Geocarto International

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tgei20

Incorporating the visibility analysis of fire lookouts for old-growth wood fire risk reduction in the Mediterranean island of Sardinia

Sergio Fantini, Mauro Fois, Romina Secci, Paolo Casula, Giuseppe Fenu & Gianluigi Bacchetta

To cite this article: Sergio Fantini, Mauro Fois, Romina Secci, Paolo Casula, Giuseppe Fenu & Gianluigi Bacchetta (2022): Incorporating the visibility analysis of fire lookouts for old-growth wood fire risk reduction in the Mediterranean island of Sardinia, Geocarto International, DOI: 10.1080/10106049.2022.2032399

To link to this article: https://doi.org/10.1080/10106049.2022.2032399

Incorporating the visibility analysis of fire lookouts for old-growth wood fire risk reduction in the Mediterranean island of Sardinia

Sergio Fantini[1,2], Mauro Fois[2*], Romina Secci[3], Paolo Casula[1], Giuseppe Fenu[2], and Gianluigi Bacchetta[2,4]

[1]Servizio tecnico, Agenzia Forestas, Cagliari, Italy

[2]Department of Life and Environmental Sciences, University of Cagliari, Cagliari, Italy

[3]Environmental engineer, Cagliari

[4]Hortus Botanicus Karalitanus (HBK), University of Cagliari, Cagliari, Italy

[*]Correspondence should be addressed to Mauro Fois: mfois@unica.it

Abstract

Sardinia is subject to many fire events each year. A visibility analysis of old-growth woods from the network of fire lookouts was performed; the visibility of fires from lookouts and the level of old-growthness of woods were then implemented to the common information of wildfire hazard maps to obtain a vulnerability map. The results show that 78% of Sardinian old-growth woods are visible from lookouts and that 99% of them fall into the network of protected areas. However, old-growth woods are unevenly protected from fires, with visibility coverages ranging from 40% in the Sulcis macro-area to 100% in others. Compared with the wildfire hazard map, the vulnerability map led to different outputs in terms of fire protection prioritisation, allowing better risk assessment and improved fire control planning. The integration of other parameters into wildfire hazard maps is a replicable focus-oriented approach that might be tested in other contexts.

Keywords Forest fires; Fire management; Geographic information system; Parametric method; Forest conservation and management

1. Introduction

Many parts of the globe are fire-prone, but especially in Mediterranean-type climate regions, fires are one of the main problems for both environmental and social security (e.g., Stefanidou et al. 2017; Urbieta et al. 2019; Achour et al. 2021). This is also the case of Sardinia, the second largest island of the Mediterranean Basin. Data collected by the Regional Administration of Sardinia (RAS; http://www.sardegnageoportale.it) show that from 2004 to 2016 the extension of forest fires (with areas greater than 1 ha) covered an average area of 17,400 ha per year. The Sardinian fire fighting system consists of a network of lookouts, ground teams, fire fighting cars, and a fleet of helicopters and planes (RAS 2019). In Sardinia, fires are facilitated by a typical Mediterranean climate, characterised by mild wet winters and warm to hot, dry summers (often prolonged during late spring and early autumn) and by frequent winds with with gust from 80 to 100 km.h^{-1} (Cardil et al. 2017). The fire mapping carried out by the RAS in the last 13 years (http://www.sardegnageoportale.it), shows that the phenomenon affects a large percentage of the regional territory and that forest fires often start near roads, which suggests a frequent anthropogenic origin (Lovreglio et al. 2010).

In this context, fire lookouts in strategic positions have proven to be effective tools for early fire detection and facilitating efforts to prevent fire spread (Rego and Catry 2006; Kucuk et al. 2017; Hognogi et al. 2020). The current fire detection system in Sardinia consists of 217 lookouts, 49 of which are integrated by patrolling for itinerant sighting (RAS 2019). Due to limited resources, not all lookouts operate 24 hours a day. For this reason, it is necessary to place lookouts in a cost-effective way, to increase the percentage of covered territory and guarantee immediate intervention by air and ground teams. With this aim, RAS created a fire hazard map in which, considering main factors contributing to occurrence of fires, the most exposed areas of Sardinia were located (RAS 2017). However, such hazard maps were not linked to the conservation value of the forests and woods. For instance, despite their usefulness, fire hazard maps were not designed to evaluate and display the presence and vulnerability of old-growth woods.

Old-growth woods are equivalent to primary or secondary forests that developed structures and host species normally associated with primary forests (FAO 2020). They have a high conservation value because they ensure a rich array of microhabitats and resources of primary importance to several taxonomic groups, such as invertebrates (Siitonen 2001; Casula et al 2021), small mammals (Casula et al 2017), lichens, mosses, fungi (Nordén et al. 2007; Nimis et al. 2018) and vascular plants (Minissale and Sciandrello 2013), some of which are not present in managed forests and woods (Lindenmayer and McCarthy 2002; Pezzi et al. 2020). The global disappearance of primary, natural or unmanaged forests and woods is of great concern and, in fact, these are rare in Europe, due to their historical exploitation (Parviainen 2005; Marchetti and Blasi 2010). Also in the island of Sardinia, the extension of such woods was estimated to be considerably reduced during the nineteenth century, mainly due to deforestation, subsequent livestock of sheep and goats, coupled with fires to maintain pastures (Pungetti 1995). In this paper, the spatial information of fire lookouts was overlaid in a Geographic Information System (GIS) with relevant information about old-growth woods with the aim to (i) evaluate the visibility of old-growth woods from the Sardinian fire lookouts network, (ii) assess their vulnerability through an implementation of RAS wildfire hazard map with values of old-growthness and visibility from the lookouts, and (iii) compare the vulnerability map with the RAS wildfire hazard map of Sardinia. The results, coupled with coverage of old-growth woods within protected areas, provide new information useful for more effective protection of woods from fires. The same approach might be applied in other contexts and with different specific biotic and abiotic parameters.

