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

Published version:

DOI:10.1016/j.ecolecon.2018.08.021

(Article begins on next page)

The economic evaluation of forest protection service against rockfall: a review of experiences and approaches

By Ettore Bianchi[a], Cristian Accastello[a], Daniel Trappmann[b] , Simone Blanc[a], Filippo Brun[a]

[a]: Department of Agricultural, Forest and Food Sciences (DISAFA), University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, TO, Italy

[b]: Bavarian State Institute of Forestry, Hans-Carl-von-Carlowitz-Platz 1, 85354 Freising, Germany

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.

Keywords

Ecosystem services; Rockfall; Alpine Space; Protection forests; Economic Evaluation; Replacement Cost, Avoided Damages

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 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 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, Cochran, and LaRocco 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 standards (Helfenstein and Kienast, 2014, Fidej et al., 2015), silvicultural interventions can be performed only when economic incentives are available (Brang et al., 2006).

Notwithstanding the importance of a proper forest management, it should be remarked that the protective effects of the forest exist only up to a certain threshold of rockfall events, in relation to their frequency, intensity and block dimensions. Beyond that, its protective effect, even when positive, is only complementary to the dedicated artificial defensive facilities (Asciuto et al., 1987, Fidej et al., 2015). Nevertheless the quantification of the effectiveness of forests is still useful for an appropriate design of these structures, which, apart from being expensive, generally have limited duration and strong environmental drawbacks (Holub and Hübl, 2008, Howald et al., 2017).

2.4 The monetary evaluation of Ecosystem Services

Ideally, the value of forests can be broken down in several components with different classifications available, ranging from “use” and “non-use” values (Krieger, 2001), to “material” and “immaterial” ones, when dealing with countable or uncountable functions, as those related to the provision of ES functions other than wood and non-wood products (Brun, 2002). According to Brouwer (2000), the evaluation of a well specified service entails the advantage of considering a lower amount of data to be processed, particularly if it takes place at a limited spatial scale, like rockfall does (Dorren et al., 2006, Rammer et al., 2015). Regulation services are difficult to assess, and a combination of technical and economic elements, also frequently involving expert opinions, have to be used (Wolff et al., 2015, Grêt-Regamey et al., 2013). Moreover, carefully defining the component to be examined is only part of the evaluation, that also has to account how far the societal needs are satisfied by such process (Villamagna et al., 2013). Regulation and protection are in fact characters of public goods, neither rival nor excludable, so the achieved results assume a political meaning, beyond the scientific one (Spangenberg and Settele, 2010, Wallace, 2007).

3 Materials and methods

The concept of this work relies upon the interaction between two elements: the regulation ES provided by the forest and the gravitational natural hazards, with a focus on rockfall. As shown in figure 1, the role of the forest in relation to rockfall events has been considered from an economic perspective.

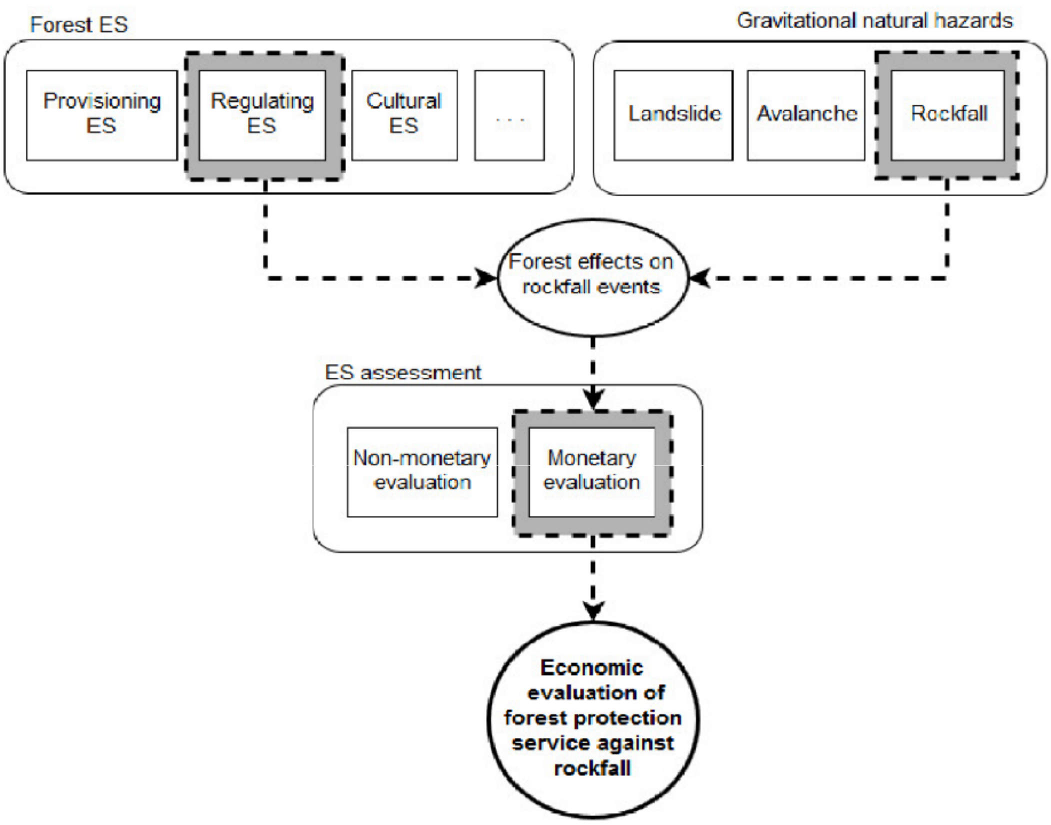

Figure 1 – *Conceptual framework of the elements considered in the review; the focus of the review lies in the interactions between the forest and rockfall, considered from an economic perspective.*

The bibliographic research we performed was aimed to review all the evaluation studies of the forest protection service against rockfall performed in the Regions included in the Alpine Space (http://www.alpine-space.eu/), i.e. Switzerland, Austria, Liechtenstein, Slovenia and some Regions of France, Italy, and Germany (see Fig. 2).

Figure 2 – *Highlighted in green the area covered by the Alpine Space, source: http://www.alpine-space.eu/*

Due to the limited research field analysed, the research also included evaluations published in a format different from the scientific paper, such as project reports, non-scientific journal articles and similar sources, in English or in other languages. Moreover, in addition to rockfall protection service evaluations, other studies related to different gravitational hazards, such as avalanches and landslides, or performing overall evaluations of the forest protection service specifically mentioning rockfall risks were included in the review. We retain this broad approach scientifically consistent since, from and economic perspective, the same methodological approach is adopted for their evaluation (Häyhä et al., 2015, Getzner et al., 2017). Therefore, the documents collected and analysed are those that satisfy the following three requirements:

- Have a main focus on natural gravitational hazard protection service supplied by forests;
- Perform an economic evaluation of the supplied service;
- Are located in the Alpine Space.

Any potential omission in the results should be considered accidental or due to the lack of one of these requirements. For each of the collected evaluations, we then extrapolated the following information:

- Subject of the evaluation, i.e. the service evaluated in consideration of which risk;
- Adopted evaluation approach, according to the classical literature distinction between methods;
- Study area name, specifying, where possible, the related municipality, region and country;
- Application scale of the evaluation, distinguishing between "local", if performed on one or few municipalities; "sub-regional" if affecting gatherings of municipalities; "regional" if referred to bigger administrative units such as statistical regions, federal states, etc.; and "national" if on entire countries, in compliance with the NUTS levels of the EUROSTAT codification (EU, 2011);
- Adopted interest rate, when stated;
- Time span of the evaluation, when stated;
- Monetary evaluation of the service, expressed as a single sum of money or a range;
- Measurement unit of the evaluation, distinguishing between values and incomes;
- Involvement of stakeholders in the evaluation process;
- Definition of an objective numeric assessment of the protective effects of the forest, e.g. through indexes, scales, energy measures, ...;
- Presence of a scenario analysis in order to evaluate different possible future developments of the current situation;
- The computation of the costs related to forest management activities for the maintenance or the improvement of the protective function.

