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► To cite this version:

Didier Josselin. Portfolio illustrant l'activité du laboratoire ESPACE, fourni au HCERES le 15 juin 2022.. CNRS. 2022, <https://www.umrespace.org/>. hal-04350907

HAL Id: hal-04350907

<https://hal.science/hal-04350907>

Submitted on 18 Dec 2023

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PORTFOLIO de l'UMR 7300 ESPACE

CAMPAGNE D'ÉVALUATION 2022-2023

VAGUE C

INTRODUCTION

Ce portfolio illustre la richesse et la portée des productions du laboratoire ESPACE. Même s'il ne couvre pas exhaustivement l'activité de l'unité, il met en exergue des points saillants et seyants, représentatifs de notre identité. La sélection des sujets présentés a été réalisée en fonction d'une part, de critères issus du document d'auto-évaluation (DAE) et, d'autre part, d'éléments considérés par les membres d'ESPACE comme particulièrement importants ou caractéristiques de l'unité, notamment dans le cadre d'une UMR multisites.

Le choix des critères, tout comme celui des sujets présentés, a été réalisé de manière collégiale et constructive, lors d'une assemblée générale en présentiel, les 7 et 8 mars 2022.

Les critères retenus sont les suivants (sans hiérarchisation particulière) :

- La **visibilité scientifique**, via la catégorisation des publications dans le premier quartile du domaine thématique et/ou leur caractère international,
- Le **caractère inclusif et structurant** de l'activité de l'unité, avec notamment la formation et la participation de jeunes chercheur.se.s d'ESPACE, le caractère transversal (intersites) de la production,
- Le **positionnement** de la production ou de l'activité au front de la connaissance thématique ou méthodologique, ainsi que ses spécificités (interdisciplinarité par exemple),
- L'**impact sur la société**, par l'innovation sociale, la dissémination de la connaissance scientifique, l'aide à la décision et l'ancrage territorial.

Compte tenu de la taille de notre UMR (49 personnels permanents), 11 points saillants ont été sélectionnés et sont classés selon deux grands types : articles publiés (au nombre de cinq) ou activités développées au sein de l'unité. Ils sont extraits des différentes actions de recherche composant les 3 axes thématiques du laboratoire et les représentent de façon consistante et équilibrée, couvrant ainsi les objectifs scientifiques fixés dans le programme du contrat sexennal 2018-2023.

Les éléments du portfolio sont organisés par domaine d'activité, sans ordre de préférence particulier :

- *Une UMR qui publie et qui innove* : 5 articles scientifiques dans des revues internationales de renom
- *Une UMR qui contribue à la vitalité et à la dynamique des interactions entre les scientifiques de son domaine* : organisation de conférences (internationales) par ESPACE
- *Une UMR qui éclaire et aide à la décision et à l'action* : ancrage territorial et recherches appliquées

- Une UMR qui forme par et pour la recherche : développement marqué du lien entre la recherche et l'enseignement supérieur
- Une UMR qui vulgarise et dissémine ses connaissances vers la société : la place de la médiation scientifique à ESPACE
- Une UMR qui collecte, gère, traite et diffuse des informations scientifiques : supports de publication en libre accès, corpus et plateformes expérimentales de données
- Une UMR qui se préoccupe de la qualité de vie au travail : actions fonctionnelles transversales et structurantes à ESPACE.

Une synthèse des éléments présentés dans ce portfolio apparaît dans la Figure 1.

ID #	Type	Activité de l'UMR	Visibilité scientifique	Caractère inclusif et structurant	Positionnement principal du contenu	Impact sociétal
1	Article scientifique	Publication, innovation	Q1 Internationale	Intersite Jeune chercheur	Thématique	Risque
2					Interdisciplinaire	Observatoire
3				Jeune chercheur	Méthodologique	Fabrique urbaine
4					Méthodologique, Interdisciplinaire	Planification urbaine
5						Santé
6	Activité scientifique	Organisation de conférences	Internationale	Intersite Jeune chercheur	Méthodologie, sciences régionales	Société numérique
7		Aide à la décision, à l'action	Internationale	Multisite	Méthodologie	Applications sur les territoires
8		Formation <i>par et pour</i> la recherche	Nationale	Intersite Jeune chercheur	Performance et adéquation des formations	Partenariat régional
9		Transfert des connaissances scientifiques	Nationale	Multisite Jeune chercheur	Médiation, vulgarisation scientifiques	Information appropriation
10		Collecte et diffusion des données scientifiques	Internationale	Intersite	Science ouverte	Information, diffusion, participation
11		Qualité de vie au travail		Intersite Transversal	Développement et cohésion internes	Qualité de l'activité scientifique

Figure 1. Positionnement des points saillants présentés selon les critères clés

Type : article en revue internationale ou activité scientifique ; *Activité de l'UMR* : détaille le type d'activité ; *Visibilité scientifique* : classement en premier Quartile pour les articles, portée nationale ou internationale de l'activité ; *Caractère inclusif et structurant* : indique la participation de jeunes chercheurs, le caractère multisites (déploiement en parallèle sur les sites) ou intersites (transversal aux sites) des activités ; *Positionnement principal* : apport caractérisant l'élément (non exhaustif) ; *Impact sociétal* : domaines et niveaux d'application.

UNE UMR QUI PUBLIE ET QUI INNOVE

5 ARTICLES sélectionnés

Les auteurs d'ESPACE sont indiqués en caractère gras avec leur statut et leur affiliation.

#1 – ARTICLE

How wildfire risk is related to urban planning and Fire Weather Index in SE France (1990-2013)

Fox D.M. (PR, Université Côte d'Azur), **Carrega P.** (PREM, Université Côte d'Azur), **Ren Y.** (stagiaire, ESPACE), **Caillouet P.** (stagiaire, ESPACE), Bouillon C., **Robert S.** (DR, CNRS).....4

#2 – ARTICLE

A framework to analyse urban sprawl in the French Mediterranean coastal zone

Robert S. (DR, CNRS), **Fox D.** (PR, Université Côte d'Azur), **Boulay G.** (MCF, Avignon Université), Grandclément A., Garrido M., Pasqualini V., **Prévost A.** (post-doc, CNRS), **Schleyer-Lindenmann A.** (MCF, Aix-Marseille Université), **Trémélo M.-L.** (IE, CNRS)..... 15

#3 – ARTICLE

From the street to the metropolitan region: Pedestrian perspective in urban fabric analysis

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#4 – ARTICLE

Vacant lands on French Mediterranean coastlines: Inventory, agricultural opportunities, and prospective scenarios

Casanova Enault L. (MCF, Avignon Université), **Popoff T.** (Ingénieure, ESPACE), **Debolini M.** ... 54

#5 – ARTICLE

Using Bayesian networks for environmental health risk assessment

Perez S. (MCF, Université Côte d'Azur), **German-Labaume C.**, **Mathiot S.**, **Goix S.**, **Chamaret P.** 72

#1 - ARTICLE

HOW WILDFIRE RISK IS RELATED TO URBAN PLANNING AND FIRE WEATHER INDEX IN SE FRANCE (1990-2013)

Fox D.M. (PR, Université Côte d'Azur), Carrega P. (PREM, Université Côte d'Azur), Ren Y. (stagiaire, ESPACE), Caillouet P. (stagiaire, ESPACE), Bouillon C., Robert S. (DR, CNRS)

2018, *Science of The Total Environment*, Volume 621, 2018, Pages 120-129, ISSN 0048-9697

<https://doi.org/10.1016/j.scitotenv.2017.11.174>

<https://www.sciencedirect.com/science/article/pii/S0048969717332333>

Dans un contexte de réchauffement climatique, le risque d'incendie de forêt s'aggrave dans de nombreuses régions du monde. Au-delà des contextes climatiques et écologiques habituels, les incendies de forêt s'étendent vers des saisons et zones géographiques jusqu'ici peu touchées par les feux. Les incendies extrêmes de l'Australie en 2019 ainsi qu'en Californie depuis quelques années montrent bien l'effet catastrophique sur la santé humaine et les écosystèmes. En France, le feu de Gonfaron de 2021 dans le département du Var a brûlé près de 7000 ha, le troisième plus grand incendie de forêt depuis 1973.

Les incendies de forêt sont un risque naturel bien évidemment étroitement lié aux conditions météorologiques. Les différents paramètres (vent, température, humidité relative, état de sécheresse) sont intégrés dans une équation pour créer un indice météorologique de risque d'incendie de forêt, ou un *Fire Weather Index (FWI)*. Cependant, le risque d'éclosion d'un feu est aussi intimement lié à la configuration de l'habitat, notamment sa densité, car des maisons isolées ou diffuses dans le paysage représentent des interfaces habitats-forêt (*Wildland Urban Interface, WUI*) particulièrement propices aux incendies.

L'article publié dans la revue *Science of the Total Environment*¹ quantifie l'évolution de l'habitat et du FWI entre 1990-2013 dans les Alpes-Maritimes et montre que, malgré une augmentation claire du risque météorologique, les superficies brûlées ont fortement diminué avec le temps. Le risque structurel d'un incendie de forêt lié à la configuration de l'habitat dans le paysage a évolué favorablement par l'augmentation de la densité de l'habitat. Des quartiers plus denses réduisent la propagation du feu et permettent une suppression de l'incendie plus rapidement. A cela s'ajoute l'impact de l'évolution de la stratégie du Service Départemental d'Incendie et de Secours (SDIS²) qui favorise une suppression rapide avant que le feu prenne de l'ampleur (l'Extinction Massive de Foyers de Feux Naissants).

Cette publication est représentative des travaux que nous essayons de mener au sein de l'UMR ESPACE par 3 caractéristiques : 1. il est pluridisciplinaire, intégrant des éléments de géographie physique (la climatologie) et de géographie humaine (les interfaces habitat-forêt) dans une perspective globale de la gestion des risques naturels et territoires ; 2. il rassemble 3 membres de 2 sites différents de l'UMR avec des compétences spécifiques (Fox : évolution de l'occupation du sol ; Carrega : climatologie ; Robert : aménagement urbain) ; 3. il est le résultat d'une collaboration avec l'IRSTEA (maintenant INRAE³) qui représente notre capacité à créer des collaborations et réseaux de partenariats de recherche. Enfin, deux des auteurs (Ren & Caillouet) sont des étudiantes stagiaires qui ont été intégrées parmi les auteurs en reconnaissance d'une contribution réelle à la publication.

La revue *Science of the Total Environment* est une revue d'excellence (IF 8.0) qui publie des articles à l'interface de différentes disciplines. L'article en question a déjà été cité 26 fois depuis 2018 (environ 8 fois par an), attestant ainsi de son intérêt dans la communauté scientifique.

¹ <https://www.journals.elsevier.com/science-of-the-total-environment>

² <http://fransylva-paca.fr/wp/services-departementaux-dincendie-et-de-secours/>

³ <https://www.inrae.fr/centres/provence-alpes-cote-dazur>



How wildfire risk is related to urban planning and Fire Weather Index in SE France (1990–2013)

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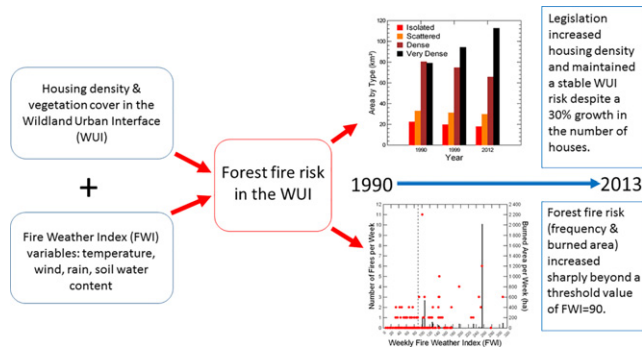
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HIGHLIGHTS

- Land use planning in SE France led to increased housing density in 1990–2012 and maintained WUI wildfire risk constant.
- The number of buildings increased by 30% but WUI area increased by less than 5% as housing density increased.
- Fire frequency and burned area increase substantially as Fire Weather Index surpasses a threshold value of 90.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 28 September 2017
 Received in revised form 15 November 2017
 Accepted 15 November 2017
 Available online xxx

Editor: D. Barcelo

Keywords:

Land use planning
 Wildfires
 Forest fires
 Wildland Urban Interface (WUI)
 Fire Weather Index (FWI)

ABSTRACT

Wildfires burn >450,000 ha of forest every year in Euro-Mediterranean countries. Many fires originate in the Wildland Urban Interface (WUI) where housing density and weather conditions affect fire occurrence. Housing density is determined by long term land use policies while weather conditions evolve quickly. The first objective was to quantify the impacts of land use policy on WUI characteristics and fire risk in SE France during 1990–2012. The second objective was to quantify how Fire Weather Index (FWI) is related to fire occurrence. WUI was mapped from 1990, 1999, and 2012 building layers and crossed with a NDVI derived vegetation layer. In all, 12 WUI categories were derived: 4 building density classes and 3 vegetation layers. The 187 FWI was based on daily temperature, wind speed, relative humidity and soil water content. Despite a 30% increase in the number of new buildings, WUI area increased by only 5% as new housing filled in open space in existing WUI area. This trend can be linked to national level urban planning legislation and forest fire protection laws. Major driver variables determining housing location were aspect, slope, and distance to city centers. Fire frequency and burned area were nonlinearly related to FWI: 73% of the 99 fires occurred during weeks with FWI values ≥ 90 even though these accounted for only 44% of all weeks. Burned area was even more sensitive to FWI since 97% of total burned area occurred during weeks with mean FWI values ≥ 90 . All days with burned areas >100 ha had FWI values >150. The study demonstrated that WUI legislation can be an efficient tool to limit WUI fire risk. FWI results suggest the predicted increase in extreme summer heat events with global warming could increase burned area as firefighting resources are stretched beyond capacity.

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1. Introduction

Forest fires in the Euro-Mediterranean Wildland Urban Interface (WUI) result from complex interactions between weather, WUI characteristics, and fire-fighting strategies (fire prevention and suppression) (San-Miguel-Ayanz et al., 2013). Although fire frequency and burned area are expected to increase with global warming (Lozano et al., 2016; Moriondo et al., 2006), this has not been a consistent trend in recent decades. For example, despite warmer summer temperatures, SE France experienced a sharp drop in fire frequency and burned area since the early 1990's due to more efficient fire prevention/suppression (Fox et al., 2015). Based on data published in the Joint Research Center 2014 report (JRC, 2014), most fire-prone Euro-Mediterranean countries (Portugal, Spain, France, Italy, and Greece) have experienced fewer fires in the past decade. Fire frequency increased rapidly in the 1990's and early 2000's as summer temperatures broke heat records, especially in Portugal, Spain and Greece, but it has decreased over the past 10 years and burned area also shows an overall declining trend (JRC, 2014). Since the 2004–2013 decade was the warmest on record in Europe (<https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-4/assessment>, consulted 31 Oct. 2017), weather conditions alone do not explain the evolution in fire occurrence. WUI characteristics and fire prevention and suppression are major factors to be taken into consideration in addition to fire weather. These trends underscore the need to study fire occurrence in a context of interacting and evolving weather and land cover characteristics, as suggested by Vilar et al. (2016). And fire-WUI and fire-weather relationships are valid only within stable fire prevention and suppression efforts (Fox et al., 2015).

Of the three components cited above (WUI characteristics, weather, and prevention/suppression), weather is naturally occurring and beyond the control of land managers. It is also the most dynamic of the three, as weather related fire risk can evolve over days to hours. Temperature, rainfall and relative humidity are major weather variables but are not enough to account for burned area since big fires need strong winds, so Fire Weather Indices (FWI) are better measures of weather-related fire risk than temperature or drought conditions alone (Carrega and Jeronimo, 2007). A number of indices have been developed to estimate weather-related fire risk: the Canadian Fire Weather Index which is used today in different countries, Mc Arthur's Fire Danger Meters, the Italian Fire Danger Index, the Portuguese Method, and Carrega's meteorological fire indices I^{85-90} and I^{87} (Arpaci et al., 2013; Bedia et al., 2015). Several indices were compared and tested on large European summer fires during the 1991–1995 interval in the context of the MEGAFiReS European research project (Bovio and Camia, 1998). The I^{87} was developed for Mediterranean environments and tested specifically in SE France where it has been proven successful (Carrega, 1991). The index (described below) includes temperature, relative humidity, wind speed, and a surrogate measure of vegetation moisture content. Since the number of extreme days is increasing in southern France (Cardil et al., 2014), relating fire risk to weather variables is a critical step in identifying high risk periods.

Fire-fighting strategy depends on risk management authorities and budget allocation, but in extreme conditions, even highly prepared and equipped firefighters can be overwhelmed by a great number of ignitions. Once a fire escapes initial suppression, it can become unstoppable in extreme heat, vegetation moisture, and wind, until weather conditions improve (Moritz et al., 2010). In general, fire prevention and suppression have contributed to decrease fire frequency and burned area in recent years in many areas (Fox et al., 2015; Pezzatti et al., 2013).

WUI characteristics evolve slowly over a period of decades as land cover, developed area, and housing density change. Different criteria and scales can be used to characterize the WUI interface. These are reviewed in Galiana-Martin et al. (2011) and generally include land use/cover, urban and suburban densities, and vegetation dynamics. In

SE France, the greatest fire risk is associated with isolated, then scattered housing, and fire risk decreases with increasing housing density (Lampin-Maillet et al., 2010; Lampin-Maillet, 2009). Despite the potential for more frequent fire ignitions in greater WUI housing densities, vegetation biomass and continuity decrease and the probability of extinguishing a fire early increases. Low housing density has also been identified as a factor contributing to structure damage by wildfires in California (Syphard et al., 2014). Housing density is regulated at the municipal level through building permits, but external land use policies orient municipal decisions in France (Prévost and Robert, 2016). The first is comprised of national-level laws (Solidarity and Urban Renewal (SRU) law, 2000; and the ALUR law of 2014) that incite municipalities to increase housing density and favor urban renewal over urban and suburban expansion.

Since the national Barnier Risk Prevention Plan law of February 1995, French municipalities are obliged to elaborate Risk Prevention Plans that take into account the dominant risks impacting their territories. In SE France, wildfires are one of the most frequent risks, so an extensive campaign has been undertaken to develop appropriate fire prevention plans. These documents, comprised mainly of fire risk maps, constrain municipal urban planning documents. Large tracts of forest can be classed as non-developable to avoid increasing the number of isolated and scattered houses and WUI area. Traditionally, the climatic and natural landscape amenities make isolated and low density housing a favored form of residential and secondary housing in the region. Although the Risk Prevention Plan law was promulgated in 1995, many municipalities have resisted state efforts to implement risk plans because the freezing of forest land represents a loss in potential residential taxes.

In a long term study (about 1960–2009), Fox et al. (2015) demonstrated that summer temperatures and WUI fire risk increased substantially with the socio-economic development of the Côte d'Azur region of SE France. The study did not take into account the impacts of land use policies aimed at increasing housing density and reducing fire risk since these were introduced only in the latter phase of the time interval studied. The study also indicated that forest fire prevention and suppression strategies intensified around 1990 after several major fires in the 1980's, but these have changed little since then, so fire risk in the time interval studied here is limited to WUI and weather factors. The first objective of this paper is to quantify how the WUI has evolved since 1990 in the light of the planning restrictions described above and how this has affected WUI fire risk in the 1990–2013 interval. In addition, the study will examine how FWI values have evolved and how these are related to fire frequency and burned area. The novelty of our approach is examining temporal trends that account for changes in the WUI in conjunction with fire weather variables in a context of stable fire prevention/suppression. The following elements will therefore be analyzed: changes in WUI configuration and WUI fire risk index, summer FWI values, and fire characteristics (frequency and burned area). We believe the results of this particular case study suggest that land use policies can effectively limit WUI fire risk in the Mediterranean and other fire-prone zones.

2. Methods

2.1. Site description

The study area is located in SE France and is comprised of 2 sub-zones – West and East (Fig. 1). Together (about 425 km²), they make up about half the total WUI area of the Alpes-Maritimes department. To the north, the distance from the coast and steep topography of the Alps limit development. Along the coast, the high density cities of Cannes, Nice and others have too little vegetation to be included in the WUI zone. Vegetation is similar in the two study zones. Dominant species are typical of Mediterranean areas and are generally highly inflammable (aromatic and resinous species). Dominant tree species

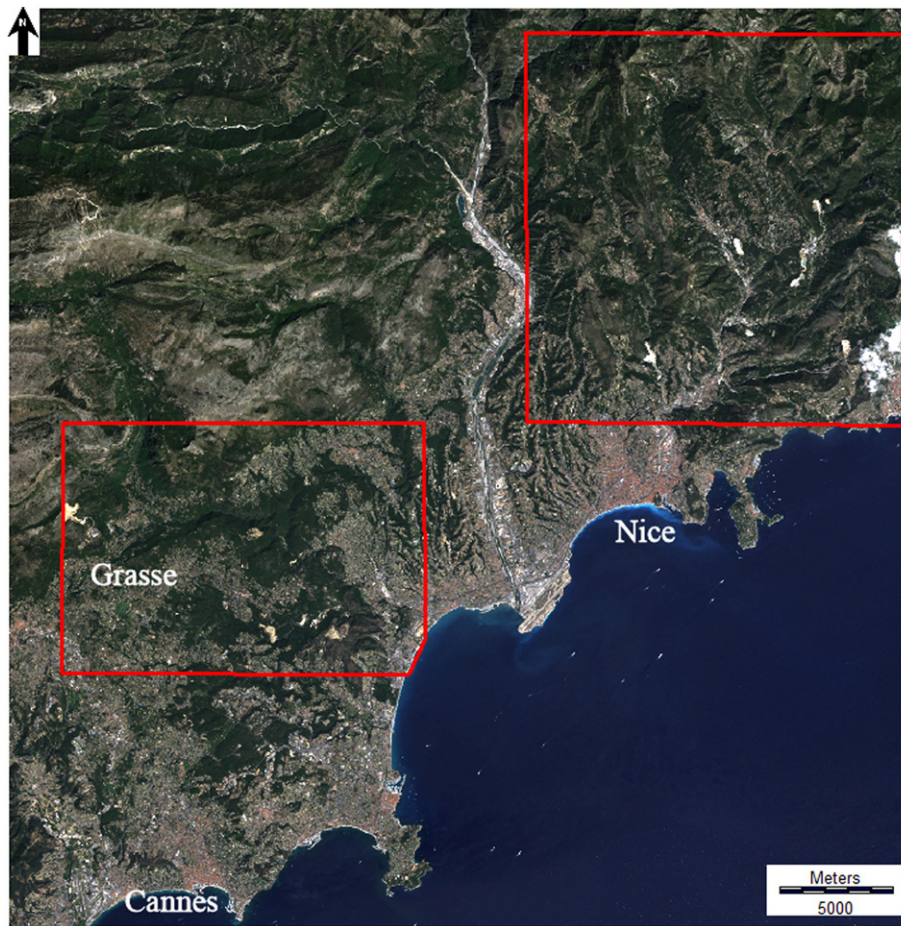


Fig. 1. The West (168 km²) and East (257 km²) WUI zones are located in the Alpes-Maritimes department of SE France near the cities of Cannes and Nice.

are a mixture of pines (*Pinus halepensis*) and oaks (*Quercus ilex*, and *Quercus Pubescens*). Shrubs include *Cistus albidus*, *Cistus monspeliensis*, *Genista cinerea*, *Spartium junceum*, *Calicotome spinosa*, *Lavandula latifolia*, and *Thymus vulgaris*.

Topographic and socio-economic characteristics differ slightly between the two zones. The West has a mean altitude of 302 m, and mean and median slopes of 14.8° and 11.6°, respectively. Topography is steeper in the East with a mean altitude of 492 m and mean and median slopes of 23.6° and 23.2°. Human settlement patterns are also slightly different. The West zone is located North of Cannes and contains a number of intermediate-sized cities. Among these we can cite the towns associated with Sophia Antipolis, a high tech industrial zone, and the city of Grasse with its perfume manufacturing industry. After tourism, Sophia Antipolis is the second major source of economic activity in the Alpes-Maritimes department while the perfume industry in Grasse is the third. The East zone, situated just north of Nice is more residential with small towns and villages aligned in narrow valleys and/or located on steep slopes. In the East, only Nice has significant employment potential. The West therefore has gentler topography and more employment opportunities than the East. The West and East zones reflect typical peri-urban WUI configurations found throughout much of the Mediterranean basin: a suburb dependent on a large city (East), and an agglomeration of smaller viable cities (West). Neither zone has any agricultural-wildland interface.

2.2. Wildland Urban Interface (WUI) characteristics

Mapping WUI housing density and calculating WUI fire risk was derived from Lampin-Maillet and Bouillon (2011) and Bouillon et al. (2014) and modifications are described in Fox et al. (2015). An initial

building vector data layer was extracted from the BD-TOPO© database, a vector database produced by the National Geographic Institute (IGN). This 2008 building layer was updated to 2012 by overlaying it on 2012 color orthorectified aerial photographs (0.5 m resolution) and screen digitizing new buildings and deleting the few buildings that were destroyed between 2008 and 2012. This building vector layer was then consecutively overlain on 1999 color and 1990 panchromatic orthorectified aerial photographs (0.5 m resolution) and buildings were deleted (mostly) and digitized (occasionally) as we went back in time. This procedure generated three comprehensive individual building layers for the East and West zones for 1990, 1999, and 2012; for each date, the number of buildings and building footprint area were quantified.

Using the RUImap ArcGIS-based model (Lampin-Maillet and Bouillon, 2011; Bouillon et al., 2014), building layers were converted to housing density based on the number of buildings within coalesced 100 m buffer zones around buildings. In all, 4 suburban categories were defined: Isolated, Scattered, Dense and Very Dense. RUImap spatial resolution output is 2.5 m.

Vegetation was mapped from 2009 infrared (IR) orthorectified aerial photographs (initial resolution 0.2 m downscaled to 0.5 m) based on NDVI indices. NDVI thresholds used to distinguish between sparse (mostly bedrock), discontinuous, and continuous vegetation were the following: <0.01, 0.01 to <0.15, and ≥0.15, respectively. These were set visually by comparing category distributions to the high resolution aerial photographs. In the absence of high resolution IR images for earlier years, only one vegetation map was used for the 3 dates, so vegetation cover was slightly underestimated for 1990 and 1999 in built areas.

The housing density and vegetation layers were upscaled to 10 m to match the Digital Elevation Model (DEM) and overlain to create 12 WUI

Table 1
Category fire risk indices for each WUI category.

WUI	Vegetation		
	Sparse	Discontinuous	Continuous
Isolated	7.5	10.0	7.5
Scattered	3.5	4.5	6.5
Dense	2.0	3.0	3.0
Very Dense	1.5	2.0	3.0

categories (4 housing \times 3 vegetation categories). Land areas outside the WUI (i.e. zones of natural vegetation without buildings) were ignored in the WUI fire risk calculation. Fire risk indices are shown in Table 1 for the 12 categories, and these were attributed according to results of Lampin-Maillet (2009) and Lampin-Maillet et al. (2010) and adapted by Fox et al. (2015). The indices take both fire frequency and burned area in SE France into account. For the study zone, WUI fire risk is calculated using Eq. (1).

$$\text{Fire risk} = \sum (\text{Category index} \times \text{Category area}) / \text{Study area} \quad (1)$$

Driver variables affecting WUI changes included the following topographic and distance variables: altitude, aspect, slope, and distances from the coast, city centers, and roads. However, only aspect, slope, and distance from city centers were retained for this article. These variables show trends that are probably typical of much of the Euro-Mediterranean region. Building density and changes in building density over time decrease exponentially with distance from main roads, and this too is probably applicable throughout the Mediterranean. However, since these trends are straightforward, the graphs were not included here to save space. Finally, altitude and distance from the coastline were considered site specific with trends that probably could not be generalized as easily to other Mediterranean regions.

2.3. Fire Weather Index (FWI)

Eq. (2) shows the I^{87} FWI calculation, where T is Air Temperature ($^{\circ}\text{C}$), V is Wind Speed (m s^{-1}), R_p is Deep Soil Water Reserve (mm), R_s is Superficial Soil Water Reserve (mm), and H is Relative Humidity (%). The I^{87} FWI requires daily data at fine resolution time steps, so T, V, and H were selected at 12:00 UTC for each day, and R_p and R_s were calculated daily using a decreasing exponential equation to empty soil water reserve from potential evapotranspiration (Carrega, 1991). Inversely, rainfall was added to soil water content which is correlated with vegetation water content during the vegetative season (spring and summer). The index was calculated for a weather station (Mandelieu) located in the west zone. Daily I^{87} FWI values were calculated for the months of July and August in the 1993–2013 interval (1993 being the first year these data were available).

$$I^{87} = (TV) / (R_p^{0.5} R_s H) \quad (2)$$

2.4. Number of fires and burned area

A complete fire record of all fires occurring in vegetation patches >1 ha is available since 1973 in the national Prométhée database (<http://www.promethee.com>). All fires >1 ha occurring in the estimated WUI zone of the Alpes-Maritimes department were selected for the months of July and August in the 1993–2013 interval to correspond with the WUI and FWI data interval. Fire frequency and burned area statistics were calculated from these data.

In summary, WUI characteristics correspond to available aerial photographs and were calculated for the years 1990, 1999, and 2012. FWI values and fire statistics were recorded at daily time-steps for the

months of July and August during the 1993–2013 interval, and these were then treated at annual, monthly and weekly scales.

2.5. Statistical analysis

Effects of driver variables (Aspect, Slope, Distance from city centers) on building area and growth rates during the 1990–1999 and 1999–2012 time intervals were tested using Analysis of Variance where categories within driver variables were explanatory variables and building area/growth rates were dependent variables.

Differences in FWI, fire frequency and burned area between the months of July and August were also tested using Analysis of Variance. Fire frequency and burned area were normalized using Log_{10} and square root transformations before running the ANOVA. Log_{10} and square root values of fire frequency and burned area were also used to identify critical threshold values of FWI indicating a jump in fire risk. FWI threshold values of 80, 85, and 90 were tested.

3. Results

3.1. WUI characteristics

Building numbers and drivers will be described before addressing WUI housing densities.

3.1.1. Building numbers and drivers

Number of buildings and building growth rates are similar for the two zones with slightly more buildings in the West than in the East: 30,793 versus 26,710 in 2012. Both zones have slightly greater building growth rates in the earlier (1990–1999) interval compared to the latter (1999–2012) period: 338 bldgs/yr versus 316 bldgs/yr in the West, and 279 bldgs/yr versus 268 bldgs/yr in the East. When surface area is taken into account, building density is greater in the West than in the East: 183 bldgs/ km^2 versus 104 bldgs/ km^2 , respectively (in 2012), due to the more favorable topographic and socio-economic conditions described above. Similarly, growth rates per unit area are greater in the West at 2.01 bldgs/yr/ km^2 than in the East (1.23 bldgs/yr/ km^2). Overall, between 1990 and 2012, the number of buildings increased by 30.3% and 28.9% in the West and East, respectively (average total growth of 29.6%).

Building number trends with respect to driver variables show similar tendencies in the West and East, so values for the two zones were grouped into common figures. Units for analyzing building drivers are based on the building footprint where the area occupied by buildings is quantified without sidewalks, roads, parking lots... Aspect strongly influences building area ($R^2 = 0.99$, $P \leq 0.001$) and growth rates ($R^2 = 0.99$, $P \leq 0.001$) (Fig. 2). The percentage of area occupied by buildings is about 3 times greater on South-facing slopes than North-facing (Fig. 2a). East and West-facing slopes have intermediate values. Growth rates (Fig. 2b) are almost 5 times slower on North-facing slopes compared to South-facing slopes and about 3 times slower on East and West-facing slopes. Building area values are statistically different for the 3 years considered ($P \leq 0.05$), and although growth rates are slightly lower in the 1999–2012 interval, these are not statistically significant.

Slope inclination plays a major role in building location ($R^2 = 0.99$, $P \leq 0.001$) and growth rates ($P \leq 0.05$) over time (Fig. 3). The percentage of area built decreases exponentially with slope (Fig. 3a) for all years with decreases of close to 50% with each increase in slope interval. The change in growth rate, however, is only about 17% less when passing from the first (0–15 $^{\circ}$) to the second (15–30 $^{\circ}$) intervals (Fig. 3b). This suggests the gentlest slopes had little space left for development and steeper slopes continued to be colonized at close to the original rate. The drop is then sharp (about 60%) for the third slope category (30–45 $^{\circ}$), and rates continue to be lower at all slope angles during the second time interval. Building area per slope varies between the different

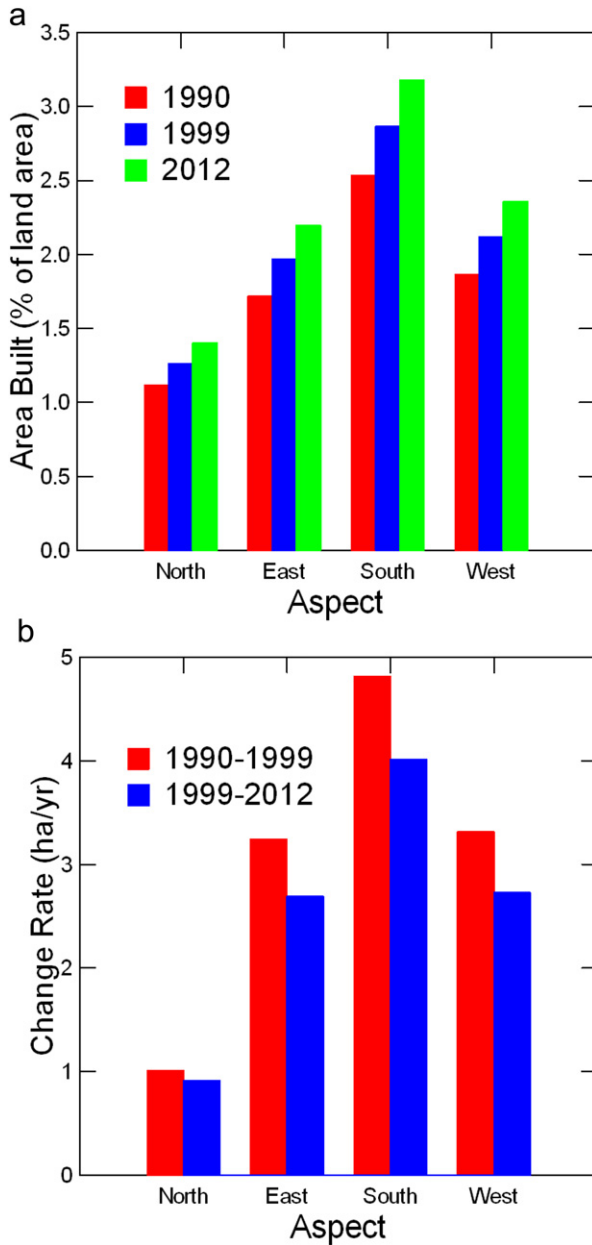


Fig. 2. a: Percentage of area built in 1990, 1999, and 2012 according to aspect. b: Change rates in area built according to aspect in 1990–1999 and 1999–2012.

years ($P \leq 0.05$), but growth rates are not statistically significant for the two time intervals shown in Fig. 3b, though the latter period shows slightly slower growth.

Distance from city centers is also statistically significant for both building area ($R^2 = 0.99$, $P \leq 0.001$) and growth rates ($P \leq 0.001$). As expected, built area is greatest close to city centers and decreases rapidly beyond a distance of 500 m; it changes little beyond a distance of about 2000 m (Fig. 4a). Growth rates (Fig. 4b) show a more complex pattern: close to city centers (0–500 m), values are low for both time intervals since there is little space left to develop. They remain high, however, for both successive distance intervals (500–1000 m and 1000–1500 m) before decreasing linearly with distance to about 3500 m. Temporally, growth rate drops sharply with time (36% decrease) in the 0–500 m distance range, but drop rates slow with successive distance intervals with values of 22% and 6% for 500–1000 m and 1000–1500 m, respectively. As city centers developed and were saturated, demand for land remained high in the closest outer ring. As for the preceding explanatory variables, building area values show statistically significant differences between

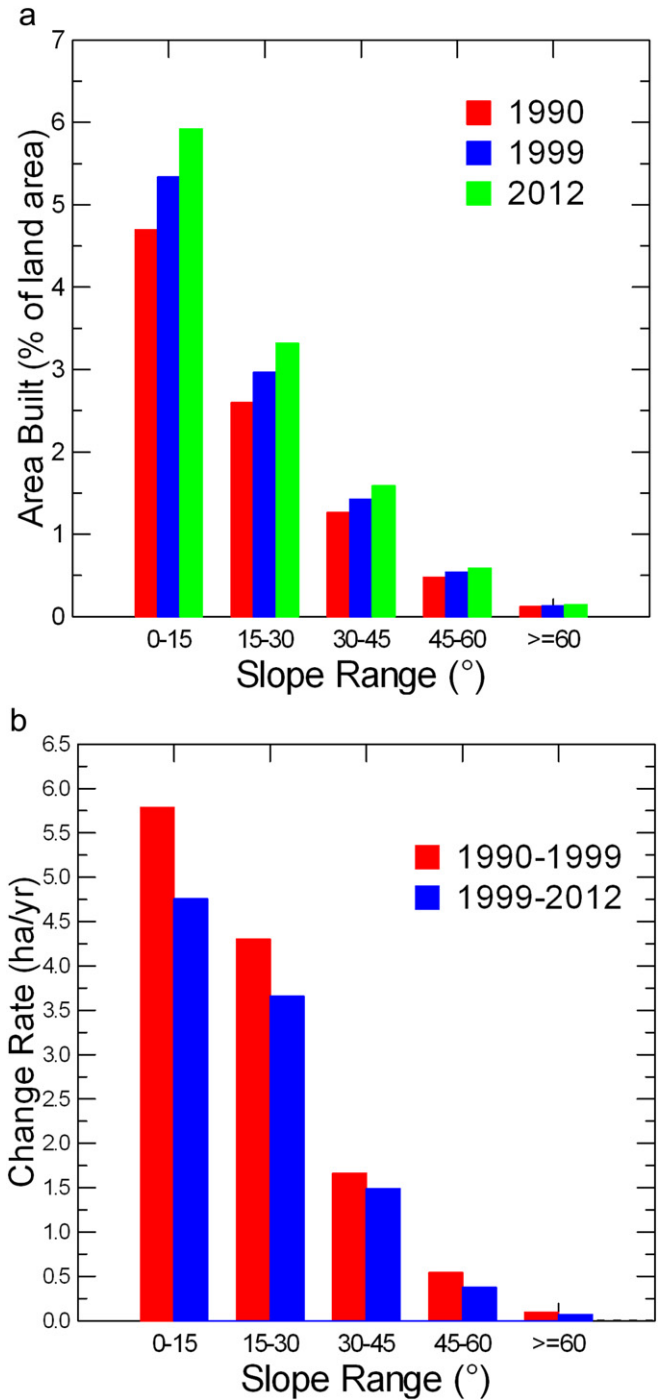


Fig. 3. a: Percentage of area built in 1990, 1999, and 2012 according to slope. b: Change rates in area built according to slope in 1990–1999 and 1999–2012.

the 3 years ($P \leq 0.001$), but change rates are not statistically different for the 2 time intervals despite slightly slower rates in the 1999–2012 interval.

3.1.2. WUI categories

Total WUI area by housing density category is shown in Fig. 5a. Dense and Very Dense housing account for the greatest area within the WUI, and total WUI area is 214.7 km², 220.6 km², and 225.3 km² for 1990, 1999, and 2012, respectively. The overall 1990–2012 areal growth rate of 4.9% contrasts sharply with the building growth rate of almost 30% described above; the number of buildings grew much faster than the WUI area, suggesting that housing density increased over time

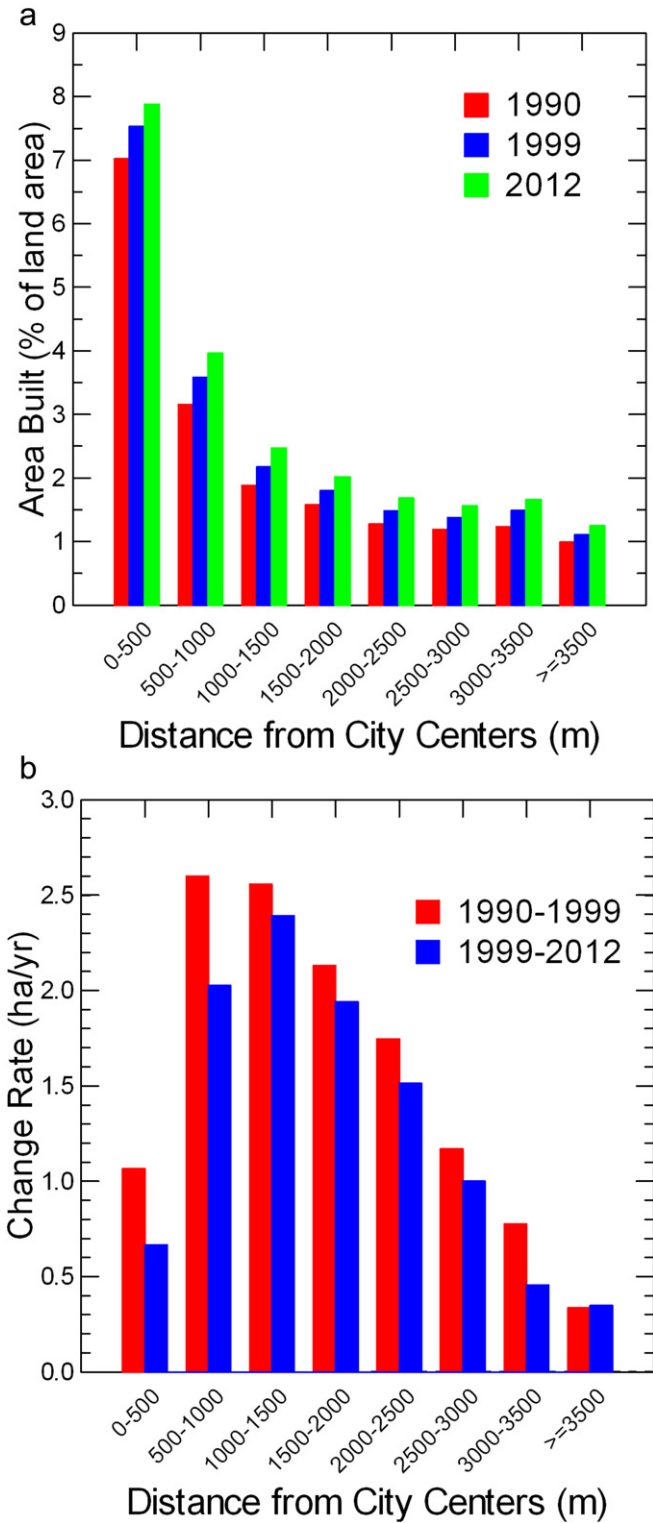


Fig. 4. a: Percentage of area built in 1990, 1999, and 2012 according to distance from city centers. b: Change rates in area built according to city centers in 1990–1999 and 1999–2012.

instead of expanding into new previously unbuilt areas. The shift to greater housing densities is clearly shown in Fig. 5a: Isolated, Scattered and Dense housing areas all decreased slightly over time while the Very Dense category gained area. These trends are confirmed in Fig. 5b, where only the Very Dense category has positive growth values and all other categories lose territory in all time intervals (1990–1999, 1999–2012, and 1990–2012). The greatest shift is from Dense to Very Dense housing.

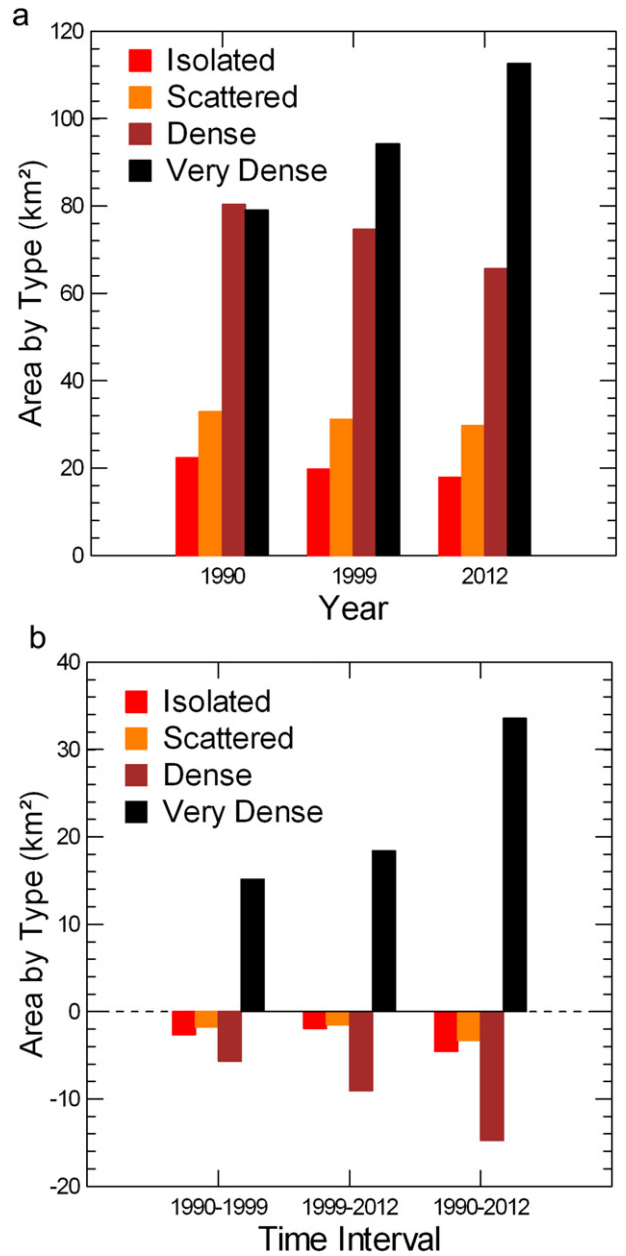


Fig. 5. a: Total (West & East) built area in 1990, 1999, and 2012. b: Change in total (West & East) built area over time in 1990–1999 and 1999–2012.

3.1.3. WUI risk evolution

The WUI fire risk for each zone depends on the areal distribution of housing densities and their evolution over time. For the West, fire risk values are 1.89, 1.89, and 1.87 for 1990, 1999, and 2012, respectively. For the East, they are 1.85, 1.83, and 1.82. Despite a 30% increase in the number of buildings and a 5% gain in WUI area, the fire risk remains stable for both zones due to a shift from high risk low density categories to low risk Very High densities.

How the fire risk is distributed at any time period depends on the spatial area of the category and risk index associated with each category, and risk distributions vary with study zone and time (Fig. 6a–b). In the West (Fig. 6a), most of the risk in 1990 is accounted for by the Dense-continuous vegetation category (about 25% of 1990 risk) and then the Very Dense category (about 22% of risk). In the East (Fig. 6b), the 1990 peak is in the Scattered-continuous (about 24% of risk) and Isolated-continuous (about 17% of risk) categories. These differences reflect the topographic and employment conditions of the West and East zones, respectively.

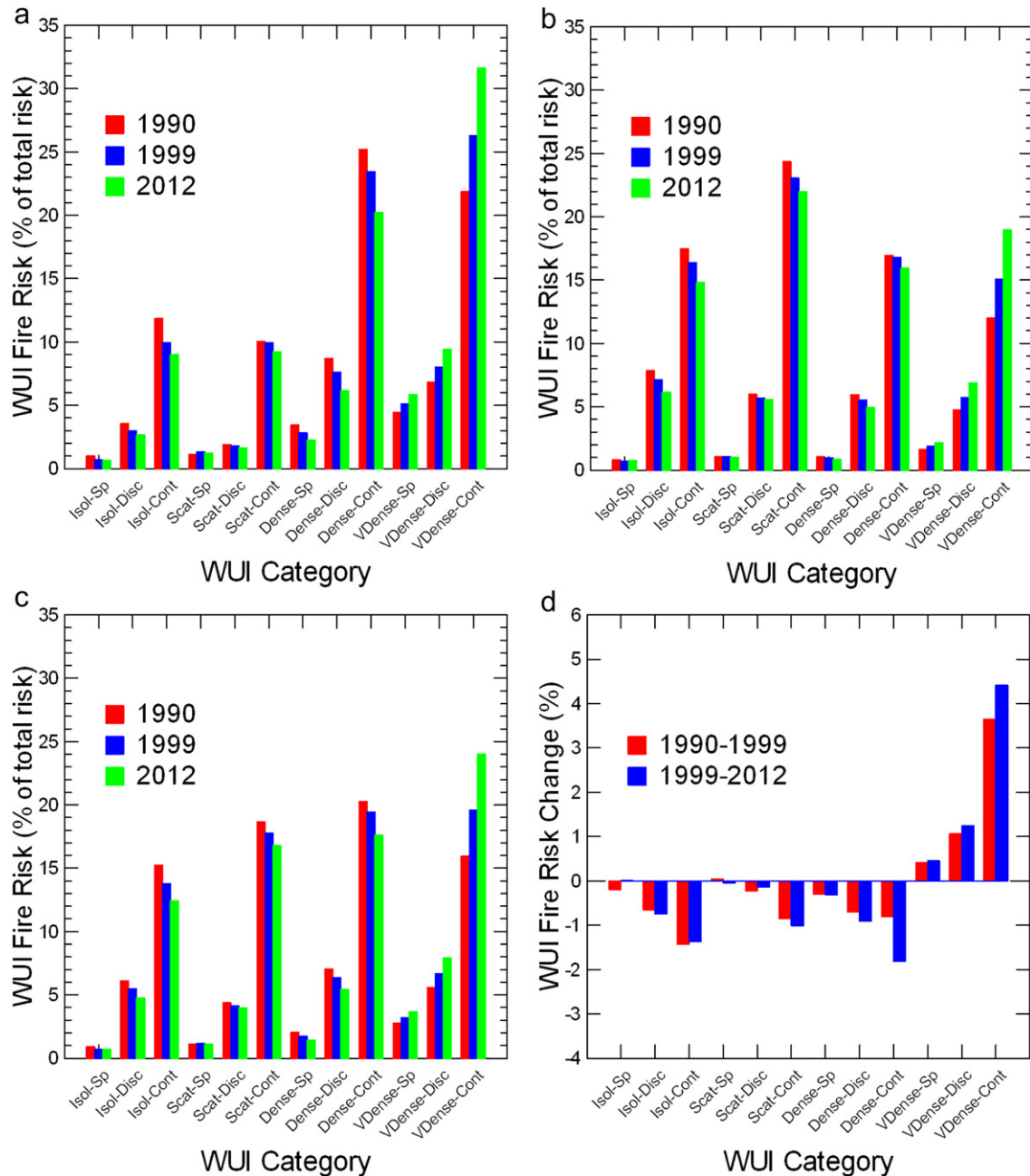


Fig. 6. a: WUI risk distribution in West in 1990, 1999, and 2012. b: WUI risk distribution in East in 1990, 1999, and 2012. c: Total WUI risk distribution in 1990, 1999, and 2012. d: Change in total WUI fire-risk distribution in 1990–1999 and 1999–2012.

Temporally, both zones show the strongest increases in WUI fire risk in the Very Dense category, and in the West (Fig. 6a), Very Dense-continuous vegetation accounts for the greatest part of the fire risk (about 32%) in 2012. In the East (Fig. 6b), the peak risk remains in Scattered-continuous in 2012 (about 22%), but Very-Dense continuous comes second (about 19%), ahead of Isolated-continuous.

The total WUI fire risk is a compromise between the West and East zone distributions, as shown in Fig. 6c, where peak risk always occurs in continuous vegetation and where Dense and then Scattered housing densities account for most of the fire risk. With time, the risk shifts to denser housing categories and decreases with housing density within the continuous vegetation category. All vegetation categories gain in risk (final % risk – initial % risk) in the Very Dense housing category and the gain is slightly greater during the second time interval (1999–2012) (Fig. 6d).

3.2. Fire Weather Index (FWI), fire frequency and burned area

Temporal changes in the FWI and fire occurrence will be analyzed at the weekly, monthly and annual scales. In all, 99 fires > 1 ha burned a total area of 3908 ha. At the weekly scale (Fig. 7), FWI (Fig. 7a) increases progressively over the summer as vegetation dries with the cumulative lack of rainfall and warm summer temperatures. Strangely, fire frequency and burned area (Fig. 7b) do not entirely reflect FWI patterns. Burned area generally depends on a few large fires and in this case, a single fire of 1595 ha (5 Aug., 2003) accounts for more than half the burned area of the peak in week 6. The number of fires peaks around mid-August and this corresponds to high FWI values. However, the first week of July has the lowest FWI values of the summer (Fig. 7a) but a high fire frequency (Fig. 7b), the second peak after mid-August. Similarly, the FWI value continues to increase right into early September while the

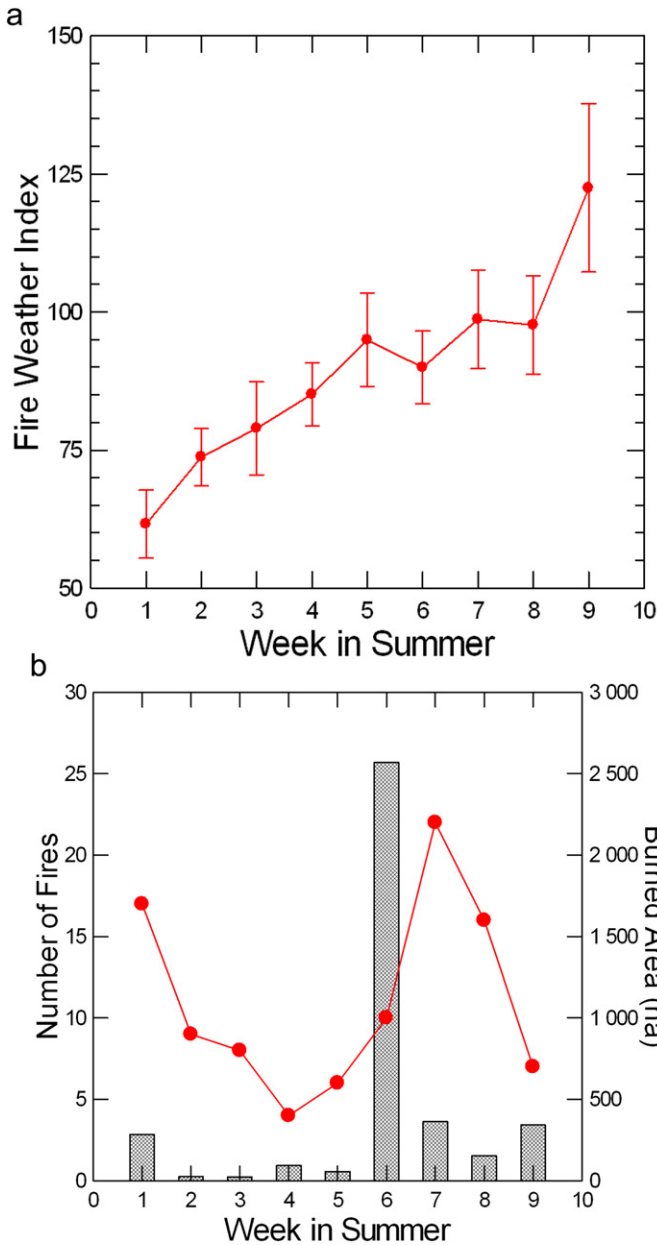


Fig. 7. a: Mean FWI values according to summer week (1 = first week of July; 9 = last week of August). b: Fire frequency (sum) and total burned area (sum) according to summer week.

number of fires drops. These inconsistencies will be taken up again in the Discussion.

Fig. 8 plots fire frequency and burned area against mean weekly FWI for the 189 weeks of the study period. The relationship is clearly not linear since a number of high FWI value weeks have no fires. However, only weeks with mean FWI values >90 have >2 fires per day, and 72.7% of the 99 fires occur during weeks with FWI values >90 even though these account for only 43.9% of all weeks. Of the different thresholds tested (80, 85, and 90) for normalized values (Log₁₀ and Square Root) of fire frequency and burned area, the threshold value of 90 gave the best explained variance. Burned area is even more sensitive to FWI since 96.8% of total burned area occurs during weeks with mean FWI values >90. Normalized values (Log₁₀) of the number of fires per week and burned area beneath and below the threshold value of FWI = 90 are statistically significantly different (P < 0.001, R² = 0.21 and 0.38, respectively).