2. Materials and methods

2.1. Study area

Sardinia is the reference area of this study; it has a surface area of approximately 24,090 km^2 and is located in the central-western part of the Mediterranean Basin (Figure 1a). Several landscapes are present here: limestone and crystalline mountains, plains, basaltic plateaus, coastal dunes, large coastal and small temporary inland wetlands, several long and pocket beaches, and coastal and inland cliffs (Fois et al. 2017). Woods in Sardinia have been estimated to cover a surface of 4,297 km^2 (Puddu et al. 2012), which mainly consists of evergreen holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) woods and deciduous oak woods (*Quercus* sp. pl.), with a wide ecological range and a widespread distribution throughout the island, occurring from coastal areas up to 1650 m above sea level (Bacchetta et al. 2009). Furthermore, particular soil-climatic conditions support the instauration of mesophilous (e.g., *Taxus baccata*, *Ilex aquifolium*, *Ostrya carpinifolia*) and edafoxerophilous woods (e.g., *Olea europaea*, *Phillyrea latifolia*, *Juniperus* sp. pl.) which make the island very diverse in this aspect. The test site was the Supramontes, in central-eastern Sardinia (Figure 1b). Supramontes is an area of great naturalistic interest, where one of the oldest holm oak woodlands of the Mediterranean area is present. Here, the woods, which find its climatic optimum in the carbonate and limestone-dolomitic substrates of the biogeographic 'Supramontano' sector (Fenu et al. 2014), are dominated by *Quercus ilex* with other sclerophylls such as *Phillyrea latifolia*, but also by relic populations of *Taxus baccata*, *Ilex aquifolium*, deciduous trees of *Acer monspessulanum*, *Quercus virgiliana* and endemic geophytes such as *Paeonia corsica*, *Aquilegia nugorensis* and *Helleborus argutifolius* subsp. *corsicus* (Susmel et al. 1976; Bacchetta et al. 2009). This area is rich in trees of large diameter (on average 40-60 cm, up to 150 cm) and height (dominant plane that touches 30 meters) with expanded and globose crowns, both single and in small groups, interspersed with trees of smaller diameter (30-40 cm). However, these woods suffered a vast fire in 1931, which reduced its former extent to smaller and scattered stands (Susmel et al. 1976).

2.2. Mapping old-growth stands in Sardinia

The study was carried out during spring-summer 2019 and is part of an inventory project of old-growth woods in Sardinia (Fantini et al. 2021). The selected 68 woods with old-growth features were identified according to peer opinion, considering the knowledge acquired during about twenty years of field investigation, and by consulting the most relevant literature concerning Sardinian forest vegetation (e.g., Bacchetta et al. 2004, 2009; Marchetti and Blasi 2010; Farris et al. 2012; Puddu et al. 2012). Within these areas, depending on forest extension, from 1 to 11 circular plots of a 13 m radius were randomly positioned and surveyed (Lombardi et al. 2015). Each site was classified according to the three old-growthness classes proposed by Badalamenti et al. (2018): high (H), medium (M) and low (L). Such classification was based on an overlay of four internationally recognised indicators of old-growthness: deadwood, tree size, structural characteristics and tree species richness. A score ranging from 1 to 3 based on the total volume of dead tree values and the number of decay classes was assigned for the proxy indicator 'deadwood'. For 'structural characteristics', a suitability (Y/N) was assigned based on cover type (single, double or multi), standard deviation value, and diameter range. Also for 'tree size' and for the 'tree species richness' only the suitability (Y/N) was assigned, based respectively on the presence of trees with DBH > 40 cm and the number of species detected. The evaluation of the presence-absence of these seven variables resulted in the classification of each site into three classes of old-growthness. Finally, the surface of each old-growth wood was polygonised in ArcGIS 10.2 software (ESRI, Redlands, CA, USA) through the photointerpretation of digital aerial images (pixel resolution of 0.2 m).

