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Developing an Integrated Capitals Approach to Understanding Wildfire Vulnerability: Preliminary Considerations from a Literature Review

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Abstract

A capitals approach deals with humans' activities and impacts on the environment and their dependencies on stocks of natural, human, social and produced capital to inform decision-making. Traditional assessments focus on one capital at a time such as natural or human capital. Conversely, a multi-capital assessment involves the analysis of more than one relevant capital and presents the results for each capital together. This paper wants to get a step further presenting preliminary findings on developing an Integrated Capitals Approach (ICA) to wildfire vulnerability considering in a holistic way the impacts on natural assets (ecological and economic values), damages on human capital (e.g., health), and the interactions between wildfires and social capital. Although some studies have recently introduced the effect of adaptation to fire, expressed mainly as the institutional capacity of improving fuel management and firefighting, the effect of social bonding and networking on training, capacity building and other actions such as volunteering activities performed at scale of community, as a means of reducing social vulnerability, is not yet thoroughly investigated. We think that it is necessary to extend the current wildfire risk frameworks proposed in the literature by adding social capital in its plurality of forms and by integrating them with the current analysis of natural, human, and economic assets as a tool to mitigate wildfire vulnerability.

1. Introduction

Although an essential disturbance for many ecosystems, wildfires affect 600 to 700 thousand ha of forest per year in Southern Europe, reaching peaks of 1,000,000 ha, and up to 100,000 ha in northern European countries (EC, 2021). These fires cause enormous impacts on socio-economic activities and population wellbeing, and their increase, magnified by climate and land use change (e.g., land abandonment), impairs the efficacy of measures implemented to contain temperature rise and adaptation to climate change. Managing the damages inflicted by wildfires requires an integrated and holistic approach, based on land-management actions such as thinning, prescribed fire and grazing (Kerns et al., 2020), investment in green infrastructures and adoption of adaptive and proactive wildfires risk prevention and management plans (Robinne et al., 2021) that account for interactions between natural and human systems (Kinoshita et al., 2016). To be effective these measures need to assess not only the likelihood that a fire ignites and propagates, but also the human, ecological and economic values potentially affected by it (in other terms, vulnerabilities) (Chuvienco et al., 2010; 2014) as well as the ability to cope with the damage through the implementation of institutional and voluntary initiatives capable of

mitigating environmental and socio-economic impacts. This paper presents a holistic view, developed under the ongoing project H2020 FirEURisk (Grant agreement 101003890), for the analysis and valuation of vulnerability to wildfires by implementing an Integrated Capitals Approach (ICA) that embraces multiple capitals (natural, human, social, economic, and manufactured) in a common framework (Capital Coalition, 2021).

To achieve this goal, we have carried out a literature review dealing with wildfires and potential assets at risk, from forests and their ecosystem services (e.g., regulating and cultural ones), to semi-natural environments like agricultural ecosystems and wildland-urban interface, but addressing more immaterial values like human life and health, and resilience for both ecosystems and socio-ecological systems. Although institutional mechanisms to cope with wildfires are considered in the recent literature (Oliveira et al., 2018; 2020), only a few papers address human and social capitals and their relations with fire risk reduction, such as the role of information on fire and awareness of correct practices, local training, capacity building, or any volunteer measures (e.g. formalised civic, non-professional initiatives, etc.) able to limit fire vulnerability (Górriz-Mifsud et al., 2019). Analysis of the latter activities remain marginal compared to the relevant literature addressing environmental, socio-economic and health damages. We emphasise this gap and illustrate the need to integrate all the capitals in the wildfire risk analysis framework, to comprehensively assess both exposure and sensitivity and adaptive capacity of local social systems.