4 Results and discussion

The bibliographic review, completed in early 2018, involved the partners of the project RockTheAlps and allowed us to collect a significant number of papers relating to the issue. The works focusing on economic evaluation of protective services against gravitational hazards in the Alpine regions were found to be 26, of which 12 in peer-reviewed journals. An ID number identifies all the 26 papers collected (annex A).

The evaluation approaches emerging from the review, in order to assess the value of the protective service provided by forests against rockfall, are briefly described as follows:

- Replacement cost method: it adopts a substitution value equal to the expenses needed to reproduce the service with artificial means(Bockstael et al., 2000), therefore reliant on project documents to evaluate the costs of the defensive facility with equal effectiveness(Notaro and Paletto, 2012). According to Bockstael et al. (2000), this approach has to satisfy three conditions: i) the hypothesized structure has to be as effective as the forest; ii) the structure with the least cost has to be chosen; iii) there must be a societal interest in maintaining the service, and in replacing it if missing.
- The avoided damages approach focuses instead on other components of the concept of risk: the goods likely to be damaged by the event, and the probability of it occurring. In this case, the beneficial function of the forest is the reduction of expected damages for the goods in the area. To evaluate it, a comparison is usually performed between scenarios of expected losses, with and without the forest, for the possible events (Bründl et al., 2009, Papathoma-Köhle et al., 2011);
- Risk analysis, adopting an approach similar to the avoided damages method, taking it one step further, by including in the computation, along with the damages to buildings and infrastructures, the costs related to emergency and first aid services and the loss of human life (Fuchs and McAlpin, 2005, Fuchs et al., 2012);
- The choice experiment method focuses on the preferences of the people actually benefitting from the protection, involving all the stakeholders, to elicit information directly from them and assess their Willingness To Pay or Willingness To Accept (Hadley et al., 2011), by means of interviews, questionnaires etc. that usually offer a set of options;
- The Hedonic price approach is a revealed preferences method that consists in defining the effect of the service on the price of the related market good, usually residential buildings (Hadley et al., 2011);
- The Benefit transfer method, which differs from the previous ones for not being based on primary data, considers the results of evaluations performed with the same aim and comparable background transferring its results to the object of the assessment (Boyle and Bergstrom, 1992).

According to the classification hereby presented, Table 1 shows the collected papers in relation to the evaluation approach adopted and the focus of the work.

Table 1 – Analysis of the studies, considering the subject of the evaluation and the adopted approach; when a study adopted more than one evaluation method or investigated more than one aspect, it was repeatedly inserted in the corresponding cell.

	Replacement cost	**Avoided damages**	**Risk management**	**Contingent choice**	**Hedonic price**	**Benefit transfer**
Protective function	[2],[6],[7],[8], [13],[17],[19], [20],[21],[22],[24]					[16]
Gravitational hazards	[3],[23],[24]	[3]		[1]	[23]	[16]
Rockfall	[11],[12],[13],[22]	[11],[12], [18]	[25],[26]			
Avalanche	[11],[14],[22]	[9],[10], [11],[14]	[4],[5],[14]	[1],[14], [15]		
Flood protection	[3]	[3]				

As expected, these studies do not always have rockfall hazard or gravitational phenomena as their main focus (7 and 5 papers respectively), but instead a broader subject is considered, encompassing all the protection services of Alpine forests (12 papers). In addition, a relevant number of studies are mainly dedicated to the economic evaluation of avalanches, adopting comparable approaches (Holub and Hübl, 2008, Getzner et al., 2017). In the collected studies, the most commonly employed approaches of environmental economics are the traditional ones; among these, the replacement cost method emerges as a clear leader, used in 18 studies, followed by the calculation of avoided damages, used in 7 studies. Only three studies rely on preferences of the service beneficiaries, although one another [20] undertakes a preliminary survey among stakeholders in order to establish a ranking list of ecosystem services, which are subsequently evaluated with different methods. These findings are consistent with some available guidelines on the evaluation of ecosystem services (Hadley et al., 2011, Wolff et al., 2015), in which the replacement costs approach appears as the most straightforward way to evaluate protection services. This approach is replicable, needs a limited amount of data and do not require the creation of a specific demand curve, as other methods do. Therefore, even when it may not account for the complexity of some processes (Farber et al., 2002), if properly adapted on the features of the study site, can produce reliable results that can be easily understood also from a non-scientific audience (Bockstael et al., 2000).

Regarding the avoided damages approach, the second most common, this relies on the assets in an area, determining the value of the protective effectiveness of forests in relation to their number, features and spatial layout, and the probabilities of the event occurring. Nonetheless, its adoption is strictly site-specific and usually limited by the difficulties in modelling the risk phenomena and determine their damage potential. The presence of the forest, for example, may determine longer return periods for disasters, and this effect can be isolated by building different scenarios (Dorren et al., 2006).

Methods dealing with preferences, stated or revealed, albeit commonly used in the literature to assess cultural and recreational services (Boyd and Banzhaf, 2007), are poorly represented among the identified studies. As expressed also by other Authors, such approaches are poorly suited to evaluate the protection services, because the high data and resource requirements do not fit the presence of this service, often taken for granted by the beneficiaries (Mattea et al., 2016, Getzner et al., 2017, Farley and Voinov, 2016). In this respect, of particular note are the comparative studies like the one undertaken by Getzner et al. (2017) [23], where the protective value of publicly owned forests are accounted with the replacement cost approach and with the hedonic price method, showing that values obtained using the latter method are substantially lower. For one study only [16] we found the definition of "benefit transfer" appropriate for the adopted approach (Brouwer, 2000), because it applies the measurements produced in another study [17] to a different territory. The scarceness of studies focused on the evaluation of the protective function is surely a circumstance that makes it difficult to use benefit transfer in those estimations, because its fruitful use is linked to the availability of so-called 'primary studies' carried out in other areas.

Concerning the geographical distribution of the collected studies, shown in Table 2, it appears that all the countries of the Alpine Space are represented, albeit unevenly.

Table 2 – Studies collected in the review by nation and scale of application of the evaluation; transnational studies were inserted in both countries

	Local	Sub-regional	Regional	National
France	[11],[12],[18]			[8]
Italy	[6],[7],[12],[17],[19], [20],[21],[22]	[16]	[2]	
Switzerland	[4],[5],[10],[12], [14],[15],[25],[26]			
Austria	[9]			[23]
Germany	[1],[3]			
Slovenia	[13]		[24]	

The vast majority of the studies concern small areas (21 out of 26), as the effects of rockfall are highly localised (Volkwein et al., 2011); while only two studies [12 and 11] involve more areas, even in different States. Conversely, some areas, mainly the ones where the avoided damages approach is used, appear in more than one study, which is reasonable due to the amount of data required to implement such evaluations. In any case, the few studies making national scale evaluations show some limitations: in one case, only the public owned forests are accounted for [23], in the other, the estimation was carried out on the whole Alpine space, in a declared outlined form, and the value obtained is markedly lower than the others [8].

The time span of the studies is equally interesting, enabling us to note how the issue, a highly specialized topic in the broad field of ecosystem services evaluation, has only been the subject of studies since the second half of nineties. After the first study in German language in 1995 [1], new studies appeared only nine years later, in Italian [2] and in the German language [3], independently of each other. Conversely, from 2007 onwards, the issue has attracted a growing interest in the academic environment, being addressed at least yearly (see Fig. 3).

