Landscape and Urban Planning 243 (2024) 104977

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Integrating cultural ecosystem services in wildfire risk assessment

Ingrid Vigna [a,*], Luca Battisti [b], Davide Ascoli [c], Angelo Besana [d], Alessandro Pezzoli [e], Elena Comino [f]

[a] Norwegian Meteorological Institute, 5007 Bergen, Norway
[b] Department of Cultures, Politics and Society, University of Turin, 10153 Torino, Italy
[c] Department of Agricultural, Forest and Food Sciences (DISAFA), University of Turin, 10095 Grugliasco, Italy
[d] Department of Humanities, University of Trento, 38122 Trento, Italy
[e] Interuniversity Department of Regional and Urban Studies and Planning (DIST), Polytechnic of Turin & University of Turin, 10125 Torino, Italy
[f] Department of Environment, Land and Infrastructure Engineering (DIATI), Polytechnic of Turin, 10129 Torino, Italy

HIGHLIGHTS

- A multidisciplinary wildfire risk assessment enhances standard approaches.
- Fire hazard simulation and ecosystem services participatory mapping are combined.
- Accounting for cultural ecosystem services refines wildfire mitigation strategies.

ARTICLE INFO

Keywords:
Cultural ecosystem services
Wildfire risk assessment
Participatory mapping
FlamMap

ABSTRACT

The impact of natural disturbances such as wildfires on ecosystem services and local communities is significant. Conventional assessments of wildfire risks often overlook the potential loss of ecosystem services, particularly cultural ones (CES). This study presents a methodology for integrating CES into wildfire risk assessment, combining expert CES participatory mapping with standard procedures based on fire hazard and vulnerability modelling. We tested the methodology in a European Alpine landscape of 143 km2 involving 8 municipalities and 30 local stakeholders. Integrating CES hotspots changed the risk classification by at least two classes for 52 of the 358 valley subwatersheds and made the distribution of high and very high-risk areas more scattered. This study demonstrates that including CES in wildfire risk assessment and prevention schemes through a participatory process can encourage stakeholder engagement and provide additional information on the indirect benefits of the ecosystem. We conclude that the application of this methodology to other contexts would strongly benefit local wildfire risk management plans.

1. Introduction

Land use and climate changes are globally affecting natural disturbance regimes, such as wildfires in terrestrial ecosystems (Bowman et al., 2009). Longer fire seasons due to modified climate circulation, the increased flammability at the landscape scale, and the expansion of the wildland-urban interface make the risk of impactful wildfire events more probable (Moreira et al., 2020). Wildfire risk assessment is a fundamental tool for limiting wildfire impacts and informing decision-makers of landscape planning. Quantifying risk and mapping its spatial distribution enables the evaluation of possible prevention and mitigation strategies, providing decision-makers with a framework of cost-effectiveness (Alcasena et al., 2021; Scott, Thompson & Calkin, 2013).

A review of the existing literature on wildfire risk assessment reveals a wide variety of approaches, such as multicriteria decision analysis (Nuthammachot & Stratoulias, 2021), fire modelling systems (Alcasena et al., 2021), contingent valuation (Molina, Moreno, Castillo, & Rodríguez y Silva, 2018), expert analysis (Alcasena, Salis, Ager, Castell, & Vega-García, 2017), social network analysis (Ager, Kline, & Fischer, 2015) and social media data analysis (Yue, Dong, Zhao, & Ye, 2021). However, risk mitigation strategies are mostly focused on protecting human lives and securing infrastructure at the wildland-urban interface (El Ezz, Boucher, Cotton-Gagnon & Godbout, 2022; Nunes, Figueiredo,

---

* Corresponding author.
E-mail address: ingridv@met.no (I. Vigna).

https://doi.org/10.1016/j.landurbplan.2023.104977
Received 7 August 2023; Received in revised form 1 December 2023; Accepted 3 December 2023

Pinto & Lourenço, 2023), thus neglecting the importance of ecosystem services to the population's well-being. Although quantifying the risk of losing ecosystem services is critical in guiding effective management and policy interventions, it is still challenging (Lecina-Diaz, Martínez-Vilalta, Alvarez, Vayreda, & Retana, 2021).

The possible loss of provision of Cultural Ecosystem Services (CES), i.e. the "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience" (McMichael et al., 2005), because of a wildfire event, could have a strong impact on the life of the local community and beyond (Vukomanovic & Steelman, 2019). Wildfires, for example, can negatively affect cultural sites (Palaiologou, Kalabokidis, Day, & Kopsachilis, 2020) and reduce recreational and tourism potential by changing the landscape for decades (Pereira, Bogunovic, Zhao, & Barcelo, 2021; Silvestro et al., 2021). Additionally, CES could indicate areas with higher anthropogenic pressure due to the presence of cultural factors, which is particularly important in emergencies or disasters. Nevertheless, as far as we know, their inclusion in wildfire risk management remains unstudied.

Since the launching of the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES) in 2013, several studies have focused on developing frameworks and indicators for mapping ecosystem services (Burkhard & Maes, 2017). Due to the dependence of CES from the contingent point of view of the benefiting community, participatory approaches have been proposed, such as participatory mapping (Battisti, Corsini, Gusmerotti, & Larcher, 2019; Plieninger, Dijks, Oteros-Rozas, & Bieling, 2013; Ridding et al., 2018). Various examples of expert elicitation through participatory GIS activities demonstrated the utility of involving local experts in analysing and mapping ecosystem services (Brown & Fagerholm, 2015; Palomo, Martín-López, Zorrilla-Miras, García Del Amo, & Montes, 2014; Ruiz-Frau, Edwards-Jones, & Kaiser, 2011). Several projects involving public participation through participatory mapping with different geographical scales - from nationwide surveys to single buildings - and topics - from green areas to transport services - have been reported in the literature (Kahila-Tani, Kytta & Geertman, 2019). This approach allows the public or specific stakeholders to be involved in the analysis and to integrate the people's perception in regional and local planning (Dossche, Primi, & Valle, 2022; Kantola, Fagerholm & Nikula, 2023).

In this study, we propose an innovative methodology for integrating CES evaluation in wildfire risk assessment plans at the landscape scale. We intend to bridge the gap between the literature on wildfire risk assessment and the literature on CES mapping, within the debate on fire-resilient landscape management and planning (Ascoli et al., 2023). The approach presented is based on the involvement of local stakeholders in a participatory mapping activity of CES and on the integration of the results into standard wildfire risk assessment procedures, with the aim of evaluating the difference between the resulting risk cartographic output and traditional fire risk maps.

The consultation of local actors and experts is crucial since it provides spatially explicit knowledge of ecosystems based on their experience and understanding of local dynamics (Grêt-Regamey, Brunner, Altwegg, Christen, & Bebi, 2013). Understanding stakeholder's perceptions is also a key step for assuring local collaboration (Stoutenborough & Vedlitz, 2014), anticipating barriers to risk prevention activities (Dessai & Sims, 2010), and promoting effective solutions based on a shared definition of the problem (De Stefano, Hernández-Mora, Iglesias, & Sánchez, 2017).

Four kinds of CES were the object of the analysis: recreational service, aesthetic value, common sense of place, and personal sense of place. The selection of categories is based on the classification adopted by (García-Díez et al., 2020), by further dividing the "sense of place" category into a "common" and "personal" one. Recreational service and aesthetic value were selected because of their relevance to the wellbeing of the inhabitants and the attraction of visitors. The common and personal sense of place categories were chosen to bring out the relationship between the inhabitants and the ecosystem in the analysis. This is a crucial topic in an area that has been subject to a major phenomenon of depopulation and rural abandonment for decades. Diverse theories, concepts and empirical approaches exist regarding the sense of place so that it is often omitted in ecosystem services assessments (Wartmann & Purves, 2018). In this work, the sense of pace is intended as "the experiential and expressive ways places are known, imagined, yearned for, held, remembered, voiced, lived, contested and struggled over" (Feld & Basso, 1996). However, in line with the distinction proposed by (Knez and Eliasson, 2017) between collective and personal place identity, we further distinguish a common and a personal sense of place. The "common sense of place" refers here to the ability of places to represent the historical, cultural, social or naturalistic identity of a community; the "personal sense of place" refers to the personal ties between the respondent and places, often linked to personal preferences, experiences and memories.

The four categories were mapped separately to facilitate the understanding of the questions by people unfamiliar with the concept of ecosystem services. They were then merged into a general CES category as a synthetic cartographic output was judged more suitable to give operational indications in the framework of territorial management for risk prevention.

We tested the methodology in an inner valley of the Southern European Alps, which is prone to wildfires and a hotspot of cultural services, including a wide range of recreational activities and heritage values. Wildfire activity and severity in the European Alps will likely increase in the future due to climate change, making the evaluation of wildfire risk increasingly crucial for the local communities (Müller et al., 2020). Moreover, the long history of anthropogenic influence on the forest ecosystem makes the changes in the disturbance regimes particularly evident in the region (Bebi et al., 2017), setting an interesting context for the evaluation of innovative risk analysis techniques.

The study area investigated and the methodology followed are described in detail in the following section. The third section illustrates the main results of the analysis, while the fourth discusses the outcomes implications and transferability of the methodology to different contexts. Finally, the Conclusion section summarises the main strengths and limitations of the work, along with insights for future research.

2. Materials and methods

2.1. Study area

The study case comprises an area of about 143 km^2 in the south-western European Alps (Fig. 1a), in the northern Italian region of Piemonte (Fig. 1b). The perimeter corresponds to the administrative boundaries of the eight municipalities in the Valchiusella valley (Fig. 1c). The altitude ranges between approximately 400 m for the lower valley villages and 2800 m for the highest peaks.

The total population on 1 January 2020 was 5237 inhabitants (data available at https://dati.istat.it). However, as in most European alpine valleys, rural depopulation has characterised Valchiusella since the end of the XIX century, resulting in the abandonment of traditional farming activities (MacDonald et al., 2000). This has caused the expansion of tall grasses, shrubs and trees on the abandoned pastures, creating extensive areas covered by unmanaged pioneering vegetation, which increases fire hazard (Ascoli, Moris, Marchetti, & Sallustio, 2021; Ascoli et al., 2020). According to the regional data on past wildfires (data available at https://www.geoportale.piemonte.it/geocatalogorp), the distribution of fire events across the year is characterised by a predominance of fires during winter, during which the vegetation is fully cured, rainfall is lowest and the frequency of strong, warm and dry foehn winds increases (Valese, Conedera, Held, & Ascoli, 2014).