2. Methods

We started from a core of 30 papers on risk vulnerability and socio-economic damage proposed by the research team and then we extended our investigation through multiple searches on the online database ISI Web of Science. Search strings used are reported in Table 1. To better characterise our integrated approach to the analysis of wildfire vulnerability, we have searched for economic damage of wildfires to natural capital and socio-economic assets and explored also 1) the impact that fires have on human capital – such as risk to health and lives; 2) the contribution that social and human capitals can bring to mitigate wildfires such as training, participation in volunteer initiatives, such as clearing scrub, and information campaigns to reduce ignition and make humans less vulnerable to fire; and 3) how these themes are considered in wildfire vulnerability and risk framework. Findings from these three points let emerge gaps that need to be addressed in order to build a more comprehensive framework for wildfire risk analysis.

Table 1: List of search strings and results returned from ISI Web of Science considering as cut-off date of publications February 2022.

Search string	Papers found
“Forest fire” AND “economic impact assessment”	53
“Economic” AND “damage” AND “wildfire”	235
“Valuation” AND “damage” AND “wildfire”	27
“Valuation” AND “damage” AND “wildfire” AND Ecosystem services”	1
“Forest fire” AND “Willingness to pay” OR “WTP”, “forest fire” AND “choice experiment”, “forest fire” AND “hedonic price method” OR “HPM”, and “forest fire” AND “travel cost”, and “forest fire” AND “replacement cost”,	40
“Forest fire” AND “built capital” OR “manufactured capital”, “forest fire” AND “capacity building”, forest fire” AND “financial capital”, “forest fire” AND “human capital”, forest fire” AND “social capital”,	55

The full dataset of 411 documents was filtered based on the analysis of title, abstract, introduction and methods. We included papers published in English and a limited number (3) in Spanish and Portuguese. Inclusion criteria were the impacts of single and multiple fires on natural capital and human assets (in monetary and non-monetary units), as well as the analysis of vulnerability in wildfire risk framework. We also included papers clearly expressing the benefits of managing fires and dealing with resilience and adaptation to mitigate vulnerabilities. We excluded a few papers proposed in some conference proceedings of difficult availability, particularly those published in Russian, Chinese and Korean.

3. Results

Papers reflecting the inclusion criteria were 187. Notwithstanding the dominance (as expected from the key strings used) of papers addressing socio-economics issues, we found a broader range of themes referring also to Natural Capital and Risk analysis. We decided to cluster these papers in three groups: “Non-economic impacts on Natural Capital” (44 studies), “Natural Capital and ecosystem services valuation and socio-economic impacts” (95 studies), and “Risk Analysis and Vulnerability” (48 papers).

Within the first group of studies focusing on impacts of fire on natural assets, ecological values and ecosystem services, a preeminent role was played by papers addressing damages and disturbances to forest ecosystem dynamics (Wu & Kim, 2013; Aleksić et al., 2009), direct changes to dominant vegetation and biodiversity (Adams, 2013) and indirect shifts caused by grass invasion (Morais et al., 2021; Kerns et al., 2020), higher impacts of pest and diseases on plant survival, variations in traits expression (Lerch et al. 2016; Bélanger et al., 2013; Salazar et al., 2020), and reduction in forest resilience (Wu & Kin, 2013, Mouillot et al., 2005). Less investigated are impacts on water and soils. Wildfire incidents can affect water quality through increased sedimentation and erosion, causing reduction in the supply of potable water (Montagné-Huck & Brunette, 2018), alterations on the hydrology of watersheds through runoff of debris produced in response to storms (Parise & Cannon, 2017), and intensity of rockfalls in the burned area (Sarro et al., 2021). They also alter soil structural properties through mineralogical and biological impacts and their fertility through nutrient volatilization (Certini, 2005).

As regards the second group (see Figure 1), many studies focused on assessing the socio-economic impacts of wildfires on agriculture and agroforestry system by using market approaches (Molina et al., 2011; Stougiannidou et al., 2020; Fagarazzi et al., 2021), but also addressed multiple forest ecosystem services, including timber, carbon and biodiversity (Aleksić et al., 2009; Mueller et al., 2019; Varela et al., 2016), landscape amenities and recreational values (Molina et al., 2019a; Molina et al., 2018) by implementing a mix of stated (contingent valuation and choice experiments) and revealed preference methods (travel cost).

