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The Economic Evaluation of Forest Protection Service Against Rockfall: A Review of Experiences and Approaches

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ABSTRACT

Aside from the provision of food and resources, the ecosystem functions supply humanity a wide array of services. Hazard reduction is one of these, and its value for communities is gaining rising attention. In the Alpine Space, rockfall and avalanches occur frequently and cause considerable damage, but are significantly mitigated by mountain ecosystems, mainly mountain forests. How to account this service in monetary terms is a current issue and several studies were undertaken with this purpose. This literature review provides a comprehensive overview depicting a “state of the art” of economic evaluation of this ecosystem service, noting their main features, approaches and results. Currently, a common background still does not exist and different studies developed a variety of methods to be adopted, both cost and preference based. We intend this review as a contribution to the increasing awareness of forests as a cost-efficient part of natural hazard management strategies in the Alpine Space.

1. Introduction

The relationships between society and the environment are manifold but the main aspect is probably the fruition of goods and services. Other than food production and raw material supply, other so-called ecosystem functions are increasingly relevant for human well-being (Pearce and Turner, 1990), providing less tangible but still essential benefits to people (Edens and Hein, 2013; Grilli et al., 2015; Miura et al., 2015). These functions are, among others, provision of drinking water, recreational and cultural values, carbon storage and protection against natural hazards, like rockfall. Those gravitational processes are common phenomena in mountain environments and frequently pose a threat for transportation corridors, settlements, and human lives. Consequently, protection from such threats can be viewed as positive externalities (Brun, 2002), as from a market perspective it is still not possible to convert their value into monetary terms (MEA, 2005; Riera et al., 2012; Grêt-Regamey and Kytzia, 2007). Thus, “ecosystem services” (hereafter ES) is the broad term adopted to include their effects, moving from financial to economic evaluations (Nuti, 2001; Gomez-Baggethun et al., 2010). Since the Sixties, an increasing number of studies were performed to detect and assess ES in economic terms (Coase, 1960; Krutilla, 1967), in order to support a sustainable environmental management through these evaluations (Daily et al., 2009; Giupponi et al., 2009; Spangenberg and Settele, 2010). Consequently, many different systemic classifications of this complex and evolving set of services were proposed (de Groot et al., 2002; Wallace, 2007; Bartczak et al., 2008; Fisher et al., 2009; Haines-Young and Potschin, 2011), leading to their inclusion in several international projects and regulations (MEA, 2005; TEEB, 2010; Maes et al., 2014).

Forests are a suitable example of a complex and dynamic ecosystem able to simultaneously supply market goods and ecosystem services, ranging from wood and non-wood products to regulation, recreational and cultural functions (Stenger et al., 2009; Ninan and Inoue, 2013; Brun, 2002). Their proper evaluation is still a debated issue, due to the changes in economy and society that have rendered the previous forms of accounting, founded on market goods only, obsolete (Goio et al., 2008). In fact, in recent years, the assessment of non-marketable goods has increasingly gained attention, in order to properly inform decision makers and forest owners and highlight their importance (Blattert et al., 2017; Riera et al., 2012). Moreover, depending on the aim of the evaluation, it would be possible to sum up into one single value all the material and immaterial benefits generated by forests, computing the so-called Total Economic Value (Markantonis and Meyer, 2011; Deal et al., 2012), or, alternatively, focus on one single service. According to these distinctions, this review involves studies that focus on the evaluation of a single, non-marketable value, that is, the forest protection service against rockfall. This service, among other regulation functions, plays an essential role in mountainous areas, where its recognition is

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increasing in parallel with the growing anthropization of these areas (Miura et al., 2015; Häyhä et al., 2015; Zoderer et al., 2016). In the last 15 years, several researches have contributed to amplify the knowledge of the interactions between forests and falling rocks. In particular, specific models were developed and tested using field experiments, to model rock trajectories along slopes (Stokes, 2006; Cordonnier et al., 2008; Jancke et al., 2013; Radtke et al., 2014; Fidej et al., 2015; Dupire et al., 2016b). Such quantitative models, grouping different skills and research fields (Wolff et al., 2015), allow the protective capacities of the forest and the frequency of the events to be assessed (Dussauge-Peisser et al., 2002; Trappmann et al., 2014), making it possible to apply methods to estimate the socio-economic value of the protection service performed by forests.

In line with the aims of the European Commission, of promoting the cooperation between European countries (EC, 2013), there is a clear need to gather the existing knowledge and to develop harmonized management strategies, at European level, for the economic evaluation of the protection service of forests against rockfall. Therefore, the aim of this bibliographic review is to achieve a state of the art on forest protection services economic assessment, devoting special focus to rockfall protection, and provide a critical analysis of the different methodologies adopted, the data needed and the results achieved. After the Results and Discussion and Conclusions paragraphs, the Annex provides the full list of papers included in the review.