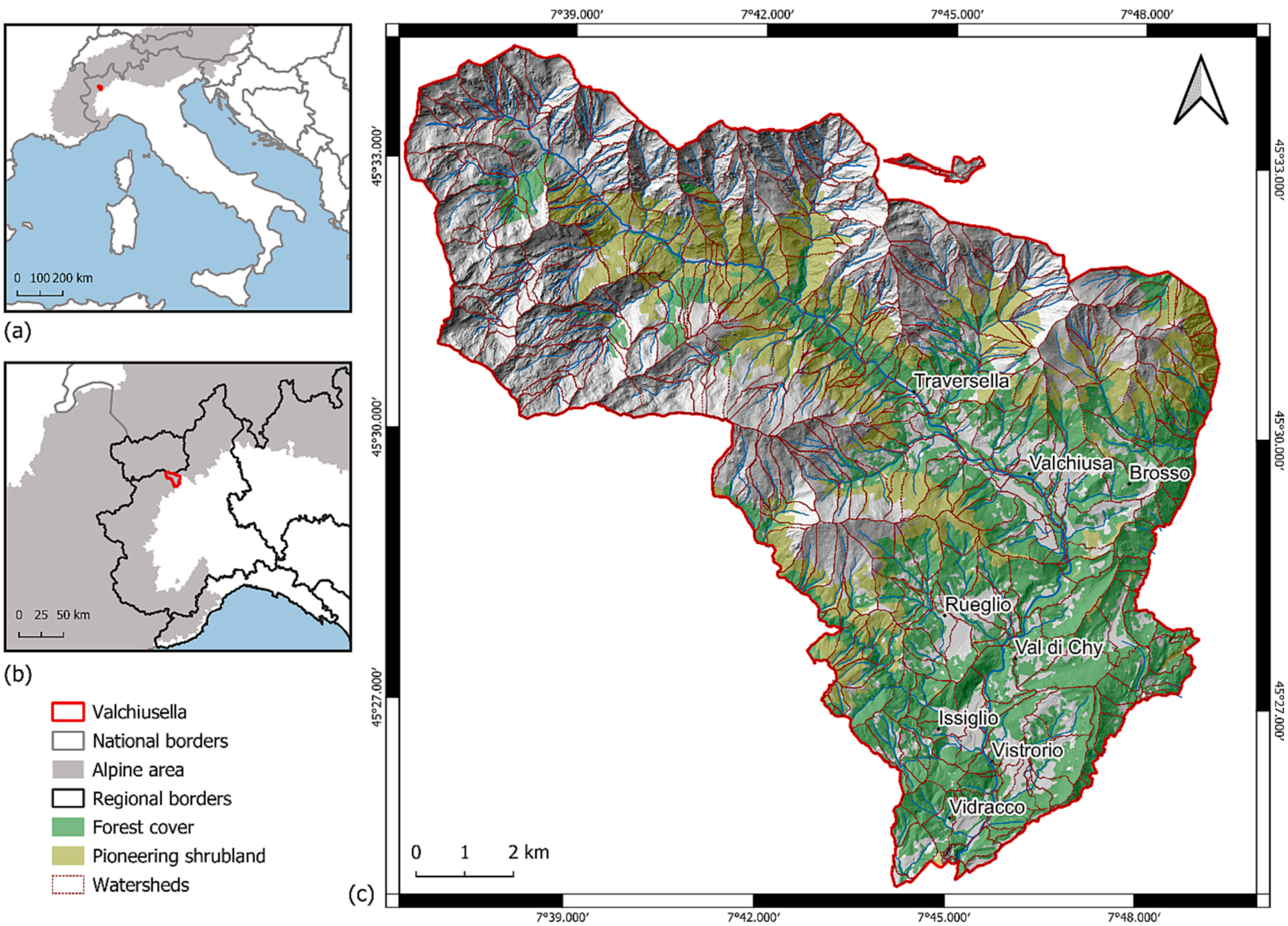


Fig. 1. Map of the study area, showing the extent of forest and pioneering shrubland cover according to the regional forest map (last update in 2016, https://www.geoportale.piemonte.it). The subwatershed used for the risk analysis are also highlighted. The displayed alpine area corresponds to the perimeter of the Alpine Convention (https://www.alpconv.org).Fig. 2 Flow-diagram of the five-step methodology adopted. For step 4, the green elements refer to the risk computation scenario which excludes CES from the analysis and the blue ones refer to the scenario including them.

2.2. Standard risk assessment procedure

The methodology relies on the operational definition of wildfire risk adopted by fire management plans. Specifically, we aligned to the risk mapping standards used in the main wildfire risk assessment document available for the case study area, that is the regional fire management plan of Piemonte region for the period 2021–2025 (henceforth referred to as the "regional FM plan") (Regione Piemonte, 2021).

In line with the IPCC guidelines for the Sixth Assessment Report (Reisinger et al., 2020), the regional FM plan adopts the generally applied definition of natural risk as the result of three different factors: hazard, exposure, and vulnerability. The regional FM plan of Piemonte adapts this framework to the specific case of vegetation fires. The hazard is then intended as the potential occurrence of wildfires of a given intensity. The vulnerability is the resistance and resilience of the ecosystem to fire occurrence (referred to as ecological vulnerability). The exposure is the level of conflict between the function of the natural resource and the fire occurrence (referred to as functional vulnerability). Ecological and functional vulnerability are then condensed into a general vulnerability factor. This approach can be summarized as:

Risk = hazard x vulnerability
Where:
Vulnerability = ecological vulnerability x functional vulnerability

More specifically, regional FM plan vulnerability takes into consideration various aspects mainly related to the ecological sphere: vegetation species' resistance and resilience to fire, landscape degradation and soil erosion, and function-fire conflict based on the main functions assigned to forests from a management point of view (e.g. protective from rock falls, biodiversity conservation, or productive). The methodology proposed here aims at expanding the vulnerability interpretation of this framework by including the cultural value of natural resources, represented by CES.

2.3. Research design

Subwatersheds with an average surface of around 40 ha (from 1.5 to 141 ha) were used as territorial units both for analysis and communication purposes. The surface of the valley was divided into 358 subwatersheds corresponding to a 5-order hydrological network, applying the functions of the hydrology toolset of ArcMap software to the DTM (data freely available at https://www.geoportale.piemonte.it) (see Fig. 1). This choice is in line with the concept of containment polygons for fire management used by (Gamboa et al., 2023), whose boundaries are defined following ridges or valley bottoms. Subwatersheds in the Alps play an important role both in the development of a fire and in active firefighting activity (Valese et al., 2014). Fire naturally moves uphill because of the closeness of the flames to the fuel in this direction and because of the updraft convection that heats the vegetation above the fire (Finney, McAllister, Grumstrup, & Forthofer, 2021). This makes the ridge lines a potential point of slowing fire and a preferred location for active firefighting. Because of their relatively small dimension, moreover, subwatersheds can effectively be considered homogeneous from an exposure perspective. They represent a buffer zone around the locations providing CES in which the passage of fire would result in the loss of the service. Finally, adopting a meaningful spatial unit helps to communicate effectively the results of the analysis to the local stakeholders and to transform the information into operational data.

The methodology adopted consists of five phases (Fig. 2). Those are described in detail in the following sub-sections.

2.3.1. *CES assessment*

We involved 30 local stakeholders (10 females and 20 males), chosen as experts in forest and land management, through one-on-one interviews. They belonged to the following categories: i) Mayors or municipal administrators in charge of land management tasks (11 participants); ii) forest firefighters volounteers (5); iii) forest workers (3); iv) forest technicians (3); v) members of local environmental associations (4); vi) farmers (4).

The interviews were carried out in July 2022. The respondents were given a hardcopy map of the valley in a large size (1:15000 scale), with Google Satellite base map and important features highlighted, such as rivers, main roads and toponyms (data freely available at https://www.geoportale.piemonte.it). We chose to use a paper map instead of a digital medium to make respondents unfamiliar with technological devices as autonomous as possible in answering, thus limiting the influence of the interviewer's intervention on the results. The respondents were asked to place as many coloured paper disks as they wanted on the map to mark the places that provide the specified CES category (recreational service, aesthetic value, common sense of place and personal sense of place) according to their knowledge. See Appendix A for a description of the four categories considering two popular ecosystem services classifications in the literature, i.e. the Millenium Ecosystem Assessment (MEA) (McMichael et al., 2005) and version 5.1 of the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2018).

A maximum number of 15 disks for each CES category was allowed for each respondent, to avoid overrepresentation of someone over others, while allowing some variability in the responses. The disks had a 500 m diameter at the scale of the map, in line with choices about the spatial representation of ecosystem services' location in other PGIS studies (Battisti et al., 2019; Ridding et al., 2018). The 500 m diameter allows for variation in the precision with which respondents place their markers (Ridding et al., 2018). Moreover, it was found to be a convenient dimension in relation to the scale of the map presented to the respondents from a practical point of view, that is for facilitating them placing the disks on the map.

For each place identified, the respondent was asked to assign a value of importance from 1 (slightly important) to 5 (very important), to provide a toponym, and to describe the choice. For additional details on the structure of the interviews, see the interview canvas in Appendix B. The position of the disks was photographed and then plotted in a GIS environment with the help of the toponyms associated. The value of importance, the toponym and the other details were associated with each place through an attribute table.

For each subwatershed, the 1–5 values of the disks whose centroids were inside the subwatershed were added together, regardless of the category. The points that were on peaks or ridge lines were counted for all adjacent subwatersheds. The resulting subwatershed values were classified into 5 classes according to natural breaks (Slocum, McMaster, Kessler, & Howard, 2022) (Appendix C). The information was then transformed into a raster with a 10 m resolution to match the resolution of the hazard outputs (see section 2.3.3).

