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A Framework for the Integration of Nature-Based Solutions into Environmental Risk Management Strategies

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Abstract: Mountainous areas are expected to face increasing societal pressure due to mass tourism and the rising intensity and frequency of natural hazards triggered by climate change. Therefore, the development of proper strategies for the management of environmental risks will be crucial to ensure their liveability. Against this backdrop, concepts such as territorial resilience and Social–Ecological Systems (SES) can support the prioritisation of protective efforts. This paper presents a conceptual framework to be applied to areas subject to natural hazards. Its aim is to support the integration of different measures, with a special focus on protection forests and other Nature-based Solutions, into current risk management strategies. The framework considers (i) the definition of SES boundaries; (ii) the identification of the main goals to be achieved; (iii) the quantification of the supply and demand of the ecosystem protection service; and (iv) the development of risk management strategies able to include the management of protection forests among the adopted solutions. This framework is intended as a tool to be adopted by local and regional decision-makers as a tool to identify the areas at risk, to recognise the potential role of protection forests, and to operationalise the concept of resilience through the deployment of "grey-green" strategies.

Keywords: nature-based solutions; protection forest; resilience; risk mitigation; social–ecological system

1. Introduction

The Alps are one of the most densely populated mountainous areas of the world, inhabited by more than 14 M people within a complex environment covered by more than 8.7 M hectares of forests [1]. Here, various factors such as mass tourism, limitations to settlement areas, the need to maintain or improve the current protective measures and infrastructure, and land use conflicts constitute severe challenges for the development of these hazard-prone zones [2]. The management of these issues will influence the liveability of these areas to a great extent, entailing a significant financial outlay for local communities and perhaps even jeopardising their social and economic interactions [2].

Among these challenges, natural hazards have always proved to be particularly threatening due to their potential to cause fatalities and substantial damages to goods, infrastructure, assets, and economic activities [3]. Considering, for instance, the Swiss territory alone, over the last 70 years, more than 1000 people have died as a consequence of natural hazard [4]. Of these fatalities, 53% were caused by avalanches (378 deaths), rockfall (85 deaths), or landslides (74 deaths) [4]. Further to their social impact, these events represent a significant share of public expenses, with an overall cost for mitigation measures (such as the planning and implementation phase of technical mitigation infrastructures) and emergency expenses ranging from 44 to 216 €/year per capita in some Alpine Regions [5]. Nonetheless, such events are expected to occur more intensely and frequently in mountainous areas due to climate change and the increasing expansion of human activities in hazard-prone areas [6,7]. Consequently, an increasing awareness of the self-recovery and adaptive capacities of these territories is emerging and the role of optimising natural ecosystem services (ES) to provide this function is becoming crucial [8,9].

Risk management in mountainous areas should be considered from a broad perspective in order to include, for example, concepts like resilience and Social–Ecological Systems (SES). The former is gaining considerable importance in studies and practices across many disciplines, showing a noteworthy evolution since its introduction in ecology studies [10,11]. Its adoption can vary largely between different disciplines and scales; however, generally, it has been defined as the ability of a system to handle an external pressure [11]. Similarly, the concept of SES investigates the possible relationships between society and environment, among which we find natural hazards and risk management [12,13]. Indeed, the occurrence of a disaster, here always intended as something caused by natural hazards, is not an isolated event, as it influences not only the affected area and its surroundings, but even other regions, with unexpected implications [7]. SES takes in account such interactions, building a multiscale network whose boundaries are determined by ecosystem features together with social and normative aspects [11,14].

Even though these concepts exist, currently, most of the adopted strategies ignore the environmental aspect of SES and adopt standard mitigation measures. The two most common solutions are (i) mapping and classifying homogeneous risk areas to implement forms of land use limitations [15] or (ii) safeguarding existing goods with artificial protection facilities to increase the level of protection [16]. The former strategy is probably the most efficient and cost-effective, but its political viability is limited, also due to the fact that numerous structures already exist in high-risk areas, thus undermining its wider adoption [16]. On the other hand, artificial protection facilities, although often essential, have some drawbacks, such as high implementation costs, limited working life, and low adaptability to change, and they may constitute a source of disturbance for the ecosystem [17]. Despite their effectiveness, these two types of solutions have yet to assign the environment an active role in the protection function, and hardly any strategy exists for integrating nature-based solutions into risk governance [18].

