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Cutting patterns as a predictor of the odds of accident among professional fellers

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ABSTRACT

The increasing share of forests that are damaged due to natural disturbances potentially increases the risk of accident when cutting the affected forests. The main goal of the study was to analyse the odds of accident by type and causes of cutting. The study was based on 316 accidents among professional fellers during cutting in Slovenian state forests over a 7-year period. The two most rational binary logistic models were selected by using Akaike's Information Criterion. The research results indicated that the odds of accident increase with the slope of the terrain and total volume of felled trees. Contrary to expectations, the odds of accident are highest during the cutting of individual healthy and undamaged trees, lower in deforestation due to urbanisation and infrastructure requirements, which is similar to clearcutting, and lowest during the cutting of trees damaged by biotic and abiotic factors. As an individual cause of accident, cutting trees damaged by insects, fires and emissions is the least dangerous, while cutting trees damaged by glaze ice and snow is the most dangerous. The results indicate that, in addition to natural factors, the likelihood of cutting-related accidents also depends on the time of exposure to hazards, type of harvesting and tree characteristics. On the basis of the results, it is concluded that measures to reduce the likelihood of professional fellers must be particularly focused on routine tasks and on adjusting the work pace and technique to the working conditions.

1. Introduction

In terms of its characteristics, tree cutting can be divided into the cutting of undamaged trees and the cutting of damaged trees. Undamaged trees are usually harvested according to the forest management plan or for forest road network construction or other non-forestry land use. The cutting of dead and damaged trees, with the main purpose of preserving the economic value of wood, is called salvage cutting, whereas sanitation cutting refers to cutting to prevent the spread of pests and diseases (Kennard, 2008). Despite having different definitions, both types of cutting may often be carried out simultaneously, since timely intervention is both economically and ecologically justified. Salvage cutting may be necessitated by fires, insect infestations, storms, floods, landslides and volcanic eruptions (Lindenmayer et al., 2008). The reasons for sanitation felling may be the same as those for salvage cutting, or they may be related to some other environmental conditions, such as overstocking, drought, air pollution, site conditions, and pests and diseases that limit the resistance of trees and thus increase their decay (Kennard, 2008).

The quantity of wood felled within the scope of salvage cutting represents a significant share of the total cut volume in many countries (Lindenmayer et al., 2008). From 1950 to 2000, 35 million cubic meters of wood that was damaged due to natural disturbances was felled on average in Europe. Storms caused 53% of the harvesting, fires 16%, insects 8%, snow 3% and other biotic and abiotic factors 20%. The quantity of damaged wood represented 8.1% of the total cut volume (Schelhaas et al., 2003). However, there are large differences between individual years and countries. In the 1995–2008 period, the average share of salvage and sanitation cutting in Slovenia was 32% of the total cut volume and 46% in 1996 (Jošt and Kolšek, 2009). In 2014, only one severe weather event, i.e. glaze ice, caused 9 million cubic meters of damaged wood in Slovenia (SFS, 2014), a quantity twice that of the allowable annual cut for 2014. Similarly, in France storm-damaged wood volume reached 325% of average annual removal after windstorms in December 1999 (CTBA, 2004). An increasing amount of damaged forest has been noticed for almost all causes. This trend is the consequence of the increased hazard due to climate change, increased vulnerability of forests due to degraded natural structure and

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higher exposures due to large forest surfaces and growing stock (Schelhaas, 2008; Seidl et al., 2014).

Because of felled and broken as well as standing dead or hung-up trees, types of harvesting and cutting not only have environmental and economic consequences, but they also affect work safety. Harvesting in changed conditions differs from regular work. This particularly applies to forest operations after windthrow, which have a high risk of accident (ILO, 1997). Thus, the findings of some authors indicating that the number of accidents and fatal accidents increased due to windstorms (Ammann et al., 2002; Tsioras et al., 2011, 2014) are not surprising. On the basis of a risk analysis, Sullman and Kirk (2001) established that the risks of accidents during felling after windthrow are different and potentially higher than in normal conditions. They cited work under broken tree crowns or branches and hung-up trees as the most dangerous procedures, with such work also resulting in frequent fatalities (Peters, 1991).

According to the ''causal" model of accidents in forest operations (Slappendel et al., 1993), the likelihood of accidents is not only influenced by operator error, where work-safety violations are most common (Rigling, 1976), but also errors associated with system failures and relatively unmanageable natural factors (terrain, climate, stand). The prevention of accidents must thus be focused not only on the reduction of human errors, which cannot be eliminated completely, but also on the reduction of hazards in the working environment (Pettersson et al., 1983).