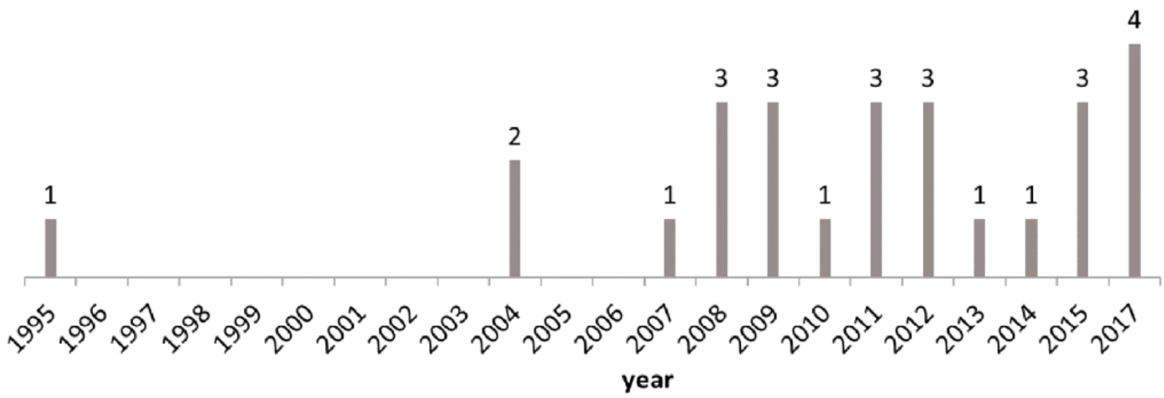

Figure 3 – Number of reviewed studies and corresponding year of publication.

In a review of monetary evaluation, it is also interesting to focus on the discount rate, due to its heavy influence on the estimation outcomes. To establish such a rate is in fact a necessary step to account the time factor into economical evaluations (Gamper et al., 2006). In fact, these evaluations entail a comparison between costs and benefits, distributed across given time frames; for this reason the chosen discount rate strongly affects the obtained results and, therefore, the consequent operative decisions (Dupire, 2011). All the studies we collected, except one [15], adopt low and fixed discount rates (see Fig.4), and justify the selection in relation to the societal function of forests and their self-renewal capacity (Dupire, 2011). One study [15] adopts a very high discount rate, equal to 14.5%, obtaining it from interviews of the people about the willingness to pay to reduce hazard.

[9],[1],[4],[8],[16],[19],
[14],[10],[25],[26]

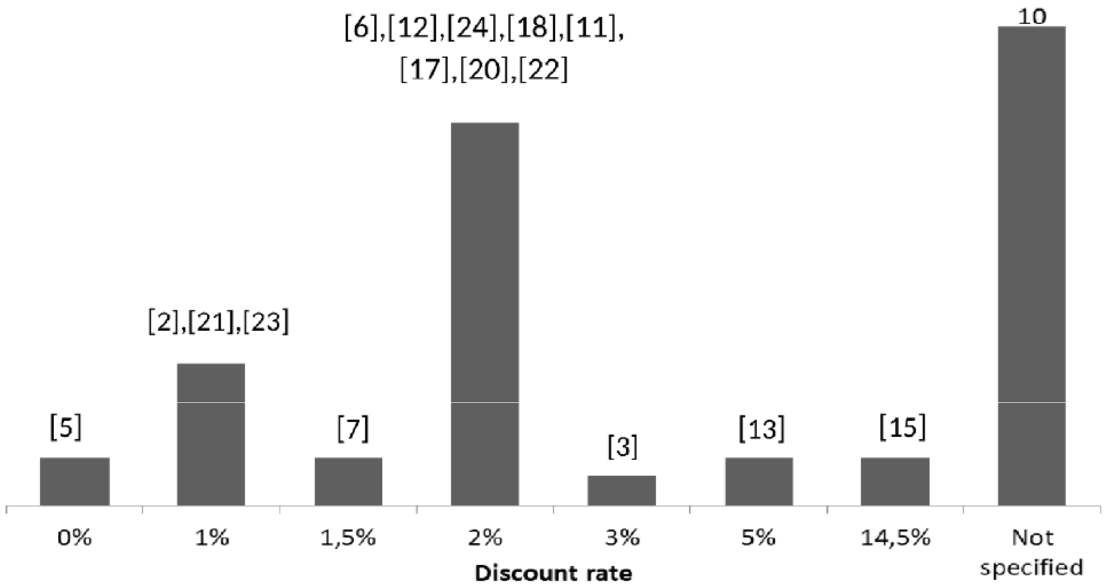

Figure 4 – Discount rates and related number of reviewed studies that adopt it; the ID number of the corresponding study is reported above each column.

Not all the reported studies, however, use financial calculation. Four of these ([3], [20], [22], [23]), use a discount rate but do not specify the time period of its application; among the reported time periods we can observe great variations, ranging from 8 to 300 years (in [12] and [10] respectively). Studies that adopt the replacement cost mostly use the working life of protective facilities to represent environmental services, which means time frames ranging from 10 to 70 years. Discount rates play a paramount role in determining the monetary value that the studies achieve, especially when long time periods are involved (Hepburn and Koundouri, 2007). This fact may partly explain the high variability of final values of the protection service, spread across several orders of magnitude, from hundreds of thousands (and even millions) of euros to negative values. Firstly, however, we have to illustrate the different measurement units adopted to express the protection service in monetary terms (Fig. 5), which we identify as total and annual values.

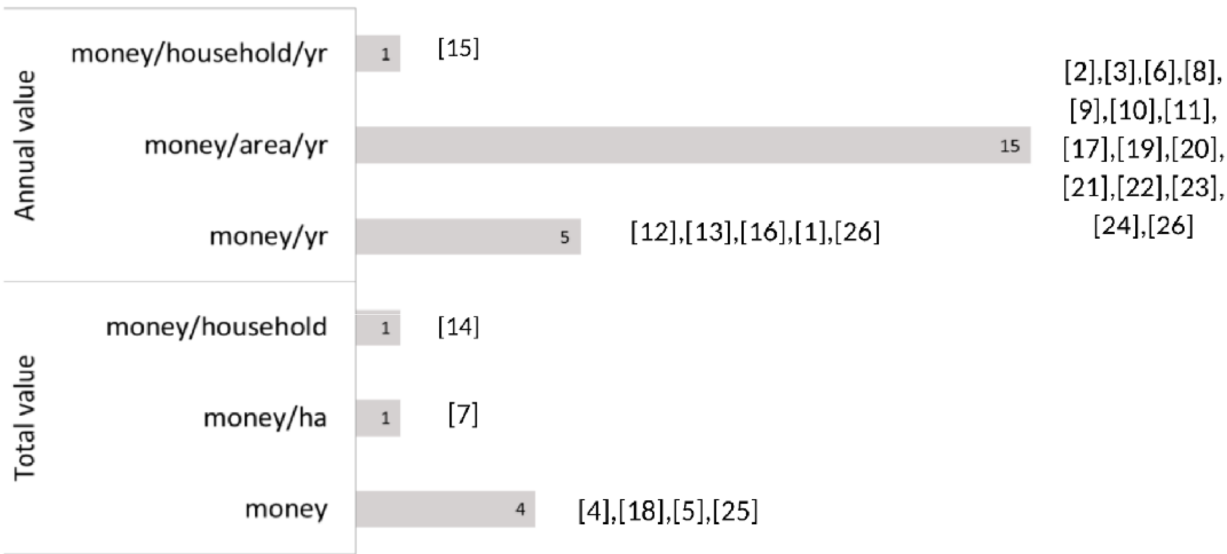

Figure 5 – Expressions of monetary value of protective function, grouped by total and annual values, the ID number of the corresponding study is reported at the end of each row.