Relevant is the number of papers dedicated to health damage such as respiratory morbidity and cardiovascular diseases caused by haze (Liu et al., 2015), smoke pollutant and contamination rates (Evangelidou et al., 2015), or other physical consequences such as reduced height in adult age (Rosales-Rueda & Triyana, 2018; Sing & Dey, 2021). However, economic estimates remain sparse, focussing on cost of medical treatment and hospital admittance (Stanke et al., 2013), willingness to pay for avoiding respiratory disease (Jones, 2018; Leslie et al., 2013) and mitigating smoke exposure (Heider et al., 2019). We have also found a relevant number of studies addressing the valuation of wildfire prevention policies (categorised as “valuing decision making”) (Shrestha et al., 2021; Gorriz-Mifsud et al., 2016; Allo & Loureiro, 2020), and sparse examples of macro-economic analysis of wildfires on employment (Nielsen-Pincus et al., 2014) and on the entire economy of a country (California) (Wang et al. 2021), labelled in Figure 1 as “other socio-economic impacts”.

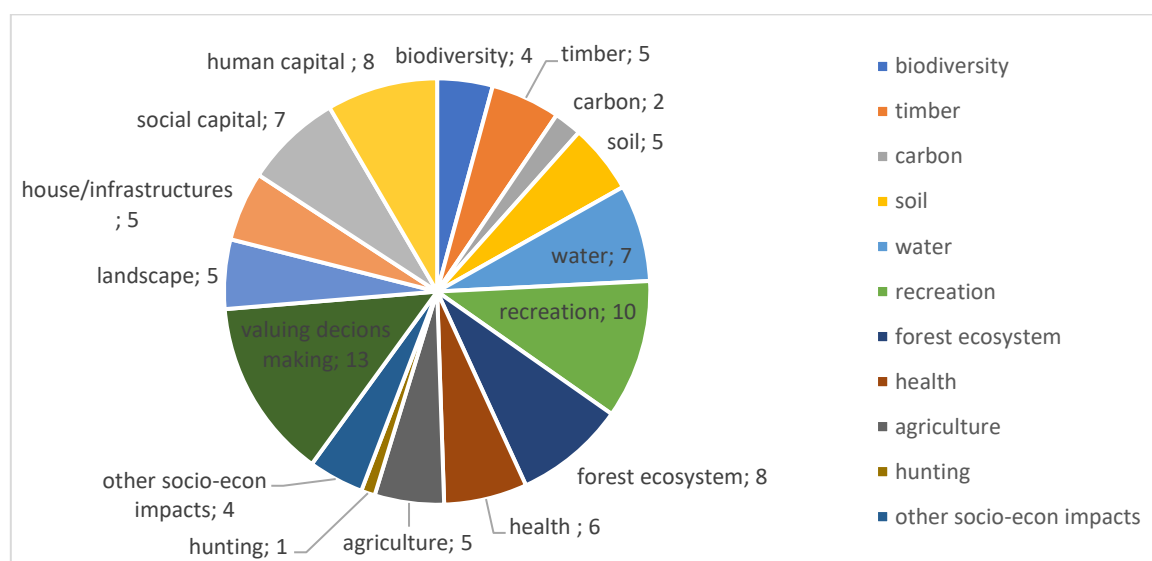


Fig. 1: Types and number of studies addressing impacts to specific ecosystem services, economic sectors and damages caused to social wellbeing and environmental values

We have dedicated attention to the interactions between wildfires and social relations. What is emerging is a limited number of studies that provide evidence of fire as a leverage to increase sound management actions to reduce wildfire risk by promoting community engagement, training and discussions. Examples from the Global South (in countries like Nepal, India, Seychelles and Indonesia – Hiratsuka et al., 2019; Chauhan et al., 2021; Etongo et al., 2021) and Western countries are found to build a stronger nexus between policy makers and scientists (Narayanan et al., 2009; Tabara et al., 2003; Huber-Stearns et al., 2021) by the integration of spatial data and models of wildfire behaviour in decision making. Relevant is the contribution that the impact of wildfires has on strengthening communities with local institutions such as municipalities and fire fighters as evidenced in Australia (Mc Dougall et al., 2014) and in developing countries like Nepal and Indonesia, where collective actions enforced rules for risk mitigation (Sapkota et al., 2015; Jalil et al., 2021). In Mediterranean countries voluntary initiatives at local levels and a series of structural and relational bonding between communities and institutions are found to statistically explain the community's operational capacity and perception of arson level (Górriz-Mifsud et al., 2019).

