Application-oriented approach to monitoring the dynamics of avalanche tracks using conventional forest inventory parameters and Lidar-based change detection.

V. Berger[1,2], H. Kirchmeir[1], M. Hirschmugl[3,4]

[1] E.C.O. Institute of Ecology, Lakeside B07b, 9020 Klagenfurt, Austria
Email: {berger; kirchmeir} @e-c-o.at

[2] Carinthia University of Applied Sciences, Europastraße 4, 9524 Villach, Austria

[3] Joanneum Research, Steyrergasse 17, 8010 Graz, Austria
Email: manuela.hirschmugl@joanneum.at

[4] University of Graz, Heinrichstr. 36, 8010 Graz

1. Introduction

Sites affected by avalanches are considered as highly dynamic sites and are therefore of high ecological value. A wide spectrum of environmental conditions occurs in a narrow space. Due to the uneven mechanical impact of avalanches within the avalanche path, important niches and microhabitats are generated. Often adjacent forest stands cause a braking effect due to deadwood, uprooted trees and breaking trees (Bartelt and Stöckli, 2001). Depending on the size of the avalanche, damage to tree cover can be limited to the loss of a few trees, but can also clear several hectares of mature forest stands (CCA, 1995). All these processes lead to a heterogeneous habitat mosaic, which has a positive effect on species diversity (Rixen and Brugger, 2004). Aside from the effect on biodiversity, the protective function of forest stands also plays an important role in alpine regions. To capture the impact on and of forests, topographic Lidar can be used to simulate runout scenario based on vegetation height models (Brožová et al., 2020). Forest and vegetation structure, on the one hand, influence the flow of avalanches and are, on the other hand, formed by the impact of avalanches. Therefore, monitoring the vegetation structure is an essential prerequisite to understand the dynamic processes within the avalanche tracks.

In order to capture the dynamics of avalanche tracks, multi-temporal area-based topographic Lidar data are of high benefit in addition to conventional forest inventory. A comparison of laser scanning data at two different points in time was used here to capture the dynamic of the avalanche path.

2. Data and Methods

2.1 Study Area, Data Acquisition and Processing

The study area is located to the southeast of Tamischbach Mountain in the Gesäuse National Park, Austria. Inventory plots are located at two avalanches paths in this area. The avalanche path Brett in the east covers an area of four hectares and is characterized by grass- and shrubland. The second avalanche path in the west is called the Hochkar, which can be divided into areas with frequent avalanche influence and areas which are only influenced during extreme events. The last extreme event happened in 2005.

Table 1. Technical specifications of ALS data used.

Year	Sensor	Point density	Frequency
2010	Riegl LMS-Q560	Min. 4 pts/m² below 2000 m a.s.l.; min. 2 pts/m² above 2000 m a.s.l.	200 KHz
2020	Riegl VUX240	200 pts/m²/overpass; 2 overpasses = 400 pts/m²	1.8 MHz

In 2010 a terrestrial baseline survey at 32 monitoring points was realised (Carli and Zimmermann, 2011). In 2021 the survey was re-conducted according to the methodological guideline for forest inventory of the Gesäuse National Park (Carli and Kreiner, 2009; Berger et al., 2020). In addition, high-resolution aerial imagery and airborne laser scanning data (ALS) were recorded in the study area. The aerial survey took place on 6/5/2020. During the evaluation, the current laser scanning data was compared with an existing laser scanning dataset from 2010 (source: GIS-Steiermark). The technical details of both ALS campaigns are shown in Table 1. Clearly, the two datasets are not fully comparable due to better sensor and lower flight altitude in 2020 compared to 2010.

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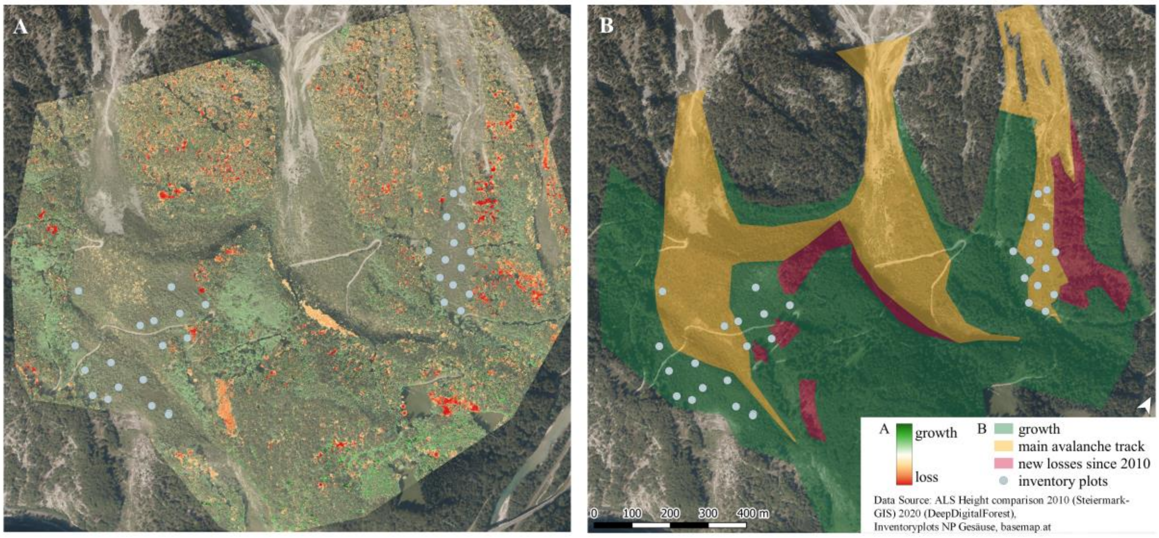
2.2 Methods