As we may observe, the majority of studies (20) express the monetary value in form of yearly benefit, referred to the forest area or, in one case, to the protected households. The yearly benefits of a portion of agricultural land, or annuity, is a common parameter to value crops and forest, and many landowners are familiar with it. Although the protection from rockfall is not as consistent as a crop yield, it too is linked to acreage, and this form of expression of the value seems to be more easily understood by practitioners and decision-makers. On the other hand, the remaining cases give one-off values, linked either to the individual household [14] or to the sheltered area [7], or deriving from the expected reduction of damages [25]; in one case [5] the value is negative, derived from a comparison between past data and a future scenario.

Finally, we report some considerations about the p [4],[18],[5],[25] lies of four elements that were identified as significant in order to further characterize the economic evaluation performed (Blattert et al., 2017, Laurans et al., 2013). Particularly, they are the stakeholder involvement, the assessment of forest effectiveness, the inclusion of costs of forest management and the use of scenario analysis.

Among the collected studies, only four works ([12], [14], [18], [23]) accounted forest management as an expenditure item. This aspect is the least considered among those recorded but, interestingly, all the studies that took in account the active management of protection forests through silvicultural interventions built some scenarios as well, confirming their long-term vision of the service. This approach is also evident when including some sort of stakeholders involvement in the evaluation. Two of these studies ([14] and

[18]) are among the five researches ([11], [14], [15], [18], [20,]) that considered the need of the society for the service supplied by the protection forests. Nonetheless, this general lack of participatory approach can be considered as a sign of the disconnection that still lays between academic research and societal actors in the topic, resulting in a limited inclusion of these economic evaluation in the local risk management strategies.

More confidence, instead, emerges with scenario building and the measurement of forest efficacy (12 and 9 cases respectively). Additionally, it is interesting to notice the increasing number of researches measuring the effectiveness of a protection forest in delivering its main service. This phenomenon is probably related to the development of experiences, methods and models recently published to study and foresee the role of trees against rockfall events (Howald et al., 2017, Dupire et al., 2016a) and, in parallel, to a larger availability of remote sensing and other geospatial technologies that fit well the data requirements (Monnet et al., 2017).

Moreover, it is also worth noting that 10 studies do not address any of these topics ([1], [2], [6], [8], [9], [19], [20], [21], [22], [24]), and in 7 studies just one of them ([3], [4], [5], [7], [13], [16], [17]). On the other hand, in two studies, [14] and [18], all these aspects were considered. Nevertheless, it should be stressed that the inclusion of those aspects may or may not serve the purpose of the evaluation, depending on the chosen approach, the aims of the evaluation and data availability. For this reason, their presence or absence should not be taken as a quality or accuracy indicator of the reviewed studies.

5 Conclusions

Rockfall is usually a small-scale phenomenon but, in the Alps, it occurs almost on a daily basis (Dorren, 2003). Thanks to the knowledge that we currently possess, it is possible to implement economic evaluation models for the protection service of forests against rockfall that rely upon high-quality quantitative data and can deliver a very accurate representation of processes when carefully calibrated and validated. Even though this evaluation is restricted to a unique ecosystem service, compared with the many that are provided by forests, obtaining reliable values of the protection service has not only scientific relevance, but rather can have notable implications on decision-making at local level. Some examples of application could be the cost-benefit analysis for public works, adjustment in forest planning and, broadly speaking, a better allocation of resources supporting a sustainable territorial management (Teich and Bebi, 2009, Moos et al., 2017a).

In the past decades, many Alpine countries developed guidelines for territorial planning, like the Territorial Integrated Plans in force in Lombardy, Italy, for example, explicitly take into account rockfall hazards, by combining the study of the process dynamics with an analysis of the context of the occurrence. In recent years, large-scale process modelling of natural hazards, in Switzerland and Austria for example, enabled the delineation of those forest with an object-protecting function (Losey and Wehrli, 2013, Perzl et al., 2014).

The cartographic information supplied can serve as a basis for target-oriented forest management and for objective allocation of financial resources. In such types of elaboration, an ecosystem service evaluation could usefully fit, creating a bridge between inhabitants and decision makers. Social awareness is a factor of preeminent importance (Spangenberg and Settele, 2010) to address local policy decisions. Concerning the protection against gravitational hazards, a topic where awareness of citizens is already prevailing on other functions, at least in the Alps (Grilli et al., 2015, Zoderer et al., 2016), the dissemination of these results may create value and enhance the relevance of forest resources (Mattea et al., 2016). The increased consideration of this nature-based solution for risk reduction could also foster the implementation of a targeted forest management, in line with the available guidelines (Kajdiž et al., 2015, Radtke et al., 2014), ensuring a long-term safety to the endangered assets via a cost-effective protection measure. Moreover, form a societal perspective, the fact that such research is included in a collaborative project between nations of the Alpine Space enhances its chances of diffusion, as well as its responsibilities. The project aims, on the one hand, to develop a common strategy for the management of rockfall hazard, and on the other, to encourage local authorities towards its adoption though this collection of the most relevant examples of economic evaluations. It is significant that the results may refer to a common language and a common interest in sharing the culture of protection.

Considering the critical issues and uncertainties still present in complex evaluations, as the protection functions are, it is worth discussing the possible advances and the very meaning of monetary evaluation. As Bockstael (2000) states: "Our ignorance does not preclude the need for these answers, nor has it prevented us from giving partial answers when complete ones were unavailable", moreover, as other Authors point out, the use of a method can draw to attention its flaws and could stimulate its improvement (Gret-Regamey and Kytzia, 2007). In spite of it being a strong approximation to reduce to a monetary value the ecosystem functions, upon which a large proportion of human communities rely (Farley and Voinov, 2016), translating those services in monetary terms is maybe the best way to carry information into decision-making processes (Spangenberg and Settele, 2010, Daily et al., 2009). In fact, with their directness and easier comprehension, their adoption could help non-academic stakeholders realizing the value hidden in these nature-based solutions for risk mitigation. In this context, this review may offer a basis for future applications, highlighting the current development of this topic in the Alps, even in such a limited field as rockfall protection evaluation, and promoting the adoption of a common framework of approaches and input data for the evaluation of this forest function. Such conditions are nowadays essential to achieve a higher acknowledgement of these practices, recognise the role of protection forest in the mountain areas and legitimate their active management with the long-term benefits of a safe and liveable Alpine Space.

Acknowledgment

The authors wish to acknowledge the support of the partners of the INTERREG Alpine Space project n. 462 “RockTheAlps” for sourcing the papers included in the review. We are deeply grateful for their promptness to cooperate and the interest shown.

We further acknowledge two anonymous reviewers for their helpful comments on an earlier version of the manuscript.

Funding

This work has been funded by the INTERREG Alpine Space project 462 “RockTheAlps”.

Annex

Annex A – Full reference and corresponding ID number of the studies compliant with the review criteria.

