Participatory mapping for integrating ecosystem services valuation in fire risk assessment: a methodological proposal from an Italian alpine valley case study.

Participatory mapping for integrating ecosystem services valuation in fire risk assessment: a methodological proposal from an Italian alpine valley case study.

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Abstract. Climate change and rural abandonment are exacerbating fire risk in alpine valleys. The analysis of the local socio-ecological system dynamics and of the community's perspective is crucial in the assessment of fire risk. This work presents the proposal of a methodology to map fire risk through the involvement of local stakeholders in a multi-step participatory approach, which is currently being tested in an alpine case study. The methodology focuses on the risk of losing cultural ecosystem services, combining quantitative analysis with interviews, game sessions and participatory mapping. The results couple the cartographic output with social learning and insights for guiding the future development of community shared prevention strategies.

Parole chiave: Fire risk assessment, participatory mapping, cultural ecosystem services

1 Introduction

Forest fires are increasingly threatening the ability of forests to provide a wide range of ecosystem services in several regions of the world, such as Mediterranean Europe, due to higher temperatures and dryer conditions. In alpine valleys, rural abandonment also contributes to exacerbating fire risk, especially concerning big fire events. The natural reforestation of pasture areas and the general lack of forest and land management enhance the territory's flammability. Since the interaction of climate, ecological and socio-economic factors shapes fire risk, a socio-ecological system (SES) approach is needed to address the issue [1]. SES models are systemic frameworks specifically developed for the analysis of the interactions between humans and nature. They imply the characterization of a comprehensive structure delimiting a particular ecosystem and problem context [2] and the integration of the typical quantitative data of ecological sciences with the qualitative data of social science [3].

Moreover, sustainable fire risk mitigation strategies must take into account the specific needs and concerns of local contexts, rely on a robust assessment of the risk, and be integrated into local land management plans. The involvement of the local community, therefore, is an essential step. The local community's direct experience on the issue, through everyday interaction with the ecosystem over a long period, and its knowledge about ongoing socio-economic dynamics and hidden conflicts make it an essential source of information [4,5]. Understanding stakeholder's perception is also crucial for anticipating barriers to risk adaptation and mitigation actions [6] and assure public collaboration [7]. The common definition of the problem helps build consensus about the management plan and promote effective solutions [8]. However, as far as we know, a clearly defined and replicable methodology for the involvement of the local community in fire risk analysis and in the definition of fire management strategies is still missing.

This work presents the proposal of a structured methodology to address wildfire risk assessment through the involvement of local stakeholders in a multi-step participatory approach. The proposed methodology is based on two main pillars. The first pillar is related to the involvement of the local stakeholders not only in the risk assessment process but also in the analysis of local constraints, needs, expectations, and traditional shared knowledge. The purpose is to assure the equity of the process and the adaptation of the results to the characteristics of the specific local context, taking into account local socio-economic dynamics and challenges. Therefore, this work proposes a methodology for the involvement of the local community based on a role-playing game, inspired by the Companion Modeling approach [9]. The serious game approach, coupled with an agent-based model (ABM), is used as a facilitating instrument for understanding and representing the local SES dynamics, communicating them to the involved stakeholders, and discussing priorities, constraints and outcomes of forest and pasture management at a local scale. This also allows the development of a new general awareness of the issue and a shared vision of the problem among local stakeholders, which is indispensable to conceive mitigation strategies in the future.

Second, prevention strategies are generally targeted at the protection of human lives and the safety of infrastructures. However, we argue that the importance of Forest Ecosystem Services (FESs) for the well-being of the population requires considering the possible loss of the ability of forests to provide them in the definition of wildfire risk. Therefore, we propose a methodology for wildfire risk mapping which takes FESs as a reference in the definition of risk. We here focus specifically on cultural FESs, which are often overlooked in this type of evaluation and whose importance for our well-being was highlighted by the movement restrictions put in place during the Covid 19 pandemic period in almost every state in the world. We propose to catty out a socio-culture evaluation [10], mapping cultural FESs distribution through a participatory mapping technique.

This methodological proposal is being tested in a South-Western European Alpine valley. The first steps of the work have already been implemented. These regard the assessment of fire hazard and vulnerability, the involvement of local stakeholders through interviews and the development of the ABM role-playing game, as described in the second chapter of this paper. The analysis of the results of the game sessions and the implementation of the participatory mapping protocol still need to be completed. However, some preliminary results and the analysis of the general structure of the methodology allow us to discuss the strengths and limits of this proposal in the third chapter, where the main conclusions are also presented.

