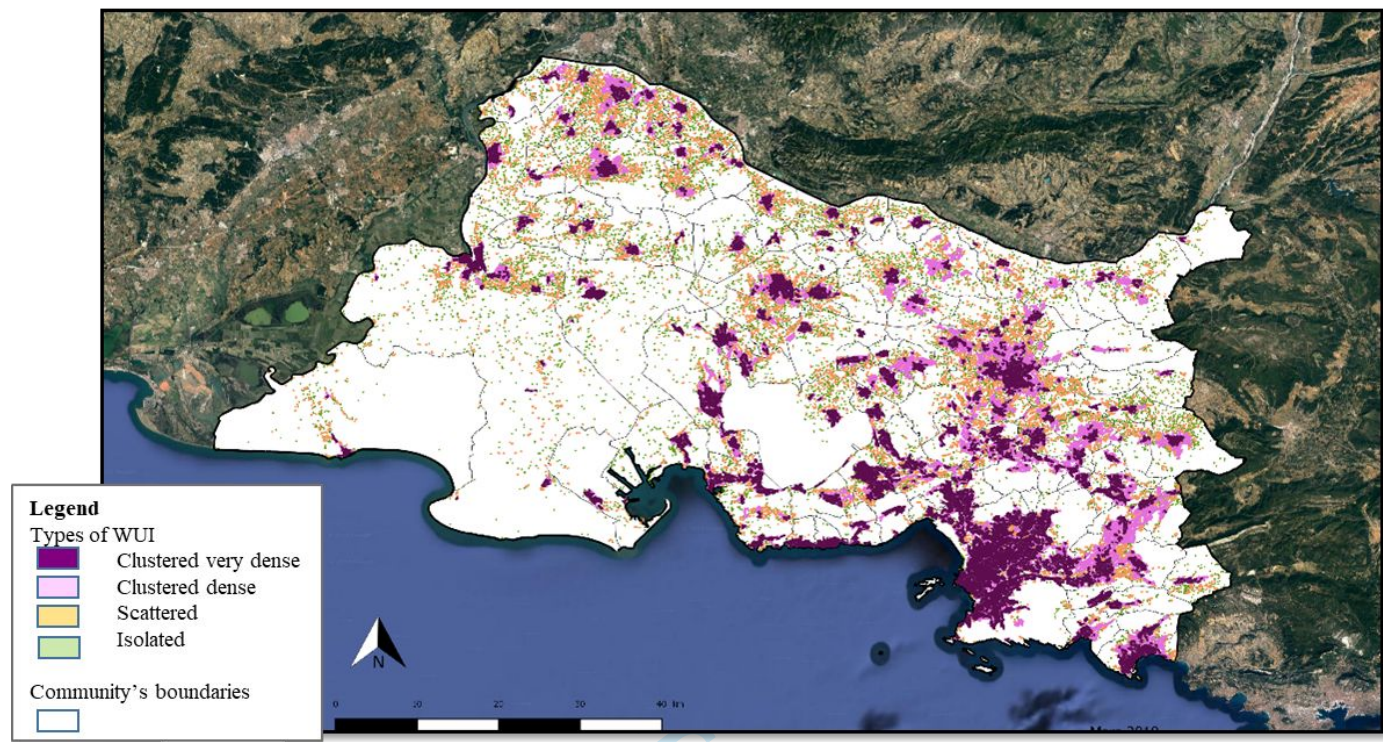


Fig. 8

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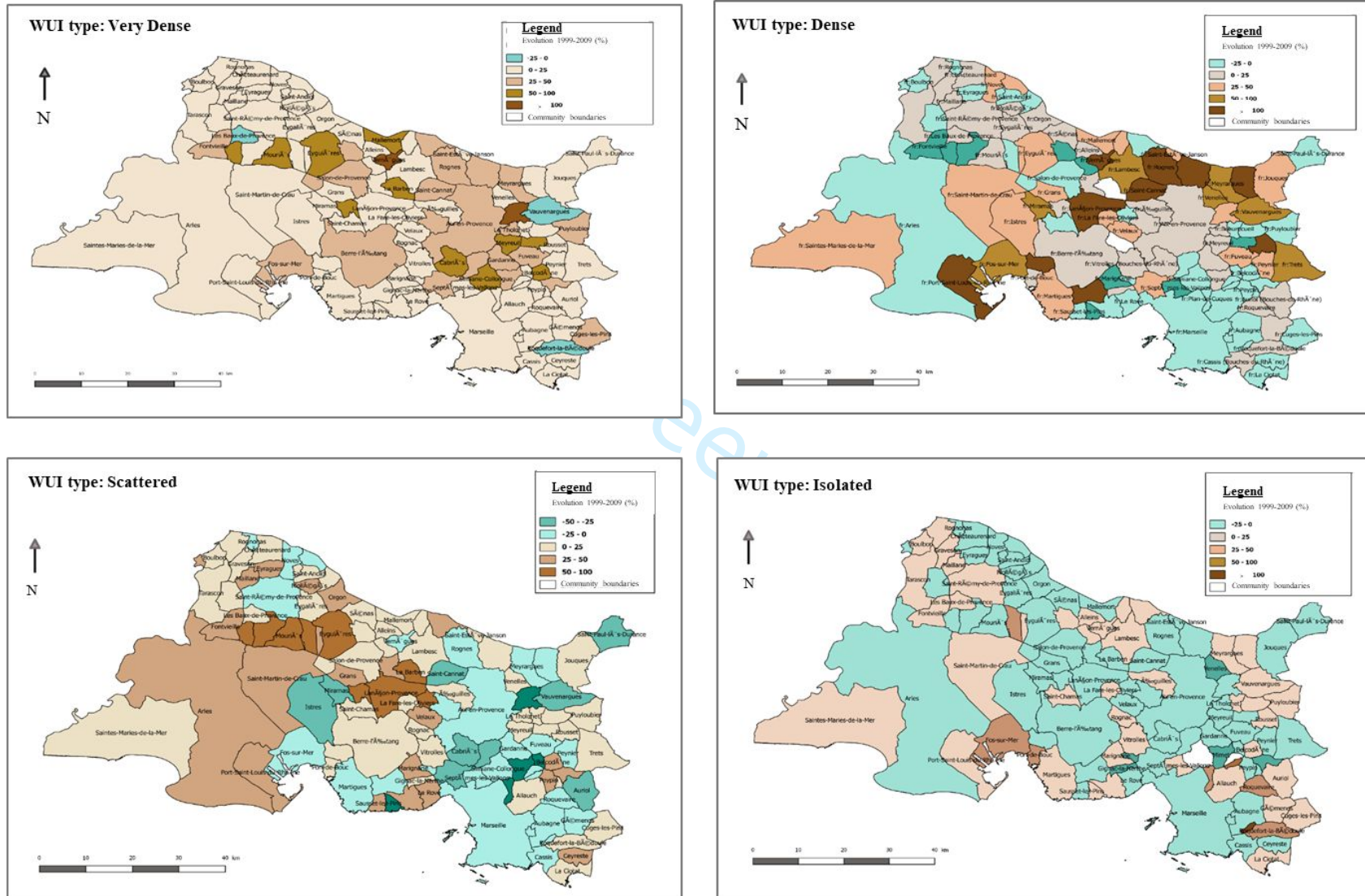


Fig. 9