2.3. Quantifying protection and studying visibility of old-growth woods

To facilitate data processing, old-growth woods were grouped into 10 geographical macro-areas (Figure 1a), defined and named according to historical and morphological regions of Sardinia (Bacchetta et al. 2009). As a first step, all old-growth woods in each macro-area were overlapped with public and private protected areas, in order to locate which surfaces are without any legal protection. As a second step, the visibility map of fire-fighting lookouts was created for all old-growth stands. By means of the Spatial Analyst Viewshed module of ArcGis 10.2, visibility analysis was carried out to determine the coverage of the territory that is visible from fire lookouts. This analysis considers the morphological constraints that might enhance or limit visibility. For this scope, all lookouts managed by the Forestas Agency were positioned over the Digital Terrain Model (DTM) at 20-m resolution. The observation point was set at a height of 3 m for each location. This choice is due to the fact that lookouts can be placed either on the ground or on a structure and therefore constitutes an average value (OFFSET A). The observation of fires refers not only to visibility of flames but also to visibility of smoke columns. Visible height was set at 100 m (OFFSET B), horizontal scan angle (Azimut 1, 2) was set from 0° to 359° and vertical scan angles at 90° in BVert1 and −90° in BVert. Visibility analysis was performed for each lookout within a 10 km radius, an established distance to see the smoke and its origins for observations made with the naked eye or binoculars under optimal visibility conditions (Kucuk et al. 2017; Hognogi et al. 2020). The visibility parameter was classified in the visible/not visible binary form.

2.4. *Method applied to estimate fire vulnerability values*

Using old-growth woods of Supramontes as a test site, a parametric method was applied through the Spatial Analyst of the ArcGIS functions which, with the 'Raster Calculator' module, allowed to sum in each grid cell the above described parameters related to (i) increasing old-growthness classes (1, 2, 3) and (ii) visibility (0= visible, 1= not visible). To these, values of (iii) increasing fire hazard (ranging from 1 to 4) were also added. This latter information was retained from the RAS wildfire hazard map of Sardinia (RAS 2007), which was defined by the association of the following parameters: flammability, slope, exposure, altitude, road network and inhabited areas. All parameters were retrieved from regional land cover maps and the Digital Terrain Model (DTM) at 20-m resolution, which are all available from the geoportal of the RAS (http://www.sardegnageoportale.it). Flammability classification was based on species composition and size reported on the land use map for each vegetation type, giving higher values to those types providing fire-prone fuels, such as pine and eucalipt stands or xerophilous tall grasslands. A higher hazard was given to areas near roads and urbanizations, both of which are potential sources of fire ignition and particularly sensitive to human safety (Salis et al. 2018). A higher hazard was also given to vegetated steep morphologies and to aridity-prone areas, i.e., at lower altitudes and South exposures. Final values of the hazard map vary on a scale from 1 to 4, where the minimum value indicates a lower hazard. Then, values of (i) old-growthness classes, (ii) visibility, and (iii) fire hazard were added together to obtain a vulnerability map with values ranging from 2 to 8. To compare this vulnerability map with the RAS wildfire hazard map of Sardinia, the classes of vulnerability were reduced to 4, through the reclassification of the original values. This resulted in a scale between 1 and 4, where 1 represents the value indicating a minimum vulnerability to fire and 4 a maximum vulnerability. The full methodological framework is resumed in Figure 2.

3. Results

3.1. *Visibility and environmental protection analysis*

These results show that 78% of old-growth woods in Sardinia are visible from the fire lookout network (Figure 3) and 99.2% fall into the network of public or private protected areas.

Particular attention should be paid to the Sulcis macro-area, where 60% of old-growth woods are not visible and 54% of these areas are unprotected. The entire macro-area of Gerrei is neither visible nor protected, but falls entirely within a military zone, whose access or activities are controlled. Finally, the two macro-areas of Sarrabus and Monte Albo are almost completely uncovered by the network of lookouts, although they fall entirely within the network of protected areas (Table 1).

3.2. *Comparison between fire vulnerability and hazard maps in old-growth woods of Supramontes*

Starting from the values of the RAS wildfire hazard map (Figure 4a) a vulnerability map was obtained by taking into account the old-growthness of the woods and the visibility from the lookouts. The results allow a different assessment of the areas most at risk (vulnerability map, Figure 4b). In the map, the areas that have the greatest vulnerability to fire are those classified with parameters 3 and 4, which in the Supramontes test site represent very small portions of territory compared to the area studied.

4. Discussion

The results obtained in this research showed that the risk of fire in the woods with old-growth features in Sardinia could be reduced by the fact that the stands are mostly visible from the lookout network and almost entirely included in protected areas. However, careful and well-designed planning of lookout locations for the conservation of Sardinian forests is still necessary. Similar gaps in forest protection and management were also detected in other Mediterranean countries (e.g., Şakar et al. 2020; Kavlak et al. 2021 Nuthammachot et al. 2021). The fact that the majority of old-growth woods stands fall within a protected area might be controversially interpreted. On the one hand, protected areas are usually better managed and controlled and hence less prone to intentional and unintentional fires; on the other hand, the declaration of protected areas may give rise to conflicts with local communities that might be the cause and motivation of intentional fires (Rodrigues et al. 2018). Consequently, forest conservation may be simultaneously ensured by both actions.