In consideration of these shortcomings, the aim of this paper is to establish a conceptual framework for the development of integrated "grey-green" risk management strategies. These plans aim to include different risk management measures, either nature-based or artificial, alone or in combination, into an integrated strategy for land use planning at the landscape level. Among the available nature-based solutions, protection forests can meet the need for protection in these hazard-prone areas with minimal weaknesses. Their effectiveness is well documented, mainly in relation to gravitational hazards such as landslides, erosion, rockfall, avalanches, or debris flow [19], which mainly occur in mountainous areas. These forests, which constitute the focus of this study, are defined as stands whose primary function is "the protection of people or assets against the impacts of natural hazards" [20]. The boundaries of the SES adopted for the framework cover a landscape-level scale, which has already proved to be suitable for these purposes in similar studies dealing with SES [14]. The framework we developed is intended as a tool for local and regional public authorities and other actors involved in risk management to operationalise the protection ES concept and to involve these nature-based solutions in decision-making processes.

The framework has yet to be tested on a real case study; rather, we intentionally focused on the description of its structure, aims, and methodology (Sections 2.1–2.4), discussing its features and framing its role from a risk management perspective. Therefore, the paper lacks a Results section, even though the findings of its potential application to a study area are described in the last Sections 2.5 and 2.6. Finally, the strengths and weaknesses of the framework are discussed, and we draw conclusions on its possible adoption and its further development (Section 3).

2. Materials and Method

2.1. Structure of the Framework

In consideration of the abovementioned main principles, the conceptual framework we developed is shown in Figure 1. The structure is composed of four stages which can be considered as steps to be followed for its application.

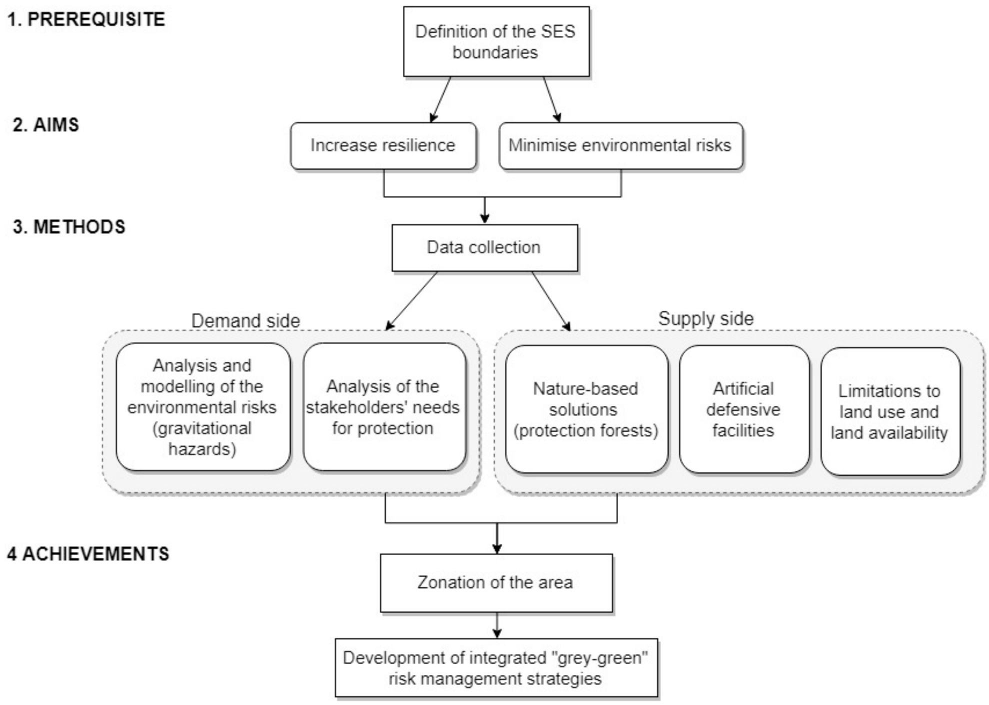

Figure 1. Conceptual framework for the development of grey-green strategies for risk management.