2 Case study

The methodology proposal is being tested in Valchiusella, a mountain valley of 14 258 ha located in northern Italy (see Fig. 1).

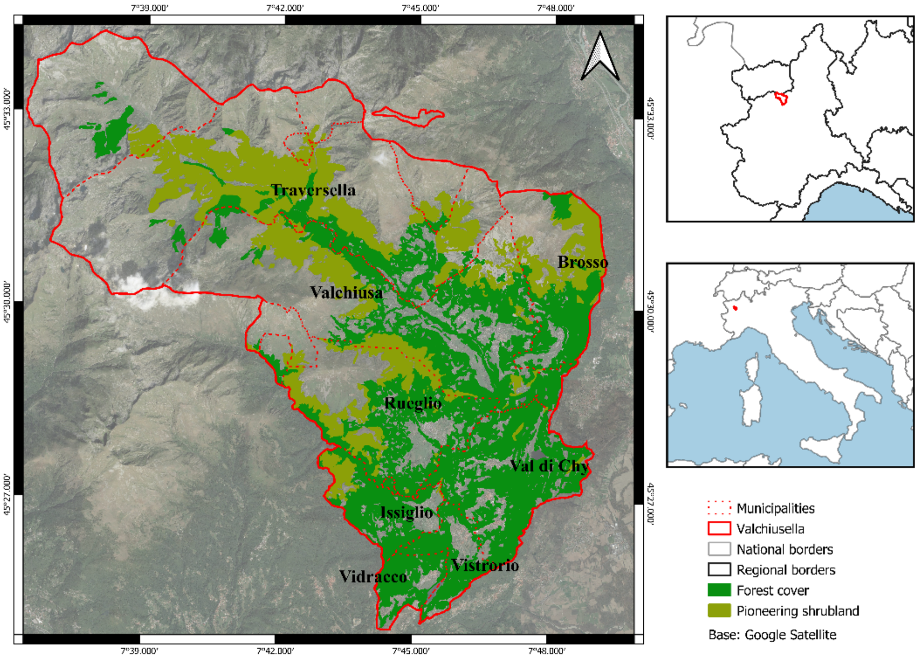

Fig. 1. Map of the study area, Valchiusella, a South-Western European Alpine valley (author's own production based on regional data on forest cover[1]).

The altitude of the valley ranges between approximately 400 m for the lower valley villages and 2800 m for the highest peaks. Its main river, Chiusella, gives the name to the valley. Eight municipalities are present (Brosso, Issiglio, Rueglio, Traversella, Valchiusa, Val di Chy, Vidracco and Vistrorio), for a total population of 5237 inhabitants on the 1st January 2020[2]. However, the population has been affected by a negative trend since the end of the nineteenth century. This phenomenon is common in many mountain rural areas in western Europe, because of the abandonment of traditional farming in remote areas due to the development of industrial activities and the mechanisation of agriculture in more fertile and accessible lands [11].

The climate of the area is characterized by humid springs and autumns, and dry winters, with a mean annual total amount of precipitation around 1400 mm. According to the regional data on past fires[3], the distribution of fire events across the year is in line with the precipitation distribution. There is a predominancy of fires during winter, which is the vegetative rest season, with peaks in March and in October.

1 Data available at: http://www.sistemapiemonte.it/popalfa/jsp/ricerca_pop/home.do
2 Data available at: http://dati.istat.it/.
3 Data available at: http://www.geoportale.piemonte.it/geocatalogorp/.

3 Methodological proposal

The methodology proposed in this work relies on the definition of risk provided by the Intergovernmental Panel on Climate Change (IPCC). Wildfire risk is therefore intended as the result of three different factors: hazard, exposure and vulnerability [12]. These factors are analysed concerning their spatial distribution (Fig. 2).

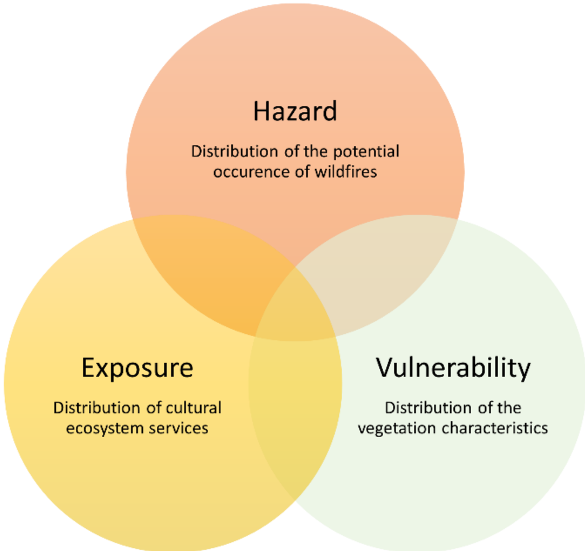

Fig. 2. The three components of wildfire risk as defined in this work.