Finally, our search returned a consistent number of studies (48) referring to the group “Risk Analysis and Vulnerability”, addressing:

1. The qualitative analysis of risk by getting information through direct interview on burnt areas, damages, local prevention and suppression techniques (Ribeiro et al., 2015; Appiah et al., 2010; Narayanan et al., 2009);
2. The quantitative analysis of:
 - fire risk by integrating spatial dataset of burnt areas and socioeconomic vulnerabilities of communities such as gender, sex, income, living conditions differences (Grala et al., 2017; Álvarez-Díaz et al., 2015; Barreal et al., 2012; Mallini et al., 2019; Andersen & Sugg, 2019);
 - fire hazard carried out through fire simulation controlling for human, biophysical, meteorological and socioeconomic variables (Guillaume et al., 2019; Molina et al., 2019b; 172- Castillo et al., 2016; Molina et al., 2019c; Castillo-Soto & Rodriguez y Silva, 2015; Rodriguez y Silva & Gonzalez-Caban, 2010; Rodriguez y Silva, 2013);
 - vulnerability as a damage function of socio-economic values (Chuvienco et al. 2010; 2014; Parente et al., 2016), resilience of vegetational types to fire intensity (Molina et al., 2018; Rodriguez y Silva, 2013; Rodriguez y Silva & Gonzalez-Caban, 2010; Chuvienco et al., 2014) and human adaptation (Oliveira et al., 2018; Oliveira et al., 2020).

Institutional aspects of coping capacity such as strengthening firefighters' activities are well reported and included in vulnerability frameworks (Oliveira et al., 2018) as well as the role of evacuation time and distance of wildfire from fire station (Oliveira et al., 2020; Oliveira et al., 2021). However, we think that many more elements making part of social capital can contribute to it and be included in the same framework. The latter can be measured, amongst others, by:

1. voluntary actions supporting fire suppression;
2. educational activities raising awareness of incorrect human behaviours (to reduce ignition causes and minimise extent of fire);
3. implementation of surveillance, patrolling and monitoring measures to reduce fire hazard (by early detection of ignition points);
4. formulation of wildfire prevention and defence plan to better manage fuel through silvicultural treatments, adoption of fire breaks and water pools.

Although recent studies are addressing some of these measures (Górriz-Mifsud et al., 2019; McDougall et al., 2014; Jalil et al., 2021), there is not yet consideration in risk analysis of the importance that training, capacity building and social bonding between citizens and institutions may have to reduce vulnerability. Ways to achieve this integration are under investigation in the FirEURisk project at the time this paper is proposed. Below we propose an example of integrated framework between capitals, building on the investigated literature (Figure 2).