Once the essential prerequisite (1) has been satisfied and the objectives to be pursued with the risk management strategy (2) have been set, the problem is framed by collecting the necessary information concerning the various factors involved in the framework: risks, forests, protection measures, and stakeholders (3). Successively, the demand and supply aspects of the ES are investigated, analysing the risks using models, testing the potential effectiveness of nature-based solutions, and ensuring that the need for protection of the stakeholders is satisfied. Finally, risk management strategies are deployed, including grey-green solutions (4).

2.2. Risk Management through the Lens of Resilience and SES

To facilitate the adoption of the proposed framework, we call for a change of perspective, shifting from a reactive to a precautionary stance [21] based on the concepts of resilience and SES. In order to develop an efficient risk management strategy, the resilience concept should be deployed at the landscape level, assuming the SES boundaries as the reference scale for the implementation of the strategy [22–24]. The adoption of SES would allow us to take into account the vast interactions that disturbances trigger: the alteration of some components of society may also impact the environment and, vice versa, elements that foster the potential recovery of the community may be present in the ecosystem [25]. Therefore, the first step to be accomplished is the definition of the area of interest of the risk management strategy, setting the borders of the SES. Several studies have already been conducted on this topic [23,26]; nonetheless, the methodology proposed by Martin-Lopez et al. [14] seems to better fit the aims of this study. More specifically, the SES is identified by juxtaposing different layers of ecological (considering climate, topology, lithology, and geomorphology) and socio-economic (considering economic, demographic, and ES use variables) features of the study area, highlighting their overlapping areas [27].

Once the background of the framework is defined, its objectives should be set. In the present study, we identified two aims to be addressed: enhanced resilience and risk mitigation. Resilience, an intrinsic characteristic of ecosystems, can play a major role in the mitigation of environmental risk [28]. Adopting solutions aimed at its enhancement can lead to positive effects in the medium and long term, ensuring a reliable and effective protective function [29,30]. Similarly, transposing the concept to local communities, resilience will be considered as the ability of a territorial system to retain a given environmental and socio-economic equilibrium, external influences notwithstanding [31,32]. Therefore, the development of risk management strategies should consider the positive effects in risk mitigation provided by the environment, such as protection forests. Indeed, the adoption of nature-based solutions would support territorial resilience and strengthen the Social–Ecological connections of the area [24,33].

2.3. The Demand Side: Risks and Stakeholder Needs

In consideration of the abovementioned concepts, nature-based solutions should be considered from an ES point of view. This perspective implies the simultaneous presence of two elements: the need of society to benefit from a function supplied by an ecosystem and the possibility of the latter to provide it [34,35]. In this section, the former element—the demand side—is discussed.

Demand for protection by society occurs when the gravitational natural hazards considered in this framework threaten goods, people, or infrastructure [36,37]. Hence, the first step to be accomplished is to analyse these risks by means of a data collection phase. The aim of this data collection phase is to identify the hazards, model their intensity and frequency, and to zone the area at risk. These operations can be supported by several GIS tools which have been recently developed in the research field, such as RockyFor3D [38], in addition to other studies from Corona et al. [39] and Monnet et al. [40] for rockfall, and other models for debris flow [41] or avalanches [42,43].

The second step is to identify the need of the society to be protected from these threats. This aspect, often disregarded, is actually fundamental in order to evaluate and prioritise the most dangerous situations in relation to the elements at risk. The perception of danger can vary widely depending on the importance of the goods and the interest of the stakeholders involved [44,45]. As an example, a situation threatening human life or essential transport routes of the SES will be valued more than abandoned buildings or seasonal routes. Additionally, a key stakeholder with relevant influence in the SES will be highly considered, taking priority over other actors holding less interest in the area [41,46]. To draw some reliable conclusions concerning the protection needs of the SES, the implementation of a stakeholder analysis can play a major role. First, a screening of the actors involved in the area should be set up, considering their role, power, and interests in the topic. These aspects can be examined by deploying well-known analysis techniques such as the power versus interest matrix [47] or the ARDI method [48], where the actors, resources, dynamics, and interest lying in the SES are mapped and linked. Once the stakeholders affected by protection issues are identified, a participatory approach can be adopted to classify the hazard-prone areas to be protected and to rank their relevance. Several techniques can be utilised to collect qualitative information from stakeholders and transform it into quantitative data: the Q-method [49], cognitive maps, and agent-based modelling [50], among others.