The assessment of the vulnerability to fire in the study area allowed to identify the most vulnerable areas through a focus-oriented approach that also considers visibility and old-growthness of woods. The analyses showed that most of the study site is not particularly vulnerable. Through a comparison of the two maps (wildfire hazard map and vulnerability map, respectively Figure 3a and 3b), most of the high hazard areas were reclassified to a lower level according to the visibility parameter, which was not considered in the wildfire hazard map, where only intrinsic hazard, related to ground features and type of fuel, was included. The assessment shown in the vulnerability map was more detailed, allowing a different and more cost-effective assessment at the level of protection planning, leading to greater accuracy and savings in human and economic resources. For instance, the vulnerability map highlighted fewer and more specific places where fires might be especially monitored. This cost reduction, in terms of human resources and facilities, can be achieved by avoiding redundant visible areas and focusing on places, such as old-growth woods, that are particularly worthy of protection. Moreover, our approach is in line with other research that highlighted fire risk reduction and biodiversity conservation as compatible objectives (Syphard et al. 2016). In this sense, several studies demonstrated the negative effect of fires on the conservation of different groups of endangered species and the interactions among them, including plants (e.g., Fois et al. 2018; Cai and Wang 2020), macrofauna (e.g., Slavchev et al. 2014; Bosso et al. 2018), fungi and microbial communities (e.g., D'Ascoli et al. 2005).

Conclusions

The devastating effects of wildfires, facilitated by limited available resources and factors linked to climate change, continues to be evident if not increasing in recent years. A recent example was in north-western Sardinia in 2021, where more than 1,000 people were evacuated during a wildfire that affected around 13,000 ha of territory (https://www.nytimes.com/2021/08/22/world/europe/italy-sardinia-fire-tree.html). The majority of wildfires could have been better controlled if more effective and timely measures had been taken. For this reason, finding new approaches to better allocate the limited resources is crucial. This paper shows that a focus-oriented approach, which also considers the parameters of visibility and of wood old-growthness, allows to better identify the most vulnerable areas where efforts need to be concentrated. It is an easily replicable method that could also be applied in other environmental conservation contexts. For instance, other biotic aspects, such as endemic species richness or priority habitats (*sensu* Habitats Directive 92/43/EEC) might be added or used instead of old-growth woods. Such valuable information for conservation should be integrated into a single system comprising fire lookouts and protected areas networks, as well as other pre-existing hazard maps with intrinsic risk parameters, in order to provide useful information for a more correct assessment of a given system and for a rational use of the available resources.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Acknowledgements

The authors would like to acknowledge the staff of the Forestry Agency of Sardinia and to the military staff of the Polygon of Inter-Service Test and Training Range of Salto di Quirra for their kind collaboration. Many thanks to Rodrigo Pardo (University of Castilla-La Mancha) for his help during the sampling phase.

References

Achour H, Toujani A, Trabelsi H, Jaouadi W. 2021. Evaluation and comparison of Sentinel-2 MSI, Landsat 8 OLI, and EFFIS data for forest fires mapping. Illustrations from the summer 2017 fires in Tunisia. Geocarto Int.

Bacchetta G, Bagella S, Biondi E, Farris E, Filigheddu RS, Mossa L. 2009. Vegetazione forestale e serie di vegetazione della Sardegna (con rappresentazione cartografica alla scala 1:350.000). Fitosociologia 46:1-82. http://www.scienzadellavegetazione.it/sisv/documenti/Articolo/pdf/112.pdf

Bacchetta G, Bagella S, Biondi E., Farris E, Filigheddu RS, Mossa L. 2004. A contribution to the knowledge of the order *Quercetalia ilicis* Br.-Bl. ex Molinier 1934 of Sardinia. Fitosociologia 41:29-51.

Badalamenti E, Pasta S, La Mantia T, La Mela Veca DS. 2018. Criteria to identify old-growth forests in the Mediterranean: A case study from Sicily based on literature review and some management proposals. Feddes Repert 129:25-37.

Bosso L, Ancillotto L, Smeraldo S, D'Arco S, Migliozzi A, Conti P, Russo D. 2018. Loss of potential bat habitat following a severe wildfire: a model-based rapid assessment. Int J Wildland Fire 27:756-769.

Cai L, Wang M. 2020. Assessing the post-fire recovery in the southeast coast of China during the early period. Geocarto Int.

Cardil, A, Delogu GM, Molina-Terrén DM. 2017. Fatalities in wildland fires from 1945 to 2015 in Sardinia (Italy). Cerne 23:175-184.

Casula P, Luiselli L, Milana G, Amori G. 2017. Habitat structure and disturbance affect small mammal populations in Mediterranean forests. Basic Appl Ecol 19:76-83.

Casula P, Fantini S, Fenu G, Fois M, Calvia G, Bacchetta G. 2021. Positive interactions between great longhorn beetles and forest structure. For Ecol Manag 486:118981.

D'Ascoli R, Rutigliano FA, De Pascale RA, Gentile A, De Santo AV. 2005. Functional diversity of the microbial community in Mediterranean maquis soils as affected by fires. Int J Wildland Fire 14:355-363.

Fantini S, Fois M, Casula P, Fenu G, Calvia G, Bacchetta G. 2020. Structural heterogeneity and old-growthness: A first regional-scale assessment of Sardinian forests. Ann For Res 63:103-120.

FAO. 2020. Global Forest Resources Assessment 2020. Main report. FAO, Rome.

Farris E, Fenu G, Bacchetta G. 2012. Mediterranean *Taxus baccata* woodlands in Sardinia: a characterization of the EU priority habitat 9580. Phytocoenologia 41:231-246.

Fenu G, Fois M, Cañadas EM, Bacchetta G. 2014. Using endemic-plant distribution, geology and geomorphology in biogeography: the case of Sardinia (Mediterranean Basin). System Biodivers 12:181-193.