2.3.2. *CES integration in the vulnerability information*

The CES information at the subwatershed level was then integrated into the vulnerability information of the regional FM plan, which was previously downscaled from 25 m to 10 m resolution with QGis "align raster" function. The regional vulnerability is provided in five classes (very low, low, medium, high and very high vulnerability) and the value "null" is associated with non-vegetation pixels. The integration of the cultural value was carried out at the pixel level, using the combination rule in Appendix D. The combination table is symmetric since we decided to give the same weight to the regional FM vulnerability and to the cultural value of ecosystems. This decision is in line with the general approach adopted in the regional FM plan, where the vulnerability layer is itself the result of merging an ecological vulnerability layer and a functional vulnerability layer through a symmetric table.

2.3.3. *Hazard assessment*

The smaller scale of analysis of this work compared to the regional FM plan suggested the need to perform a local scale hazard assessment, instead of simply adopting the regional one. A simulation procedure was applied, based on the quantitative spatial estimate of fire probability and fireline intensity metrics (Parisien, Dawe, Miller, Stockdale, & Armitage, 2019) by using FlamMap (Finney, 2006), a commonly used model for fire hazard analysis (e.g. Jahdi et al., 2016; Salis et al., 2023). It was chosen for this analysis because of its reliability and simpler approach, which provides it with low uncertainty susceptibility and computational intensity (Parisien et al., 2019).

A set of spatial layers was used as input data, describing the

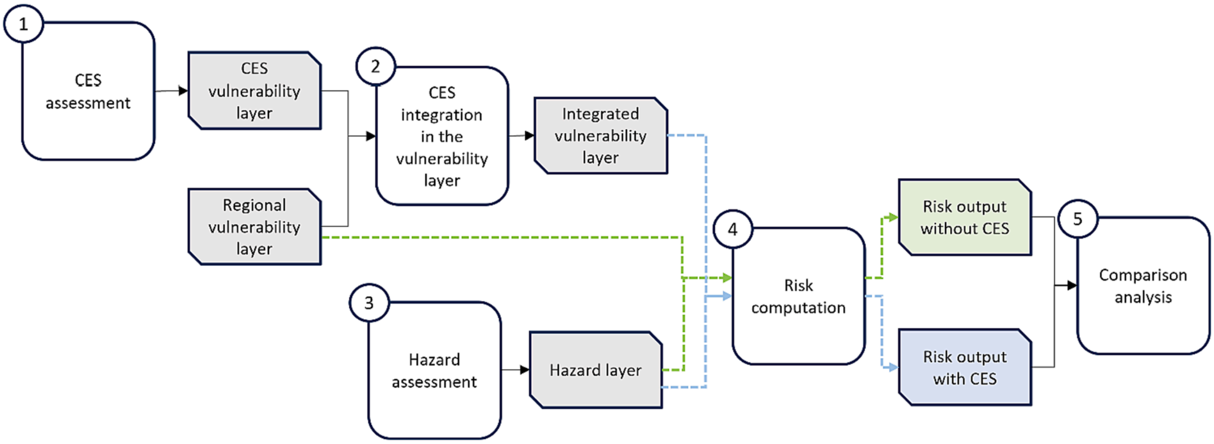


Fig. 2. Flow-diagram of the five-step methodology adopted. The green elements refer to the risk computation scenario which excludes CES from the analysis and the blue ones refer to the scenario including them.

elevation, aspect, slope, surface fuel models, canopy cover, crown height, crown base height and crown bulk density of the area (see Appendix E for details). Since almost all historical fires in the area are linked to human-related causes, as in the rest of Europe (de Rigo, Libertà, Houston Durrant, Artés Vivancos, & San-Miguel-Ayanz, 2017), the ignition points of simulated fires were positioned in the proximity of human assets, using roads as a proxy of human activity presence. We used the data from the regional cartographic base BDTRE (https://www.geoportale.piemonte.it) and the data about suburban and tractor-trail roads furnished by the local forestry consortium, Consorzio Forestale del Canavese (CFC). Three levels of buffer (50 m, 100 m, 200 m) were created around the geometries and 600 ignition points were randomly created in the buffer areas, 200 for each buffer level.

The number of ignition points was chosen through an expert evaluation based on the surface of the study area. It corresponds to around 4,1 points per km^2. This allows for a significantly finer analysis than the approximately 0,6 points per km^2 used by the regional FM plan, in line with the higher scale of analysis of this work. Since in mountain regions fire behaviour is mostly driven by topography, initiating 4 wildfires from the same spatial unit of 1 km^2 allows to cover most of the potential upslope trajectories of a fire front. Increasing the number of ignitions would generate wildfires following the same trajectory, i.e. increasing computational cost without adding new information.

As regards meteorological conditions, we used a scenario of full alignment between wind and slope (wind intensity of 10 km/h) and the standard fuel moisture scenarios D2L1 (low moisture content for dead fuel, very low moisture content for live fuel) developed by (Scott and Burgan, 2005). This scenario corresponds to the typical moisture conditions of the vegetation in winter, when the majority of the burnt area occurs in the Alpine region (Valese et al., 2014). Because of the low temperatures, dead fuels remain within the D2 scenario ranges despite the prolonged dry period. Since the surface vegetation in winter is fully cured, the L1 scenario applies. 80 % of tree crown foliar moisture content was selected for conifer trees because of the low physiological activity in winter.

The simulation was carried out with 800 min of Maximum Simulation Time, 30 m of Resolution of calculation,500 m of Interval for Minimum Travel Paths and 10 m of output resolution.

The values of the Burn Probability output were then classified into 5 progressive classes (Appendix F). The values of the Fireline Intensity were classified into seven classes according to the potential effects of fire (Appendix G). The classes of Burn Probability and Fireline Intensity were then combined according to an adaptation of the table provided by (Regione Piemonte, 2021) (Appendix H).

2.3.4. Risk computation

The fourth step consisted of the computation of the fire risk by combining the hazard information with the vulnerability information, for two scenarios: excluding the CES from the analysis and including them. To make the results comparable, we used the combination rules adopted by the regional FM plan (Regione Piemonte, 2021, page 106) for both scenarios and we applied them at the pixel level (Appendix I).

For both scenarios, the resulting values of risk for each pixel of the map were then averaged at the subwatershed level and the resulting risk values were in turn classified into 5 risk classes (very low, low, medium, high, very high) according to quantiles intervals.

2.3.5. Comparison of the two-scenario risk results

Finally, a comparative analysis of the two resulting wildfire risk maps (standard vs. CES integrated risk assessment) was performed to evaluate the impact of including the CES in the procedure, by means of both a qualitative and a quantitative assessment. This last was carried out by calculating the distance in terms of the number of classes among the two scenarios for each subwatershed.

3. Results

The total number of points identified by the participants for each CES category was 179 for the recreational service, 159 for the aesthetic value, 105 for the common sense of place, and 92 for the personal sense of place. 86 points (27, 39, 4 and 16 respectively) were on peaks or ridge lines and so were counted for all adjacent subwatersheds. Most of the points corresponded to places that were indicated by more than one respondent. Fig. 3 shows the distribution of those places for each CES category in relation to the number of participants indicating them and to the mean 1–5 value accorded.

The recreational service is more represented in the lower altitude areas in the south of the valley. These areas are characterised by a well-developed network of hiking, biking and horseback riding trails. Their stronger accessibility, which was specifically taken into consideration by some respondents in the 1–5 valuation, makes them more frequently visited.

The aesthetic value category has many points on the peaks of the valley, which are highly rated because of their beautiful view. On the other hand, the points of the common sense of place category are more distributed in the valley bottom, where human activities (pastoralism, mining and stream-related manufactures) have been historically more developed. Other places classified in this category are areas with unique natural characteristics, traditional hamlets and accessible touristic areas, which are representative of the valley's image to visitors.

The respondents often identified the spots of the personal sense of place category based on positive personal experiences, which were frequently related to childhood memories. Sometimes they refer to the personal relationship between the respondent and the territory, but more often they also involve the relationship between the respondent and other people, such as family members or friends. For some, they are related to memories of social gatherings, such as traditional open-air festivals.

The hazard map, the regional FM plan vulnerability map, the CES weighted density map, and the output of the integration of the latter two are shown in Fig. 4.

Concerning the CES density, many places are recurrent in the answers of the different respondents and in relation to more than one CES category, so that a few subwatersheds have a strongly higher value of weighted density than the others.

The results of the fire behaviour simulation show no high and very high hazard areas. Medium and medium/high hazard zones are scattered in the valley, such as in the eastern area close to Brosso, along the Chiusella stream close to Traversella and Rueglio, and in some secondary valleys in the northern part.

Concerning the regional FM plan vulnerability, most of the valley area is classified as low or very low vulnerability. Higher vulnerability areas are in the northern part of the valley on the left orographic slope, in correspondence with some artificial coniferous plants around the municipalities of Valchiusa and Brosso, and near a Chiusella tributary on the southwestern border.

Due to the concentration of CES hotspots in a few subwatersheds, the integration of CES decreased the vulnerability class for most of the valley surface. Indeed, the areas where CES hotspots are located have been affected by the opposite phenomenon.

Fig. 5 shows the two final outputs of the risk assessment at the subwatershed level. A map showing the difference between the two scenarios in terms of the number of risk classes of positive or negative variation is also presented.

The comparison of the two fire risk classifications shows that the inclusion of CES changed the risk classification by at least two classes (positive or negative change) for 52 of the 358 subwatersheds. Risk reduction mainly concerned a group of subwatersheds in the north, while the subwatersheds with an increased risk are more scattered in the whole valley area, in line with the scattered distribution of CES hotspots.

