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Invited review

Ecosystem-based disaster risk reduction in mountains

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A B S T R A C T

Since the late 1960s it became clear that a more sustainable protection of people and property from the negative impacts of natural hazards will require a more balanced use of structural and non-structural measures, such as land-use planning and ecosystem-based solutions for disaster risk reduction, also called Eco-DRR. The most prominent example of Eco-DRR in mountainous regions are forests that protect people, settlements and infrastructures against gravitational natural hazards such as avalanches, landslides and hazards related to mountain torrents. The goal of this paper is to provide an overview on the influence of forests on risks induced by natural hazards and the associated challenges and uncertainties concerning risk analysis. Approaches from natural hazard risk are presented, along with recent results from forest research, thereby offering new ways to integrate forests into risk analysis. We discuss the potential effects of forests on the three important hazard components of the risk concept, namely the onset probability, the propagation probability and the intensity, and propose a set of guiding principles for integrating forests into quantitative risk assessment (QRA) for natural hazards. Our focus thereby lies on snow avalanches, rockfalls, floods, landslides, and debris flows. This review shows that existing methods and models for assessing forest effects on natural hazards suffice for integrating forests into QRA. However, they are mostly limited to the stand- or slope-scale, and further efforts are therefore needed to upscale these approaches to a regional level, and account for uncertainties related to forest effects and natural dynamics. Such a dynamic, rather than a static assessment of risk will finally allow for planning and implementing intelligent combinations of Eco-DRR and technical protection measures.

1. Introduction

Each year, natural hazards are causing losses in the order of 130 billion US$ worldwide (Munich Re, 2016), and a substantial number of casualties. Without adaptation, natural hazard risks are very likely to increase continuously in the future: Global average annual loss is estimated to increase up to 415 billion US$ by 2030 (UNISDR, 2015a). Since early settlement, human societies are trying to avoid risks by appropriate spatial planning or to mitigate the negative impacts of natural hazards by structural measures such as dikes, mounds, dams and barriers (Sauermoser et al., 2011). Although many of these preventive measures have, in general, reduced natural hazard risks, it has become quite clear since the late 1960s and early 1970s that an improved sustainable protection of people and property from the negative impacts of natural hazards will require a more balanced use of structural and non-structural measures than what is generally observed nowadays (Cruz, 2007; Lacambra et al., 2008; Li and Eddleman, 2002). This paradigm shift was mainly motivated by the negative aspects of structural measures, such as high costs due to construction and maintenance, negative environmental and aesthetical impacts, and effects in inducing further exposure of people and property (Delage, 2003; Godschalk et al., 1999). By way of example, coastal management in the United States, similar to flood management, has shifted away from exclusive reliance on "shore hardening" to much "softer" approaches during the same period (Beatley et al., 1994). Examples of non-structural measures or softer approaches include the proper implementation

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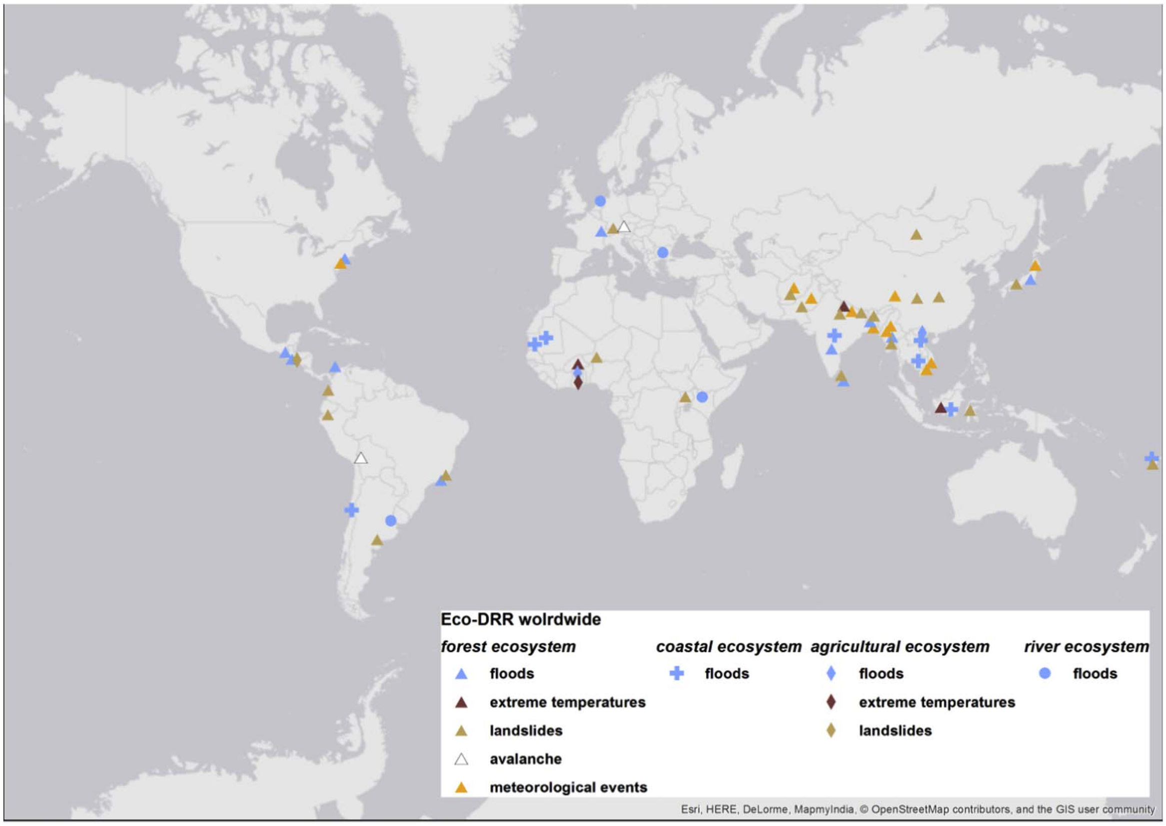