Fois M, Bacchetta G, Cuena-Lombraña A, Cogoni D, Pinna MS, Sulis E, Fenu G. 2018. Using extinctions in species distribution models to evaluate and predict threats: a contribution to plant conservation planning on the island of Sardinia. Environ Conserv 45:11-19.

Fois M, Fenu G, Cañadas EM, Bacchetta G. 2017. Disentangling the influence of environmental and anthropogenic factors on the distribution of endemic vascular plants in Sardinia. PloS one 12:e0182539.

Hognogi GG, Pop AM, Mălăescu S, Nistor MM. 2020. Increasing territorial planning activities through viewshed analysis. Geocarto Int.

Kavlak MO, Cabuk SN, Cetin M. 2021. Development of forest fire risk map using geographical information systems and remote sensing capabilities: Ören case. Environ Sci Pollut Res 28: 33265–33291.

Kucuk O, Topaloglu O, Altunel AO, Cetin M. 2017. Visibility analysis of fire lookout towers in the Boyabat State Forest Enterprise in Turkey. Environ Monit Assess 189:329.

Lindenmayer D, McCarthy MA. 2002. Congruence between natural and human forest disturbance: a case study from Australian montane ash forests. For Ecol Manag 155:319-335.

Lombardi F, Marchetti M, Corona P, Merlini P, Chirici G, Tognetti R, Burrascano A, Alivernini A, Puletti N. 2015. Quantifying the effect of sampling plot size on the estimation of structural indicators in old-growth forest stands. For Ecol Manag 346:89-97.

Lovreglio R, Leone V, Giaquinto P, Notarnicola A. 2010. Wildfire cause analysis: four case-studies in southern Italy. iForest 3:8.

Marchetti M, Blasi C. 2010. Old-growth forests in Italy: towards a first network. L'Italia Forestale e Montana 65:679-698.

Minissale P, Sciandrello S. 2013. A relic wood of *Juniperus turbinata* Guss. (Cupressaceae) in Sicily: Structural and ecological features, conservation perspectives. Plant Biosyst 147:145-157.

Nimis PL, Martellos S, Spitale D, Nascimbene J. 2018. Exploring patterns of commonness and rarity in lichens: a case study from Italy (Southern Europe). Lichenol 50:385–396.

Nordén B, Paltto H, Götmark F, Wallin K. 2007. Indicators of biodiversity, what do they indicate?–Lessons for conservation of cryptogams in oak-rich forest. Biol Conserv 135:369–379.

Nuthammachot N, Stratoulias D. 2021. A GIS-and AHP-based approach to map fire risk: a case study of Kuan Kreng peat swamp forest, Thailand. Geocarto Int 36:212-225.

Parviainen J. 2005. Virgin and natural forests in the temperate zone of Europe. For Snow Landsc Res 79:9-18.

Pezzi G, Gambini S, Buldrini F, Ferretti F, Muzzi E, Maresi G, Nascimbene J. 2020. Contrasting patterns of tree features, lichen, and plant diversity in managed and abandoned old-growth chestnut orchards of the northern Apennines (Italy). For Ecol Manag 470:118-207.

Puddu G, Falcucci A, Maiorano L. 2012. Forest changes over a century in Sardinia: implications for conservation in a Mediterranean hotspot. Agrofor Syst 85:319-330.

Pungetti G. 1995. Anthropological approach to agricultural landscape history in Sardinia. Landsc Urban Plan 31:47-56.

RAS, Regione Autonoma della Sardegna. 2017. Carta del rischio boschivo e di interfaccia. [accessed 2019 Feb 22]. http://dati.regione.sardegna.it/dataset/carta-del-rischio-incendio-boschivo-e-di-interfaccia-2017

RAS, Regione Autonoma della Sardegna. 2019. Piano regionale di previsione, prevenzione e lotta attiva contro gli incendi boschivi 2017-2019. [accessed 2020 Nov 11] http://www.sardegnaambiente.it/documenti/20_679_20190719180619.pdf.

Rego FC, Catry FX. 2006. Modelling the effects of distance on the probability of fire detection from lookouts. Int J Wildland Fire 15:197-202.

Rodrigues M, Jiménez-Ruano A, Peña-Angulo D, de la Riva J. 2018. A comprehensive spatial-temporal analysis of driving factors of human-caused wildfires in Spain using geographically weighted logistic regression. J Environ Manage 225:177-192.

Salis M, Del Giudice L, Arca B, Ager AA, Alcasena-Urdiroz F, Lozano O, Bacciu V, Spano D., Duce P. 2018. Modeling the effects of different fuel treatment mosaics on wildfire spread and behavior in a Mediterranean agro-pastoral area. J Env Manag 212:490-505.

Şakar D, Aydin A, Akay AE. 2020. Using GIS-based multicriteria decision support system for planning road networks with visual quality constraints: a case study of protected areas in Ankara, Turkey. Environ Monit Assess 192: 447.

Stefanidou A, Dragozi E, Stavrakoudis D, Gitas IZ. 2018. Fuel type mapping using object-based image analysis of DMC and Landsat-8 OLI imagery. Geocarto Int 33:1064-1083.