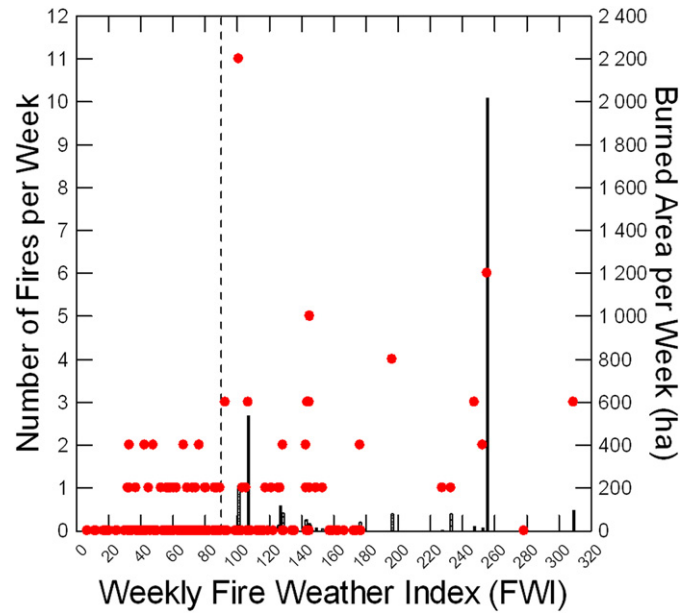


Fig. 8. Weekly number of fires and burned area versus weekly FWI.

Differences in FWI values and fire characteristics (Table 2) are coherent and reflect local summer fire dynamics. FWI values, fire frequency and burned area are all greater in August than in July. FWI values increase by about 32% between July and August (both month and year are statistically different at P < 0.05, R² = 0.89). The number of days above a FWI value of 90 increases by about 71% between July and August. Fire frequency and burned area increase by 54% and 718%, respectively; differences between years are statistically significant (P < 0.05, R² = 0.78) for normalized (square root) values of fire frequency, but not for any of the normalized values of burned area, and differences between months are not statistically different (P < 0.05) for any normalized values of fire frequency or burned area. Despite the lack of statistical differences, some monthly tendencies are worth noting. Of the 99 fires >1 ha recorded, 60 (60.6%) occur in August, and of the 3908 ha burned, >3482 ha (89.1%) were due to fires in August. Only 6 days have burned areas >100 ha (accounting for about 79% of total burned area), and 5 of these (83.3%) occur in August. FWI values for these 6 days are all >150.

At the annual time scale, there are no signs of increasing FWI values or fire occurrence with time (Fig. 9). The greatest mean FWI values are generally around the peak 2003 year (Fig. 9a), but inter-annual variability remains high. Apart from the 1994 anomaly, where fire frequency and burned area are high (Fig. 9b) but FWI is only moderate (Fig. 9a), fire frequency and burned area are moderately correlated with FWI values: Pearson correlations between July fires and burned area with FWI are 0.42 and 0.58, respectively. Values for August are 0.48 and 0.65, respectively.

4. Discussion

Despite strong growth in the number of buildings and a local preference for South-facing residential villas, there is a clear shift towards increased housing densities in the Alpes-Maritimes WUI. This reflects tighter land use policies aimed at limiting expansion of low density housing into unbuilt forests. Hence WUI fire risk has remained constant

Table 2
FWI, number of fires and burned area at the monthly time scale.

Month	Mean FWI	Days with FWI > 90	Number of fires	Burned area (ha)
July	76.3	145	39	425.6
August	100.9	248	60	3482.5

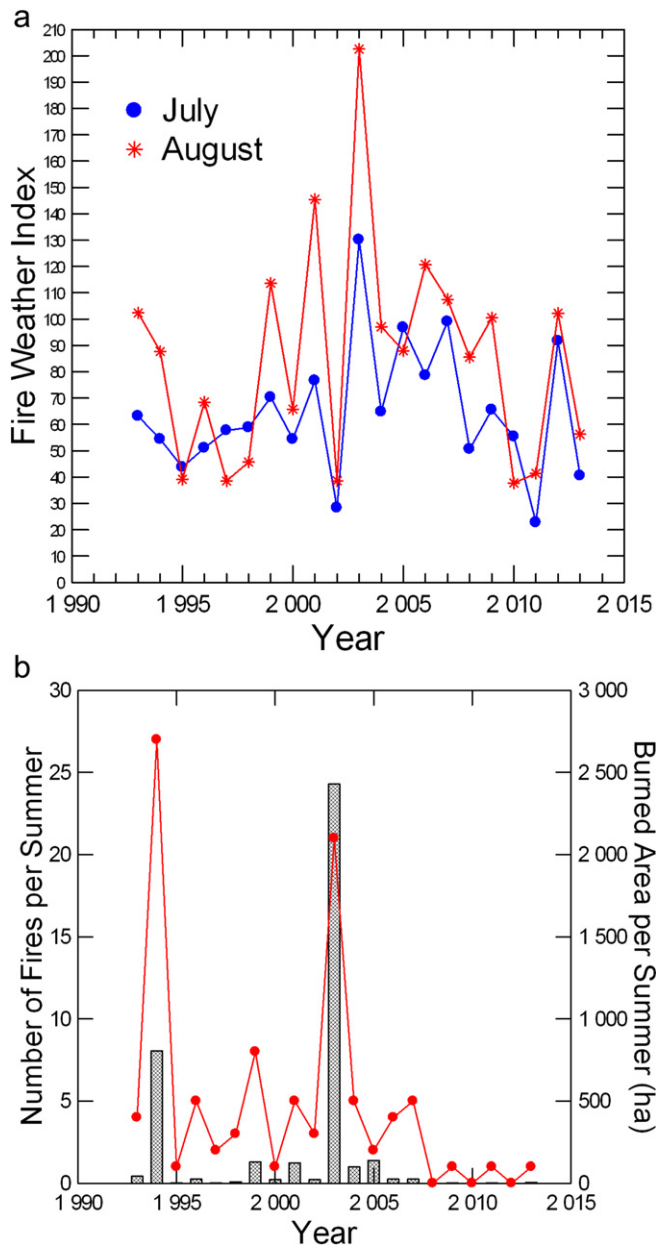


Fig. 9. a: Mean FWI values by month and year. b: Fire frequency and burned area distributions by year.

despite the construction of 13,145 new buildings (29.6% growth in building numbers). This clearly demonstrates the effectiveness of limiting fire risk through urban planning policies. WUI area is significantly related to fire occurrence for Portugal, Spain, France and Italy (Modugno et al., 2016; Vilar et al., 2016), so the results found here present a realistic strategy for all Euro-Mediterranean countries. Badia et al. (2011) suggest that WUI fires extend well beyond the Mediterranean and occur throughout the world, especially in developed countries. The main drivers affecting housing location in our study zone were aspect, slope, and distance from city centers. Although not shown graphically in this paper, distance from main roads was also a major driver of building growth as noted above.

Mann et al. (2014) predict an increase in housing density from low to medium density and an increase in total WUI area over time (2000–2050) in California. Syphard et al. (2007) demonstrate the impact of WUI on fire frequency, and to a lesser extent on burned area, so increased WUI area will probably be translated into greater fire occurrence. Mann et al. (2014) estimate that the number of houses

in high and very high wildfire risk zones will increase by about 50% over the 2000–2050 time interval, so unlike Mediterranean France, WUI is expected to continue to grow over the next decades in California. A modeling study based on different land use planning scenarios in California (Syphard et al., 2013) confirms that increasing housing density can have a substantial impact on fire risk in the WUI, so results from this study can be extended beyond the Mediterranean basin. However, despite the effectiveness of land use policy in controlling WUI fire risk in SE France, cultural reactions to centrally imposed government legislation may not make this solution acceptable in a North American context.

In addition to limiting WUI fire risk, greater housing densities are probably easier to protect and require fewer resources, so fewer firefighters need to be mobilized to defend a greater number of buildings and people. This becomes critical in extreme weather conditions where firefighters have to deal with a large number of ignitions and resources are spread among numerous ignitions or fire clusters (San-Miguel-Ayanz et al., 2013). Southern Europe has shown an increase in the number of extreme temperature days since 1978, so we can expect more days surpassing high risk FWI thresholds in the future. Better urban planning is one solution to mitigating wildfire risks due to climate change (Cardil et al., 2014). In addition, Syphard et al. (2014) demonstrated the effectiveness of creating defensible space around structures (reducing woody cover close to structures and ensuring vegetation does not touch structures), and higher density housing reduces the defensible area necessary to protect homes – less area protects more structures.

Temporal trends in weekly fires show a complex pattern where FWI increases progressively while fire frequency and burned area peak in mid-August and again in early July. The relationship is not improved when fire frequency and burned area are compared to the number of days above a FWI value of 90 within each week. The abnormal peak in fires in the first week of July may be related to accidental ignitions from garden fires used to burn vegetation residues. Officially, the last day of June marks the end of these fires but some residents may continue burning into the first days of July, thereby provoking accidental fires. The weak correlation between FWI and fire occurrence in late August may be due to the number of tourist-related ignitions, but since these are not quantified there are no data to test this hypothesis. Human population densities and activities and fire weather all influence fire frequency, but their nonlinear nature makes it difficult to establish simple relationships (Syphard et al., 2007; Moritz et al., 2010).

In the absence of changes in WUI fire risk, and in a context of stable fire prevention and suppression efforts, fire-related weather becomes the only variable to account for fire dynamics in the study zone. The threshold FWI value of 90 marks a clear transition to much greater fire risk, particularly for burned area, and this is valid at both the weekly (when all weeks are analyzed independently without a summer temporal trend) and monthly scales. The threshold will vary from site to site and between indices. San-Miguel-Ayanz et al. (2013) also observed critical thresholds in FWI values using the Canadian FWI for large fires in Portugal. This is particularly relevant in a context of climate change where the frequency of extreme heat/drought events is expected to increase, in addition to longer drier summers (Lindner et al., 2014; Lozano et al., 2016; Moriondo et al., 2006).

Finally, the combination of WUI and FWI results indicate that fire prevention strategies can be more refined when both WUI and FWI are considered together. In the Euro-Mediterranean zone, south-facing slopes can be expected to have a greater number of high FWI days due to their greater exposure to incoming solar radiation. These slopes are also preferential areas for WUI development as described above. In practice, no difference is made between north facing and south facing slopes in terms of biomass control or preventive measures. However, given the greater WUI and fire weather risks, preventive measures (vegetation clearing, fire hydrant deployment...) should be developed to target these slopes more specifically.

5. Conclusions

Land use policy legislation in France has evolved over the past decades to favor increased housing density over suburban sprawl. Both national level laws and more Mediterranean-specific fire risk prevention legislation have significantly altered the evolution in housing density in SE France: between 1990 and 2013, building numbers increased by almost 30% but WUI built area increased by only about 5%. Isolated, Scattered, and Dense residential housing all declined in area while Very Dense housing increased. The WUI forest fire risk therefore shifted to this category over time, so the overall risk has remained constant despite the increase in new buildings. Land use planning is therefore an effective tool in managing forest fire risk in the Mediterranean context and beyond.

Three factors contribute to forest fire risk: WUI fire risk, fire prevention and suppression, and fire-related weather. In SE France, two of these, WUI risk and prevention/suppression, have remained constant over the past 2 decades, so inter-annual variations in fire frequency and burned area depend on weather. Fire frequency and burned area do not increase linearly with the I^{87} FWI, but fire risk jumps when FWI values surpass a threshold of about 90. No temporal trend in FWI was observed since 1993, but the time interval is too short to reveal medium to longer term climate change trends.

Acknowledgements

Y. Ren benefitted from an EMMA scholarship for which the authors express their gratitude. The authors are also grateful for the financial support provided by the Université Côte d'Azur for the acquisition of the historical orthorectified aerial photographs.

References

- Arpaci, A., Eastaugh, C.S., Vacik, H., 2013. Selecting the best performing fire weather indices for Austrian ecoregions. *Theor. Appl. Climatol.* 114:393–406. <https://doi.org/10.1007/s00704-013-0839-7>.
- Badia, A., Serra, P., Modugno, S., 2011. Identifying dynamics of fire ignition probabilities in two representative Mediterranean wildland-urban interface areas. *Appl. Geogr.* 31: 930–940. <https://doi.org/10.1016/j.apgeog.2011.01.016>.
- Bedia, J., Herrera, S., Gutiérrez, J.M., Benali, A., Brands, S., Mota, B., Moreno, J.M., 2015. Global patterns in the sensitivity of burned area to fire-weather: implications for climate change. *Agric. For. Meteorol.* 214–215:369–379. <https://doi.org/10.1016/j.agrformet.2015.09.002>.
- Bouillon, C., Fernandez Ramiro, M., Sirca, C., Fierro Garcia, B., Casula, F., Vila, B., Long Fournel, M., Pellizzaro, G., Arca, B., Tedim, F., Trebini, F., Derudas, A., Cane, S., 2014. In: Viegas, D. (Ed.), *A Tool for Mapping Rural-Urban Interfaces on Different Scales*. Coimbra University Press, Coimbra, pp. 611–625.
- Bovio, G., Camia, A., 1998. An analysis of largest forest fires danger conditions in Europe. In: Viegas, D. (Ed.), *Third International Conference on Forest Fire Research*. University of Coimbra, Coimbra, pp. 975–994.
- Cardil, A., Molina, D.M., Kobziar, L.N., 2014. Extreme temperature days and their potential impacts on southern Europe. *Nat. Hazards Earth Syst. Sci.* 14:3005–3014. <https://doi.org/10.5194/nhess-14-3005-2014>.
- Carrega, P., 1991. A meteorological index of forest fire hazard in Mediterranean France. *Int. J. Wildland Fire* 2, 79–86.
- Carrega, P., Jeronimo, N., 2007. Risque météorologique d'incendie de forêt et méthodes de spatialisation pour une cartographie à fine échelle. *Actes Du XXème Colloque International de l'AIC. Association International de Climatologie*, Tunis, pp. 168–173.
- Fox, D.M., Martin, N., Carrega, P., Andrieu, J., Adnès, C., Emsellem, K., Ganga, O., Moebius, F., Tortorollo, N., Fox, E.A., 2015. Increases in fire risk due to warmer summer temperatures and wildland urban interface changes do not necessarily lead to more fires. *Appl. Geogr.* 56:1–12. <https://doi.org/10.1016/j.apgeog.2014.10.001>.
- Galiana-Martin, L., Herrero, G., Solana, J., 2011. A wildland-urban interface typology for forest fire risk management in mediterranean areas. *Landsc. Res.* 36:151–171. <https://doi.org/10.1080/01426397.2010.549218>.
- http://www.promethee.com, n.d. Forest Fires Database for Mediterranean Area in France (WWW Document).
- <https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-4/assessment>, n.d. European Environment Agency: Global and European Temperature (WWW Document).
- JRC, 2014. *Forest fires in Europe, Middle East and North Africa 2014. Joint Research Center Technical Report*.
- Lampin-Maillet, C., 2009. *Caractérisation de la relation entre organisation spatiale d'un territoire et risque d'incendie: Le cas des interfaces habitat-forêt du sud de la France (Ph.D. Thesis)*.
- Lampin-Maillet, C., Bouillon, C., 2011. WUImap: a software for mapping wildland urban interfaces in the Mediterranean european context. *J. Environ. Sci. Eng.* 5, 631–642.
- Lampin-Maillet, C., Jappiot, M., Long, M., Bouillon, C., Morge, D., Ferrier, J.P., 2010. Mapping wildland-urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the South of France. *J. Environ. Manag.* 91:732–741. <https://doi.org/10.1016/j.jenvman.2009.10.001>.
- Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., van der Maaten, E., Schelhaas, M.J., Lasch, P., Eggers, J., van der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., Hanewinkel, M., 2014. Climate change and European forests: what do we know, what are the uncertainties, and what are the implications for forest management? *J. Environ. Manag.* 146:69–83. <https://doi.org/10.1016/j.jenvman.2014.07.030>.
- Lozano, O.M., Salis, M., Ager, A.A., Arca, B., Alcasena, F.J., Monteiro, A.T., Finney, M.A., Del Giudice, L., Scoccimarro, E., Spano, D., 2016. Assessing climate change impacts on wildfire exposure in Mediterranean areas. *Risk Anal.* <https://doi.org/10.1111/risa.12739>.
- Mann, M.L., Berck, P., Moritz, M.A., Batllori, E., Baldwin, J.G., Gately, C.K., Cameron, D.R., 2014. Modeling residential development in California from 2000 to 2050: integrating wildfire risk, wildland and agricultural encroachment. *Land Use Policy* 41:438–452. <https://doi.org/10.1016/j.landusepol.2014.06.020>.
- Modugno, S., Balzter, H., Cole, B., Borrelli, P., 2016. Mapping regional patterns of large forest fires in Wildland-Urban Interface areas in Europe. *J. Environ. Manag.* 172: 112–126. <https://doi.org/10.1016/j.jenvman.2016.02.013>.
- Moriando, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., 2006. Potential impact of climate change on fire risk in the Mediterranean. *Area* 31, 85–95.
- Moritz, M., Moody, T., Krawchuk, M., Hughes, M., Hall, A., 2010. Spatial variation in extreme winds predicts large wildfire locations in chaparral ecosystems. *Geophys. Res. Lett.* 37.
- Pezzatti, G.B., Zumbrennen, T., Bürgi, M., Ambrosetti, P., Conedera, M., 2013. Fire regime shifts as a consequence of fire policy and socio-economic development: an analysis based on the change point approach. *Forest Policy Econ.* 29:7–18. <https://doi.org/10.1016/j.forpol.2011.07.002>.
- Prévost, A., Robert, S., 2016. Local spatial planning practices in four French Mediterranean coastal territories under pressure. *Land Use Policy* 56:68–80. <https://doi.org/10.1016/j.landusepol.2016.04.034>.
- San-Miguel-Ayanz, J., Moreno, J.M., Camia, A., 2013. Analysis of large fires in European Mediterranean landscapes: lessons learned and perspectives. *For. Ecol. Manag.* 294: 11–22. <https://doi.org/10.1016/j.foreco.2012.10.050>.
- Syphard, A., Radeloff, V., Keeley, J., Hawbaker, T., Clayton, M., Stewart, S., Hammer, R., 2007. Human influences on California fire regimes. *Ecol. Appl.* 17:1388–1402. <https://doi.org/10.1890/06-1128.1>.
- Syphard, A.D., Bar Massada, A., Butsic, V., Keeley, J.E., 2013. Land use planning and wildfire: development policies influence future probability of housing loss. *PLoS One* 8. <https://doi.org/10.1371/journal.pone.0071708>.
- Syphard, A.D., Brennan, T.J., Keeley, J.E., 2014. The role of defensible space for residential structure protection during wildfires. *Int. J. Wildland Fire* 23:1165–1175. <https://doi.org/10.1071/WF13158>.
- Vilar, L., Camia, A., San-Miguel-Ayanz, J., Martín, M.P., 2016. Modeling temporal changes in human-caused wildfires in Mediterranean Europe based on Land Use-Land Cover interfaces. *For. Ecol. Manag.* 378:68–78. <https://doi.org/10.1016/j.foreco.2016.07.020>.

#2 - ARTICLE

A FRAMEWORK TO ANALYSE URBAN SPRAWL IN THE FRENCH MEDITERRANEAN COASTAL ZONE

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2019, *Regional Environmental Change*, Volume 19 (2), pages 559-572

<https://www.doi.org/10.1007/s10113-018-1425-4>

Cet article rend compte des compétences et de l'effort de recherche développé à ESPACE sur les modalités d'implantation et d'évolution de l'urbanisation côtière en Méditerranée. Sur les littoraux, la connaissance des ressorts de l'urbanisation reste encore trop sectorielle et trop générale, fondée sur le rôle de la distance à la mer, le niveau d'accessibilité des territoires, l'augmentation des mobilités, l'héliotropisme, etc. Elle n'est guère porteuse d'enseignements pour l'action publique, en particulier à l'échelle locale où tout se joue. Appréhender ce phénomène multidimensionnel requiert donc une approche systémique, multiscalaire et pluridisciplinaire.

L'article expose un cadre d'analyse et de recherche mis en place par ESPACE, au sein de l'Observatoire Hommes-Milieus « Littoral méditerranéen » (OHM-LM⁴, composante du LabEx DRIHM⁵). Il présente le développement d'un questionnement portant sur les types et les formes d'espaces urbains qui s'étendent le long des rivages, les périodes et les lieux de leur apparition, leur évolution au cours du temps, les politiques publiques qui les encadrent, certains des facteurs économiques qui les soutiennent, et les représentations qu'en ont les acteurs territoriaux comme les habitants. La recherche a débuté sur quatre sites géographiques de la côte méditerranéenne française, mais elle peut être transposée sur d'autres terrains. D'ores et déjà, l'article sert de référence aux travaux qui sont publiés dans le domaine, avec plus d'une dizaine de citations dans des supports listés dans le Web of Science. Trois ans après sa parution, il est en effet l'objet de 11 citations sur 11 supports différents. Certes, cette démarche n'épuise pas la totalité des actions de recherche possibles pour un décryptage complet du phénomène d'urbanisation des littoraux. Toutefois, un cadre d'observation et d'analyse solide s'est mis en place, conforté et exploité par les travaux conduits avec d'autres collègues au sein de l'OHM-LM.

Cette publication témoigne par ailleurs de la capacité d'ESPACE à élaborer et développer ses recherches avec d'autres laboratoires de sciences humaines et sociales comme de sciences de l'environnement, ici les laboratoires TELEMME⁶ (UMR 7503) et SPE⁷ (UMR 6134), et avec des acteurs territoriaux, ici l'Office de l'environnement de la Corse. Elle illustre également l'aspect transversal des recherches menées au sein d'ESPACE, puisque l'article associe des membres des trois sites d'implantation de l'unité (Aix-Marseille, Avignon, Nice), ainsi que la capacité à travailler en synergie, en associant des auteurs de statuts et compétences diversifiés (chercheur CNRS, enseignant-chercheur, ingénieur et post-doctorant).

Enfin, la recherche présentée témoigne clairement de la mise en relation des domaines de compétences inscrits dans le programme scientifique d'ESPACE. Elle s'insère à la fois dans l'axe « Complexité spatiale et trajectoires de territoires » (action « Systèmes territoriaux littoraux en Méditerranée : entre opportunités et contraintes »), dans l'axe « Méthodologies des spatialités » (actions « Référentiels de l'observation statistique et spatiale » et « Dynamiques de changement et espace »), et dans l'axe « Transition écologique, savoirs et innovation » (action « Transfert des connaissances territoriales complexes »). La publication démontre donc que l'articulation des questionnements apporte une plus-value certaine aux travaux mis en œuvre. D'autres publications, dont la liste est fournie avec le bilan du contrat scientifique, ainsi que l'obtention du financement de plusieurs projets de recherche lauréats de différents appels d'offre, en témoignent également.

⁴ <https://www.drihm.fr/les-ohms/128-l-ohm-littoral-mediterraneen>

⁵ <https://www.drihm.fr/>

⁶ <https://telemme.mmsh.fr/>

⁷ <https://spe.universita.corsica/>

A framework to analyse urban sprawl in the French Mediterranean coastal zone

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Regional Environmental Change

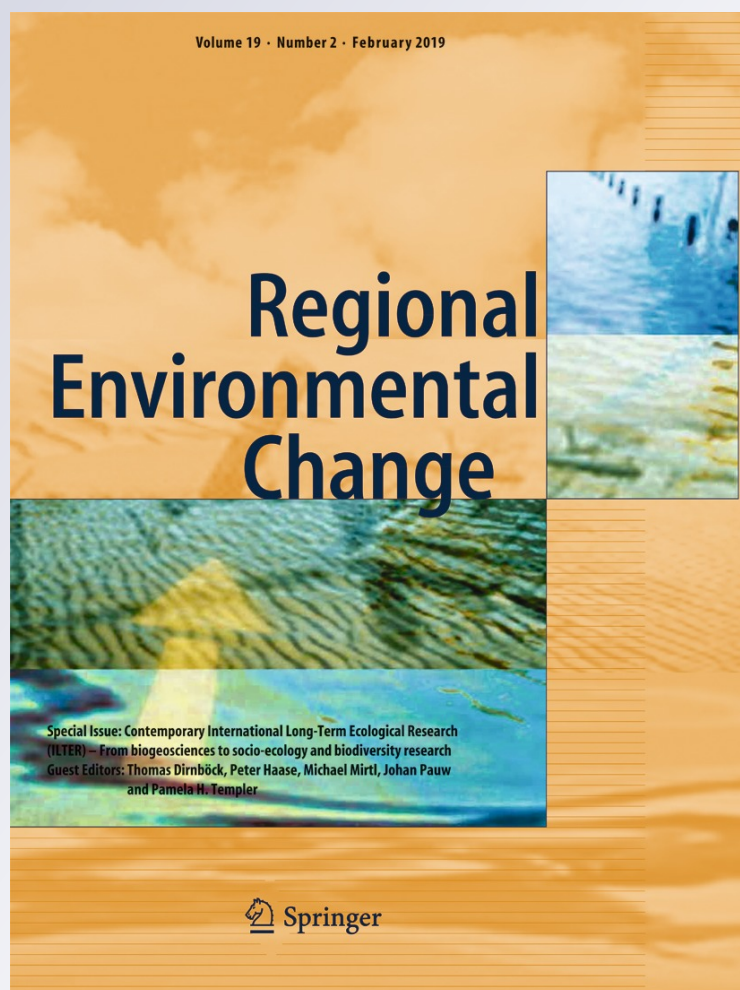
ISSN 1436-3798

Volume 19

Number 2

Reg Environ Change (2019) 19:559-572

DOI 10.1007/s10113-018-1425-4



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A framework to analyse urban sprawl in the French Mediterranean coastal zone

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Received: 31 October 2016 / Accepted: 26 September 2018 / Published online: 9 October 2018
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Abstract

As in many other European countries, urbanisation and urban sprawl along the French Mediterranean coast are a major concern. Understanding this phenomenon requires both multi-level and multi-disciplinary approaches. In this perspective, this article presents a framework for the observation and analysis of urban sprawl in the French Mediterranean coastal zone. Developed in the context of a scientific coastal observatory with four contrasting study sites, the framework was designed to structure the observation and analysis of urban sprawl dynamics and their driver variables. Although urban expansion is currently slowing in coastal zones, local exceptions can be found and accounted for by historical urban planning and environmental protection measures, local residential tax policies and contradictory perceptions of coastal zones by residents. Our multi-disciplinary initiative is capable of integrating different temporal and spatial scales and has proven relevant in analysing urban sprawl in coastal areas. It shows the need to study coastal areas at finer scales to identify specific dynamics in their local contexts, since these represent the scale at which administrative decisions are made.

Keywords Urban sprawl · Coastal zone · Mediterranean · Analytical framework

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Introduction

Increased pressure to develop sound land-use policies, protect biodiversity and anticipate coastal natural risks has made the rapid urbanisation of coastal areas a major environmental issue. Coastal zones came under pressure during the second half of the twentieth century as people migrated for both tourism and residential purposes and as maritime shipping increased in the global economy (Small and Nicholls 2003; Nicholls et al. 2007). This trend caused a number of environmental and socio-economic problems, particularly in the Mediterranean basin (Cori 1999; Datar 2004; Benoit and Comeau 2005; Gómez and Picarzo 2006; McDonald et al. 2008; Hadley 2009).

The Mediterranean coast of France, one of Europe's most urbanised coastal areas (EEA 2006), embodies many of the issues underlying urban sprawl. Agricultural areas and unprotected natural areas (offshore and inland) are threatened by urban expansion (Meinesz et al. 1991; Medail and Diadema 2006; Abrantes et al. 2010; Doxa et al. 2017), resulting in a loss of habitats and biodiversity and a standardised landscape quality. The strong land pressure also makes it very difficult for locals to obtain housing (DATAR 2004) and for businesses to set up close to the coast, except in the tourism and real estate sectors (Daviet and Robert 2012). In 2006, artificial land cover accounted for 31.6% of land located within 500 m of the sea (compared to a mean of 28.2% for French coastal zones in general) but reached 49.6% in southeastern France between Marseille and the Italian border (ONML 2009). Between 2008 and 2012, French coastal municipalities occupying only 4% of the territory accounted for 11.2% of new housing areas, and 40.4% of new housing areas in coastal municipalities were located on the Mediterranean coast (ONML 2014). This trend is likely to continue (Léon 2010) and raises several social, political and scientific issues. For example, how has coastal development been integrated into land-use planning since the landmark Brundtland report (1985) and especially Agenda 21 of the 1992 Rio summit (Cicin-Sain and Knecht 1998; Vallega 1999), whose principles were transposed to France (Deboudt et al. 2008)? Since a total freeze on coastal development is neither feasible nor acceptable, how can coastal benefits be maximised while protecting the environment? Given the exceptionally high tourism pressure on the Mediterranean basin coast (500 million tourists predicted in 2030 compared to 343 million in 2014, according to UNTWO¹), can the French coast escape an urbanisation process that spares only a few privileged protected natural habitats? These questions are pushing researchers to identify current dynamics, analyse the underlying processes and orient public policy.

Coastal development has been studied for some time, and rapid urbanisation has attracted considerable attention as a dominant trend that is fundamentally non-sustainable if coastal areas are to be preserved. Studies have quantified the area lost to urbanisation, characterised urban morphologies, and at times modelled future trends according to different scenarios (Weng 2002; Catalàn et al. 2008; Petrov et al. 2009; Pons and Rullan 2014; Romano and Zullo 2014). In addition, some studies have focused on the factors driving urbanisation, including the impacts of land market and urban planning policies, which can orient coastal development (Razin 1998; Malvárez Garcia et al. 2003; Crawford 2007; Tang 2008; Abrantes et al. 2016). In recent years, coastal submersion and relocation strategies have begun to appear in the scientific literature (Duvat et al. 2013; Meur-Férec 2014; Poumadère et al. 2015; Rey-Valette et al. 2015). Yet despite the number of studies and fields of research, there is a lack of integrated multi-disciplinary studies of urban dynamics and their environmental impacts. In general, studies isolate one aspect of the issue, and obtaining a complete picture is difficult.

Our objective is to present a framework for the observation and analysis of urban sprawl on the French Mediterranean coast. Its design was based on a scientific coastal observatory with four study sites. Both the framework and its results are described below.

Framework description

The human-environment observatory for Mediterranean coasts

The 'Observatoire Hommes-Milieux Littoral Méditerranéen' (OHM-LM)² was co-created by the Institute of Ecology and Environment (INEE) and the Institute of Social and Human Sciences (INSHS) of the French National Scientific Research Centre (CNRS)³ in 2012 with a mandate to study and compare human-environment interactions in Mediterranean coastal zones. Each year, it publishes a call for proposals to finance research projects on a wide range of topics and to encourage interactions among disciplines and with local land managers through seminars and other events (Chenorkian 2014). Since its creation, the OHM-LM has financed 36 studies, six of which focused specifically on coastal urbanisation; two additional studies on this issue had external funding but were conducted under the OHM-LM. The observatory fosters the development of multi-disciplinary research on urban sprawl and urbanisation integrating a range of themes like land use, land ownership, landscapes, urban planning and hydrology. Initially launched as individual projects, the studies tend to

¹ United Nations World Tourism Organisation press release, 15035, 27 May 2015

² URL: <http://www.ohm-littoral-mediterraneen.fr/>

³ Centre national de la recherche scientifique. URL: <http://www.cnrs.fr/>

converge over time as researchers meet to present results, harmonise their spatial and temporal scales of analysis and share data. This evolution has led to the ongoing development of a scientific framework for the study of urban sprawl in coastal areas.

Study sites

The framework relies on studies conducted in the four OHM-LM observatory sites shown in Fig. 1. Two of the sites are located on the continent (Marseille coastal zone and Gulf of Aigues-Mortes) while the other two are situated on the island of Corsica (Coast of Balagne and Coast of Biguglia). These sites were selected to represent a gradient from low to high urban pressure contexts (Table 1). Balagne is the least urbanised while Marseille is the third largest urban area in France, with major industrial and port infrastructures. However, the two Corsican study sites have recently recorded a strong population increase, unlike the two continental sites. In all, 50 municipalities are included within the observatory perimeter and represent a wide range of environmental and socio-economic conditions: low-lying lagoon coasts, rugged coastlines, coastal risks (erosion, marine submersion), different categories of protected areas, seaside resorts, large and small towns, industrial and yachting harbours, more or less seasonal tourism. This enables a wide range of topics and contexts to be taken into account.

Depending on research objectives, the actual geographical area under study may differ from one project to another. Coastal zone limits for the study sites depend on municipal administrative limits (1986 coastal law), which explains why some municipalities do not extend to the sea but have shores along a lagoon. To address the actual geographical area in question, some studies focus on smaller areas while others extend further inland.

Research themes

Four main research themes form the core of the OHM-LM framework (Fig. 2).

Land use/cover change (A)

The study of land use/cover change (LUCC) examines how urban areas have evolved over space and time. Based on aerial photographs and geographical databases, large-scale land-use maps are created in a Geographical Information System (GIS) environment as we already explained in Robert et al. (2015) and Robert (2016). In addition to describing changes in land cover and urban morphology, particular attention is paid to land cover transition dynamics between categories. Both urban sprawl and renewal are quantified and discrepancies in rates between major urban areas are analysed. National

(‘Institut Géographique National’—IGN) and local databases are merged with data acquired from digitising high-resolution aerial photographs to create thematic maps and characterise urban structures and changes at different spatial and temporal scales.

Spatial planning (B)

Coastal LUCC dynamics and urban sprawl can only be understood in the light of historical land-planning documents and how elected representatives have exploited these tools or not since the 1967 land planning law, a milestone in the French spatial planning system. For each municipality, a database that includes all past zoning documents and environmental regulations was created, as presented in Prévost and Robert (2016). The database has two major entries: (1) environmental protection measures with the areas concerned and corresponding urban constraints, and (2) all zoning documents approved at municipal and supra-municipal levels since 1967. These data are then run through statistical and multi-criteria analyses to define territorial urban planning anticipation and land-use management typologies. These can then be used to generate maps at municipal level in order to identify local trends and anomalies.

Local tax policies (C)

In addition to urban planning strategies, fiscal policies also play an important role in orienting urban sprawl and LUCC as we demonstrated in Grandclément and Boulay (2016). The research objective is to investigate how tax income from new residents can be a driver or obstacle to urban sprawl. Generating income from local taxes in a context of diminishing state funding transfers can be perceived as attractive and even essential for some municipalities. Data from the public finance department (‘Direction générale des finances publiques’—DGFIP) were used to calculate the proportion of municipal funding from residential taxes,⁴ and this was then used to characterise municipal resources. Identifying municipalities with a strong income dependence on residential taxes is a first step in investigating how this impacts urbanisation and determining which municipalities maintain or lose potential for future growth. The different scenarios may help predict trends for the near future. The study area goes beyond the limits of the OHM-LM observatory sites by including the entire French continental Mediterranean coast (60 km inland, 1450 municipalities). Corsica is not included because of unavailability of data. The study covers the Gulf of Aigues-Mortes and coast of Marseille (34 municipalities in all).

⁴ ‘Residential taxes’ mean taxes paid by households to their municipality of residence. They refer to both the housing tax and the property tax on buildings.

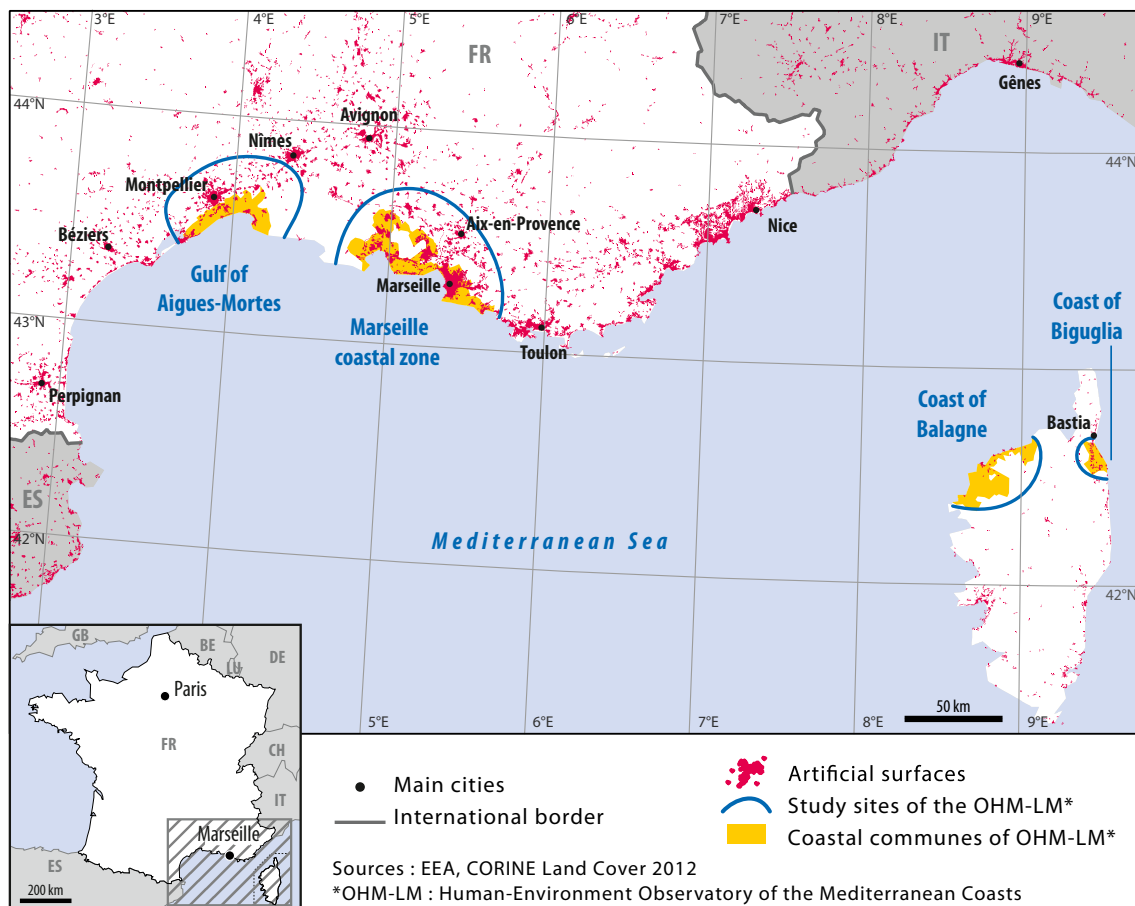


Fig. 1 OHM-LM observatory study sites

Stakeholders' representations (D)

A wide range of social groups have direct and indirect interests in LUC dynamics, either because they support urbanisation or because they wish to slow/stop urban sprawl. Such groups include residents, tourists, elected representatives, municipal employees and businesses. The research objective is to identify their perceptions of urbanisation in the coastal zone by bringing to light competing visions of socio-economic and environmental priorities and relating them to actual LUC trends. This work was carried out mainly by sociologists, psychologists and geographers. One study⁵ in particular brought out the inherent ambiguities of perception by different interest groups (Robert et al. 2016). Through an online questionnaire (developed with LimeSurvey), we targeted all residents living in a Mediterranean coastal municipality between the Italian border and the Spanish border. In addition to basic identification questions (age, sex, profession, municipality of residence, number of years in municipality, type of residence), the

⁵ VIPLI-Med (Intégrer une connaissance de la représentation et de la visibilité et des représentations du paysage pour la gestion et la planification de l'espace en zone côtière. Analyse spatiale et approche socio-culturelle sur trois littoraux méditerranéens): projet funded by Fondation de France.

questionnaire was designed to elicit residents' perception of the coastal landscape. Dominant themes and associations between themes were identified by asking participants to build and give a title to two lists of words that they established from a pre-established list of terms evoking different aspects of the landscape (physical, biological, human impacts) and its perception (uses, emotional responses). A quantitative analysis (frequency, similarity, multivariate and automated content analyses using IRAMUTEQ) was run on the data collected to highlight the strongest associations within the lists and to build graphs representing the social representations of the French Mediterranean coastal zone (methodology developed by Degenne and Vergès (1973)). Between March and July 2014, 922 valid responses were recorded.

Results

At this early stage in the OHM-LM history, a full systematic comparison of all themes and sites is not possible, so selected examples are considered below. In some cases, studies were limited to the two sites most relevant to research objectives. As expected, sites do not display a single homogeneous

Table 1 Main characteristics of the four study sites

Study area	Coast of Balagne	Coast of Biguglia	Gulf of Aigues-Mortes	Marseille coastal area
Number of municipalities	12	4	14	20
Area (km ²)	482	123	438	965
Population 2012	17,563	25,971	121,939	1,196,852
Population density 2012 (people/sq. km)	36	211	278	1241
Mean annual population growth rate 1999–2012 (%)	1.53	2.99	1.45	0.49
Artificial area (CLC 2012) %	2.9	17.0	13.3	35.8
Main characteristics of the coastal zone	Rocky shores. Small old cities on the seashore. Recent coastal resorts. Villages on the hilltops. First tourist destination in Corsica	Protected coastal lagoon. Inland urban development close to Bastia (major economic pole in northern Corsica)	Vast complex of several lagoons. Strong coastal erosion of the barrier beach. Small cities, large coastal resorts and yachting harbours on the barrier beach. Close to Montpellier (popn. about 500,000)	Large coastal plain (west), lagoon (north), rocky shores and hilly topography (south and east). Largest industrial harbour in France. Third largest city of France. Calanques national park and other protected areas on the coast nearby

Data: INSEE 2015; EEA 2014

dynamic, but reflect site heterogeneities that arise from the local context. However, all sites provide evidence that urban sprawl is the dominant model of local development, contradicting principles of integrated management and balanced development.

Land use/cover changes

In terms of LUCC dynamics, two of the four study sites (four Marseille site municipalities located in what is known as the ‘Côte Bleue’ and four from the Biguglia coast) show opposing

trends in urban sprawl patterns over recent years (Robert et al. 2015). The two sub-zones of the study sites have similar populations (about 25,000) and are located near major urban centres dominating urban change dynamics. However, urban growth in 2002–2011 in the Biguglia sub-zone was more than nine times greater than that in the ‘Côte Bleue’ Marseille site sub-zone (Table 2). Urban renewal ratios vary substantially both within and between sites. While urban renewal was well established in the municipalities of the ‘Côte Bleue’, it remains weak in Biguglia. The maximum ratio between artificial area annual growth rates is 4.7 in Biguglia (Furiani versus

Fig. 2 Urban sprawl assessment framework at a local level

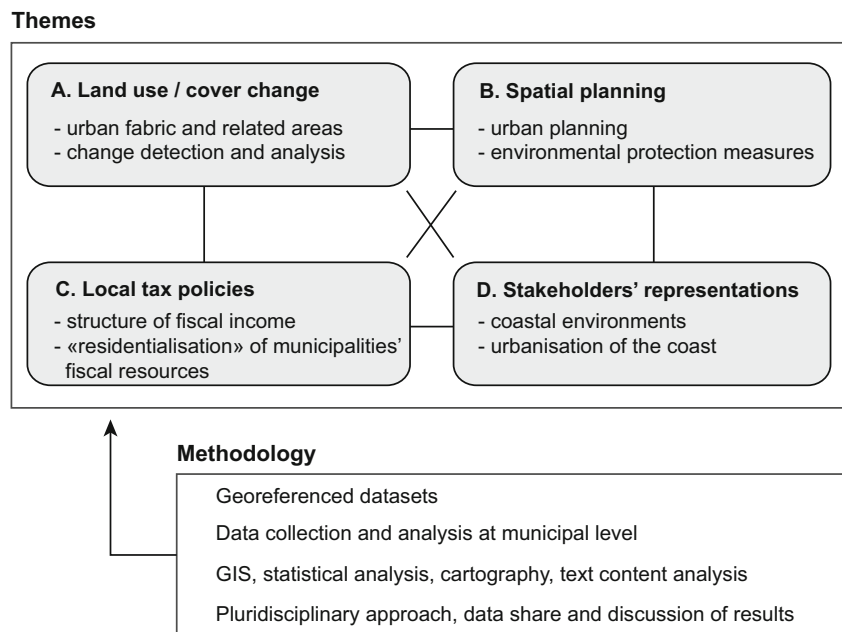


Table 2 Urban LUCC dynamics

Site	Commune	Artificial areas 2011 (%)	Mean annual evolution (%)*	Urban sprawl (ha)*	Urban renewal (ha)*	Ratio urban renewal/urban sprawl*
'Côte Bleue'		16.24	0.33	33.4	52.4	1.6
	Carry-le-R.	30.62	0.08	1.9	11.2	5.9
	Ensuès La R.	12.69	0.39	10.5	22.0	2.1
	Le Rove	10.17	0.60	13.0	9.3	0.7
	Sausset-les-P.	23.61	0.33	8.0	9.9	1.2
Biguglia area		19.14	3.04	587.0	136.5	0.2
	Biguglia	23.29	2.60	132.0	26.2	0.2
	Borgo	15.81	3.97	229.7	53.0	0.2
	Furiani	18.14	0.85	31.8	18.3	0.6
	Lucciana	21.50	3.78	193.5	39.0	0.2

*Period 2002–2011 for the Biguglia site and 2003–2011 for the Blue Coast site

Borgo) and more than 7.5 in the 'Côte Bleue' (Le Rove versus Carry-le-Rouet). This demonstrates that although the framework for planning laws is national, local priorities and dynamics dominate trends.

In Biguglia, the urban footprint shows greater growth and urban expansion is more dispersed spatially, with new artificial surfaces popping up in discrete patterns (Fig. 3). This violates the dominant national-level governing principle of allowing growth to expand from current urban areas. Several new urbanised sites created in 2002–2011 are isolated from pre-existing urban space, with no apparent spatial strategy for development. In the 'Côte Bleue' municipalities, contrastingly, new urban spaces are relatively rare and generally established in continuity with existing urban zones.

Urban renewal in both sites led to increased urban density and new residential developed areas, especially in the 'Côte Bleue' zone as we demonstrated in Robert (2016). Individual housing outnumbers collective housing, evidence of residents' preferences as favoured by zoning laws. For Biguglia, however, urban renewal also generated new developed areas for economic activities serving the logistics needs of the zone close to Bastia (the main point of entry to Corsica).

Spatial planning and environmental protection measures

One of the explanations for these differences between the two sites ('Land use/cover changes' section) lies in their zoning documents and environmental protection measures. We were able to make a full comparison of the four study sites since documentation was collected and analysed for the 50 municipalities concerned. The analysis shows that despite an extensive legal framework empowering municipalities to act on ecological issues, its use by elected representatives varies from site to site, regardless of the biogeographic or ecological pertinence of local conditions. The Gulf of Aigues-Mortes is

among the most active in promoting environmental protection, both in terms of the number of decisions and in terms of the ensuing constraints (Fig. 4). In Balagne, six municipalities are poorly protected while protection in Biguglia is intermediate. The coastal zone of Marseille is quite well-protected, but protection is weaker around the Berre lagoon, a large industrial zone, than in the 'Côte Bleue' and bay of Marseille areas.

Urban planning policies reflect the discrepancies in environmental protection described above, which we highlighted in Prévost and Robert (2016). At the inter-municipal level, analysis shows that municipalities vary widely in their capacity to anticipate urban pressure by implementing planning documents according to national legal frameworks (Fig. 5). Only the four municipalities of the 'Côte Bleue' showed an early and consistent will to anticipate change and control urban sprawl in conformity with the national framework and local priorities, which may explain their limited urban expansion in recent years. Other municipalities hesitated to implement inter-municipal land planning. At best, planning occurred within the 'SCOT' framework (French territorial-level planning guidelines), but no other inter-municipal planning documents were produced before 2000 (Gulf of Aigues-Mortes and half the remaining municipalities of the coast of Marseille). While the west of the coast of Marseille and Balagne have their 'SCOT' under study but not approved, urban planning is at its worst at the Biguglia site, where inter-municipal planning documents have not even been prepared. This indicates that the management of urban sprawl is worst at the Biguglia site, which is failing to meet national-level priorities and where growth is most sporadic.

Local tax policies

The income tax study monitors changes in the share of municipal incomes derived from residential taxes (which we call

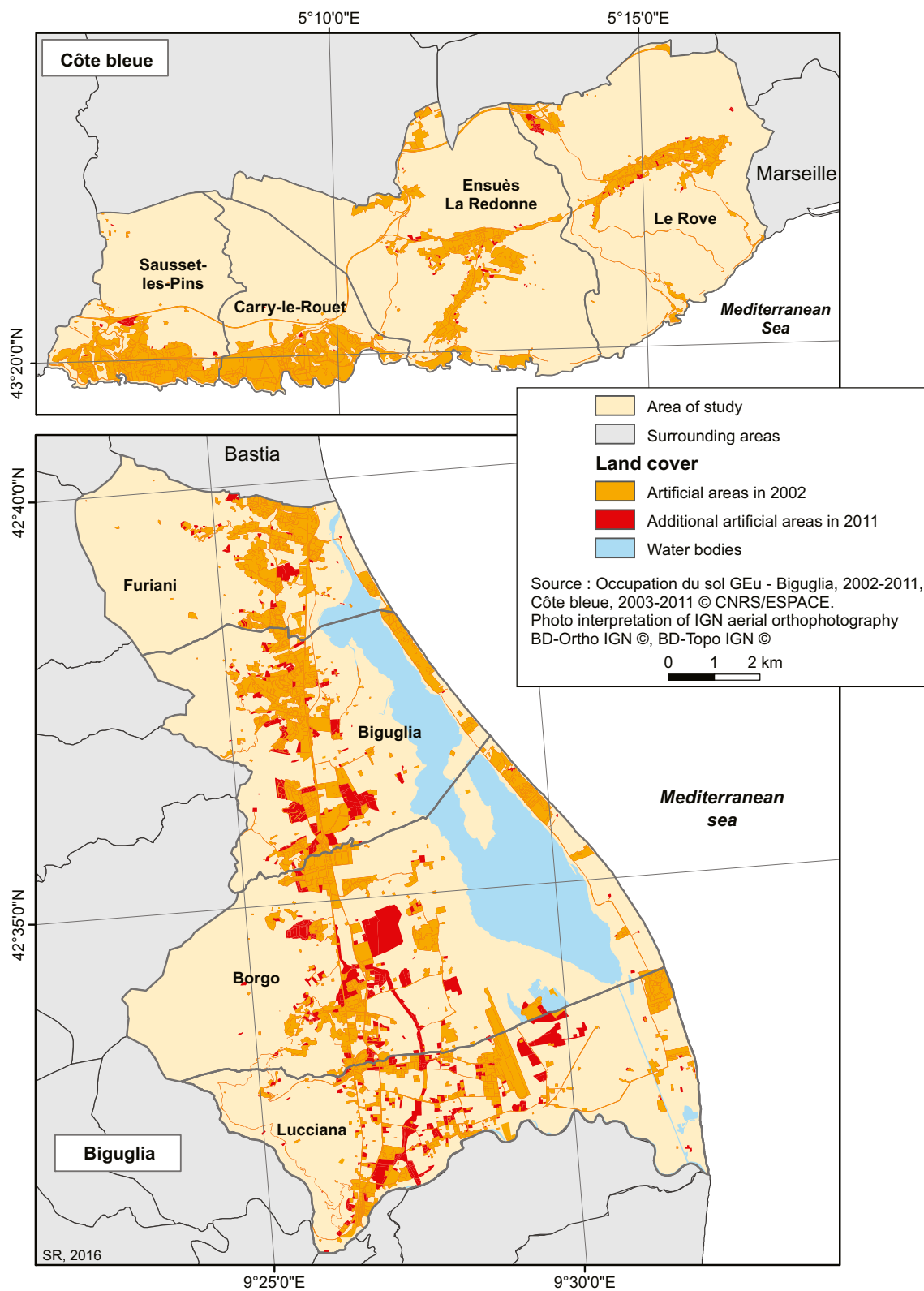
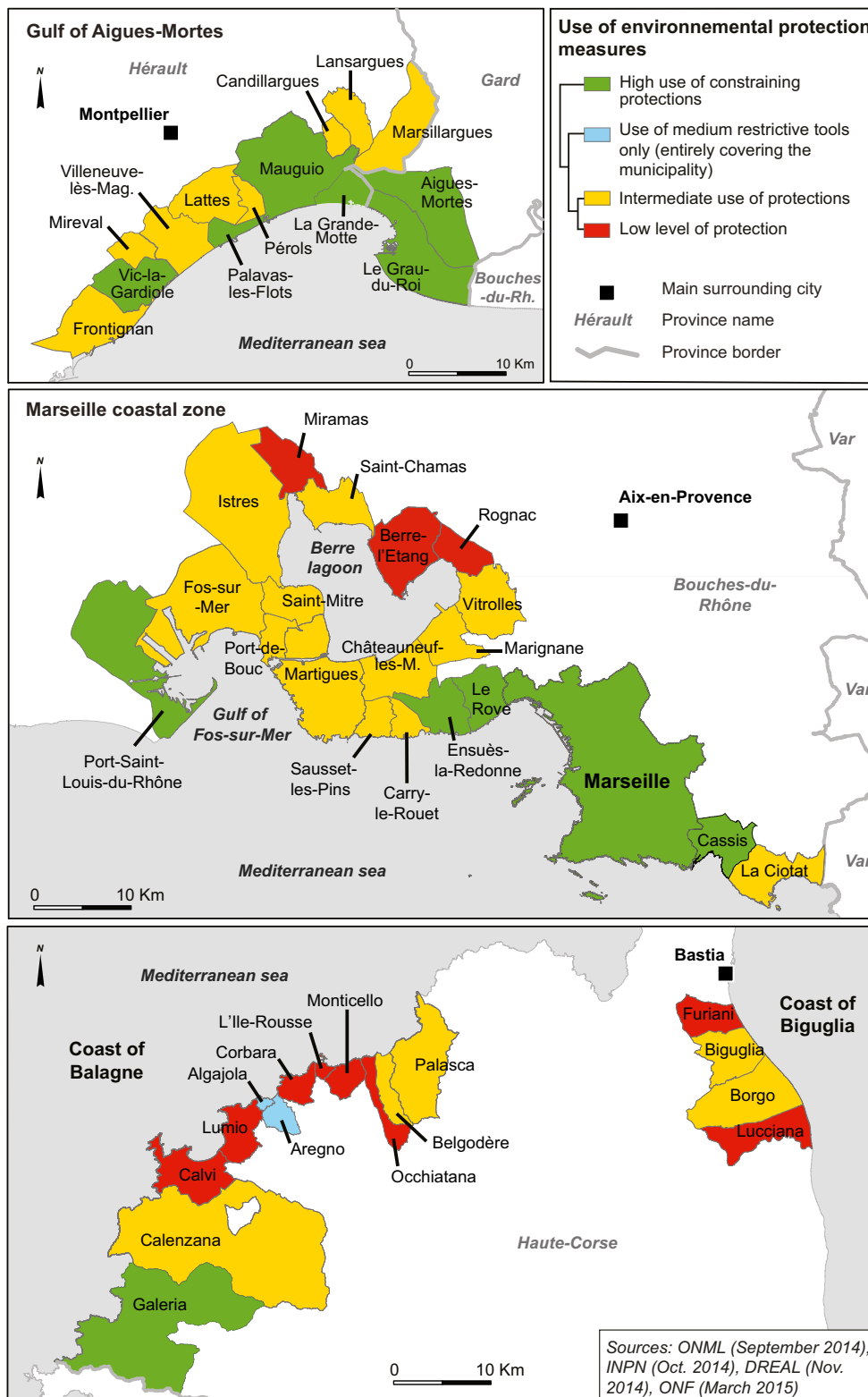


Fig. 3 Urban sprawl on the Blue coast and the Biguglia lagoon area

‘residentialisation’) and the fiscal levers pulled by municipalities. Our results highlight that income from residential taxes is greater than the French national average, 63% versus 58%

respectively (Grandclément and Boulay 2016). Between 2002–2003 and 2009–2010, the share of income derived from residential taxes increased but at a rate slower than the national

Fig. 4 Environmental protection levels

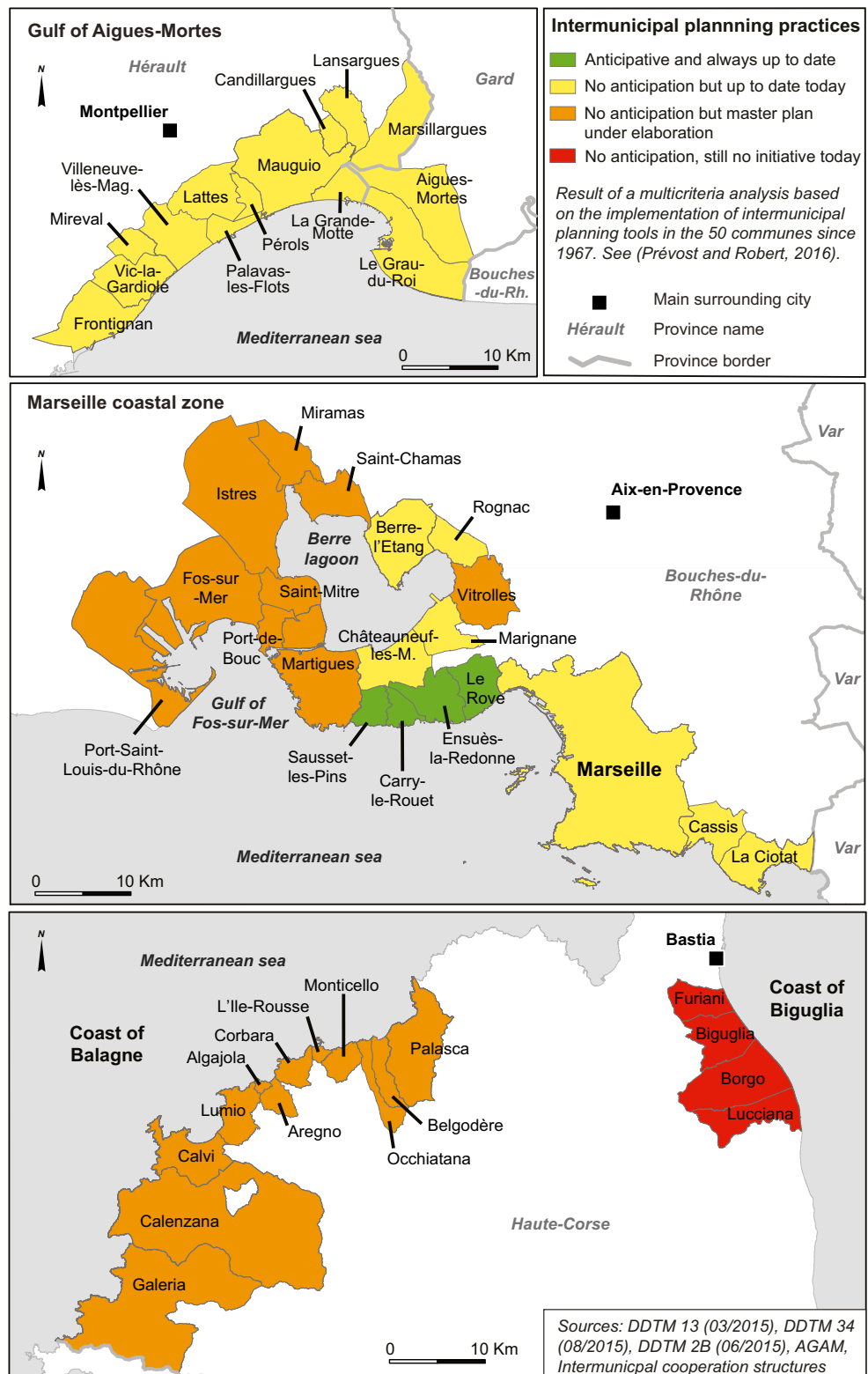


average, +3.3% versus +4.2%. A finer analysis of the two continental observatory sites reveals some interesting details.

