Mountain geoecosystems. GIS modelling of rockfall and protection

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SUMMARY

Many livelihoods in the European Alps rely heavily on mountain forests for protection against rockfall and snow avalanches. Mountain forests provide this protection in the long term only if they are managed adequately. Forest management, also known as silviculture, requires information about the state, the dynamics and the future development of the forest ecosystem. The main objective of this study is to develop an efficient method which gives information on the level of protection mountain forests provide against rockfall at a regional scale (~500 km^2) to improve management of those forests.

Management of protection forests aims at maintaining forests in a stage during which effective protection is secured in the long term. As the natural evolution of a forest ecosystem is a dynamic process, 'close-to-nature' silvicultural interventions have to be pinpointed and executed well to maintain or improve the stability and the protective function of the forest ecosystem. Currently, forest authorities are aware of techniques to improve the stand stability of protection forests, but the problem is that forest management is often still a kind of trial and error, because the exact consequences of interventions for forest ecosystem dynamics are not known.

Before developing management plans for specific forests stands, regional scale information on the forest cover is needed. Remote sensing is often considered a useful basis for preparing regional forest cover maps. In general, a forest stand type map of a homogeneous forest covering flat terrain derived from a Landsat Thematic Mapper (TM) image is fairly accurate. However, in case of a heterogeneous forest covering rugged terrain the accuracy decreases. The accuracy of the derived information can be increased by correcting the DN values of a Landsat TM image for the topography and by using the digital elevation model (DEM) as an additional band during the classification. Local foresters consider the results of an object-based classification better than those of a traditional classification technique. The advantage of object-based classification is that the derived digital map is composed of objects which correspond with forest stands. Such a map with delineated forest stands is a useful basis for setting up a regional forest inventory.

In addition to forest cover data, knowledge of rockfall mechanics is required for modelling the interaction between rockfall and protection forests. A review of the most important rockfall modelling approaches indicates that a Geographical Information System (GIS)-based distributed model, which combines a detailed process-based model and a GIS, would be most suitable for predicting rockfall runout zones at a regional scale.

For developing such a model, more insight into the relationship between protection forests and rockfall impacts is needed. Therefore, a detailed investigation at a slope scale is carried out, which combines field and modelling techniques. In this study the determining factors for rockfall source areas, rockfall tracks and rockfall runout zones on a forested slope in mountainous terrain are assessed. The area under investigation was mapped geomorphologically and the major planes in the bedrock exposed in the rockfall source areas were measured. At a test site, which is defined for validating the developed rockfall model, both a forest and a slope inventory were carried out to obtain detailed forest and slope surface characteristics. These data serve as input for the developed rockfall simulation model, which allows assessing the slope characteristics that mainly determine the distribution of rockfall accumulation areas. The geotechnical measurements show that all the mapped steep cliff faces are potential rockfall source areas. Therefore, all these cliff faces are defined as start areas in the developed simulation model. By defining in the developed model that firstly, the amount of lying tree stems, secondly, the surface roughness and thirdly, rockfall resistant shrubs determine the energy loss of falling rocks, if they do not collide with standing trees, the model shows the best similarities with reality regarding present rockfall accumulation areas. Older rockfall accumulation patterns could be reconstructed by removing the current forest cover in the developed model. It is concluded that a combined approach as applied in this study is a prerequisite for obtaining insight into the dynamics of rockfall on a forested slope.

The previous study provides sufficient basis for developing a regional scale rockfall simulation model in which protection forest structure is incorporated. This developed simulation model is used to predict patterns of rockfall runout zones at a catchment scale. In addition, the developed model is compared with two existing regional scale rockfall models. The developed model is the only model that calculates the rockfall velocity on the basis of energy loss due to impacts on trees and the soil surface. The two existing models calculate energy loss over the distance between two cells centres on the basis of a friction coefficient. The patterns of rockfall runout zones produced by the three models are compared with rockfall patterns derived from geomorphological field maps. Furthermore, the rockfall velocities modelled by the three models are compared. It is found that the three models produce rockfall runout zone maps with rather similar accuracies. The developed model however performs best on forested slopes and it also produces velocities that match best with field estimates on both forested and non-forested slopes irrespective of slope gradient.

The subsequent accuracy assessment indicates that rockfall simulation at a regional scale using a GIS-based distributed model is feasible and realistic regarding simulation of rockfall runout zones, but not regarding simulation of tree damage caused by rockfall. The latter is mainly caused by the fact that tree damaged by rockfall cannot be simulated accurately at a large support. This study also shows that the use of a regional DEM with high quality requires data on forest structure with a much higher quality than the use of a regional DEM with poorer quality.

Finally, it is concluded and discussed that the developed method genuinely helps improving management of mountain forests that protect against rockfall. Summarising, the techniques used and developed within this study could improve management by applying the following approach:

- Forest could be characterised at a regional scale as detailed as possible by combining remotely sensed data and forest inventories.
- Then the protective function against rockfall at regional scale could be assessed with the developed regional rockfall model.
- On this basis, areas could be defined for high priority silvicultural interventions.
- For those areas, a slope scale assessment, using combined field and modelling techniques has to be carried out.

In the future this will include combined forest growth – rockfall modelling, which allows the evaluation of the effects of different silvicultural interventions. On the basis of modelled scenarios the optimal silvicultural measures could be defined.