Siitonen J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecol Bull 49: 11-41.

Slavchev M, Tzankov N, Popgeorgiev G. 2014. Impact of fires on spatial distribution patterns of the Hermann's Tortoise (*Testudo hermanni*) in a heavily affected area in Bulgaria. Bulg J Agric Sci 20:135-138.

Susmel L, Viola F, Bassato G. 1976. Ecologia della lecceta del Supramonte di Orgosolo: (Sardegna Centro-orientale). Cedam, Padova.

Syphard AD, Butsic V, Bar-Massada A, Keeley JE, Tracey JA, Fisher RN. 2016. Setting priorities for private land conservation in fire-prone landscapes: Are fire risk reduction and biodiversity conservation competing or compatible objectives? Ecol Soc 21:2.

Urbieta IR, Franquesa M, Viedma O, Moreno JM. 2019. Fire activity and burned forest lands decreased during the last three decades in Spain. Ann For Sci 76:1-13.

Table 1. Coverage and percentage of visibility from fire lookouts and protection of old-growth woods in each macro area of Sardinia.

	Area (m^2)	**Visibility (m^2)**	**Visibility (%)**	**Protected (m^2)**	**Protected (%)**
Sulcis	65,995	26,120	39.6	30,363	46.0
Gerrei	234,858	9	0.0	0	0.0
Limbara	437,935	235,064	53.7	437,935	100.0
Supramontes	27,978,980	21,800,302	77.9	27,978,980	100.0
Gennargentu	400,817	308,031	76.9	400,817	100.0
Goceano	135,159	37,808	28.0	135,159	100.0
Iglesiente	2,737,735	2,737,735	100.0	2,737,735	100.0
Marghine	3,309	3,309	100.0	2,358	71.3
Sarrabus	125,409	1,963	1.6	125,409	100.0
Monte Albo	132,376	0	0.0	132,376	100.0
TOT	**32,252,573**	**25,150,341**		**31,981,132**	