Both risk maps are characterized by a prevalence of very low and

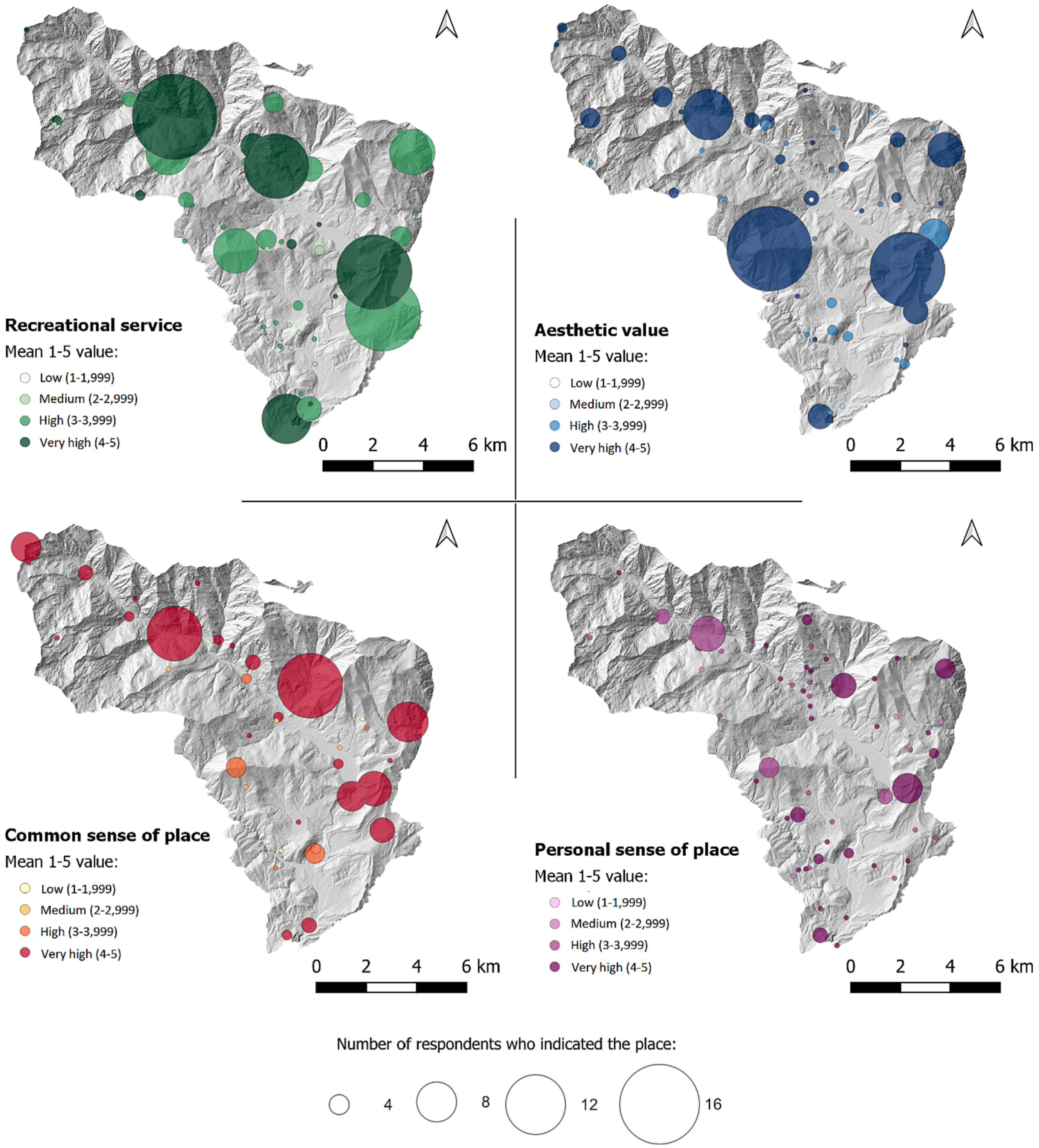


Fig. 3. Maps of the distribution of the CES in the valley according to the stakeholders interviewed. The maps highlight the number of respondents who indicated each place and the mean of the 1–5 value assigned to each place.

low-risk basins at the highest altitude, where the vegetation is sparse. However, while groups of high and very high subwatersheds can be distinguished in the classification excluding CES, those are more scattered in the second one.

4. Discussion

This work proposed an innovative method for including CES in wildfire risk assessment procedures. We tested it in an inner alpine valley of the European Alps prone to fire disturbance by comparing the analysis results with the standard approach currently used by regional FM plans in the Italian Alps. Based on the results, we argue that considering CES in fire risk assessment causes significant revision and improvement of the information produced. The qualitative analysis of the spatial distribution of higher-risk areas revealed a consistent shift from a more clustered one to a more scattered one. This is due to the peculiar, scattered distribution of CES hotspots, which depends on the perception of nature rather than on nature itself (Bing, Qiu, Huang, Chen, Zhong & Jiang, 2021; Buchel et Frantzseskaki, 2015).

These results must be considered in combination with evidence from

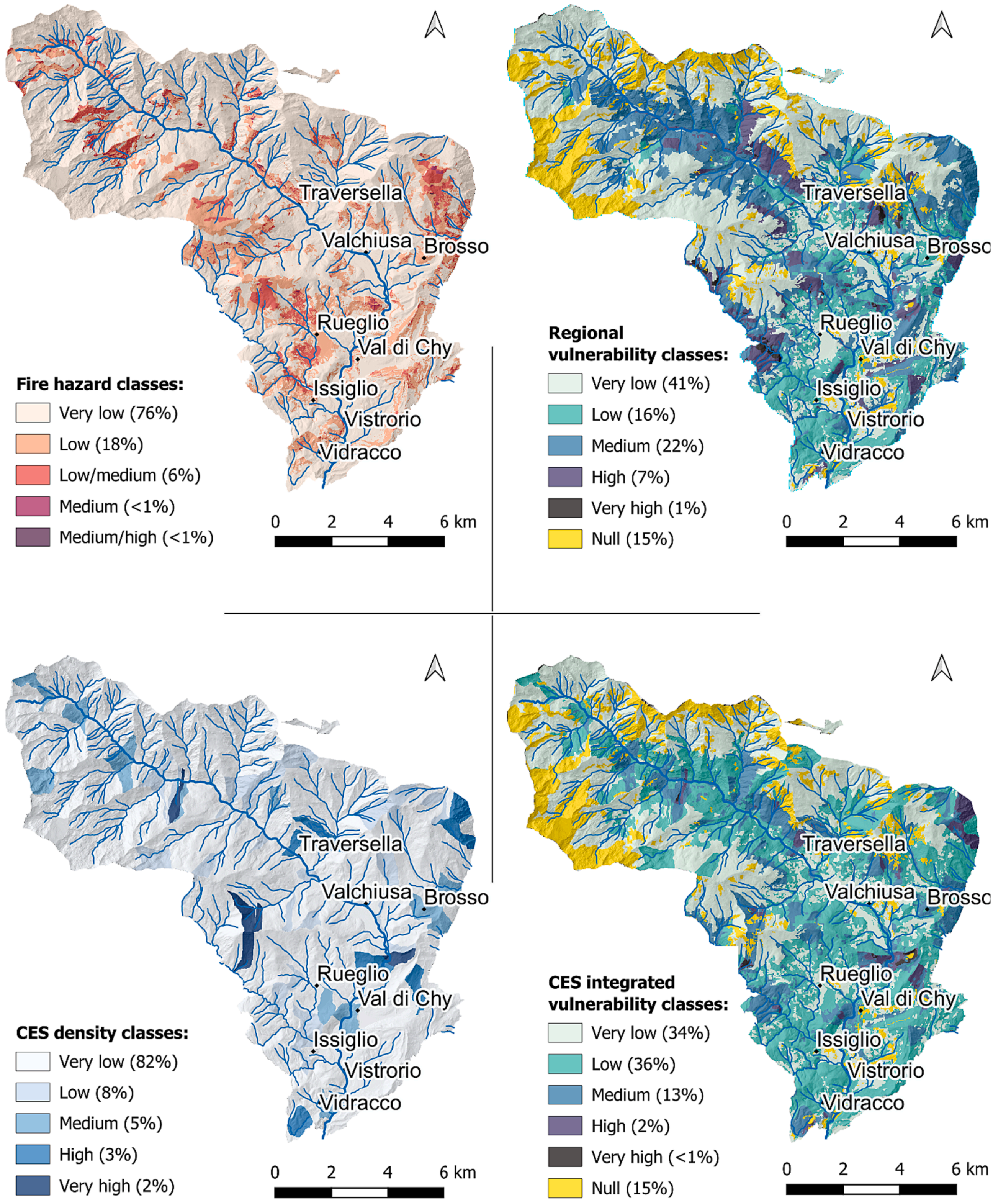


Fig. 4. Maps of the fire hazard analysis result, the vulnerability as assessed by the regional FM plan, the output of the CES distribution assessment and the result of the integration of the CES distribution into the vulnerability information. The percentage of surface covered by each class is reported in brackets in the legends. The "null" value corresponds to the areas where the absence of vegetation prevented the author of the regional FM plan from assigning a vulnerability value.

the literature about the potentially high negative impact of fires on CES provision (e.g. Pereira et al., 2021) and demonstrate the relevance of taking into consideration the cultural value of ecosystems in the analysis. Some previous works focused on the negative effect of wildfire events on the sense of place perception (Kooistra, Hall, Paveglio & Pickering, 2018). (Knez, Butler, Sang, Ångman, Sarlöv-Herlin, & Åkerskog, 2018) have explored how the sudden changes in the landscape can cause loss of place attachment and emotional bond in the people living in or regularly visiting the area in proximity of the event, weakening the level of wellbeing provided by frequenting the site. Developing fire