ID	**Full references**
[1]	Löwenstein W. (1995); *Die monetäre Bewertung der Schutzfunktion des Waldes vor Lawinen und Rutschungen in Hinterstein (Allgäu)*. In: Bergen V, Löwenstein W, Pfister G (1995) Studien zur monetären Bewertung von externen Effekten der Forst- und Holzwirtschaft. Schriften zur Forstökonomie Bd. 2. Frankfurt a.M.: Sauerländer’s Verlag. 185 S.
[2]	Notaro S., Paletto A. (2004); *Economic evaluation of the protective function of mountain forests: a case study from the Italian Alps*. In Buttoud et al. (2004) The Evaluation of Forest Policies and Programmes, EFI proceedings.
[3]	Kennel M. (2004); *Vorbeugender Hochwasserschutz durch Wald und Forstwirtschaft in Bayern*. LWF Wissen Nr. 44. 76 S.
[4]	Grêt-Regamey A., Kytzia S. (2007); *Integrating the valuation of ecosystem services into the Input-Output economics of an Alpine region*. Ecological Economics, 63, 786-798.
[5]	Grêt-Regamey A., Walz A., Bebi P. (2008); *Valuing ecosystem services for sustainable landscape planning in Alpine regions*. Mountain Research and Development, 28, 156-165
[6]	Notaro S., Paletto A. (2008); *Natural disturbances and natural hazards in mountain forests: a framework for the economic valuation*. Discussion paper
[7]	La Notte A. and Paletto A. (2008). *La funzione protettiva dei boschi del Cansiglio: una preliminare valutazione economica*. Dendronatura 2: 37-53.
[8]	Chevassus-au-Louis B. et al. (2009) ; *Approche économique de la biodiversité et des services liés aux écosystèmes. Contribution à la décision politique*. Centre d'analyse stratégique, rapport n°18, Paris, 399 p.

[9] Borsky S., Weck-Hannemann H. (2009) ; *Sozio-ökonomische Bewertung der Schutzleistung des Waldes vor Lawinen*. AlpS Projekt C.2.5 Endbericht. 79 S.

[10] Teich, M., Bebi, P. (2009); *Evaluating the benefit of avalanche protection forest with GIS-based risk analyses-A case study in Switzerland*. Forest Ecology and Management, Volume: 257 Issue: 9 Pages: 1910-1919

[11] Cahen M. (2010) ; *Ouvrages de parade contre les risques naturels en montagne et fonction de protection de la forêt : analyse économique comparative*. Irstea (Cemagref) Grenoble, ONF de Haute-Savoie, mémoire de fin d'études à AgroParisTech, 133p.

[12] Dupire S. (2011) ; *Action 2.4.1 Étude économique. Démarche et principaux résultats. In: Projet Interreg «Forêts de protection»*. AgroParisTech – ENGREF, Nancy.

[13] Žujo J., Marinšek M. (ACTUM) (2011); *Ekonomsko vrednotenje ekosistemskih storitev Lovrenških jezer*

14] Olschewski R., Bebi P., Teich M., Wissen Hayek U., and Grêt-Regamey A. (2011); *Lawinenschutz durch Wälder – Methodik und Resultate einer Zahlungsbereitschaftsanalyse*. Schweizerische Zeitschrift fur Forstwesen: November 2011, Vol. 162, No. 11, pp. 389-395.

[15] Olschewski R., Bebi P., Teich M., Wissen Hayek U., Grêt-Regamey A. (2012); *Avalanche protection by forests — A choice experiment in the Swiss Alps*. Forest Policy and Economics, 17, 19-24.

[16] De Marchi M., Scolozzi R. (2012); *La valutazione economica dei servizi ecosistemici e del paesaggio nel Parco Naturale Adamello Brenta*. Valutazione Ambient 22, 54–62.

[17] Notaro S., Paletto A. (2012); *The economic valuation of natural hazards in mountain forests: An approach based on the replacement cost method*. Journal of Forest Economics, 18, 318-328.

[18] Gouin V. (2013); *Analyse coût-bénéfice appliquée aux risques naturels de montagne : Intégration des fonctions de la forêt dans l'évaluation économique des stratégies de protection contre les chutes de blocs*. Mémoire de fin d'études, AgroParis Tech.

[19] Schirpke, U., Scolozzi, R., De Marco, C. (2014); *Modello dimostrativo di valutazione qualitativa e quantitativa dei servizi ecosistemici nei siti pilota. Parte1: Metodi di valutazione*. Project report Making Good Natura (LIFE+11 ENV/IT/000168), EURAC research, Bolzano, p. 75.

[20] Grilli G., Nikodinoska N., Paletto A., De Meo I. (2015); *Stakeholders' Preferences and Economic Value of Forest Ecosystem Services: an Example in the Italian Alps*. Baltic Forestry, 21, 298-307.

[21] Häyhä T., Franzese P., Paletto A., Fath B. (2015); *Assessing, valuing, and mapping ecosystem services in Alpine forests*. Ecosystem Services, 14, 12-23.

[22] Paletto A., Geitner C., Grilli G., Hastik R., Pastorella F., Garcia L. (2015); *Mapping the value of ecosystem services: A case study from the Austrian Alps*. Annals of Forest Research, 58, 157-175.

[23]	Getzner M., Gutheil-Knopp-Kirchwald G., Kreimer E., Kirchmeir H., Huber M. (2017); *Gravitational natural hazards: Valuing the protective function of Alpine forests*. Forest Policy and Economics, 80, 150-159.
[24]	Grilli G., Ciolli M., Garegnani G., Geri F., Sacchelli S., Poljanec A., Vettorato D., Paletto A. (2017); *A method to assess the economic impacts of forest biomass use on ecosystem services in a National Park*. Biomass and Bioenergy 98, 252-263.
[25]	Moos, C., Fehlmann, M., Trappmann, D., Stoffel, M. and Dorren, L. (2017); *Integrating the mitigating effect of forests into quantitative rockfall risk analysis - two case studies in Switzerland.* International Journal of Disaster Risk Reduction.
[26]	Trappmann, D., Moos, C., Dorren, L. and Stoffel, M. (2017); *Forschungsprojekt „Risikoreduktion Steinschlag": Welchen Einfluss hat der Schutzwald auf das Steinschlag-Risiko*? FAN Agenda 2/2017, P. 13-19.

References

ACCASTELLO, C., BLANC, S., MOSSO, A. & BRUN, F. 2018. Assessing the timber value: A case study in the Italian Alps. *Forest Policy and Economics*, 93, 36-44.

ADGER, W. N. 2006. Vulnerability. *Global environmental change*, 16, 268-281.

ASCIUTO, G., AGNESE, C. & GIORDANO, G. La valutazione del servizio idrogeologico del bosco in un bacino: aspetti metodologici e applicativi. Il bosco e l'ambiente : aspetti economici, giuridici ed estimativi, 1987 Firenze, Italy. Aestimum, 399-425.

BARTCZAK, A., LINDHJEM, H., STENGER, A., BERGSENG, E., DELBECK, G. & HOEN, H. 2008. Review of benefit transfer studies in the forest context. *Scandinavian Journal of Forest Research*, 42, 276-304.

BAVEYE, P. C., BAVEYE, J. & GOWDY, J. 2013. Monetary valuation of ecosystem services: It matters to get the timeline right. *Ecological Economics*, 95, 231-235.

BERGER, F., DORREN, L., KLEEMAYR, K., MAIER, B., PLANINSEK, S., BIGOT, C., BOURRIER, F., JANCKE, O., TOE, D. & CERBU, G. 2013. Eco-Engineering and Protection Forests Against Rockfalls and Snow Avalanches. *In:* CERBU, G. A., HANEWINKEL, M., GEROSA, G. & JANDL, R. (eds.) *Management Strategies to Adapt Alpine Space Forests to Climate Change Risks*. Rijeka: Intech Europe.

BERGER, F. & DORREN, L. K. 2007. Principles of the tool Rockfor. net for quantifying the rockfall hazard below a protection forest. *Schweizerische Zeitschrift fur Forstwesen*, 158, 157-165.

BERGER, F., QUETEL, C. & DORREN, L. K. A. Forest: a natural protection mean against rockfalls, but with which efficiency. 2002 2002. 815-826.