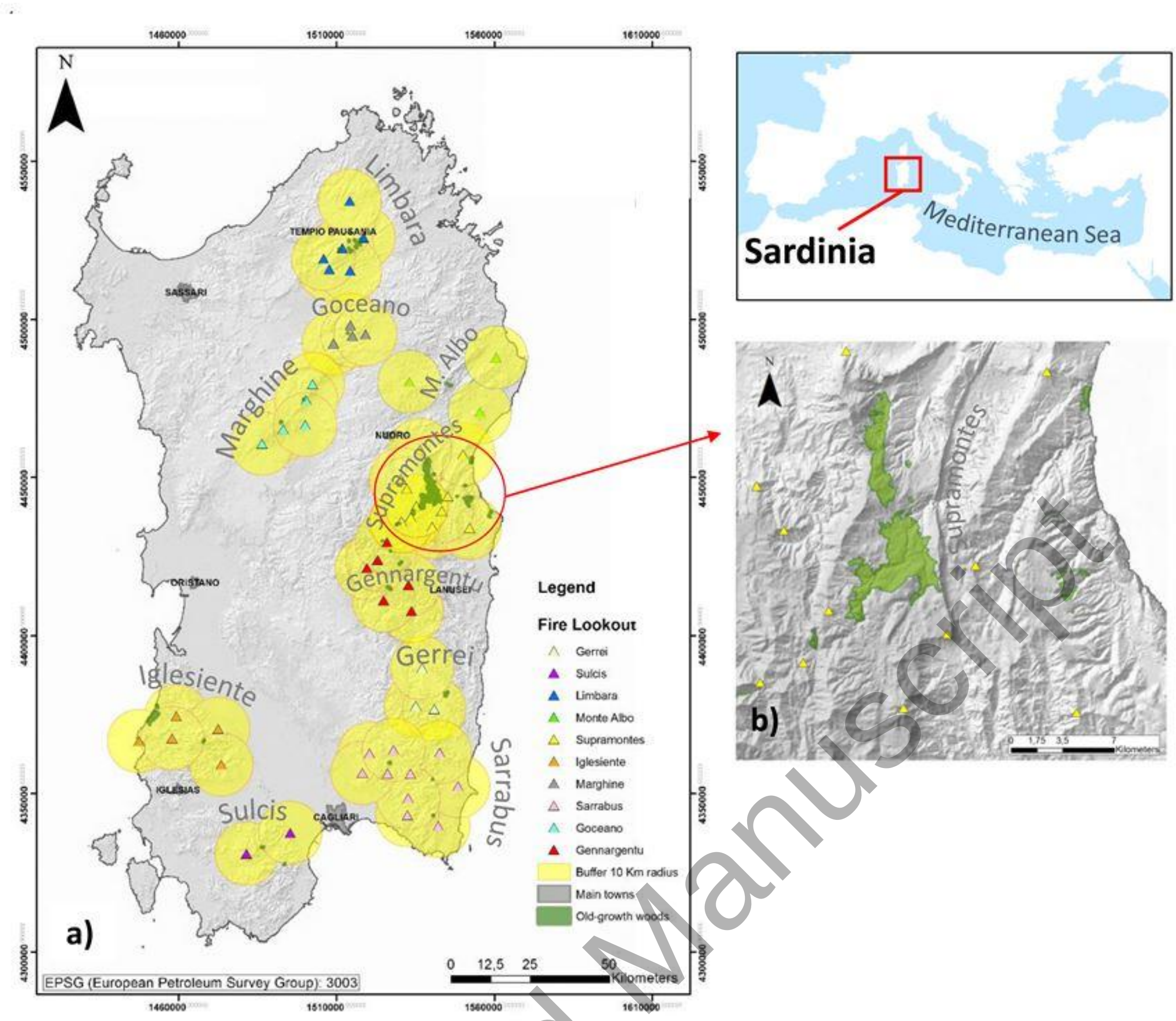

Figure 1. (a) study area, old-growth stands, fire lookouts and scanning radius. Colors differ according to the macro areas were each of fire lookout falls in; (b) territorial framework of Supramontes, fire lookouts and old-growth stands.

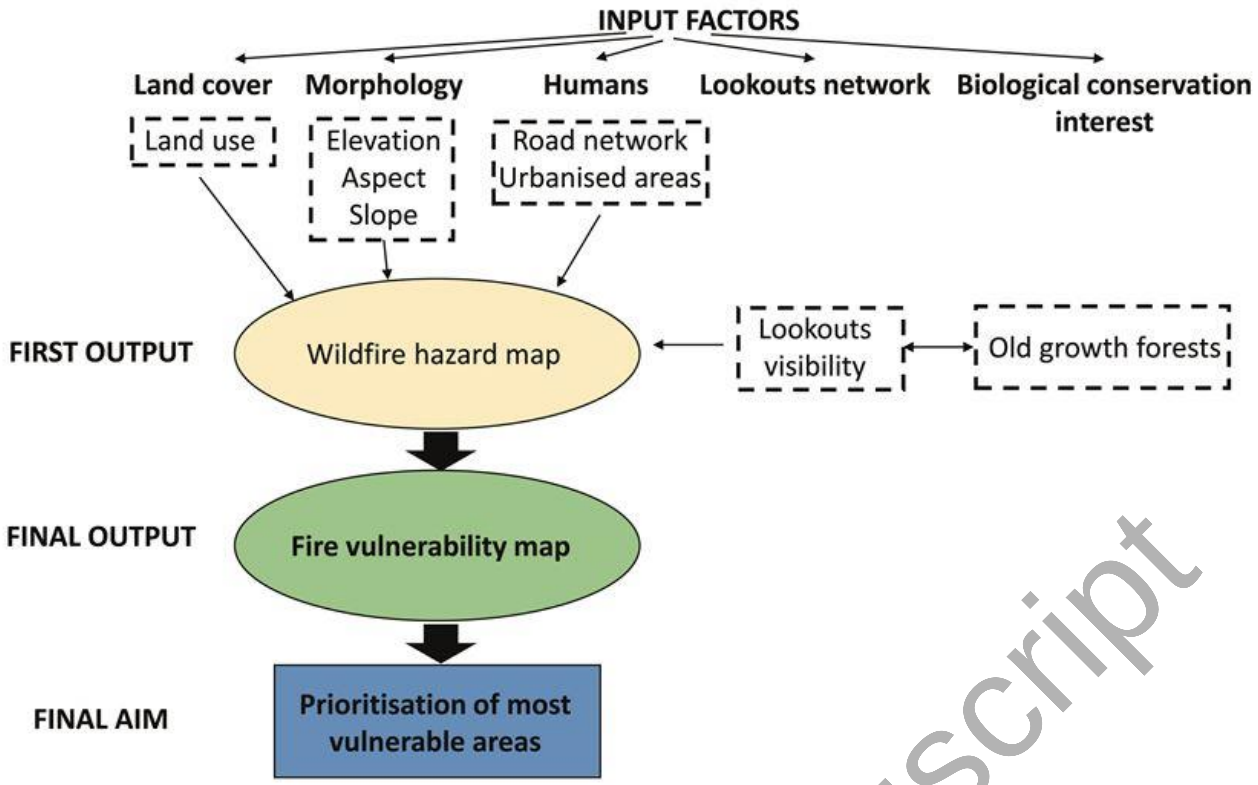

Figure 2. Flow chart of the used methodology.