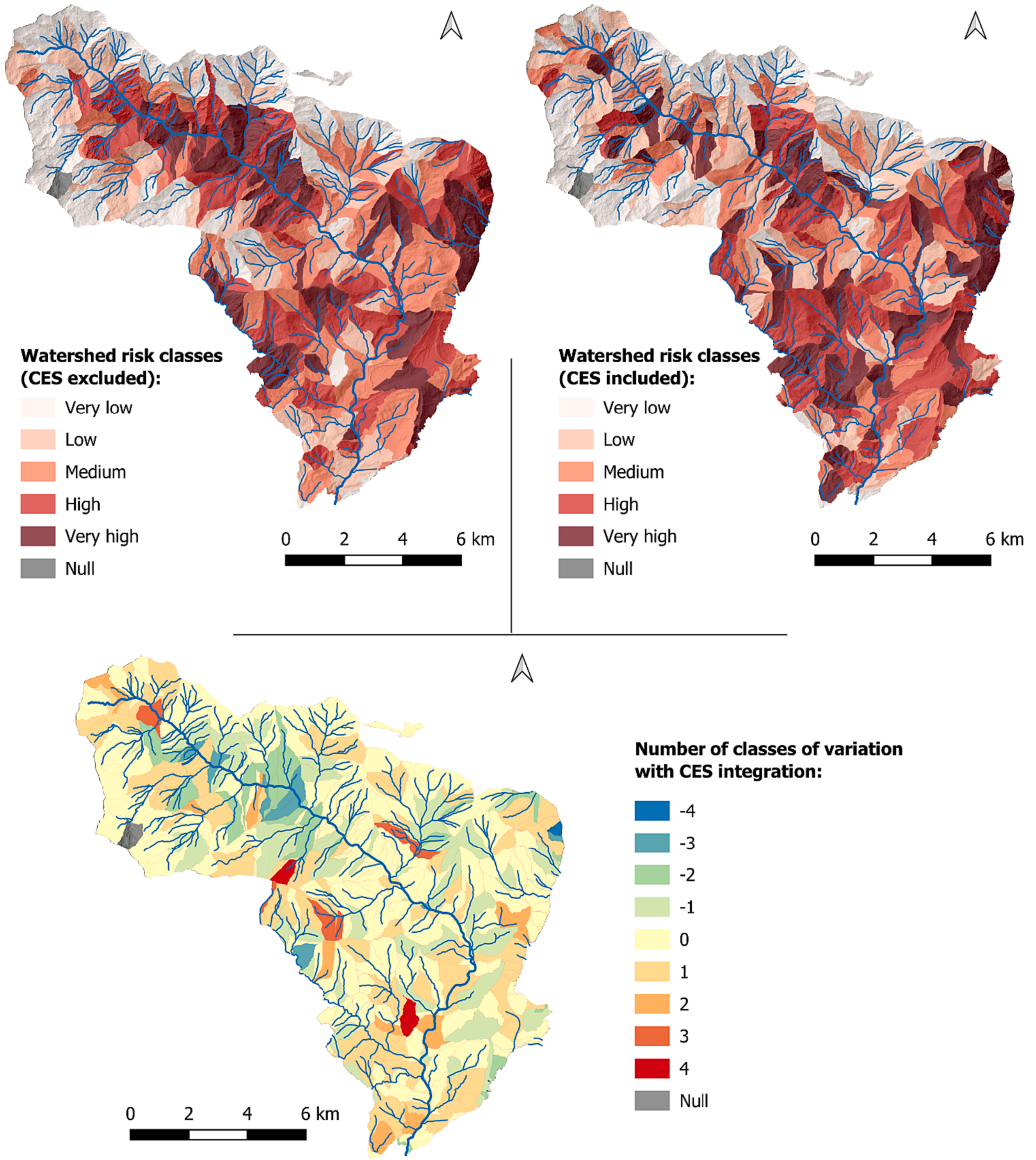


Fig. 5. Map of Valchiusella subwatersheds classified according to the two methodologies of fire risk assessment, the standard one excluding CES from the analysis and the one considering CES.

prevention strategies targeted at preserving CES hotspot sites, therefore, would significantly contribute to the wellbeing of the local community.

The change in the distribution pattern with the integration of CES is made particularly evident by the procedural decision to give the same weight to the regional vulnerability layer and the CES distribution layer in the calculation of the integrated vulnerability, for the sake of homogeneity with the regional assessment procedure. This decision allowed us to appreciate the effect of integrating CES information on the map output. The high weight given to CESs reflects also the fact that areas with a higher CES value are also crucial from a civil protection perspective since the presence of CES indicates a higher possible presence of people, e.g. for recreational activities. However, a criticism to this approach is that such a strong emphasis on human values could undermine the consideration of the physical-ecological drivers of fires. This could lead to the allocation of few resources for fire prevention activities in areas considered not crucial from a purely anthropocentric point of view, but where the ecological effects of fires could be disastrous. To address this drawback, an additive method for integrating the CES density and the general vulnerability layers was also explored, as reported in Appendix L and M. This method relies on class combination rules that only allow for an increase in the vulnerability class of a pixel when CES density is integrated. The fire risk map produced shows a distribution of high and very-high-risk watersheds which is closer to that of the risk map without the addition of the CESs, while maintaining a more scattered pattern. Nevertheless, the additive combination rules used in this case are the results of merely arbitrary choices. How to carefully weigh the different factors contributing to fire risk remains an important question for future research.

A critical advantage of the multidisciplinary approach presented is the possibility to combine very different sources of information, with the support of spatial analysis and the adoption of subwatershed territorial units. Subwatersheds are considered here both as homogenous and operational units, which make the results communicable to the stakeholders and effectively usable for defining planning strategies. The cartographic results clearly show the areas with higher fire risk and, therefore, the subwatersheds where prevention actions need to be implemented with priority.

The involvement of local stakeholders allowed for a novel insight into the relationship between the local community and its landscape. It was also fundamental for building consensus on the outputs and raising awareness about its potential application in local planning strategies. According to Steelman and McCaffrey's (2013) analysis of the existing literature on fire risk communication, a preference for interactive processes and consideration of the local context are key factors for better understanding and support of wildfire prevention interventions. Since limiting the involvement of local stakeholders to the CES assessment phase could have limited their general understanding and recognition of the whole risk assessment process, a broad overview of the methodology was presented during the participatory mapping activity. A public presentation of the process and results was also held at the conclusion of the analysis.

During the participatory mapping activity, many places received high scores in more than one CES category, sometimes in all four. Some relatively recent studies have referred to this phenomenon of recurrence with the term "ecosystem service bundle" (Spake et al., 2017; Turner, Odgaard, Bøcher, Dalgaard, & Svenning, 2014). According to the definition by (Raudsepp-Hearne, Peterson and Bennett, 2010), ecosystem service bundles are "sets of ecosystem services that repeatedly appear together across space or time". Clearly, we here refer to a specific group of ES, so the occurrence of interactions among different services is more often linked to synergies than trade-offs. Both ecological and social processes contribute to shaping these interactions. For example, the unique natural characteristics of an area can contribute to its attractiveness for recreational activities, its aesthetic value and its representativeness of the valley's naturalistic identity at the same time.

The personal sense of place category needs special consideration. The answers for this category are more linked to the participants' personal experience than to some knowledge derived from their role. Some places, which are generally highly scored also in the other CES categories, are recurrent in the answers. However, most of the places are linked to very personal experiences and so are identified only by one or a maximum of a few respondents. The output of the mapping activity for this category, therefore, is hardly generalisable and extremely dependent on the selection of the single participant, whose expertise as a local stakeholder of land management is almost irrelevant. This leads us to question whether the assessment procedure adopted is well suited for this specific CES category. Two considerations can be made for future research: the need for a larger sample of interviewees and the opportunity for a different assessment approach. On the one hand, a larger sample of participants would make the results statistically more representative of the whole local community's perception. On the other hand, an approach aimed at going beyond the mere arithmetic sum of personal values might be more appropriate to adequately portray the perception of a community of individuals. This proposal is consistent with the observations of Raymond and colleagues (2014), who described the contrast between instrumental assessments (focused on rating and ranking contextual values, by arithmetically aggregating individual values) and deliberative assessments (focused on communication, participation, social learning and negotiation) of cultural ecosystem services, and suggested a combination of them. However, further work is needed to explore how a deliberative assessment approach could be coupled with the need of fire risk mapping for spatially explicit quantitative information.

These considerations are also in line with the suggestion expressed by some respondents to extend the CES assessment phases to other participants and to transform the participatory mapping exercise into a tool for enhancing public discussion. This would allow for a dialogue among inhabitants about the role of the ecosystem and the priorities of planning strategies, as well as some knowledge exchange about the territory. According to the interviewees, it would increase residents' awareness of the services that the ecosystem provides and of the importance of land management. This suggestion highlights the ability of this approach to promote a positive process of awareness raising and stimulate the stakeholders' willingness to explore the issues further. This added value of the proposed methodology is consistent with the benefits described in the broad literature on participatory processes for environmental risk management, such as the strengthening of local capacity and the engagement of local actors in imagining possible solutions (De Stefano et al., 2017; Bustillos Ardaya, Evers & Ribbe, 2019).

A final consideration from this case study concerns the applicability of the procedure to other contexts and the recommendation to update local fire risk management plans accordingly. Wildfire risk assessment is a crucial step for identifying priority areas for risk prevention strategies and providing decision-makers with operational information (Scott et al., 2013; Thompson & Calkin, 2011). This work demonstrated the impact of taking into account CES on the results and thus its relevance in guiding resource allocation. However, the proposed methodology requires a local-scale application, since it requires an in-depth knowledge of the territory by the participants, and a considerable amount of time and resources, as most participatory methods. This might conflict with the capabilities of local administrations, especially in disadvantaged contexts. A challenge for the next steps of the research is the further elaboration of a less resource-intensive procedure without losing the benefits of directly involving local stakeholders in the process, e.g. based on online tools.

5. Conclusion

In this work, we proposed an innovative procedure for including CES distribution in wildfire risk mapping, bridging the gap between the literature on wildfire risk assessment and the literature on CES assessment. We described its application in an inner valley of southwestern European Alps, and we compared the results with the output of the assessment procedure currently in use at the regional level, demonstrating the relevance of CES inclusion. The main strength of this methodology relies on its ability to couple fire hazard simulation results, ecological vulnerability data and participatory mapping outputs. The method also allows the local stakeholders to be directly involved in the mapping procedure. The consideration for the local community knowledge and point of view makes the results relevant for the specific socio-ecological system analysed and meaningful for the local stakeholders, who would then use them for the elaboration of fire prevention strategies at the landscape level. A recommendation for the application of the procedure concerns the need to make local stakeholders aware of the entire process beyond the mapping activity, to assure their trust in the process and the final results.

Finally, the application of this procedure to other contexts would strongly benefit local wildfire risk management plans. However further elaborations are needed to make it less resource-intensive while ensuring the direct and indirect positive outcomes of a participatory approach.