BERGER, F. & REY, F. 2004. Mountain Protection Forests against Natural Hazards and Risks: New French Developments by Integrating Forests in Risk Zoning. *Natural Hazards*, 33, 395-404.

BLATTERT, C., LEMM, R., THEES, O., LEXER, M. J. & HANEWINKEL, M. 2017. Management of ecosystem services in mountain forests: Review of indicators and value functions for model based multi-criteria decision analysis. *Ecological Indicators*, 79, 391-409.

BOCKSTAEL, N. E., FREEMAN, A. M., KOPP, R. J., PORTNEY, P. R. & SMITH, V. K. 2000. On measuring economic values for nature. *Environmental Science & Technology*, 34, 1384-1389.

BOYD, J. & BANZHAF, S. 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63, 616-626.

BOYLE, K. J. & BERGSTROM, J. C. 1992. Benefit transfer studies: myths, pragmatism, and idealism. *Water Resources Research*, 28, 657-663.

BRANG, P., SCHÖNENBERGER, W., FREHNER, M., SCHWITTER, R. & WASSER, B. 2006. Management of protection forests in the European Alps: an overview. *For. Snow Landsc. Res.*, 80, 23-44.

BRAUNER, M., WEINMEISTER, W., AGNER, P., VOSPERNIK, S. & HOESLE, B. 2005. Forest management decision support for evaluating forest protection effects against rockfall. *Forest ecology and management*, 207, 75-85.
BROUWER, R. 2000. Environmental value transfer: state of the art and future prospects. *Ecological Economics*, 32, 137-152.
BRUN, F. 2002. Multifunctionality of mountain forests and economic evaluation. *Forest Policy and Economics*, 4, 101-112.
BRÜNDL, M., ROMANG, H. E., BISCHOF, N. & RHEINBERGER, C. M. 2009. The risk concept and its application in natural hazard risk management in Switzerland. *Natural Hazards and Earth System Sciences*, 9, 801-813.
BUSCH, M., LA NOTTE, A., LAPORTE, V. & ERHARD, M. 2012. Potentials of quantitative and qualitative approaches to assessing ecosystem services. *Ecological Indicators*, 21, 89-103.
COASE, R. H. 1960. The Problem of Social Cost. *The Journal of Law & Economics*, 3, 1-44.
CORDONNIER, T., COURBAUD, B., BERGER, F. & FRANC, A. 2008. Permanence of resilience and protection efficiency in mountain Norway spruce forest stands: A simulation study. *Forest Ecology and Management*, 256, 347-354.
CORONA, C., LOPEZ-SAEZ, J., FAVILLIER, A., MAINIERI, R., ECKERT, N., TRAPPMANN, D., STOFFEL, M., BOURRIER, F. & BERGER, F. 2017. Modeling rockfall frequency and bounce height from three-dimensional simulation process models and growth disturbances in submontane broadleaved trees. *Geomorphology*, 281, 66-77.
DAILY, G. C., POLASKY, S., GOLDSTEIN, J., KAREIVA, P. M., MOONEY, H. A., PEJCHAR, L., RICKETTS, T. H., SALZMAN, J. & SHALLENBERGER, R. 2009. Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, 7, 21-28.
DE GROOT, R. S., WILSON, M. A. & BOUMANS, R. M. J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41, 393-408.
DEAL, R. L., COCHRAN, B. & LAROCCO, G. 2012. Bundling of ecosystem services to increase forestland value and enhance sustainable forest management. *Forest Policy and Economics*, 17, 69-76.
DORREN, L., BERGER, F., FREHNER, M., HUBER, M., KÜHNE, K., MÉTRAL, R., SANDRI, A., SCHWITTER, R., THORMANN, J.-J. & WASSER, B. 2015. Das neue NaiS-anforderungsprofil steinschlag. *Schweizerische Zeitschrift fur Forstwesen*, 166, 16-23.
DORREN, L. K. A. 2003. A review of rockfall mechanics and modelling approaches. *Progress in Physical Geography*, 27, 69-87.
DORREN, L. K. A., BERGER, F. & PUTTERS, U. S. 2006. Real-size experiments and 3-D simulation of rockfall on forested and non-forested slopes. *Natural Hazards and Earth System Sciences*, 6, 145-153.
DORREN, L. K. A., MAIER, B., PUTTERS, U. S. & SEIJMONSBERGEN, A. C. 2004. Combining field and modelling techniques to assess rockfall dynamics on a protection forest hillslope in the European Alps. *Geomorphology*, 57, 151-167.
DUPIRE, S. 2011. Action 2.4.1 Étude économique – Méthodologie. *Projet Interreg IV – Forêts de protection.* AgroParisTech – ENGREF, Nancy.
DUPIRE, S., BOURRIER, F., MONNET, J. M., BIGOT, S., BORGNIET, L., BERGER, F. & CURT, T. 2016a. Novel quantitative indicators to characterize the protective effect of mountain forests against rockfall. *Ecological Indicators*, 67, 98-107.
DUPIRE, S., BOURRIER, F., MONNET, J. M., BIGOT, S., BORGNIET, L., BERGER, F. & CURT, T. 2016b. The protective effect of forests against rockfalls across the French Alps: Influence of forest diversity. *Forest Ecology and Management*, 382, 269-279.
DUSSAUGE, C., GRASSO, J. R. & HELMSTETTER, A. 2003. Statistical analysis of rockfall volume distributions: Implications for rockfall dynamics. *Journal of Geophysical Research: Solid Earth*, 108.
DUSSAUGE-PEISSER, C., HELMSTETTER, A., GRASSO, J. R., HANTZ, D., DESVARREUX, P., JEANNIN, M. & GIRAUD, A. 2002. Probabilistic approach to rock fall hazard assessment: potential of historical data analysis. *Nat. Hazards Earth Syst. Sci.*, 2, 15-26.
EC 2013. A new EU forest strategy: for forests and the forest-based sector. Bruxelles, Belgium: European Commission.

EDENS, B. & HEIN, L. 2013. Towards a consistent approach for ecosystem accounting. *Ecological Economics*, 90, 41-52.

EU 2011. Amending annexes to Regulation (EC) No 1059/2003 of the European Parliament and of the Council on the establishment of a common classification of territorial units for statistics (NUTS). Official Journal of the European Union.

FAO 2015. *Global Forest Resources Assessment 2015; How are the world's forests changing?*, Rome, Italy, FAO.

FARBER, S. C., COSTANZA, R. & WILSON, M. A. 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, 41, 375-392.

FARLEY, J. & VOINOV, A. 2016. Economics, socio-ecological resilience and ecosystem services. *Journal of environmental management*, 183, 389-398.

FIDEJ, G., MIKOŠ, M., RUGANI, T., JEŽ, J., KUMELJ, Š. & DIACI, J. 2015. Assessment of the protective function of forests against debris flows in a gorge of the Slovenian Alps. *iForest-Biogeosciences and Forestry*, 8, 73.

FISHER, B., TURNER, R. K. & MORLING, P. 2009. Defining and classifying ecosystem services for decision making. *Ecological economics*, 68, 643-653.

FREHNER, M., WASSER, B. & SCHWITTER, R. 2005. Nachhaltigkeit und Erfolgskontrolle im Schutzwald. *Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion.* Bern, Switzerland: Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern.

FUCHS, S., BIRKMANN, J. & GLADE, T. 2012. Vulnerability assessment in natural hazard and risk analysis: current approaches and future challenges. *Natural Hazards*, 64, 1969-1975.

FUCHS, S. & MCALPIN, M. C. 2005. The net benefit of public expenditures on avalanche defence structures in the municipality of Davos, Switzerland. *Nat. Hazards Earth Syst. Sci.*, 5, 319-330.