Within the Gulf of Aigues-Mortes site, the proportion of residential taxes evolved differently: in half the municipalities, it decreased, while in seven others, it increased. Increases tend

to be concentrated in the eastern sector of the study site, in municipalities farther from the major urban centres of Montpellier and Nîmes (Fig. 6). Maps in Fig. 6 also show a decrease in the proportion of municipal income from residential taxes in municipalities bordering the coast. In the coast of

Fig. 5 Planning practices at the inter-municipal level



Marseille zone, the evolution is more homogeneous. In 12 out of 20 municipalities, there is a moderate increase, while in the industrial zone west of the Berre lagoon, three municipalities show strong increases and three others slight decreases. High-tourism municipalities show a clear negative trend in the

proportion of income attributable to residential taxes. In the municipalities of Sausset-les-Pins and Carry-le-Rouet in the ‘Côte Bleue’ zone, evolution is coherent with urban planning, showing that residential tax income is not encouraging municipalities to expand their urbanised areas.

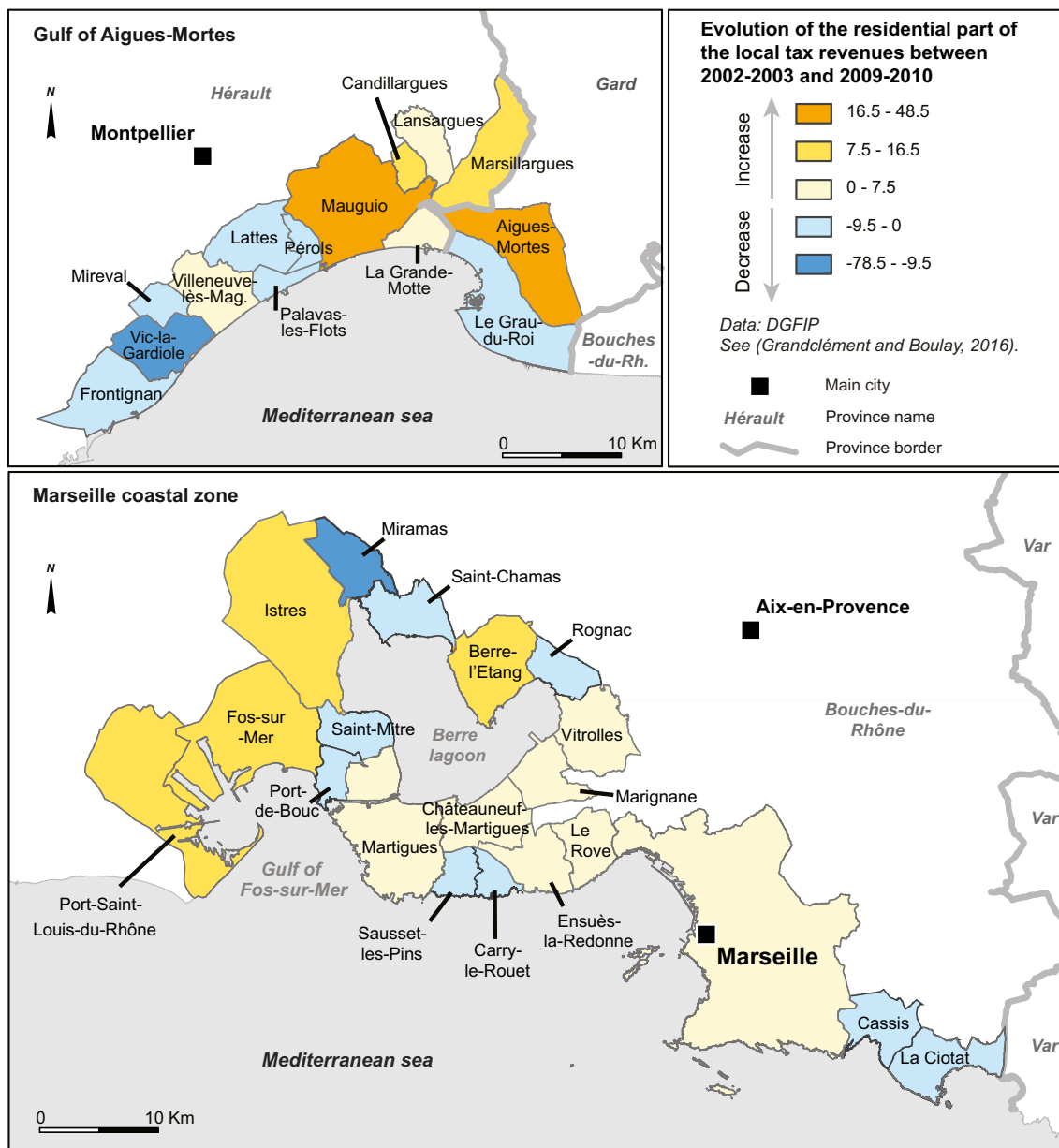


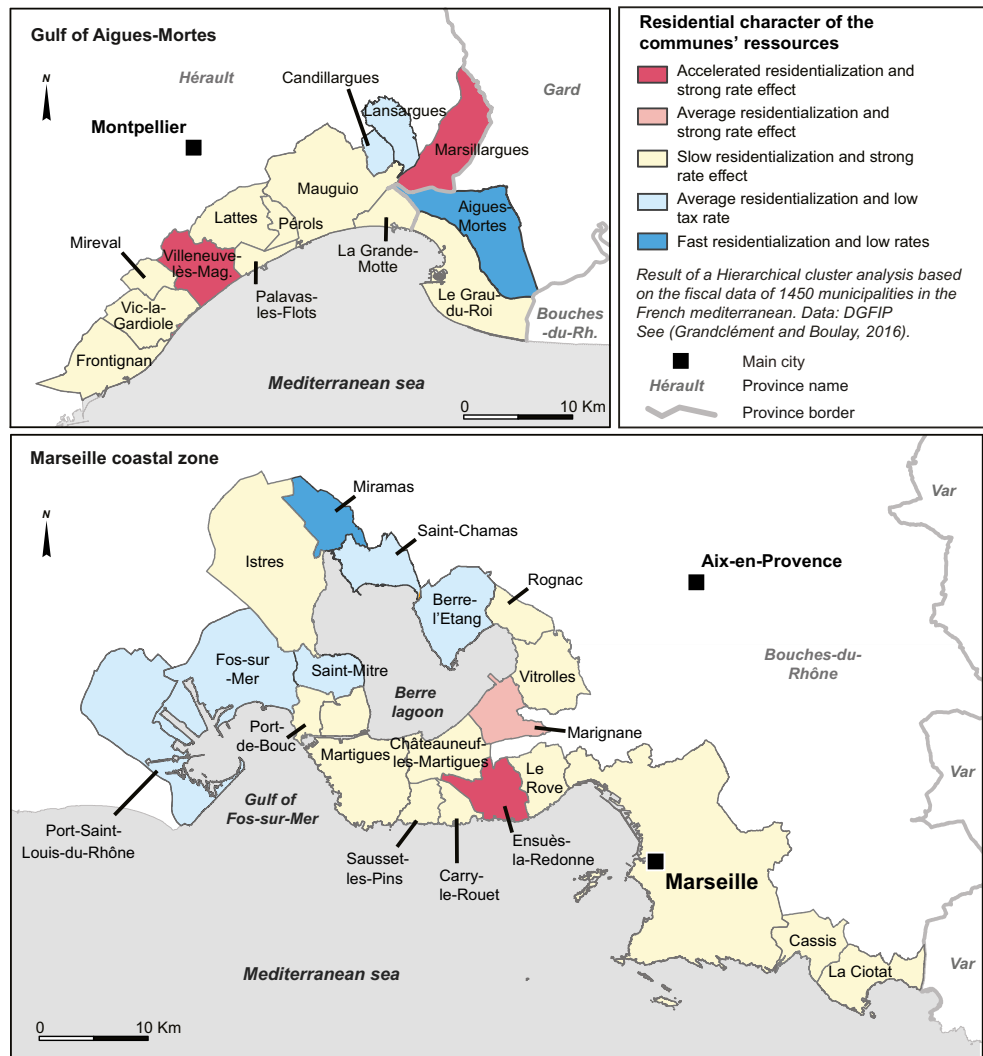
Fig. 6 Evolution in the share of residential taxes in municipal incomes

Municipalities can increase residential tax income either by expanding fiscal bases (new residences) or by raising tax rates. Growth of the proportion of residential taxes has slowed in most municipalities (Fig. 7), so it appears that they no longer wish to, or cannot, use new urbanisation or higher tax rates to increase their incomes. Only three municipalities clearly diverge from this trend: Villeneuve-lès-Maguelonne, Marsillargues and Ensues-la-Redonne. Here, both fiscal bases—contributing surface area and tax rate—have increased. Others, near the Berre lagoon and the Gulf of Fos-sur-Mer, show more moderate growth patterns. In summary, tax strategies are constrained by urban structure, since coastal municipalities do not have substantial leeway to develop new urban areas due to a lack of available space.

Stakeholders' representations

Local populations perceive land cover changes in the coastal zone in various ways, and our study brings out some of the ambiguities in this perception (Robert et al. 2016). Associations identified by at least 20% of the participants revealed two distinct poles in Fig. 8. The first corresponds to positive associations with the coastal zone: centred on the term 'coastal footpath' ('sentier côtier'), it reveals associations with the natural landscape, recreational uses and pleasant feelings. This pole is relatively well-structured, with terms related in numerous word triangles, but the strongest association is between 'coastal footpath' and scrubland ('garrigue'), indicating that land elements feature more strongly in perceptions than

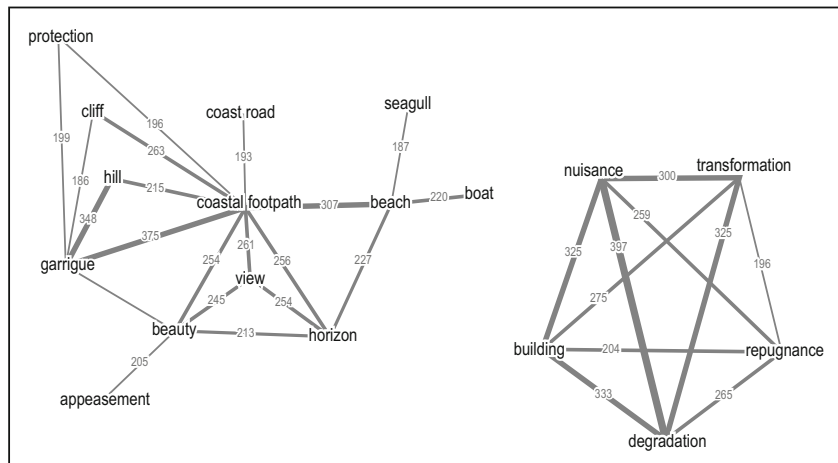
Fig. 7 Residentialisation of municipal income



marine elements. The second pole, made up of fewer terms, appears to stand in opposition to the first, associating negative aspects of urbanisation such as 'building' and 'transformation'. This pole is highly structured, therefore strongly representative of the social perception of the coast.

The coastal zone appears to generate contradictory feelings in local residents. On the one hand, they appreciate it as a natural environment and recreational area, but on the other they feel that land cover changes, urbanisation in particular, are deteriorating it. Despite this, the residents idealise the

Fig. 8 Characteristics of the coastal landscape showing word associations between at least 20% of respondents



environment and consider themselves fortunate to live and holiday there. This tends to legitimise urbanisation and may explain our observations in the 'Côte bleue' and Biguglia sites ('Land use/cover changes' section), where both urban expansion and renewal have mainly produced individual houses in recent years, reinforcing the residential function of these territories.

Discussion and perspectives

The framework as a key to understanding urban sprawl in coastal zones

Although national-level data show that coastal development is slowing (ONML 2014), more detailed studies of our sites indicate that some municipalities diverge substantially from this trend. While the coast of Marseille follows national trends, the area around Biguglia, for example, is undergoing rapid urban expansion. These differences are related to how long ago urbanisation began and to a general metropolisation. As elsewhere in France, municipalities located farther from big cities are growing most rapidly. However, urban development is not necessarily compromised in regions where urban expansion is limited, because urban renewal and densification allow municipalities to continue to grow socially and economically. Both urban planning (and anticipation) and residential tax income policies are important factors explaining trends in urban development. For example, municipalities pursuing active environmental protection and strong urban planning policies have mastered urban expansion best. Municipalities that have done neither show strong, sometimes negligent, urban expansion. These trends can also be related to municipal fiscal policies. Further studies are needed, but our results suggest several hypotheses. Municipalities where residential tax contributions have increased as a proportion of total municipal income are probably municipalities where urban planning has been limited or largely absent. Municipalities showing opposite trends tend to have a long history of urban planning that is continuously updated. Yet regardless of coastal urban dynamics, the results on social perceptions of coastal zones show contradictory trends. Coastal areas are perceived as natural environments well suited to relaxation and recreational activities, and urban development as a negative encroachment on the landscape. However, development is needed to enable and maintain recreational activities, so it is difficult to have one without the other. Urban expansion in the coastal zone is therefore at the heart of coastal management in general and the conflicting positions of conservation and development. This, in turn, indicates that coastal management must be dealt with at different territorial scales, in particular beyond municipal limits, i.e., by reconsidering the perimeter for management of coastal resources.

A framework that needs to be consolidated

While our results are promising, they point to the need to expand the field of study: the explanatory framework remains incomplete. Useful additional factors include geographical (distance to urban centres, service provider locations, available land area for development), socio-political (general principles, local cultural practices, local political priorities) and, of course, a range of economic factors. In addition, past and ongoing studies need to be expanded to include all four OHM-LM observatory sites and even, on some issues, covering the entire French Mediterranean coast. This would enable a fuller comparison of results from the different contexts. Urban planning and fiscal strategies could be treated more systematically at the municipal administrative scale. Integrating recent and developing databases would help extend analyses to new directions, fostering a better understanding of the urbanisation process as a whole. Finally, longer time scales need to be considered. Most studies have looked at relatively recent changes (last 50 years for urban planning, 20 years for land cover mapping and 10 years for fiscal policies). But socio-economic dynamics evolve over longer periods, so many observatory studies should consider longer time scales (at least from the mid-nineteenth century, taking into account both the effect of the industrial revolution and rising coastal tourism), as recently done for the coast of Balagne (Cancelieri and Maupertuis 2016). Modelling needs to be reinforced to include predictive studies of future urban expansion, as was done for the Marseille coast site (Voiron et al. 2014). These changes must be carried out in collaboration with local land managers to enhance our collective understanding of LUCC dynamics and better identify strategic options for the future in a decision-support perspective.

Widening the scope

Four new directions have been identified to widen the scope of future research priorities in the OHM-LM observatory sites. The first concerns the potential for maintaining agricultural practices within the coastal zone to promote a balance between land uses, landscape types and ecological entities. This research would require the involvement of a wide range of disciplines (especially ecology, agronomy, geography, sociology and economy). The second new research direction concerns environmental risks created by urban expansion along coasts, seeking to improve risk management strategies and land-use planning. Both coastal submersion and erosion are important, but other risks, such as flooding, storm runoff accumulation, mass movements and forest fires, must also be included depending on local circumstances. In a context of climate change, whether urban dynamics are oriented towards expansion or densification, there are major implications for risk exposure and social vulnerability. Recent tragic events

have demonstrated this: catastrophic 2015 flooding on the Côte d'Azur, 2014 and 2015 flooding in Corsica, 2014 flooding in the Hyères Bay area and devastating fires in the 'Côte Bleue' in 2009 and 2016, in Corsica in 2014, and along the Var coast in 2003. The third research priority is oriented towards maintaining ecological continuity within coastal cities and between the coast and inland areas. Urban dynamics in coastal environments influence habitat quality and morphology, environmental priorities and the place of living species in developed environments. An integrated approach linking urban, agricultural and natural coastal environments could be based on priorities defined in the above two research areas. The fourth and final research axis should deal with whether socio-demographic dimensions of urbanisation are consistent with the model of sustainable development. The numerous amenities of coastal zones make them particularly attractive (and therefore expensive), so they are often occupied by wealthier social classes, and access is often more limited for the less wealthy. This corresponds to the concept of ecological inequality, and coastal development should evolve to integrate more equal access to landscapes, beaches and the coast in general.

Conclusion

Although France remains a country with a strong central government, and even though its territorial management policies are generally considered efficient, coastal development along the Mediterranean shows strong regional contrasts. Despite a tendency towards slower urban expansion in coastal zones, local exceptions can be found and accounted for by historical urban planning and environmental protection measures, local residential tax policies and contradictory perceptions of coastal zones by residents. These factors contribute to the different urban trajectories encountered in the study sites. The multi-disciplinary framework capable of integrating different temporal and spatial scales described here has proven useful for analysing urban sprawl and LUCC dynamics in coastal areas. It also shows the need to study coastal areas at a fine scale in order to identify specific dynamics in their local context, since this is the scale at which administrative decisions are made. Despite repeated calls in recent years to change our relationship with the environment, to adapt to climate change, to reduce our ecological footprint and to develop integrated management strategies, it is clear that coastal management frequently fails to meet these expectations. Local scale studies are therefore necessary to measure how local interests and priorities interact with national-scale policies. Scientists must collaborate more closely with local land managers and residents in order to develop a shared understanding of dynamics and to envisage new pathways for future development.

Funding information This work was funded by the Labex DRIIHM, French programme "Investissements d'Avenir" (ANR-11-LABX-0010) which is managed by the ANR.

References

- Abrantes P, Soulard C, Jarrige F, Laurens L (2010) Dynamiques urbaines et mutations des espaces agricoles en Languedoc-Roussillon (France). *Cybergeo Eur J Geogr*. <https://doi.org/10.4000/cybergeo.22869>
- Abrantes P, Fontes I, Gomez E, Rocha J (2016) Compliance of land cover changes with municipal land use planning: evidence from the Lisbon metropolitan region (1990–2007). *Land Use Policy* 51: 120–134. <https://doi.org/10.1016/j.landusepol.2015.10.023>
- Benoit G, Comeau A (eds) (2005) A sustainable future for the Mediterranean. The blue plan's environment and development outlook. Earthscan, London
- Cancelier J, Maupertuis MA (2016) Le jardin de la Corse. La Balagne entre villes et campagnes (XI^e-XXI^e siècle). Cnrs Editions, Paris
- Catalán B, Saurí D, Serra P (2008) Urban sprawl in the Mediterranean?: Patterns of growth and change in the Barcelona Metropolitan Region 1993–2000. *Landsc Urban Plan* 85:174–184. <https://doi.org/10.1016/j.landurbplan.2007.11.004>
- Chenorkian R (2014) Elements constitutifs des Observatoires hommes-milieus, origine et évolutions. In: Chenorkian R, Robert S (eds) Les interactions hommes-milieus. Questions et pratiques de la recherche en environnement. Quae, Paris, pp 23–38
- Cicin-Sain B, Knecht R (1998) Integrated coastal and ocean management: concepts and practices. Island Press, Washington
- Cori B (1999) Spatial dynamics of Mediterranean coastal regions. *J Coast Conserv* 5:105–112. <https://doi.org/10.1007/BF02802747>
- Crawford TW (2007) Where does the coast sprawl the most? Trajectories of residential development and sprawl in coastal North Carolina, 1971–2000. *Landsc Urban Plan* 83:294–307. <https://doi.org/10.1016/j.landurbplan.2007.05.004>
- DATAR (2004) Construire ensemble un développement équilibré du littoral. La Documentation française/DATAR, Paris
- Daviet S, Robert S (2012) Faut-il bannir l'industrie des territoires méditerranéens ? : Analyser la place de l'industrie dans la durabilité des territoires. In: Mésini B (ed) Aménagement durable des territoires méditerranéens. Presses Universitaires de Provence, Aix-en-Provence, pp 93–110
- Deboudt P, Dauvin JC, Lozachmeur O (2008) Recent developments in coastal zone management in France : the transition towards integrated coastal zone management (1973–2007). *Ocean & Coastal Management* 51:212–228. <https://doi.org/10.1016/j.ocecoaman.2007.09.005>
- Degenne A, Vergès P (1973) Introduction à l'analyse de similitude. *Rev Fr Sociol* 14:474–512
- Doxa A, Albert CA, Leriche A, Saatkamp A (2017) Prioritizing conservation areas for coastal plant diversity under increasing urbanization. *J Environ Manag* 201:425–434. <https://doi.org/10.1016/j.jenvman.2017.06.021>
- Duvat V, Magnan A, Pouget F (2013) Exposure of atoll population to coastal erosion and flooding : a South Tarawa assessment, Kiribati. *Sustainability Science, Understanding and Managing Global Change in Small Islands* 8:423–440. <https://doi.org/10.1007/s11625-013-0215-7>
- EEA (2006) The changing faces of Europe's coastal areas. European Environment Agency, Copenhagen, EEA Report 6. http://www.eea.europa.eu/publications/eea_report_2006_6
- Gómez R, Picarzo L (eds.) (2006) Destrucción a toda costa 2006. Informe sobre la situación del litoral español. Greenpeace España, Madrid

- Grandclément A, Boulay G (2016) Residential function and local fiscal resources on the French Mediterranean coastal areas. *L'Espace Géographique* 44:57–72
- Hadley D (2009) Land use and the coastal zone. *Land Use Policy* 26S: S198–S203. <https://doi.org/10.1016/j.landusepol.2009.09.014>
- Léon O (2010) La Population des régions en 2040. Les écarts de croissance démographique pourraient se resserrer. INSEE Première, 1326. <http://www.insee.fr/fr/ffc/ipweb/ip1326/ip1326.pdf>. Accessed 30 september 2016
- Malvarez Garcia G, Pollard J, Domínguez Rodriguez R (2003) The planning and practice of coastal zone management in Southern Spain. *J Sustain Tour* 11:204–223. <https://doi.org/10.1080/09669580308667203>
- Mcdonald RI, Kareiva P, Forman RTT (2008) The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biol Conserv* 141:1695–1703
- Medail F, Diadema K (2006) Biodiversité végétale méditerranéenne et anthropisation : approches macro et micro-régionales. *Annales de géographie* 651:618–640
- Meinesz A, Lefevre JR, Astier JM (1991) Impact of coastal development on the infralittoral zone along the southeastern Mediterranean shore of continental France. *Mar. Pollut. Bull.* 343–347. doi [https://doi.org/10.1016/0025-326x\(91\)90698-r](https://doi.org/10.1016/0025-326x(91)90698-r)
- Meur-férec C (2014) Plonevez-les-Flots : un territoire fictif pour souligner les dilemmes des élus locaux face à la gestion des risques côtiers. *L'Espace Géographique* 43:18–34
- Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay JE, McLean RF, Ragoonaden S and Woodroffe CD (2007) Coastal systems and low-lying areas. *Climate Change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315–356
- ONML (2009) Occupation du sol en 2006 et artificialisation depuis 2000 en fonction de la distance à la mer. Les fiches thématiques de l'Observatoire National de la Mer et du Littoral, MEDDE-SOeS, 6 p
- ONML (2014) Evolution de la construction de logements entre 1990 et 2012 sur le littoral métropolitain. Les fiches thématiques de l'Observatoire National de la Mer et du Littoral, MEDDE-SOeS, 5 p
- Petrov L, Lavalley C, Kasanko M (2009) Urban land use scenarios for a tourist region in Europe: applying the MOLAND model to Algarve, Portugal. *Landsc Urban Plan* 92:10–23. <https://doi.org/10.1016/j.landurbplan.2009.01.011>
- Pons A, Rullan O (2014) The expansion of urbanisation in the Balearic Islands (1956–2006). *Journal of Marine and Island Cultures* 3:78–88. <https://doi.org/10.1016/j.imic.2014.11.004>
- Poumadère M, Bertoldo R, Idier D, Mallet C, Oliveros C, Robin M (2015) Coastal vulnerabilities under the deliberation of stakeholders: the case of two French sandy beaches. *Ocean Coast Manag* 105: 166–176. <https://doi.org/10.1016/j.ocecoaman.2014.12.024>
- Prévost A, Robert S (2016) Local spatial planning practices in four French Mediterranean coastal territories under pressure. *Land Use Policy* 56:68–80. <https://doi.org/10.1016/j.landusepol.2016.04.034>
- Razin E (1998) Policies to control urban sprawl: planning regulations or changes in the 'rules of the game'? *Urban Stud* 35:321–340
- Rey-Valette H, Rulleau B, Hellequin AP, Meur-Férec C, Flanquart H (2015) Second-home owners and sea level rise: the case of the Languedoc-Roussillon region (France). *Journal of Policy Research in Tourism, Leisure and Events* 7:32–47. <https://doi.org/10.1080/19407963.2014.942734>
- Robert S (2016) Entre étalement et densification: une approche fine de l'urbanisation littorale sur la Côte bleue, Provence. *Cybergeo Eur J Geogr.* <https://doi.org/10.4000/cybergeo.27451>
- Robert S, Prévost A, Fox D, Trémélo ML, Pasqualini V (2015) Coastal urbanization and land planning in Southern France. In: Özhan E (Ed.). *Proceedings of the Twelfth International Conference on the Mediterranean Coastal Environment, MEDCOAST 15*, 1–2, 119–130
- Robert S, Cicille P, Schleyer-Lindenmann A (2016) Appréhender les modes d'habiter le littoral par les représentations sociales du paysage. In: Robert S and Melin H (Eds.). *Habiter le littoral. Enjeux contemporains*. Presses universitaires de Provence, Aix-en-Provence, pp 79–93
- Romano B, Zullo F (2014) The urban transformation of Italy's Adriatic coastal strip: fifty years of unsustainability. *Land Use Policy* 38:26–36. <https://doi.org/10.1016/j.landusepol.2013.10.001>
- Small C, Nicholls RJ (2003) A global analysis of human settlement in coastal zones. *J Coast Res* 19:584–599 URL : <http://www.jstor.org/stable/4299200>
- Tang Z (2008) Evaluating local coastal zone land use planning capacities in California. *Ocean Coast Manag* 51:544–555. <https://doi.org/10.1016/j.ocecoaman.2008.06.001>
- Vallega A (1999) *Fundamentals of integrated coastal management*. Kluwer Academic Publishers, Dordrecht
- Voiron C, Decoupigny F, Liziard S, Ormon A, Roussel D, Séry R (2014) PLUMES : Pression Littorale Urbaine : Modélisation, Environnement, Simulation. <halshs-00980986><https://hal.archives-ouvertes.fr/halshs-00980986/document>
- Weng Q (2002) Land use change analysis in the Zhujiang delta of China using satellite remote sensing, GIS and stochastic modelling. *J Environ Manag* 64:273–284. <https://doi.org/10.1006/jema.2001.0509>

#3 - ARTICLE

FROM THE STREET TO THE METROPOLITAN REGION: PEDESTRIAN PERSPECTIVE IN URBAN FABRIC ANALYSIS

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2019, *Environment and Planning B: Urban Analytics and City Science*, Volume 46(7), pages 1243-1263

<https://doi.org/10.1177/2399808319832612>

<https://hal.archives-ouvertes.fr/hal-02557278v1>

Cette publication constitue un jalon fondamental pour les recherches d'ESPACE en matière d'« *urban morphometrics* », c'est-à-dire des méthodes issues de l'analyse spatiale pour l'étude de la forme urbaine et de ses transformations plus récentes. Elle participe à la fois à l'action « Complexité urbaine et réseaux » de l'axe 1 et à l'action « Données géographiques massives, modélisation et IA » de l'axe 2. Elle témoigne également de la capacité du laboratoire à former et faire émerger des jeunes chercheurs, son premier auteur ayant été doctorant puis post-doctorant à ESPACE.

L'article, publié sur EPB⁸, une des revues de référence en géographie urbaine quantitative, présente un protocole novateur d'urban morphometrics, le *Multiple Fabric Assessment (MFA)*. Le protocole permet l'identification et la caractérisation data-driven de différents types de tissus urbains à l'échelle d'une aire métropolitaine. Dans ce programme sexennal, le MFA a permis une forte accélération des recherches sur la complexité de la forme urbaine des métropoles contemporaines, l'établissement de nombreuses collaborations de recherche à l'international (Univ. Catholique de Louvain⁹, Univ. de Tokyo¹⁰, Univ. Dokuz Eylül Izmir¹¹, Chalmers Univ. Göteborg¹², Univ. of Strathclyde Glasgow¹³) et la création d'un partenariat stratégique avec un industriel, la start-up sophilopolitaine Kinaxia¹⁴, d'abord dans le cadre du projet UrbaSpace de l'IDEX UCA JEDI (2019-2021), ensuite par l'obtention de l'ANR LabCom K-City-E-Space (2021-2026).

Le tissu urbain est la forme typique de relations spatiales existant entre les bâtiments, les rues, les parcelles et le site à l'échelle la plus fine de l'analyse morphologique (celle de l'îlot, de la rue ou du fragment urbain). Notre premier objectif a été de développer une méthode d'identification et d'analyse par géo-traitement des tissus urbains d'un vaste espace métropolitain intégrant le point de vue du piéton qui se déplace dans la ville. Il devient alors possible d'appréhender la diversité des formes urbaines des grandes métropoles, de parvenir à la délimitation de leurs régions morphologiques, d'en étudier l'organisation spatiale et d'évaluer l'apport de la métropolisation au développement de nouvelles formes. Le MFA s'articule en trois phases :

1. Le calcul d'indicateurs morphométriques, permettant de décrire les caractéristiques du tissu urbain observables par un piéton qui se déplace dans l'espace public ;
2. Le développement d'une nouvelle procédure géostatistique de clustering spatial sur réseau pour identifier des structures spatiales significatives ;
3. Le clustering à base d'IA bayésienne des structures spatiales ainsi trouvées pour identifier et caractériser des tissus urbains sur l'ensemble des indicateurs retenus.

Grâce à son approche vectorielle (parcellaire, bâti et réseau viaire), le MFA évite l'appauvrissement de l'appréhension de la forme urbaine des démarches à base de maillages. Un schéma archétypique de l'organisation spatiale a ainsi pu être établi, montrant des régularités dans les relations entre régions morphologiques des principales villes azuréennes.

⁸ <https://journals.sagepub.com/home/epb>

⁹ <https://uclouvain.be/fr/index.html>

¹⁰ <https://www.u-tokyo.ac.jp/en/>

¹¹ <https://www.deu.edu.tr/>

¹² <https://www.chalmers.se/en/Pages/default.aspx>

¹³ <https://www.strath.ac.uk/>

¹⁴ <https://www.kinaxia.fr>

From the street to the metropolitan region: Pedestrian perspective in urban fabric analysis

EPB: Urban Analytics and City Science

2019, Vol. 46(7) 1243–1263

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DOI: 10.1177/2399808319832612

journals.sagepub.com/home/epb



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Abstract

The urban fabric is a fundamental small-scale component of urban form. Its quantitative analysis has so far been limited either in its geographical extent or in the diversity of components analysed. Moreover, the planning approach has traditionally privileged an aerial perspective. A new approach integrating the pedestrian point of view is proposed. Spatial analysis procedures are implemented with a twofold objective: identifying urban fabrics and studying their spatial organization within a large metropolitan area. The former is achieved through multiple fabric assessment, a three-step protocol using a network-based partition of urban space: (i) a set of skeletal streetscape indicators is implemented on each spatial unit, considering different constituents of the urban fabric; (ii) spatial patterns on the street network are identified, applying geostatistical analysis to each indicator; and (iii) spatial patterns with Bayesian clustering are recombined, allowing the identification and characterization of urban fabric types and subspaces within the city. This methodology is tested on the French Riviera metropolitan area, where nine families of urban fabric are identified. Disentangling the spatial organization of urban fabrics represents the second objective of this paper: the geographical distribution of urban fabrics is investigated, applying mathematical morphology and variography while considering network-constrained topological contiguities.

Keywords

Urban form, urban fabric, network constrained local indicators of spatial association, Bayesian clustering, multiple fabric assessment

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Introduction

Since Jacobs (1961) defended the idea that modern planning did not take into account the needs of city-dwellers, academics and practitioners have increasingly worked on the importance of pedestrian perspectives in urban studies, policies and planning. This is also true in the study of the physical form of the city, as pioneered by Lynch (1960). The pedestrian point of view is thus integrated into the analysis of urban spaces, focusing more specifically on the study of streetscapes. Both physical and qualitative aspects have been studied by urban designers (Ewing and Clemente, 2013) and computer-aided techniques are enriching the description of the physical streetscape. Nevertheless, streetscapes are not the only feature of urban form, and their morphological characteristics need to be put into the urban context where they are measured.

Urban morphologists proposed to study urban contexts through the analysis of the urban fabric, which is defined as a specific combination of local patterns made up of buildings, streets and plots and considered as the original and unique outcome of conscious and unconscious design of the physical city (Caniggia and Maffei, 1979). In turn, different types of urban fabric must be understood in the context of morphological regions (Conzen, 1960), revealing the multi-scale structuring of urban form. Thanks to the ever-growing availability of data and powerful geoprocessing tools, new methodologies have been developed to analyse the urban fabric by quantitative approaches. Specific goals underlie each procedure and result in different methodological choices. However, they barely consider the pedestrian point of view. In contrast, configurational approaches like Space Syntax (SSx) capture the pedestrian perspective, but do not focus on the urban fabric as defined by urban morphologists. The potential and constraints introduced by the pedestrian perspective of the urban fabric require specific methodological and conceptual considerations. These have been overlooked in traditional and more recent procedures.

Innovative approaches from other disciplines could bring several solutions that would allow traditional urban fabric analysis to fully integrate the pedestrian perspective. In particular, quantitative urban geography is well positioned to study urban form and design (Talen, 2011). Moreover, geographers have already adapted several geostatistical approaches to network-constrained space, being aware of its importance for the study of human activity in the city (Okabe and Sugihara, 2012).

The main goal of our paper is to present a new computer-aided methodology for the study of urban fabric, which is capable of integrating the pedestrian point of view. Geoprocessing, geostatistics and artificial intelligence (AI)-based clustering are implemented in a new procedure to analyse and combine 'geometry and geography' (Batty, 2007): from the geostatistical detection of urban fabric types to the study of their spatial organization within the urban space. A real-world case study of the size of an entire metropolitan area is used to test the method and evaluate the quality of the results obtained.

The paper is organized as follows. The next section provides an overview of computer-assisted methods available to analyse urban form, highlighting issues related to the pedestrian point of view. 'Case study' section introduces the study area of the French Riviera. 'Urban fabric identification: A new methodology' section describes multiple fabric assessment (MFA), a new three-step procedure for the identification of different urban fabrics. 'Results: Identification of the urban fabric families' section presents MFA results for the area studied. 'Spatial organization of urban fabrics' section shows how further geographical approaches might be applied to MFA outcomes to analyse the spatial organization of urban fabrics and to identify settlement boundaries. A discussion pertaining to future developments concludes the paper.

Computer-aided approaches to urban morphology

The classical analysis of urban fabric

Defined as the study of the urban form, urban morphology deals with the analysis of the physical layout and design of a city, a town or an urban fragment within these. Urban morphology involves the study of patterns of its components and the processes of their formation and transformation (Vernez-Moudon, 1997).

Literature on the analysis of urban form has its origins in the seminal works of urban geographers of the early 20th century, in German-speaking countries (Hofmeister, 2004). The works of the Conzenian and Muratorian schools after Second World War jointly developed the concept of the urban fabric. This is defined as a typical pattern of buildings, parcels and streets, characterizing the form of the physical city in a given historical and cultural context, at the scale of an urban fragment (Conzen, 1960; Muratori, 1959). The concept of the morphological region is also proposed to describe urban sectors characterized by consistent extents of a single urban fabric and to produce more global schemes of the morphological organization of the city. Despite efforts to develop systematic approaches for the analysis of the urban fabric, these methodologies relied heavily on manual measurements, treatment and interpretation of calculus. This has limited the extent of case studies (Allain, 2004; Borie and Denieul, 1984; Caniggia and Maffei, 1979). Morphological regions could be identified in small cities like Alnwick, Northumberland (Conzen, 1960), or in medium ones like Versailles (Castex et al., 1980), but have only been hinted at for big cities. Furthermore, the approach of classical urban morphologists to study the urban fabric left little space for the pedestrian perception of the physical city. Meanwhile, Lynch's (1960) seminal work established little link between the perception of cityscapes and the analysis of the urban fabric.

The configurational approach

Starting from the late 1970s, technologies allowed the implementation of computer-aided quantitative approaches for the analysis of urban form (Kruger, 1977; Steadman, 1983). Graph analysis played an important role in these early models. Paralleling the development of social network analysis (Freeman, 1977), configurational approaches to urban street networks were proposed. SSx (Hillier, 1996; Hillier and Hanson, 1984) proposed the most innovative reconceptualization of urban form analysis by focusing on the open space available for pedestrians and by building on the theory of natural movement within this (Hillier et al., 1993). The urban open space is partitioned into convex polygons approximated with visual axial lines. Topological measurements of centrality are carried out on the resulting graph, which is a dual representation of the axial line network. A similar approach is the multiple centrality assessment (MCA, Porta et al., 2006; Sevtsuk and Mekonnen, 2012), which develops centrality measurements on the primal representation of metric street networks. Links represent street centrelines while nodes correspond to their junctions. Hybrid approaches have also been proposed between SSx and MCA (Cutini et al., 2005; Turner, 2007).

The use of visual lines and the natural movement theory might be considered as an integration of the pedestrian perspective applied to the analysis of urban form, and in SSx this is even truer than for MCA. But the final goal of configurational approaches is to study the organization of public space, open to pedestrian through-movement and to-movement. Such methods open the way to a deeper understanding of the relationship

between urban form and pedestrian movement. Seeing them as a computer-aided implementation of the analysis of the urban fabric, as suggested by Lévy (2005), is thus questionable. Important components of the urban fabric (buildings, plots, site), and their dimensional and geometrical relationships, lie outside of the scope of configurational analyses. Work is presently being carried out to combine urban fabric and configurational metrics in the description of urban form (Gil et al., 2012; Ye and Van Nes, 2014). However, Kropf (2017) highlights the need to reconceptualize urban fabric analysis when combining these different approaches. Our paper goes in this direction, leaving the integration with a configurative description of urban form as a future endeavour.

Computer-aided analysis of the urban fabric

One of the main motivations of our paper is the development of new computer-aided methods to analyse both the form of the different urban fabrics, as defined by classical urban morphologists, and their organization in morphological regions within the city. Thus, we will turn our attention to the different methods that have been developed in this direction during the last decades. We propose to renew these by integrating the street-based pedestrian point of view. This will allow us to bridge the gap with works on streetscape perceptive analysis and to open the way for future convergence with other street-based analyses, like configurational approaches.

Following the founding concept of urban fabric, the reviewed methods aim to describe in different ways the arrangements of buildings, plots and streets. While configurational studies built their strength around a small number of shared methodologies, within this second group more goal-oriented procedures have been developed. All the methods considered integrate geoprocessing approaches to analyse the multidimensional character of the urban fabric. Different degrees of computer-aided automation allow the study of vast settlements at the fine grain scale of the single urban constituent (street, building, plot). The urban block represents the spatial unit of urban morphologists' traditional analysis: its historical permanence allows an easier diachronic analysis of built-up forms included in its limits. It is thus privileged in many geoprocessing methods as in Berghauser-Pont and Haupt (2010), Puissant et al. (2010), Bernabé et al. (2013), Gil et al. (2012), Vialard (2013) and Hermosilla et al. (2014). Other spatial partitions like regular grids have been adopted in the study of urban form for climatological purposes (Long and Kergomard, 2005). Despite differences in the final goal and spatial unit choice, these methodologies share a similar multivariate approach based on the cross-analysis of different dimensions of urban form components, like their density and geometrical properties. Typo-morphologies of city blocks represent the main outcomes of these methodologies. Another important phase in geoprocessing of the urban fabric is the computer-aided algorithms used to identify different empirical typologies of city blocks: spacematrix diagrams (Berghauser-Pont and Haupt, 2010), k-means (Bernabé et al., 2013; Gil et al., 2012; Vialard, 2013) and decision trees (Hermosilla et al., 2014).

The integration of the pedestrian point of view in the analysis of urban form is nevertheless absent from all the aforementioned methods. First, streets are normally considered as the limits for spatial partitioning, rather than as the core of a fragment of the urban fabric. Second, typo-morphologies of urban blocks are identified through clustering approaches, applied to individual spatial units, considering their local geometrical descriptors without any reference to their spatial relations to neighbouring units that could be explored by pedestrians. Spatial analysis is limited here to an a posteriori visual/qualitative study of the clusters identified.

The skeletal streetscape

Contrary to geoprocessing methods in urban fabric analysis, the impact of street design on human perception represents the main focus of environmental psychology studies of urban form. Within this domain, recent developments might present valuable insights for our study. Harvey and Aultman-Hall (2016) define and measure the streetscape of a simplified 3D model of the street for the study of human perception. More specifically, they focus on the *skeletal streetscape*, defined as the main geometric characteristics of buildings and trees along the streets (size, spacing, frequency, etc.). The skeletal streetscape provides the structural support onto which the *skin*, made of design details, is fitted, completing the description of the streetscape. The authors propose a set of indicators implemented through a geoprocessing approach describing the geometrical organization of façades along the streets. Like in geoprocessing of the urban fabric, streetscape indicators are combined for classification purposes. Once again, the spatial distribution of the identified patterns is assessed qualitatively by analysts.

The quantitative measurement of the skeletal streetscape allows the study of aspects related to the street–building interface, highlighted and debated by several architects and urban designers (Alexander et al., 1987; Gehl, 2010; Lynch, 1960). More recently, innovative procedures have been proposed to measure further constituents of streetscapes like vegetation (Dubey et al., 2016), sky view (Leduc and Chauvat, 2015) and façade colours (Nguyen and Teller, 2017, etc.). In conclusion, streetscape analysis, whether limited to the skeletal structure or extending to include other constituents, focuses on the street–building interface and ignores both the content of buildings and the urban fabric as a whole.

Indications for a new computer-aided and human-centred analysis of the urban fabric

We have discussed the main computer-aided methods for the analysis of urban form, focusing on those aimed at the form of the urban fabric. We also highlighted their conceptual and methodological limits when it comes to integrating the pedestrian point of view. The methodological challenges underlying the goal defined in the ‘Introduction’ section are now pointed out.

Our first need is to define a new spatial unit putting the street at the centre of the analysis. From the street, pedestrians can perceive the surrounding elements of the urban fabric (buildings, open spaces, plots, trees). Urban form indicators should be conceived and redefined from this perspective. Measurements of skeletal streetscapes as proposed by Harvey and Aultman-Hall (2016) seem to be an interesting starting point. Nevertheless, other important aspects of the urban fabric, well-identified by classical urban morphology schools, should be integrated into the approach, always including the pedestrian point of view. Finally, the urban fabric will be defined as a morphologically attentive urban streetscape.

Moreover, the pedestrian perspective to define the urban fabric should not simply be reduced to the capacities of human vision. It is by moving from one street to another that pedestrians can experience the spatial variability or homogeneity of urban fabric characteristics. Each indicator, describing a geometrical aspect of urban form within a spatial unit, should be evaluated considering its spatial distribution and variation. Geostatistical analysis on street networks might then provide methodological solutions for the study of spatial heterogeneity/homogeneity of perceivable morphological characteristics and serve as the input for subsequent clustering models. Thus, the street network becomes the underlying

spatial support, as in street-based configurational approaches, but with a different role in the very nature of ensuing analyses.

Finally, types of urban fabric defined as morphological streetscapes might be characterized by specific sub-groups of morphological patterns, which may vary from one subspace to another. The homogeneity of a whole set of morphological descriptors, which is imposed by traditional classification methods (k-means, hierarchical clustering, etc.), might represent a methodological limitation.

Bearing in mind these indications, we will show in the following sections how well-established methodologies from geoprocessing, geostatistics and AI might converge in a new protocol of analysis of the urban fabric to provide a more appropriate integration of the pedestrian point of view.

Case study

In order to evaluate the new methodological protocol, we will test it on a real-world case study: that of the French Riviera metropolitan area, in southern France (see Supplemental Appendix Figure S1). With a population of more than one million inhabitants over 1500 km², this space represents a unique conjunction of natural and urban landscapes. First, the topography, with an elevation ranging from sea level up to the 1700 m of the pre-Alps (passing through differently sloped hills and valleys). Second, the socio-political and historical influences on urban planning. Traditional villages and suburban developments are spread around three high-density urban areas. From east to west, we find: Monaco and its skyscrapers, the most densely populated sovereign nation in the world; the urban agglomeration of Nice with a regular meshed core inspired by the Turin model (Graff, 2013) surrounded by hilly and less tightly planned areas; the urban agglomeration of Cannes–Grasse–Antibes characterized by land irregularity together with the car-centred sprawling development of the last 50 years. The combination of all these elements produces a sequence of urban centres and peripheral areas of different sizes and morphologies. This study area will give us the opportunity to test our method and to identify different urban fabrics by a bottom-up approach.

Urban fabric identification: A new methodology

MFA is a new methodology for the identification and characterization of different urban fabrics within a large study area (see Supplemental Appendix Figure S2). After defining appropriate goal-specific spatial units (1), it can be summed up as follows: (2.a) geoprocessing protocols to calculate a matrix of morphological indicators of the urban fabric; (2.b) identification of spatial associations of indicator values (local patterns) on a network constrained space; (2.c) clustering of local patterns through Bayesian methods. The outcomes of MFA allow the identification of urban fabrics in large study areas (3.a) and the study of their spatial organization (3.b).

A new spatial unit partition of urban space: The pedestrian point of view

As discussed in the first part of this paper, when analysing urban fabrics through geoprocessing, we first need to define the base spatial unit. In order to analyse the skeletal streetscape, Harvey and Aultman-Hall (2016) selected the proximity space on the two sides of each street centreline, where the relative disposition of the built-up façades is measured. In her study of the block-face, Vialard (2013) also proposed a morphological description of

elements within a one-sided buffer, going from the street-edge to the block interior. Here, centrelines and street-edges assume a major value of geometrical reference for the description of the urban fabric. The interface between streets and buildings/plots is the starting point to measure specific street-based indicators like corridor effects, façade alignments, setbacks, etc. Other representations of the public space overlook this specific aspect and focus on different criteria (e.g. convex spaces of axial maps and derivatives), losing this geometrical reference. Hermosilla et al. (2014) also recognized the need to integrate morphological descriptors of street-related spaces to characterize different urban fabrics, but their analysis was still centred on the urban block, which encompasses the descriptors of its surrounding streets.

As highlighted in previous sections, Harvey's approach allowed a local description of streetscapes disregarding their spatial relations. Spatial contiguities between these street-centred fragments of urban space should be reintroduced to explore their spatial variability. Studying different issues from urban form, Okabe and Sugihara (2012) proposed a similar partition of urban space, namely network-based Thiessen tessellation, with the intent of redistributing socio-demographic data on the street network.

Inspired by these studies, we propose a new division of urban space. A generalization of Thiessen polygons is created around each street segment, to identify the portion of planar space conventionally served by each segment. Only the closest space to street-edges can be observed by pedestrians. A double-sided buffer approximating to visible space is selected from the Thiessen partition (Figure 1). The resulting partition, the proximity bands (PBs) considers different visual depths, depending on the specific aspect of the urban fabric under analysis ('Decomposing urban fabric components' section). Moreover, the connectivity of the underlying street network is transferred to PBs, allowing the implementation of network-constrained spatial statistics ('Spatial patterns on networks: ILINCS' section). Finally, their

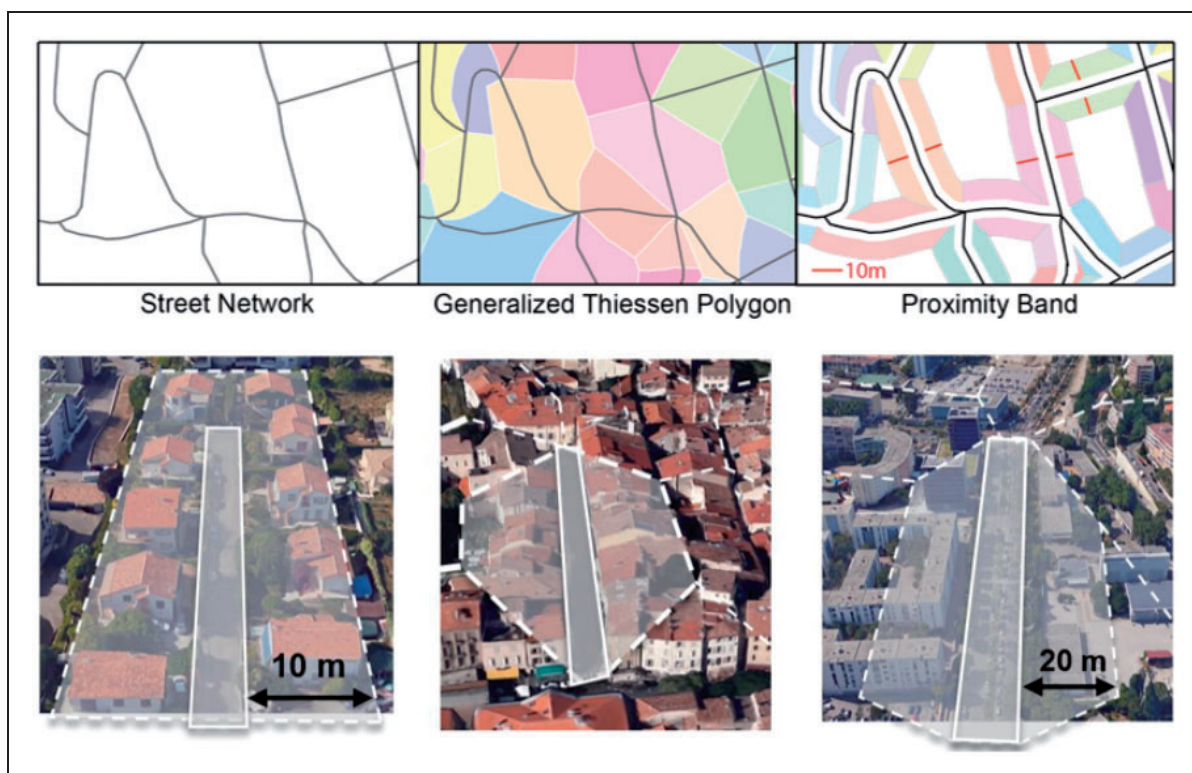


Figure 1. From the Street Network to the PB implementation (above): some examples (below).

small size variability reduces the potential bias induced by the modifiable area unit problem in statistical analysis. In our study area, 99,562 PBs were identified with street segment lengths of between 4 and 300 m and an average conventional surface of 4680 m² when a 20 m band of visible space was considered (see Supplemental Appendix Table S1).

Decomposing urban fabric components

Twenty-one indicators obtained through geoprocessing in GIS were calculated for each PB. Selection criteria of indicators are the relevance and complementarity of the information carried by each of them when describing the urban fabric following the theory of urban morphology analysis (Borie and Denieul, 1984) reinterpreted from the pedestrian point of view¹ (see Supplemental Appendix Figure S3).

Network morphology is analysed through the street segment *Length* and *Linearity* (or inversely, its *Windingness*) (Harvey and Aultman-Hall, 2016). Three indicators measure the *Local Connectivity* of the street network: each street junction is described by Boolean values that indicate the presence/absence of nodes of degree one (cul-de-sac), four (crossings) and other (mainly bifurcations). Their averages on each street segment are later used to identify areas characterized by tree-like networks or meshed street grids (as in Marshall, 2012). **Built-up morphology** is studied within a 50 m wide PB and is first characterized by the traditional building *Coverage Ratio* index (Berghauser-Pont and Haupt, 2010). This indicator is then enriched by information about *Built-up Type prevalence*. The building footprint area is used as a proxy for categorization of buildings (Sevtsuk, 2014). For the French Riviera case study, the footprint segmentation is defined as follows: 0–125 m² (independent small houses), 125–250 m² (large villas and small traditional multi-family buildings, which are particularly frequent in our study area), 250–1000 m² (townhouses and medium-sized blocks of flats), 1000–4000 m² (modern large blocks of flats, commercial, industrial or service buildings), greater than 4000 m² (mainly functionally specialized large buildings).² We calculate the *Specialization of Building Types* by considering the presence/absence of ordinary dwellings. *Building Contiguity* informs us whether the urban fabric is characterized by adjoining buildings linked to the compactness of the urban built-up environment at a very fine grain. The role of these two indicators in the characterization of the urban fabric is recognized by classical urban morphologists (Caniggia and Maffei, 1979; Pinon, 1991). **Site Morphology** measures the presence of steeply sloped surfaces in the 50 m PB.

Network–Building Relationship indicators describe the building geometry analysed in relation to the street segment. For this reason, they are computed on narrower PBs of 10 or 20 m. They include the *Street Corridor Effect* (Araldi and Fusco, 2016), as a ratio between the total length of parallel façades and the street segment (similar to Harvey and Aultman-Hall, 2016 and Vialard, 2013, only considering parallel façades); *PB Building Height* (Berghauser-Pont and Haupt, 2010); *Open Space Width; Height/Width Ratio* (Harvey and Aultman-Hall, 2016). The *Building frequency along the street network* informs us about the serial vision of different buildings along a street (Hallowell and Baran, 2013). Following the same approach, *Land ownership fragmentation* is used as an indicator of the **Network–Plot Relationship**. Finally, the relationship between street **Network and Site Morphology** is analysed through *Street Acclivity*. Plot morphology per se, although central to the study of morphogenetic processes (Caniggia and Maffei, 1979; Conzen, 1960) is considered less relevant for pedestrian perception. The operational definition of each indicator is given in Table 1.

Table 1. The 21 indicators matrix for urban fabric morphology.