2. Literature Review

2.1. Regulation Ecosystem Services in Alpine Forests

The Alps are one of the most densely populated mountainous areas in the world: historically inhabited, they host important urban centres and a complex infrastructural network (Rudolf-Miklau et al., 2014). In this context, forests, covering 52% of their surface, play an important role for the local economies (Price et al., 2011). Here, considering the socio-economic changes of the last 50 years and the anthropization of this territory (Holub and Hübl, 2008; Zimmermann and Keiler, 2015), the regulation and protection services ensured by forests (La Notte and Paletto, 2008; Getzner et al., 2017) are gaining increased consideration (Grêt-Regamey et al., 2008; Miura et al., 2015; Grilli et al., 2017). Researches concerning ES are a relatively recent field of study, but already rely on a vast volume of literature, mainly produced over the last 20 years, not without diverging opinions and criticisms (Boyd and Banzhaf, 2007; Baveye et al., 2013; Seppelt et al., 2011). However, in these studies, there is a general consensus on the importance of the need for a precise definition of the ES studied, at a proper territorial scale (Wallace, 2007; Busch et al., 2012; Lindborg et al., 2017), in order to avoid overlapping and, consequently, value miscalculation (Bateman et al., 2011; Deal et al., 2012; Spangenberg and Settele, 2010).

According to the classifications aforementioned, regulation and protection ES, are here intended as physical or chemical-physical interactions between biomass and mineral fraction (de Groot et al., 2002), which in a forest are numerous and intense (Motta and Haudemand, 2000; Ninan and Inoue, 2013; FAO, 2015). While these functions of the forest are always present, the protection service only occurs when all the risk components can be observed (Fuchs et al., 2007; Olschewski et al., 2012), that is, when an event generates an abrupt release of energy in presence of an object prone to be damaged, standing the need of the society to protect it (Adger, 2006). In fact, the risk mitigation supplied by protection forests cannot be taken in account for events occurring in absence of interactions with humans or human-related goods (Brun, 2002; Grêt-Regamey et al., 2012).

2.2. Gravitational Natural Hazards: Rockfall

Forests can play a relevant role for the protection of human goods and infrastructures against gravitational natural hazards. Among these destructive events, we define rockfall as the movement of rocky fragments of metric and sub-metric dimensions with movement patterns unlike fluid masses, as occurring in landslides (Volkwein et al., 2011). Rock detachments usually involve small areas but have the capacity to cause significant damage especially in mountainous areas, where steep slopes and strong seasonal climatic variations favour their occurrence. These events are strictly linked to local site conditions and, even if more frequent during thawing periods (Matsuoka and Sakai, 1999), are practically still not predictable nor avoidable, both due to the multiplicity of elements that can trigger them (Dorren, 2003) and the speed at which they occur (Holub and Hübl, 2008). The main parameters used to characterize these events are intensity, frequency, height of rebound and runout distance (Volkwein et al., 2011; Berger et al., 2002). Intensity consists in the kinetic energy of the falling body, while frequency depends on the probability of departure; finally, the last parameters may vary depending on the features of the block (dimension, shape and volume mainly) and of the terrain (slope, soil type and forest features) (Jaboyedoff et al., 2005). Evaluating the frequency of the events is one of the most difficult aspects, but some studies (Dussauge et al., 2003; Hantz et al., 2016) illustrated the power law distribution that links boulder size and falling frequency, demonstrating the reliability of the extrapolations based on this law (Moos et al., 2017b). Moreover, new promising methods, using dendrochronology techniques to analyse the scars left on the tree trunks, have been developed recently (Trappmann et al., 2014; Moos et al., 2017c; Corona et al., 2017). Protection forests against rockfall generally can be considered effective in relation to other gravitational hazards too, as debris flow, avalanches or landslides (Getzner et al., 2017) but, in relation of the relevant differences in effectiveness that a forest stand can have in relation to different hazards, this multifunctional role has not been investigated in the present study.

2.3. Effects of Forests on Rockfall Events

The role of forests for the mitigation of rockfall events has been widely recognised (Berger et al., 2013; Dorren, 2003): in fact, boulder impacts on trees dissipate kinetic energy, reducing the probability of damage to buildings, infrastructures and people (Berger and Rey, 2004; Saroglou et al., 2015; Brauner et al., 2005). Nonetheless, given the scarcity of available evaluation methods, for a long time this service has been assessed only through empirical or qualitative methods (Volkwein et al., 2011). Only in the last 15 years, a number of quantitative models, able to quantify the protective effect ensured by forests, have become available (Berger and Dorren, 2007; Dorren et al., 2004; Berger et al., 2002), in addition to integrating LiDAR techniques more recently (Monnet et al., 2017; Dupire et al., 2016a). These studies highlighted the importance of stand density, basal area, specific composition and, above all, the structure of the forest, to determine its effectiveness against rockfall events (Fuhr et al., 2015; Wehrli et al., 2006; Jancke et al., 2013). In this respect, a considerable wealth of scientific knowledge has grown and various silvicultural practices and forest management measures were developed in order to favour the ability of forests to mitigate these hazards and to recover from the damage sustained (Motta and Haudemand, 2000; Brang et al., 2006; Helfenstein and Kienast, 2014; Frehner et al., 2005). Such management strategies mainly aim to reduce the intensity of commercial harvesting and lead the stand towards uneven-aged structures (Wehrli et al., 2006; Rammer et al., 2015), preserving some trees with large diameters (Fuhr et al., 2015) or suggest site-specific target profiles for rockfall protection forests (Dorren et al., 2015). In any case, questions related to possible trade-offs between ecosystem services (Stokes, 2006; Cordonnier et al., 2008) and on the profitability of the interventions remain. Often, only low value assortments can be obtained from these practices, which, together with the high harvesting costs due to slope and other logistic aspects, negatively influence their Timber Value (Accastello et al., 2018). Therefore, despite their importance for maintaining high safety