Therefore, the main objective of the study was to calculate the odds of accidents among professional fellers by type of cutting and individual causes of tree felling. Given previous research, it is reasonable to expect that the likelihood of accidents in forests where sanitation and salvage cutting are carried out would be higher than that during the cutting of undamaged trees.

2. Materials and methods

2.1. Study area

The study covered 316 accidents among professional fellers that occurred in Slovenian state forests over a 7-year period. During this period, 5,684,724 m^3 of wood was felled in the 9758 compartments included in the study. During the research period, cutting was mostly carried out motor-manually by chainsaw, whereas the share of fully mechanized harvesting (cut-to-length logging), which strongly reduces the probability of accident (Axelsson, 1998), was relatively low (Beguš and Krč, 2012).

The research data were acquired by merging two databases (Fig. 1). The first database included data on the location (compartments) of accidents among professional fellers employed by forest companies with a concession for the exploitation of state forests. This database is collected and updated in cooperation with these forest companies at the Department of Forestry and Renewable Forest Resources, Biotechnical Faculty, University of Ljubljana. The second database is the forest inventory database provided by the Slovenia Forest Service and includes, among other data, information on the cut volume by the type and cause of cutting (reason for individual tree selection for cutting) for individual compartments (SFS).

Both databases were merged at the level of compartment. The compartments had an average size of 39.2 ha at the state level and were used as the sample unit in the study. The type and cause of cutting and accident occurrence was annually assigned to the compartments. Despite the fact that in the forest management plan only one cutting intervention is planned in a 10-year period, cutting may be carried out more frequently in individual compartments due to unplanned felling. Thus, in the research period, cutting was carried out only once in 55% of compartments, twice in 29%, and even three times or more in 16%. Similarly, 95% of accidents occurred in different compartments, and 5% (or 10 cases) occurred in the same compartment.

2.2. Statistical analysis

2.2.1. Model definition, building and selection

To analyse the impact of the types of cutting and cutting causes on the odds of accident occurrence, multivariate binary logistic regression was applied. This analysis has already been used in some other accident studies (Al-Ghamdi, 2002; McLeod et al., 2003; Sze et al., 2014). In binary multiple logistic regression, the odds of each outcome are specified as:

$$\ln \frac{P\left(Y = \frac{1}{x_1, x_2, \ldots, x_n}\right)}{1 - P\left(Y = \frac{1}{x_1, x_2, \ldots, x_n}\right)} = \operatorname{logit} P(Y=1) = b_0 + b_1 X_1 + \cdots + b_n X_n \quad (1)$$

where P is the accident probability at the sample object, x denotes the value of the independent variables and b denotes the model coefficients. The level of significance of the independent variables influences the likelihood of accident, reflected in the respective p-level. The maximum likelihood estimation procedure was employed to estimate the value for model parameters from 1 to n parameters (Hosmer and Lemeshow, 2000).

For the purpose of this study, two groups with four binary multiple logistic models were defined (Fig. 1, Table 1). In the ''types" models the odds of accident were explained with cutting types variables, and with cutting causes variables in the ''causes" models. Both types of variables were used as continuous or binary (denoted as BIN in models) scaled.

All models were constructed on the basis of previous research on accident risk during harvesting (Poje, 2006) and the goal of the study. The first models (Table 1) in both groups examined the impact of total cut volume (denoted as ALL in models) on accident odds. In the second models, the cut volume was presented with cutting types (T_i) or causes (C_i), and the slopes of the linear regression lines were compared. The third models compared regression line slopes and parallel deviations from those lines with the use of a binary form (denoted as BIN in models) of cutting types or causes variables. The fourth models are a combination of the first and third models, with one regression line and several parallel deviations from this line.

All models contain the control variable, the slope of the terrain (denoted as S in models), as one of the most important worksite variables influencing the risk of accident (Poje, 2006). Because the odds of accident in the models were assumed to be the result of all work done inside the compartment, each model contains the total volume of wood harvested in compartments.

In the first stage of model building, the linearity in the logits was visually checked by using the plots of estimated logistic regression coefficients versus quartile midpoints (Hosmer and Lemeshow, 1989). Based on the results, all continuous scaled variables in the models were assumed to be in a linear relationship with the risk of accident.

For the model selection, the principle of parsimony was used as in other studies from the field of safety research (Sze et al., 2014; van Petegem and Wegman, 2014; Shen and Neyens, 2015). This principle is based on the trade-off between bias and variance versus the number of estimable parameters in the model. As the number of parameters in the model increases, the bias decreases, but the variance increases (Posada and Buckley, 2004). The evaluation of the most parsimonious model to explain accident probability was based on Akaike's Information Criterion (AIC) and AIC weights,