FUCHS, S., THÖNI, M., MCALPIN, M. C., GRUBER, U. & BRÜNDL, M. 2007. Avalanche hazard mitigation strategies assessed by cost effectiveness analyses and cost benefit analyses—evidence from Davos, Switzerland. *Natural Hazards*, 41, 113-129.

FUHR, M., BOURRIER, F. & CORDONNIER, T. 2015. Protection against rockfall along a maturity gradient in mountain forests. *Forest ecology and management*, 354, 224-231.

GAMPER, C. D., THÖNI, M. & WECK-HANNEMANN, H. 2006. A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. *Natural Hazards and Earth System Science*, 6, 293-302.

GETZNER, M., GUTHEIL-KNOPP-KIRCHWALD, G., KREIMER, E., KIRCHMEIR, H. & HUBER, M. 2017. Gravitational natural hazards: Valuing the protective function of Alpine forests. *Forest Policy and Economics*, 80, 150-159.

GIUPPONI, C., GALASSI, S. & PETTENELLA, D. 2009. Definizione del metodo per la classificazione e quantificazione dei servizi ecosistemici in Italia. *MINISTERO DELL'AMBIENTE, DELLA TUTELA DEL TERRITORIO E DEL MARE, DIREZIONE PER LA PROTEZIONE DELLA NATURA (a cura di), Progetto Verso la Strategia Nazionale per la Biodiversità: i contributi della Conservazione Ecoregionale, Roma*.

GOIO, I., GIOS, G. & POLLINI, C. 2008. The development of forest accounting in the province of Trento (Italy). *Journal of Forest Economics*, 14, 177-196.

GOMEZ-BAGGETHUN, E., DE GROOT, R., LOMAS, P. L. & MONTES, C. 2010. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics*, 69, 1209-1218.

GRET-REGAMEY, A. & KYTZIA, S. 2007. Integrating the valuation of ecosystem services into the Input-Output economics of an Alpine region. *Ecological Economics*, 63, 786-798.

GRILLI, G., CIOLLI, M., GAREGNANI, G., GERI, F., SACCHELLI, S., POLJANEC, A., VETTORATO, D. & PALETTO, A. 2017. A method to assess the economic impacts of forest biomass use on ecosystem services in a National Park. *Biomass and Bioenergy*, 98, 252-263.

GRILLI, G., NIKODINOSKA, N., PALETTO, A. & DE MEO, I. 2015. Stakeholders' Preferences and Economic Value of Forest Ecosystem Services: an Example in the Italian Alps. *Baltic Forestry*, 21, 298-307.

GRÊT-REGAMEY, A., BRUNNER, S. H., ALTWEGG, J., CHRISTEN, M. & BEBI, P. 2013. Integrating Expert Knowledge into Mapping Ecosystem Services Trade-offs for Sustainable Forest Management. *Ecology and Society*, 18.

GRÊT-REGAMEY, A., BRUNNER, S. H. & KIENAST, F. 2012. Mountain Ecosystem Services: Who Cares? *Mountain Research and Development*, 32, 23-34.

GRÊT-REGAMEY, A. & KYTZIA, S. 2007. Integrating the valuation of ecosystem services into the Input-Output economics of an Alpine region. *Ecological Economics*, 63, 786-798.

GRÊT-REGAMEY, A., WALZ, A. & BEBI, P. 2008. Valuing ecosystem services for sustainable landscape planning in Alpine regions. *Mountain Research and Development*, 28, 156-165.

HADLEY, D., D'HERNONCOURT, J., FRANZÉN, F., KINELL, G., SÖDERQVIST, T., SOUTUKORVA, Å. & BROUWER, R. 2011. Monetary and non monetary methods for ecosystem services valuation–Specification sheet and supporting material. *Spicosa Project Report, University of East Anglia, Norwich*.

HAINES-YOUNG, R. & POTSCHIN, M. 2011. Common international classification of ecosystem services (CICES): 2011 Update. *Report to the European Environmental Agency*. Nottingham, UK: Centre for Environmental Management, University of Nottingham.

HANTZ, D., VENTROUX, Q., ROSSETTI, J. P. & BERGER, F. A new approach of diffuse rockfall hazard. 12th Int. Symp. On Landslides, 2016 Napoli, Italy.

HELFENSTEIN, J. & KIENAST, F. 2014. Ecosystem service state and trends at the regional to national level: a rapid assessment. *Ecological Indicators*, 36, 11-18.

HEPBURN, C. J. & KOUNDOURI, P. 2007. Recent advances in discounting: Implications for forest economics. *Journal of Forest Economics*, 13, 169-189.

HOLUB, M. & HÜBL, J. 2008. Local protection against mountain hazards? state of the art and future needs. *Natural Hazards and Earth System Science*, 8, 81-99.

HOWALD, E. P., ABBRUZZESE, J. M. & GRISANTI, C. 2017. An approach for evaluating the role of protection measures in rockfall hazard zoning based on the Swiss experience. *Natural Hazards and Earth System Sciences*, 17, 1127-1144.

HÄYHÄ, T., FRANZESE, P. P., PALETTO, A. & FATH, B. D. 2015. Assessing, valuing, and mapping ecosystem services in Alpine forests. *Ecosystem Services*, 14, 12-23.

JABOYEDOFF, M., DUDT, J.-P. & LABIOUSE, V. 2005. An attempt to refine rockfall hazard zoning based on the kinetic energy, frequency and fragmentation degree. *Natural Hazards and Earth System Science*, 5, 621-632.

JANCKE, O., BERGER, F. & DORREN, L. K. A. 2013. Mechanical resistance of coppice stems derived from full-scale impact tests. *Earth Surface Processes and Landforms*, 38, 994-1003.

KAJDIŽ, P., DIACI, J. & REBERNIK, J. 2015. Modelling Facilitates Silvicultural Decision-Making for Improving the Mitigating Effect of Beech (Fagus Sylvatica L.) Dominated Alpine Forest against Rockfall.

KRIEGER, D. J. 2001. *Economic value of forest ecosystem services: a review*, Washington D.C., USA, The Wilderness Society.

KRUTILLA, J. V. 1967. Conservation reconsidered. *The American Economic Review*, 57, 777-786.

LA NOTTE, A. & PALETTO, A. 2008. La funzione protettiva dei boschi del Cansiglio: una preliminare valutazione economica. *DENDRONATURA*, 2, 37-53.

LAURANS, Y., RANKOVIC, A., BILLÉ, R., PIRARD, R. & MERMET, L. 2013. Use of ecosystem services economic valuation for decision making: Questioning a literature blindspot. *Journal of Environmental Management*, 119, 208-219.

LINDBORG, R., GORDON, L. J., MALINGA, R., BENGTSSON, J., PETERSON, G., BOMMARCO, R., DEUTSCH, L., GREN, Å., RUNDLÖF, M. & SMITH, H. G. 2017. How spatial scale shapes the generation and management of multiple ecosystem services. *Ecosphere*, 8.

LOSEY, S. & WEHRLI, A. 2013. Schutzwald in der Schweiz: Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald. Bern, Switzerland: Bundesamt für Umwelt (BAFU).

MAES, J., TELLER, A., ERHARD, M., MURPHY, P., PARACCHINI, M. L., BARREDO, J. I., GRIZZETTI, B., CARDOSO, A., SOMMA, F. & PETERSEN, J. E. 2014. Mapping and Assessment of Ecosystems and their Services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020.

MARKANTONIS, V. & MEYER, V. Valuating the intangible effects of natural hazards: a review and evaluation of the cost-assessment methods. European Society for Ecological Economics conference, 2011 Istanbul, Turkey.

MATSUOKA, N. & SAKAI, H. 1999. Rockfall activity from an alpine cliff during thawing periods. *Geomorphology*, 28, 309-328.