Fig. 1. Ecosystem-based disaster risk reduction plays an important role in risk prevention worldwide: map with a selection of recent Eco-DRR projects based on Sudmeier-Rieux et al. (2006), Estrella et al. (2014) and Renaud et al. (2016).

of land-use planning (Burby et al., 2000; Glavovic et al., 2010), the installation of early warning systems (Basher et al., 2010; Baum and Godt, 2010), improved emergency response preparedness (e.g. Kapucu, 2008) and/or ecosystem-based solutions for disaster risk reduction (Eco-DRR, also referred to as nature-based solutions).

Eco-DRR refers to the conservation, restoration and management of ecosystems for disaster risk reduction aiming at sustainable and resilient development of communities (Estrella and Saalismaa, 2013). Examples of Eco-DRR include the renaturation of rivers, where additional flooding space is (re-)created in river beds, or dunes and salt marshes that provide protection against coastal floods, as well as forests that mitigate mass movements in steep environments (Fig. 1; Borsje et al., 2011; Copper and McKenna, 2008; Murti and Buyck, 2014; Temmerman et al., 2013).

The combination of structural and non-structural measures is increasingly promoted as being a more flexible, effective, and efficient solution to reducing the negative impacts of hazard events (EC, 2015; Spalding et al., 2014). It is often seen as a no-regret measure for disaster risk reduction that improves the resilience of society against natural hazards and the impacts of climate change (Dawson et al., 2011; Mazza et al., 2011; Mileti, 1999; WWAP, 2012). The advantage of Eco-DRR is that it has the potential to simultaneously reduce natural hazard risks and to provide ecosystem services such as cleaner drinking water, increased biodiversity, recreation or wood production (Moberg and Rönnbäck, 2003; Potschin et al., 2016). As such, Eco-DRR is a holistic approach with an emphasis on prevention rather than on the reaction to ongoing or past natural hazards (Estrella et al., 2014). Despite its widely recognized potential, however, structural measures are often still preferred over Eco-DRR, mainly because they are generally considered as being more effective and faster to implement (Sudmeier-Rieux and Ash, 2009). An additional reason is that technical norms and methods for quantifying the risk reduction effect of Eco-DRR still hardly exist in research and practice (Renaud et al., 2013).

The most important example of Eco-DRR in mountainous regions are forests that protect people, settlements and infrastructures against gravitational natural hazards, such as avalanches (Anderson and McClung, 2012; Teich et al., 2012), landslides (Bathurst et al., 2010; Schwarz et al., 2010) or floods (Forbes and Broadhead, 2007; Jones and Perkins, 2010) (Fig. 4). Such forests are also referred to as protection forests, as they are often – and effectively – protecting people and their assets from natural hazard risks (Sakals et al., 2006). In many countries, they have a long tradition as communities endeavored to preserve forests protecting their livelihood. In Japan, for example, institutionalization of forest protection to prevent landslides and floods already started in the 17th century (NBSAP, 2016). Taiwan's government, on the other hand, implemented a watershed management program which explicitly includes forest management and landslide prevention 50 years ago (Cheng et al., 2000). In Switzerland, a multitude of so-called "Letters of Ban" exemplify how people were prevented from exploiting a forest that protected mountain villages from avalanches and rockfall (Fig. 2). In the case of the village of Andermatt, located north of the Gotthard Pass, the first "Letter of Ban" dates back to the late 13th century (Schuler, 1987). Large and destructive floods during the 19th century triggered the introduction of forest and water acts in most Alpine countries which define the management of mountain forests as one of the key governmental tasks (e.g., Schuler, 2000). Nowadays, the Swiss federal railways estimate the economic value of forests protecting their rail network (with a length of ~3200 km) to be in the order of 2 billion US$ per year (SBB, 2016). As a result, extensive research has been conducted on the protective effect of forests against several natural hazard processes, especially in the Alps (Bathurst et al., 2010; Fidej et al., 2015; Kim et al., 2013; Lopez-Saez et al., 2016; Moos et al., 2015; Rammer et al., 2015; Stoffel et al., 2006; Teich and Bebi, 2009). Based on this research, a wide range of methodologies for the