The results achieved in this phase consist of a thorough analysis of the different hazards threatening the SES, including their modelling, the zonation of the areas at risk, and their prioritisation in consideration of the goods involved and of the stakeholder needs. These elements constitute the demand side of the protection service.

2.4. The Supply Side: Limitations to Land Use, Artificial Facilities, and Protection Forests

As mentioned in the introduction, the current standard mitigation solutions are mainly the following two: limitations to land use and implementation of artificial protection facilities. The former consists of the zonation of the area under threat in order to establish different levels of risk and, consequently, the implementation of limitations to land use and land use changes. These measures include temporary road closures, building restrictions in areas at risk, and evacuations. If implemented in time, these solutions are generally effective; however, they entail high opportunity costs, since major transport routes and productive activities in general can be highly affected [5]. Moreover, their application can result in an adverse stance of stakeholders: land use limitations and interruptions in the local road network may be perceived as interferences with private interests, with relevant policy drawbacks [51]. Concerning this type of mitigation measure, an example of their successful implementation is the hydrogeological restraint established in Italy in 1923 which largely contributed to improving the safety of unstable Italian mountainous areas [52].

The second set of mitigation measures is constituted by artificial facilities such as walls, nets, and other barriers. Unlike land use limitation, these solutions, which are the most common in the Alps [20], ensure high effectiveness only within well-defined intensity and frequency thresholds. This range is related to the material and structural characteristics of these artificial devices [53,54]. On the other hand, from a societal perspective, they entail less policy drawbacks than the previous set of measures, since their adoption has a less pronounced interference with productive and recreational activities when compared to road closures or evacuation measures. Although the establishment of these artefacts is accepted in order to protect endangered goods, a number of other issues should be taken into account, including a short expected lifetime, a range of effectiveness limited to one single hazard, visual impact, and high construction and maintenance costs [16].

Finally, the most relevant nature-based solutions against gravitational hazards are protection forests. Historically, the protection role of forests in mountainous areas has always been recognised and preserved [55], whereas only recently has their service started to be modelled by means of a scientific approach, also in relation to the increasing number of natural and social threats triggered by climate change [9]. Several studies have demonstrated the effectiveness of managing forests to maintain or increase their protective function [56,57], underlining the importance of various factors such as stand density, basal area, specific composition, and structure [58,59]. Numerous studies have already illustrated the various silvicultural practices that can be used to favour the ability of forests to mitigate these risks [60–62]. The aim of these interventions is usually to promote the development of uneven-aged stands [63,64], preserving some trees with large diameters [58] to increase their resilience towards disturbances [65]. Therefore, the main benefits of adopting forests as protection measures are their cost-effectiveness, the long-term efficacy, the positive visual and environmental impact of their implementation, and the multihazard effectiveness [60]. On the other hand, their role can be relevant only within a certain threshold of event intensity and frequency (similar to the artificial structures, but unlike land use limitations), and they are subject to events that can compromise their effectiveness (such as fires and pathogen outbreaks) [19]. In any case, questions related to the possible ES trade-offs [66,67] and to the profitability of the interventions still remain, given the high harvesting costs of these stands [41,61,68].

From a perspective of supporting forests as a nature-based solution to provide protection against natural hazards, their presence should be mapped and their features measured to assess their role, potential or actual, in supplying this service. Therefore, the results of the Supply side of the framework consist of the zonation of the area of interest, illustrating the protection supplied by all the mitigation measures described above. Moreover, an evaluation of the effectiveness of these solutions should be included and displayed in the maps in order to classify the SES accordingly.

2.5. Zonation of the Area

The integration of the supply and demand sides of the framework provides manifold results for the development of integrated grey-green risk management strategies. The first layer of the map, the demand, divides the SES into areas characterised by different intensities of risk, highlighting those where the probability of various gravitational events is higher and the need for protection of the stakeholders is at its maximum. Therefore, management strategies on these sites aim to reduce the risks and meet stakeholders' needs. Successively, other areas with lower levels of demand are identified, and where demand is absent, the lowest priority category is assigned.