The hazard is defined as the potential occurrence of wildfires, while the exposure represents "the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected" [13]. Here we decided to focus on the risk for the ecosystem of losing the ability to provide ecosystem services because of a fire event. The exposure factor, therefore, is represented by the presence of the selected ecosystem services on the landscape. Vulnerability is defined as the propensity or predisposition of an element to be adversely affected [13]. It is here referred to as the predisposition of the ecosystem to lose the service provision capacity because of the fire passage. This factor is strictly liked to the vegetation characteristics of the landscape.

Hazard, exposure and vulnerability are analysed and mapped as separated factors and finally combined. Different approaches are integrated, as summarized in Fig. 3. Step 1 constitutes the technical analysis of fire hazard through software simulations. Step 2 refers to the evaluation of the vulnerability based on the characteristics of the different kinds of vegetation. Steps 3, 4 and 5 are related to the involvement of the local stakeholders in a participatory process, while Step 6 aims at mapping the distribution of cultural ecosystem services according to their perception. Finally, Step 7 refers to the combination of hazard, vulnerability and exposure for the definition of a wildfire risk map.

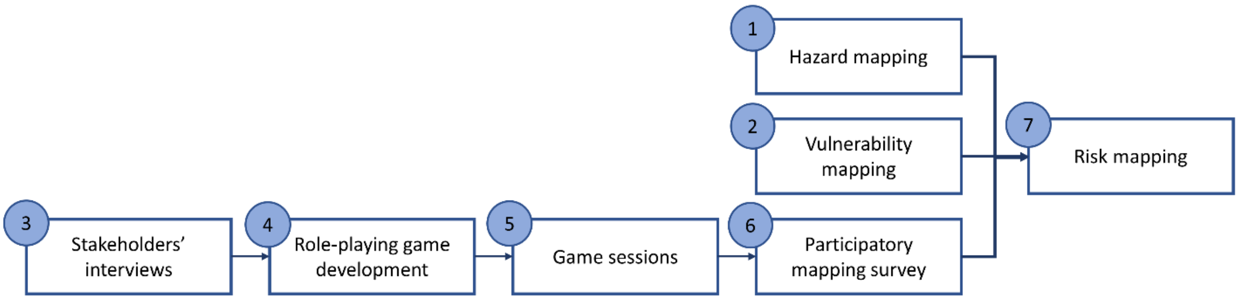

Fig. 3. Schematic representation of the methodological proposal.

3.1 Hazard mapping

The assessment of fire hazard is carried out with the support of FlamMap, a software for wildfire behaviour simulation [14]. FlamMap simulations require a certain amount of spatial information about the flammability and characteristics of the vegetation, the topography and the climate conditions.

For the Valchiusella case study, the information from the regional forest map, integrated with the high-resolution data on species distribution provided by the local forestry consortium, is used for the definition of the fuel models map for the area [15]. The regional digital terrain model, the regional digital surface model and the Copernicus tree canopy cover are used as supplementary input information for the landscape characterization. The medium conditions of humidity and wind are used for the simulation, based on the analysis of the data collected during the period 1990-2020 by the nearest meteorological station, located in Borgofranco d'Ivrea, which is about 3 km outside the study area. The uphill wind direction is selected, while the D2L1 moisture scenario is chosen [15]. This represents usual conditions for the area during fire season.

600 wildfires are simulated by the software, starting from 600 ignition points randomly located in a 200 m buffer around local roads. The burnt areas and fire intensities generated by the simulation for the 600 fires are combined for defining a burnt probability and a potential fireline intensity for each pixel (5 m x 5 m) of the map. The two data are then combined and standardized from 0 to 1 to obtain the estimated hazard for each pixel.