Urban fabric component	Indicator	Definition and implementation formulae	Proximity band width	
Network morphology	Street length	Street segments length between two intersections	L_{street} /	
	Windingness	$1 - (\text{Euclidean distance} / \text{Network distance})$ between two intersection	$1 - \frac{L_{eucl.}}{L_{street}}$ /	
	Local connectivity	Average of the presence nodes of degree 1 (ND1)	$\sum ND_i [0, 1] / 2$	/
		Average presence nodes of degree 4 (ND4)		/
Average presence nodes of degree 3, 5+ (ND35+)			/	
Built-up morphology	Prevalence of building types	(0:125] m ² building surf./total built-up surf.	$\frac{S_i}{S_{built}}$	50
		(125:250] m ² building surf./total built-up surf.		
		(250:1000] m ² building surf./total built-up surf.		
		(1000:4000] m ² building surf./total built-up surf.		
		(4000: max] m ² building surf./total built-up surf.		
	PB coverage ratio	Built-up Surface/PB Surf.	$\frac{\sum S_{tot}}{\sum S_{PB}}$	
Building contiguity	Weighted average of buildings frequency on built-up units	$\frac{\sum S_{b-u(i)} \left(\frac{1}{N_{build\ in\ b-u(i)}} \right)}{\sum S_{b-u(i)}}$		
Specialization of building types	Specialized building surf./PB surf.	$\frac{\sum S_{spec}}{\sum S_{PB}}$		
Network–building relationship	Street corridor effect	Parallel façades length/street length	$L_{par\ fac} / L_{street}$	10
	PB building height H	Building volume/PB surface	$\sum V_{built} / \sum S_{built}$	20
	Open space width W	(PB surf. – built surf.)/street length	$(S_{PB} - S_{built}) / L_{street}$	
	Height/width ratio	PB building height/open space width	H/W	
	Building frequency along SN	Number of buildings/street length	N_{build} / L_{street}	
Network–plot relationship	Land ownership fragmentation along the street network	Number of plots/street length	N_{plot} / L_{street}	50
Site morphology	Surface slope	High sloped surf. (S>30%)/PB surface	$\sum Sloped\ Surf_i / \sum S_{PB}$	50
Network–site relationship	Street acclivity	Avg. arct(slope) along the street centreline	$E [\arct(slope)_i]$	/

PB: proximity band.

Spatial patterns on networks: ILINCS

The local value of an indicator for each spatial unit is not adapted to describe the wider spatial patterns that are typical of the urban fabric, the latter being characterized by the arrangement in space of urban components with consistent morphological values. Spatial continuity and aggregation are key factors for their significance, especially if we adopt the pedestrian point of view. Several authors have suggested clustering spatial units using the raw values of morphological indicators, for example through k-means (Bernabé et al., 2013; Gil et al., 2012; Vialard, 2013). Spatial relations between adjoining spatial units are then overlooked and clustering of spatial units does not necessarily lead to the identification of urban fabrics. Through Geo-SOM, Hamaina et al. (2013) introduced spatial constraints into clustering, but their use of Euclidean distances between buildings is not coherent with our pedestrian viewpoint of the street network. We thus propose a preliminary phase of the detection of patterns for each morphological indicator, considering the spatial distribution of its values.

Local indicators of spatial association (LISA; Anselin, 1995) characterize the spatial autocorrelation of values around each unit using a local computation of Moran's Indicator. We propose the application of their network-constrained version (ILINCS, Yamada and Thill, 2010) to morphological indicators at the street level. For each spatial unit i , w_{ij} describes local contiguities j on a street network

$$Local I_i = \frac{n(p_i - \bar{p}) \sum_j w_{ij}(p_j - \bar{p})}{\sum_i^n (p_i - \bar{p})^2} \quad (1)$$

where p_i is the local value of a given variable in i and \bar{p} is the average value in the study area. Araldi and Fusco (2016) discussed the application of LISA and ILINCS to the analysis of urban morphology indicators, showing how ILINCS is best fitted when analysing patterns from the pedestrian point of view. Despite the reduction in the variability of the spatial unit size (Table 1), ILINCS patterns might still be biased. In another study, Fusco and Araldi (2018) focused on the study of the statistical distribution of morphological indicators to propose appropriate variability corrections. To consider the heteroscedasticity of morphological rates, empirical Bayesian corrections (Assunção and Reis, 1999) were applied.

Through these network-constrained geostatistical analyses, we pass from a collection of morphological values for each spatial unit to statistically significant spatial patterns that correspond to hot- and cold-spots of given morphological characteristics, using the usual categories of LISA analysis (High–High, Low–Low, Low–High, High–Low and Not-Significant, see Supplemental Appendix Figure S4). These geostatistical classifications are the result of the analysis of the values of each PB, considering the local neighbourhood connected through the street network, with a topological depth of 3 units.

Recomposing and characterizing urban fabrics: Bayesian clustering

Our geostatistical analysis produced 21 sets of significant spatial patterns. The next step consists of studying how these overlap to yield specific combinations. The urban fabric from the pedestrian point of view is precisely the perception of persistent co-occurrences of given morphological characteristics upon exploring urban space. At the same time, a few key characteristics could identify a given urban fabric even in the presence of a certain variability of other morphological aspects. For example, a specific compact and dense traditional

urban fabric could be characterized by consistently high building coverage ratio, street corridor effect, building contiguity and height/width ratio, while some heterogeneity of building types and network connectivity is seen. Clustering approaches aiming to achieve high intra-cluster homogeneity based on variance minimization of the values of all the indicators (like k-means, SOM and geo-SOM) are not well fitted to this task.

Bayesian clustering is applied here. This methodology is based on the Bayes' Theorem and it allows each spatial unit PB_i to be described with a set of probabilities of belonging to each Urban Fabric class UF_j considering its description given by the set of attributes $A_{1i}, A_{2i}, \dots, A_{ni}$ (morphological patterns)

$$p_{PB_i}(UF_j|A_{1i}, A_{2i}, \dots, A_{ni}) = \frac{\prod_{k=1}^n p(A_{ki}|UF_j)p(UF_j)}{p(A_{1i}, A_{2i}, \dots, A_{ni})} \quad (2)$$

with the constraint

$$\sum_j p_{PB_i}(UF_j) = 1 \quad (3)$$

Two main reasons led to this choice: first, Bayesian clustering allows the identification of groups of individuals sharing a few key characteristics among the set of attributes A_1, A_2, \dots, A_n , which could vary from one group to another (as discussed in Fusco, 2016). Second, Bayesian probabilities can address the uncertain assignment of observations: hybrid street segments could have non-null probabilities of belonging to different urban fabrics. The careful theory-driven feature selection of our analysis justifies the use of a naive Bayesian classifier on the 21 morphological indicators.³

The combination of ILINCS and Bayesian clustering is a key feature of MFA. Instead of grouping streets depending on the similarity of their internal geometrical profile (row indicators on spatial units), we will thus perform Bayesian clustering of categorical values (HH, LL, HL, LH, NS),⁴ which, in turn, summarize the statistical significance of morphological spatial patterns defined on a street network.

Results: Identification of the urban fabric families

Using eight different random seeds, 1000-step random walks explored the solution space to obtain optimal Bayesian clustering of spatial units. The search constraints were a minimum cluster content of 1% of the spatial units, a minimum average probability of 0.9 for the assignment of units to each cluster and a maximum of 20 clusters. The optimal solution is obtained by minimizing Akaike's (1974) information criterion, which combines the log-likelihood of the clustering solution given the data with penalization for the increasing number of clusters.

Within our eight random-walk searches, the nine-cluster solution was always found to be the optimum. A successive refining phase of the nine-cluster solution was carried out by imposing this fixed number of clusters to eight new random-walk searches. The results obtained were almost identical and the best one showing a contingency table fit score of 59.4%.

The projection of the 21 variables (resulting from geostatistical analyses) in mutual information space (see Supplemental Appendix Figure S5a) shows little redundancy among morphological indicators. Variables are well separated, with the exception of *Building Coverage*

Table 2. Indicator mutual information with cluster variable (left) and frequency of observation among the 10 collectively most informative variables (right).

Indicator name	Mutual information (%)	Indicator name	Frequency of observation (%)
Height/width ratio	37.68	Height/width ratio	100
Building coverage ratio	37.46	Building coverage ratio	97.13
Building frequency	33.88	Street acclivity	79.63
Building contiguity	29.27	Building frequency	75.61
Street corridor effect	28.22	Street length	72.01
Average building height	26.87	Buildings (0–125 m ²)	64.18
Street length	21.80	Street windingness	61.70
Open space width	21.27	Buildings (1000–4000 m ²)	59.10
Plot frequency	16.98	Average building height	51.56
Street windingness	16.34	Buildings (125–250 m ²)	49.57
Street acclivity	15.83	Street corridor effect	47.91
Buildings (0–125 m ²)	14.05	PB slope	43.15
Buildings (125–250 m ²)	12.83	Plot frequency	41.13
Buildings (250–1000 m ²)	12.46	Building contiguity	38.94
Buildings (1000–4000 m ²)	11.31	Open space width	36.62
PB slope	8.90	Buildings (250–1000 m ²)	35.57
Nodes 1	7.11	Nodes 1	11.77
Building Specialization	4.60	Building Specialization	9.59
Nodes 4	3.90	Buildings (S > 4000 m ²)	4.31
Buildings (S > 4000 m ²)	2.38	Nodes 4	3.19
Nodes 3, 5+	1.82	Nodes 3, 5+	0.00

PB: proximity band.

Ratio, *Building Contiguity*, *Height/Width Ratio* and *Building Frequency*. The latter also have the highest mutual information with the cluster variable (Table 2 – left). However, their redundancy does not play an important role in the clustering results. When asked to select the 10 collectively (rather than just individually) most informative variables for each spatial unit, the Bayesian classifier identifies the indicators listed in Table 2 – right, in descending order of frequency, and obtains a clustering accuracy of 93.14%. *Height/Width Ratio* and *Building Coverage Ratio* are thus normally coupled with *Street Acclivity*, *Building Frequency*, *Street Length* and the presence of *Small Buildings*, and identify the same urban fabric cluster obtained with all 21 indicators. Table 2 – right also tells us that the last five morphological indicators are seldom needed to correctly predict the cluster variable. The clustering results are relatively robust in terms of sensitivity to input data. The use of the 10 most informative variables on 10 test sets obtained in a 10-fold cross-validation schema produces a mean clustering accuracy of 92.62%, just half-a-point less than the one for the model learned on the whole data set.

Nevertheless, even the indicators that have the lowest mutual information with urban fabric clusters in general (Table 2 – left) or that are seldom used as the most informative variables (Table 2 – right) can have a non-negligible role in characterizing a given urban fabric, like the *PB slope* for cluster 6 or the frequency of *Nodes 4* for cluster 2 (see Supplemental Appendix Table S2).

Even more clearly, the projection of the clustering solution (see Supplemental Appendix Figure 5(b)) shows nine well defined clusters of urban fabrics (identified as UF1, UF2, etc.).

Their interpretation in terms of urban fabric characteristics (given by the Bayesian network in terms of probabilities, see Supplemental Appendix Table S2, Figure S6) goes beyond the scope of this methodological paper. We will briefly say that clusters 1, 2 and 3 correspond to the urban fabrics of the traditional compact city, cluster 4 to the modern discontinuous urban fabric, clusters 5 and 6 to residential suburban fabrics, clusters 8 and 9 to non-urbanized areas with sparse buildings and cluster 7 to a very specific connective artificial fabric, with sparse specialized buildings, bonding modern and suburban fabrics together to the traditional urban ones. Above all, when they are projected in geographic space, the clusters identify well-defined spatial patterns of connected spatial units defining the spatial extent of a given urban fabric type. Figure 2(a) represents the area around the city of Antibes. Street segments are assigned to the most probable class to which they belong. The old city centre is clearly distinguishable on the right, in a brown colour (UF1), surrounded by the traditional urban fabric of the late 19th and early 20th (UF2). More peripheral urban sectors belong to clusters 3 and 4, whereas vast suburban areas (UF5) border the city to the north and south, corresponding to the Antibes Cape. The traditional fabrics of smaller cities (here Vallauris) are islands within suburbia. Finally, the connective artificial fabric corresponds to retail developments around extra-urban roads and to the technical space around the port of Antibes. Similar results are found for the cities of the French Riviera (see Supplemental Appendix Figure S7) and these are consistent with expert knowledge of the study area (Graff, 2013). The contrast is striking with the nine-cluster solution being obtained with raw values of morphological indicators (see Supplemental Appendix Figure S8). Lacking any spatial constraint, the clustering procedure produces a mere typology of spatial units and fails to recognize that specific spatial arrangements of these typologies could be characterized as a unique urban fabric.

As we already mentioned in ‘Computer-aided approaches to urban morphology’ section, different objectives lead to different methodological choices in the analysis of urban fabrics. We assess the results obtained for the cities of the French Riviera as being particularly satisfactory with respect to the objective of identifying different urban fabrics potentially perceived by pedestrians moving on a street network, at the scale of a whole metropolitan area (Fusco and Araldi, 2017).

Spatial organization of urban fabrics

In the previous section, the probabilistic results of Bayesian clustering were used for the identification and description of each class of urban fabric. In what follows, new insights about urban fabric organization within settlements are disclosed through the analysis of the spatial distribution of these probabilistic outcomes. These analyses provide quantitative support to the visual exploration of outcomes of urban form clustering. Moreover, they reveal the multi-scale nature of urban form upon passing from the street level (skeletal streetscape), to the neighbourhood level (urban fabric) and to the spatial organization within a metropolitan area.

Where does the city end? Settlement boundaries and uncertainty

In the last few decades, several studies investigated indicators and techniques for measuring characteristics of settlements such as sprawl, compactness and contiguity. Nevertheless, a general consensus does not exist for the definition of urban boundaries and morphological agglomerations (Chaudhry and Mackaness, 2008; Parr, 2007; Tannier et al., 2011). Methods based on population distribution and density (Rozenfeld et al., 2008) or socio-economic

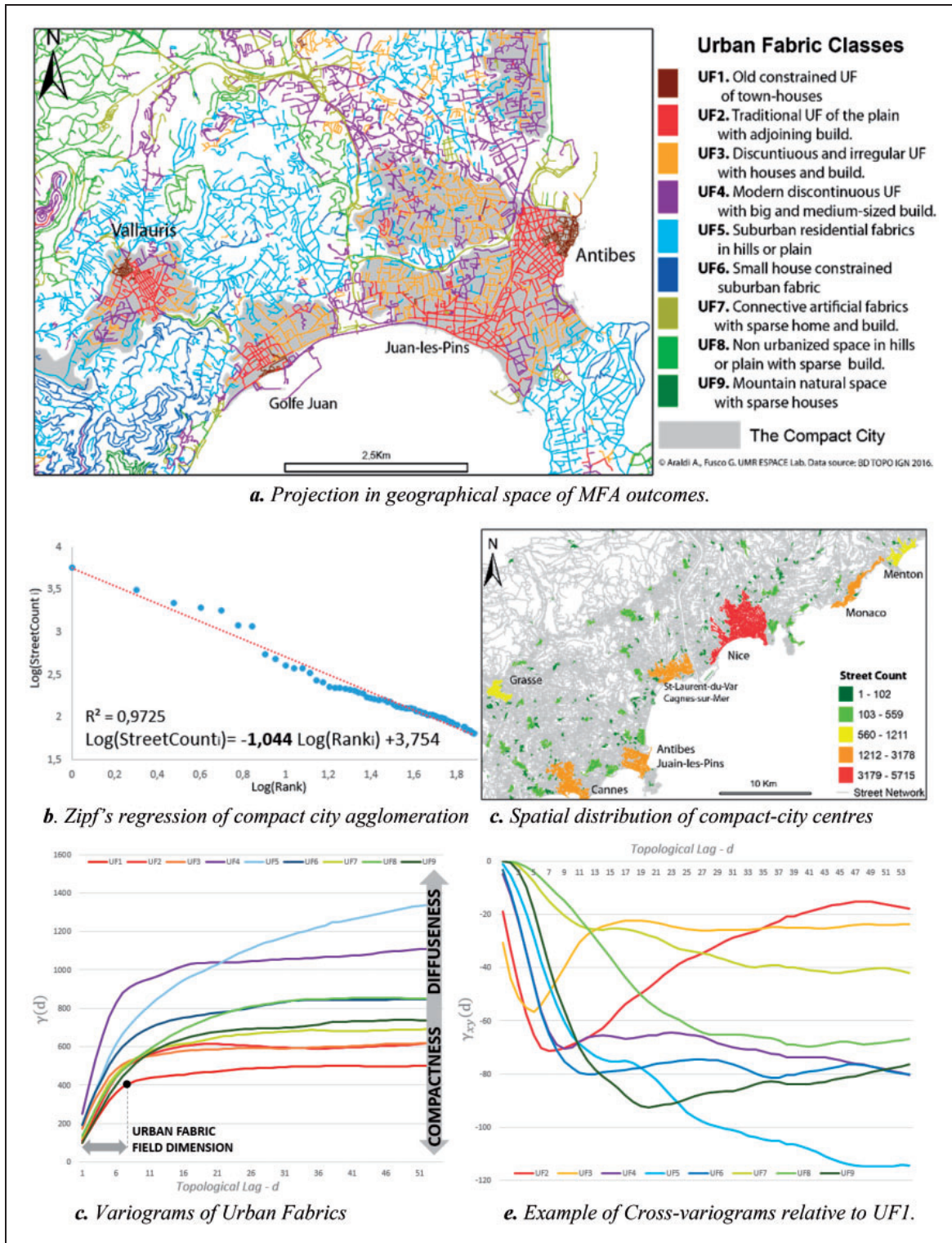


Figure 2. MFA outcomes and quantitative analysis of their spatial arrangement. (a) Projection in geographical space of MFA outcomes, (b) Zipf's regression of compact city agglomeration, (c) spatial distribution of compact-city centres, (d) variograms of urban fabrics and (e) example of cross-variograms relative to UF1.

administrative partitions (Parr, 2007) mainly consider functional factors. If urban morphology is considered independently, other procedures have been proposed: a dilation-erosion procedure applied to the building footprint (Chaudhry and Mackness, 2008) or fractal approaches applied to both raster and vector representation of the building surfaces

(Longley et al., 1991, 1992). A dilation method is the starting point of both these approaches: Minkowski dilation for Tannier et al. (2011); morphological mathematics in Benediktsson et al. (2003), Chaudhry and Mackaness (2008). The former investigates the variation in the number of aggregated elements at each dilation step in the overall space study, while the latter combines the dilation procedure with subsequent erosion. Both methods are applied to a Euclidean space and to elementary components (buildings, built-up pixels, etc.) without any semantic characterization of their urban content.

We were motivated by the same underlying principles as described in ‘Computer-aided approaches to urban morphology’ section and propose here the application of the aforementioned dilation-erosion procedure to the MFA probabilistic outcomes, while respecting network contiguities. MFA results are used for the delineation of the boundaries of the traditional compact city. We will first use the semantic information of our urban fabric types and select clusters 1, 2 and 3 as sharing similar characteristics specific to the traditional urban compact environment. We will filter PBs for which $p(\text{UF1})+p(\text{UF2})+p(\text{UF3})\geq 0.8$ to focus on those elements that were assigned to the compact city with relatively low uncertainty. Applying topological dilation-erosion to networks of selected spatial units, we can identify urban spaces where compact city characteristics might be considered as belonging to the same urban continuum, thus defining compact city borders (Figure 2(a) to (c)).

Moreover, the count of the number of street segments in each resulting aggregation describes the hierarchy of compact urban settlements within the French Riviera. Zipf’s regression on $\log(S_i)-\log(\text{Rank}_i)$ shows a regression coefficient of 1.04 with a R^2 value of 0.97 (Figure 2(b) and (c)). Despite the different implementation technique used, this value is close to the 1.095 obtained at the national scale by Oliveira et al. (2018). This observation seems to endorse the universal validity of Zipf’s Law as defended in Jiang et al. (2015). A discussion of the validity of Zipf’s Law for urban settlements transcends the goal of this paper. What we intended to show here is how MFA results could be used to identify and study borders of traditional settlements within a wider metropolitan area as well as their spatial organization at the regional scale with a network-based morphological approach.

From quantitative outcomes to the archetype model

Correlography and variography represent quantitative approaches that are usually applied in geology and ecology for the analysis of the spatial organization of phenomena under study (Legendre and Legendre, 1998). The former investigates and tests the presence of significant spatial autocorrelation in the data set, while the latter allows the description of its spatial organization and the observed structure to be related to hypothesized generation processes.

‘Spatial patterns on networks: ILINCS’ section described the adoption of autocorrelation analysis to identify statistically significant spatial patterns for each morphological indicator. The classification outcomes identify subspaces with a specific combination of spatial autocorrelation values by construction. Variography is adopted in this section, to quantitatively describe the spatial arrangement of urban fabrics throughout the network.

Within the Regionalized Variables Theory, empirical semi-variograms (called variograms for simplicity) are geostatistical functions conceived by Matheron (1965) to describe spatial phenomena combining the structural factor with a random noise component. In this theory, fluctuations of spatial distributions are considered to be a characteristic of the phenomena with a specific structure at a given scale, rather than statistical noise. Variograms quantify the similarity between the value observed at a point i and those observed at increasing distances within its surrounding area. The final aim of these functions is to quantify the

zone of influence of a phenomenon. Variogram function $\gamma(d)$ is defined by the following equation

$$\gamma(d) = \frac{1}{2W} \sum_{h=1}^n \sum_{i=1}^n w_{hi} (y_n - y_i)^2 \quad (4)$$

where γ decomposes the spatial variability of the observed variable among distances d . W is the matrix of weight describing the spatial relation between values y_i and the surrounding values y_h at distance d .

The application of variograms could reveal the spatial structures of the study field, the presence of nested structures, discontinuities, anisotropies and the size of the influence zone of phenomena (Dauphiné and Voiron-Canicio, 1988). An interesting variation of the variogram is the cross-variogram, which focuses on the co-variance of two phenomena in space. Equation (1) is reformulated as

$$\gamma_{xy}(d) = \frac{1}{2W} \sum_{h=1}^n \sum_{i=1}^n w_{hi} (x_n - x_i)(y_n - y_i) \quad (5)$$

Here, we will use the probabilistic outcomes of Bayesian clustering as an input of variography in order to disentangle the complex spatial arrangement of urban fabrics. A network-constrained topological variogram is implemented where y_i represents the probability that a PB will be associated to a UF of class j , $p(PB_i = Class_j)$, while the weight matrix W is determined by network topological contiguities.

From empirical variograms applied to each probability distribution (Figure 2(d)), two pieces of information can be retained: the *range* is the distance at which data are no longer correlated. This informs us about the extent of each *urban fabric field* (similarly to the concept of *urban field* in Longley et al., 1991), which could be used to characterize homogeneous morphological regions made up of a single urban fabric type. The *sill* is calculated as the limit of the variogram tending to infinity distances and informs us about the relative compactness/dispersion of the spatial distribution of each urban fabric in the metropolitan area. Higher $\gamma(d)$ values detect strong dissimilarities between association probability values at a given distance d and they characterize those morphological regions with larger extents combined with spatial fluctuations (namely suburbs made of urban fabrics 5 and 6 but that integrate fragments of different types). Vice versa, smaller, compact spatial distribution are identified by lower $\gamma(d)$ values (as for UF 1, 2 and 3).

γ_{xy} cross-variograms inform us about the spatial co-variation of two urban fabric types at increasing distances. As Bayesian probabilities add up to one for each street segment, the resulting function γ_{xy} applied to each couple of urban fabrics is always negative. The relative distance from x-coordinates detects which urban fabrics surround the one analysed (x) at increasing distances. In see Supplemental Appendix Figure S7(b), for example, cross-variograms for the traditional urban fabric F1 are illustrated. This graphical representation of the relative spatial organization could answer three questions: (a) *which UF comes first when we leave UF1?* The order of $|\gamma_{xy}|$ represents the most probable UF to be found in the surrounding space at a given distance d from the UF studied (for UF1: UF2 and UF3 at small distances, UF5 at larger ones); (b) *at which distance are neighbouring UFs located?* The inverted bell described by γ_{xy} identifies the minimal and maximum radii of the disks where each UF will most probably be found; (c) *how similar is the analysed UF to the others?* The

max of $|\gamma_{xy}|$ is limited for similar urban fabrics. The connective urban fabric (UF7) is an exception. It is organized in the form of ribbons and does not produce patches or disks around other morphological regions.

The information extracted by variograms and cross-variograms helps analysts in the generalization of urban fabric organization of the study area. This results in a proposal of the archetypical model of urban settlements in the French Riviera (see Supplemental Appendix Figure 9; see Fusco and Araldi, 2017 for a more detailed description).

Conclusions and perspectives

This paper presented MFA, a new methodology for the analysis of the urban fabric, and showed how to exploit MFA results in the study of a vast metropolitan area. MFA is characterized by three main methodological innovations. First, the definition of morphological indicators for PBs, integrating the pedestrian point of view of the urban fabric. Second, geostatistical analysis is used to transform quantitative local measurements in categorical network-based patterns that are later used as inputs for clustering. Third, unlike more traditional approaches, Bayesian clustering considers specific subsets of indicators for each class identified. The method proved successful in the identification of urban fabrics and their spatial arrangements in the real-world case of the French Riviera metropolitan area.

Bayesian calculus was also used to assess the capacity of optimal subsets of morphological indicators to produce the same clustering results. The calculus cannot be used to identify missing variables. Only a qualitative assessment of results can provide hints in this direction. For example, the integration of vegetation into the characterization of urban forms could allow finer distinctions within urban and suburban fabrics. Another advantage of Bayesian clustering is its probabilistic content, which has been exploited in this analysis of spatial structures within the metropolitan area. Probabilities could also be used to assess uncertain characteristics of some urban fabrics and/or the uncertain assignment of street segments to urban fabrics.

The use of street PBs to study the urban fabric might bring new perspectives to the analysis of pedestrian-related phenomena. The contextual information resulting from MFA could represent the input for further analysis such as geographically weighted regression, hedonistic and multilevel modelling that is traditionally implemented in domains like walkability, retail, crime or environmental psychology.

The combination of geostatistics and Bayesian clustering represents an innovative procedure which is not limited to our definition of spatial units. These two approaches could also be applied to other spatial partitions, more appropriate for other research goals (i.e. block-, plot- or building-based partitions). This would allow traditional urban fabric analysis to integrate both the study of spatial heterogeneity of morphometric indicators and their specific combinations in defining urban forms.

In the second part of the paper, mathematical morphology and variography, both adapted to urban street networks, were implemented on MFA outcomes. These methods represent two valid procedures for a quantitative analysis of the spatial organization of urban fabrics. Several topics could be investigated, like compact city limits, urban fabric fields and arrangements within settlements. Through these procedures, MFA makes a contribution to the long-felt need for more clarity in the identification of morphological regions (Larkham and Morton, 2011).

In our analyses of the physical city's form, we drew a careful distinction between the study of the urban fabric and that of the configurational properties of street networks. MFA is devoted solely to the former. We envisage the convergence of the urban fabric analysis

and configurational analysis as a future research perspective to better understand urban space. After all, streets represent ‘the strongest and most familiar connection’ between these two approaches of urban morphology studies (Kropf, 2017). The street network-based partition of MFA shares the same primal representation as MCA in configurational studies. Their combination is therefore easily achievable. Some adaptation is needed when results from MFA and SSx are combined. This convergence could also be the most promising perspective in the study of form–function relations in urban space.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was carried out thanks to a research grant of the Nice Côte d’Azur Chamber of Commerce (CIFRE Agreement Number 2015/1478 with UMR ESPACE).

Notes

1. The set of indicators here presented could be adapted to the specificities and data availability of each case study: Araldi et al. (2018) presented new geoprocessing algorithms for indicators, showing the versatility and adaptability of the MFA method.
2. Going beyond this expert based-approach, Perez et al. (2018) proposed to identify building types through Bayesian clustering of building morphological descriptors.
3. In a more exploratory data-mining approach, multi-step Bayesian clustering with latent factors should be preferred to counter strong variable redundancy (Fusco, 2016).
4. In MFA, HL segments are normally associated to LL patterns and LH segments to HH patterns to integrate exceptional units within a neighbouring prevalent urban fabric.

Supplemental material

Supplemental material for this article is available online.

References

- Akaike H (1974) A new look at the statistical model identification. *Automatic Control IEEE Transactions* 19(6): 716–723.
- Alexander C, Neis H, Anninou A, et al. (1987) *A New Theory of Urban Design*. Oxford: Oxford University Press.
- Allain R (2004) *Morphologie Urbaine: Géographie, Aménagement et Architecture de la Ville*. Paris: Armand Collin.
- Anselin L (1995) Local indicators of spatial association. *Geographical Analysis* 27(2): 93–115.
- Araldi A and Fusco G (2016) Urban form from the pedestrian point of view: Spatial patterns on a street network. In: *INPUT 2016 proceedings*, Turin, pp.32–37. Available at: file:///D:/Downloads/INPUT2016_Conference_proceedings_Book%20(4).pdf (accessed 5 July 2018).
- Araldi A, Perez J, Fusco G, et al. (2018) Multiple fabric assessment: Focus on method versatility and flexibility. In: Gervasi O, et al. (eds) *Comput Science and Its Applications – ICCSA 2018, Part III, LCNS*. Springer, Cham, Vol. 10962, pp.251–267.
- Assunção RM and Reis EA (1999) A new proposal to adjust Moran’s I for population density. *Statistic in Medicine* 18: 2147–2162.
- Batty M (2007) Model cities. *Town Planning Review* 78(2): 125–151.

- Benediktsson, JA, Pesaresi M and Amason K (2003) Classification and feature extraction for remote sensing images from urban areas based on morphological transformations. *IEEE Transactions on Geoscience and Remote Sensing* 41(9): 1940–1949.
- Berghauser-Pont MY and Haupt P (2010) *SPACEMATRIX, Space, Density and Urban Form*. Rotterdam: NAI Publishers.
- Bernabé A, Calmet I, Musy M, et al. (2013) Classification automatique des tissus urbains par la méthode des nuées dynamiques. In: *31e Rencontres AUGC*, Cachan, France.
- Borie A and Denieul F (1984) Methode d'analyse morphologique des tissus urbains traditionnels. UNESCO. Available at: <http://unesdoc.unesco.org/images/0006/000623/062310fb.pdf> (accessed 26 September 2018).
- Caniggia G and Maffei G (1979) *Lettura Dell'edilizia di Base*. Firenze: Alinea.
- Castex J, Celeste P and Panerai P (1980) *Lecture D'une Ville: Versailles*. Paris: Moniteur.
- Chaudhry O and Mackaness WA (2008). Automatic identification of urban settlement boundaries for multiple representation databases. *Computer, Environment and Urban Systems* 32(2): 95–109.
- Conzen MRG (1960) *Alnwick, Northumberland: A Study in Town-Plan Analysis*. Institute of British Geographers Publication 27. London: George Philip.
- Cutini V, Petri M and Santucci A (2005) Dalla space syntax alla MaPPA: Un contributo per l'evoluzione dell'analisi configurazionale. In: Bruzzo A and Occelli S (eds) *Le Relazioni Tra Conoscenza e Innovazione Nello Sviluppo dei Territori*. Milano: Franco Angeli, pp.351–370.
- Dauphiné A and Voiron-Canicio C (1988) *Variogrammes et Structures Spatiales*. Montpellier: GIP Reclus.
- Dubey A, Naik N, Parikh D, et al. (2016) Deep learning the city: Quantifying urban perception at a global scale. In: *European conference on computer vision*, pp.196–212. Available at: <https://arxiv.org/pdf/1608.01769.pdf> (accessed 5 July 2018).
- Ewing R and Clemente O (2013) *Measuring Urban Design: Metrics for Livable Places*. Washington, DC: Island Press.
- Freeman L (1977) A set of measures of centrality based on betweenness. *Sociometry* 40(1): 35–41.
- Fusco G (2016) Beyond the built-up form/mobility relationship: Spatial affordance and lifestyles. *Computer, Environment and Urban Systems* 60: 50–66.
- Fusco G and Araldi A (2017) The nine forms of the French Riviera: Classifying urban fabrics from the pedestrian perspective. In: *ISUF2017*, Valencia, pp.1313–1325. Available at: <http://ocs.editorial.upv.es/index.php/ISUF/ISUF2017/paper/viewFile/5219/3567> (accessed 15 September 2018).
- Fusco G and Araldi A (2018) Significant patterns in urban form. Spatial analysis of morphological indicators. *Revue Internationale de Geomatique* 27(4): 455–479.
- Gehl J (2010) *Cities for People*. New York: Island Press.
- Gil J, Beirão JN, Montenegro N, et al. (2012) On the discovery of urban typologies: Data mining the many dimensions of urban form. *Urban Morphology* 16(1): 27–40.
- Graff P (2013) *Une Ville D'exception. Nice Dans L'effervescence du 20e Siècle*. Nice: Serre.
- Hallowell GD and Baran PK (2013). Suburban change: A time series approach to measuring form and spatial configuration. *The Journal of Space Syntax* 4(1): 74–91.
- Hamaina R, Leduc T and Moreau G (2013) A new method to characterize density adapted to coarse city model. In: *IF AND GIS 2013*, pp.249–263. Berlin: Springer.
- Harvey C and Aultman-Hall L (2016) Measuring urban streetscapes for livability: A review of approaches. *The Professional Geographer* 68(1): 149–158.
- Hermosilla T, et al. (2014) Using street-based metrics to characterize urban typologies. *Computer, Environment and Urban Systems* 44: 68–79.
- Hillier B (1996) *Space Is the Machine*. Cambridge: Cambridge University Press.
- Hillier B and Hanson J (1984) *The Social Logic of Space*. Cambridge: Cambridge University Press.
- Hillier B, Penn A, Hanson J, et al. (1993) Natural movement: Or, configuration and attraction in urban pedestrian movement. *Environment and Planning B* 20(1): 29–66.
- Hofmeister B (2004) The study of urban form in Germany. *Urban Morphology* 8: 3–12.
- Jacobs J (1961) *The Death and Life of Great American Cities*. New York: Random House.

- Jiang B, Yin J and Liu Q (2015) Zipf's law for all the natural cities around the world. *International Journal of Geographical Information Science* 29(3): 498–522.
- Kropf K (2017) Bridging configurational and urban tissue analysis. In: *Proc. 11th space syntax symposium*, Lisbon, p. 165, 1–13. Available at: <http://www.11ssslisbon.pt/docs/proceedings/papers/165.pdf> (accessed 22 October 2018).
- Kruger M (1977) *An approach to built form connectivity at an urban scale*. PhD Thesis, University of Cambridge, UK.
- Larkham PJ and Morton N (2011) Drawing lines on maps: Morphological regions and planning practices. *Urban Morphology* 15(2): 133–151.
- Leduc T and Chauvat G (2015) Étude comparée de quatre indicateurs qualifiant le champ visuel d'un piéton en milieu urbain. *Revue Internationale de Géomatique* 25(1): 75–98.
- Legendre P and Legendre L (1998) *Numerical Ecology*. Vol. 24. Developments in Environmental Modelling. Amsterdam, Netherlands: Elsevier Scientific Publication Corporation.
- Lévy A (2005) Formes urbaines et significations: Revisiter la morphologie urbaine. *Espace et Sociétés* 122: 25–48.
- Long N and Kergomard C (2005) Classification morphologique du tissu urbain pour des applications climatologiques. *Revue Internationale de Géomatique* 15(14): 487–512.
- Longley P, Batty M and Shepherd J (1991) The size, shape and dimension of urban settlements. *Transactions of the Institute of British Geographers* 16(1): 75–94.
- Longley P, Batty M, Shepherd J, et al. (1992) Do green belts change the shape of urban areas? *Regional Studies* 26(5): 437–452.
- Lynch K (1960) *The Image of the City*. Cambridge: MIT Press.
- Marshall S (2012) Science, pseudo-science and urban design. *Urban Design International* 17(4): 257–271.
- Matheron G (1965) *Les Variables Régionalisées et leur Estimation*. Doctoral Dissertation. Masson et Cie, Paris.
- Muratori S (1959) *Studi per Una Operante Storia di Venezia*. Rome: Ist. Poligrafico dello Stato.
- Nguyen L and Teller J (2017) Color in the urban environment: A user-oriented protocol for chromatic characterization and the development of a parametric typology. *Color Research & Application* 42(1): 131–142.
- Okabe A and Sugihara K (2012) *Spatial Analysis Along Networks: Statistical and Computational Methods*. Hoboken, NJ: John Wiley & Sons.
- Oliveira EA, Furtado V, Andrade JS, et al. (2018) A worldwide model for boundaries of urban settlements. *Royal Society Open Science* 5(5): 180468.
- Parr JB (2007) Spatial definitions of the city: Four perspectives. *Urban Studies* 44(2): 381–392.
- Perez J, Fusco G, Araldi A, et al. (2018) Building typologies for urban fabric classification: Osaka and Marseille case studies. In: *First international conference on spatial analysis and modeling*, Tokyo, 8–9 September 2018, pp.1–13. Available at: <http://ua.t.u-tokyo.ac.jp/sam2018/abstract/A-1-5> (accessed 10 November 2018).
- Pinon P (1991) *Lire et Composer L'espace Public*. Paris: DAU-STU.
- Porta S, Crucitti P and Latora V (2006) The network analysis of urban streets: A primal approach. *Environment and Planning B* 33(5): 705–725.
- Puissant A, Lachiche N and Skupinski G (2010) Classification des tissus urbains à partir de données vectorielles. In: *SAGEO 2010 proceedings*, Toulouse, pp.198–211. Available at: http://sageo10.univ-toulouse.fr/IMG/pdf/SAGEO10_Toulouse_ACTES_MonteilPaegelowEds.pdf (accessed 10 November 2018).
- Rozenfeld HD, Rybski D and Andrade JS (2008) Laws of population growth. *Proceedings of the National Academy of Sciences* 105(48): 18702–18707.
- Sevtsuk A (2014) Location and agglomeration: The distribution of retail and food businesses in dense urban environments. *Journal of Planning Education and Research* 34(4): 374–393.
- Sevtsuk A and Mekonnen M (2012) Urban network analysis. *Revue Internationale de Géomatique* 22(2): 287–305.

- Steadman P (1983) *Architectural Morphology: An Introduction to the Geometry of Building Plans*. Milton Park: Taylor & Francis.
- Talen E (2011) The geospatial dimension in urban design. *Journal of Urban Design* 16(1): 127–149.
- Tannier C, Thomas I, Vuidel G, et al. (2011) A fractal approach to identifying urban boundaries. *Geographical Analysis* 43(2): 211–227.
- Turner A (2007) From axial to road-centre lines: A new representation for space syntax. *Environment and Planning B* 34(3): 539–555.
- Vernez-Moudon A (1997) Urban morphology as an emerging interdisciplinary field. *Urban Morphology* 1: 3–10.
- Vialard A (2013) *A typology of block-faces*. PhD Dissertation, Georgia Institute of Technology, USA. Available at: <https://smartech.gatech.edu/handle/1853/52182> (accessed 7 January 2018).
- Yamada I and Thill JC (2010) Local indicators of network-constrained clusters in spatial patterns represented by a link attribute. *Annals of the Association of American Geographers* 100(2): 269–285.
- Ye Y and Van Nes A (2014) Quantitative tools in urban morphology: Combining space syntax, spacematrix and mixed-use index in a GIS framework. *Urban Morphology* 18(2): 97–118.

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#4 - ARTICLE

VACANT LANDS ON FRENCH MEDITERRANEAN COASTLINES: INVENTORY, AGRICULTURAL OPPORTUNITIES, AND PROSPECTIVE SCENARIOS

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2021, *Land Use Policy*, Volume 100, 2021, 104914, ISSN 0264-8377

<https://doi.org/10.1016/j.landusepol.2020.104914>

Cet article propose une méthodologie originale d'élaboration de scénarios de prospective territoriale alternatifs au modèle de développement touristique-résidentiel à l'œuvre sur le littoral méditerranéen. L'article étudie précisément les deux intercommunalités varoises de Toulon Provence Métropole (TPM¹⁵) et du Golfe de Saint-Tropez (GST¹⁶). Ces territoires sont concernés par une forte attractivité touristique-résidentielle qui a pour conséquence une dynamique soutenue d'artificialisation des espaces, réalisée préférentiellement en extension résidentielle (500 ha artificialisés au sein de TPM entre 2003 et 2011, 750 ha artificialisés au sein de GST entre 2003 et 2014). Ce modèle de développement touristique-résidentiel, par la surexploitation des ressources et les rejets qu'il induit, contribue à la fragilisation de l'écosystème littoral et à la perte irréversible d'espaces agricoles et naturels. Or, des alternatives sont possibles à la condition qu'elles soient soutenues par des politiques publiques volontaristes en la matière.

Cet article s'inscrit dans le projet scientifique de l'action de recherche intersites « Littoral » et est issu du programme « DURB¹⁷ » (*La dépendance à l'urbanisation des territoires littoraux : existe-t-il des alternatives au tout résidentiel ?*) dirigé par Guilhem Boulay, UMR ESPACE et conduit de 2017 à 2019.

L'originalité de l'article réside dans la méthodologie mise en œuvre. **Premièrement**, une méthode a été développée pour identifier les gisements fonciers au sein des deux intercommunalités étudiées à partir d'une exploitation des données des Fichiers Fonciers (CEREMA¹⁸) à l'échelle de la parcelle cadastrale. **Deuxièmement**, la qualification de l'opportunité de valorisation du gisement foncier pour une valorisation agricole a été établie, à partir d'une méthode mixte fondée sur l'analyse des caractéristiques des parcelles à partir d'un jeu d'indicateurs spatiaux et sur une analyse à dire d'experts. **Troisièmement**, des scénarios prospectifs spatialisés ont été élaborés selon une approche multi-échelles : à partir du choix d'un modèle de développement agricole à l'échelle du territoire (maraîchage et horticulture en circuit-court, mixité entre viticulture et arboriculture), ont été sélectionnées les parcelles susceptibles de répondre au mieux à ce projet. La réflexion s'est appuyée sur deux opérations de concertation : l'une menée dans le cadre de travaux dirigés du master 2 GEOTER¹⁹ d'Avignon Université (promotion 2018-2019), l'autre menée dans le cadre d'ateliers de concertation avec des acteurs locaux, dont la démarche et les enseignements ont été restitués dans un article paru dans la revue *Netcom*²⁰ en 2022. La spatialisation des scénarios donne à voir une image future possible de ces territoires, qui pourrait se concrétiser si les décideurs locaux décidaient de mener une action volontariste en faveur d'un développement territorial plus soutenable. **Enfin**, les retombées socio-économiques de chaque scénario ont été mesurées à travers trois indicateurs évaluant les impacts en matière de création de surfaces agricoles cultivées, de création d'emplois dans ce secteur, et de retombées économiques issues des productions agricoles.

Cette publication témoigne par ailleurs de l'étroite collaboration de recherche menée avec l'INRAE²¹, par l'intermédiaire de Marta Debolini, chargée de recherche à l'INRAE, membre du projet DURB et co-auteur de l'article. L'article montre également la capacité du laboratoire à intégrer des jeunes diplômés de Master dans un projet de recherche et une publication internationale dans une revue de référence en géographie.

Cette publication constitue un jalon important de la recherche du laboratoire ESPACE dans trois domaines clés que sont le développement territorial des littoraux méditerranéens, l'élaboration de scénarios prospectifs spatialisés et l'analyse des dynamiques du foncier et de l'immobilier.

¹⁵ <https://metropoletpm.fr/>

¹⁶ <https://www.cc-golfedesainttropez.fr/>

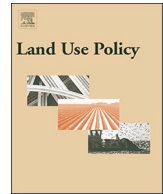
¹⁷ <http://www.ohm-littoral-mediterraneen.fr/spip.php?article223>

¹⁸ <https://www.cerema.fr/fr>

¹⁹ <https://univ-avignon.fr/rechercher-une-formation/master-geographie-geomatique-et-projets-territoriaux-1258.kjsp>

²⁰ <https://journals.openedition.org/netcom/>

²¹ <https://www6.paca.inrae.fr/emmah/>



Vacant lands on French Mediterranean coastlines: Inventory, agricultural opportunities, and prospective scenarios



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ARTICLE INFO

Keywords:

Littoral areas
Urbanization
Land planning
Agriculture potential
Var department
Prospective scenarios
Spatial analysis

ABSTRACT

Mediterranean coastlines are undergoing a strong process of urbanization due not only to demographic growth, but also to the development of tourism. Moreover, municipalities have become more dependent on residential tax income, which creates a vicious circle for local urban planning. The Var department, in south-eastern France, can be considered as a relevant example of these dynamics, where residential urban sprawl is threatening existing vacant lands. At the same time, most of these territories still have a high natural value and agricultural potential. In this paper, we describe our inventory of vacant lands on a large territory (two intermunicipalities, which include 24 municipalities) at parcel scale, to give an innovative assessment of this phenomenon. We investigated non-residential development possibilities for existing vacant lands through possible pathways for sustainable planning projects. In particular, the impacts of increases in agricultural spaces were explored in the normative scenarios and were measured through socio-economic indexes. This work shows that there is still a large amount of vacant land (23.5% and 37% respectively for the two case studies) with different opportunities for agricultural valorization. It had to be taken into account that these lands are often on the fringe of urban areas, where the urbanization process is stronger. The possible alternative scenarios suggested here can be used as examples for policy makers, to encourage a different point of view regarding land use planning.

1. Introduction

1.1. MedCoast urban background

Mediterranean coastlines (hereafter MedCoast) have been experiencing strong, rapid urbanization during the last decades, partly due to demographic growth (from 90 million in 1950 to 290 million in 2005), and also related to urban and tourism development (UNEP, 2012; Burak et al., 2004). The Mediterranean area is also considered as a biodiversity hotspot (Cuttelod et al., 2008). Given the fact that an irreversible decrease in this resource is expected in response to climate change (see IPCC, 2014; Malcolm et al., 2006), attention has to be paid to the growing areas of artificialized lands (France Stratégie, 2019), which represent an additional threat to natural resources (Narducci et al., 2019; García-Ayllón, 2018b; Holon et al., 2015). While around 40 % of the MedCoast area is estimated to be artificialized in terms of land cover (UNEP, 2017), a major part of this is due to scattered residential urbanization. Urban sprawl has progressively increased in all European countries since the 1970s (Lagarias and Sayas, 2019; Salvati et al., 2013; Catalán et al., 2008; Kasanko et al., 2006), mainly at the expense

of agricultural areas, and has led to fragmentation of the rural mosaic (e.g. Debolini et al., 2018; Aksoy et al., 2017; Salvati 2019; Salvati et al., 2012). In France, despite protective legislation for coastlines (Le Berre, 2016) and urban densification policies (to preserve both traditional city centers and natural lands), wide urban sprawl has developed (Pumain, 2004), and this process is continuing (Melot et al., 2018).

Nowadays, MedCoast areas are under pressure from different conflicting interests. This pressure is the main cause of land use competition, leading to land price rises and even to the subsequent exclusion of some social categories from land access (García-Ayllón, 2015; Coskun Hepcan, 2013). This competition has always favoured of urban residential use, because of the differential soil rent (Dachary-Bernard et al., 2011). For these reasons, MedCoast municipalities have progressively become more dependent on residential taxes (Grandclement and Boulay, 2016), with local policy makers increasingly interested in urban residential development (Membrado et al., 2016; Chabert, 2016). Urbanization is mainly taking place on natural or agricultural spaces, even though there is usually an officially-proclaimed intention to maintain them (Colsaet et al., 2018; Prévost and Robert, 2016; Padeiro, 2016; Abrantes et al., 2016). Such an urban residential development

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implies an economic specialization, mainly in the local services sector, which can destabilize the local economy if there is a disruption of the tourist, retiree or commuter flux (Davezies, 2009; Spilanis, 2009). We have therefore studied alternative territorial development with agriculture. It has been recognized that agriculture is a lever of local sustainable development which can facilitate the reinjection of productive activities on the coast (Ragkos and Theodoridis, 2016; Blandford, 2011; Benoit and Comeau, 2005), give local employment (Nicholls et al., 2020), provide ecosystem services (Ricart et al., 2019), and also improve local food security (Filippini et al., 2018; Zezza and Tasciotti, 2010). Moreover, agriculture has been identified as one of the key sectors for preserving and restoring European natural capital on the recently released documents for a European Green deal and the Biodiversity strategy for 2030. The European strategy underline the importance of agricultural sustainable practice for improving environmental and climate performance and the need to support rural development to help rural areas to harness opportunities in the circular and bio-economy through “farm to fork” initiatives (EC, 2019; EC, 2020). Thus, there is a growing interest in the remaining places where agriculture is possible, and the type of agricultural projects that could be developed in coastline areas under pressure.

1.2. Vacant lands inventory and valorization

In the literature, three different definitions of vacant lands can be found. They can be unbuilt constructible lands with potential for housing construction and urban densification (Saiz, 2010). Secondly, they can also be defined as unbuilt lands (constructible or not) currently unused or abandoned (e.g. brownfields, transportation-related sites), located in urban areas (mainly in the form of small residual plots) with a low value on the property markets (Gedal and Ellen, 2018). Since the 2000s, studies in this field have shown how cities deal with vacant lands through different urban renewal projects (Kim et al., 2018; Németh and Langhorst, 2014), including transforming vacant lands into productive ones (e.g. Sanches and Mesquita Pellegrino, 2016; Kim et al., 2015). This means a valorization of vacant lands in terms of re-development (e.g. for urban gardening or urban agriculture) to set up urban renewal and thus with impacts expected on the limitation of urban sprawl, and also to avoid city decline (Goldstein et al., 2001). Thirdly, studies focusing on agricultural land suitability analysis usually undertake a vacant lands inventory in order to assess the possible development of urban farming (Mcdougall et al., 2020; McClintock et al., 2013; Erickson et al., 2013). For the majority of them, the starting point is however the analysis of soil quality data (rather than land-use data) for specific crops, and the lands are located within agricultural zones (e.g. Seyedmohammadi et al., 2019 - study on barley cultivation).

In this paper, we lie at the intersection of the three definitions and we propose then a specific one. With the term “vacant lands”, we mean all the lands not currently occupied by urbanization and which do not need specific treatment to be developed, such as demolition or decontamination. They need to be exploitable according to geographical (e.g. land-use), physical (e.g. excluding steep slopes), and some regulatory criteria (e.g. excluding military areas). They thus include uncultivated lands, natural and forest areas, and urban wastelands. We considered vacant lands in the broad sense of available lands, without taking into account temporary constraints of non-availability (e.g. local planning documents, land ownership etc.). The field of study developed at a very local scale in an urban context was thus enlarged to go beyond the urban areas, and the concept of vacant lands was applied to an extended territory. In this context and in order to improve sustainable planning and development of the MedCoast, we attempted to answer the following main research questions: what are the possibilities for vacant land valorization other than by residential use, and which territorial scenarios of agricultural development could be explored, depending on the agricultural opportunities of existing vacant lands? We

considered the term agricultural opportunities as the type and level of agricultural production possibly suitable for vacant lands, according to Erickson et al. (2013). These questions were investigated in two coastal areas in southern France, both characterized by a rising demographic pressure, a strong residential- and tourism-based economy, and an environmental heritage.

Land use scenarios have been widely applied to help decision makers in anticipating the future. In methodological terms, land use transformation models have mainly been employed for scenario simulations, using past land use transitions to study the location and/or the nature of future changes (Vannier et al., 2019; Sinha and Griffith, 2019; Lee et al., 2018; Loubier et al., 2017; Houet et al., 2016; Gutiérrez Angonese and Grau, 2014). Other scenarios have been built from a geostatistical approach which gives an important place to landscape spatial patterns (e.g. García-Ayllón, 2018a, 2018b). In this field, some pro-agricultural scenarios have been developed (e.g. Rega et al., 2019; Rounsevell et al., 2006; Iverson Nassauer and Corry, 2004; Abrantes et al., 2017) to study alternatives to urban and periurban dynamic continuation. Estimations of the urban agricultural potential of cities to provide a local food supply have also been developed (Mcdougall et al., 2020; McClintock et al., 2013), deepening existing works on the agricultural potential of vacant lands (Sanches and Mesquita Pellegrino, 2016; Erickson et al., 2013). In line with these previous works, our study assessed vacant lands from a GIS-based inventory and a spatial and expert analysis of their suitability for agricultural production. In addition, spatialized normative scenarios for sustainable agriculture were built, and include a co-constructive approach with stakeholders and researchers. They studied both which agricultural system types could arise in the future and what spatial implementation of the scenario could be possible. Territorial scenarios were quantified and mapped, and their impacts were measured through socio-economic indexes.

2. Study areas

The two areas studied are located in the South of France, in the Var department.

The first is the inter-municipality of Toulon Provence Méditerranée (hereafter TPM). This territory includes twelve municipalities and had about 431 000 inhabitants in 2015 (INSEE). It is the third largest metropolitan area of the region. TPM has had a huge increase in its urban areas, which doubled in the 40 years between 1970 and 2010 (Syndicat Mixte Provence Méditerranée, 2009). Today, much of the territory is covered by urban areas (40 % in 2011), and the urban sprawl - although slowing down - is still ongoing, at a rate of +3.8 % (512.6 ha) between 2003 and 2011 (Table 1). Most of this urban sprawl is at the expense of agricultural areas (70 %, or 359 ha, of new artificialized spaces in 2011 were agricultural until between 2003 and 2011), and as a result, agricultural land is continually shrinking and becoming more fragmented.

Table 1

Main characteristics of the two case study areas: Toulon Provence Metropole (TPM) and Golfe de Saint Tropez (GST). The years of the land use data are not the same for our two case studies. The TPM territory has land use data for the years 2003 to 2011, while for the GST intermunicipality territory the data concerns the years 2003 to 2014. To be able to compare the evolutions of the two territories, we used average annual growth rates.

Indicators	TPM	GST
Area of the zones studied	37 224 ha	43 395 ha
Urban areas in 2011/2014	40 %	17 %
Agricultural areas 2011/2014	16.7%	10 %
New urban areas between 2003 and 2011/2014	+ 3.8 %	+ 11.2 %
Average annual growth rate of urban areas	+ 0.47 %	+ 0.97 %
Average annual area of new urbanization	64 ha	67.5 ha
New urban areas which were agricultural in 2003	70 %	26 %

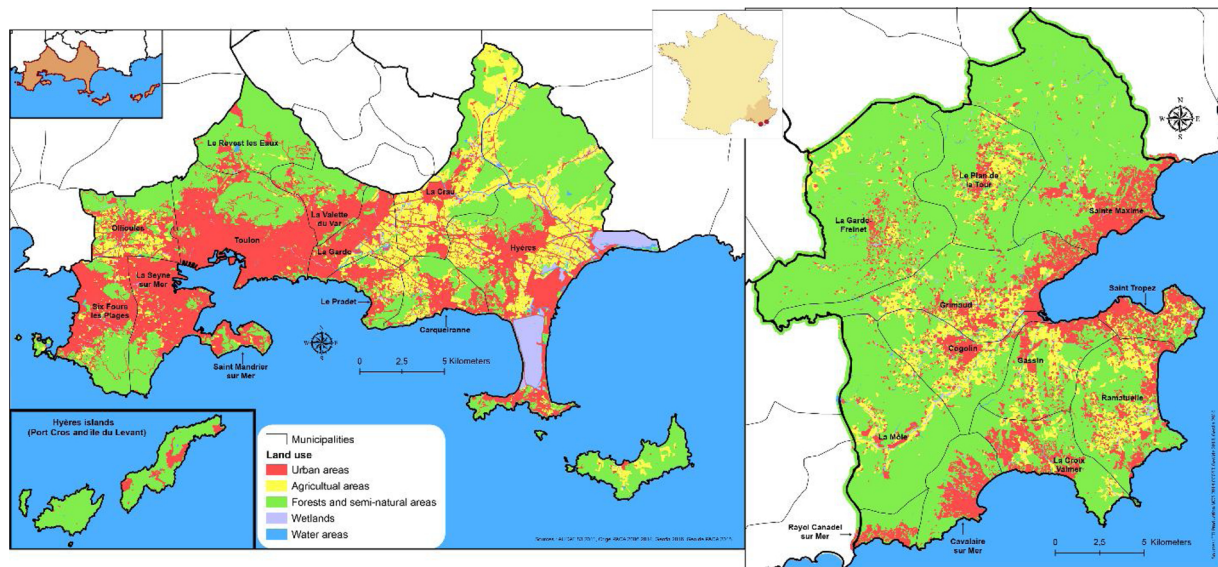


Fig. 1. Locations of the two case studies.

Nevertheless, despite the size of its urban areas and their growth, TPM is attractive to tourists with 84 500 additional people in 2011 (Syndicat Mixte Provence Méditerranée, 2009). At present, some areas are protected (former saline zones, wetlands, classified woodlands) and the coastline is attractive, even if a part is reserved for military activities. Therefore, this case study is an example of a metropolitan littoral territory, which must strike a balance between hosting or housing its tourists and the permanent population, and preserving its natural and agricultural areas.

The second area is the inter-municipality called “Golfe de Saint-Tropez”, the Saint-Tropez Gulf. Located to the east of TPM, this territory also includes twelve municipalities but had only 57,600 inhabitants in 2015 (INSEE). Nevertheless, even if the urban areas represent only 17 % of the territory, the urban sprawl development has been greater than that of TPM, with an average annual growth rate of +0.97 % (+0.47 % compared to TPM). Between 2003 and 2014, 743 ha of new urban areas appeared. This urban growth could be explained in part by the high attractiveness of this territory for tourists. In the peak season, the population of the inter-municipality is multiplied by four (Communauté de communes du Golfe de Saint Tropez, 2019). The Gulf of Saint-Tropez is a highly popular destination, with its 70 km of coastline, its large forested areas (the Maures massif) and its typical local agriculture. Natural areas make up more than 70 % of the territory, including agricultural areas which are dominated by vineyards (62 %). Nevertheless, these areas are being increasingly gained by urbanization. Our case studies are therefore good examples of a touristic littoral territory with a high residential development rate, which must be controlled as there is a significant risk of landscape degradation. Both case study areas have suffered over recent decades from an increasing land consumption due to the progressive shift of the local economy toward the tourism and residential accommodation sectors.