In parallel, the supply side provides a similar but reversed zonation of the SES. In this case, the most important sites correspond to the areas where the provision of protection supplied by forests and other solutions is lacking or very low. As occurred previously, a lower priority level can be assigned to areas where protection forests are effective. Once the two layers have been acquired, their comparison enables the identification of four regions characterised by different needs and aims, as shown in Table 1.

Table 1. The combination of different levels of supply and demand of protection and their consequent policy insights.

		Protection Demand	
		Low	High
Protection Supply	Low	Increase resilience	Risk Hotspot
	High	Risk Coldspot	Increase Resilience

The Table depicts the possible combinations of different levels of protection achievable in the SES. Since the present framework does not deal with actual case studies and defined values, the terms "low" and "high" should not be intended as referring to precise values, but rather as levels to be compared in order to highlight gaps and peaks of protection. From the analysis of the four areas shown in Table 1, it is therefore possible to gain relevant risk management insights for the SES.

In the upper right-hand corner, we find the Risk Hotspot areas. Here, the demand for protection is high due to significant environmental risks threatening stakeholders, while the supply of protection is low or, in any case, insufficient. This is the scenario presenting the highest risk level and should be considered as the most urgent to be addressed, deserving the greatest effort to improve the current situation. Possible solutions are represented by an increase in the protection supplied by adding artificial facilities or, if present, improvement of the forest effectiveness through management dedicated to its protective function. Concerning land use limitation measures, it should be noted how the existing strong social pressure already sustained by these areas suggest the limitation or avoidance of their adoption. These measures entail strong societal resistance; therefore, they should be implemented only in situations of extreme and immediate risk, when other alternatives are lacking. Conversely, the Risk Coldspot areas depicted in the lower left-hand corner of Table 1 represent the least problematic sites of the SES. In this case, the protection provided is enough to fulfil stakeholder needs; therefore, no specific action is required. Nonetheless, from a long-term perspective, maintenance of the current mitigation measures, in order to preserve their effectiveness, should not be disregarded.

In the remaining two cells of the matrix, similar conditions are envisaged. To all effects, in both cases, the protection supply and demand are similar, resulting in safe conditions. Nonetheless, small changes in the current situation could easily alter this unstable equilibrium, putting goods and people once considered safe at risk. In consideration of this aspects, the two areas represent the second most urgent regions where effort needs to be spent to improve the current situation. Therefore, decision-makers should focus on increasing the territorial resilience of the SES and, where possible, improving the provision of the protection ES. Nature-based solutions such as protection forests can play a relevant role in achieving this goal, providing long-term protective measures able to adapt to possible variations in both supply and demand. In addition, the social components of the SES should be equally considered in order to support the relevant role that stakeholders can provide in steering the protective needs of the SES by means of their perceptions of risk [69–71].

2.6. Development of Integrated "Grey-Green" Risk Management Strategies

In consideration of the different features of the protection measures and of the different needs of each situation displayed in Table 1, an effective risk management strategy should involve reliance on the mutual integration of several measures to achieve the highest protection. In this respect, protection forests have emerged, once more, as the most suitable protection measure for this purpose due to their adaptive features, allowing their design as a complementary solution to artificial defensive facilities [19,41]. This mixed mitigation strategy, here named "grey-green", is consistent with the precautionary principle expressed above and implies several advantages that could help decision-makers and practitioners to meet the policy recommendations reported in Table 1.

The presence of a protection forest stand (the "green" side of the strategy) together with a defensive facility (the "grey" one) ensures an increased reduction in the propagation probabilities of hazards and the establishment of a resilient mitigation measure. In most cases, this solution can be achieved through dedicated management of the forest situated above the previously built structure. Nonetheless, if properly planned, this solution can also be adopted for newly established facilities. More specifically, the implementation of artificial structures on sites where protection forests are already effective but not sufficient to fulfil the stakeholder needs implies the construction of smaller structures, without eroding the overall protection level supplied, and consequently achieving a relevant optimisation of the implementation costs of the facility. Taking the forest role into account would effectively determine a decrease in the structure size while maintaining the high protective performance required. Thus, this grey-green strategy would ensure the highest cost-effectiveness ratio among the mitigation measures available, combining the silvicultural practices necessary to manage the forest with the scientific knowledge to evaluate its effectiveness. Such strategies are particularly suitable for those areas characterised by no urgent protection needs but where an overall increase in resilience of the SES is desirable (see Table 1). There, the integration of different solutions would naturally lead to achieving a protection level able to both satisfy the current needs and to adapt to possible future variations, due to the inherent features of resilience of the protection forests.

