Modelling the damage status of silver fir trees (Abies alba Mill.) on the basis of geomorphological, climatic and stand factors

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Abstract

The paper investigates the possibility of assessing damage (health status) of silver fir (Abies alba Mill.) using multivariate regression models in the function of geomorphological, climatic and stand factors. Research was carried out in beech-fir forests (Abieti-Fagetum), on limestone-dolomite substrate, in the Dinaric part of the silver fir range in the Republic of Croatia. A general linear modelling method was used, where square terms and interaction terms (multiplication products) of original variables were treated as independent linear predictors. Twenty-seven separate models (all of them with significant part of explained fir damage variability) were developed regarding the different subsets of input data, different subsets of independent variables and different model design. Some of these models could be preliminary used for spatial predicting and mapping of fir damage in a frame of raster-GIS, for entire area of Dinaric part of Abieti-Fagetum in Croatia.

1. Introduction

Forests are permanently influenced by numerous biotic and abiotic factors. Some of these lead to the weakening of life force (vitality) and dieback of forest trees. Forest conditions depend on soil, tree age, climate, pests and diseases and other natural stressors (Aamlid et al., 2000).

Beech-fir forests (Abieti-Fagetum) are the most widely distributed alimontane forests on Croatian karst, taking up an area of over 300,000 ha (Trinajstić et al., 1992). These are uneven-aged forests (stands containing trees of different heights, diameters and ages over a unit area) managed on a selection basis. Accounting for 10% in the total growing stock, fir is one of the most important tree species (and the most important conifer species) in Croatia (Mestrović, 2001). For some time now silver fir has been faced with growing damage and decline. The direct consequence of increased tree damage (decreased vitality) is reflected in a reduced increment (Bert, 1993; Bezak et al., 1991; Kalafadžić and Kušun, 1989; Klepac, 1972, Pernar et al., 2000, Prpić and Seletković, 1992, Prpić et al., 1994, Schipper and Hradetzky, 1986). An increase in the damage degree reduces the variability of diameter increment, which means that damaged trees show a weakened reaction to environmental effects (Kalafadžić and Kušun, 1989).

Tomaševski (1958) puts the cause of intensive dieback of fir in Croatia immediately after the Second World War down to chaotic felling, which disturbed the biocoenological balance. Physiologically debilitated trees are prone to attacks by
secondary pests: bark beetles (Tomaslevski, 1958) and Argyresthia fundella (Andric and Klepac, 1969; Klepac, 1972). Prpic (1987) links their gradation to warming up and decreased humidity in the sites of fir forests. In recent times, a number of authors have connected increased dieback of forest trees (especially fir) in Croatia with the impact of harmful pollutants (Glavac et al., 1985; Kauzlarić, 1988; Plese-Lukeza, 1997; Prpic, 1987), similar to other authors in different countries (Aamld et al., 2000; Innes and Cook, 1989; Lagana et al., 2000; Nellemann et al., 2003; Oszlany, 1997). The highest degree of damage is seen in trees on massifs exposed to prevailing winds (Bert, 1993), which probably bring pollutants (Antonic and Legovic, 1999). The real causes of fir dieback in Croatia are still unknown, and so are the causes of decline of some other tree species (see, e.g. Akashi and Mueller-Dombois, 1995).

Health condition of stands is also affected by geomorphological factors (terrain aspect, slope and altitude). In his study of fir tree dieback, Tomaslevski (1958) concluded that dieback was more intensive on the warmer terrain orientations than on the colder ones. Safar (1951) and Prpic and Seletkovic (1992) reached similar conclusions relating to more intensive damage in warm positions. A higher terrain slope and altitude also increase damage to fir trees (Kalafadzic et al., 1992; Prpic et al., 1991; Seletkovic and Potocic, 2001; Safar, 1951). In none of the above research into dieback of fir trees in Croatia were geomorphological variables used as predictors for the assessment of the damage degree.