The inter-municipality level was chosen because it is currently the most relevant in terms of planning, linking municipal and regional scales of governance, and it is where the agricultural orientations are defined. Moreover, it is an intermediate level between the micro scale of the municipality and the bigger department scale. The two case study areas were also chosen because of the residual presence of productive agriculture. Table 1 shows the main land use characteristics of the areas studied, and Fig. 1 shows their location.

3. Material and methods

In this work, a GIS-based inventory of vacant lands was carried out at parcel scale over a vast territory. Classification tools based on a scoring analysis and on a multivariate statistical analysis (AHC) were then applied, in order to prioritize the interest of lands for an agricultural valorization according to a set of geographical, morphological, and regulatory criteria, which defined agricultural opportunities. This methodological part is in line with the work of Sanches and Mesquita Pellegrino (2016), and Erickson et al. (2013). Looking ahead, prospective scenarios were then built (Pérez-Soba and Maas, 2015; Börjeson et al., 2006) to show decision makers potential pathways for alternatives to residential use for future territorial developments. Considering the high urbanization threat to agricultural lands, confirmed by trend scenarios (e.g. Rounsevell et al., 2006), normative scenarios concerning sustainable planning projects were favoured. They are built in a combined quantitative and qualitative approach. A spatial analysis method operationalized the hypothesis of agricultural expansion on the vacant lands of the two case studies. An expert approach was employed to define future agricultural systems. The method was aligned with spatial prospective approaches (Gourmelon et al., 2012; Casanova and Helle, 2012) and integrate a concerted process between researchers, local stakeholders, and students (Vannier et al., 2019; Abrantes et al., 2017; Maestripietri et al., 2017; Iverson Nassauer and Corry, 2004; Loubier et al., 2017). Such an approach fosters creativity within the limits of possible new planning strategies (e.g. depending on the suitability of vacant lands).

GIS queries based on a set of parcel scale geographical data were carried out first to inventory vacant lands (Fig. 2; Step1). The starting point was the identification of all the existing whole or part(s) of parcels potentially available in purely land use terms (corresponding to the non-urban areas). Then, all the possible factors excluding the use of these lands for agriculture were considered, such as morphological factors (e.g. slope) or regulatory aspects (e.g. environmentally protected areas, military areas). The existing regulatory measures in local planning documents were deliberately not taken into account, since the aim of the work was to provide alternatives to current planning, and also because the documents can be changed over time. For example, at the municipal scale planning is based on a document which can be

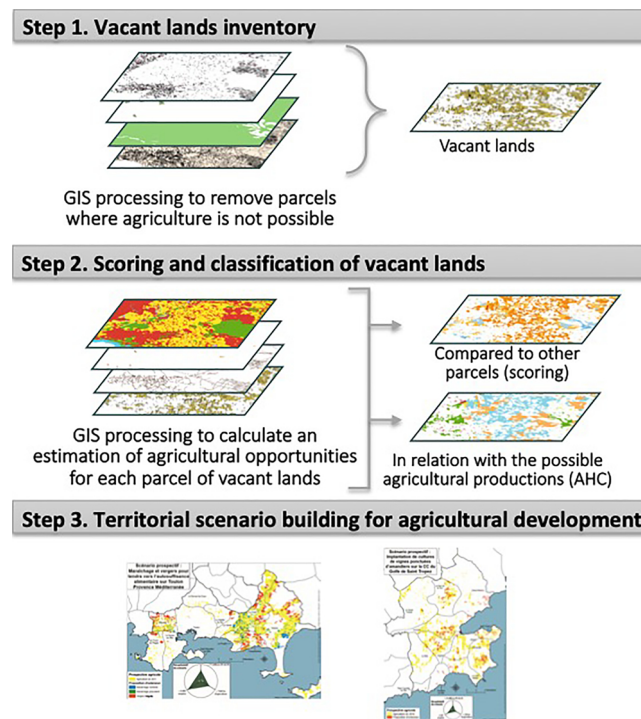


Fig. 2. The overall methodological workflow. Each step is detailed in the following sections.

revised three years after its initial approval. At the inter-municipal scale, land use planning is based on a document revisable every six years. Through these GIS queries, we obtained an overall inventory of vacant lands.

The agricultural opportunities for the vacant lands were estimated next (Fig. 2; Step2). For this, we made two classifications: the first provides a scoring of vacant land parcels in order to evaluate their agricultural potential; the second, based on an Ascending Hierarchical Classification (AHC), clusters profiles of parcels in terms of their spatial characteristics. The results give indications as to the spectrum of possible future agricultural developments in the territories.

In order to explore these possibilities for the future, we used the results of the two classifications in a third step to build possible future territorial scenarios, fitting in sustainable agricultural development. The scenarios, one for each case study (Fig. 2; Step 3), are proposed as examples of the possible applications of this work for policy makers.

3.1. Datasets

3.1.1. Cadaster dataset

The cadaster, or land registry, dataset gives an annual overview of property ownership. This data is used by the French government services for fiscal purposes. It therefore includes full and precise information concerning land ownership for unbuilt or built property (DGALN-AD3 - CEREMA Nord-Picardie, 2017). We particularly focused on the parcel map and on data concerning landowners and householders (e.g. number of owners, public or private status), land use, and building types (e.g. flat, house, industrial or commercial buildings).

The intersections of the data provide detailed geospatial information on urbanization processes (ownership changes, construction pace etc.).

3.1.2. Land use and planning datasets

In addition to the cadaster dataset - the reference data for the study - other geographical datasets were included in the analysis to complete

the information about land use, topography, agricultural systems, and planning. Table 2 shows the complete dataset list.

3.2. Inventory of vacant lands suitable for agricultural use

As agriculture cannot be developed on all vacant lands, we analyzed vacant land parcel characteristics based on a set of exclusion constraints corresponding to major obstacles to agricultural valorization. Six main exclusion constraints were selected. Cultivated lands were included, to assess (and show to decision makers) the interest of maintaining them for agricultural use. Constraints were defined by the researchers and shared with experts from the regional and local public planning institutions specialized either in agricultural, rural, or urban land management, or in overall intermunicipality planning. The exclusion constraints identified were: (1) slope > 35 %, (2) inclusion in a military area, (3) inclusion in a protected environment area, (4) intersection with an ICPE (see Fig. 2), (5) intersection with built-up areas, streets, or cemeteries, and (6) parcel or parcel aggregation dimension < 200 m². Fig. 3 summarizes the exclusion factors. Once these exclusion constraints were defined, the spatial dataset was processed to remove the vacant land parcels where agriculture is not possible. An additional GIS analysis was done to remove residual errors, especially those related to the morphology of parcels. In particular, we aimed to eliminate plots with a very slender shape, unsuitable for agriculture, which in the majority of cases correspond to residual portions of private roads (public roads are not mapped in the cadaster plan). To do this, a compactness coefficient (first given by Gravelius and often used in hydrology studies) was applied, and calculated as follows: $K = 0.28 * (P/\sqrt{A})$, where P is the perimeter of the plot given in meters and A the surface area of the plot given in m². The closer the K value is to 1, the closer its shape is to a circle. The higher it is than 1, the longer and more slender its shape is. In accordance with empirical test validations (including comparisons with orthophotos), a threshold of 2.2 was applied to remove these linear plots.

Table 2
List of datasets used for vacant land identification and classification.

Name of data	Source	Date	Metadata complement
Digital Terrain Model	IGN	2008	
Land use of the PACA region	CRIGE PACA	2006	Scale of interpretation 1:25 000 to 1:50 000
Land use	AUDAT Var	2014	
Land use in the area of the Gulf of St-Tropez	TTI Production via CRIGE PACA	2011 ^a	Scale of interpretation 1:1 500 to 1:3 000
Irrigable perimeters of the Canal of Provence Company	Canal of Provence Company via CRIGE PACA	2014	Scale of interpretation 1:1 500 to 1:3 000
Others irrigable perimeters	Base Hydra of the Regional Agricultural Chamber	2016	
Environmental zoning	Geoide PACA	2014	
Military areas	Open Street Map	2018	
Installations Classified for the Protection of the Environment (ICPE)	Geoide PACA	2018	It contains the Decrees for the Protection of Biotopes, wetlands, Sensitive Natural Areas and some Conservatory of Natural Spaces estates.
Areas submitted to a clearance authorization	DDTM 83	2018	Buildings with potentially negative environmental and/or human health risk or impact
Roads	Open Street Map	2017	In these areas authorization must be requested before deforestation.
Local markets	New layer	2018	The roads were extracted from OSM and processed with the Grass tools (cleaning, reconnection).
Cooperatives	New layer	2018	The market locations were found on different web sites, and then compiled and put in a vector format.
			The cooperative locations were found on the web site “coopdefrance”, and then put in a vector format.

^a Access to the 2014 version was denied to our research group because the dataset producer considered that the information contained in the dataset was too sensitive in policy terms.

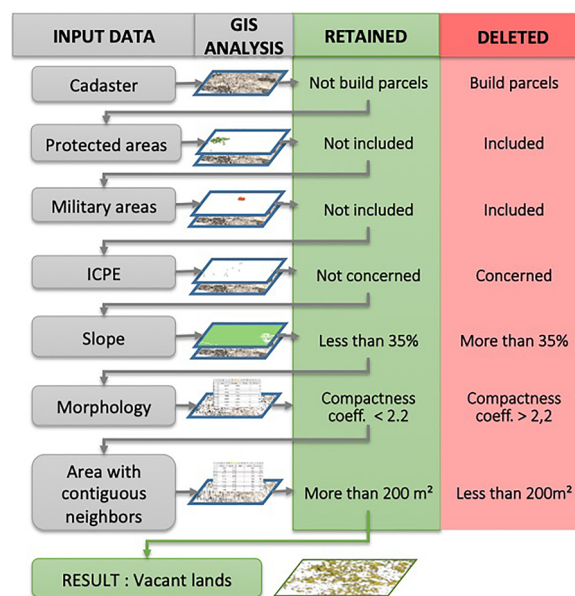


Fig. 3. Exclusion constraints for agricultural valorization of vacant lands.

3.3. Scoring and classification of vacant lands for agricultural opportunities estimation

In order to prioritize vacant lands in terms of their opportunities for agricultural valorization, we considered a set of geographical, morphological, and regulatory criteria. When the criteria results are not significant, agriculture can still be developed but its potential is reduced (requiring, for example, parcel remodeling or adapting farming practices). As above, we used an expert-based method to define our nine criteria, which were assessed through GIS at parcel scale (Fig. 4).

Each criterion category concerning vacant land spatial distribution characteristics, land use, and parcel facilities for an agricultural activity, refers to a quantitative value or a qualitative modality, which was then converted into a score. In order to estimate the level of agricultural opportunities for a vacant land parcel, a value was assigned

for each criterion, which all had the same weight: values range from 1, the least suitable lands, to 3, the most suitable. For each parcel, the allocation of a quantitative value or a qualitative modality to a score value was respectively determined by the classes defined in the statistical distribution (i.e. classes of equal intervals) and by an expert decision.

Table 3 summarizes the list of criteria selected and their values. The values were then totaled for each parcel to obtain a global score for parcel agricultural opportunities. Results were next converted into a center-reduced standardization depending on the standard deviations, to highlight parcels with the highest potential (thus, values between the two case studies refer to different orders of magnitude, and are not directly comparable).

In parallel, using an Ascending Hierarchical Classification (AHC), parcels were clustered into different classes of agricultural

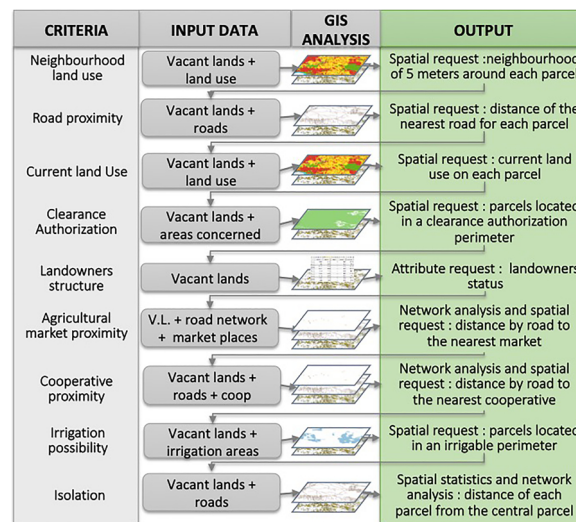


Fig. 4. Spatial analysis methods for criteria calculation.

Table 3
Scoring parameters and settings for the estimation of parcel agricultural opportunities.

Criteria Score	1	2	3
Current Land use	Urban area only	Natural area/wetlands	Agricultural area
Neighborhood land use	Urban area only	Natural area/wetlands but no agriculture	Agricultural area
Road proximity	More than 100m	50 m to 100m	Less than 50m
Agricultural market proximity	Isochron > 20min	10 min to 20min	Less than 10min
Cooperative proximity	More than 20min	10 min to 20min	Less than 10min
Isolation (distance from the central parcel)	More than 20km	10km to 20km	Less than 10km
Clearance authorization	Submitted	/	Not submitted
Irrigation possibility	No	/	Yes
Landowners' structure	Multi-private landowners	Mono-private landowner	Public landowners

opportunities. The classification was based on the same criteria as those defined for Fig. 4 (without taking into account the scoring step). Thus, this classification provides an overview of the agricultural production possible in each cluster.

Finally, we examined the possible threat which urban and suburban fronts represent for the vacant lands which offer the highest opportunities for an agricultural valorization. We carried out a proximity analysis of the newly artificialized spaces compared to the vacant lands with a score higher than 1. This analysis intends to draw the attention of decision makers to the urgent need to protect prime farmlands.

3.4. Territorial scenario building for agricultural development

In order to show the possible usefulness of this study for policy makers, we built two possible future agricultural development scenarios, one for each case study. The two criteria that we applied in order to build these scenarios were (1) the main agricultural system already existing in the area (existing crops, productive orientation, distribution chain already active, etc.), and (2) the environmental sustainability of the whole system. The links between the current agricultural system in the case study areas and the future possibilities explored in the normative scenarios are detailed in Table 4 below.

For instance, we selected a possible agricultural system which involved the greatest preservation of the forest cover and the optimum utilization of the water resource. The two scenarios were built in collaboration with a group of students and researchers, and with the preliminary advice of local stakeholders. Researchers then defined the normative hypotheses of the prospective scenarios which provide for sustainable agricultural development. Then, using collaborative GIS tools, students and researchers detailed and spatialized scenarios for each case study during workshops.

Spatial analysis methods were applied to the vacant land inventory in order to select the most suitable lands for the scenario's agricultural project. Then the impacts of the scenarios in terms of territorial development were estimated for the three following criteria: agricultural employment generated, added economic resources, and agricultural cover extension. These criteria were evaluated using national statistics for agricultural prices and also agricultural statistics for job increase evaluation (Table 5). In particular, the average number of jobs per hectare by crop type and the average added value per hectare by crop type (in France) were used. Then the new crop type distribution and the new agricultural area added (from current vacant lands) in the scenarios were converted into agricultural jobs and added economic resources for the territory.

Table 4
Relationships between the current agricultural system and the prospective agricultural scenarios proposed.

	Main economic sector (% of firms in the sector in 2015, INSEE)	Main agricultural production (% of areas farmed in 2010, SCOT)	Main distribution channel	Other agricultural production	Weakness of the agricultural system	Main local agricultural policy	Scenario for a sustainable local agriculture
GST agricultural system	Trade, transport and services: 73 % of firms (Agriculture: 2.7 % of firms)	Vineyards: 82 % Quality labels	National / international export	Olive growing Market gardening Forestry	Export dependency Competition between vineyards and small local farming Fewer farmers Deficiency of irrigation system	Agricultural landscape conservation Short supply chains	Planting of vineyards and almond orchards to maintain a high added value activity
TPM agricultural system	Public administration, education, social work: 66 % of firms (Agriculture: 0.2 % of firms)	Vineyards: 46 % Market gardening: 11 % Horticulture: 11 % Quality labels Irrigation	National / international export (1 st flower growing area of France)	Fig cultivation	Decrease of farmers Housing affordability for farmers	Agricultural land conservation and spatial continuum Support to flower growing industry	Development of market gardening and orchards to reach foodstuff self-sufficiency Short supply chains and organic production

Source: French national public statistics (Insee, Agreste) and intermunicipal planning documents.

Table 5

List of datasets used for the estimation of the socio-economic impacts of the scenarios.

Data	Source	Date	Metadata complement
Annual added values by crop production in France	INSEE,	2017	Estimated accounts of agriculture, base 2010
Areas of different crop production in France	AGRESTE	2016 – 2017	Annual agricultural statistics 2016 – 2017 Published in 2019
Dominant crop on the property, cultivated area, farm size, number of employees, farm location	RGA AGRESTE	2010	Farm scale
MOS GST	TTI production	2014	Scale of interpretation 1:1 500 to 1:3 000
MOS TPM	AUDAT83	2011	Scale of interpretation 1:1 500 to 1:3 000

4. Results

4.1. A reserve of vacant lands with unequal opportunities for agricultural valorization

Despite the on-going urbanization process and the increase in lands taken over, the two coastal areas have large amounts of vacant land, almost 8800 ha for TPM and 16,100 ha for GST (Table 6 and Fig. 5). In TPM, they represent 39 % of non-urban areas and 23.5 % of the intermunicipality area, while in GST, they represent 48 % of non-urban areas and 37 % of the intermunicipality area.

The topography constraints, the presence of buildings on parcels disconnected from urban areas, and the presence of strictly-protected natural lands and forests explain why only half of the vacant lands have interesting agricultural opportunities.

The nine criteria classified from 1 to 3 were totaled for each parcel, with the minimum possible score being 9 and the maximum possible score 27. Thus we considered that the parcels with an absolute score above 18 (i.e. the median) present a real potential for agriculture. In TPM, these parcels correspond to 5398 ha, i.e. 61.6 % of the total amount of vacant lands and 14.5 % of the intermunicipality area. For GST they represent 5419 ha, i.e. 33.6 % of the total amount of vacant lands and 12.5 % of the intermunicipality area.

In order to prioritize the agricultural interest of the vacant lands in each territory and to compare the two case studies, we standardized the parcel scores. The results are shown in Table 6.

The vacant lands include areas impacted by various planning projects or environmentally-related authorization requirements (weak, because not stable over time), concerning natural and forest lands, as well as brownfields and wastelands. This means that not all vacant lands can be considered as being available for agriculture. Fig. 5 shows vacant land areas with their agricultural opportunities scores.

The results show that almost half of the vacant lands have a significant or very significant potential for agriculture, according to our geographical, morphological, and regulatory criteria. Vacant lands with a score higher than 0 (i.e. the average) represent 3863 ha in GST and 7967 ha in TPM. In TPM, they are concentrated in two main zones: one municipality in the western part of the territory (Ollioules) and one wider area in the eastern part of the territory, extending over five municipalities and mainly corresponding to coastal plains drained by

Table 6
Vacant lands - potential agricultural areas by score class. In red, the plots with high agricultural opportunities; in blue, the plots with low agricultural opportunities; in yellow, the plots with medium agricultural opportunities.

	TPM		GST	
	(ha)		(ha)	
Urban areas	14144		7783	
Non-urban area	22841		33655	
Total vacant lands	8764		16124	
Vacant lands for each score	(ha)	(%)	(ha)	(%)
+2 to +3	14	0.2	177	1.1
+1 to +2	1569	17.9	2424	15.0
0 to +1	2280	26.0	5366	33.3
-1 to 0	2274	26.0	3313	20.5
-2 to -1	2167	24.7	4843	30.0
-3 to -2	459	5.2	0.4	0.0
-4 to -3	2	0.0	0.0	0.0

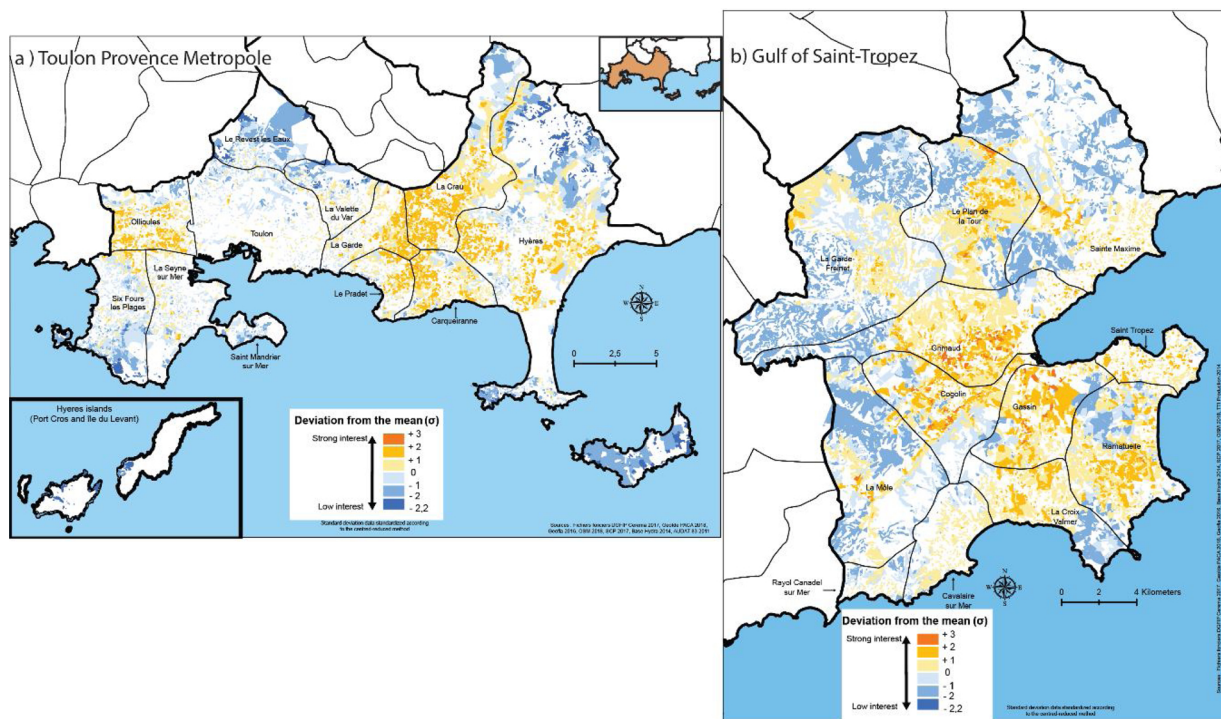


Fig. 5. Location of vacant lands and their agricultural opportunities scores.

the Gapeau River. In GST, they are located in the inland part of the territory, away from the artificialized coastal line and not including the Maures mountain ranges. They are mainly concentrated on plains (of the Grimaud municipality, in particular), drained by little coastal rivers (e.g. La Gisle) and their tributaries. It can also be noted that some municipalities have very few vacant land areas with agricultural interest, in particular in TPM due to land already taken by urban expansion (e.g. Six-Fours-les-Plages, Sanary-sur-Mer, Saint-Mandrier, Toulon).

4.2. Artificialization threat to vacant lands

Combining the vacant land agricultural opportunities scores with data concerning new artificialization from between 2006 and 2014 (Crige data), we could better estimate the proximity – and thereafter the threat – of urban and suburban fronts. To do this, we analyzed the proximity of the newly artificialized spaces (urban extension or urban densification) to the vacant lands with a score higher than 1. These parcels represent 1583 ha in TPM and 2601 ha in GST. About 60 % of the areas newly artificialized between 2006 and 2014 are located

Table 7
Proximity between new urban spaces and high score vacant lands.

Buffer distance from newly artificialized spaces	% of high score vacant lands in the buffer/ total high score vacant lands		% of vacant lands in the buffer /total vacant lands	
	TPM	GST	TPM	GST
5m	58.3 %	62.5 %	1.9 %	2.1 %
50m	67.3 %	77.4 %	3 %	3.6 %
100m	68.9 %	81.9 %	4.6 %	5.4 %
200m	72.8 %	84.8 %	7.6 %	9.6 %

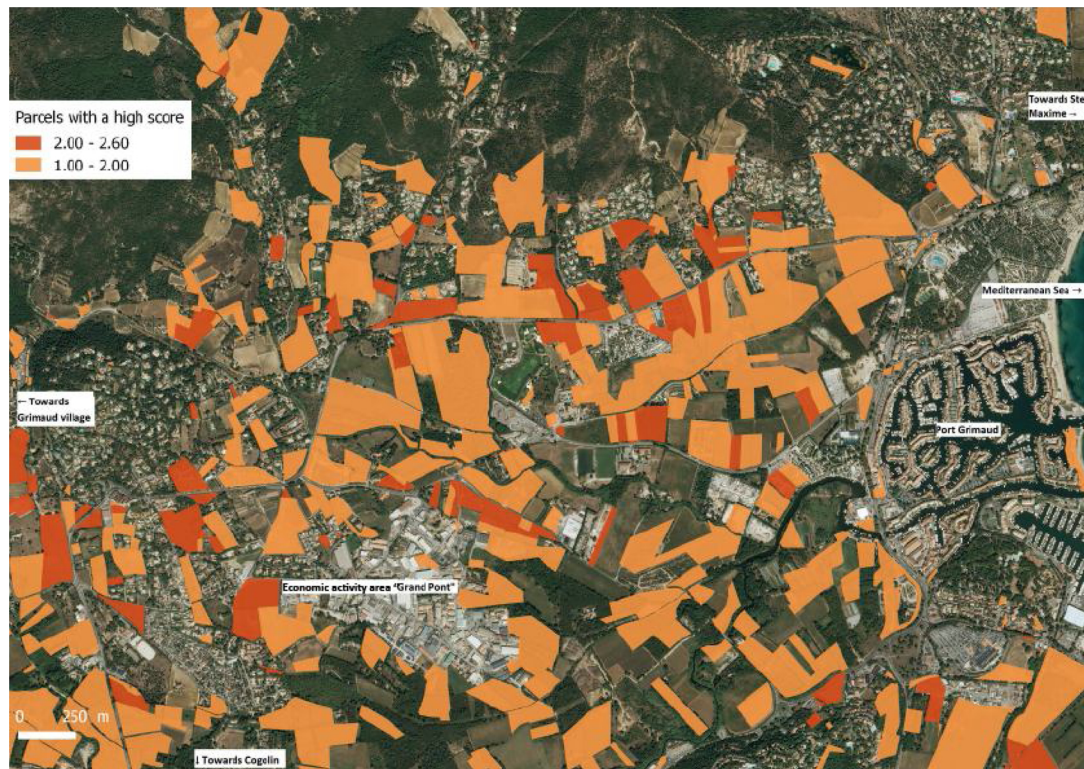


Fig. 6. Urban and suburban threat to the high-score vacant lands on the plain of the Grimaud municipality (GST).

within 5 m of the vacant land parcels with the highest scores. For a distance of 200 m, the results exceed 70 % in TPM and reach nearly 85 % in GST (Table 7). Fig. 6, based on an aerial photograph, spatially illustrates the threat of new urbanization to the vacant lands with the highest potential.

Fig. 6 focuses on the Grimaud plain, located in the GST territory. It highlights the proximity between urban spaces (mostly for residential use) and parcels with high scores for agricultural opportunities. The Grimaud plain was originally an agricultural area, which is why it has a concentration of parcels with good scores. However, urban spread has been progressively developing on this plain, creating an urban continuum between the different municipalities. The villages of Grimaud (center-west) and Cogolin (south-west) are contiguous. There are a number of residential subdivisions making an almost continuous urban line between Grimaud (west-center) and Sainte-Maxime (north-east). Moreover, a large economic activity area is located in the center of this agricultural plain.

4.3. Varied agricultural opportunities for vacant lands

In order to deepen the analysis of the vacant lands, we carried out a classification (AHC) of vacant land parcels, based on the criteria previously selected (Fig. 4). Results for the agricultural opportunities of parcels as given by the AHC are summarized in Fig. 7.

The two AHC classifications identified six vacant land classes (Fig. 8 and Fig. 9).

Two classes (represented in red and violet) have a similar profile for the two territories. The red class characterizes vacant lands located in an urban context (very small parcel size) and without irrigation system access. The violet class characterizes vacant lands located in a rural context (mainly natural lands) which are distant from inhabited areas and from points of sale (e.g. farm cooperative, market place). Two classes show that there are some specific local characteristics: class 6 describes very isolated vacant lands in TPM, while class 5 in GST describes all the vacant lands with the possibility of an irrigation system,

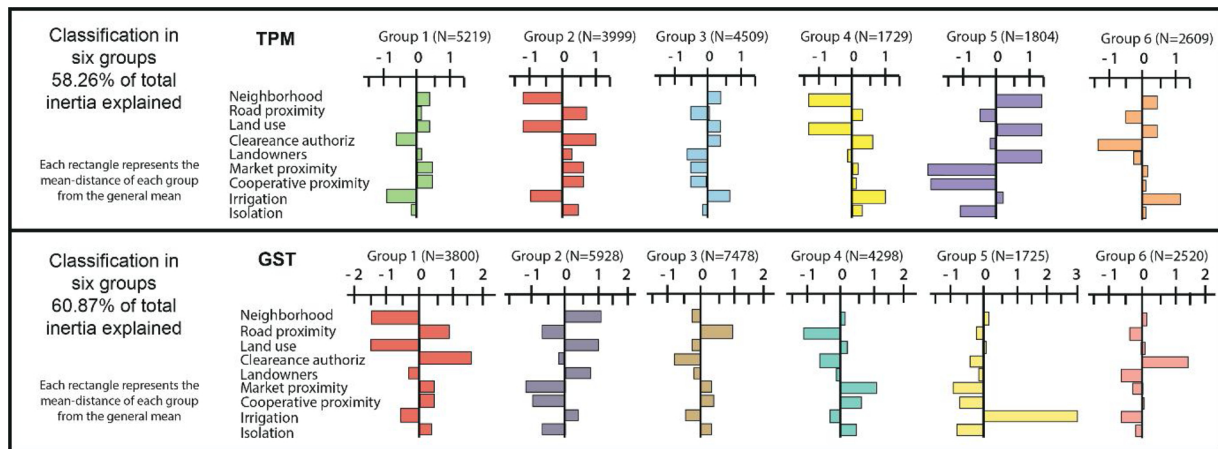


Fig. 7. Results of the AHC for the two case studies.

which is a differentiating criterion (infrequently available in this territory). Other classes have more heterogeneous profiles in terms of types of agricultural opportunities.

The distribution of the red class, the parcels concerned by urban constraints (e.g. neighbors, road proximity, current land use) shows that these vacant lands are very scattered within urban areas (plots with an average area of just 620 m²), and thus they are not really usable for agriculture, except perhaps for urban gardening.

Fig. 8 The distribution of the violet class, i.e. parcels located in a

rural context, shows that these vacant lands are very isolated and located on steep slopes, thus not really exploitable for agricultural purposes. The blue and the yellow classes have an intermediate situation compared to the previous ones: the parcels present opportunities for agriculture (irrigable, not concerned by clearance authorization). They are located in current agricultural areas or in a suburban context. The orange class, similar to the previous ones, characterizes parcels also suitable for agriculture but in natural vegetation land use and with a forest cover which would require a clearance authorization. The parcels

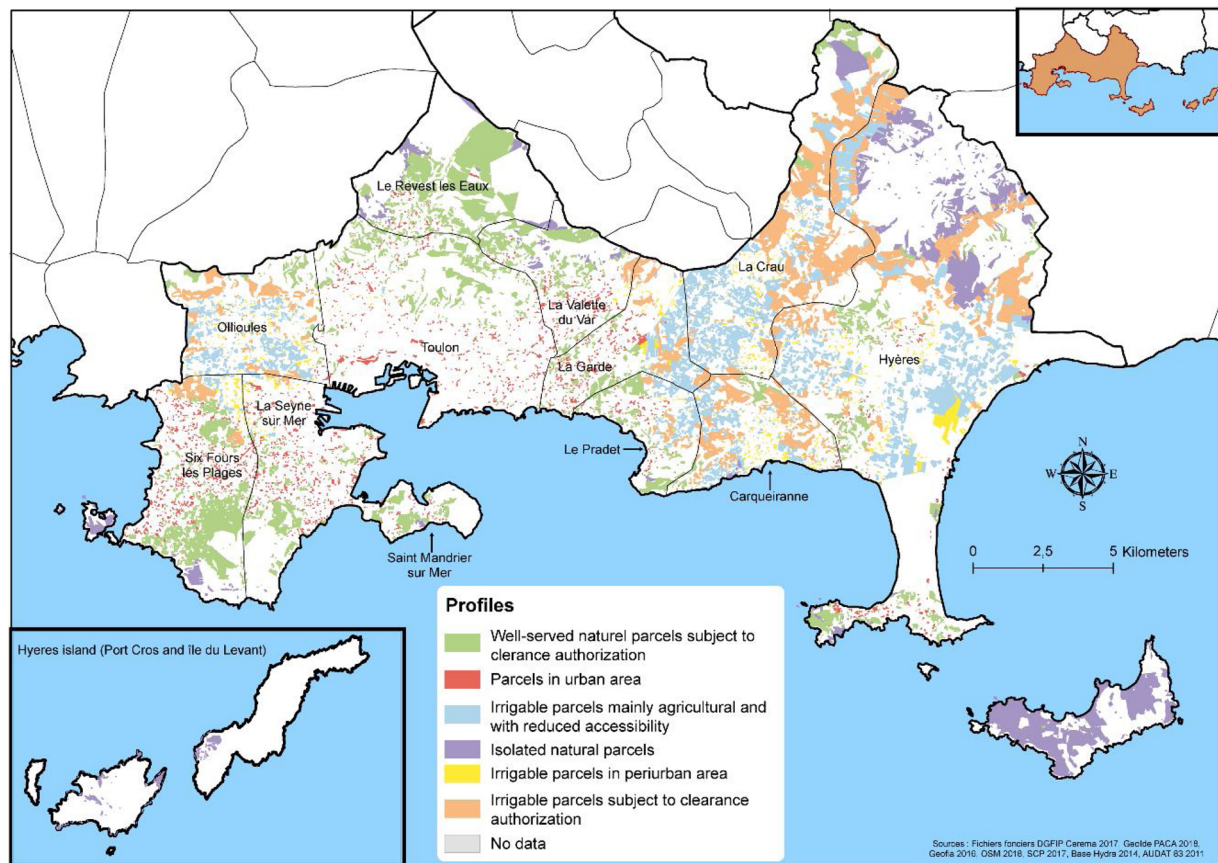


Fig. 8. Classes of agricultural opportunities for vacant lands in TPM. The colors used in the key are the same as those employed in Table 8.

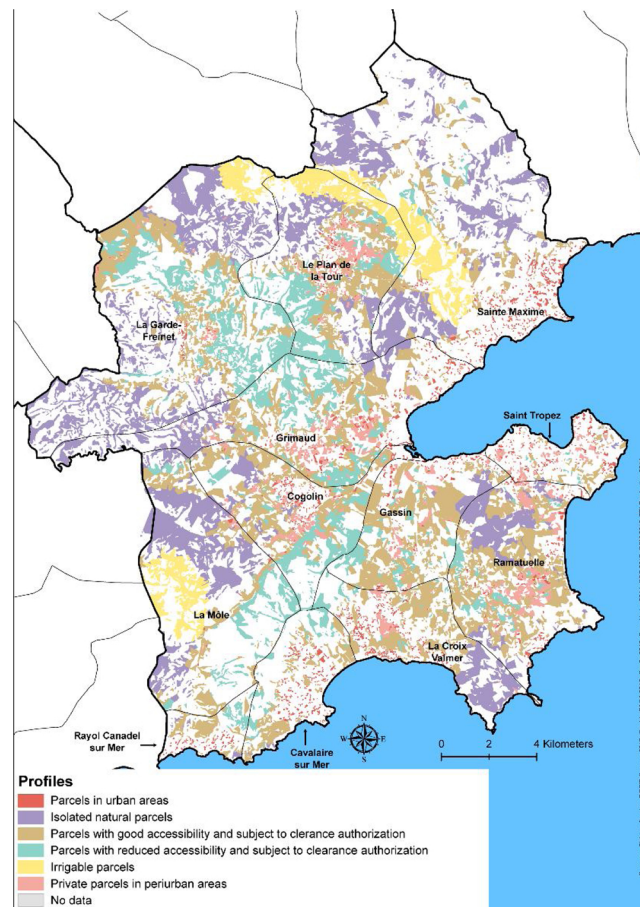


Fig. 9. Classes of agricultural opportunities for vacant lands in GST. The colors used in the key are the same as those employed in Table 8.

are large and geographically concentrated, in particular in the Gapeau Valley. Possible agricultural development in these areas should consider the conservation of natural vegetation, for instance through agroforestry or natural pastures. The green class also includes lands with forest cover covered by a clearance authorization. Agricultural development should consider non irrigable crops and/ or forestry exploitation.

In Fig. 9, the violet and blue classes offer low opportunities for agriculture. Vacant lands are located on the mountains of the Massif des Maures, in a forest-covered area requiring clearance authorization, and

where some parcels are very isolated. As in the TPM classification, the red class describes parcels in an urban context with potential for urban gardening. The pink class shows lands where agriculture has to be developed or maintained. Here, the unbuilt or already cultivated lands concerned are close to inhabited areas. However as they are not irrigable, agricultural opportunities are probably limited to viticulture or other rainfed crops, such as agroforestry or permanent grassland. The yellow class includes irrigable parcels and offers a wide range of agricultural possibilities. The brown class offers good opportunities for low water-need agriculture, for example agroforestry compatible with the

Table 8
Distribution of vacant lands with a high score (class > + 1) by classes (AHC). The class numbers and colors used in the key are the same as those employed in Figs. 7 and 8.

TPM			GST		
Class number	ha	%	Class number	ha	%
1	43	2.7	1	1 61	6.2
2	0	0	2	34	1.3
3	1358	85.8	3	133	5.1
4	0	0	4	1552	59.7
5	0	0	5	0	0
6	167	10.6	6	720	27.7
No Data	14	0.9	No Data	0	0.0

existing forest cover (e.g. orchards and pastoral farming).

By combining the AHC classification with the scoring analysis it can be seen that for the two case studies, vacant lands with a high score (higher than +1 in Table 6) are mainly concentrated in two classes (Table 8). In TPM, they are concentrated (97 %) in classes 3 and 6. In GST, they are 88 % concentrated in classes 4 and 6. In contrast, some classes (like the violet class) do not contain any high-score parcels, confirming that these parcels are not really interesting for agriculture.

4.4. Scenarios for future agricultural projects

Prospective scenarios can enlighten the public policy debate and more precisely, assess the possible greater place for agriculture. Starting from the hypothesis of agricultural land expansion, we explored a possible pathway for a sustainable planning project. Impacts of an agricultural space increase explored in the normative scenarios were measured through socio-economic indexes.

For the TPM study area, we suggest a scenario focused on market gardening and orchards, given the public’s increasing awareness about short supply chains and organic production. Moreover, a good system of local farmers’ markets is already established in this region. The new agricultural areas should be located in areas where irrigation is available and in parcels not subjected to land clearance authorization requirements. Moreover, a slope criterion is added: irrigated orchards can be located on plots with slopes between 20 % and 35 %, whereas for plots with an area greater than 3 ha and with a slope of less than 20 %, specialized market gardening is proposed. Otherwise, a more

polyvalent and extensive form of market gardening could be proposed. The map concerning vacant lands suitable for this scenario shows that market gardening would be located in the remaining narrow urban spaces, while orchards are located in valleys with irrigation systems (Fig. 10). If this scenario were to be adopted, agricultural areas would increase by 1560 ha, potentially providing 17 million euros of added value in terms of production from the activities, and creating 6000 jobs.

Wine is the leading production for the Var department in terms of surface areas and value. This is why we proposed further developing this agricultural system for the GST study area, possibly associated with other fruit plantations. Such an orientation is also compatible with the context of climate change, as this kind of mixed cropping includes benefits for the thermal regulation of soils, the nutrient supply, etc. Almond production was thus proposed in order to improve crop diversification and because of its low water needs and good potential market valorization (Prgomet et al., 2020; Monks et al., 2017). Moreover, the scenario considered developing new agricultural areas near the already existing ones, on groups of parcels greater than 1 ha (through land consolidation) and not subject to land clearance authorization, therefore not in classified forest areas, in order to preserve the natural vegetation. Results concerning vacant lands suitable for this scenario show a balanced spread of this agricultural development across the territory as well as good conservation of protected forest areas (Fig. 11). Under this scenario, the agricultural areas would increase by about 330 ha, with 4 million euros of added value and 620 more jobs created. Fig.11 shows where the new agricultural parcels could be located, and summarizes the economic benefits of the scenario.

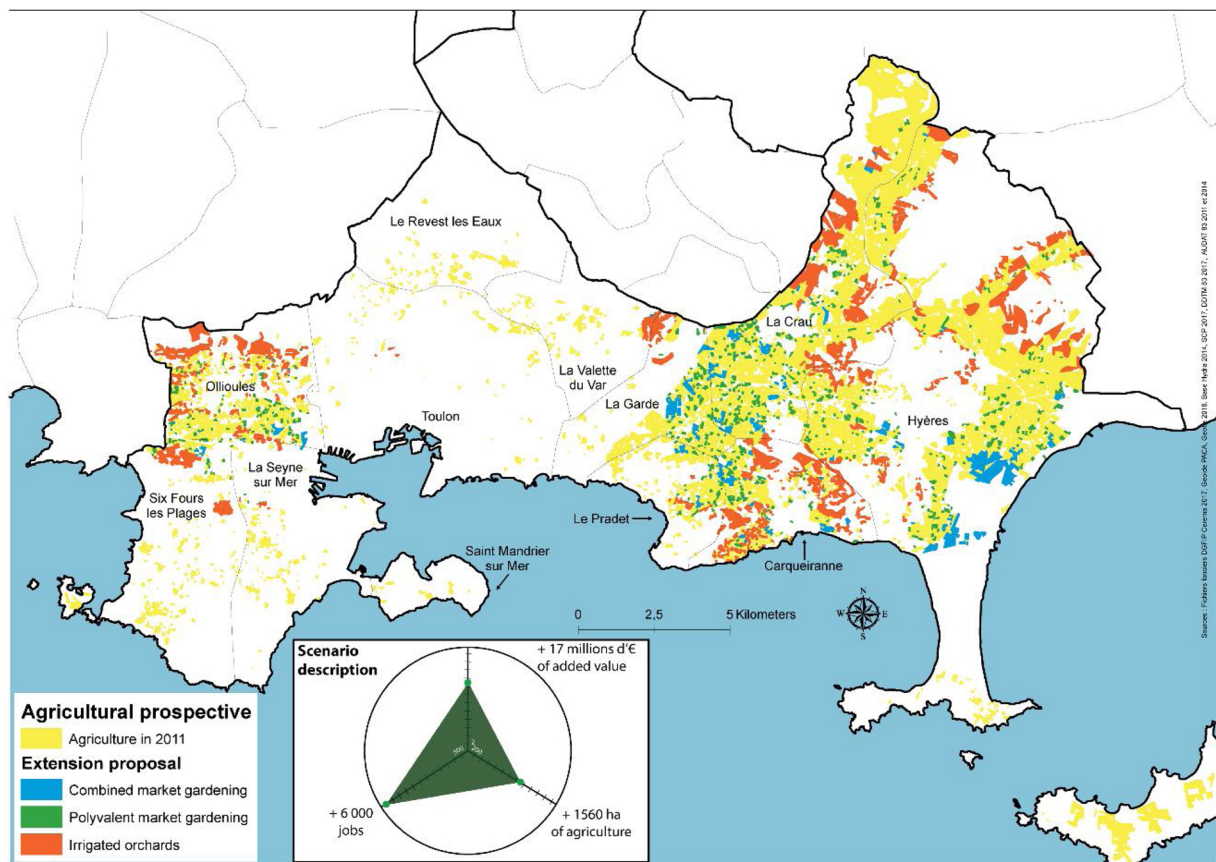


Fig. 10. Scenario 2: market gardening and orchards to reach foodstuff self-sufficiency (TPM).

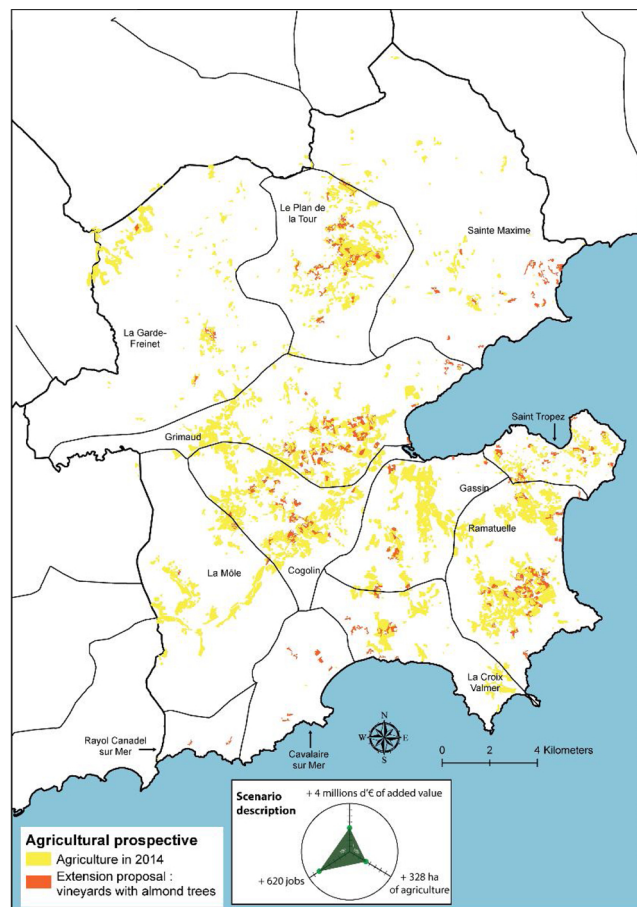


Fig. 11. Proposed scenario for the GST study area, with location of vineyards and almond orchards.

5. Discussion

5.1. Vacant lands and agricultural valorization

Similar studies on vacant lands have been conducted at a fine scale during the last few decades. Our proposals differ in terms of valorization analysis (e.g. housing development, ecosystem services, urban gardening). The difference concerns also the scale and the extent of the analysis, as well as the associated data and the methodology possible to develop in these contexts. As mentioned in the introduction, different meanings and measurements are used to inventory vacant lands, and thus results are not directly comparable (Newman et al., 2018).

In 2015, Kremer and Hamstead, 2015 brought out a Special Issue entitled “Transformation of Urban Vacant Lots for the Common Good”, in which they estimated the amount of vacant lands in US cities at between 12.5 % and 15 % of the total land area. These numbers are valid for a restrictive meaning of vacant lands and for a limited urban context. In addition, the results were obtained from remote sensing or photointerpretation methods, which cannot be replicated over a vast area.

Two relevant studies assessed vacant lands for potential greening uses. In the city of São Bernardo do Campo (region of São Paulo, Brazil), Sanches and Mesquita Pellegrino (2016) inventoried 8% of derelict and urban vacant lands (defined as natural abandoned lands > 1 ha and determined with a photointerpretation method), and next applied

several indexes to estimate their role in the city from different aspects such as ecological or social dimensions. Pursuing the same objective, Smith et al. (2017) applied a more accurate methodology (i.e. using remote sensing and cadastral data) to the Phoenix area. They identified from 4 to 18 % of vacant lands mainly located in the core and on the fringe of the different cities, considering vacant lands with different morphological criteria than those used for our analysis (e.g. parcel size from 56 m², < 5% slope). Other studies have provided estimations of the amount of vacant lands in a city using sampling and estimation methods, as in Mcdougall et al. (2020) or Kim et al. (2018).

While the majority of vacant lands inventories concern city contexts, in our case studies we enlarged the area of two coastal inter-municipalities, obtaining as a result an amount of vacant lands of 23.5 % and 37 % respectively for the TPM and GST case studies. Nevertheless, just a small part of this total area of vacant lands has interest for agricultural valorization according to the geographical, physical and regulatory criteria considered in the analysis: in TPM and GST respectively, 61.6 % and 33.6 % of the total of vacant lands and almost 14.5 % and 12.5 % of the TPM and GST intermunicipality area.

Other studies have been carried out with an in-depth analysis of the agricultural potential of vacant lands, for example in the work of Erickson et al. (2013) by the inclusion of data on soil quality. The authors gave an estimation of lands with prime soil in Chittenden County, Vermont, which represent 74 % of lands with agricultural opportunity. This finding shows what could be an interesting continuation of our

work, with the integration of soil quality data unfortunately not available in our context.

Moreover, our results highlight the proximity of the urban front to the best lands: 60 % of spaces newly artificialized between 2006 and 2014 are located within 5 m of the vacant land parcels with the highest scores. These results confirm previous studies analyzing the artificialization of prime farmlands (Martellozzo et al., 2020; Ceccarelli et al., 2014; Ferrara et al., 2014). In their recent study, Aksoy et al. (2017) showed that France belongs to the group of European countries with the highest quantity of lands where development strongly impacts the biomass productivity potential of arable lands. They also noted that the southern region is considered as a hotspot from this point of view. Furthermore, in a comparison of EU countries, Tóth (2012) demonstrated that the largest total loss of cropland area between 2000 and 2006 (corresponding to half of the total land taken in Europe), occurred in Spain followed by France. Our work can therefore be considered as a confirmation of these assertions.

5.2. Implications for future urban planning and agricultural policies

These findings indicate the need for new protection measures for agricultural lands. More specifically, and beyond the protection of current agricultural lands, what is required is the protection of lands offering opportunities to develop global and coherent agricultural planning projects. In the coastal context, the integrated coastal management tool should better take into account the relationships between settlements and environmentally-important or agricultural areas (Prévost and Robert, 2016; Cori, 1999). This perspective is becoming more and more essential to regulate land use on coastal areas. Past experience has shown that sector-specific regulation (i.e. concerning agricultural lands) is not efficient in the face of market forces. Geniaux et al. (2015) provided an interesting result from their examination of the same cadastral data: in the Provence-Alpes-Côte d'Azur area between 1999 and 2007, land supply (i.e. lands within constructible zoning) reduced significantly (-40 %, that is -56 123 ha) due to housing increase (+14 %) and changes in urban planning zoning (loss of 55 000 ha). In fact, from local planning documents to national tools of – agricultural – land conservation, current sector-based measures just enable the artificialization process to be slowed down, but do not permit the promotion of agricultural planning projects. A recent measure has been created reflecting this (named the “territorial foodstuff circuit project” based on the agricultural law of 2014), but it has not had much impact up to now (just 150 projects in 2019 whereas 500 were expected by 2020, as indicated by the Caisse des Dépôts, 2019). For example, it organizes, at a municipal scale, local channel distribution of the agricultural production to establishments with mass catering. The second pillar of the Common Agricultural Policy (CAP) also represents a tool available for implementing agricultural projects. This co-funding aims to improve the sustainable development of rural regions and communities in the EU (Gomez-Limon and Atance, 2004), and can be integrated in the objectives of local planning (Sanz Sanz et al., 2018). In this sense, the enforced prospective scenarios give a central place to agricultural land valorization and explore a valorization of multifunctional agriculture (e.g. Scorsino and Debolini, 2020; Renting et al., 2009).

A concerted approach combined with spatial analysis was used for a spatialized and quantitative analysis of the opportunities for agricultural expansion in the territories. In order to encourage public debate on the inventory and prospective scenario results, workshops were organized on the two case studies with local players (Casanova Enault et al., 2020). In terms of farming system typology, our choice was to propose scenarios sustainable from both the environmental and the

socio-economic points of view. This involved finding a compromise between more agro-ecological systems and specialized/intensive ones. In this paper, we did not analyse the possible use of limited resources in farm management, such as water for irrigation systems, because our scenarios were simply illustrative of the possible realization of break-away futures. Future works in this field should consider these implications (Ricart et al., 2019; Nicholls et al., 2020). Elsewhere, similar normative scenarios have been built with strong hypotheses regarding the need for climate change adaptation (Carter, 2018; Milestad et al., 2014; Rounsevell et al., 2006). This parameter is not included in our study, which focused on the present situation to raise questions for decision makers about the existing residential issues of the territory, and the current opportunities to change planning project directions.

5.3. Methodological discussion

In terms of methodology, one of the main challenges was the detailed scale of work. As previously mentioned, all the spatial analyses were carried out at parcel scale in order to enable the use of the results as a base for spatial planning by policy makers. On such a vast study area, the investigations employed mainly land-use data with a larger mesh size (e.g. Corine Land Cover dataset) which just consider polygons bigger than 25 ha (Schmit et al., 2006; Santa Olalla Manas et al., 2003). This potentially hides a part of the vacant lands, in particular within the urban fabric. However, this approach is limited by the low number of relevant datasets available at the parcel scale, and which are therefore not included in the analysis, such as soil quality. Nevertheless, we consider here that the quality of soils is a less determining factor influencing the possibility of extending agricultural development in the case studies than the major factor of land availability. In addition, given the Mediterranean context, several agricultural activities can potentially be developed in most places, like viticulture. A more significant factor is water access, which is included in the analysis.

Another methodological question concerns the choice of thresholds for the scoring settings. Results are sensitive to these settings and may be refined to a more local scale of analysis (e.g. municipal scale).

In scenario building, it should be remembered that the expansion of agricultural lands does not mean that the agricultural activity chain will systematically improve (e.g. in terms of jobs). Socio-economic impacts assessed for the scenarios do show encouraging results (Figs. 10 and 11). However, they correspond to global estimations, based on aggregated data. In addition, they are dependent on the current context. Possible macro-economic (e.g. market regulation) or social (e.g. farming conditions) changes may occur in the future, and are not taken into account. In a broader perspective, uncertainty as to the future was not measured here, as the main goal of the normative scenario building was to inform and question local stakeholders regarding the possibility of alternatives to residential development.

6. Conclusion

In this paper, we inventoried existing vacant lands at the parcel scale in two intermunicipality areas of south-eastern France, characterized by a high urbanization trend and a strong tourism and residential economy. Next, we evaluated the possible opportunities in valorizing vacant lands other than via residential development. Despite the common belief of local stakeholders according to which the MedCoast is now saturated, we found several vacant land hotspots with high opportunities for agricultural valorization in our case study areas. These parcels are especially located on coastal plains, excluding artificialized coastlines and inland mountainous areas. Starting from this inventory of vacant lands suitable for agricultural valorization, two

territorial scenarios were built, one for each case study, compatible with sustainable development principles. The two scenarios demonstrated that alternatives to residential development are potentially possible, with the expansion of agricultural activities. At the same time, it can be seen that some vacant lands with higher agricultural interest are threatened by the strong expansion of the urban and periurban front, which is often very close.

A continuation of this study could be to explore a diverse set of other possible future scenarios, which could also consider agricultural systems and food chains in the region which do not exist at present, and taking into account potential future climate change and its impacts on the resource availability. Moreover, our research demonstrated that while vacant lands represent almost half of the intermunicipality areas, those with high interest for agriculture are only 12–15 % of such areas. A future line of work should also concern effective agricultural land protection strategies which go beyond the simple issue of urban planning, as the various existing land use regulatory systems have failed to protect such lands (Melot et al., 2018; Abrantes et al., 2016; Padeiro, 2016; Geniaux et al., 2015).

CRedit authorship contribution statement

Laure Casanova Enault: Conceptualization, Methodology, Writing - original draft, Supervision. **Tatiana Popoff:** Formal analysis, Investigation, Writing - original draft, Visualization. **Marta Debolini:** Methodology, Writing - original draft, Supervision.

Acknowledgements

This work was supported by the Fondation de France, 40 avenue Hoche 75008 Paris through the DURB project, headed by Guilhem Boulay (UMR ESPACE, Avignon University). The authors also wish to thank all the local experts who agreed to answer our questions and to participate in our workshops, as well as the students of the GEOTER Master's degree of Avignon University (year 2018-19). We thank Beverley Marshall of IBL for the English revision. We finally wish to thank the reviewers for their constructive comments.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.landusepol.2020.104914>.

References

Abrantes, P., Fontes, I., Gomes, E., Rocha, J., 2016. Compliance of land cover changes with municipal land use planning: evidence from the Lisbon metropolitan region (1990–2007). *Land Use Policy* 51, 120–134. <https://doi.org/10.1016/j.landusepol.2015.10.023>.

Abrantes, P., Queirós, M., Mousselin, G., Ruault, C., Anginot, E., Fontes, I., 2017. Building a prospective participatory approach for long-term agricultural sustainability in the Lezíria do Tejo region (Portugal). *Cahiers de géographie du Québec* 60 (170), 303–323. <https://doi.org/10.7202/1040537ar>.

