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Research article

# Effects of extreme natural events on the provision of ecosystem services in a mountain environment: The importance of trail design in delivering system resilience and ecosystem service co-benefits

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ABSTRACT

A continued supply of ecosystem services (ES) from a system depends on the resilience of that system to withstand shocks and perturbations. In many parts of the world, climate change is leading to an increased frequency of extreme weather events, potentially influencing ES provision. Our study of the effects of an intense rainfall event in Gorce National Park, Poland, shows: (1) the intense rainfall event impacted heavily on the supply of ES by limiting potential recreation opportunities and reducing erosion prevention; (2) these negative impacts were not only restricted to the period of the extreme event but persisted for up to several years, depending on the pre-event trail conditions and post-event management activities; (3) to restore the pre-event supply of ES, economic investments were required in the form of active repairs to trails, which, in Gorce National Park, were an order of magnitude higher than the costs of normal trail maintenance; and (4) when recreational trails were left to natural restoration, loss of biodiversity was observed, and recovery rates of ES (recreation opportunities and soil erosion prevention) were reduced in comparison to their pre-event state. We conclude that proper trail design and construction provides a good solution to avoid some of the negative impacts of extreme events on recreation, as well as offering co-benefits in terms of protecting biodiversity and enhancing the supply of regulating services such as erosion prevention.



## 1. Introduction

The concept of ecosystem services (ES) has recently become a very popular framework in environmental management (e.g. Burkhard et al., 2012; Jacobs et al., 2014; Kareiva, 2011), despite the controversy over how, and if at all, we should quantify the value of nature in monetary units (Bockstael et al., 2000; Daily et al., 2000; McCauley, 2006). ES are identified as the benefits which society obtains (directly or indirectly) from ecosystems. The three main groups of ecosystem services are: provisioning (e.g. freshwater, crops, timber), regulating (e.g. water purification, erosion prevention) and cultural (e.g. recreation, aesthetics). The general concept of ES is well known and widely described (Bolund and Hunhammar, 1999; Carpenter et al., 2009; De Groot et al., 2002; Millennium Ecosystem Assessment, 2005a, 2005b). However, the transition from the general concept to more detailed theoretical and/or practical approaches related to specific aspects of ES and landscape characteristics remains challenging.

Cultural ecosystem services (CES), which are defined as "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience" (Millennium Ecosystem Assessment, 2005a), are among the least frequently-studied ES. This is because they are complex and multi-faceted, and it can be difficult to develop appropriate spatial indicators to represent them (Daniel et al., 2012; Hernández-Morcillo et al., 2013; Martínez-Harms and Balvanera, 2012). Therefore, there is a need for further research concerning the quantification and spatial distribution of the provision and supply of CES, to provide data to support more integrated land use planning (e.g. Goldman and Tallis, 2009; Goldstein et al., 2012).

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A continued supply of CES from a system is reliant on the resilience of that system to withstand shocks and perturbations. In many parts of the world, climate change is leading to an increased frequency of extreme weather events (Beniston and Stephenson, 2004; Coumou and Rahmstorf, 2012; IPCC, 2012; Jentsch and Beierkuhnlein, 2008; Mirza, 2003; Planton et al., 2008; Van Aalst, 2006). These extreme events can threaten the provision of ES (e.g. Bangash et al., 2013; Terrado et al., 2014), including CES. However, the impact of extreme events on CES has received very little attention.

Here, we describe the impact of extreme weather, in the form of an intense rainfall event, on the provision of CES within a protected mountain environment. Protected natural areas (PNAs), such as National Parks, are managed mainly for two purposes: nature or landscape conservation and recreation (Dudley, 2008). PNAs are usually located in regions of scenic beauty (e.g. coasts, mountains) and/or areas rich in biodiversity (Adamowicz et al., 2011). Hence, they have substantial potential to be a source of CES (Leung and Marion, 2000; Siikamäki, 2011). Biodiversity is also important in its own right as a supporting ES (Millennium Ecosystem Assessment, 2005a), and there is growing evidence that it can contribute significantly to enhanced health and wellbeing (Clark et al., 2014; Keesing et al., 2010; Sandifer et al., 2015; Taylor and Hochuli, 2014).

To maximize delivery of CES, PNAs must be managed so that appropriate infrastructure for visitors is provided. Recreational trails are particularly important in providing visitor access to remote destinations (Cole, 1993; Olive and Marion, 2009), and support activities such as walking, rock climbing, bicycling and horseback riding. Of these, walking is considered to be the most popular (Simmons, 2013). As an example, according to the Central Statistics Office in Poland, the number of beneficiaries of recreational ecosystem services (measured as a number of visitors in 23 National Parks, which cover 1% of the country) was approximately 12 million per year. For these visitors, nearly 3600 km of recreational trails (mainly walking and bicycling) were prepared (CSO, 2013).