CRediT authorship contribution statement

Ingrid Vigna: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Luca Battisti:** Writing – review & editing, Methodology, Conceptualization. **Davide Ascoli:** Writing – review & editing, Methodology, Conceptualization. **Angelo Besana:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Alessandro Pezzoli:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Elena Comino:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgement

We would like to thank all the participants in the mapping activities for their fundamental contribution. We also would like to acknowledge Prof. Luca Battaglini for the initial fruitful discussions, Evelyn Joan Momo for the support with FlamMap analysis, and the technicians of the Consorzio Forestale del Canavese for providing data and assistance. The contribution of DA was carried out within the Italian Agritech National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022).

Appendix A

Categories of CESs used for the participatory mapping activity in relation to the Millenium Ecosystem Assessment and the CICES classifications.

	Ecosystem Services' classifications	
Participatory mapping CES categories	**Millennium Ecosystem Assessment**	**CICES**
1. Recreational service	**Recreation and ecotourism.** People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.	**3.1.1.1.** Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions. **3.1.1.2.** Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions.
2. Aesthetic value	**Aesthetic values.** Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, "scenic drives," and the selection of housing locations.	**3.1.2.4.** Characteristics of living systems that enable aesthetic experiences.
3. Common sense of place	**Cultural heritage values.** Many societies place a high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species. **Sense of place.** Many people value the "sense of place" that is associated with recognized features of their environment, including aspects of the ecosystem	**3.1.2.3** Characteristics of living systems that are resonant in terms of culture or heritage. **3.2.1.1.** Elements of living systems that have symbolic meaning
4. Personal sense of place	**Sense of place.** Many people value the "sense of place" that is associated with recognized features of their environment, including aspects of the ecosystem	/

Appendix B

Interview canvas used for the participatory mapping activity.

CES categories	Questions
Recreational service	1. Indicate the places that are potentially most enjoyable by residents and tourists for outdoor recreational activities. Score their attractive potential from 1 to 5. What their attractive potential consists of? For which activities are they suitable?
Aesthetic value	2. Indicate the places that, in your opinion, are more beautiful from a merely aesthetic point of view. Score their aesthetic value from 1 to 5.Which characteristics make them beautiful? Which aspects is their aesthetic value based on (biodiversity, ecological value, landscape, view…) ?
Common sense of place	3. Indicate the places that most represent the identity of Valchiusella. Score their importance from 1 to 5. What does their representativity consists of? Do they have historical/cultural/environmental… value?
Personal sense of place	4. Indicate the places to which you feel personally attached. Score their importance for you from 1 to 5. Are these places linked to your personal experience? Do they have sentimental value for you?

Appendix C

Classification of the subwatershed values derived from the participatory mapping of CES into weighted density classes.

CES weighted density class	Subwatershed values
Very low	0 – 10
Low	11 – 32
Medium	33 – 52
High	53 – 117
Very high	118 – 196

Appendix D

Rule table for the combination of the CES weighted density classes and regional vulnerability classes in integrated vulnerability classes at the pixel level.

		CES weighted density classes				
		Very high	**High**	**Medium**	**Low**	**Very low**
Regional vulnerability classes	**Very high**	Very high	Very high	High	High	Medium
	High	Very high	High	High	Medium	Medium
	Medium	High	High	Medium	Medium	Low
	Low	High	Medium	Medium	Low	Low
	Very low	Medium	Medium	Low	Low	Very low

Appendix E

Spatial layers characterising the landscape used as input for FlamMap simulations.

Layer	Source	Descriptions	Resolution
Fuel models map	Elaboration of the regional fuel model map and of CFC's forestry cover data.	The regional fuel model map, personally furnished by the authors of the regional FM plan (Regione Piemonte, 2021) as a polygon shape file, derives from the regional forestry map. It is the result of the translation of forestry cover classes into fuel models. We applied the same translation rules to the polygon data about forestry cover furnished by the CFC for its areas of competence, which are more detailed than the regional ones. The final fuel models map was created by merging this result with the regional fuel data for the area not covered by CFC's data. The polygon layer was then rasterized with a resolution of 5 m.	5 *m*
Altitude, exposition and slope	Processing of the regional Digital Terrain Model (DTM) available at the regional geoportal (https://www.geoportale.piemonte.it).	The DTM data derives from the aerial shooting ICE 2009–2011. It was processed with QGIS software.	5 *m*
Canopy cover	Copernicus Land Monitoring Service (https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density).	The canopy cover was derived by the Tree Cover Density layer, which shows the level of tree cover density in a range from 0 to 100 %. The data for the reference year 2018 was used.	20 *m*
Canopy height model (CHM)	Processing of the regional DTM and regional Digital Surface Model (DSM).	The CHM was created by subtraction of the DTM from the DSM. The latter was not officially validated at the time of the analysis, so it was not freely available through the regional geoportal. It was furnished by the regional cartographic service with the recommendation to specify this limit.	5 *m*
Canopy base height (CBH)	Elaboration of the canopy high model	The CBH concerns canopy fires. This kind of fire occurs when the flames jump from the terrain surface to the crowns and are extremely dangerous. They usually occur in forests with highly flammable foliage, such as coniferous forests in the northern hemisphere (Thomas, McAlpine, Hirsch, & Hobson, 2010). Therefore, the data used for the simulations are limited to coniferous areas, while it is equal to 0 for the rest of the valley. It was created using the following rules: Where the CHM is minor than or equal to 5 m (shrub-bearing plants): $CBH = CHM$Where the CHM is major than 5 m, a correction factor was applied (arboreal bearing plants):$CBH = CHM*0.6$	5 *m*
Crown bulk density (CBD)	Elaboration of the regional forestry map and of the CFC's forestry cover data.	As for the fuel model map, the CFC forestry cover data was merged with the regional one, choosing the more detailed data available for each area. The forest classes of the result were translated into CBD on a tabular basis, adapting the data furnished by Brown (1978) to the local species as follows: 0.400754 kg/m3 for *Larix decidua* (equated to *Larix occidentalis*) 0.96181 kg/m3 for *Picea abies* (equated to *Picea englemannii*) 0.769448 Kg/m3 for *Abies Alba* (equated to *Abies grandis*) 0.96181 kg/m3 for *Pinus strobus* and *Pinus pinaster* (equated to *Pinus albicaulis*)	5 *m*

Appendix F

Classification of the Burn Probability values.

Class	Burn Probability Values
Very low	0 – 0.005
Low	0.005 – 0.010
Medium	0.010 – 0.015
High	0.015 – 0.02
Very high	> 0.02

Appendix G

Classification of the Fireline Intensity values. The seven classes are an adaptation of the classification described by the regional FM plan (Regione Piemonte, 2021). Two of the five original classes have been split up to be more representative of the variability of the Fireline Intensity values for the area, most of which falls in the lower classes.

Class	Fireline Intensity value	Description
Very low	< 200 kw/m	Surface fire with negligible effects
Low	200 – 600 kw/m	Intense surface fire, increase in crown scorch and tree mortality rates
Low/Medium	600 – 1000 kw/m	Very intense surface fire and high mortality rates of most tree species
Medium	1000 – 1500 kw/m	The probability of crown fire initiation in conifers increases and most of the crowns are scorched
Medium/High	1500 – 3000 kw/m	Transition from dependent to independent crown fire and complete crown mortality
High	3000 – 8000 kw/m	Independent crown fire and high severity fire effects
Very high	> 8000 kw/m	Extreme crown fire and stand replacing fire effects

Appendix H

Rules used for the combination of Fireline Intensity classes and Burn Probability classes into hazard classes.

		Fireline Intensity						
		Very high	**High**	**High/ Medium**	**Medium**	**Low/ Medium**	**Low**	**Very low**
Burn Probability	**Very high**	Very high	Very high	High	High	High/ Medium	Medium	Low/ Medium
	High	Very high	High	High	High/ Medium	Medium	Low/ Medium	Low
	Medium	High	High	High/ Medium	High/ Medium	Medium	Low/ Medium	Low
	Low	High	High/ Medium	High/ Medium	Medium	Low/ Medium	Low	Very low
	Very low	High/ Medium	High/ Medium	Medium	Low/ Medium	Low/ Medium	Low	Very low

Appendix I

Rule table for the combination of the vulnerability classes and the hazard classes in fire risk classes at the pixel level. The vulnerability classes refer here both to the regional vulnerability classes and to the CES integrated vulnerability classes.

		Vulnerability classes				
		Very high	**High**	**Medium**	**Low**	**Very low**
Hazard classes	**Very high**	Very high	Very high	High	Medium	Low
	High	Very high	High	High	Medium	Low
	Medium	High	High	Medium	Low	Low
	Low	High	Medium	Low	Low	Very low
	Very low	Medium	Medium	Low	Very low	Very low