Aksoy, E., Gregor, M., Schröder, C., Löhnertz, M., Louwagie, G., 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth* 8, 683–695. <https://doi.org/10.5194/se-8-683-2017>.

Benoit, G., Comeau, A., 2005. A sustainable future for the Mediterranean: the Blue plan's environment and development. *Environment and Development Outlook*. Earthscan, London 464.

Blandford, D., 2011. The Contribution of Agriculture to Green Growth. OECD 36 pp. <http://www.oecd.org/greengrowth/sustainable-agriculture/48258861.pdf>.

Börjeson, L., Höjer, M., Dreborg, K., Ekvall, T., Finnveden, G., 2006. Scenario types and techniques: towards a user's guide. *Futures* 38 (7), 723–739. <https://doi.org/10.1016/j.futures.2005.12.002>.

Burak, S., Dogan, E., Gazioglu, C., 2004. Impact of urbanization and tourism on coastal environment. *Ocean Coast. Manag.* 47, 515–527. <https://doi.org/10.1016/j.ocecoaman.2004.07.007>.

Caisse des Dépôts, 2019. Alimentation: Des PAT, Des PAT, Oui Mais Comment? <https://www.banquedesterritoires.fr/alimentation-des-pat-des-pat-oui-mais-comment>.

Carter, J., 2018. Urban climate change adaptation: exploring the implications of future land cover scenarios. *Cities* 77, 73–80. <https://doi.org/10.1016/j.cities.2018.01.014>.

Casanova, L., Helle, C., 2012. What land purchase patterns have to say about the Future of territories: prospective elements in Southeast France. *L'Espace géographique* 41, 111–127 2.

Casanova Enault, L., Debolini, M., Popoff, T., De Flore, R., 2020. Jouer un scénario d'aménagement foncier : analyse des pratiques d'aménagement et recherche d'alternatives au développement résidentiel », Netcom [En ligne], Articles, mis en ligne le 05 juin 2020. URL : <http://journals.openedition.org/netcom/5041>.

Catalán, B., Saurí, D., Serra, P., 2008. Urban sprawl in the Mediterranean? *Landscape Urban Plan.* 85, 174–184. <https://doi.org/10.1016/j.landurbplan.2007.11.004>.

Ceccarelli, T., Bajocco, S., Perini, L., Salvati, S., 2014. Urbanisation and land take of high quality agricultural soils - exploring long-term land use changes and land capability in Northern Italy. *Int. J. Environ. Res.* 8 (1), 181–192. <https://doi.org/10.22059/ijer.2014.707>.

Chabert, J.B., 2016. L'action foncière : une ressource pour des mobilisations riveraines. L'exemple de la requalification patrimoniale d'un lieu de conflits dans la presqu'île de Saint-Tropez. *Norois* 238–239, 43–58. <https://doi.org/10.4000/norois.5855>.

Colsaet, A., Laurans, Y., Levrel, H., 2018. What drives land take and urban land expansion? A systematic review. *Land Use Policy* 79, 339–349. <https://doi.org/10.1016/j.landusepol.2018.08.017>.

Communauté de communes du Golfe de Saint Tropez, 2019. Schéma De Cohérence Territoriale, Approuvé Le 2 Octobre 2019.

Cori, B., 1999. Spatial dynamics of Mediterranean coastal regions. *J. Coast. Conserv.* 5, 105–112. <https://doi.org/10.1007/BF02802747>.

Coskun Hepcan, C., 2013. Quantifying landscape pattern and connectivity in a Mediterranean coastal settlement: the case of the Urla district, Turkey. *Environ. Monit. Assess.* 185, 143–155. <https://doi.org/10.1007/s10661-012-2539-7>.

Cuttelod, A., Garcia, N., Abdul Malak, D., Temple, H., Katariya, V., 2008. The Mediterranean: a biodiversity hotspot under threat. In: Vié, J.-C., Hilton-Taylor, C., Stuart, S.N. (Eds.), *The 2008 Review of The IUCN Red List of Threatened Species*. IUCN Gland, Switzerland, pp. 1–13.

Dachary-Bernard, J., Gaschet, F., Lyser, S., Pouyanne, G., Virol, S., 2011. L'impact de la littoralisation sur les marchés fonciers. Une approche comparative des côtes basque et charentaise. *Econ. Stat.* 444, 127–154. <https://doi.org/10.3406/estat.2011.9647>.

Davezies, L., 2009. L'économie Locale « Résidentielle ». *Géographie, Économie, Société* 1.11, 47–53. <https://www.cairn.info/revue-geographie-economie-societe-2009-1-page-47.htm>.

Debolini, M., Marraccini, E., Dubeuf, J.P., Geijzendorffer, I., Guerra, C., Simon, M., Targetti, S., Napoleone, C., 2018. Land and farming system dynamics and their drivers in the Mediterranean Basin. *Land Use Policy* 75, 702–710. <https://doi.org/10.1016/j.landusepol.2017.07.010>.

Erickson, D.L., Lovell, S.T., Méndez, V.E., 2013. Identifying, quantifying and classifying agricultural opportunities for land use planning. *Landscape Urban Plan.* 118, 29–39. <https://doi.org/10.1016/j.landurbplan.2013.05.004>.

Ferrara, C., Salvati, L., Tombolini, I., 2014. An integrated evaluation of soil resource depletion from diachronic settlement maps and soil cartography in peri-urban Rome, Italy. *Geoderma* 232–234, 394–405. <https://doi.org/10.1016/j.geoderma.2014.05.020>.

Filippini, R., Lardon, S., Bonari, E., Marraccini, E., 2018. Unraveling the contribution of periurban farming systems to urban food security in developed countries. *Agron. Sustain. Dev.* 38 (2), 21.

France Stratégie, 2019. Objectif « Zéro Artificialisation Nette »: Quels Leviers Pour Protéger Les Sols?», Rapport Au Ministre De La Transition Écologique Et Solidaire, Au Ministère De La Cohésion Des Territoires Et Des Relations Avec Les Collectivités Territoriales Et Au Ministre Chargé De La Ville Et Du Logement, Juillet 2019. <https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-rapport-2019-artificialisation-juillet.pdf>.

García-Ayllón, S., 2015. La Manga case study: consequences from short-term urban planning in a tourism mass destiny of the Spanish Mediterranean coast. *Cities* 43, 141–151. <https://doi.org/10.1016/j.cities.2014.12.001>.

García-Ayllón, S., 2018a. Predictive diagnosis of agricultural periurban areas based on territorial indicators: comparative landscape trends of the so-called "Orchard of Europe". *Sustainability* 10, 1820.

García-Ayllón, S., 2018b. Long-term GIS analysis of seaside impacts associated to infrastructures and urbanization and spatial correlation with coastal vulnerability in a Mediterranean Area. *Water* 10, 1642. <https://doi.org/10.3390/w10111642>.

Gedal, M.G., Ellen, I., 2018. Valuing urban land: comparing the use of teardown and vacant land sales. *Reg. Sci. Urban Econ.* 70, 190–203. <https://doi.org/10.1016/j.regsciurbeco.2018.03.006>.

Geniaux, G., Napoléone, C., Leroux, B., 2015. Les Effets Prix De l'offre Foncière. *Revue d'Economie Regionale Urbaine*, 1/2: 273–320. https://www.sfer.asso.fr/source/jrss2013/jrss2013_c4_geniauxG.pdf.

Goldstein, J., Jensen, M., Reiskin, E., 2001. Urban Vacant Land Redevelopment:

- Challenges and Progress. Lincoln Institute of Land Policy, Cambridge, MA, USA.
- Gomez-Limon, J.A., Atance, I., 2004. Identification of public objectives related to agricultural sector support. *J. Policy Model.* 26, 1045–1071.
- Gourmelon, F., Houet, T., Voiron-Cancio, C., Joliveau, T., 2012. La Géoprospective. *Points De Vue Conceptuels Et Applicatifs De l'apport Du Spatial à La Prospective. L'Espace Géographique.* pp. 203.
- Grandclement, A., Boulay, G., 2016. Residential function and local fiscal resources on the French Mediterranean coastal areas. *L'Espace géographique* 44, 57–72. <https://doi.org/10.3917/eg.441.0057>.
- Gutiérrez Angonese, J., Grau, H.R., 2014. Assessment of swaps and persistence in land cover changes in a subtropical periurban region, NW Argentina. *Landscape Urban Plan.* 127, 83–93. <https://doi.org/10.1016/j.landurbplan.2014.01.021>.
- Holon, F., Mouquet, N., Boissery, P., Bouchoucha, M., Delaruelle, G., Tribot, A.-S., Deter, J., 2015. Fine-scale cartography of human impacts along french mediterranean coasts: a relevant map for the management of marine ecosystems. *PLoS One* 10 (8), e0135473. <https://doi.org/10.1371/journal.pone.0135473>.
- Houet, T., Aguejidad, R., Doukari, O., Battaia, G., et Clarke, K., 2016. Description and validation of a “non path-dependent” model for projecting contrasting urban growth futures. *Cybergeo.* <https://doi.org/10.4000/cybergeo.27397> <http://journals.openedition.org/inshs.bib.cnrs.fr/cybergeo/27397>.
- IPCC, 2014. AR5 synthesis report: climate change. In: Pachauri, R.K., Meyer, L.A. (Eds.), *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland, pp. 151.*
- Iverson Nassauer, J., Corry, R.C., 2004. Using normative scenarios in landscape ecology. *Landscape Ecol.* 19, 343–356. <https://doi.org/10.1023/B:LAND.0000030666.55372.ae>.
- Kasanko, M., Barredo, J.I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V., Brezger, A., 2006. Are European cities becoming dispersed? *Landscape Urban Plan.* 77, 111–130. <https://doi.org/10.1016/j.landurbplan.2005.02.003>.
- Kim, G., Miller, P.A., Nowak, D.J., 2015. Assessing urban vacant land ecosystem services: urban vacant land as green infrastructure in the City of Roanoke, Virginia. *Urban For. Urban Green.* 14, 519–526. <https://doi.org/10.1016/j.ufug.2015.05.003>.
- Kim, G., Miller, P.A., Nowak, D.J., 2018. Urban vacant land typology: a tool for managing urban vacant land. *Sustain. Cities Soc.* 36, 144–156. <https://doi.org/10.1016/j.scs.2017.09.014>.
- Kremer, P., Hamstead, Z., 2015. Transformation of Urban Vacant Lots for the Common Good: an Introduction to the Special Issue 8(2): 1–6.
- Lagarias, A., Sayas, J., 2019. Is there a common typology of urban sprawl in Mediterranean cities? A comparative analysis utilizing spatial metrics. *Rev. Écon. Rég. Urbaine* 4, 813–850 <https://doi.org/3917/reru.194.0813>.
- Le Berre, M., 2016. A probabilistic model of residential urban development along the French Atlantic coast between 1968 and 2008. *Land Use Policy* 50, 461–478. <https://doi.org/10.1016/j.landusepol.2015.09.007>.
- Lee, J., Newman, G., Park, Y., 2018. A comparison of vacancy dynamics between growing and shrinking cities using the land transformation model. *Sustainability* 10 (1513). <https://doi.org/10.3390/su10051513>.
- Loubier, J.C., Voiron-Cancio, C., Genoud, D., Hunacek, D., Sant, Floriant, 2017. Modélisation géoprospective et simulation 3D immersive. *Revue Internationale de Géomatique, Lavoisier* 27 (4), 547–566. <https://doi.org/10.3166/riq.2017.00042>.
- Maestripieteri, N., Houet, T., Paegelow, M., Selleron, G., Toro Balbontín, D., Sáez Villalobos, N., 2017. Dynamic simulation of forest management normative scenarios: the case of timber plantations in the southern Chile. *Futures* 87, 65–77. <https://doi.org/10.1016/j.futures.2015.10.013>.
- Malcolm, J.R., Liu, C., Neilson, R.P., Hansen, L., Hannah, L., 2006. Global warming and extinctions of endemic species from biodiversity hotspots. *Conserv. Biol.* 20 (2), 538–548. <https://doi.org/10.1111/j.1523-1739.2006.00364.x>.
- Martellozzo, F., Ramankutty, N., Hall, R.J., et al., 2020. Urbanization and the loss of prime farmland: a case study in the Calgary–Edmonton corridor of Alberta. *Reg. Environ. Change* 15, 881–893. <https://doi.org/10.1007/s10113-014-0658-0>.
- McClintock, N., Cooper, J., Khandeshi, S., 2013. Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landscape Urban Plan.* 111, 46–58. <https://doi.org/10.1016/j.landurbplan.2012.12.009>.
- Mcdougall, R., Rader, R., Kristiansen, P., 2020. Urban agriculture could provide 15% of food supply to Sydney, Australia, under expanded land use scenarios. *Land Use Policy* 94 (104554).
- Melot, R., Delattre, L., Napoléone, C., 2018. Construire dans les espaces agricoles et naturels. *Revue études Rurales Études rurales* 201, 118–139. <https://www-cairn-info.buproxy.univ-avignon.fr/revue-etudes-rurales-2018-1-page-118.htm>.
- Membrado, J.C., Huete, R., Manticón, A., 2016. Urban sprawl and northern european residential tourism in the spanish Mediterranean Coast. *Via. Tour. Rev.* <https://doi.org/10.4000/viatourism.1426>.
- Milestad, R., Svenfelt, A., Dreborg, K.H., 2014. Developing integrated explorative and normative scenarios: the case of future land use in a climate-neutral Sweden. *Futures* 60, 59–71. <https://doi.org/10.1016/j.futures.2014.04.015>.
- Monks, D.P., Taylor, C., Sommer, K., Treeby, M.B., 2017. Deficit irrigation of almond trees did not decrease yield. *Acta Hort.* 1150, 251–259. <https://doi.org/10.17660/ActaHortic.2017.1150.35>.
- Narducci, J., Quintas-Soriano, C., Castro, A., Som-Castellano, R., Brandt, J.S., 2019. Implications of urban growth and farmland loss for ecosystem services in the western United States. *Land Use Policy* 86, 1–11. <https://doi.org/10.1016/j.landusepol.2019.04.029>.
- Németh, J., Langhorst, J., 2014. Rethinking urban transformation: temporary uses for vacant land. *Cities* 40, 143–150. <https://doi.org/10.1016/j.cities.2013.04.007>.
- Newman, G., Park, Y., Bowman, A., Jung Lee, R., 2018. Vacant urban areas: causes and interconnected factors. *Cities* 72, 421–429. <https://doi.org/10.1016/j.cities.2017.10.005>.
- Nicholls, E., Ely, A., Birkin, L., Base, P., Goulson, D., 2020. The contribution of small-scale food production in urban areas to the sustainable development goals: a review and case study. *Sustain.* <https://doi.org/10.1007/s11625-020-00792-z>.
- Padeiro, M., 2016. Conformance in land-use planning: the determinants of decision, conversion and transgression. *Land Use Policy* 55, 285–299. <https://doi.org/10.1016/j.landusepol.2016.04.014>.
- Pérez-Soba, M., Maas, R., 2015. Scenarios: Tools for Coping With Complexity and Future Uncertainty? The Tools of Policy Formulation: Actors, Capacities, Venues and Effects. pp. 52–75. <https://doi.org/10.4337/9781783477043.00014>.
- Prévost, A., Robert, S., 2016. Local spatial planning practices in four French Mediterranean coastal territories under pressure. *Land Use Policy* 56, 68–80. <https://doi.org/10.1016/j.landusepol.2016.04.034>.
- Prgomet, I., Pascual-Seva, N., Morais, M., Aires, A., Barreales, D., Castro Ribeiro, A., Silva, A.P., Barros, A., Gonçalves, B., 2020. Physiological and biochemical performance of almond trees under deficit irrigation. *Sci. Hortic.* 261, 108990. <https://doi.org/10.1016/j.scienta.2019.108990>.
- Pumain, D., 2004. Urban sprawl: is there a French case. In: Richardson, H.W., Bae, C.C. (Eds.), *Urban Sprawl in Western Europe and the United States*, Ashgate, pp. 137–157.
- Ragkos, A., Theodoridis, A., 2016. Valuation of environmental and social functions of the multifunctional Cypriot agriculture. *Land Use Policy* 54, 593–601. <https://doi.org/10.1016/j.landusepol.2016.03.023>.
- Rega, C., Helming, J., Paracchini, M.L., 2019. Environmentalism and localism in agricultural and land-use policies can maintain food production while supporting biodiversity. Findings from simulations of contrasting scenarios in the EU. *Land Use Policy* 87 <https://doi.org/10.1016/j.landusepol.2019.05.005>.
- Renting, H., Rossing, W.A.H., Groot, J.C.J., Ploeg, J.D.Van Der, Laurent, C., Perraud, D., Stobbelaar, D.J., Ittersum, M.K.Van, 2009. Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework. *J. Environ. Manag.* 90, S112–S123.
- Ricart, S., Kirk, N., Ribas, A., 2019. Ecosystem services and multifunctional agriculture: unravelling informal stakeholders' perceptions and water governance in three European irrigation systems. *Environ. Policy Gov.* 29 (1), 23–34. <https://doi.org/10.1002/eet.1831>.
- Rounsevell, M.D.A., Reginster, I., Araújo, M.B., Carter, T.R., Dendoncker, N., Ewert, F., House, J.I., Kankaanpää, S., Leemans, R., Metzger, M.J., Schmit, C., Smith, P., Tuck, G., 2006. A coherent set of future land use change scenarios for Europe. *Agric. Ecosyst. Environ.* 114 (1), 57–68. <https://doi.org/10.1016/j.agee.2005.11.027>.
- Saiz, A., 2010. The geographic determinants of housing supply. *Q. J. Econ.* 125 (3), 1253–1296. <https://doi.org/10.1162/qjec.2010.125.3.1253>.
- Salvati, L., 2019. Farmers and the city: urban sprawl, socio-demographic polarization and land fragmentation in a mediterranean region, 1961–2009. *City Cult. Soc.* 18, 100284. <https://doi.org/10.1016/j.ccs.2019.03.001>.
- Salvati, L., Munafò, M., Morelli, V.G., Sabbì, A., 2012. Low-density settlements and land use changes in a Mediterranean urban region. *Landscape Urban Plan.* 105, 43–52. <https://doi.org/10.1016/j.landurbplan.2011.11.020>.
- Salvati, L., Morelli, V.G., Rontos, K., Sabbì, A., 2013. Latent exurban development: city expansion along the rural-to-urban gradient in growing and declining regions of Southern Europe. *Urban Geogr.* 34, 376–394. <https://doi.org/10.1080/02723638.2013.778675>.
- Sanches, P.M., Mesquita Pellegrino, P.R., 2016. Greening potential of derelict and vacant lands in urban areas. *Urban For. Urban Green.* 19, 128–139. <https://doi.org/10.1016/j.ufug.2016.07.002>.
- Santa Olalla Manas, M., Soria, A., Ramirez, A., 2003. Validation of the CORINE land cover database in a pilot zone under semi-arid conditions in La Mancha (Spain). *Cybergeo.* <https://doi.org/10.4000/cybergeo.4233>.
- Sanz Sanz, E., Martinetti, D., Napoleone, C., 2018. Operational modelling of peri-urban farmland for public action in Mediterranean context. *Land Use Policy* 75, 757–771.
- Schmit, C., Rounsevell, M.D.A., La Jeunesse, I., 2006. The limitations of spatial land use data in environmental analysis. *Environ. Sci. Policy* 9, 174–188. <https://doi.org/10.1016/j.envsci.2005.11.006>.
- Scorsino, C., Debolini, M., 2020. A Mixed Approach for Multi-Scale Assessment of Land System Dynamics and Future Scenario Development on the Vaucluse Department (Southeastern France). *Land* 9, 180. <https://doi.org/10.3390/land9060180>.
- Seyedmohammadi, J., Sarmadian, F., Jafarzadeh, A.A., McDowell, R.W., 2019. Development of a model using matter element, AHP and GIS techniques to assess the suitability of land for agriculture. *Geoderma* 352, 80–95. <https://doi.org/10.1016/j.geoderma.2019.05.046>.
- Sinha, P., Griffith, D.A., 2019. Incorporating sprawl and adjacency measures in land-use forecasting model: A case study of Collin County, TX. *Trans. GIS* 23 (4), 745–768. <https://doi.org/10.1111/tgis.12554>.
- Smith, J., Xiaoxiao, L., B.L., Turner, I., 2017. Lots for greening: identification of

- metropolitan vacant land and its potential use for cooling and agriculture in Phoenix, AZ, USA. *Appl. Geogr.* 85, 139–151. <https://doi.org/10.1016/j.apgeog.2017.06.005>.
- Spilanis, L., 2009. Profile of sustainability in some Mediterranean tourism destinations. Plan Bleu/UNEP/MAP Regional Activity Centre. Available at: http://planbleu.org/sites/default/files/publications/note_methodo_profil_durabiliteuk.pdf.
- Syndicat Mixte Provence Méditerranée, 2009. Schéma De Cohérence Territoriale, Approuvé Le 16 Octobre 2009. .
- Tóth, G., 2012. Impact of land-take on the land resource base for crop production in the European Union. *Sci. Total Environ.* 435–436, 202–214. <https://doi.org/10.1016/j.scitotenv.2012.06.103>.
- UNEP, 2012. Green economy in a blue world. In: 15th Global Meeting of the Regional Seas Conventions and Action Plans. Montego Bay, Jamaica. .
- UNEP, 2017. Mediterranean Quality Status Report. . https://www.medqsr.org/sites/default/files/inline-files/2017MedQSR_Online_0.pdf.
- Vannier, C., Bierry, A., Longaretti, P.-Y., Nettier, B., Cordonnier, T., Chauvin, C., Bertrand, N., Quétier, F., Lasseur, R., Lavorel, S., 2019. Co-constructing future land-use scenarios for the Grenoble region, France. *Landsc. Urban Plan.* 190, 103614. <https://doi.org/10.1016/j.landurbplan.2019.103614>.
- Zeza, A., Tasciotti, L., 2010. Urban agriculture, poverty, and food security: empirical evidence from a sample of developing countries. *Food Policy* 35 (4), 265–273.

#5 - ARTICLE

USING BAYESIAN NETWORKS FOR ENVIRONMENTAL HEALTH RISK ASSESSMENT

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2021 (Epub et preprint), 2022 (publication en revue), *Environmental Research*, Volume 204, Part B, 112059

<https://doi.org/10.1016/j.envres.2021.112059>

<https://www.sciencedirect.com/science/article/pii/S0013935121013542>

<https://hal.archives-ouvertes.fr/hal-03347898/>

Dans cet article, l'espace est au cœur de la recherche, et notamment sa capacité à entrer dans les corps (de l'espace au corps) et à induire des maladies. Cet article expose une chaîne méthodologique inédite qui repose sur les réseaux bayésiens (Intelligence Artificielle, algorithmes non supervisés et supervisés). La méthodologie employée a permis de révéler à très fine échelle (IRIS), et en faisant appel à 178 variables de natures différentes (polluants atmosphériques, bio-indication et bio-imprégnation lichéniques, socio-économiques, sanitaires) :

- un lien entre cadmium et diabète chez les plus de 65 ans au sein du Pays de Martigues pris en étau entre un des plus grands complexes pétrochimiques européens (Lavéra²²) qu'il abrite et les émissions de Fos-sur-Mer ;
- un lien entre le *vanadium* (présent naturellement dans le pétrole brut) et des maladies respiratoires avérées ;
- plusieurs effets de seuil, comme un seuil actif pour le SO₂ dès 6 µg/m³ (alors que la norme est établie à 50 µg/m³), ou bien encore, dès que l'*acide fluorhydrique* dépasse 0.0028 µg/m³, ce qui se traduit par plus de cancers du poumon chez les 15-65 ans, enfin lorsque le *benzo[k]fluoranthène* dans sa phase particulaire s'approche de 0.672 µg/m³ plus de séjours hospitaliers respiratoires chez les 15-65 ans sont enregistrés dans les hôpitaux alentours ;
- une vulnérabilité différenciée aux polluants selon l'âge ;
- des comorbidités entre maladies respiratoires et cardiovasculaires (confirmant les connaissances de la littérature) ;
- l'influence de la socio-économie (familles monoparentales, sortie du système scolaire sans qualification à 15 ans) sur certaines pathologies (maladies cardio-vasculaires dues à des conditions de vie et/ou de travail difficiles, qui peuvent donc se cumuler).

Enfin, plus de 120 analyses de sensibilité ont mis en lumière des effets cocktails particulièrement délétères sur la santé des habitants dans certains quartiers. La méthodologie exposée est facilement transposable pour toute personne s'intéressant à ces questions de pollution de l'air sur la santé.

²² <http://www.naphtachimie.com/index.php/plateforme>



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journal homepage: www.elsevier.com/locate/envres

Using Bayesian networks for environmental health risk assessment

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ARTICLE INFO

Keywords:

Bayesian networks
Biomonitoring
Health
Lichens
Risk assessment

ABSTRACT

The study investigated the potential relationships between air pollution, socio-economy, and proven pathologies (e.g., respiratory, cardiovascular) within an industrial area in Southern France (*Etang de Berre*), gathering steel industries, oil refineries, shipping, road traffic and experiencing a Mediterranean climate. A total of 178 variables were simultaneously integrated within a Bayesian model at intra-urban scale. Various unsupervised and supervised algorithms (maximum spanning tree, tree-augmented naive classifier) as well as sensitivity analyses were used to better understand the links between all variables, and highlighted correlations between population exposure to air pollutants and some pathologies. Adverse health effects (bronchus and lung cancers for 15–65 years old people) were observed for hydrofluoric acid at low background concentration ($<0.003 \mu\text{g m}^{-3}$) while exposure to particulate cadmium ($0.210\text{--}0.250 \mu\text{g m}^{-3}$) disrupts insulin metabolism for people over 65 years-old leading to diabetes. Bronchus and lung cancers for people over 65 years-old occurred at low background SO_2 concentration ($6 \mu\text{g m}^{-3}$) below European limit values. When benzo[k]fluoranthene exceeded $0.672 \mu\text{g m}^{-3}$, we observed a high number of hospital admissions for respiratory diseases for 15–65 years-old people. The study also revealed the important influence of socio-economy (e.g., single-parent family, people with no qualification at 15 years-old) on pathologies (e.g., cardiovascular diseases). Finally, a diffuse polychlorinated biphenyl (PCB) pollution was observed in the study area and can potentially cause lung cancers.

1. Introduction

Outdoor air pollution is a major public health issue in the world (e.g., Lelieveld et al., 2015; Cohen et al., 2017; Khaniabadi et al., 2018; Sicard et al., 2019; Rovira et al., 2020) leading to half a million premature deaths in the European Union in 2015 (European Environment Agency, 2018). Industrial activities, motor vehicle emissions, transport, and domestic heating are different sources of air pollution in urban areas (European Environment Agency, 2019) releasing air pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), sulphur oxides (SO_x), black carbon, polycyclic aromatic hydrocarbon (PAH) and particulate matter (PM) in the atmosphere (European Environment Agency, 2019). In Europe, 74% of the population lives in cities (European Union, 2016), and is usually exposed to about 200 air pollutants or classes of air pollutants (Sicard et al., 2012, 2021). Previous studies have reported an association between ambient air pollution exposure and mortality and hospital admissions for respiratory and cardiovascular

diseases (e.g., Amoatey et al., 2020; Pascal et al., 2014; Cai et al., 2016; Cohen et al., 2017; Guo et al., 2018; Mannucci et al., 2019; Yang et al., 2020a, 2020b; Khaniabadi et al., 2019; Park et al., 2021). The European Union and the World Health Organization regulate the concentrations of air pollutants by setting limit and target values for the protection of human health (e.g., Directive, 2008/50/EC European Council, WHO, 2006 Air Quality Guidelines 2006).

Martigues conurbation is an urban-industrial area located in Southern France, open onto the Mediterranean Sea, nearby the biggest industrial area in Southern Europe, namely Berre Pond (*Etang de Berre*). The pond is surrounded by major industrial complexes and oil refineries, and experiences high levels of air pollutants impacting the health and well-being of citizens (Allen et al., 2017; Goix et al., 2018; Mantey et al., 2019; Pérez, 2016, 2019). From 2013, epidemiological and scientific studies were carried to investigate the health effects of air pollution on local population (Mantey et al., 2019). The REVELA study (Rein, VESSIE et Leucémie Aigüe) was conducted by Santé Publique France between 2013

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Received 12 August 2021; Received in revised form 9 September 2021; Accepted 10 September 2021

Available online 15 September 2021

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Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/envres

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Received 12 August 2021; Received in revised form 9 September 2021; Accepted 10 September 2021

Available online 15 September 2021

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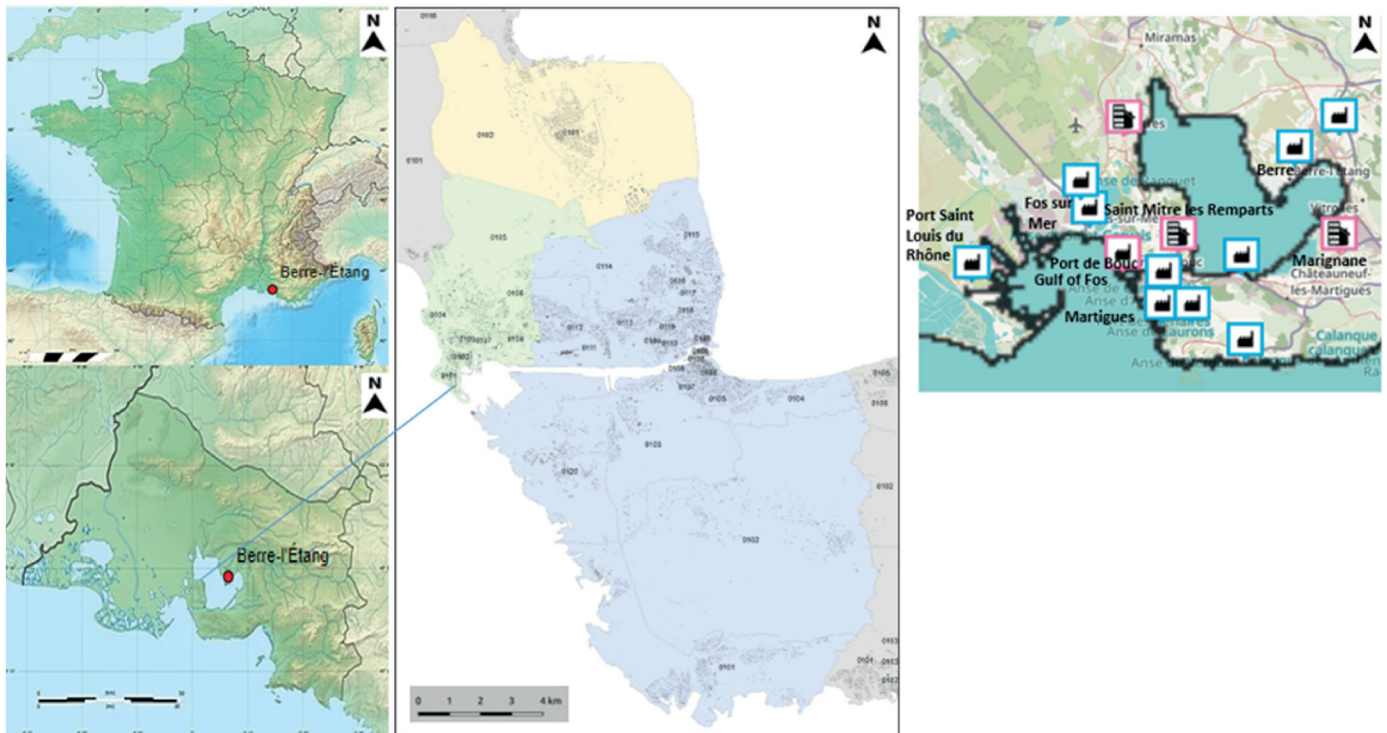


Fig. 1. Location of the study area and air quality monitoring stations (blue/pink: industrial & pre-urban/urban station; square: fixed station. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and 2016, focussing on kidney and bladder cancers and acute myeloid leukaemia. This study showed that the incidence rate for bladder cancers, among people >20 years-old, was higher than those observed at the national level (Mantey et al., 2019). In 2015, the Fos-EPSEAL study (*Étude Participative en Santé Environnement Ancrée Localement*) was conducted in two urban areas (Fos-sur-Mer and Port-Saint-Louis-du-Rhône) and allowed collecting health data on a random sample of inhabitants through a participatory approach (Allen et al., 2017; Fortin et al., 2017; Jeanjean et al., 2021). Chronic diseases and acute symptoms were often observed in both cities. The prevalence of asthma in adults, of cancers (notably for women) and diabetes (type 1) is significantly higher in both cities than at national level (Allen et al., 2017; Jeanjean et al., 2021). Respiratory ailments (except hayfever) concern almost one in two adults and one in four children (Jeanjean et al., 2021). Then, the INDEX (*Etude d'imprégnation de la population aux polluants atmosphériques de la zone industrialo-portuaire de Fos-sur-Mer*) study was conducted in 2016 in Fos-sur-Mer by the *Institut Ecocitoyen pour la Connaissance des Populations* on blood and urine samples of 138 inhabitants, and revealed an over-impregnation by lead and two heptachlor furans (i.e., 1,2,3,4,6,7,8-HpCDF and 1,2,3,4,7,8,9 HpCDF), characteristic of industrial emissions, and by benzene for people over 65 years-old (Goix et al., 2018). In this area, gardening was associated with a high impregnation by polychlorinated biphenyl (PCBs), and the consumption of vegetables from garden was associated with a high impregnation by cadmium (Goix et al., 2018). Similarly, the consumption of local seafood (fish, shellfish, and sea fruits) was associated with a high impregnation by PCBs, dioxins/furans, mercury, and chrome (Goix et al., 2018). Finally, the SCE-NARII (*Simulation de scénarii de pollution atmosphérique pour une Evaluation des Risques Sanitaires - Zone Etang de Berre*) and POLIS (*Plan d'Observation des Polluants d'Intérêt Sanitaire*) studies were conducted in 2010 in 66 cities around the Berre Pond and allowed calculating an excess risk considering 39 substances (AtmoSud, 2016; AtmoSud, 2015). The limit values were exceeded for nitrogen dioxide (NO₂), fine particles with an aerodynamic diameter lower than 2.5 and 10 µm (PM_{2.5} and PM₁₀, respectively), diesel particles, benzene, 1,3-Butadiene and 1,

2-Dichloroetane. Some areas have presented higher level of risk i.e., Gulf of Fos, Martigues, Berre, Marignane and road transport axes.

In Southern France, where air pollution is a major public health issue (Salameh et al., 2018; Khaniabadi and Sicard, 2021), most of published studies focused on the health impacts of exposure to common ambient air pollutants such as PM, NO₂, and tropospheric ozone (e.g., InVS, 2008; Pascal et al., 2014; Sicard et al., 2019). For the first time, a risk assessment was focused on an industrial area in Southern France (Berre Pond as study case). Using Bayesian networks, this study aimed to better understand the relationships between air pollution, biodiversity (lichens), socio-economy, and proven pathologies by age group (i.e., 178 variables in total, Tab. 1S) at intra-urban scale in 2015.

2. Materials and methods

2.1. Study area

Martigues conurbation gathers three municipalities i.e., Martigues, Port-de-Bouc, and Saint-Mitre-les-Remparts with a total population of 71,000 inhabitants in 2015 (Fig. 1), and experiences a Mediterranean climate, with an annual mean rainfall and air temperature of 606 mm and 19.5 °C, respectively. Along the French Mediterranean coastline, air pollution is a major public health issue, mainly due to industrial development, oil refineries, road traffic increment, high insolation, and sea/land breeze recirculation (Salameh et al., 2018; Sicard et al., 2019), including tropospheric ozone (O₃) with rising levels in cities in Southern France (on average + 0.31 ppb per year) since the early 2000s (Sicard, 2021).

2.2. Health data

We have selected some pathologies linked to air pollution (e.g., Suissa et al., 2013; Adam et al., 2015; Atkinson et al., 2015; Münzel et al., 2016; Mazonq et al., 2017; Guo et al., 2018; Doiron et al., 2019; Hwang et al., 2020) i.e., corresponding to the following International

Table 1a

Annual mean concentration of each **gaseous air pollutant** (in $\mu\text{g}/\text{m}^3$) for the year 2015 in the study area. M: model, m: measurement, * the background is taken at the level of a point distant from any source (Etang de Rolland area). Limit and target values for air pollutants as given in the European Ambient Air Quality Directive (Directive, 2008/50/EC) for the protection of human health.

Pollutant	Model/ Measurement	Concentration ($\mu\text{g}/\text{m}^3$)	EU limit and target value
Sulphur dioxide - SO ₂	M + m	6	Number of exceedance of 24-h mean (125 $\mu\text{g m}^{-3}$) ^a
Nitrogen dioxide - NO ₂	M + m	8.0	Annual mean (40 $\mu\text{g m}^{-3}$) ^b
Carbon monoxide - CO	M + m	263	
Hydrochloric acid - HCl	M	8.23E-04	
Hydrofluoric acid - HF	M	5.29E-04	
Benzene - C ₆ H ₆	M + m	0.7	Annual mean (5 $\mu\text{g m}^{-3}$)
Benzo [a]pyrene - BaP	M	2.42E-06	
Polycyclic Aromatic Hydrocarbons - PAHs	M	2.11E-3	Annual mean (1.0 ng BaP/m ³)
Dioxins and furans - PCDD and PCDF	M	2.31E-10	
Mercury - Hg	M + m	1.06E-06	
Benzo [a]anthracene - BaA	M	3.42E-06	
Benzo [b]fluoranthene - BbF	M	2.68E-06	
Benzo [k]fluoranthene - BkF	M	1.88E-06	
Indeno [1,2,3-c,d]pyrene - IcdP	M	1.52E-06	
Dibenzo [a,h]anthracene - DahA	M	3.12E-07	
Fluoranthene - Fluoran	M	2.24E-05	
Polychlorobiphenyls - PCB	M	5.663E-07	
1,3-butadiene - CAH ₆	M + m	0.13	
Hydrogen sulphide - H ₂ S	M	5.72E-06	
1,2-dichloroethane - DCE	M + m	0.03	

^a The 24-h SO₂ mean concentration does not to exceed 125 $\mu\text{g m}^{-3}$ more than 3 times a year.

^b The annual mean NO₂ concentration does not to exceed 40 $\mu\text{g m}^{-3}$.

Classification of Diseases ICD-10 codes: I00 to I199 all diseases of the circulatory system (e.g., ischemic heart diseases, coronary diseases), J00 to J199 all diseases of the respiratory system (e.g., asthma, bronchitis, bronchiolitis, bronchopulmonary diseases, laryngitis, pharyngitis, sinusitis, tracheitis), E10 to E14 all diabetes types (type 1 insulin-dependent, and type 2 non-insulin-dependent), C34 all types of lung and bronchus cancers, C67 for bladder cancer, and C64 for kidney cancer.

For each pathology, we retrieved the numbers of hospital admissions, classified into three age groups (<15, 15–65, and >65 years-old) for patients having stayed either at the Martigues Centre Hospitalier, the Martigues Clinique, the Paoli Calmettes Institute or in one of the five nearby public hospitals (Hôpital de la Timone, Hôpital de la Conception, Hôpital Nord, Sainte Marguerite and Salvator) in 2015. We did not obtain the “gender” in addition to the “age” because the use of both information mutually was considered as discriminatory by the National Commission on Informatics and Liberty. For statistical studies, the National Institute for Statistics and Economic Studies (INSEE) developed a system for dividing the country into units of equal size, known as IRIS 2000. In French, IRIS is an acronym of “aggregated units for statistical information”, and the 2000 refers to the target size of 2000 residents per basic unit. IRIS represented the fundamental unit for dissemination of infra-municipal data. The fact of dealing with a fine territorial scale imposes having enough cases per IRIS and consequently to work by

Table 1b

Annual mean concentration of each **particulate air pollutant** (in $\mu\text{g}/\text{m}^3$) for the year 2015 in the study area. M: model, m: measurement, * the background is taken at the level of a point distant from any source (Etang de Rolland area). Limit and target values (threshold in $\mu\text{g m}^{-3}$) for air pollutants as given in the European Ambient Air Quality Directive (Directive, 2008/50/EC) for the protection of human health.

Pollutant	Model/ Measurement	Concentration ($\mu\text{g}/\text{m}^3$)	EU limit and target value
Particles with an aerodynamic diameter lower than 10 μm - PM ₁₀	M + m	16.0	40 ^a
Particles with an aerodynamic diameter lower than 2.5 μm - PM _{2.5}	M + m	10.0	25
Benzo-a-pyrene - BaP	M + m	1.63E-04	
Polycyclic Aromatic Hydrocarbons - PAHs	M	1.38E-03	Annual mean (1.0 ng BaP/m ³)
Dioxins and furans - PCDD and PCDF	M + m	2.16E-08	
Lead - Pb	M + m	4.02E-03	Annual mean (0.5)
Arsenic - As	M + m	3.86E-04	Annual mean (0.006 $\mu\text{g m}^{-3}$)
Cadmium - Cd	M + m	1.39E-04	Annual mean (0.005 $\mu\text{g m}^{-3}$)
Nickel - Ni	M	2.03E-04	Annual mean (0.02 $\mu\text{g m}^{-3}$)
Mercury - Hg	M + m	0	
Chromium - Cr	M + m	1.97E-03	
Chromium VI - Cr VI	Cr VI/total Cr	1.40E-04	
Copper - Cu	M + m	3.75E-03	
Selenium - Se	M + m	3.65E-04	
Vanadium - V	M + m	2.51E-03	
Zinc - Zn	M + m	1.93E-02	
Benzo [a]anthracene - BaA	M + m	1.38E-04	
Benzo [b]fluoranthene - BbF	M + m	3.09E-04	
Benzo [k]fluoranthene - BkF	M + m	1.36E-04	
Indeno [1,2,3-c,d]pyrene - IcdP	M + m	2.32E-04	
Dibenzo [a,h]anthracene - DahA	M + m	4.20E-05	
Fluoranthene - Fluoran	M	8.28E-06	
Polychlorobiphenyls - PCB	M	6.30E-07	
Diesel particles - PM ₁₀ diesel	diesel/PM10	5.00E-01	

^a For the protection of human health, the annual mean PM₁₀ concentration does not to exceed 40 $\mu\text{g m}^{-3}$ (Directive, 2008/50/EC).

batches of codes (e.g., I00 to I199) rather than by separated codes.

2.3. Air pollution data

In risk assessment, exposure is considered equal to air pollutants concentrations at a specific point in space and time (Bogaert et al., 2009). The data for 44 pollutants were provided by the Certified Associations of Air Quality Monitoring in Southeastern France (Atmo Sud) and obtained from January 1, 2015 to December 31, 2015 (Table 1). In the study area, there are 11 industrial and 4 urban monitoring stations (Fig. 1). Only background stations, with more than 90% of validated hourly data in a year, were selected to better represent average exposure (Directive, 2008/50/EC). AtmoSud has developed an Information Technology tool producing maps of annual mean concentrations for air pollutants at 3×3 km of spatial resolution from both modelling (Atmospheric Dispersion Modelling System) and *in situ* measurements (AtmoSud, 2016). The air pollution maps were produced for built-up areas on which a 100 m buffer was applied to have a more accurate

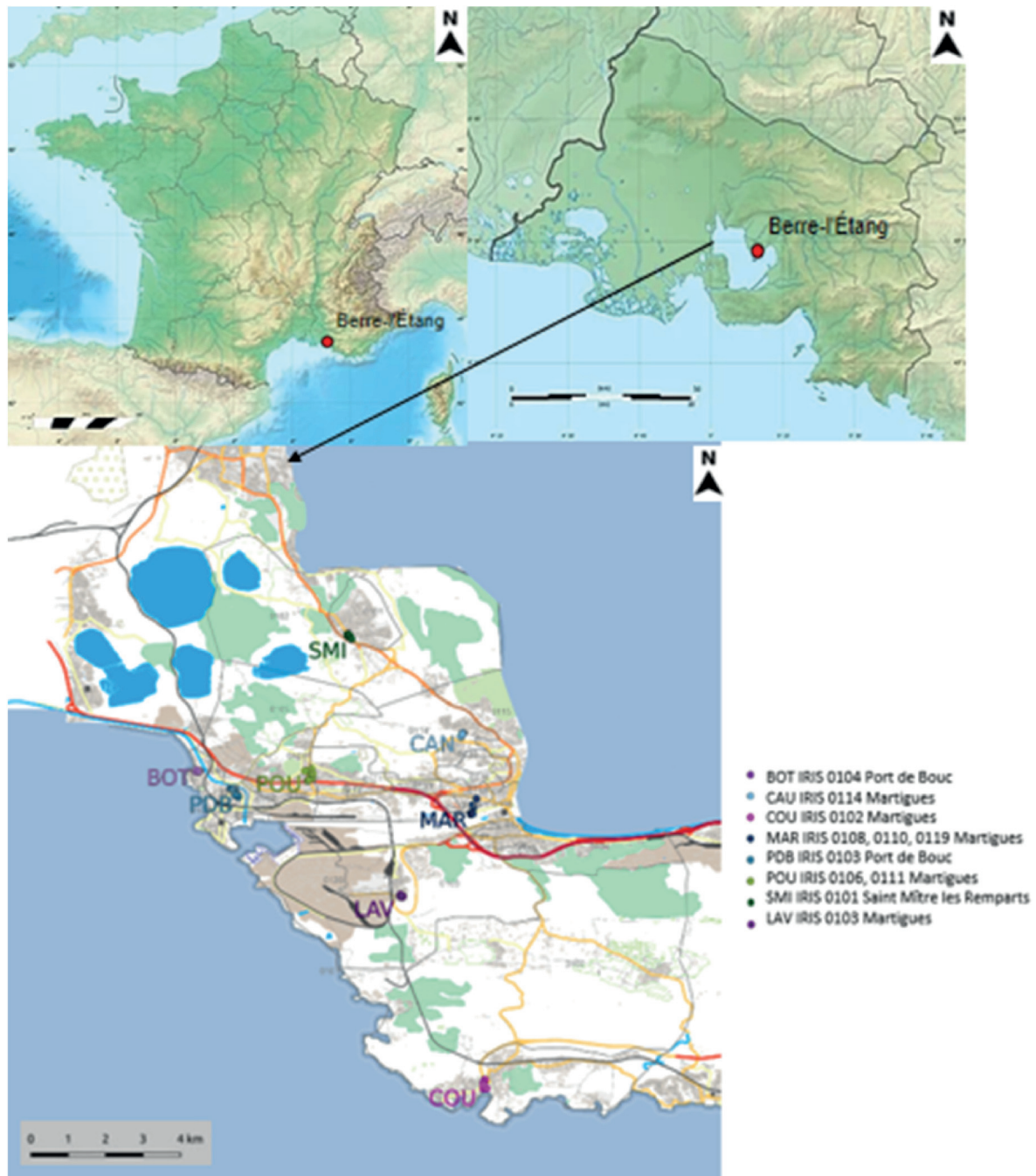


Fig. 2. Location of the lichen sample plots within the study area (source IECP).

measurement of pollution in the population's living spaces (Fig. 1S).

2.4. Lichens: bio-indication and bio-impregnation

In addition to the 44 air pollution variables, 109 chemical analyses (bio-impregnation measurements) were carried out on lichen samples in September 2017 by the *Institut EcoCitoyen pour la Connaissance des Pollutions* (IECP) on specific plots (Fig. 2). For spatial representativeness of each plot, a 500 m radius around the bio-impregnation plot was considered, as recommended by the IECP (Ratier et al., 2018). A variability of maximum 35% for metals and 30% for various congeners PAH has been measured in a plot within a 500 m radius (Ratier et al., 2018). Samples were taken with a knife after humidification and stored at + 39.2 °F for maximum 5 days. The impurities were removed, and the

samples were frozen at - 113 °F, then lyophilized at - 131 °F before to be crushed and again frozen at - 113 °F. The chemical analyses were carried out at the laboratory of La Timone (Aix-Marseille University, Faculty of Pharmacy) for PAHs and PCBs, as well as at the "La Drôme Laboratoires" in Valence, for Dioxins and Furans. The impregnation results represent a 6-month integration. These measurements on lichens are useful to limit a confounding factor that could be linked to the residents' way of life more than the effects of air pollution (notably addiction to smoking); most of them are in IRIS area known to be socio-economically disadvantaged.

Looking to the bio-indication, several indicators relating to the biodiversity (Chao et al., 2016) were calculated (abundance of species, lichen diversity value, Index of Atmospheric Purity, and the Shannon's diversity index). The Index of Atmospheric Purity is used for the



Fig. 3. The bio-indication survey (source IECP).

assessment of air quality in polluted urban areas based on phytosociological data of epiphytic lichen communities (Chao et al., 2016). The survey was done on 10 trees per plot, on all four faces of the tree and according to a 5-box observation grid (Fig. 3). The frequency of each species is the ratio of the number of observations of the species per plot divided by 200 (10 trees * 4 faces * 5 boxes).

2.5. Socio-economic data

We have also retrieved seven socio-economic variables, as the air pollution effects will not affect everyone in the same way (Jiao et al., 2018, Næss et al., 2007). The disadvantaged communities might be more exposed to air pollution, but also might have less resources to counter them e.g., by postponing medical consultations by lack of resources, or asthma poorly controlled (Temam, 2017, Fosse-Edorh et al., 2014). These variables were provided by the INSEE from the sub-municipal databases in 2017, including: i) the number of people living in households for more than 10 years (P14_PMEN_ANEM10P), ii) number of unschooled people of at least 15 years-old and without qualification (P14_NSCOL15P_DIPLO), iii) number of people living in single-parent households (C14_PMEN_MENFAMMONO), iv) number of people in main homes occupied by tenants (P14_NPER_RP_LOC), v) number of immigrants (P14_POP_IMM), vi) number of unemployed in the 15-64 years-old age group (P14_CHOM1564), and vii) median income (DEC_MED14).

For comparison between each IRIS area, the above variables were used as percentage of the IRIS total population. All these indicators were

used to know the level of precariousness or social disadvantage in each IRIS area. We used disaggregated variables to precisely investigate on which variables differences between IRIS appear. In total, 178 variables (Tab. 1S) were measured within 30 IRIS areas, corresponding to 5340 data. These data were integrated within the same Bayesian model.

2.6. The Bayesian networks

The Bayesian networks allow establishing relations among various variables to analyse their interrelations and combinations by using probabilities (Pearl, 2009a,b; Sottas et al., 2009; Pearl, 2014; Conrady and Jouffe, 2015; Pearl and Mackenzie, 2018). The probabilistic approach is particularly well suited to health risk issues, because relations between variables are not always deterministic but rather indirect (Pearl, 2009a; b, 2014). Moreover, Bayesian networks allow at the same time modelling knowledge and producing new knowledge by revealing causal relations until now hidden (causal inference), or latent variables, and this, within the framework of unsupervised analysis (causal knowledge discovery). They bring added value in terms of knowledge and are an interesting tool for quantitative modelling of complex systems in uncertain fields, whether health or others. This is the reason why they are increasingly used worldwide, in fields as diverse as industry, finance, marketing, security, and many others (Weber and Simon, 2016).

A Bayesian network is made up of two elements: a conceptual map and a database (Pearl, 2009a,b). The conceptual map defines the network structure used for knowledge organization and representation. This map is either built from the database, or from expert's knowledge of the investigated subjects. In our case, we decided to extract knowledge included in our database. All processing was carried out using the specific software devoted to Bayesian networks, i.e., BayesiaLab 7.0.1. The conceptual map is visually represented by directed arcs representing the causal relations linking the variables, represented by nodes (Fig. 2S). Between the nodes, causal relationships are drawn using an unsupervised artificial intelligence learning algorithm of the "maximum spanning tree" type. Thereafter, the conceptual map of the 178 variables appears in unsupervised form (Fig. 4).

2.7. Statistical and sensitivity analyses

Data were tested for normal distribution by the Kolmogorov-Smirnov one-sample D test. The correlation analyses were performed using the parametric Pearson test for annual data (Table 2). For health data analysis, we also applied a Hierarchical Cluster Analysis (HCA) to group similar objects into groups called clusters. The distance between two clusters has been computed based on the Euclidean distance. The main output of HCA is a dendrogram showing the hierarchical relationship between the clusters (Govender and Sivakumar, 2020). All health data and number of hospital admissions for each age group and IRIS area were normalized to the total population.

The relations between variables at a finer scale were investigated using sensitivity analyses for each of the 30 IRIS areas, taking simultaneously into account the 44 air pollutants, the 17 variables obtained from the lichen surveys and acting on pathologies (Chlorobiphenyl CB169, TEQ-2005, CB187, 2,3,4,7,8-PeCDF, As, 2,3,7,8-TeCDF, crustaceans, Lichen diversity value, CB149, CB114, CB157, CB20, CB28, Co, CB194, Lichen abundance, PCB indicators), and the 7 socio-economic variables, i.e. a total of 68 variables (Fig. 5S). Fig. 6S represents all sensitivity analyses per pathology and enabled us to observe the heterogeneity between all IRIS areas.

3. Results and discussion

3.1. Analysis of the correlations

Looking the health variables (Table 2), we found that the number of

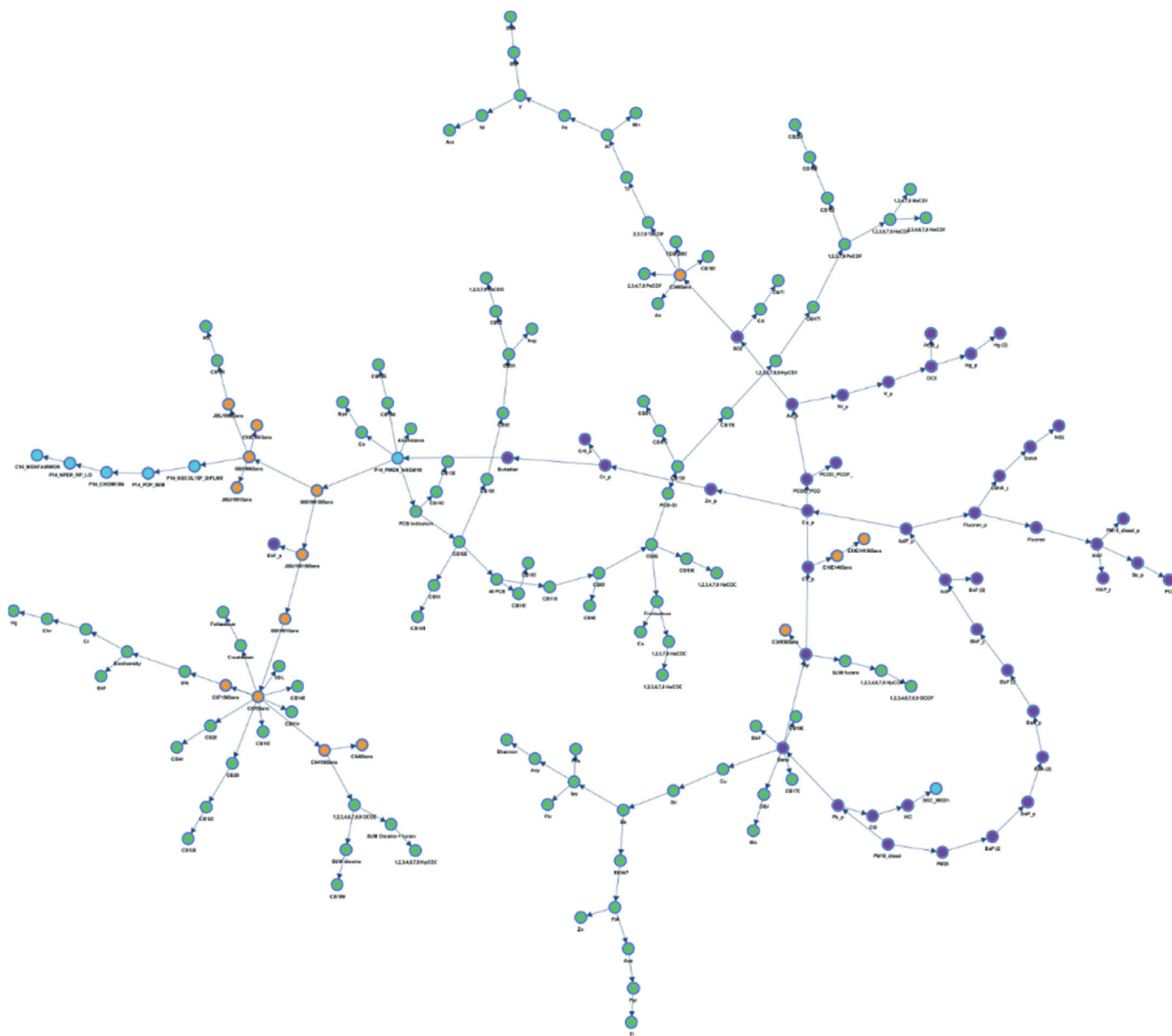


Fig. 4. The Bayesian network - Conceptual map of the 178 variables: orange for pathologies, green for variables resulting from lichens measurements, purple for air pollutants, and blue for socio-economic variables. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

people living the same IRIS area for more than 10 years (P14_PME-N_ANEM10P) is well correlated to the relative abundance of lichen species ($r = 0.70$). Higher relative abundance of lichen is related to more people living in the same area at long time, and this could be explained by the benefits provided by natural amenities and green infrastructure. Indeed, urban green spaces can reduce air pollution, regulate air temperature, but also reduce noise and provide recreational, social, psychological, and aesthetic benefits (Sicard et al., 2018). We found a negative correlation between the relative abundance of lichen species and Chlorobiphenyl CB194 ($r = -0.70$) while a positive correlation was found between the number of people living in the IRIS area for more than 10 years (P14_PME-N_ANEM10P) and carbon monoxide ($r = 0.60$), and cardiovascular diseases for 15-65 years-old people ($r = 0.65$). Significant correlations were found between cardiovascular and respiratory diseases ($r = 0.70$) for patients over 65 years-old, revealing a comorbidity which is well known by doctors (Carter et al., 2019), and also appearing in 15-65 years-old patients ($r = 0.52$). This is explained by the

chronicity of these pathologies as is the case with diabetes ($r = 0.73$). A strong correlation was observed between respiratory diseases for people >65 years-old and a dioxin-like PCB ($r = 0.78$) recognized for its toxicity, i.e., CB169 (Van den Berg et al., 2006). A relationship is observed ($r = 0.63$) between cardiovascular diseases for patients >65 years-old and the socio-economic variable “no qualification”, and between mean income and exposure to the hydrochloric acid ($r = -0.65$) meaning that more the households income increases less they are exposed to such pollutant. As regards bronchus and lung cancers for people >65 years-old, we observed positive relationships, in particular with CB187 ($r = 0.80$), TEQ-2005 ($r = 0.83$), 2,3,7,8-TeCDF ($r = 0.86$), 2,3,4,7,8-PeCDF ($r = 0.84$), As ($r = 0.78$) and SO_2 ($r = 0.62$). Concerning bladder cancer, relations appeared between people >65 years-old and Value of Lichen Diversity ($r = 0.67$), CB20 ($r = 0.64$), and two dioxin-like PCBs i.e., CB114 ($r = 0.85$) and CB157 ($r = 0.52$).