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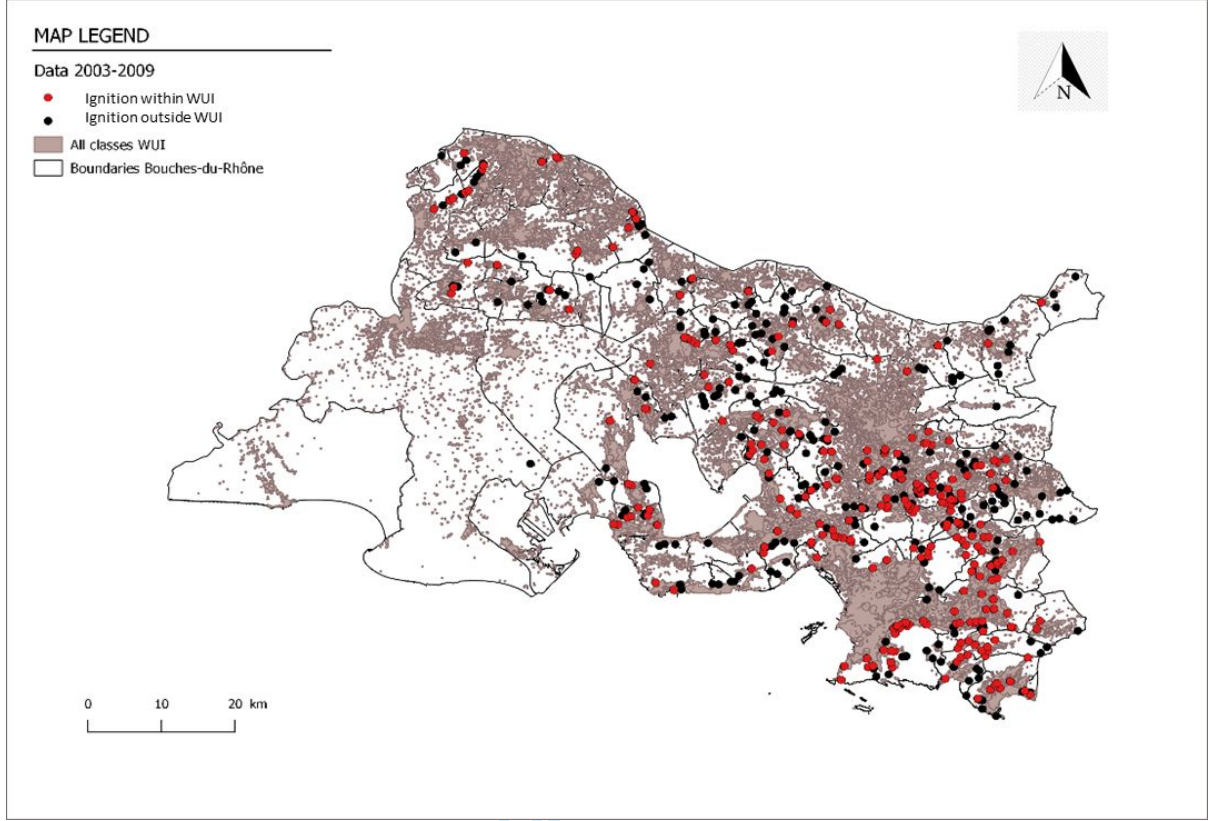


Fig. 10

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