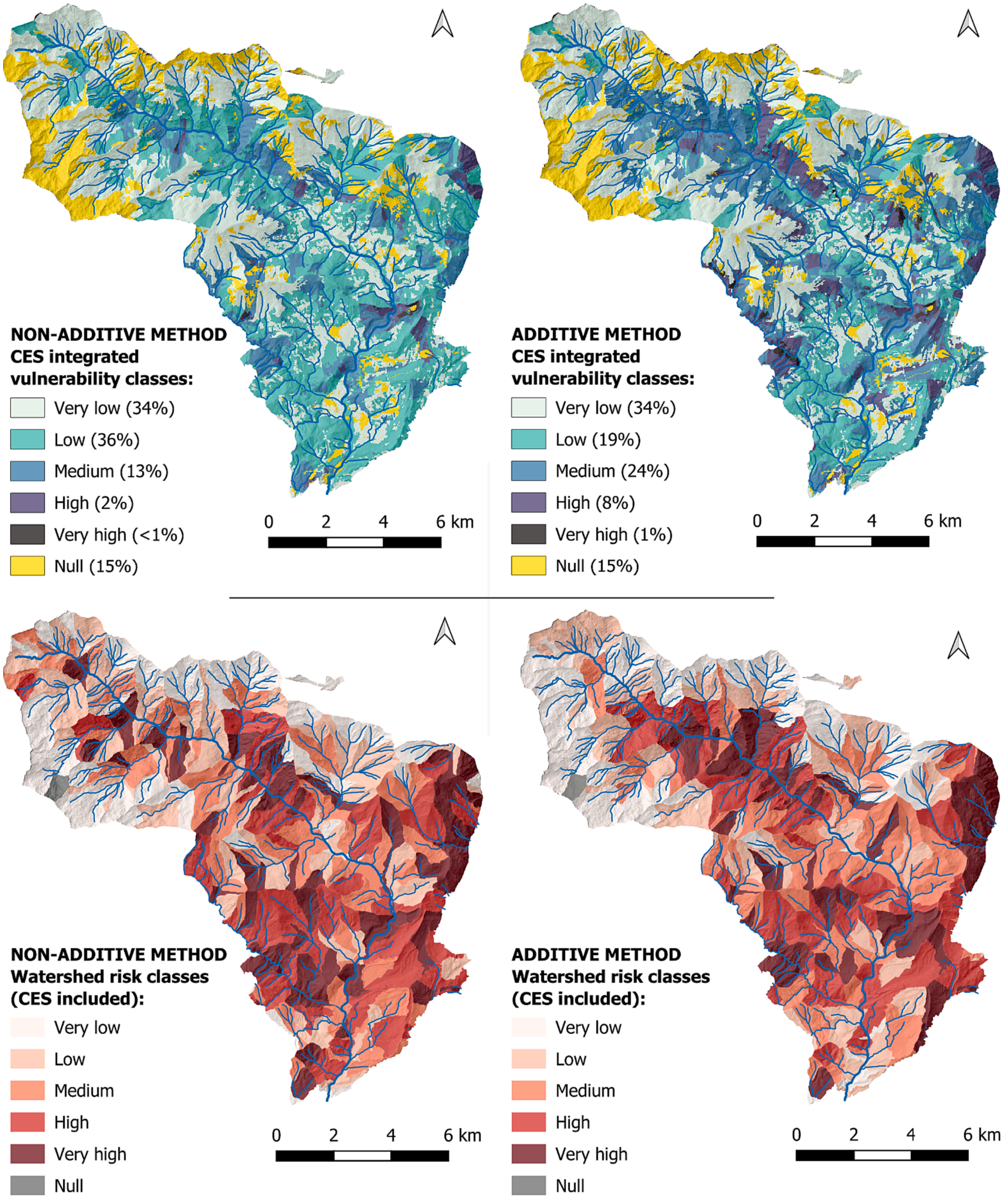
Appendix L

Rule table for the combination of the CES weighted density classes and regional vulnerability classes in integrated vulnerability classes at the pixel level, according to the additive method.

		CES weighted density classes				
		Very high	**High**	**Medium**	**Low**	**Very low**
Regional vulnerability classes	**Very high**	Very high	Very high	Very high	Very high	Very high
	High	Very high	High	High	High	High
	Medium	High	High	Medium	Medium	Medium
	Low	High	Medium	Medium	Low	Low
	Very low	Medium	Medium	Low	Low	Very low

Appendix M

Comparison of the integrated vulnerability and risk maps obtained with the non-additive method and those obtained with the additive method.



.

References

Ager, A. A., Kline, J. D., & Fischer, A. P. (2015). Coupling the Biophysical and Social Dimensions of Wildfire Risk to Improve Wildfire Mitigation Planning. *Risk Analysis, 35*(8), 1393–1406. https://doi.org/10.1111/risa.12373

Alcasena, F., Ager, A., Le Page, Y., Bessa, P., Loureiro, C., & Oliveira, T. (2021). Assessing wildfire exposure to communities and protected areas in Portugal. *Fire, 4*(4), 82. https://doi.org/10.3390/fire4040082

Alcasena, F. J., Salis, M., Ager, A. A., Castell, R., & Vega-García, C. (2017). Assessing wildland fire risk transmission to communities in northern Spain. *Forests, 8*(2), 30. https://doi.org/10.3390/f8020030

Ascoli, D., Moris, J., Marchetti, M., & Sallustio, L. (2021). Land use change towards forests and wooded land correlates with large and frequent wildfires in Italy. *Annals of Silvicultural Research, 46*(2). https://doi.org/10.12899/asr-2264

Ascoli, D., Plana, E., Oggioni, S. D., Tomao, A., Colonico, M., Corona, P., … Barbati, A. (2023). Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. *International Journal of Disaster Risk Reduction, 92*, Article 103715.

Ascoli, D., Vacchiano, G., Scarpa, C., Arca, B., Barbati, A., Battipaglia, G., … Bacciu, V. (2020). Harmonized dataset of surface fuels under Alpine, temperate and Mediterranean conditions in Italy. A synthesis supporting fire management. *IForest - Biogeosciences and Forestry, 13*(6), 513–522. https://doi.org/10.3832/ifor3587-013

Battisti, L., Corsini, F., Gusmerotti, N. M., & Larcher, F. (2019). Management and Perception of Metropolitan Natura 2000 Sites: A Case Study of La Mandria Park (Turin, Italy). *Sustainability, 11*(21), 6169. https://doi.org/10.3390/su11216169

Bebi, P., Seidl, R., Motta, R., Fuhr, M., Firm, D., Krumm, F., … Kulakowski, D. (2017). Changes of forest cover and disturbance regimes in the mountain forests of the Alps. *Forest Ecology and Management, 388*, 43–56. https://doi.org/10.1016/j.foreco.2016.10.028

Bing, Z., Qiu, Y., Huang, H., Chen, T., Zhong, W., & Jiang, H. (2021). Spatial distribution of cultural ecosystem services demand and supply in urban and suburban areas: A case study from Shanghai, China. *Ecological Indicators, 127*. https://doi.org/10.1016/j.ecolind.2021.107720

Bowman, D. M., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M. A., D`Antonio, C. M., DeFries, R. S., Doyle, J. C., Harrison, S. P., & Johnston, F. H. (2009). Fire in the Earth system. *Science, 324*(5926), 481–484. https://doi.org/10.1126/science.1163886

Brown, G., & Fagerholm, N. (2015). Empirical PPGIS/PGIS mapping of ecosystem services: A review and evaluation. *Ecosystem Services, 13*, 119–133. https://doi.org/10.1016/j.ecoser.2014.10.007

Brown, J. K. (1978). *Weight and density of crowns of Rocky Mountain conifers*. Ogden, Utah: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture. doi:10.5962/bhl.title.68796.

Buchel, S., & Frantzeskaki, N. (2015). Citizens' voice: A case study about perceived ecosystem services by urban park users in Rotterdam, the Netherlands. *Ecosystem Services, 12*, 169–177. https://doi.org/10.1016/j.ecoser.2014.11.014

B. Burkhard J. Maes Mapping Ecosystem Services 2017 Pensoft Publishers Sofia 10.3897/ab.e12837.

Bustillos Ardaya, A., Evers, M., & Ribbe, L. (2019). Participatory approaches for disaster risk governance? Exploring participatory mechanisms and mapping to close the communication gap between population living in flood risk areas and authorities in Nova Friburgo Municipality, RJ. *Brazil. Land Use Policy, 88*, Article 104103. https://doi.org/10.1016/j.landusepol.2019.104103

de Rigo, D., Libertà, G., Houston Durrant, T., Artés Vivancos, T., & San-Miguel-Ayanz, J. (2017). *Forest fires danger extremes in Europe under climate change: variability and uncertainty*, EUR 28926 EN, Publications Office of the European Union, Luxembourg. doi:10.2760/13180, JRC108974.

De Stefano, L., Hernández-Mora, N., Iglesias, A., & Sánchez, B. (2017). Defining adaptation measures collaboratively: A participatory approach in the Doñana socio-ecological system, Spain. *Journal of Environmental Management, 195*, 46–55. https://doi.org/10.1016/j.jenvman.2016.10.042

Dessai, S., & Sims, C. (2010). Public perception of drought and climate change in southeast England. *Environmental Hazards, 9*(4), 340–357. https://doi.org/10.3763/ehaz.2010.0037

Dossche, R., Primi, A., & Valle, A. (2022). Landscape Services and Their Impact on the Well-Being of Local Actors Through Participatory Mapping. A Case-Study in the Inner Areas of Northern Apennines, Piedmont. *Geomatics for Green and Digital Transition*: *25th Italian Conference, ASITA 2022, Genova, Italy, June 20–24, 2022, Proceedings* (pp. 304-316). Cham: Springer International Publishing.

El Ezz, A. A., Boucher, J., Cotton-Gagnon, A., & Godbout, A. (2022). Framework for spatial incident-level wildfire risk modelling to residential structures at the wildland urban interface. *Fire safety journal, 131*, Article 103625. https://doi.org/10.1016/j.firesaf.2022.103625

Feld, S., & Basso, K. H. (1996). *Senses of place*. Santa Fe, New Mexico: School of American Research Press.

Finney, M. A. (2006). An overview of FlamMap fire modeling capabilities. In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management-How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 213-220. Retrieved from https://www.fs.usda.gov/rm/pubs/rmrs_p041/rmrs_p041_213_220.pdf.

M.A. Finney S.S. McAllister J.M. Forthofer T.P. Grumstrup Wildland Fire Behaviour: Dynamics, Principles and Processes 2021 CSIRO Canberra, Australia 10.1071/9781486309092.

Gamboa, G., Otero, I., Bueno, C., Arilla, E., Ballart, H., Camprubí, L., … Castellnou, M. (2023). Participatory multi-criteria evaluation of landscape values to inform wildfire management. *Journal of Environmental Management, 327*, Article 116762. https://doi.org/10.1016/j.jenvman.2022.116762

García-Díez, V., García-Llorente, M., & González, J. A. (2020). Participatory Mapping of Cultural Ecosystem Services in Madrid: Insights for Landscape Planning. *Land, 9*(8), 244. https://doi.org/10.3390/land9080244

Grêt-Regamey, A., Brunner, S. H., Altwegg, J., Christen, M., & Bebi, P. (2013). Integrating Expert Knowledge into Mapping Ecosystem Services Trade-offs for Sustainable Forest Management. *Ecology and Society, 18*(3), art34. https://doi.org/10.5751/ES-05800-180334

Haines-Young, R., & Potschin, M. (2018). Revision of the common international classification for ecosystem services (CICES V5. 1): A policy brief. *One Ecosystem, 3*, e27108.