Recreational use of trails, if not handled properly, can cause severe impacts through trampling damage, including soil erosion, muddiness, trail widening and, in the long term, changes in plant composition. These problems have been described from all around the world (e.g. Arrowsmith and Inbakaran, 2002; Ballantyne and Pickering, 2015; Belnap, 1998; Cole, 1993; Dixon et al., 2004; Hill and Pickering, 2006; Leung and Marion, 1996, 2000; Marion et al., 1993; Monz et al., 2010; Ólafsdóttir and Runnström, 2013; Özcan et al., 2013; Pickering et al., 2010; Tomczyk, 2011; Tomczyk and Ewertowski, 2013b). Extreme weather events, particularly intense rainfall, have similar adverse effects on trails. Erosion regulation capacity can be quickly exceeded, resulting in the loss of vegetation, which further exacerbates erosion, since bare soil is more prone to soil erosion than vegetated soil (Olive and Marion, 2009; Tomczyk and Ewertowski, 2013b). This will have knock-on consequences for CES, specifically recreation, since degraded trails have a negative impact on visitor numbers, experience and safety (Hammitt et al., 2015; Kim et al., 2003; Kim and Shelby, 2006; Moore et al., 2012; Roggenbuck et al., 1993; Verlič et al., 2015). Adverse impacts on trails may be limited to some extent by appropriate management activities such as planning, robust construction and regular maintenance (Cole, 1993; Leung and Marion, 1996; Olive and Marion, 2009; Wimpey and Marion, 2010). However, evaluations of management practices related to trail rehabilitation remain limited and have not previously been conducted within an ES framework.

In this paper, we build on a long-term study of recreation in Gorce National Park (GNP) in Poland to model the impact of an intense rainfall event on three types of ecosystem services in the Park: a supporting service (biodiversity); a regulating service (erosion prevention); and a cultural service (recreation). We also evaluate the cost and effectiveness of alternative management strategies in effecting the recovery of these different services following the rainfall event.

## 2. Study settings

### 2.1. Gorce National Park

Gorce National Park (GNP), comprising the Gorce Mountains (1311 m a.s.l.), is situated in the outer Carpathians mountain system (the Beskidy Mountains) in southern Poland (Fig. 1). The study area covers 70.3 km$^2$. Most of GNP belongs to the state (94%), with the remainder (6%) being in private ownership. Forests are the main type of land cover (94%) (Ruciński and Tomasiewicz, 2006). Apart from the forests, GNP also includes an abundance of areas of high biodiversity value, especially its glades and pastures. Because of the natural character of its landscapes, which offer scenic views of the surrounding mountains, the Park is popular with visitors from the whole country (Semczuk, 2012).

Recreational trails in Gorce National Park are single or multi-use and hiking is the most popular activity – walkers constitute 96–98% of the Park visitors (Popko-Tomasiewicz, 2006; Semczuk, 2012). According to the estimation by CSO (2011, 2012, 2013), visitors in GNP increased in numbers from 60,000 in 2010, to 65,000 in 2011 and 70,000 in 2012.

### 2.2. Extreme weather event: intense rainfall in May 2010

In May 2010, a large part of Europe (including the southern part of Poland) was affected by extreme rainfall events during a short period lasting a few days. More than 2000 mm of rain fell during a 24 h period on 16th–17th May, and in many places in the Beskidy Mountains, the amount of precipitation between 16 and 19 May was 1.5–3 times more than monthly long-term mean for 1951–2000 (Bissolli et al., 2011; Woźniak, 2013). The situation was similar for GNP, where typically, a mean annual precipitation varies from 700 mm in the foothills to 1200 mm at the highest altitudes (Miczyński, 2006). As precipitation was also recorded at the beginning of May 2010, the water retention capacity of the soil was already very limited. Hence, these heavy rainfall events caused serious problems in many lowland areas due to flooding and increased sedimentation rates (Bissolli et al., 2011; Skolasińska et al., 2014; Wierzbicki et al., 2013). In upland and mountain areas, the rainfall intensified soil erosion and initiated mass movements of soil, with consequent delivery of debris to streams and rivers and damage to infrastructure such as houses, roads and bridges.

## 3. Methods

### 3.1. Scenario development

We estimated the provision of supporting (biodiversity), regulating (erosion prevention) and cultural (recreation) ecosystem services for four different scenarios and five time periods. The four scenarios were:

- Scenario 0 – background scenario, i.e. an area is unavailable to visitors for conservation reasons and no recreational trails have been constructed.
- Scenario 1 – well designed, constructed and maintained trails which were not destroyed during the extreme rainfall event.