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Mapping ecological vulnerability to fire for effective conservation management of natural protected areas

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ABSTRACT

The challenge for conservation managers is to ensure the long-term sustainability of an area by preserving its ecological and cultural values against predictable and unpredictable natural and human pressures and, at the same time, ensuring the fruition of the environmental resources. This research proposes an integrated use of GIS–based Decision Support System (DSS) with a conceptual linear model of vulnerability to foster conservation strategies in protected areas, by identifying: (1) the most vulnerable areas, requiring specific protection measures to enhance the natural features, as well as the prevention of natural and human risks; (2) the most effective management interventions to reduce system vulnerability to fire. The development of such a tool has been tested on the natural protected area of Torre Guaceto, through the selection of suitable indicators that enable discrimination among different levels of sensitivity and pressures, in order to provide evidence of its potential utility for the management of protected areas and the mitigation of their vulnerabilities. The results highlight that the most vulnerable areas are represented by contiguous patches of wetlands, the load of fuel at wetlands-agricultural lands interface areas, and the small patches of century-old forests, Mediterranean maquis and coastal dunes. On the basis of the results it is desirable that future researches on vulnerability should not only consider the “of what to what”, but also consider “for who, where and when” with a focus on the spatial and temporal scale dimensions of vulnerability.

1. Introduction

In recent years, the concept of vulnerability has been studied and applied at different spatial scales and in a wide range of disciplines, such as in economic and social welfare studies (e.g., Abson et al., 2012; Bocquier et al., 2010; Julca and Paddison, 2010; Khandlhela and May, 2006; Rodríguez y Silva et al., 2012; Tanaka et al., 2005), ecological/environmental researches (e.g., De Lange et al., 2010; Metzger et al., 2006; Tran et al., 2010), natural hazards' effects (e.g., Coletti et al., 2013; Cutter et al., 2003; Huang et al., 2013; Wang and Yarnal, 2012), climate change (e.g., Moreno and Becken, 2009; O'Brien et al., 2004; Preston et al., 2009; White et al., 2014), agriculture and food security (e.g., Berry et al., 2006; Guiqin et al., 2011; Luers et al., 2003; Pearson et al., 2011), sustainability science (e.g., Bo and Lianjun, 2008; Lee, 2014; Turner et al., 2003), and global environmental changes (e.g., Adger and Mick, 2001; Füssel, 2007; McClanahan and Cinner, 2011; Parry and IPCC, 2007).

Despite its multidisciplinary applications, vulnerability, in its most basic sense, is defined as the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor (White, 1974). The relevant system may be an individual or population, a business enterprise or an entire regional economy, a single species or an entire ecosystem (Preston et al., 2011).

According to Adger (2006) there are at least three ways how vulnerability can be conceptualized. In the first view, the focus of vulnerability analysis is on the “end-point” impacts and the effectiveness of adaptation measures (Ensor and Berger, 2009; Kelly and Adger, 2000). The second approach to vulnerability emphasizes the “starting point” through the analysis of communities' or regions' characteristics that make them susceptible to change. For example, the IPCC defines vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse

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effects of climate change" (McCarthy and IPCC, 2001). Finally, the third way of interpreting vulnerability is more comprehensive and integrated, by conceptualizing vulnerability as a function of interactions among three elements: exposure, sensitivity, and adaptive capacity (Adger, 2003; Bennett et al., 2014; Marshall et al., 2010; Tuler et al., 2008; Turner et al., 2003). In this view, exposure refers to the presence and extent to which a region, resource, or group experiences stressors, in terms of various changes occurring at different scales that cause stress (Marshall et al., 2010). Sensitivity is the degree to which a system is affected or harmed by exposure to a stressor (Marshall et al., 2010; Tuler et al., 2008). Turner et al. (2003) suggest sensitivity is related to local social and environmental conditions. The combination of exposure and sensitivity define the potential impact of a stressor. The third component is represented by adaptive capacity, which determines the ultimate impact of a stressor or the overall level of vulnerability, and it can be defined as "the ability to respond to challenges through learning, managing risk and impacts, developing new knowledge and devising effective approaches" (Marshall et al., 2010). In other words, comprehensive vulnerability assessments require the examinations of "how?", "why?", and "to what?" the system is vulnerable.

Closely related to the concepts of vulnerability and adaptive capacity is the concept of resilience (Burkhard et al., 2011), defined as the ability of a system to recover, reorganize and develop following external stresses and disturbances (Adger, 2000; Walker et al., 2004). Only resilience relates to the capacity to tolerate and to deal with disturbances, whereas adaptability (or adaptive capacity; Smit and Wandel, 2006) allows for continuous development.