3. Discussion and Conclusions

In the light of increasing societal pressure on mountainous areas and the rising intensity and frequency of natural hazards triggered by climate change, a shift in the current protection paradigm is needed. As shown in the present paper, standard risk management strategies considering only land use limitations and artificial protection facilities should recognise the role of nature-based solutions in mitigating gravitational risks and include them among the available protection measures. When properly managed, protection forests, due to their resilience and long-term effectiveness against several hazards, have proved that they can fulfil the protection needs of the stakeholders. Therefore, in order to provide instruments to be applied in real case studies, we deemed the creation of a conceptual framework to simplify complex systems, providing support in order to prioritise the interventions and enhance the relevance of the decisional process policies, as stated by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) [72]. The creation of frameworks is considered a common step to operationalise the ES concept and territorial resilience, two boundary concepts often believed to be lacking actual applications [71,73,74]. This framework recognises the importance of integrating nature-based solutions into mixed grey-green strategies, fostering their adoption through a roadmap to be implemented by regional public authorities and decision-makers. Naturally, it would not be possible to replace artificial structures entirely by natural systems like forests, but a better knowledge of the ES the latter supply would allow for cost-effective and sustainable environmental planning. Moreover, this SES approach would allow the improvement of the territorial resilience of the area of interest, the implementation of a participative approach to land planning, and the achievement of a long-term minimisation of environmental risks at the landscape level [51,75].

Nonetheless, some limitations need to be taken in account. First, the time scale: while spatial aspects are included in the SES definition, the temporal consequences of risk management strategies should also be considered. The mitigation measures available are characterised by very different performances in the short (0–25 years) and long (25–100 years) term. While land use limitations are always effective, artificial protective structures may be considered highly effective in the short term, given the design and building timeframe, but are subject to an abrupt decrease in their performance by the end of their expected lifetime. Conversely, forests may require longer periods to reach the relevant mitigation effects, but, if properly managed, their natural regeneration capacity ensures long-term effectiveness. In consideration of these aspects, the development of grey-green strategies should calibrate the presence of both measures in different timeframes in order not to fail in satisfying stakeholder needs. Moreover, forests are prone to biotic and abiotic disturbances, such as insect outbreaks, wildfires, and windstorms. Fostering an increase in the resilience of protection forests, this framework would bring positive outcomes on the ability of these stands to face these threats whose impact is currently more relevant than ever in past millennia [76]. Since a targeted forest management would help to reduce, but not to overcome, these risks and would adapt to their effects, a review of management strategies should be planned. A cyclical repetition of the process, taking into account the expected positive or negative variations of effectiveness of the protective solutions and revising the prioritisation of the area accordingly, is therefore recommended.

The legislative context should also be considered when adopting this framework. Since the SES boundaries at the landscape level often cover more than one municipality, the development of a risk management strategy should be implemented in a shared and participative way in order to cover the whole area subject to these natural hazards. Nonetheless, this could be hampered by jurisdictional limitations which may differ from country to country, or even among different regions, as is the case in Italy [52]. This would necessarily represent a limit to the implementation of strategies capable of taking into account the demand side of this ES and the consequent channelling of this demand into the legislative planning instruments of the area.

Nonetheless, the next steps in the development of the present study will consider its adoption in an existing study area in order to support the inclusion of protection forests in local integrated risk management strategies. In this light, the efforts of several INTERREG Alpine Space projects, such as "RockTheAlps" and "GreenRisk4Alps", are noteworthy in recognising the role of protection forests and in promoting their importance among stakeholders and decision-makers. It is the authors' intention to apply the present framework to the study areas selected by these projects and to achieve the results envisaged by the present framework.

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