Jahdi, R., Salis, M., Darvishsefat, A. A., Alcasena, F., Mostafavi, M. A., Etemad, V., … Spano, D. (2016). Evaluating fire modelling systems in recent wildfires of the Golestan National Park, Iran. *Forestry: An International Journal of Forest Research, 89* (2), 136–149. https://doi.org/10.1093/forestry/cpv045

Kahila-Tani, M., Kytta, M., & Geertman, S. (2019). Does mapping improve public participation? Exploring the pros and cons of using public participation GIS in urban planning practices. *Landscape and urban planning, 186*, 45–55.

Kantola, S., Fagerholm, N., & Nikula, A. (2023). Utilization and implementation of PPGIS in land use planning and decision-making from the perspective of organizations. *Land Use Policy*, *127*, 106528. Kantola, S., Fagerholm, N., & Nikula, A. (2023). Utilization and implementation of PPGIS in land use planning and decision-making from the perspective of organizations. *Land Use Policy*, *127*, 106528.

Knez, I., Butler, A., Sang, Å. O., Ångman, E., Sarlöv-Herlin, I., & Åkerskog, A. (2018). Before and after a natural disaster: Disruption in emotion component of place-identity and wellbeing. *Journal of Environmental Psychology, 55*, 11–17. https://doi.org/10.1016/j.jenvp.2017.11.002

Knez, I., & Eliasson, I. (2017). Relationships between Personal and Collective Place Identity and Well-Being in Mountain Communities. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00079

Kooistra, C., Hall, T. E., Paveglio, T., & Pickering, M. (2018). Understanding the factors that influence perceptions of post-wildfire landscape recovery across 25 wildfires in the northwestern United States. *Environmental management, 61*, 85–102. https://doi.org/10.1007/s00267-017-0962-9

Lecina-Diaz, J., Martínez-Vilalta, J., Alvarez, A., Vayreda, J., & Retana, J. (2021). Assessing the Risk of Losing Forest Ecosystem Services Due to Wildfires. *Ecosystems*. https://doi.org/10.1007/s10021-021-00611-1

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., … Gibon, A. (2000). Agricultural Abandonment in Mountain Areas of Europe: Environmental Consequences and Policy Response. *Journal of Environmental Management, 59*. https://doi.org/10.1006/jema.1999.0335

McMichael, A., Scholes, R., Hefny, M., Pereira, E., & Palm, C. (2005). Linking Ecosystem Services and Human Wellbeing. In C. Capistrano, M. J. Lee, C. Raudsepp-Hearne, & K. Samper (Eds.), *Ecosystem and Human Well-being: Multiscale Assessment* (pp. 43–60). Washington, DC, USA: Island press:

Molina, J. R., Moreno, R., Castillo, M., & Rodríguez y Silva, F.. (2018). Economic susceptibility of fire-prone landscapes in natural protected areas of the southern Andean Range. *Science of The Total Environment, 619–620*, 1557–1565. https://doi.org/10.1016/j.scitotenv.2017.11.233

Moreira, F., Ascoli, D., Safford, H., Adams, M. A., Moreno, J. M., Pereira, J. M., … Fernandes, P. M. (2020). Wildfire management in Mediterranean-type regions: Paradigm change needed. *Environmental Research Letters, 15*(1), Article 011001. https://doi.org/10.1088/1748-9326/ab541e

M. Müller L. Vilà Vilardell H. Vacik C. Mayer S. Mayr P. Carrega … M. Sautter Forest fires in the Alps. State of knowledge, future challenges and options for an integrated fire management White Paper for Policy Makers; EUSALP Action Group 8 2020 Vienna, Austria Retrieved from.

Nunes, A. N., Figueiredo, A., Pinto, C., & Lourenço, L. (2023). Assessing Wildfire Hazard in the Wildland-Urban Interfaces (WUIs) of Central Portugal. *Forests, 14*(6), 1106. https://doi.org/10.3390/f14061106

Nuthammachot, N., & Stratoulias, D. (2021). Multi-criteria decision analysis for forest fire risk assessment by coupling AHP and GIS: Method and case study. *Environment, Development and Sustainability, 23*(12), 17443–17458. https://doi.org/10.1007/s10668-021-01394-0

Palaiologou, P., Kalabokidis, K., Day, M. A., & Kopsachilis, V. (2020). Evaluating Socioecological Wildfire Effects in Greece with a Novel Numerical Index. *Fire, 3*(4), 63. https://doi.org/10.3390/fire3040063

Palomo, I., Martín-López, B., Zorrilla-Miras, P., García Del Amo, D., & Montes, C. (2014). Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change, 14* (1), 237–251. https://doi.org/10.1007/s10113-013-0488-5

Parisien, M.-A., Dawe, D. A., Miller, C., Stockdale, C. A., & Armitage, O. B. (2019). Applications of simulation-based burn probability modelling: A review. *International Journal of Wildland Fire, 28*(12), 913. https://doi.org/10.1071/WF19069

Pereira, P., Bogunovic, I., Zhao, W., & Barcelo, D. (2021). Short-term effect of wildfires and prescribed fires on ecosystem services. *Current Opinion in Environmental Science & Health, 22*, Article 100266. https://doi.org/10.1016/j.coesh.2021.100266

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy, 33*, 118–129. https://doi.org/10.1016/j.landusepol.2012.12.013

Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences, 107*(11), 5242–5247. https://doi.org/10.1073/pnas.0907284107

Raymond, C. M., Kenter, J. O., Plieninger, T., Turner, N. J., & Alexander, K. A. (2014). Comparing instrumental and deliberative paradigms underpinning the assessment of social values for cultural ecosystem services. *Ecological economics, 107*, 145–156.

Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., … Ranasinghe, R. (2020). *The concept of risk in the IPCC Sixth Assessment Report: a summary of cross-Working Group discussions.* Geneva, Switzerland: Inergovernmetal Panel on Climate Change, 15. Retieved from https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf.

Regione Piemonte (2021). Piano Regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi 2021-2025 (Regional Plan for the planning of the activities of forecasting, prevention and active fight against forest fires 2021-2025). Retrieved from https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/protezione-civile/incendi-boschivi/dgr-12-5791-13102022-piano-regionale-per-programmazione-delle-attivita-previsione-prevenzione-lotta.

Ridding, L. E., Redhead, J. W., Oliver, T. H., Schmucki, R., McGinlay, J., Graves, A. R., … Bullock, J. M. (2018). The importance of landscape characteristics for the delivery of cultural ecosystem services. *Journal of Environmental Management, 206*, 1145–1154. https://doi.org/10.1016/j.jenvman.2017.11.066

Ruiz-Frau, A., Edwards-Jones, G., & Kaiser, M. (2011). Mapping stakeholder values for coastal zone management. *Marine Ecology Progress Series, 434*, 239–249. https://doi.org/10.3354/meps09136

Salis, M., Del Giudice, L., Alcasena, F., Jahdi, R., Arca, B., Pellizzaro, G., … Duce, P. (2023). Assessing cross-boundary wildfire hazard, transmission, and exposure to communities in the Italy-France Maritime cooperation area. *Frontiers in Forests and Global Change, 6*, 1241378. https://doi.org/10.3389/ffgc.2023.1241378

Scott, J. H., & Burgan, R. E. (2005). *Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model* (No. RMRS-GTR-153) (p. RMRS-GTR-153). Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-153.

Scott, J. H., Thompson, M. P., & Calkin, D. E. (2013). *A wildfire risk assessment framework for land and resource management* (No. RMRS-GTR-315) (p. RMRS-GTR-315). Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-315.

Silvestro, R., Saulino, L., Cavallo, C., Allevato, E., Pindozzi, S., Cervelli, E., … Saracino, A. (2021). The Footprint of Wildfires on Mediterranean Forest Ecosystem Services in Vesuvius National Park. *Fire, 4*(4), 95. https://doi.org/10.3390/fire4040095

T.A. Slocum R.B. McMaster F.C. Kessler H.H. Howard Thematic Cartography and Geovisualization Fourth Edition (4th ed.). 2022 CRC Press Boca Raton 10.1201/9781003150527.

Spake, R., Lasseur, R., Crouzat, E., Bullock, J. M., Lavorel, S., Parks, K. E., … Eigenbrod, F. (2017). Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services. *Global Environmental Change, 47*, 37–50. https://doi.org/10.1016/j.gloenvcha.2017.08.004

Steelman, T. A., & McCaffrey, S. (2013). Best practices in risk and crisis communication: Implications for natural hazards management. *Natural hazards, 65*, 683–705. https://doi.org/10.1007/s11069-012-0386-z

Stoutenborough, J. W., & Vedlitz, A. (2014). Public Attitudes Toward Water Management and Drought in the United States. *Water Resources Management, 28*(3), 697–714. https://doi.org/10.1007/s11269-013-0509-7

Thomas, P. A., McAlpine, R. S., Hirsch, K., & Hobson, P. (2010). *Fire in the Forest*. Cambridge, UNITED KINGDOM: Cambridge University Press.

Thompson, M. P., & Calkin, D. E. (2011). Uncertainty and risk in wildland fire management: A review. *Journal of Environmental Management, 92*(8), 1895–1909. https://doi.org/10.1016/j.jenvman.2011.03.015

Turner, K. G., Odgaard, M. V., Bøcher, P. K., Dalgaard, T., & Svenning, J.-C. (2014). Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. *Landscape and Urban Planning, 125*, 89–104. https://doi.org/10.1016/j.landurbplan.2014.02.007

Valese, E., Conedera, M., Held, A. C., & Ascoli, D. (2014). Fire, humans and landscape in the European Alpine region during the Holocene. *Anthropocene, 6*, 63–74. https://doi.org/10.1016/j.ancene.2014.06.006

Vukomanovic, J., & Steelman, T. (2019). A Systematic Review of Relationships Between Mountain Wildfire and Ecosystem Services. *Landscape Ecology, 34*(5), 1179–1194. https://doi.org/10.1007/s10980-019-00832-9

Wartmann, F. M., & Purves, R. S. (2018). Investigating sense of place as a cultural ecosystem service in different landscapes through the lens of language. *Landscape and Urban Planning, 175*, 169–183. https://doi.org/10.1016/j.landurbplan.2018.03.021

Yue, Y., Dong, K., Zhao, X., & Ye, X. (2021). Assessing wild fire risk in the United States using social media data. *Journal of Risk Research, 24*(8), 972–986. https://doi.org/10.1080/13669877.2019.1569098