3.2 Vulnerability mapping

The methodology followed for the definition of the vulnerability mapping relies on the definition of vulnerability used by the regional plan for forecasting, prevention and fighting against forest fires (regional AIB plan) adopted by the Piemonte Region for the 2021-2025 period. The plan defines two kinds of vulnerability: a functional vulnerability and an ecological vulnerability. The functional vulnerability is linked to the main function fulfilled by the considered forest area, such as wood provision or hydrogeological regulation. It depends on the compatibility between a fire event and the ability of the forest to still provide the service. Ecological vulnerability is linked to the stability of the ecosystem, which is defined as a combination of resistance and resilience characteristics. The resistance is the ability of the vegetation to protect itself from fire and maintain its vitality, while the resilience is the ability of the ecosystem to re-establish the conditions preceding the fire event, for example through vegetative regrowth. The plan identifies four classes of ecosystem stability (null, low, medium, and high) and associates one class with each forest category and land use type. Finally, it combines these classes with three classes of erosion risk (low, medium, and high) based on local topography.

In this work, we assume the existence of a strong incompatibility between fire events and all kinds of cultural services. We assume a generally high level of functional vulnerability for all the areas identified as providers of cultural ecosystem services. In this way, we identify the vulnerability factor with the ecological vulnerability alone. Therefore, we map the ecological vulnerability of the valley by adopting the resistance classification and the erosion risk index defined by the Piedmont regional AIB plan[4], and by standardizing the values obtained from 0 to 1.

3.3 Stakeholders' interviews

The involvement of local stakeholders through semi-structured interviews is the first step of the participatory section of this work. 25 interviews are carried out in Valchiusella, focusing on the perception of local stakeholders in forest and fire management about the health of the forest ecosystem, the impact of wildfires, the role played by forest management and the importance of ecosystem services. The interviewees are chosen among five different categories of people who already had direct experience and thus familiarity with land management, forest management and wildfires issues:

- Mayors or municipal administrators in charge of land management tasks;
- Forest firefighter volunteers;
- Forest workers;
- Members of local environmental associations;
- Farmers.

The canvas of the interview is made of a total of 20 questions, structured in four sections:

1. Personal context in relation to the community life and forest management experience;
2. Perception of the health of Valchiusella forests, the link between forest health and human health and the role of wildfires;
3. Perception of the status and the actors of forest management in the valley and ideas for wildfire mitigation strategies;
4. Personal importance accorded to the different forest ecosystem services and the state of their valorisation and conservation.

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[4] See the Piemonte regional AIB plan for more details [16].

A thematic analysis of the answers is applied, to find the main issues and the recurrent topics, and to identify the main actors and natural resources involved in the socio-ecological processes leading to wildfire risk in the valley, such as rural abandonment.

3.4 Role-playing game development

Based on the analysis of the interviews' outcomes, a simplified representation of the local socio-ecological system dynamics involved in wildfire risk is defined. The elements of the system are the following:

1. Actors: the actors directly or indirectly involved in fire risk and forest management in Valchiusella;
2. Resources: tangible and intangible resources of the area linked to land management for fire prevention;
3. Dynamics: main dynamics affecting fire risk and forest management economic sustainability. They can be divided into ecological, economic, sociological and political dynamics;
4. Interactions: interactions between the actors and the resources.

These elements are transformed into the actual elements of a role-playing game, such as the players' roles and actions, the game board, the players' interactions and scenarios. The conceptual model is transformed into an agent-based numerical model, which is the core element at the base of the game. The ABM simulates ecological dynamics and fire events based on land management decisions taken by the players. NetLogo is used for the ABM implementation, as it is the most widely used free agent-based modelling language [17].

3.5 Game sessions

Three game sessions, involving between 7 and 10 players each, are organized in the valley[5]. All three sessions are organized with the support of the major of the municipality concerning both the location and the participants' identification and invitation. The invited participants are local stakeholders of forests, pastures and fire management, in line with the same criteria used for the choice of the interviewees (see "Stakeholders' interviews" subsection). Some of the stakeholders participate both in the interview step and in the game sessions.

The game session is divided in:

- an introductory part, during which the framework and aim of the research are explained, together with the rules of the game;

- the core part, during which the participants play the game. The participants are asked to switch their roles, therefore to "put themselves in the others' shoes", for helping the mutual understanding of each one point of view;

- a final debriefing part, during which the discussion about the links with the game dynamics and the real situations the participants face is stimulated.

[5] The first session has already taken place in Issiglio, a municipality in the lower section of the valley. One session in Rueglio (central section) and one in Valchiusa (higher section) have not yet taken place at the time of the submission of this work.

A facilitator is in charge of presenting the aims of the meeting, explaining the rules of the game, facilitating the involvement of all the participants and leading the discussion. One informatic assistant is in charge of managing the ABM model, such as translating the choices of the players in inputs for the model and showing the participants the results of the fire simulations in the system represented. One to three observers are in charge of observing and noting the behaviours of the players, their strategies, the references to the real situation they make and the evolution of the discussions.