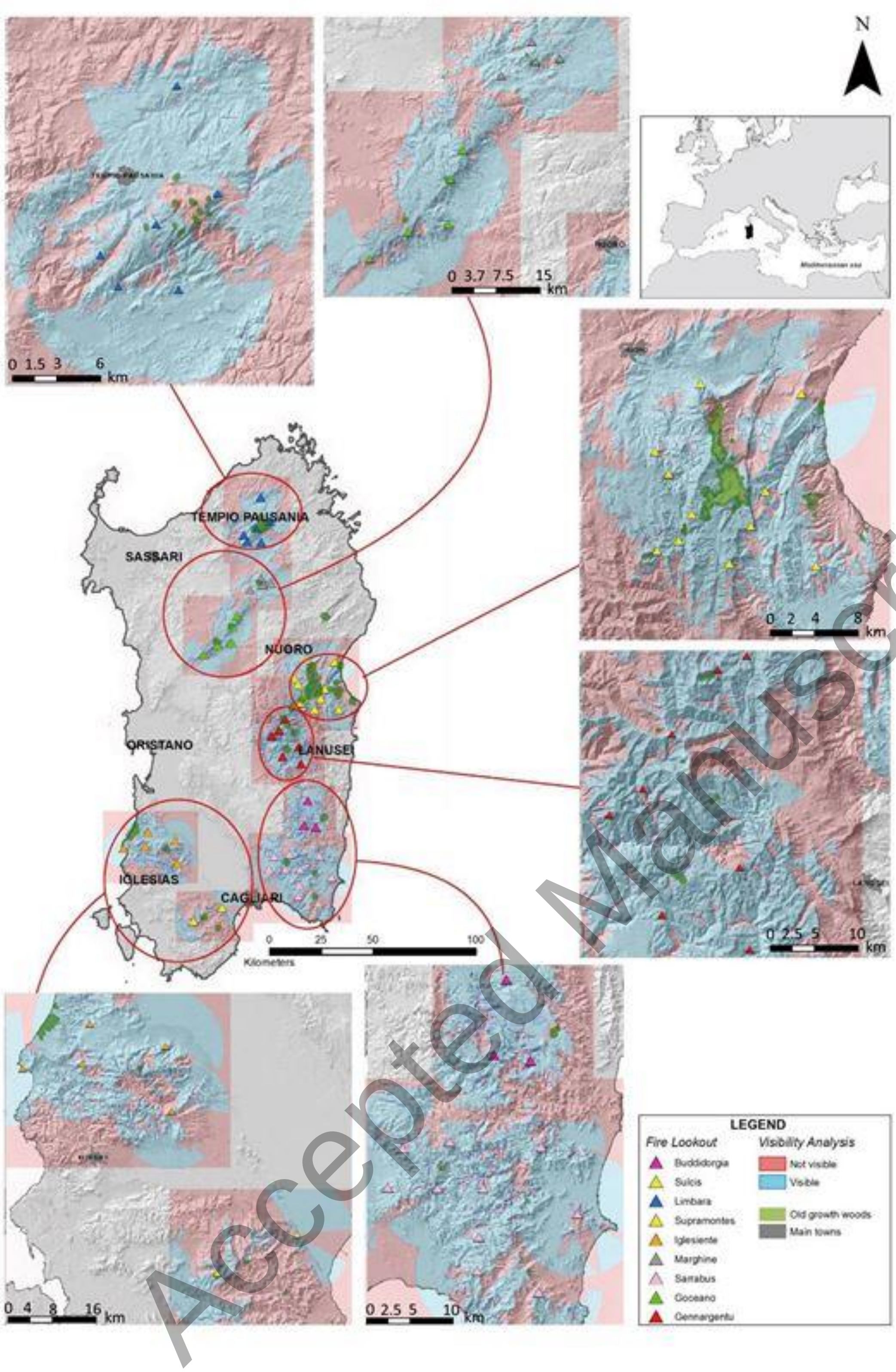

Figure 3. Visibility map of old-growth woods in Sardinia. Numbers indicate the main macro areas, also reported in Table 1: (1) Sulcis, (2) Iglesiente, (3) Limbara, (4) Goceano, (5) Marghine, (6) Supramontes, (7) Gennargentu, (8) Gerrei, (9) Sarrabus.

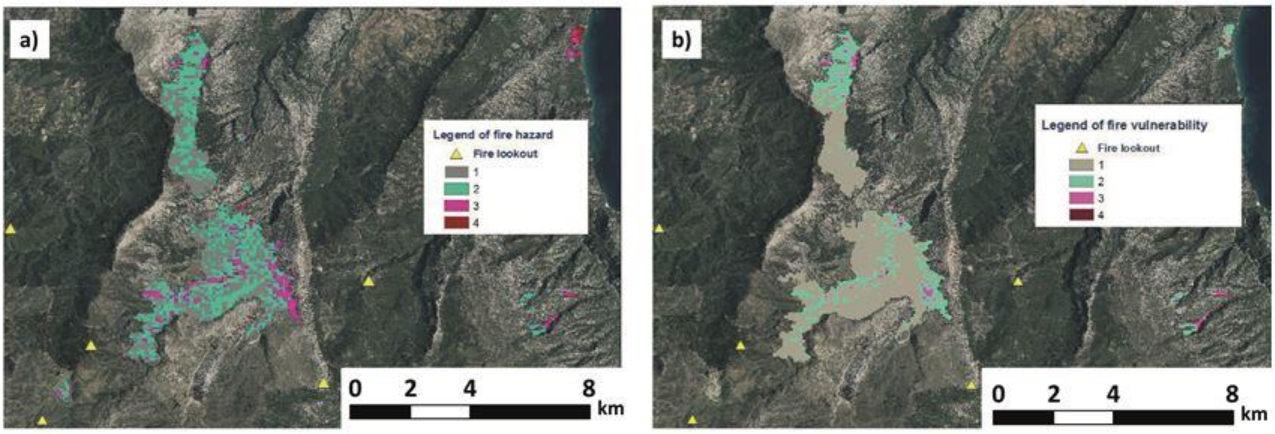

Figure 4. Levels from low (1) to high (4) of (a) wildfire hazard and (b) vulnerability of old-growth woods in Supramontes.