Although rooted in different disciplines, numerous scholars recognize the potential linkages between vulnerability and resilience frameworks (Engle, 2011). Both vulnerability and resilience can be viewed as being specific of a system and to a perturbation (vulnerability and resilience "of what to what"), highlighting that a system can be vulnerable to certain disturbances, but not to others (Béné et al., 2012; Carpenter et al., 2001; Downing et al., 2005; Miller et al., 2010). Other conceptual similarities and differences between these two concepts can be found across the academic literature (Anderies et al., 2004; Cinner et al., 2013; Gallopín, 2006; Miller et al., 2010). In particular, adaptive capacity has been identified as a common thread linking vulnerability and resilience literature (Engle, 2011). Adaptive capacity is generally accepted as a desirable property or positive attribute of a system for reducing vulnerability (Engle, 2011) and increasing resilience (Anderies et al., 2004), and as a prerequisite for adaptation to take place. In the language of vulnerability, adaptive capacity can offset sensitivity to a perturbation (Cinner et al., 2013) and in resilience terms it can enhance the robustness of a system (Anderies et al., 2004). Finally, the concept of ecosystem services, because effectively managing relationships among ecosystem services, which represent a component of system sensitivity, can reduce the overall system vulnerability and can strengthen its ecosystem resilience, enhance the provision of multiple services, and help avoid catastrophic shifts in ecosystem service provision (Bennett et al., 2009).

To provide information on where the adaptation actions may be necessary and beneficial, the assessment of vulnerability involves the analysis of the factors that determine the potential for harm from exogenous threats as well as the endogenous adaptive capacity of systems (Preston et al., 2011). Vulnerability is a highly complex phenomenon with both biophysical (e.g. climatic conditions, natural hazards, topography, land cover) and socio-economic (e.g. demography, poverty, trade, employment, gender, governance) factors that influence the potential for harm (Adger, 2006; Preston and Stafford-Smith, 2009).

Vulnerability is both context-specific, because what makes one region or community vulnerable may be different from another region or community (Brooks et al., 2005), and dynamic, since it may change as a result of changes in the biophysical as well as the socio-economic characteristics of a particular region (Adger and Kelly, 1999). Hence, vulnerability assessments should be ongoing processes in order to highlight the spatial and temporal scales of vulnerability of a region (Luers, 2005).

Multiple vulnerability assessment frameworks are based on different conceptual models of how these factors interact to influence vulnerability. The risk-hazard (RH) model, often applied in environmental and climate impact assessment, aims to understand the impact of a hazard as a function of exposure to the hazard event and the dose–response (sensitivity) of the entity exposed (Burton et al., 1978), but ignores the system's capacity to influence sensitivity as well as the role of social structures and institutions in shaping differential exposure and consequences (Blaikie et al., 1994; Kasperson et al., 1988). On the other side, the social vulnerability (SV) model focuses specifically on characterizing the geography of socio-political factors of vulnerability that influence how human and natural systems cope with or respond to stress (Preston et al., 2011). More holistic approaches to vulnerability assessment require a more systemic understanding of human-environment interaction (Preston et al., 2011). In particular, the pressure-and-release (PAR) model, common to social science–related vulnerability research, defines risk as a function of the perturbation, stressor, or stress and the vulnerability of the exposed unit (Blaikie et al., 1994; Wisner et al., 2004). However, PAR model emphasizes the social conditions and the root causes of exposure more than the hazard as generating unsafe conditions. To overpass these limitations Turner et al. (2003) suggest the expanded vulnerability (EV) model that "directs the attention to coupled human-environment systems, the vulnerability and sustainability of which are predicated on synergy between the human and biophysical subsystems as they are affected by processes operating at different spatiotemporal scales".

A potential visual tool for communicating the results of vulnerability assessment to other researchers, policy-makers, and the community at large is the spatial vulnerability assessment providing maps of the vulnerability distribution and making extensive use of geographic information system (GIS) and remotely sensed environmental data (Eakin and Luers, 2006). Preston et al. (2011) in their review on climate change vulnerability mapping, found out that the objectives of the vulnerability assessment are most related to the risk identification, the understanding of the factors of vulnerability, the development of methods for analyzing vulnerability and, lastly, to support decision-making process. In particular, Preston et al. (2009) have emphasized the use of vulnerability mapping to help the stakeholders' engagement and the understanding of the various factors that will influence vulnerability for four reasons: (1) it provides a spatially explicit rendering of the potential for harm across a landscape that helps place information in its appropriate spatial context (Sheppard, 2005); (2) the spatially-explicit vulnerability assessment at the local level enables the potential for harm and the factors of vulnerability to be considered in their local context and the recognition of locally-relevant consequences; (3) it can combine both biophysical and socio-economic factors of vulnerability enabling the engagement of different stakeholders; and (4) the identification of vulnerability hotspots can guide the adaptation strategies.

In the context of spatial vulnerability assessment, this paper focuses on the valuation of the biophysical/ecological factors that may influence the potential of fire to determine the vulnerability in a natural protected area. In particular a GIS-based decision support system (DSS) is proposed to be integrated with a conceptual model