3.6 Participatory mapping survey

The participatory mapping activity involves the participants of the game session to evaluate the exposure component of the fire risk assessment. The activity focuses on mapping the distribution of the cultural ecosystem services in the valley. The method adopted is part of the so-called Participation Geographic Information System (PGIS), which has been typically implied in rural areas of developing countries to build social capital, collecting information through non-digital mapping technologies among a selected sample of local stakeholders [18]. PGIS has been increasingly used to collect information about ecosystem services based on local knowledge and is particularly suitable for cultural ecosystem services, whose benefits are often less tangible and therefore much more difficult to locate and quantify [19,20].

The participatory mapping activity is carried out through personal interviews with the stakeholders already involved in the other steps of the research, therefore here considered experts. A hardcopy map of the valley is furnished in a large size to the interviewee. A satellite image from Google Earth is used as a base map and important features, such as rivers and main roads, are highlighted to make it easier for the respondent to orientate himself on the map. The respondent is asked to identify up to 5 places for each category, corresponding to:

- The areas with the higher touristic potential;
- The areas with the higher aesthetic value;
- The most representative areas of the valley, which are linked to its identity.

The respondent is asked to place a round piece of paper with a predefined size on each of the chosen areas. He is also asked to give a value to the place, ranging from 1 (slightly important) to 5 (very important). The value is associated with the corresponding circle.

The answers of all the respondents are combined in a Geographic Information System (GIS) environment by summing the values of the overlapping circles for each category for each pixel of the map. The values are then standardized from 0 to 1.

3.7 Risk mapping

The fire risk map is finally produced by combining the standardized hazard map, vulnerability map and exposure map through the multiplication of their values for each pixel in a GIS environment.

4 Discussion and conclusion

This work provides a methodological proposal for integrating the evaluation of cultural ecosystem services into the assessment of wildfire risk. The issue is approached by combining quantitative and qualitative analysis and by involving the local stakeholders in a participatory process. The methodology steps are structured around the IPCC definition of risk, which makes this approach replicable also for other kinds of risk.

As mentioned in the Introduction section, the methodology is being tested in Valchiusella, an Italian alpine valley. The process has not been concluded at the moment of the submission of this paper. However, the preliminary results and the analysis of the principles on which the methodology is based allow us to make some considerations about its strengths and limits.

First, the quantitative evaluation of hazard is based on internationally recognised techniques and instruments, specifically developed for the assessment of fire risk. This constitutes a solid base on which the following steps are developed. The quantitative evaluation of vulnerability is based on the official institutional framework adopted in the region of the case study. This makes the procedure comparable with the regional analysis and makes it possible to integrate the results into local policies for fire risk prevention.

The long participatory process, involving interviews, game sessions and participatory mapping activities, makes the results specifically tailored to the local territory. Socio-economic dynamics, land management issues and local stakeholders' expectations are discussed and taken into account. Therefore, the outcome of this methodology is not limited to the wildfire risk map, but involves also the insights and suggestions that emerged during the public discussion. These are very helpful for guiding the development process of prevention policies and integrated fire management strategies, as well as to make them accepted by the local community and thus effective. Moreover, as observed during the game session already performed for the case study of this work, the often-contrasting opinions of the different stakeholders can be discussed by the participants during the game sessions, enhancing mutual understanding and social learning. These are fundamental for the development of community shared strategies.

However, the methodology here proposed is quite complex, since it involves very different expertise: FlamMap and general GIS skills, interviews design and conduction competencies, ABM coding abilities, game design, participatory mapping experience and focus groups facilitation competencies. This factor, in addition to the high amount of time needed to apply all the proposed steps, reduces the replicability of the entire methodology for analysis at larger scales than the case study here proposed. However, we suggest the possibility to adapt it to different contexts and constraints by applying only some steps. These should be chosen based on local needs, stakeholders' expectations and researchers' previous knowledge of the context. The interview step, for example, could be superfluous in the case of a deep awareness of local SES dynamics on the part of researchers, and the hazard and vulnerability assessments could be substituted by already existing analysis for the area.

In conclusion, the Valchiusella case study constitutes a pilot project for testing the methodology here proposed. Once the procedure will be completed, it will be possible to assess in more detail two aspects: on the first side, its ability to integrate qualitative and quantitative results for producing valuable information and guidelines for the development of land management policies in the framework of wildfire risk mitigation strategies; on the other side, its capacity to successfully involve local stakeholders, thus integrating local community needs in the guidelines produced and enhancing the development of a local collective critical and proactive thinking about these issues.

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