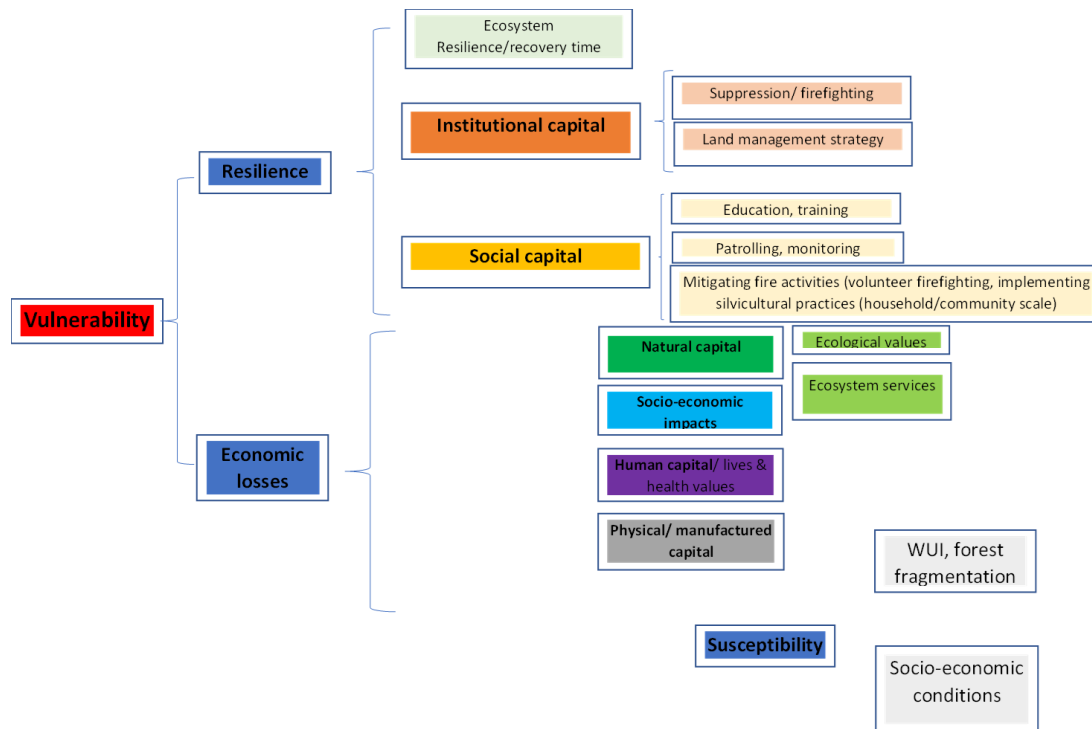


Fig. 2: A preliminary vulnerability framework to wildfires accounting for four types of capital: natural, manufactured, human and social

In the above framework we consider economic losses (as assessed in monetary units) of three different capitals (natural, human, and manufactured) corrected for the resilience of the natural and socio-ecological system. Ecosystems are in fact characterised by resistance and resilience, while societies can change their vulnerability to wildfires through the institutionalization of mechanisms such as strengthening fire suppression and addressing wise land use management strategies. Finally, educating and empowering communities may limit wildfires formation and propagation through actioning preventive measures at household scale, as well as the reduction of landscape fragmentation and other major social challenges (low income, low level of education, etc.) that are all considered relevant to explain wildfire risk.

4. Conclusion

Our preliminary analysis for the development of an integrated capital approach to wildfire vulnerability shows that studies addressing impacts on natural capital, ecosystem services and socio-economic assets are the most represented. We found also human capitals to be well proposed in terms of impacts to human health. However, gaps are evidenced by the limited analysis of social aspects such as role of communities in reducing wildfire risk, as expression of social enfranchisement emerging from the strengthening of relations in communities affected by wildfire. Other frameworks on wildfires vulnerability have introduced the impacts on ecological and economic values (Chuviero et al., 2010), stressing the importance of ecosystem resistance to fire (Parente and Pereira, 2016) and resilience to recover to post-fire conditions (Chiuvienco et al., 2014). More recently, aspects dealing with the capacity of society and communities to cope with wildfires by institutional mechanisms of fire suppression and mitigation by changes in land use management have been proposed (Oliveira et al., 2018; Oliveira et al., 2020). To bridge the gap on the holistic understanding of vulnerability, research and practice should also consider exposure to hazards/stressors, susceptibility of the system/community exposed, and its resilience and adaptive capacity (Birkmann et al., 2013; Burton, Rufat & Tate, 2018). A final consideration can be made on the importance of risk perception and how it influences fire vulnerability: perception acts indeed as a filter through which the different kinds of capital which are at risk assume specific values and/or play different roles in wildfire risk assessment, prevention and management (Paveglio et al., 2009). We consider necessary to investigate in the ongoing steps of the FirEUrisk project the integration of all these aspects in a structured index of vulnerability following the framework suggested in Figure 2.

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