The comparison of the height provides an insight into the change in vegetation height, which records the development of the vegetation since the last aerial survey. Image processing followed standard Lidar data handling. From the 2010 data, a digital terrain model (DTM) was generated using the point classification and a set of interpolation. This DTM was used to calculate vegetation height in both time periods for two reasons. First, there are not major changes in the terrain to be expected and second, we wanted to avoid potential differences coming from the data properties and processing to jeopardize comparability. For both time periods, digital surface models (DSMs) at a spatial resolution of 0.5 m were extracted using only points classified as vegetation. Clearly, the 2020 data would allow to extract a much higher resolutions DSM based on the given point density, but again, for comparability, we decided to process both data set to the same spatial resolution. As the maximum value per pixel is extracted from the laser scanning data, no overall bias caused by the different point density is to be expected. These DSMs were combined with the DTM to generate the two vegetation height models. They were clipped to a maximum of 60 m to remove outliers, mainly stemming from birds in the high resolution 2020 data. This clipping further reduces differences caused by the different acquisition settings rather than vegetation changes. Finally, both nDSMs were smoothed by a 3x3 median filter. The two vegetation height models were then subtracted to visualize the patterns of vegetation change. The colours represent the changes in vegetation height: while greenish colours indicate vegetation growth, yellow-orange colours indicate areas where the trees have been pushed down by avalanches. The small red patches are missing individual trees that had fallen between surveys (Figure 1).



Data Source: ALS Height comparison 2010 (Steiermark-GIS) 2020 (DeepDigitalForest), Inventoryplots NP Gesäuse, basemap.at

Figure 1: A) The difference in vegetation height between the years 2010 (source: GIS-Steiermark, 2010) and 2020 (DeepDigitalForest) shows the loss of trees (orange to red) and the growth of trees (green) B) The green area reflects an increase in vegetation height since 2010, the main avalanche track is displayed in orange and the loss of forest stands since 2010 in red.

3. Results and Discussion

From the orthophoto, it can be seen that some trees have fallen due to an avalanche event, as the orientation of the dead wood coincides with the flow direction of the avalanche track. The red patches in the map indication significant loss of vegetation height where individual trees have fallen. The yellow-orange areas indicate areas where trees have been downed by avalanches, but most have not been destroyed. Open areas without significant regeneration since 2010 show no increase in stand height. A general growth of trees can be observed in areas of closed forest stands that have not suffered impact of avalanches during the period considered. On the map, some gaps caused by natural mortality of individual trees are visible. Thus, growth can be used to infer the impact of avalanche events on the tree population. When analysing the entire avalanche path, it is clear that only small-scale tree stands have been destroyed by avalanches since 2010.

Based on the 116-hectare survey area, 41 hectares have been affected by avalanches on a more or less yearly basis since 2010. These areas are characterized by grassland and lying or hanging living young trees with an average diameter at breast height (DBH) of 30 mm. Since 2010, about 7 hectares of previously mature forest was changed into grassland due to an avalanche event. There are also 68 hectares within proximity to the affected area which show an increase of height compared to 2010. The results of the ALS height comparison reflect the forest stand parameters that were assessed within the conventional forest inventory. The basic structure of the vegetation distribution can also be read from the laser scanning data. While the Hochkar avalanche path has average vegetation heights of 2.06 m, the Brett avalanche track has significantly lower vegetation with heights of only 1.32 m on average. The standard deviation is on a similar level with 2.35 m and 2.15 m, respectively.

4. Conclusions

The recording of forest structure in the context of long-term monitoring with conventional survey methods is particularly difficult. A description of the forest structure with lying trees is often impossible with existing inventory keys. Above all, the threshold values are not designed for the representation of lying or hanging trees. The application of a clipping threshold, whereby only trees above a certain diameter are surveyed, results in hardly any trees being recorded, although the biomass on the plots is relatively high due to the dense stand despite the low DBH. Furthermore, the recording of single trees from a height of 5 m leads to the fact that living trees that are lying or bent are not recorded, because their absolute height above ground is below this threshold. An extension of the existing inventory keys is therefore inevitable, especially for ecological questions that exceed the forestry usability.

By combining methodological conventional in-situ approaches with topographic Lidar technologies, a higher comparability of parameters, such as structural elements, can be achieved since they no longer depend solely on the estimation of the operator. The two-dimensional recording of the forest structure by means of aerial laser scanning images makes it possible to record the forest structure and the individual trees along the entire avalanche path.

The main advantages of the topographic Lidar approach in the practical assessment compared to field measurements are:

- the wall-to-wall information without any interpolation needed
- the information on otherwise inaccessible areas
- the area-based change detection on vegetation dynamics

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