Table 2

Correlation analysis (Pearson test, r value) between the environmental, socio-economic and health variables. We reported here the more significant correlations i.e. with $r > 0.50$.

versus		r value
P14_PMEN_ANEM10P - Number of people living in the IRIS for more than 10 years	Abundance of lichen species	0.70
	Carbon monoxide - CO	0.60
	Cardiovascular diseases 15–65 years old	0.65
Cardiovascular diseases >65 years old	Respiratory diseases >65 years old	0.70
Cardiovascular diseases 15–65 years old	Respiratory diseases 15–65 years old	0.52
Cardiovascular diseases 15–65 years old	Cardiovascular diseases >65 years old	0.67
	Diabetes >65 years old	0.73
Diabetes 15–65 years old	Diabetes >65 years old	0.73
	Respiratory diseases >65 years old	0.78
Cardiovascular diseases >65 years-old	Hexachlorobiphenyl	
	No qualification at 15	0.63
Bronchus and lung cancers >65 years old	CB187: 2,2',3,4',5,5',6-Heptachlorobiphenyl	0.80
	TEQ-2005	0.83
Bronchus and lung cancers >65 years old	2,3,7,8 TeCDF	0.86
	2,3,4,7,8 PeCDF	0.84
Bronchus and lung cancers >65 years old	Arsenic - As	0.78
	Sulphur dioxide - SO ₂	0.62
Bladder cancers >65 years old	Lichen diversity	0.67
	CB20: 2,3,3'-Trichlorobiphenyl	0.64
Bladder cancers >65 years old	CB114: 2,3,4,4',5-Pentachlorobiphenyl	0.85
	CB157: 2,3,3',4,4',5'-Hexachlorobiphenyl	0.52
Diabetes >65 years old	Cd _p : particulate Cadmium	0.52
	Relative abundance of lichen species	-0.70
Mean income	CB194: 2,2',3,3',4,4',5,5'-Octachlorobiphenyl	
	Hydrochloric acid	-0.65

3.2. Interactions between variables

To deeply investigate the interactions between pathologies, air pollutants and socio-economy, we focussed on relationships between a pathology and a type of variable (either environmental or socio-economic). Here, we focussed on the interactions between respiratory diseases for people >65 years-old and CB169, and the interactions between diabetes for patients >65 years-old and the heavy metal, cadmium (Table 2).

3.2.1. Interactions between respiratory diseases & CB169

We found a significant correlation ($r = 0.78$) between respiratory diseases for people >65 years-old and CB169 (Table 2). To investigate the interactions between variables, first the relation was spotted in the Bayesian network (Fig. 5a), then we monitored the variables (Fig. 5b), and we saw what happens at the level of their modalities (Fig. 5c). The number of modalities corresponds to the number of classes requested (K-means 5 classes). What is particularly interesting now is to force one of these classes, for example the modality corresponding to the highest number of hospital admissions (here: number of stays >51.75), which then becomes green, and to observe how the associated probabilities of CB169 are then instantly updated. Thus, we observed that if we focus on the highest numbers of stays, the values of CB169 increase, mainly for the two last modalities (e.g., evolution from 16.67 in the initial monitoring to 31.86 in Fig. 5d). Which means that when we consider the highest numbers of hospital stays recorded for respiratory pathologies in the over 65 in this territory, it is in relation with the highest values of CB169 found in the lichen surveys. The most frequent modality (44.38%) has also been forced without showing in that case notable changes in the monitoring.

3.2.2. Interactions between diabetes & Cd

We found a significant correlation ($r = 0.52$) between diabetic people >65 years-old and particulate Cadmium (Table 2). Cadmium is absorbed in food (dry/wet deposition, air/soil pollution) and can disturb insulin metabolism in the pancreas (Schwartz et al., 2003; Buha et al., 2020). This relation is very strong (Fig. 4S) for the highest modality of diabetes patients (>45.1 number of stays) and concerns a value of Cd_p between 0.214 and 0.250 $\mu\text{g m}^{-3}$ (Fig. 4S). For the most frequent modality, the relation already appears with the lowest values of Cd_p (38.18% under or equal to 0.181 $\mu\text{g m}^{-3}$).

3.3. Health profiles of the IRIS areas

For instance, in IRIS 130560101 in Martigues, the probability to find people over 65 years-old with respiratory diseases is high, approximately 50%, followed by 15–65 years-old people with cardiovascular diseases, about 35% (Fig. 6). Based on the HCA, five groups with a similar health profile can be clearly distinguished (Fig. 7). The Group 1 includes atypical IRIS areas with the highest occurrence rates for all pathologies. The second Group differs from the others by less cardiovascular, respiratory and diabetes diseases, but a higher rate of lung cancers for people over 65 years-old (Fig. 7). In Group 3, we can observe high rates of cardiovascular diseases for young people (<15 years-old) and elderly i.e., over 65 years-old (1.21 on average), higher than in the first group (0.81 on average). The same is true for respiratory diseases from the age of 15 years-old with rates almost twice as high as those of Group 1 (1.33 versus 0.70). Diabetes for young people (<15 years-old) also individualises these IRIS areas. Bronchus and lung cancers for people over 65 years-old, without reaching the values of Group 2, are also noteworthy (0.62 on average), just like bladder cancers in the same age group, without nonetheless exceeding Group 1 (0.64 on average). In Group 4, we observed more cardiovascular diseases for people over 65 years-old (1.13 on average), respiratory diseases and a lower cancer rate for people over 65 years-old (1.13, 0.45) and people <15 years-old (0.74). Finally, Group 5 includes IRIS areas with pathology rates comparatively lower than in the other Groups. It can be used as control Group “out-of-area” for model validation with less exposed people to air pollution. However, the endocrine disruptors to which the population can be exposed via pesticides can induce the same pathologies (e.g., diabetes), which could confuse the “control cases” comparisons (Evangelou et al., 2016; Mendes et al., 2021).

3.4. IRIS health profiles and causal factors

The causal factor of health profiles can be either environmental and/or socio-economic, and the combination of both form the pathogenic spaces (Picheral, 1983). Based on the sensitivity analyses, we distinguished the IRIS areas according to the probability of prevalence of environmental and socio-economic factors. First, we have distinguished three IRIS profiles based on a cocktail of air pollutants (Sarigiannis and Hansen, 2012; Svingen and Vinggaard, 2016) with either many HAPs (7 IRIS areas), or many PCBs (8 IRIS areas), or other pollutants (15 IRIS areas).

In the HAPs group, the number of HAPs varied by a factor two (6–12 HAPs) with a direct impact on pathologies. Indeed, the severity of pathology depends on the number of HAPs due to the carcinogenic nature of each HAP (BaP, BaA, BbF, BkF, DahA, Fluoranthene, IcdP) and to their potential noxious mixing (ATSDR, 2012). The favourable socio-economy of the IRIS “Jonquières Foulettes” (income above average) seems to make up for the residents’ exposure, similarly to the IRIS “Coudoulière” but to a lesser extent due to less numerous HAPs. Looking the cocktail of PCBs, their health impact is well characterised by e.g., bladder cancers (IRIS Plan de Fossan) even at low doses due to their toxicity (ATSDR, 2012). Finally, the category “Others” refers to air pollutants that cannot be classified in the previous categories. It includes “traditional” air pollutants such as NO₂, SO₂, hydrofluoric acid (HF) and particulate

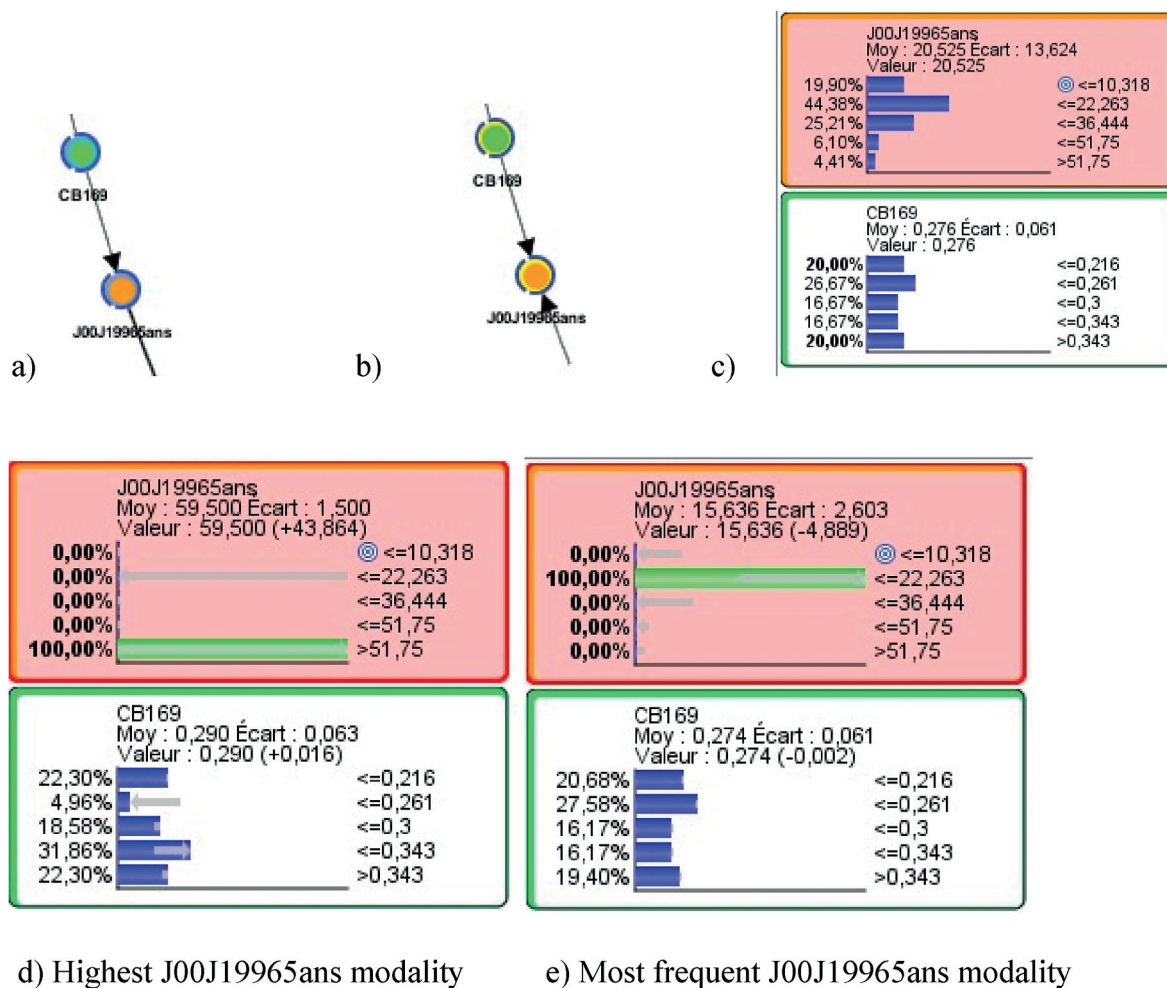


Fig. 5. Interactions between respiratory diseases for people >65 years-old (J00J19965) & CB169.

elements such as Zn, Cd, Cu and the PCDD_PCDF.

Based on the HCA dendrogram, people living in IRIS areas classified as Group 1 (Fig. 7S) was exposed to harmful pollutants: PCDD_PCDF at La Lèque, CB28 at Plan Fossan, Dibenzo (a, h)anthracene at Boudème, HF at PdB Centre and St-Jean Bergerie. In 4 of the 6 IRIS areas, socio-economy combines with air pollutants and corresponds to single-parent families. In fact, it is the prevailing variable for the IRIS “Rayettes”. Within IRIS areas of the Group 2 (Fig. 8S), people are exposed to PCBs (Tassy Est, St-Pierre and St-Julien), SO₂ (Tassy Ouest) and to vanadium at much higher levels than in other IRIS areas. The IRIS “Jonquières Est” was exposed to 11 different HAPs while the IRIS “Notre Dame Paradis” was exposed to NO₂. In Group 2, socio-economy (i.e., unschooled at 15 years-old and unemployment) had a pernicious impact. The type of pollutants (PCB, vanadium) and their multiplicity (11 different HAPs) could explain the pathologies found (i.e., bronchus, lung cancers and bladder cancers) in the IRIS areas of this Group 2 (Lees, 1980; ATSDR, 2012). In Group 3 (Fig. 9S), the IRIS “Ferrière” had a similar PCBs profile like the IRIS “St-Mitre Périphérie”. This IRIS area is simultaneously exposed to several pollutants (Co, Zn_p, Cr_p, Cr6_p, PCDD_PCDF, HCl, BkF_p) at low concentrations, except from BkF_p leading to respiratory diseases. As regards the IRIS “Gaps”, Hg is the most important air pollutant, followed by Co, Cu_p and HF, while the IRIS “Croix Sainte” is rather characterised by the presence of Zn_p, followed by several pollutants of the PCB type, and As. Finally, socio-economic variables seem to have a greater impact on the IRIS “Colline” (immigrant population, single-parent families, unemployment and unschooled 15 years-old, the latter variable having an impact on

cardiovascular diseases), and Cd_p, that disrupts insulin metabolism, is the only pollutant in this IRIS area. Starting from this 4th group (Fig. 10S), the number of hospital admissions is relatively low: both IRIS areas “Canto Perdrix” and “Les Comtes Est” stand out in regard to cardiovascular diseases for people over 65 years-old, with a prevalence of BkF_p for the IRIS “Canto Perdrix”. Here, we observed a disadvantaged socio-economy and a seemingly deleterious cocktail for “Les Comtes Est” (DCE, V_p, Hg and HF), since the impact is also observed on respiratory diseases for people over 65 years-old. Finally, the control Group (Fig. 11S) was characterised by an overall number of pathologies lower than elsewhere, and less dangerous pollutants and/or in lower quantity than in other IRIS areas of Groups 1–4. Moreover, socio-economy being more favourable (except in the IRIS “Comtes Ouest”) tends to offset the pollutants effects. This is particularly true for the IRIS “St-Mitre Centre”. Nevertheless, we observed that the presence of SO₂ only had an influence on respiratory diseases in the age range 15–65 years-old within the IRIS “Figueroles”. By gathering all HCA outputs and IRIS profiles (Fig. 8), we observed HAP emissions in the north-east of the study area (Jonquières, Boudème), a vanadium and SO₂ emission in South (Lavéra, Côte Bleue), and a PCB pollution over the whole territory. In study area centre, disadvantaged socio-economy combined with the pollutants.

In this study, we highlighted some limitations. First, here the health data are related to the number of hospital admissions, instead of the number of patients. The number of patients was not available when this study was conducted. Therefore, an overestimation of the number of cases is plausible because some pathologies can necessitate several hospital admissions (in particular for bladder cancers). Likewise, as we

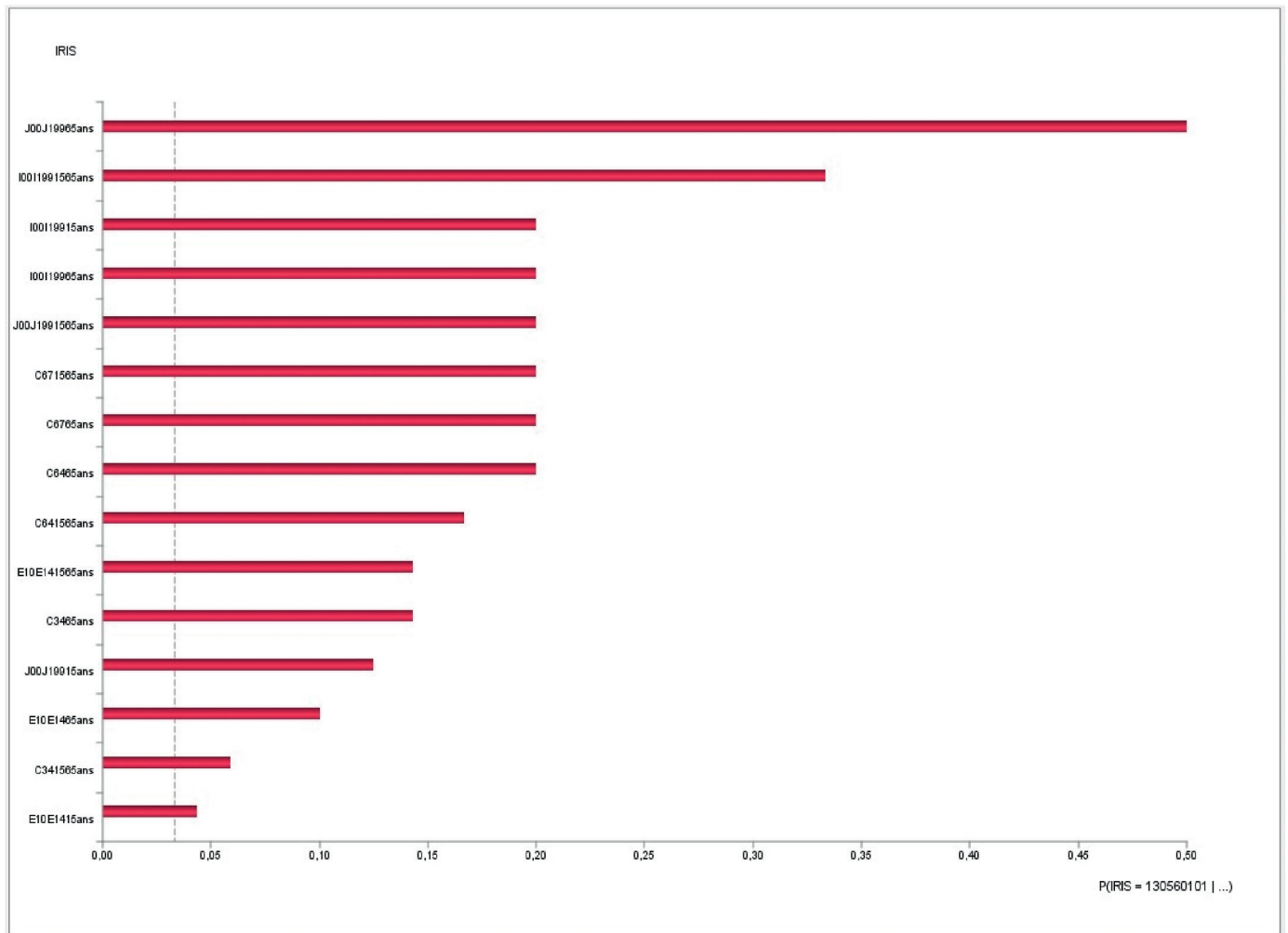


Fig. 6. Sensitivity analysis for all pathologies within the IRIS area "Côte Bleue" (13560101) in Martigues. The probability for respiratory diseases for people over 65 years-old is 0.50.

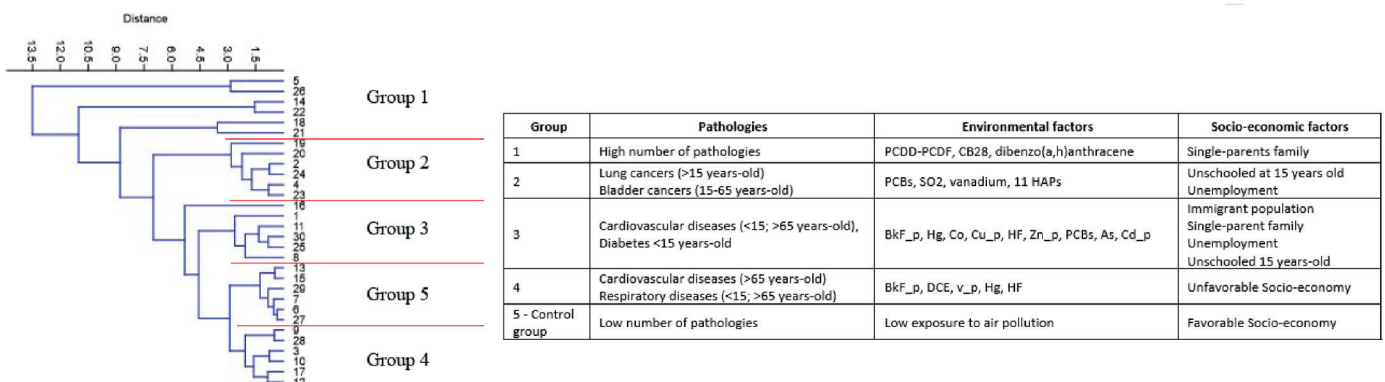


Fig. 7. Hierarchical Cluster Analysis - Health profiles of the 30 IRIS areas subdivided into 5 Groups.

worked at fine scale, the number of cases for some pathologies in some IRIS areas can be low and induce biases. However, Bayesian networks compare the evolution of proportion between variables, the risk of bias is minimised. By selecting annual averages for air pollutants smooth out the effects of air pollutants. Air pollutant and health data are those of 2015. The estimated effects are erroneous by omitting the lag effect of air pollutants exposure, i.e., by assuming that all effects occur in one day (Schwartz, 2000). In this study, air pollutants concentrations were

averaged from air quality monitoring stations, and we assumed that all individuals shared the same air pollution levels in the study area, therefore the individual exposure estimate is erroneous (Park and Kwan, 2017). Human mobility was also ignored by considering residential exposure, and not professional or related to daily commuting. In addition, only the outdoor exposure to air pollutants was considered while people spent about 80–90% of time in indoor environments (Laumbach et al., 2015).

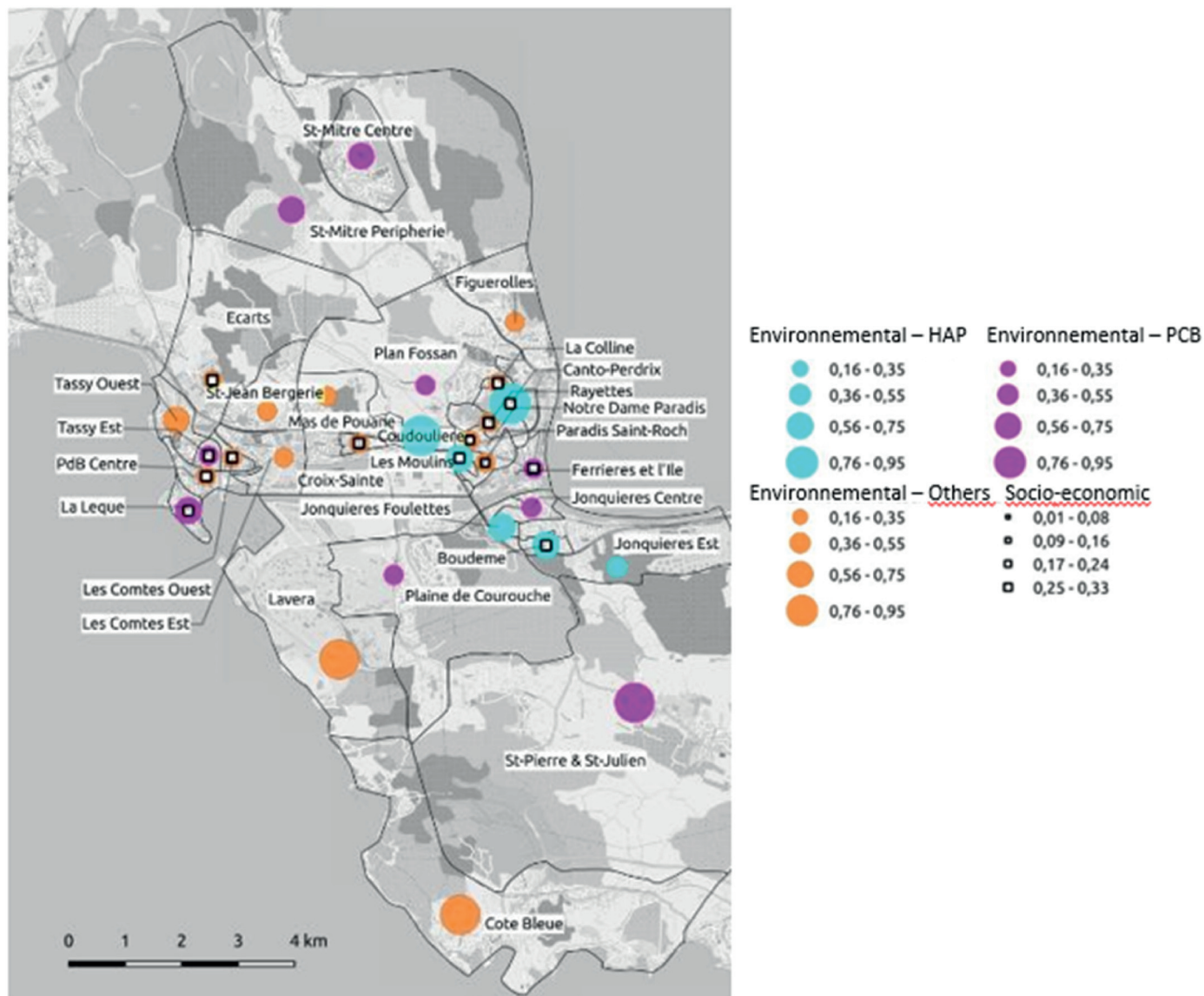


Fig. 8. Profile of IRIS areas according to the prevalence of environmental and/or socio-economic factors. The value indicates the highest probability (scale 0–1) found in the IRIS (sensitivity analyses) according to the type of factor (HAP, PCB, Others and socio-economic). Group 1 – IRIS areas characterised by an increased prevalence of hospital admissions for the whole of the pathologies studied. Group 2 – IRIS areas characterised by an increased prevalence of hospital admissions related to lung cancers (>15 years-old) and bladder cancers (15-65 years-old). Group 3 – IRIS areas characterised by an increased prevalence of hospital stays related to cardiovascular diseases (<15 and > 65 years-old) and diabetes (<15 years-old). Group 4 – IRIS areas characterised by an increased prevalence of hospital stays related to cardiovascular diseases (> 65 years-old) and respiratory diseases (<15 and > 65 years-old). Group 5 – IRIS areas characterised by a lower prevalence of “Control group” pathologies.

Although the lichen plots are scattered over the entire study area and located according to the IRIS areas socioeconomic level, more of them would have enabled us to ascertain our results even better. Studies carried out on environmental health are most of the time criticised because of the difficulty to get to the root causes of pathologies. Another frequently heard argument is the multifactorial character of an individual’s health. Furthermore, the design of these studies is most of the time of the ecological kind and can also lead to attribute to individuals the effect of pollutants measured in a space (ecological fallacy), but this argument is itself put into question (Schwartz, 1994). By taking into account a high number of variables (pollutants, pathologies, and socio-economy) which can potentially affect the citizens health and well-being, and by using a robust mathematical formalism at fine city-scale, based on conditional probabilities, we found causal factors. Thus, we have been able to bring forward several relations between exposure to xenobiotics and proven pathologies, sufficient to require an

hospital admission in 2015, and which suggest the following recommendations.

Control strategies, and local policy, must focus on reducing SO₂ emissions, as we observed health effects at very low levels, even below European and WHO standards. Companies must continue and ramp up the desulphurisation process of their installations, or, when possible, use a lower-sulphur fuel. However, SO₂ is also emitted by tankers bringing their load to the nearby “Fos-sur-Mer” industrial harbour. The use of a lower-sulphur fuel could contribute to improve the citizens health. In the study area, we observed a diffuse PCB pollution, linked to respiratory diseases for people over 65 years-old, and this major issue should be deeply investigated to take appropriate measures e.g., site remediation by phytomanagement (Aken et al., 2010; Passatore et al., 2014). We can highlight several thresholds above which certain pollutants are particularly noxious, e.g., adverse health effects (bronchus and lung cancers) can be observed for hydrofluoric acid (HF) at 0.0028 µg m⁻³ threshold

(Fig. 12.S), while exposure to particulate cadmium, between 0.214 and 0.250 $\mu\text{g m}^{-3}$ (Fig. 4S) disrupts insulin metabolism for people over 65 years-old. Finally, benzo [k]fluoranthene exceeded the 0.672 $\mu\text{g m}^{-3}$ threshold (Fig. 13.S), and this exceedance was associated to a high number of hospital admissions for respiratory diseases for 15-65 years-old people. Specific pollutants such as chrome, chrome VI, and vanadium in their particle phase, need a continuous monitoring. Therefore, emissions of these pollutants should be reduced, when it is technically and financially possible by e.g., substitute products, less polluting industrial processes, and more effective filters.

4. Conclusions

The study has revealed differentiated health profiles between the different IRIS areas in Martigues conurbation, which should lead to supplying health care that would be better suited to the population needs, from a prevention perspective, and even to promote consultations with certain specialists. For example, with a cardiologist in the IRIS areas where the number of unqualified 15 years-old people is significant, as a relation was found, likely due to more difficult living or working conditions for such people. Likewise, prevention and social support measures should be taken to the benefit of single-parent families. Lastly, present-day pathologies are most of the time the result of former exposures when pollution levels were overall higher. In this study, human mobility, and exposure to indoor air pollutants, where people spend more than 80% of time, were ignored. Therefore, our estimates due to air pollutants exposure were biased. It would be interesting to obtain older measurements concerning the incriminated pollutants and redo the calculations. The industries in the study area should continue to reduce their emissions concerning the harmful air pollutants. To reduce population's exposure to air pollution, adequate mitigation measures should be implemented to reduce the emissions and concentrations in the air of air pollutants such as an update of national emissions ceilings, an introduction of electric/hybrid cars, green public transportation, regulation of fuel quality, and implementation of green infrastructure to ameliorate urban air quality at city scale (Sicard et al., 2018; Sofia et al., 2020).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank all those with whom they have been in touch during this study, and more particularly the Conseil de Territoire du Pays de Martigues within the Métropole Aix-Marseille-Provence, and the CIAS of Pays de Martigues for their trust and support.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2021.112059>.

Authors' contributions

Project conceptualizing, design of the study, data analysis, writing: SP, Project administration, Funding acquisition, Literature review: GL, Manuscript preparation: SP, SG, Visualization: SG, Participation in the data collection and provided technical input to the data analyses: SM, PC, Validation: SM. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not Applicable.

Consent for publication

This manuscript does not contain any individual person's data in any form.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request, excepting the health data, because the French national commission for Informatics and Freedoms (CNIL) does not allow their sharing.

Funding

The feasibility study has been financed by ARS ACA within the framework of the AAP PRSE 2015, and the study itself by the Conseil de Territoire du Pays de Martigues within the Métropole Aix-Marseille-Provence, and the Pays de Martigues Centre Intercommunal d'Action Sociale (CIAS). Trial registration Decision DE-2017-413 authorising the Métropole d'Aix Marseille Provence to carry out the processing of personal health data for a retrospective and local environmental health study titled "Air-Health study in the Pays de Martigues territory" (Authorisation application No. 917120).

References

- Adam, M., Schikowski, T., Carsin, A.E., Cai, Y., Jacquemin, B., Sanchez, M., et al., 2015. Adult lung function and long-term air pollution exposure. ESCAPE: a multicentre cohort study and meta-analysis. *Eur. Respir. J.* 45, 38–50.
- Aken, B.V., Correa, P.A., Schnoor, J.L., 2010. Phytoremediation of polychlorinated biphenyls: new trends and promises. *Environ. Sci. Technol.* 44, 2767–2776.
- Allen, B., Cohen, A., Ferrier, Y., Lees, J., 2017. Fos EPSEAL, Étude participative en santé environnement ancrée localement sur le front industriel de Fos-sur-Mer et Port-Saint-Louis-du-Rhône, Rapport final. Centre Norbert Elias, Marseille.
- Amoatey, P., Sicard, P., De Marco, A., Khaniabadi, Y.O., 2020. Long-term exposure to ambient PM_{2.5} and impacts on health in Rome, Italy. *Clinical Epidemiology and Global Health* 8, 531–535.
- Atkinson, R.W., Carey, I.M., Kent, A.J., van Staa, T.P., Anderson, H.R., Cook, D.G., 2015. Long-term exposure to outdoor air pollution and the incidence of chronic obstructive pulmonary disease in a national English cohort. *Occup. Environ. Med.* 72, 42–48.
- AtmoSud, 2015. Etude SCENARII : Simulation de scénarii de pollution atmosphérique pour une Evaluation des Risques Sanitaires - Zone Etang de Berre. <https://www.atmosud.org>.
- AtmoSud, 2016. Etude Polis : Plan d'Observation des Polluants d'Intérêt Sanitaire. <http://www.atmosud.org>.
- Agency for Toxic Substances and Disease Registry (ATSDR), 2012. Toxicological Profile for Vanadium. Department of Health and Human Services, Public Health Service, Atlanta, GA.
- Bogaert, P., Christakos, G., Jerrett, M., Yu, H.L., 2009. Spatio-temporal modelling of ozone distribution in the State of California. *Atmos. Environ.* 43, 2471–2480.
- Buha, A., Đukić-Čosić, D., Čurčić, M., Bulat, Z., Antonijević, B., Moulis, J.-M., et al., 2020. Emerging links between cadmium exposure and insulin resistance: human, animal, and cell study data. *Toxics* 8, 63.
- Cai, Y., Zhang, B., Ke, W., Feng, B., Lin, H., Xiao, J., et al., 2016. Associations of short-term and long-term exposure to ambient air pollutants with hypertension: a systematic review and meta-analysis. *Hypertension* 68, 62–70.
- Carter, P., Lagan, J., Fortune, C., Bhatt, D.L., Vestbo, J., Niven, R., et al., 2019. Association of cardiovascular disease with respiratory disease. *J. Am. Coll. Cardiol.* 73, 2166–2177.
- Chao, A., Chiu, C.H., Jost, L., 2016. Phylogenetic Diversity Measures and Their Decomposition: A Framework Based on Hill Numbers, Biodiversity Conservation and Phylogenetic Systematics. Springer International Publishing, pp. 141–172, 10.1007/978-3-319-22461-9_8.
- Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., et al., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet* 389, 1907–1918.
- Conrady, S., Jouffe, L., 2015. Bayesian Networks and BayesiaLab: A Practical Introduction for Researchers.
- Doiron, D., de Hoogh, K., Probst-Hensch, N., Fortier, I., Cai, Y., De Matteis, S., et al., 2019. Air pollution, lung function and COPD: results from the population-based UK Biobank study. *Eur. Respir. J.* 54, 1802140.

- European Council Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. Official Journal L 152, 11.6.2008 P. 0001-0044.
- European Environment Agency, 2018. Air Quality in Europe - 2018 Report. <https://doi.org/10.2800/777411>. EEA Technical Report No 12/2018.
- European Environment Agency, 2019. Air Quality in Europe - 2019 Report. <https://doi.org/10.2800/822355>. EEA Technical Report No 10/2019.
- European Union, 2016. Urban Europe Statistics on Cities, Towns and Suburbs. Eurostat Statistical book. <https://doi.org/10.2785/91120>.
- Evangelou, E., Ntritsos, G., Chondrogiorgi, M., Kavvoura, F.K., Hernández, A.F., Ntzani, E.E., et al., 2016. Exposure to pesticides and diabetes: a systematic review and meta-analysis. *Environ. Int.* 91, 60–68.
- Fortin, M., Haggerty, J., Sanche, S., Almirall, J., 2017. Self-reported versus health administrative data: implications for assessing chronic illness burden in populations. A cross-sectional study. *CMAJ Open* 5, E729–E733.
- Fosse-Edorh, S., Fagot-Campagna, A., Detournay, B., Bihan, H., Gautier, A., Dalichamp, M., Druet, C., 2014. Type 2 diabetes prevalence, health status and quality of care among the North African immigrant population living in France. *Diabetes & Metabolism* 40, 143–150.
- Goix, S., Periot, M., Douib, K., 2018. Etude INDEX. Etude d'imprégnation de la population aux polluants atmosphériques de la zone industrielle-portuaire de Fos-sur-Mer. Institut Ecocitoyen pour la Connaissance des Pollutions (IECP), p. 296p.
- Govender, P., Sivakumar, V., 2020. Application of k-means and hierarchical clustering techniques for analysis of air pollution: a review (1980–2019) *Atmos. Pollut. Res.* 11, 40–56.
- Guo, C., Zhang, Z., Lau, A.K.H., Lin, C.Q., Chuang, Y.C., Chan, J., et al., 2018. Effect of long-term exposure to fine particulate matter on lung function decline and risk of chronic obstructive pulmonary disease in Taiwan: a longitudinal, cohort study. *The Lancet Planetary Health* 2, e114–e125.
- Hwang, J., Kwon, J., Yi, H., Bae, H.-J., Jang, M., Kim, N., 2020. Association between long-term exposure to air pollutants and cardiopulmonary mortality rates in South Korea. *BMC Publ. Health* 20, 1402.
- InVS, 2008. Programme de surveillance air et santé (PSAS) « Analyse des liens à court terme entre pollution atmosphérique urbaine et mortalité dans neuf villes françaises », p. 41. Paris, 2008.
- Jeanjean, M., Lees, J., Allen, B.L., Cohen, A., 2021. Interdisciplinary community-based participatory health research across the industrial region of the Étang de Berre: the EPSEAL Fos Crau study. *Revue d'Épidémiologie et de Santé Publique*. <https://doi.org/10.1016/j.respe.2021.04.141>. S0398762021003254.
- Jeanjean, M., Goix, S., Périot, M., et al., 2021. Expositions environnementales et alimentaires à proximité d'un grand port industriel (Fos-sur-Mer, France) identifiée comme une voie importante pour l'accumulation de PCB et de PCDD/F dans le sérum sanguin des résidents. *Expo Santé* 13, 447–464. <https://doi.org/10.1007/s12403-021-00395-8>.
- Jiao, K., Xu, M., Liu, M., 2018. Health status and air pollution related socioeconomic concerns in urban China. *Int. J. Equity Health* 17, 18. <https://doi.org/10.1186/s12939-018-0719-y>.
- Khaniabadi, Y.O., Sicard, P., 2021. A 10-year assessment of ambient fine particles and related health endpoints in a large Mediterranean city. *Chemosphere* 278, 130502.
- Khaniabadi, Y.O., Daryanoosh, M., Sicard, P., Takdastan, A., Hopke, P.K., Esmaili, S., et al., 2018. Chronic obstructive pulmonary diseases related to outdoor PM₁₀, O₃, SO₂, and NO₂ in a heavily polluted megacity of Iran. *Environ. Sci. Pollut. Control Ser.* 25, 17726–17734.
- Khaniabadi, Y.O., Sicard, P., Takdastan, A., Hopke, P.K., Taiwo, A.M., Khaniabadi, F.O., et al., 2019. Mortality and morbidity due to ambient air pollution in Iran. *Clinical Epidemiology and Global Health* 7, 222–227.
- Laumbach, R., Meng, Q., Kipen, H., 2015. What can individuals do to reduce personal health risks from air pollution? *J. Thorac. Dis.* 7, 96–107, 2015 Jan.
- Lees, R.E.M., 1980. Changes in lung function after exposure to vanadium compounds in fuel oil ash. *Occup. Environ. Med.* 37, 253–256.
- Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., Pozzer, A., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* 525, 367–371.
- Mannucci, P.M., Harari, S., Franchini, M., 2019. Novel evidence for a greater burden of ambient air pollution on cardiovascular disease. *Haematologica* 104, 225086.
- Mantey, K., Pascal, L., Cortaredona, S., 2019. Observatoire des cancers du rein, de la vessie et des leucémies aiguës chez l'adulte dans le département des Bouches-du-Rhône (REVELA13). Analyses spatiales, 2013-2016. Saint-Maurice : Santé publique France 80. <https://www.santepubliquefrance.fr/regions/provence-alpes-cote-d-azur-et-corse/documents/rapport-synthese/2019/observatoire-des-cancers-du-rein-d-e-la-vessie-et-des-leucemies-aigues-chez-l-adulte-dans-le-departement-des-bouches-du-rhone-revela13-analyses>.
- Mazenq, J., Dubus, J.-C., Gaudart, J., Charpin, D., Nougarede, A., Viudes, G., et al., 2017. Air pollution and children's asthma-related emergency hospital visits in southeastern France. *Eur. J. Pediatr.* 176, 705–711.
- Mendes, V., Ribeiro, C., Delgado, I., Peleteiro, B., Aggerbeck, M., Distel, E., et al., 2021. The association between environmental exposures to chlordanes, adiposity and diabetes-related features: a systematic review and meta-analysis. *Sci. Rep.* 11, 14546.
- Münzel, T., Sørensen, M., Gori, T., Schmidt, F.P., Rao, X., Brook, F.R., et al., 2016. Environmental stressors and cardio-metabolic disease: part II—mechanistic insights. *Eur. Heart J.* ehw294.
- Næss, Ø., Piro, F., Nafstad, P., Smith, G.D., Leyland, A.H., 2007. Air Pollution, Social Deprivation, and Mortality. *Epidemiology*: November 18 (6), 686–694. <https://doi.org/10.1097/EDE.0b013e3181567d14>.
- Park, Y.M., Kwan, M.P., 2017. Individual exposure estimates may be erroneous when spatiotemporal variability of air pollution and human mobility are ignored. *Health Place* 43, 85–94.
- Park, J., Kim, H.-J., Lee, C.-H., Lee, C.H., Lee, H.W., 2021. Impact of long-term exposure to ambient air pollution on the incidence of chronic obstructive pulmonary disease: a systematic review and meta-analysis. *Environ. Res.* 194, 110703.
- Pascal, M., Falq, G., Wagner, V., Chatignoux, E., Corso, M., Blanchard, M., et al., 2014. Short-term impacts of particulate matter (PM₁₀, PM_{10-2.5}, PM_{2.5}) on mortality in nine French cities. *Atmos. Environ.* 95, 175–184.
- Passatore, L., Rossetti, S., Juwarkar, A.A., Massacci, A., 2014. Phytoremediation and bioremediation of polychlorinated biphenyls (PCBs): state of knowledge and research perspectives. *J. Hazard Mater.* 278, 189–202.
- Pearl, J., 2009a. Causal Inference in Statistics: an Overview, vol. 3. *Statist Surv.*
- Pearl, J., 2009b. *Causality: Models, Reasoning, and Inference*, second ed. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9780511803161>.
- Pearl, J., 2014. Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference.
- Pearl, J., Mackenzie, D., 2018. *The Book of Why: the New Science of Cause and Effect*, first ed. Basic Books, New York.
- Pérez, S., 2016. Etude de faisabilité sur le croisement des informations disponibles sur les zones à risques potentiels et le recensement de pathologies avérées et géo-localisées à l'échelle du territoire du Pays de Martigues, p. 35.
- Pérez, S., 2019. Étude AIR-SANTÉ en Pays de Martigues : apports de l'Intelligence Artificielle aux questions de santé environnementale. Université Côte d'Azur, Nice, France, p. 255, 2019.
- Picheral, H., 1983. Complexes et systèmes pathogènes : approche géographique ?, De l'épidémiologie à la géographie humaine. *Trav. Doc. Geograph. Trop.* 48, 5–22.
- Ratier, A., Dron, J., Revenko, G., Austruy, A., Dauphin, C.-E., Chaspoul, F., et al., 2018. Characterization of atmospheric emission sources in lichen from metal and organic contaminant patterns. *Environ. Sci. Pollut. Res.* 25, 8364–8376.
- Rovira, J., Domingo, J.L., Schuhmacher, M., 2020. Air quality, health impacts and burden of disease due to air pollution (PM₁₀, PM_{2.5}, NO₂ and O₃): application of AirQ + model to the Camp de Tarragona County (Catalonia, Spain). *Sci. Total Environ.* 703, 135538.
- Salameh, D., Pey, J., Bozzetti, C., El Haddad, I., Detournay, A., Sylvestre, A., et al., 2018. Sources of PM_{2.5} at an urban-industrial Mediterranean city, Marseille (France): application of the ME-2 solver to inorganic and organic markers. *Atmos. Res.* 214, 263–274.
- Sarigiannis, D.A., Hansen, U., 2012. Considering the cumulative risk of mixtures of chemicals – a challenge for policy makers. *Environ. Health* 11, S18.
- Schwartz, S., 1994. The fallacy of the ecological fallacy: the potential misuse of a concept and the consequences. *Am J Public Health* 84, 819–824.
- Schwartz, J., 2000. The distributed lag between air pollution and daily deaths. *Epidemiology* 11, 320–326.
- Schwartz, G., Il'Yasova, D., Ivanova, A., 2003. Urinary cadmium, impaired fasting glucose, and diabetes in the NHANES III. *Diabetes Care* 26, 468–470.
- Sicard, P., 2021. Ground-level ozone over time: an observation-based global overview. *Current Opinion in Environmental Science & Health* 19, 100226.
- Sicard, P., Talbot, C., Lesne, O., Mangin, A., Alexandre, N., Collomp, R., 2012. The Aggregate Risk Index: an intuitive tool providing the health risks of air pollution to health care community and public. *Atmos. Environ.* 46, 11–16.
- Sicard, P., Agathokleous, E., Araminiene, V., Carrari, E., Hoshika, Y., De Marco, A., Paoletti, E., 2018. Should we see urban trees as effective solutions to reduce increasing ozone levels in cities? *Environ. Pollut.* 243, 163–176.
- Sicard, P., Khaniabadi, Y.O., Perez, S., Gualtieri, M., De Marco, A., 2019. Effect of O₃, PM₁₀ and PM_{2.5} on cardiovascular and respiratory diseases in cities of France, Iran and Italy. *Environ. Sci. Pollut. Control Ser.* 26, 32645–32665.
- Sicard, P., Agathokleous, E., De Marco, A., Paoletti, E., Calatayud, V., 2021. Urban population exposure to air pollution in Europe over the last decades. *Environ. Sci. Eur.* 33, 28.
- Sofia, D., Gioiella, F., Lotrecchiano, N., Giuliano, A., 2020. Mitigation strategies for reducing air pollution. *Environ. Sci. Pollut. Control Ser.* 27, 19226–19235.
- Sottas, P.-E., Lavoué, J., Bruzzi, R., Vernez, D., Charrière, N., Droz, P.-O., 2009. An empirical hierarchical Bayesian unification of occupational exposure assessment methods. *Stat. Med.* 28, 75–93.
- Suissa, L., Fortier, M., Lachaud, S., Staccini, P., Mahagne, M.-H., 2013. Ozone air pollution and ischaemic stroke occurrence: a case-crossover study in Nice, France. *BMJ Open* 3, e004060.
- Svingen, T., Vinggaard, A.M., 2016. The risk of chemical cocktail effects and how to deal with the issue. *J. Epidemiol. Community Health* 70, 322–323.
- Temam, S., 2017. Déterminants sociaux et asthme : approche épidémiologique. Santé publique et épidémiologie. Université Paris-Saclay. Français. ffnNT : 2017SACL110ff. ffilet-01821462f.
- Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., et al., 2006. The 2005 world health organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicol. Sci.* 93, 223–241.
- Weber, P., Simon, C., 2016. *Benefits of Bayesian Network Models*. ISTE; Wiley, London, UK: Hoboken, NJ, USA.

#6 - UNE UMR QUI CONTRIBUE À LA VITALITÉ ET À LA DYNAMIQUE DES INTERACTIONS ENTRE LES SCIENTIFIQUES DE SON DOMAINE

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&

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Structurer et animer des débats scientifiques est une des missions qui incombent aux laboratoires de recherche. Cela passe notamment par l'organisation de séminaires, colloques et autres symposiums. Si la plupart des UMR s'acquittent avec plus ou moins d'intensité de cette mission, l'UMR ESPACE se distingue en la matière par la variété des niveaux auxquels elle intervient dans la structuration et l'animation des débats scientifiques.

1. Des niveaux complémentaires d'organisation de conférences

L'unité organise en effet, seule ou avec des partenaires :

- des **colloques et séminaires sur des thématiques spécifiques**. Ils peuvent être « classiquement » à destination des acteurs de la recherche et ont pour mission de faire avancer le front de la connaissance (exemples sur le site de Nice : le colloque *Smart Data Smart City*,²³ à Nice en 2020, qui traitait de l'utilisation des technologies d'information et de communication dans les Smart Cities, le XXXIII^e colloque de *l'Association Internationale de Climatologie* en 2017 ou la 10^e Conférence Internationale de l'IDRIM, *Integrated Disaster Risk Management*, en 2019), ou être plus orientés vers un public de professionnels et d'acteurs opérationnels, en ayant alors davantage pour objectif de diffuser la connaissance et de faire évoluer les pratiques (exemple : le colloque *Cap'Alert*²⁴, à Avignon en 2019, qui questionnait les moyens d'alerte et leur pertinence en fonction des caractéristiques des aléas et des territoires et ouvrait le débat sur « comment alerter la population dans les années à venir »)
- des **colloques non thématiques ouverts sur des domaines scientifiques** qui rassemblent une grande partie de la communauté de la géographie théorique et quantitative, à l'image du colloque *SAGEO* « Spatial Analysis and Geomatics »²⁵ (Nice, 2016)
- des **conférences pluridisciplinaires portant sur des questions méthodologiques pointues**, à l'image de la conférence internationale *Spatial Accuracy*²⁶, co-organisée avec le LISAH de Montpellier en 2016, qui portait sur les techniques d'analyse de sensibilité pour la modélisation spatiale et la gestion de l'incertitude dans les systèmes à base de connaissance
- des **colloques de réflexion sur les concepts et les pratiques de la géographie et de l'aménagement, ainsi que sur l'interface Homme-Milieu**. Outre les séminaires *ERE* (Espace Rencontre Espace) internes au laboratoire, on peut citer les séminaires interdisciplinaires de l'OHM Littoral Méditerranéen à Aix-en-Provence, ou le colloque *Géopoint*²⁷, qui a lieu tous les deux ans depuis plus de 40 ans, et qui est historiquement un des piliers de la géographie théorique et quantitative en France. Par exemple, en 2016 à Lausanne sur le thème « De l'espace pour la théorie ! » et à Avignon en 2018, intitulé « Espaces citoyens. Sciences de l'espace et politique »
- des **conférences internationales à large spectre scientifique** : l'exemple du 57^e colloque de l'ASRDLF (Association de Science Régionale De Langue Française) à Avignon, en septembre 2021

2. Zoom sur le 57^e colloque de l'ASRDLF

L'UMR ESPACE sait aussi rassembler largement au-delà de la seule communauté des géographes/aménageurs/géomaticiens et s'adapter à son environnement de recherche. L'organisation, en septembre 2021, à Avignon Université, du 57^e colloque de l'ASRDLF²⁸ (Association de Science Régionale De Langue Française), avec pour thème « *Territoire(s) et Numérique* », en est un exemple (Figure 2).

²³ <https://imredd.fr/en/sdsc2020/#index>

²⁴ <https://cap-alert2019.sciencesconf.org/resource/page/id/3>

²⁵ <https://sageo2016.sciencesconf.org/>

²⁶ <https://colloque.inrae.fr/spatial-accuracy2016/Partners>

²⁷ <http://www.geopoint.space/>

²⁸ <https://asrdlf2021.org/>

Le colloque annuel de l'ASRDLF, association de langue française fondée en 1961 et qui compte plus de 1 000 membres, est une « institution » dans le paysage européen des sciences régionales. Celui d'Avignon qui s'est tenu en présentiel a, malgré la pandémie et les restrictions de visas, rassemblé plus de 200 participants (ce qui était inespéré pendant cette période particulière), dont 20% d'étrangers (Suisse, Belgique, Allemagne, Roumanie, Tunisie, etc.). Quarante-trois sessions ont été organisées pour 191 présentations.

Il a mobilisé les membres des trois sites universitaires du laboratoire. Seize communications ont été proposées par des membres d'ESPACE et cinq membres du laboratoire ont présidés des sessions.

Les sessions proposées étaient soit :

- des *sessions récurrentes du colloque* : Méthodes et modélisation ; Ressources et facteurs de la croissance régionale et urbaine soutenable ; Concurrence spatiale, économie publique ; Fiscalité locale et territoriale...
- des *sessions spéciales proposées par la communauté des sciences régionales* : Production Agricole, action publique et alimentation des villes ; Géographie du mécontentement ; Territoires en décroissance ; Le financement de l'action publique local, etc.
- des *sessions spécifiques à la thématique du colloque* : Massification des données et production de la connaissance territoriale ; Numérique et identités territoriales ; Numérique et optimisation de l'espace ; Numérique et démocratie locale ; Big data et production de la connaissance, etc.

L'organisation de ce colloque « Territoire(s) et Numérique » par l'UMR ESPACE à Avignon Université n'est pas fortuite. Outre le fait qu'une telle manifestation apporte naturellement une grande visibilité au laboratoire et permet à ses membres de tisser des relations avec des partenaires rencontrés moins fréquemment (économistes spatiaux par exemple), cela illustre aussi la capacité de l'UMR ESPACE à se positionner stratégiquement dans l'environnement de recherche prôné par ses tutelles. En effet, la politique scientifique d'Avignon Université se structure historiquement autour de deux axes : *Agrosciences* d'une part et *Culture, Patrimoine et Société Numérique* d'autre part, dont relève notamment la FR AGORANTIC²⁹. Organiser une manifestation d'ampleur internationale comme le colloque de l'ASRDLF et choisir comme thème « Territoire(s) et Numérique » est donc un moyen à la fois de réfléchir à une problématique centrale qui porte sur ce que le numérique fait aux sociétés et aux territoires, également de conforter l'ancrage du laboratoire au sein de sa tutelle avignonnaise.



Figure 2. Vue du site internet du 57^e colloque de l'ASRDLF à Avignon, en septembre 2021

Organiser des événements pour un public académique issu de diverses disciplines, mais aussi à destination des professionnels, autour d'objets scientifiques communs thématiques, comme méthodologiques, qui rassemblent des communautés de géographes aménageurs, géomaticiens, modélisateurs et qui ont une dimension réflexive sur les concepts, les théories et les pratiques de nos disciplines, constitue assurément une des singularités d'ESPACE.

²⁹ <https://agorantic.univ-avignon.fr/presentation/>

#7 - UNE UMR QUI ÉCLAIRE ET AIDE À LA DÉCISION ET À L'ACTION

Rédactrices

Nathalie DUBUS (MCF, Université Grenoble Alpes)

&

Christine VOIRON (PR, Université Côte d'Azur)

« *Eclairer là où l'on ne regarde pas et fournir les lunettes pour aider à voir* ». Cette métaphore, empruntée à Jean-Marc Offner, illustre parfaitement le parti adopté dans le cadre de recherches menées en partenariat avec des collectivités, des entreprises et des acteurs de la société civile. ESPACE s'est emparé de questions essentielles, qui interpellent la science, la société et l'action publique, telles que les mutations socio-environnementales en cours, la capacité d'adaptation des espaces au changement global, les réponses des territoires aux défis des transitions, etc. Autant de questions qui requièrent de nouvelles articulations entre la recherche géographique et l'action collective, et qui sont ainsi devenues des objets d'étude, traités sous des angles originaux et par des méthodes inédites : géogouvernance, géoprospective, hybridation des savoirs et des modèles, analyse opérationnelle des résiliences de type environnemental, morphologique, territorial.