MATTEA, S., FRANCESCHINIS, C., SCARPA, R. & THIENE, M. 2016. Valuing landslide risk reduction programs in the Italian Alps: The effect of visual information on preference stability. *Land Use Policy*, 59, 176-184.

MEA 2005. Ecosystems and human well-being: Synthesis. *In:* ISLAND PRESS (ed.) *Millennium Ecosystem Asessment*. Washington, D.C.: World Resources Institute.

MIURA, S., AMACHER, M., HOFER, T., SAN-MIGUEL-AYANZ, J., ERNAWATI & THACKWAY, R. 2015. Protective functions and ecosystem services of global forests in the past quarter-century. *Forest Ecology and Management*, 352, 35-46.

MONNET, J.-M., BOURRIER, F., DUPIRE, S. & BERGER, F. 2017. Suitability of airborne laser scanning for the assessment of forest protection effect against rockfall. *Landslides*, 14, 299-310.

MOOS, C., BEBI, P., SCHWARZ, M., STOFFEL, M., SUDMEIER-RIEUX, K. & DORREN, L. 2017a. Ecosystem-based disaster risk reduction in mountains. *Earth-Science Reviews*.

MOOS, C., DORREN, L. & STOFFEL, M. 2017b. Quantifying the effect of forests on frequency and intensity of rockfalls. *Natural Hazards and Earth System Sciences*, 17, 291-304.

MOOS, C., FEHLMANN, M., TRAPPMANN, D., STOFFEL, M. & DORREN, L. 2017c. Integrating the mitigating effect of forests into quantitative rockfall risk analysis-two case studies in Switzerland. *International Journal of Disaster Risk Reduction*.

MOTTA, R. & HAUDEMAND, J.-C. 2000. Protective forests and silvicultural stability: an example of planning in the aosta valley. *Mountain Research and Development*, 20, 180-187.

NINAN, K. N. & INOUE, M. 2013. Valuing forest ecosystem services: what we know and what we don't. *Ecological Economics*, 93, 137-149.

NOTARO, S. & PALETTO, A. 2012. The economic valuation of natural hazards in mountain forests: An approach based on the replacement cost method. *Journal of Forest Economics*, 18, 318-328.

NUTI, F. 2001. *La valutazione economica delle decisioni pubbliche: dall'analisi costi-benefici alle valutazioni contingenti*, G. Giappichelli.

OLSCHEWSKI, R., BEBI, P., TEICH, M., WISSEN HAYEK, U. & GRÊT-REGAMEY, A. 2012. Avalanche protection by forests — A choice experiment in the Swiss Alps. *Forest Policy and Economics*, 17, 19-24.

PAPATHOMA-KÖHLE, M., KAPPES, M., KEILER, M. & GLADE, T. 2011. Physical vulnerability assessment for alpine hazards: state of the art and future needs. *Natural Hazards*, 58, 645-680.

PERZL, F., HUBER, A. & FROMM, R. 2014. GRAVIPROFOR, Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Innsbruck, Austria: Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW).

PRICE, M. F., BOROWSKI, D., MACLEOD, C., RUDAZ, G. & DEBARBIEUX, B. 2011. *The Alps, From Rio 1992 to 2012 and beyond: 20 years of Sustainable Mountain development. What have we learnt and where should we go?*, Perth, UK & Geneva, Switzerland, Centre for Mountain Studies, University of the Highlands and Islands, Perth College; University of Geneva.

RADTKE, A., TOE, D., BERGER, F., ZERBE, S. & BOURRIER, F. 2014. Managing coppice forests for rockfall protection: lessons from modeling. *Annals of Forest Science*, 71, 485-494.

RAMMER, W., BRAUNER, M., RUPRECHT, H. & LEXER, M. J. 2015. Evaluating the effects of forest management on rockfall protection and timber production at slope scale. *Scandinavian Journal of Forest Research*, 30, 719-731.

RIERA, P., SIGNORELLO, G., THIENE, M., MAHIEU, P.-A., NAVRUD, S., KAVAL, P., RULLEAU, B., MAVSAR, R., MADUREIRA, L. & MEYERHOFF, J. 2012. Non-market valuation of forest goods and services: Good practice guidelines. *Journal of Forest Economics*, 18, 259-270.

RUDOLF-MIKLAU, F., PICHLER, A., SUDA, J., RIMBÖCK, A., HÖHNE, R., MAZZORANA, B. & PAPEŽ, J. 2014. Persistence of Alpine natural hazard protection. Meeting multiple demands by applying systems engineering and life cycle management principles in natural hazard protection systems in the

perimeter of the Alpine Convention. Vienna: Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW).
SAROGLOU, H., BERGER, F., BOURRIER, F., ASTERIOU, P., TSIAMBAOS, G. & TSAGKAS, D. 2015. Effect of Forest Presence on Rockfall Trajectory. An Example from Greece. *Engineering Geology for Society and Territory-Volume 2*. Springer.
SEPPELT, R., DORMANN, C. F., EPPINK, F. V., LAUTENBACH, S. & SCHMIDT, S. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of applied Ecology*, 48, 630-636.
SPANGENBERG, J. H. & SETTELE, J. 2010. Precisely incorrect? Monetising the value of ecosystem services. *Ecological Complexity*, 7, 327-337.
STENGER, A., HAROU, P. & NAVRUD, S. 2009. Valuing environmental goods and services derived from the forests. *Journal of Forest Economics*, 15, 1-14.
STOKES, A. 2006. Selecting tree species for use in rockfall-protection forests. *For. Snow Landsc. Res*, 80, 77-86.
TEEB 2010. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Edited by Pushpam Kumar. ed. London and Washington: Earthscan.
TEICH, M. & BEBI, P. 2009. Evaluating the benefit of avalanche protection forest with GIS-based risk analyses-A case study in Switzerland. *Forest Ecology and Management*, 257, 1910-1919.
TRAPPMANN, D., STOFFEL, M. & CORONA, C. 2014. Achieving a more realistic assessment of rockfall hazards by coupling three-dimensional process models and field-based tree-ring data. *Earth surface processes and landforms*, 39, 1866-1875.
VILLAMAGNA, A. M., ANGERMEIER, P. L. & BENNETT, E. M. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity*, 15, 114-121.
VOLKWEIN, A., SCHELLENBERG, K., LABIOUSE, V., AGLIARDI, F., BERGER, F., BOURRIER, F., DORREN, L. K. A., GERBER, W. & JABOYEDOFF, M. 2011. Rockfall characterisation and structural protection - a review. *Natural Hazards and Earth System Sciences*, 11, 2617-2651.
WALLACE, K. J. 2007. Classification of ecosystem services: problems and solutions. *Biological conservation*, 139, 235-246.
WEHRLI, A., DORREN, L. K. A., BERGER, F., ZINGG, A., SCHÖNENBERGER, W. & BRANG, P. 2006. Modelling long-term effects of forest dynamics on the protective effect against rockfall. *For. Snow Landsc. Res*, 80, 57-76.
WOLFF, S., SCHULP, C. J. E. & VERBURG, P. H. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators*, 55, 159-171.
ZIMMERMANN, M. & KEILER, M. 2015. International Frameworks for Disaster Risk Reduction: Useful Guidance for Sustainable Mountain Development? *Mountain Research and Development*, 35, 195-202.
ZODERER, B. M., LUPO STANGHELLINI, P. S., TASSER, E., WALDE, J., WIESER, H. & TAPPEINER, U. 2016. Exploring socio-cultural values of ecosystem service categories in the Central Alps: the influence of socio-demographic factors and landscape type. *Regional Environmental Change*, 16, 2033-2044.