1. Originalité et spécificité

La conduite de la recherche en partenariat avec des acteurs locaux se doit de répondre à un certain nombre d'exigences. Celles-ci ont alors été analysées à travers les retours d'expériences et par une approche réflexive sur les pratiques de la recherche, initiée au sein d'ESPACE. Les enseignements retirés, couplés à l'objectif premier de ce type de recherche, qui est de mettre la connaissance scientifique au service de l'action collective, ont permis de jeter les bases d'une démarche reproductible, qui sert de cadre à la conduite de projets comme aux expertises (Axe « Méthodologies des spatialités »).

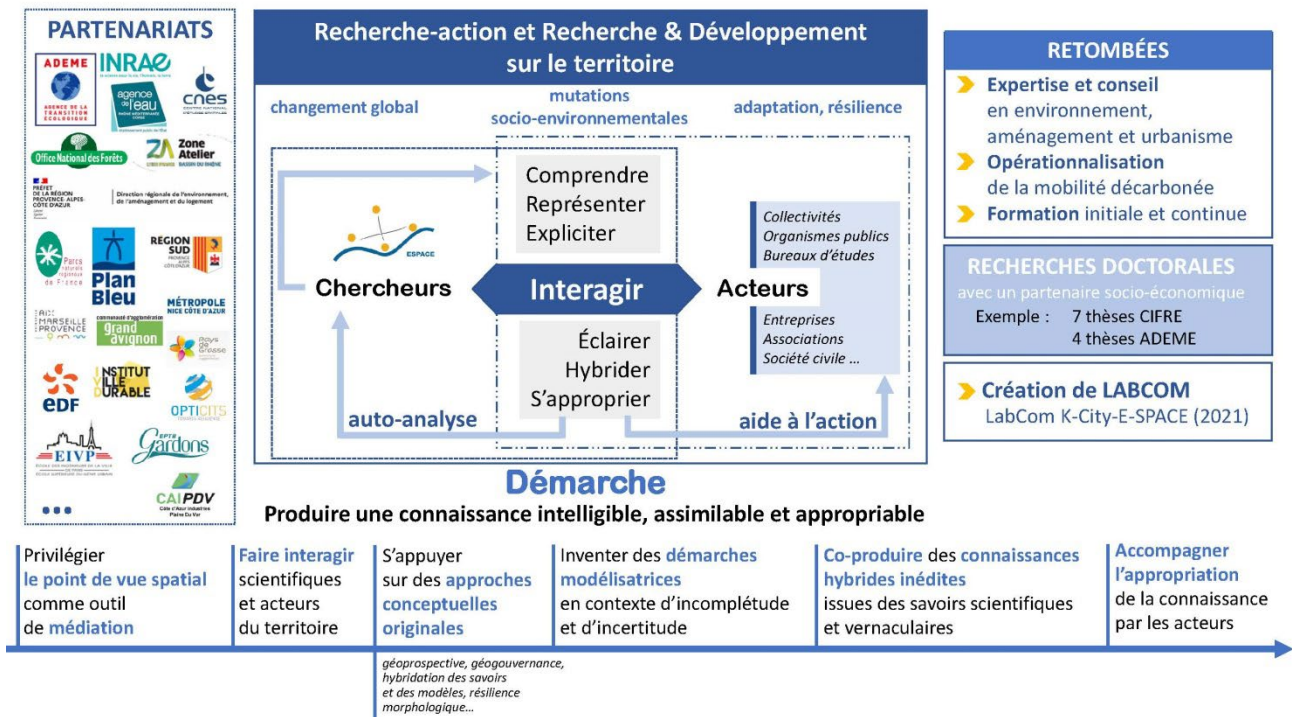


Figure 3. Production de connaissances scientifiques intelligibles, assimilables et appropriables

Cette démarche (cf. Figure 3) est axée sur l'exigence d'une représentation de la connaissance produite qui soit assimilable et appropriable par les parties prenantes, en veillant à rendre intelligible la complexité des dynamiques spatio-temporelles étudiées. La ligne directrice consiste à :

1. Privilégier le point de vue spatial comme outil de médiation, à tous les stades de la recherche, de l'entrée dans la problématique à la cartographie des résultats (projets RADHY-BUËCH, TRAJECTOIRES) ;
2. Faire interagir scientifiques, citoyens et acteurs publics dans des processus de co-construction des savoirs territoriaux, via la géogouvernance (projets CATIMINI, OUIGEF, jeu sérieux foncier ALTERé) et la science participative (projet HYDROPOP-2) ;
3. Porter un regard scientifique neuf par l'inventivité conceptuelle - rétentivité, espace à enjeu, changement, résilience morphologique, écosystème territorial de l'électromobilité,

etc. La conceptualisation opérée dans le cadre de travaux académiques (recherches doctorales et HDR, notamment) est ensuite opérationnalisée en collaboration avec des partenaires non académiques (collectivité territoriale, club d'entreprises, ADEME, EDF, etc.) selon les projets considérés et les degrés d'intrication entre les partenaires (projets POPSU Métropole Nice Côte d'Azur, MODESTE) ;

4. *Inventer des démarches modélisatrices* en contexte d'incomplétude de la connaissance relatifs à l'anticipation des futurs possibles, aux chemins de transitions, aux potentiels d'adoption d'innovations (projets CATIMINI, REACTIV'cité, AutoCoPartage) ;
5. *Nourrir la réflexion des acteurs par la co-production d'informations pertinentes* issues de données de terrain inédites sur la végétation, le climat, l'hydrologie (Ex. bases de données sur les zones arctique et subarctique, projets RICOCHET, OSAMA, CliMedSCALE, Interreg CONCERT-EAUX, PSDR4), sur les perceptions, les modes de vie et les pratiques (Perception des risques côtiers et de l'adaptation par les acteurs territoriaux dans l'étude PRECOAST, bases de données sur le foncier et l'immobilier) ;
6. *Mettre à disposition la connaissance issue des analyses et modèles* (exemple : les formes physiques du e-commerce dans le bassin de vie d'Avignon - programme Ville Productive du PUCA) ; et *accompagner dans le temps leur appropriation par des outils dédiés* : guides, sites et plateformes sur le Web, *dashboards*, webinaires, ateliers participatifs, outils de simulation interactifs en libre accès, MOOC et SPOC.

2. Quelques retombées opérationnelles de la recherche et de l'aide à l'action

Les exemples de recherche appliquée d'ESPACE sont nombreux. Nous en présentons quelques-uns de nature à illustrer cette expertise qui participe fortement au profil d'activité du laboratoire.

Les **cartographies climatiques** à fine résolution spatiale sur les Alpes-Maritimes, et les projections 1986-2055 et 2081-2100, à partir de la méthode de descente d'échelle climatique statistique (N. Martin), servent de base aux PCAET du département (Métropole NCA, SCOT'Ouest³⁰).

La **grille d'évaluation** de la résilience morphologique (G. Fusco) est utilisée pour évaluer la résilience des formes urbaines de l'OAP Plaine du Var (Métropole NCA³¹).

L'**outil interactif Homme-Machine pour l'orientation spatiale des malvoyants** (D. Josselin et S. Boularouk) a été co-construit avec la fondation Frédéric Gaillanne³² d'éducation de chiens pour malvoyants.

Le **Système expert spatialisé déterminant le potentiel d'adoption des territoires à la mobilité décarbonée** (CATIMINI, C. Voiron-Canicio et G. Voiron) est référencé par le Ministère de la Transition Ecologique dans le guide à l'attention des collectivités « Schémas directeurs pour les infrastructures de recharge pour véhicules électriques », appliqué en Nouvelle Aquitaine, Bretagne, Pays de la Loire, et Hauts de France.

En complément, **les membres de l'UMR répondent favorablement aux sollicitations émanant d'organismes publics et privés qui sont multiples** : expertises nationales et internationales, notamment prospectives (MED 2050³³ du Plan Bleu/ONU, mise en réseau des aires protégées de l'Arc Alpin, projet ESPON LinkPAs, intervention à la cellule R&D de la SNCF), nominations à divers conseils scientifiques : parcs naturels nationaux et régionaux (3), institutions publiques (Ministère des Affaires étrangères, Pôle de compétitivité SAFE³⁴, SRADDET³⁵ de la Région SUD, CAUE³⁶,

³⁰ http://scotouest.com/?page_id=975

³¹ <https://www.nicecotedazur.org/habitat-urbanisme/evolution-du-plum/plum-approuv%C3%A9-le-25-10-2019>

³² <https://www.fondationfg.org/>

³³ <https://med2050.org/>

³⁴ <https://www.safecluster.com/>

³⁵ <https://connaissance-territoire.maregionsud.fr/srddet-avenir-de-nos-territoires/le-schema-regional/>

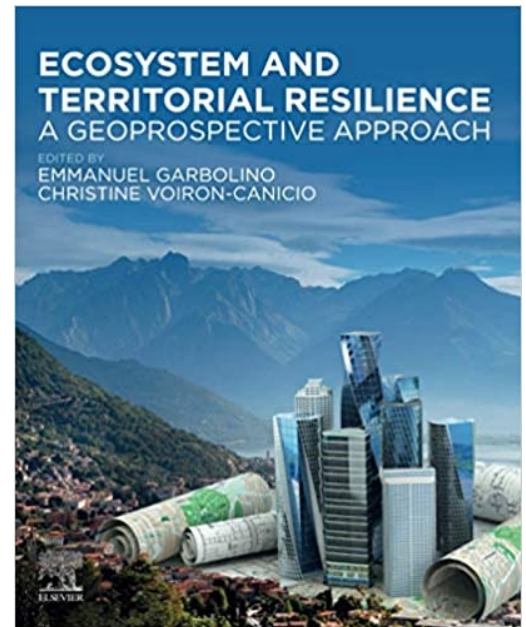
³⁶ <https://www.fncaue.com/caue-et-urcaue-de-paca/>

plateforme « Mon Littoral »³⁷), et, à la demande de l'Institut de la Ville Durable, portage scientifique de la formation continue « Stratégie de résilience territoriale », destinée aux décideurs et ingénieurs du public et du privé, délivrée depuis 2018, en partenariat avec l'École des Ingénieurs de la Ville de Paris et la start-up Opticits de Barcelone.

3. Zoom sur une publication méthodologique internationale

Ce pan d'activité d'ESPACE s'accompagne de publications méthodologiques.

Ainsi, l'ouvrage *Ecosystem and Territorial Résilience: a geopropective approach*, (co-édité par E. Garbolino et C. Voiron-Canicio), publié par Elsevier en 2020 (372 pages), est emblématique de la démarche géopropective portée par l'UMR ESPACE, de son apport en recherche-action, et de son rayonnement international dans le domaine public et privé. Les 13 chapitres qui le composent ont été co-rédigés par 30 auteurs de différentes disciplines qui se rejoignent sur les méthodes de géopropective formalisées par ESPACE, dont 5 sont rattachés à ESPACE et 7 appartiennent à des institutions étrangères (universités, ministère de l'environnement du Mexique, Commission européenne), à la Métropole de Lyon ainsi qu'à un bureau d'études. Ces acteurs non académiques y expliquent les raisons des collaborations de recherche qu'ils ont souhaitées nouer, et leurs retombées en matière de prospective et de planification.



³⁷ <https://www.monlittoral.fr/>

#8 - UNE UMR QUI FORME PAR ET POUR LA RECHERCHE

Rédacteurs

Julien ANDRIEU (MCF-HDR, Université Côte d'Azur)

&

Cyrille GENRE-GRANDPIERRE (PR, Avignon Université)

L'UMR ESPACE se caractérise par un lien très fort entre recherche et enseignement.

1. Connexion entre activités scientifiques et pédagogiques au sein de l'UMR

Cette forte connexion entre recherche et enseignement transparaît notamment à travers les cours, de la L1 aux M2, dispensés, d'une part par les enseignants-chercheurs membres de l'unité, dont certains pilotent en outre des masters proposés sur les 3 sites universitaires, et d'autre part par le personnel CNRS : DR et CR bien entendu, mais aussi par certains personnels d'appui, qui interviennent dans les formations (exemple : cours de cartographie et statistiques en L3 et M1 à Avignon, dispensés par Mathieu Coulon, IE travaillant notamment pour la revue Mappemonde). Tous veillent à intégrer très rapidement dans les maquettes de cours les résultats de leurs recherches, qu'ils soient thématiques ou méthodologiques. On peut par exemple citer l'UE « l'optimisation dans la décision spatiale » du master 2 GEOTER, qui reprend les développements les plus récents réalisés dans l'axe « Méthodologie des spatialités », renforçant ainsi l'originalité de la formation.

Si le master Structures et Dynamiques Spatiales, qui était commun aux différents sites de l'UMR, n'existe plus (la dernière évaluation HCERES avait pointé la fragilité de ses effectifs), les enseignements communs à l'échelle de l'UMR n'ont pour autant pas disparu. En effet, dans les 3 masters de Nice, Aix-Marseille et Avignon, les étudiants choisissant « l'option recherche » ont la possibilité de suivre hors de leur site de rattachement, deux semaines d'enseignement qui portent sur les savoir et savoir faire les plus discriminants de chaque site de l'UMR. Ces interrelations permettent d'élargir l'offre de formation et de mieux préparer les étudiants au doctorat en leur faisant découvrir les ressources spécifiques présentes sur chaque site.

Outre ces éléments généraux, trois exemples permettent de matérialiser ce lien fort enseignement-recherche et la logique de l'enseignement par et pour la recherche présente à ESPACE.

2. Une participation massive de l'UMR ESPACE à l'opération « Fabriques de la Connaissance » de la Région Sud (PACA)

Chaque année, la Région PACA finance des projets de recherche dans le cadre de son programme « Fabriques de la connaissance ». Ces recherches visent à combler des déficits de connaissance ou d'expertise, pour mieux définir et articuler les stratégies d'aménagement aux différentes échelles territoriales.



Les projets de recherche soumis par ESPACE dans le cadre de ce programme sont très fréquemment sélectionnés et les travaux menés mobilisent le plus souvent des étudiants de master, soit dans le cadre de projets étudiants s'inscrivant dans leur maquette de formation, soit dans le cadre de stages rémunérés. C'est l'occasion pour les étudiants d'expérimenter ce qu'est la recherche, en mettant en pratique leurs connaissances et compétences. Les résultats de ces travaux sont mis en ligne sur le site de la Région³⁸, ils peuvent être publiés dans la « Focale régionale »³⁹ ou faire l'objet de productions scientifiques (article cosigné dans la revue québécoise *Geomatica*). Le projet « Amélioration et diffusion de connaissance de l'écosystème vélo lié à l'Eurovélo 8 pour en développer l'usage pour le tourisme » (réalisé en 2019)⁴⁰, auquel ont participé simultanément les

³⁸ <https://connaissance-territoire.maregionsud.fr/parcours-thematiques/les-partenariats-detudes-et-expertise/les-fabriques-de-la-connaissance/>

³⁹ https://connaissance-territoire.maregionsud.fr/fileadmin/user_upload/Focale/La_Focale_Regionale_8_web_1_.pdf

⁴⁰ <https://connaissance-territoire.maregionsud.fr/connaissance-du-territoire/la-bibliotheque-detudes/detail-etudes/fiche/lecosysteme-velo-lie-a-leurovelo-8/>

étudiants des 3 masters GEAD⁴¹ (à Aix), GEOPRAD⁴² (à Nice) et GEOTER⁴³ (à Avignon), illustre bien à la fois le lien entre formation et recherche et l'intérêt d'une UMR multisites régionale. Il s'agissait en effet de collecter sur le terrain (de la frontière italienne au Gard) des informations et données liées à l'EUROVELO 8⁴⁴ (réparateurs vélos, tables de pique-nique etc.) et de les mettre en ligne sur la plateforme OpenStreetMap, qui alimente de nombreuses applications dédiées au tourisme à vélo. Le fait d'impliquer des étudiants localisés à Nice, Aix et Avignon a permis de répartir la tâche et de traiter la totalité du linéaire de l'EV8 en Région Sud. D'autres projets du même type à l'échelle régionale (*géodatadays* sur les services de transport public par exemple) n'ont pu être réalisés que parce que l'UMR est présente via ses 3 sites universitaires sur toute la Région Sud.

En définitive, ce sont 10 projets du programme « Fabriques de la Connaissance »⁴⁵ qui ont été sélectionnés entre 2016 et 2021 (tous sites d'ESPACE confondus), ayant permis de financer et de former pas moins de 24 stagiaires, pour la plupart issus de Masters de Géographie.

3. L'UMR ESPACE contribue à la spécialisation de l'offre de formation des établissements de tutelle à travers les EUR

Les EUR (Écoles Universitaires de Recherche) proposent des offres de formations innovantes, pluridisciplinaires et très articulées avec la recherche, occupant une place croissante dans les projets d'établissements. L'UMR ESPACE est très présente dans ce nouveau paysage de l'ESR et contribue à orienter significativement les projets des tutelles.

Ainsi, Julien Andrieu est co-fondateur de l'EUR ODYSSEE⁴⁶ (Université Côte d'Azur), qui propose une offre de formation articulant les sciences de l'Homme et de la Société en lien avec les sciences de l'environnement. L'EUR couvre, entre autres, les champs des dynamiques de la société, mais aussi de la transition socio-environnementale, de l'avenir climatique et énergétique de la planète ou encore de l'anticipation du devenir des territoires face aux enjeux du développement durable. Parmi les 12 parcours de master proposés par l'EUR, trois sont portés par des membres de l'UMR : *Parcours Geoprospective et Aménagement pour la Durabilité des Territoires ; Gestion de l'Environnement et du Développement Durable ; Air : Pollution atmosphérique, changement climatique, impacts sanitaires, énergies renouvelables*. La création de cette EUR démontre aussi la capacité d'ESPACE à interagir avec les instances de l'université dans les prises de décision stratégiques alliant recherche et formation.

De même, Cyrille Genre-Grandpierre et Didier Josselin ont rédigé et porté pour Avignon Université le projet d'EUR « INTERMEDIUS » soumis dans le cadre du PIA 3. Cette EUR, regroupant 8 laboratoires, dont 2 de sciences exactes, traitant des inter-relations entre le numérique et les processus de création, médiation, décision et régulation (« ce que le numérique fait aux territoires et à la société ») a été bien évaluée par l'ANR, mais non retenue pour être financée. Avignon Université a néanmoins décidé de la mettre en place dès 2022 sur fonds propres. Le recrutement récent par l'université d'une chargée de mission venant épauler le directeur de l'EUR (Didier Josselin), va permettre de finaliser la structuration de l'offre de formation, ainsi que les orientations de recherche à venir, en lien avec les SHS.

A travers ces deux exemples d'EUR, on mesure bien le poids de l'UMR ESPACE et sa capacité à orienter durablement les projets des établissements, à l'interface entre l'enseignement et la recherche.

⁴¹ <https://formations.univ-amu.fr/fr/master/5HGA>

⁴² <https://univ-cotedazur.fr/formation/offre-de-formation/geoprospective-amenagement-et-durabilite-des-territoires-geoprad>

⁴³ <https://univ-avignon.fr/rechercher-une-formation/master-geographie-geomatique-et-projets-territoriaux-1258.kjsp>

⁴⁴ <https://fr.eurovelo.com/ev8>

⁴⁵ https://connaissance-territoire.maregionsud.fr/fileadmin/user_upload/Magazine-mmsh-pages-20_mai_BD.pdf

⁴⁶ <https://odyssee.univ-cotedazur.fr/>

4. Doctorant à l'UMR ESPACE Nice, puis MCF à l'UMR ESPACE Avignon

L'encadrement doctoral est un élément central dans la politique du laboratoire et constitue le principal lien entre formation et recherche. Parmi ces thèses, un exemple individuel permet d'illustrer que l'UMR ESPACE forme par et pour la recherche : le parcours de Matthieu Vignal. Après avoir été formé dès la L1 de géographie à Nice, Matthieu a soutenu brillamment en 2020 une thèse intitulée « *L'impact du changement global sur la flore du Sud-Est de la France : Modélisation multiscalaire de la répartition de 25 espèces à l'horizon 2100 par la dynamique de population* », sous la direction de Julien Andrieu. Cette thèse est l'un des points forts illustrant la recherche de l'axe B du projet scientifique. La qualité de cette thèse, notamment du point de vue de l'innovation méthodologique et de son inscription dans les défis sociétaux actuels, a permis à Matthieu d'être auditionné sur de nombreux postes de MCF, pour finalement choisir le poste de géographie physique quantitative proposé à Avignon.

Au-delà de ce bel exemple d'intégration à ESPACE qui permet d'assurer la transmission des connaissances et de maintenir l'identité scientifique d'ESPACE, l'examen du devenir des doctorants indique la grande variété des débouchés de nos formations doctorales, dans les milieux académiques, privés ou dans les collectivités, où continuent de percoler les méthodes et les outils développés et enseignés par l'UMR ESPACE.

#9 - UNE UMR QUI VULGARISE ET DISSÉMINE DES CONNAISSANCES VERS LA SOCIÉTÉ

Rédacteurs

Johnny DOUVINET (PR, Avignon Université)

et

Karine EMSELLEM (MCF, Université Côte d'Azur)

Une partie des activités de l'UMR ESPACE est consacrée à la dissémination et la vulgarisation des recherches qui sont menées par ses membres.

1. Illustration de la démarche de dissémination des connaissances scientifiques au sein d'ESPACE : l'alerte

Un article publié dans la revue *Sciences et Avenir*⁴⁷ en novembre 2021 a été choisi pour illustrer la démarche de dissémination. Cet article est le fruit d'un travail collectif, impliquant plusieurs membres de l'UMR : 2 enseignants-chercheurs (J. Douvinet, K. Emsellem), 1 jeune docteur (E. Bopp), 1 post-doctorante (C. Cavalière), 3 stagiaires financés en Master 2 (A. César, T. Jezierski, L. Roussel), mais aussi des collègues d'autres établissements (B. Gisclard, K. Weiss) ou des acteurs privés (G. Martin, L. Pinganaud). C'est dans le cadre du projet Cap-4-Multi-Canal'Alert⁴⁸ (2020-2021), financé par le programme ANR « JOP 2024 », que cette publication a été réalisée. Le format très court des pages publiées dans cette revue, spécialisée dans l'actualité scientifique à destination du grand public, a nécessité plusieurs discussions de rédaction, notamment pour définir le niveau adéquat du discours, scientifique et opérationnel.

Divers événements survenus en 2021 (feux de forêt, inondations rapides) ont souligné à quel point il était urgent d'alerter la population dans des délais adaptés (ni trop tôt, ni trop tard), et avec des messages explicites sur les conduites à tenir. Attendue au plus tard en juin 2022 sur l'ensemble de la métropole et les territoires d'outre-mer, la plateforme *FR-Alert* permettra la diffusion d'une alerte par messages textuels sur les téléphones des individus, localisés en temps réel. La diffusion cellulaire (CB) consiste à envoyer une notification sur les smartphones, sur un réseau 4G, et elle s'achève en quelques secondes, quelle que soit la taille de la population alertée. Elle permettrait de contacter 81% des Français (Figure 4). Le LB-SMS consiste à envoyer l'alerte par SMS localisé, sur un réseau 2G minimum, sans distinction avec d'autres SMS classiques. Si 94,8% des Français seraient potentiellement atteignables (Figure 4), l'effet de congestion sur les réseaux peut toutefois allonger le temps de diffusion, et les LB-SMS ne sont pas préconisés en cas d'urgence massive immédiate. Mais en hybridant ces canaux autour d'un standard international (le CAP, *Common Alerting Protocol*), le but est de rendre l'alerte ajustable et adaptable, et de tirer profit des avantages de chaque solution.

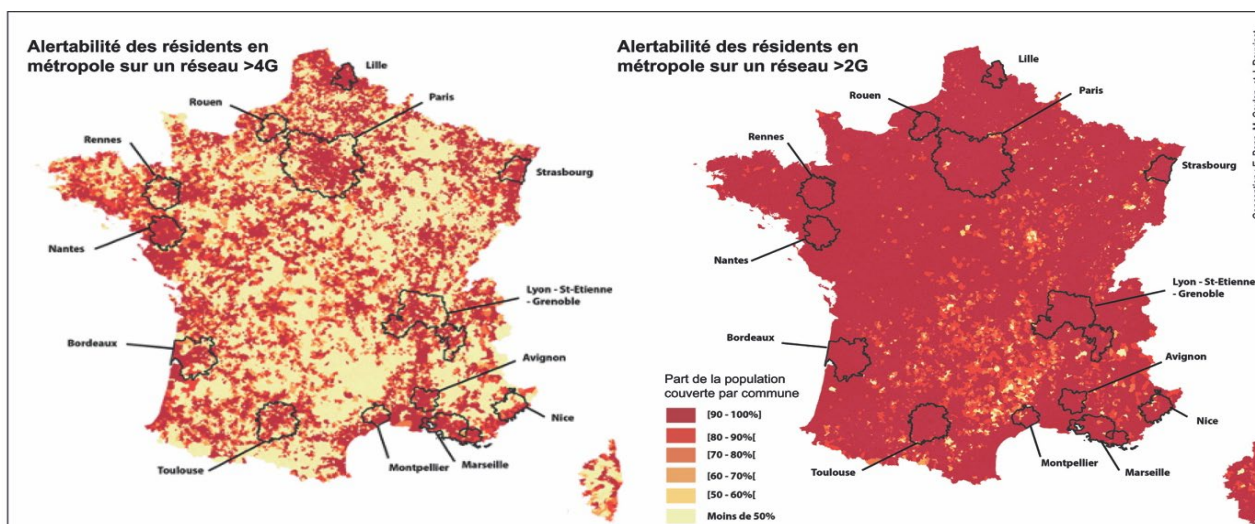


Figure 4. Couverture théorique d'une alerte sur la 4G (pour la diffusion cellulaire) ou sur les réseaux 2G, 3G et 4G en métropole (pour la diffusion de SMS géolocalisés) - Sciences et Avenir © 2021

⁴⁷ https://www.sciencesetavenir.fr/high-tech/moderniser-l-alerte-aux-populations-en-france-des-attendus-considerables_158514

⁴⁸ <https://capalert.univ-avignon.fr/>

2. Indicateurs factuels de portée

Il demeure difficile de savoir avec précision combien de personnes ont lu cet article, au format papier ou sur le site internet. En théorie, *Sciences et Avenir* affiche une audience globale sur Internet de plus 1,960 million de visiteurs uniques (576 K internautes / 953 K mobinautes / 435 K tablonantes). Elle est imprimée à 235 000 exemplaires, pour une audience de 3,261 millions de lecteurs. Cette revue a été choisie parce qu'elle valorise les travaux de recherche avec une tonalité opérationnelle et qu'elle offre une culture indispensable pour comprendre, prévoir et agir. C'est aussi la presse la plus lue dans cet univers.

A la suite de la publication, plusieurs mails ont été reçus, pour souligner la qualité du papier, mais aussi, pour suggérer des pistes de réflexion, pas forcément imaginées par l'équipe. Ainsi :

1. une entreprise nous a sollicité pour travailler sur le contenu des messages à panneaux variables (OXIALIVE⁴⁹) ;
2. un lecteur nous a indiqué qu'une personne autiste, par exemple victime du syndrome d'Asperger, avec troubles de l'attention et quelques hypersensibilités sensorielles, pouvait avoir du mal à comprendre les mots d'un message ;
3. la responsable pédagogique d'un Master 2 (Gestion des Risques Sécurité et Sûreté) nous a demandé d'intervenir sur cette question à partir de la rentrée 2022.

Ces retombées sont originales ou ouvrent des perspectives autant en termes d'exploration scientifique que d'impact sociétal.

3. Autres productions transversales de l'UMR à destination du monde non académique

Si l'on se réfère au fichier agrégeant les actions de vulgarisation et de dissémination scientifiques (tableau « Données de production de l'UMR »), plusieurs chiffres symbolisent la force de la médiatisation des travaux de l'UMR (sur la période 2016-2021) :

- 13 produits de médiation grand public (dont 3 vidéos YouTube, 5 conférences)
- 18 articles dans des revues techniques ou opérationnelles⁵⁰
- 25 émissions de radio, TV ou articles dans la presse écrite (ex : 20 minutes, France 3, France Bleu, France Culture) ;
- 48 invitations à des débats et conférences sur les relations Sciences et Sociétés

À noter également, la participation non négligeable des jeunes chercheurs dans cette démarche, qui montre à quel point la valorisation sociétale de la recherche est une pratique ancrée et partagée au sein d'ESPACE.

4. Une médiation scientifique devenue une action spécifique de l'unité

Si l'UMR ESPACE porte une attention toute particulière à ces activités de vulgarisation, c'est parce qu'une partie des travaux de recherche de l'UMR traite de la circulation des connaissances scientifiques, dans des perspectives de co-productions entre acteurs (chercheurs, citoyens, élus, techniciens, etc.), mais aussi d'appropriation et de diffusion de savoirs scientifiques spatiaux. Ainsi, l'action *TACTIC* (*Transfert de connaissances territoriales complexes*), initiée dans le projet scientifique actuel, va donner naissance à de nouvelles réflexions dans le prochain contrat quinquennal. Elle interroge la façon dont les savoirs spatiaux sont co-construits et l'apport des interactions entre chercheurs et membres de la société. Ces travaux de recherche vont donc au-delà d'une simple dissémination, puisqu'ils apportent aussi une dimension réflexive sur la vulgarisation au sens large, tout en permettant de questionner l'utilité et l'utilisation des connaissances territoriales produites.



⁴⁹ <https://www.oxialive.fr/>

⁵⁰ Assises de la Transition Écologique et Citoyenne Alpes-Maritimes Alpes du Sud 2018
<https://peertube.scic-tetris.org/videos/watch/b393cfa5-351a-41a1-be92-996922d58deb>

#10 - UNE UMR QUI COLLECTE, GÈRE, TRAITE ET DIFFUSE DES INFORMATIONS SCIENTIFIQUES

Rédacteurs

Pierre-Alain AYRAL (IR, CNRS)

et

Didier JOSSELIN (DR, CNRS)

L'UMR ESPACE est très impliquée dans la collecte, le traitement et la diffusion d'informations scientifiques, dans le cadre de la science ouverte respectant autant que faire se peut les principes du FAIR data : *Findable, Accessible, Interoperable, Reusable*.

1. Le partage des données et des informations scientifiques à ESPACE

Cette volonté de partage des données et des informations scientifiques transparaît à plusieurs niveaux :

- **Soutien de revues numériques en double accès libre sur internet**, gratuites pour les auteurs comme pour les lecteurs. L'UMR ESPACE exerce une double action, régulière et assumée, envers ces revues. En effet, même si dans le système bibliométrique actuel, la part belle est faite aux revues classiques payantes, soit pour les auteurs (en « open-access »), soit pour les lecteurs, ESPACE fait le pari que l'avenir est à la libération des flux d'information scientifique, en phase avec la *Déclaration de San Francisco*⁵¹, rappelée notamment par l'HCERES lors du lancement de cette nouvelle campagne d'évaluation de la vague C et impliquant des formes de reconnaissance plus équilibrées de la science.
 - o D'une part, les membres de l'unité ont publié de nombreux articles dans *Cybergéo* (en moyenne 2 par an sur la période 2016-2021, revue en Q4).
 - o D'autre part, ESPACE porte quatre revues essentiellement en langue française, dont trois du même modèle économique (dit « Diamant ») : *Mappemonde*⁵², *Journal of Interdisciplinary Methodologies and Issues in Science*⁵³ et *Méditerranée*⁵⁴. Pour les deux premières revues, l'UMR est entièrement responsable de l'édition et de la publication des numéros, avec notamment, à l'interface des flux, une ingénieure dédiée à cette activité (L. Faure) et jusqu'en 2022, un ingénieur cartographe à temps partiel pour *Mappemonde* (M. Coulon). ESPACE est impliqué dans une quatrième revue, en open access standard : *Risques Urbains*⁵⁵.
- **Production de données géographiques**. Le laboratoire ESPACE se distingue également par sa propension à gérer et à alimenter des bases de données ou à produire des données socio-géographiques. Cela se traduit à plusieurs niveaux :
 - o *Gestion de Geo-catalogue* : ESPACE, via notamment la Direction de l'Observatoire Hommes-Milieus Littoral Méditerranéen (OHM-LM⁵⁶) entre 2012 et 2020 (S. Robert), a créé un géo-catalogue avec l'appui de ressources informatiques de la fédération de recherche ECCOREV⁵⁷ et du labEx OT-Med⁵⁸ ; M.-L. Trémélo gère ainsi les données en sciences de l'environnement produites dans le cadre des projets labellisés par l'OHM-LM, en concordance avec les choix techniques et scientifiques du LabEx DRIIHM⁵⁹ (INEE CNRS) ;
 - o *Alimentation de bases de données collaboratives* : ESPACE produit un ensemble de méta-données décrivant les corpus de l'OHM-LM, contribue à plusieurs Bases de Données internationales (Universités de Yakutsk et Kaunas en Arctique) et alimente depuis de nombreuses années la Base de Données des Observatoires en Hydrologie

⁵¹ <https://sfdora.org/read/>

⁵² <https://journals.openedition.org/mappemonde/>

⁵³ <https://jimis.episciences.org/>

<https://www.inshs.cnrs.fr/fr/journal-interdisciplinary-methodologies-and-issues-science>

⁵⁴ <https://journals.openedition.org/mediterranee/>

⁵⁵ <http://www.openscience.fr/Risques-urbains>

⁵⁶ <http://www.ohm-littoral-mediterraneen.fr/>

⁵⁷ <https://www.eccorev.fr/>

⁵⁸ <https://www.otmed.fr/>

⁵⁹ <https://www.driihm.fr/>

de l'INRAE⁶⁰ (BDOH), via l'Observatoire Hydro-Météorologique Cévennes Vivarais (OHM-CV), connectée à Théia-OZCAR⁶¹.

- *Diffusion libre de corpus de données* : l'UMR a mis en place une politique de diffusion de ses méthodes et données sous DOIs normalisés (via *Nakala*).
- **Autres vecteurs de diffusion scientifique.** Les membres d'ESPACE inventent des méthodes d'analyse spatiale et les partagent via leur code source en ligne sur *Zenodo* (travaux de J. Perez). Pour soutenir et structurer ce type d'initiative, l'unité a créé un groupe de travail intersites dont le but est de recenser, structurer, mutualiser et rationaliser la production et l'usage des données du laboratoire, conformément au RGPD. Il s'agit également de promouvoir et d'encourager les pratiques de science ouverte et de faire le lien entre les publications et les données ayant permis d'obtenir les résultats de recherche.

2. Zoom sur la plateforme expérimentale de l'implantation cévenole

Débutée sur le site historique du Mont-Lozère au début des années 1980, l'implantation cévenole de l'UMR ESPACE développe aujourd'hui une instrumentation dédiée à l'*observation hydro-socio-climatique*, souvent sur le long terme (plus de 40 ans), sur 8 sites localisés dans les Cévennes. Avec des questions de recherche interdisciplinaires à l'interface homme-milieu, centrées sur les extrêmes hydrologiques (crues et étiages), le changement climatique et les changements globaux, les observations réalisées invitent à des collaborations au sein et à l'extérieur de l'UMR ESPACE. Plusieurs sites sont intégrés à l'Observatoire Hydrométéorologique Cévennes Vivarais (OHM-CV⁶², ORE de l'INSU) et dans le Site Atelier Rivières Cévenoles⁶³ de la ZABR (Zone Atelier Bassin du Rhône⁶⁴, une des ZA de l'INEE). À ce titre, l'implantation Cévenole de l'UMR ESPACE fait partie intégrante de la Très Grande Infrastructures de Recherche OZCAR (Observatoire de la Zone Critique, Applications et Recherche⁶⁵) et du Réseau des Zones Ateliers (RZA), ainsi que de l'infrastructure de recherche européenne eLTER (Long-term Ecosystem Research in Europe⁶⁶). Elle est également associée au projet de PEPR Monenvi (soumis dans le cadre du PIA4 et actuellement en seconde phase d'évaluation) et au *master site* P3M porté par les laboratoires de recherche d'Occitanie, candidat aux plateformes internationales d'OZCAR (cf. Figure 5).

⁶⁰ <https://bdoh.irstea.fr/OHM-CV/>

⁶¹ <https://www.theia-land.fr/theiaozcar-un-portail-unique-dedie-aux-donnees-dobservation-in-situ/>

⁶² <https://ohmcy.osug.fr/>

⁶³ <https://www.graie.org/zabr/sites/site8.html>

⁶⁴ <https://www.zabr.assograie.org/>

⁶⁵ <https://www.ozcar-ri.org/fr/ozcar-observatoires-de-la-zone-critique-applications-et-recherche/>

⁶⁶ <https://www.lter-europe.net/elter>

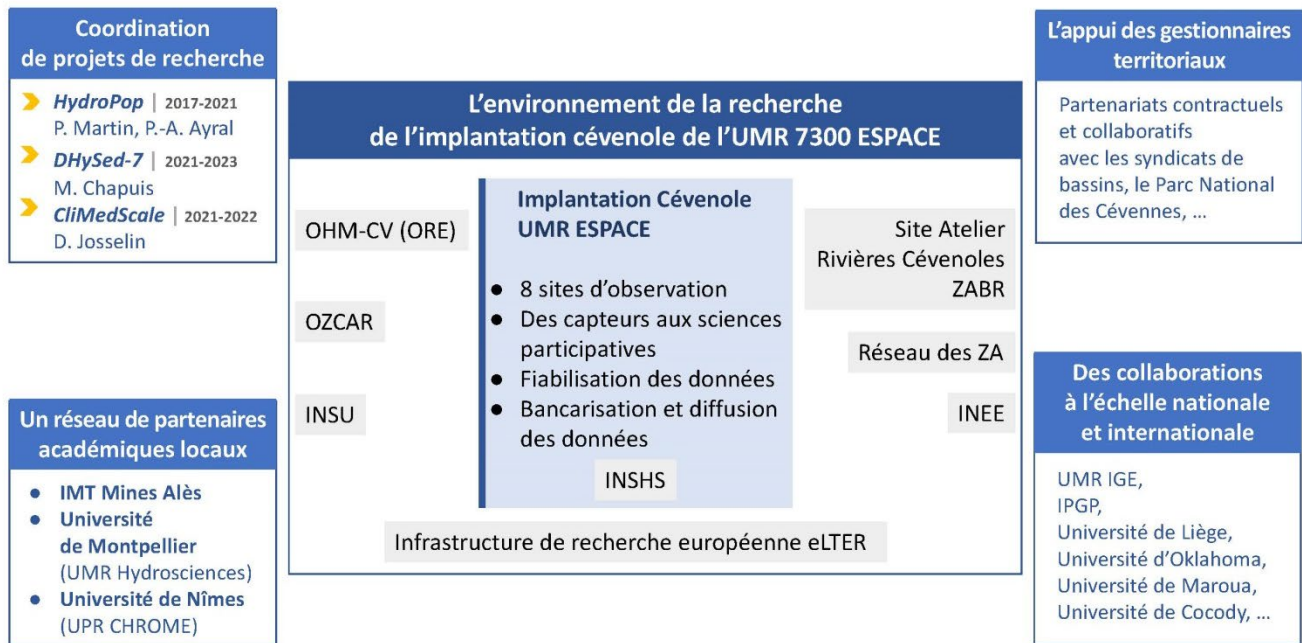


Figure 5. L'environnement de recherche de l'implantation cévenole

Durant ce sexennal, plusieurs projets ont été portés par ESPACE dans les Cévennes (cf. Figure 5), dont notamment le programme de recherche « *HydroPop : vers une hydrologie populaire et participative* ». Dédié à la connaissance des basses eaux, ce programme de recherche piloté par Philippe Martin depuis 2017 et coanimé à partir de 2019 par Pierre-Alain Ayrat, a permis de mettre en place une démarche interdisciplinaire et une science impliquée avec les habitants et les gestionnaires du territoire. En parallèle de la réalisation d'une enquête sur les perceptions des habitants permanents et non permanents sur cette question de l'aridité et de la sécheresse, une stratégie de suivi hebdomadaire des débits en période estivale (une quinzaine de stations réparties sur l'amont des bassins versants du Gardon et de la Cèze) a été mise en place. L'élaboration d'une échelle de gravité des sécheresses, la diffusion de ces résultats avec une communication dédiée (média, conférences) et la mise en œuvre d'une démarche participative ont permis de mobiliser le territoire sur cette question et d'approfondir les connaissances sur cette période de tension sur la ressource en eau. La question de la gestion de crise face à ce risque a enfin été abordée, avec la réalisation de scénarios de gestion de crise sécheresse qui ont pu être testés par un simulateur auprès d'élus et de gestionnaires du territoire.

Les prochains défis de l'implantation cévenole de l'UMR ESPACE seront de poursuivre la modernisation et la fiabilisation du réseau d'observation, de s'inscrire pleinement, en collaboration avec les autres producteurs de données du laboratoire, dans une démarche de science ouverte et de continuer à animer, à susciter des projets de recherche interdisciplinaires, impliquant les acteurs de la recherche, nationaux et internationaux, ainsi que les gestionnaires du territoire et les citoyens.

#11 - UNE UMR QUI SE PRÉOCCUPE DE LA QUALITÉ DE VIE AU TRAVAIL

Rédactrices

Nathalie BRACHET (IE, CNRS)

&

Marie-Laure TRÉMÉLO (IE, CNRS)

Par qualité de vie au travail, nous entendons toutes les actions et organisations améliorant les échanges et la vie d'un laboratoire multisites et multi-tutelles.

Depuis 2015, à l'initiative de N. Brachet (site d'Avignon) et M.-L. Trémélo (site d'Aix-en-Provence), une évolution de l'organisation des activités de fonctionnement, d'appui et d'accompagnement de la recherche a été engagée, afin d'apporter plus de mutualisation et de partage dans le contexte multi-tutelles et multi-sites de notre unité.

En effet, l'éloignement géographique des trois sites universitaires et de l'antenne cévenole, et la localisation de l'UMR « à cheval » sur le périmètre de deux délégations CNRS peuvent être un frein majeur aux échanges inter-sites et à un fonctionnement transverse. Cette volonté de favoriser le partage inter-sites nous a conduit à trouver des solutions pour faciliter le travail et les échanges à distance, harmoniser les pratiques et mutualiser les informations. La mise en place de cette organisation, bien avant l'arrivée de la pandémie, nous a permis de poursuivre sereinement nos activités durant les divers épisodes de confinement.

Ce projet de ré-organisation, mis en place avec l'appui de la Direction du projet quinquennal 2018-2022, qui a soutenu et accompagné les actions engagées durant cette période, a également bénéficié d'un soutien financier du CNRS, via le projet « **Vers une dynamique de partage et de mutualisation** », lauréat de l'Appel à projet QVT 2017 du CNRS, et piloté par les deux initiatrices du projet.

Nous considérons que ce travail réflexif et opérationnel, même s'il ne prétend pas couvrir l'ensemble des problématiques rencontrées dans l'activité de notre UMR, constitue aujourd'hui une **expertise à partager avec les autres laboratoires multisites et/ou multi-tutelles**⁶⁷. Si l'accompagnement de la recherche constitue pour bon nombre de laboratoires un simple service d'appui, le laboratoire ESPACE, quant à lui, considère qu'il représente un véritable levier d'amélioration de la qualité de l'activité scientifique dans toutes ses dimensions. Cette expertise se traduit par l'identification de besoins et l'élaboration de propositions et solutions concrètes, assorties de points de vigilance, pour identifier les nouvelles pistes d'amélioration. Le tableau qui suit synthétise les principaux points abordés dans le présent contrat sexennal.

Contexte, besoin initial	Proposition	Solution et vigilance
Vie de Laboratoire		
Budget		
a- Inégalité des enveloppes budgétaires de chaque site en fonction des tutelles b- Accès difficile aux contrats de recherche de chaque site car présentés sur les plateformes de chaque tutelle (absence de base de données globale)	a- Utiliser les crédits CNRS pour aider les sites les moins dotés par leur université b- Permettre à la Responsable Administrative (RA) d'accéder à l'ensemble des plateformes pour avoir une vue d'ensemble des contrats en cours, terminés ou à venir	a- Redistribution <i>per capita</i> d'une partie du budget CNRS b- La plateforme commune de suivi des contrats des tutelles a été mise en place par la RA, via des tableaux de bord (suivi des contrats et suivi de la consommation du budget), partagés sur CORE (CNRS)
Compétences de fonctionnement, d'appui et d'accompagnement de la recherche		
a- Au moment du renouvellement du laboratoire, constat de la méconnaissance des compétences et activités des personnels d'appui (PAR) b- Politique de recrutement : définition des postes à pourvoir rédigée en conseil de laboratoire avec classement en fonction des besoins prioritaires sur chaque site	a- Utilisation de questionnaires adressés aux PAR et analyse des réponses b- Création d'un comité opérationnel (comité de Direction + responsables des axes de recherche + 2 représentants élus des personnels du laboratoire), permettant une prise en compte des besoins en relation avec les compétences déjà présentes	a- Présentations en AG des compétences présentes au sein du laboratoire amenant à : • demande de poste CNRS via DIALOG • mutualisation des activités des PAR au profit de tous les sites, quel que soit le lieu d'affectation b- Participation du comité opérationnel aux recrutements des personnels (NOEMI, CDD...) pour accompagner les choix de la direction
Outils collaboratifs de communication		
a- Préconisations de chaque tutelle en matière d'outils collaboratifs et de communication	a- Étude et test de l'offre des quatre tutelles b- Recherche d'outils nomades, peu contraignants, d'utilisation simple, pour se soustraire à la difficulté d'accès à des salles de visio	a- Choix évolutifs en fonction des avancées et des préférences de chaque tutelle (nécessité d'une grande agilité) : <i>Renaviso, Zoom et BBB, MyCom, Tixeo</i> ,

⁶⁷ Ce partage a d'ailleurs été réalisé lors de la venue d'une délégation du laboratoire EVS de Lyon, le 28 janvier 2020 à Avignon.

<p>b- Utilisation de la visioconférence : obligation de réservation de salles spécifiques dédiées à la visio (peu nombreuses)</p> <p>c- Réunions en présentiel : les réunions sur un des trois sites ne permettent pas toujours de mobiliser les membres à 100% (contraintes familiales ou professionnelles « de proximité »)</p> <p>d- Élections : vote sur site distant, organisation complexe</p>	<p>c- Recherche de lieux de réunion (AG, etc.) sur site « neutre » (hors sites UMR) pour favoriser la mobilisation de chacun, créer une dynamique de groupe et minimiser l'impact carbone des déplacements</p> <p>d- Trouver un outil fiable et sécurisé de vote en ligne</p>	<p>b- Acquisition de 4 LogiCam grâce au budget CNRS QVT 2017 ainsi que de HP Jabra</p> <p>c- Plusieurs AG organisées en résidence sur 2 jours ou à la journée (Aix-en-Provence, Cannes, Sausset-les-Pins, Fréjus)</p> <p>d- Mise en place de votes électroniques à partir de 2018 via l'outil <i>Belenios</i></p>
Pôle d'activités « Gestion administrative et financière »		
Mutualisation des documents et Plateforme collaborative		
<p>a- Multiplication de documents en fonction des tutelles (ordres de mission)</p> <p>b- Pas de fichier global des personnels, référencement opéré par chaque site, manque de visibilité pour l'ensemble des sites, un seul référent ESPACE identifié à Nice pour alimenter la base des personnels (CNRS)</p> <p>c- Absence d'espaces communs de stockage des documents, accessibles par tous</p>	<p>a- Travail sur l'intersection des renseignements demandés par chacune des tutelles et DR CNRS</p> <p>b- Identifier une base unique de référencement des membres de l'unité (permanents et non permanents) et partager les droits d'accès pour faciliter la saisie et l'alimentation en continu</p> <p>c- Identifier et tester des solutions sécurisées de stockage et partage de dossiers ; Tests via <i>Dropbox</i>, puis <i>MyCore</i> pour le partage de documents entre Avignon et Aix-en-Provence pour faciliter la gestion des contrats de recherche</p>	<p>a- Rédaction d'une fiche unique et complète pour les demandes de mission quelle que soit la tutelle</p> <p>b- Choix de la base <i>Labintel</i> qui devient <i>RESEDA</i> (en 2015) ; prise en main par deux PAR puis par la RA (à son arrivée) de ce nouveau portail et nettoyage complet de la base avec saisie de tout le personnel rattaché à ESPACE depuis janvier 2016 (plateforme néanmoins peu ergonomique, qui nécessite de suivre les informations en parallèle dans un tableau pour faciliter la gestion quotidienne)</p> <p>c- Développement d'un espace CORE (Sharepoint) propre à ESPACE pour le partage de documents des différents sites (gestion, administration, suivi RH...)</p>
<p>→ Vigilance</p> <ul style="list-style-type: none"> • sensibiliser et former à l'utilisation de l'espace CORE, outil plus sécurisé mais moins convivial que des solutions grand public, notamment en matière d'édition collaborative et en raison de spécificités de protections informatiques de chaque site universitaire • développer l'espace partagé, en faire la base de référence pour la documentation administrative et d'aide à la gestion et au montage de projets 		
Procédures		
<p>a- Affichage des procédures par tutelle, peu clair et parfois inexistant</p> <p>b- Non-respect des délais préconisés par les gestionnaires et méconnaissance des circuits de validation d'une demande d'ordre de mission et d'une demande d'achat, accumulation des demandes de remboursement de frais en fin d'exercice</p> <p>c- Nécessité de « continuité de service » sur les outils de gestion administrative et financière (maladie, congés)</p>	<p>a- Rédaction de fiches de procédures applicables à toutes les tutelles et mise en commun de ces procédures sur CORE</p> <p>b- Schématisation du processus (logigrammes) des tâches administratives pour un bon de commande ou une mission, en utilisant les expériences des gestionnaires</p> <p>c- Pour chaque tutelle, identifier les outils disponibles et quelles personnes y ont accès. Pour les outils CNRS, répartir entre les gestionnaires les tâches et les droits d'accès en ayant au moins un binôme par application et une représentativité des sites (quand cela est possible)</p>	<p>a et b - Fiches de procédures déposées sur CORE</p> <p>c- Duplication des accès entre gestionnaires quand possible, accès accordé à la RA sur l'ensemble des outils CNRS (possibilité de suppléer les gestionnaires pour bons de commande ou missions) et (en consultation seulement) aux outils financiers des universités (possibilité de suppléer les gestionnaires pour reporting)</p>
<p>→ Vigilance</p> <ul style="list-style-type: none"> • Risque de peu de visibilité et peu de consultation sur CORE : faire des rappels réguliers sur l'existence de ces sources • Veiller à mettre à jour et compléter la base documentaire et les fiches de procédure, rendre systématique le réflexe de recherche d'informations sur CORE • Sensibiliser (avec persuasion) à la problématique des déplacements de dernière minute, qui sont encore nombreux et perturbent l'organisation du travail des gestionnaires (stress) • Identifier les ressources hors ESPACE (DR CNRS, tutelles) qui pourraient être le relais des gestionnaires en cas d'absences longues cumulées 		
Pôle d'activités « Communication »		
Améliorer la visibilité institutionnelle		
<p>a- Nécessité de comprendre les attentes des chercheurs et des tutelles sur les besoins en communication à ESPACE</p> <p>b- Site internet développé sous <i>spip</i> devenu obsolète</p>	<p>a- Création d'un groupe de travail en 2018 « Outils numériques de communication » composé de PAR, d'enseignants-chercheurs et de chercheurs</p> <p>b- Refonte du site Internet en utilisant les préconisations du CNRS, modèle sous <i>wordpress</i></p> <p>c- Identifier une solution permettant à tous de saisir et d'afficher des actualités en lien</p>	<p>a- Discussions et propositions d'outils à développer, en discussion et évolution permanentes</p> <p>b- En constante évolution et mise à jour : annuaire des personnels, présentation des différents sites de l'UMR, des axes et actions du contrat quinquennal en cours, référencement des thèses en cours et des publications, etc.</p> <p>c- Création d'un carnet de recherche Hypothèses, avec un lien vers le site internet pour afficher les</p>

c- Site internet : accès restreint aux webmasters, manque d'un espace d'échange pour les chercheurs d – En-tête ESPACE des documents souvent composée uniquement du logo CNRS et de celui de la tutelle de site, parfois obsolète	avec les projets de recherche et actions développées dans l'unité d- Création d'une nouvelle charte graphique d'ESPACE intégrant les logos des quatre tutelles, mise à jour régulière	actualités. Une formation des chercheurs à cet outil est dispensée d- Mise à disposition de modèles de documents : courrier Word, présentation PPT, etc. intégrant la nouvelle charte et les logos à jour sur la plateforme CORE
<p>→ Vigilance</p> <ul style="list-style-type: none"> • Bien veiller à enrichir régulièrement le site internet de contenus concernant les contrats de recherche, les réseaux de recherche (partenaires, relations internationales, liaisons institutionnelles avec les dispositifs existants LabEx, EUR, FR..., ainsi que le prochain projet de recherche • Inciter les membres d'ESPACE à participer aux formations sur les carnets Hypothèses • Encourager l'utilisation de la charte graphique ESPACE pour tous les documents 		
Améliorer la communication interne		
a - Transmettre l'information en interne, auprès de chacun des sites, de la manière la plus fluide possible b – Améliorer l'appréhension des procédures et des outils par les nouveaux arrivants	a- Création et gestion de listes de diffusion, en lien avec les tableaux de bord de suivi des personnels (mises à jour par la RA en lien avec le suivi RH) b-Rédiger un guide d'accueil du nouvel arrivant	a- Création de listes de diffusion spécifiques et ciblées : • générale, pour l'ensemble des personnels des différents sites • pour chacun des sites universitaires • pour les jeunes chercheurs doctorants/post-docs • pour les chercheurs/enseignants-chercheurs
<p>→ Vigilance</p> <ul style="list-style-type: none"> • Construire et diffuser à bon escient le guide du nouvel arrivant, contenant l'ensemble des informations favorisant la découverte de l'environnement institutionnel et humain de l'unité 		
Améliorer la visibilité des résultats de recherche		
a- Répondre aux directives de la Science Ouverte en améliorant la « traçabilité » des publications et des chercheurs	a- Assurer la visibilité des chercheurs via une ou des identités pérennes, rendre visibles les publications scientifiques, résultats de la recherche via une archive ouverte et le site internet	a- mise au propre et suivi des identifiants idHAL pour l'ensemble des membres d'ESPACE ; lien avec l'ORCID ; mise au propre des collections HAL (obligation de dépôt des publications sur HAL depuis 2015) ; formation des enseignants chercheurs et des chercheurs aux dépôts dans HAL et à la création de leur CV HAL
<p>→ Vigilance</p> <ul style="list-style-type: none"> • assurer la lisibilité des contenus HAL sur notre site internet • développer et promouvoir les pratiques de science ouverte auprès des différents publics (enseignants-chercheurs, doctorants et personnels) 		
Pôle d'activités « Formation »		
a- Proposition de formations spécifiques diffusées par chaque tutelle, plan de formation de l'unité demandé par chaque tutelle à des dates différentes, faibles retours sur les besoins de la part des personnels vers les référents formation de l'unité b- Perte de compétences du fait du départ des ingénieurs contractuels sur projets	a- Améliorer le recensement des besoins en formation et du nombre de réponses des personnels b - Avoir la capacité d'anticiper les besoins en fonction des projets de recherche	a- Rédaction d'un PFU commun à ESPACE adressé aux 2DR du CNRS et transmis aux tutelles universitaires b- Mise en place de courtes sessions de formation en interne via ERE / Espace rencontre Espace
<p>→ Vigilance</p> <ul style="list-style-type: none"> • Mobiliser les agents sur leurs besoins en formation • Promouvoir la transmission de compétences via des formations internes de plus grande ampleur 		
Pôle d'activités « Données »		
Structure, partager et ouvrir les données de la recherche		
a- Pas de politique commune de gestion et partage de données (organisée par site, voire par projet de recherche), « sensibilité » des tutelles en termes de sécurité d'accès aux données distantes b- Pérennisation des données climatiques et hydrologiques collectées par l'antenne des Cévennes sur plusieurs décennies	a et b - Création d'un groupe de travail sur la bancarisation des données en 2018	a- Recours à Huma-Num pour la mise en place de serveurs ou de serveurs dédiés sur site selon nécessité de sécurité (données foncières) b- Un exemple : avant le départ à la retraite de l'ingénieur des Cévennes ayant coordonné ces collectes, bancarisation des données sur <i>Nakala</i>
<p>→ Vigilance</p> <ul style="list-style-type: none"> • Nécessité de se former aux nouvelles directives de Science ouverte et de gestion des données • Qualifier et appliquer une politique de gestion de données pour l'ensemble du laboratoire • Développer les compétences en matière de diffusion de données (FAIR et respect du RGPD) 		

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