Olthof et al. (2004) and Zierl (2004) investigate forest damage on the basis of climatic indicators. Dobbertin and Brang (2001) prove the correlation between tree mortality and tree damage of the previous year and the social position of a tree in the stand, whereby the impact of competition is regarded as a stress factor. According to Heski (1990), the thickest and thin trees (in a selection forest) are less resistant to the impact of defoliation-related factors than medium-thick trees. Greater damage to thin trees is probably the consequence of exposure to air currents and air pollutants. Tree age (which in a fir, as a sciophylic species is not necessarily correlated with tree thickness) is an important factor that affects defoliation (Klap et al., 2000; Mayer, 1999; Pouttu and Dobbertin, 2000; Seletkovic and Potocic, 2001; Safar, 1965).

This paper investigates the possibility of assessing and making spatial predictions of the damage (health) status of silver fir in Croatian karst beech-fir forests as the function of geomorphological, climatic and stand factors (especially in the light of recent experiences with the application of raster-GIS modelling in ecological research of karst areas (Antonovic and Legovic, 1999; Antonovic et al., 2000, 2001a, 2003)).

2. Materials and methods
2.1. Study area
Research was carried out within the area of beech-fir forests (Fig. 1a) on limestone-dolomite substrate in the Dinaric part of the silver fir range in the Republic of Croatia (following Trinajstic et al., 1992), as most frequent, economically most important and most endangered (regarding the fir health status) forest type with fir as dominant (or co-dominant) species.

2.2. Forest damage data
Data used as dependent variables for model development were collected with field sampling in 151 plots (Fig. 1b). One to four trees of varying breast diameters (10–30, 30–50, 50–70 and >70 cm) closest to the plot centre were sampled in each plot. The plots were organized in transects, traced to cover existing local variability of geomorphological variables (altitude, terrain aspect and slope). A total of 531 trees of silver fir (Abies alba Mill.) were sampled.

To perform the damage assessment, tree crowns were compared with the existing photo-interpretation key (Anon., 1989; Kusan et al., 1991), on the damage scale of 5%.

In addition, data collected independently of this research within the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects in Forests (ICP Forest) were compared with the results obtained by spatial predictions using developed models. Data from the points of 4 km × 4 km and 16 km × 16 km networks were used, in which there were ≥6 (25%) of fir trees. The mean damage of fir trees was calculated.

![Fig. 1 – (a) Dinaric part of the silver fir range (grey area) on limestone-dolomite substrate in the Republic of Croatia (Trinajstic et al., 1992); (b) position of groups of sample plots and ICP forest plots.](image-url)
2.3. Independent variables

Independent variables used as a basis for the performed modelling of spatial damage distribution were divided into three groups: (1) climatic variables (monthly mean air temperature, monthly precipitation, monthly potential evapotranspiration on the horizontal surface at ground level and monthly potential evapotranspiration on the horizontal surface) as macroclimatic predictors, (2) geomorphological variables, all of them derived from a digital elevation model (DEM) in spatial resolution of 100 m × 100 m (altitude, terrain slope, terrain aspect, flow accumulation, sinkhole depths, terrain curvature indicators, terrain exposure to the horizontal wind flux), as topoclimatic predictors (Antonić, 1996; Antonić et al., 2001a) or as predictors of pollutant-related damage (Antonić and Legović, 1999); (3) stand variables (diameter breast height (DBH), tree basal area without age) and, therefore, influences erosion and deposition) and (2) in the direction perpendicular to the direction of the maximal terrain slope (profile curvature; affects the acceleration and deceleration of flow) and divergence of flow).

Terrain curvature (the rate of change of the surface slope in a given direction) was included in research with two variables: (1) in the direction of maximal terrain slope (profile curvature; affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition) and (2) in the direction perpendicular to the direction of the maximal terrain slope (planform curvature; influences the convergence and divergence of flow).

DBH was used as the estimator of social position of a particular tree in the forest, while gG was used as the estimator of silver fir damage status at the entire research area.
of competitors’ pressure. Tree age was also used as an independent variable due to the fact that it is not necessarily correlated with DBH in uneven-aged forests, especially those with sciophytic tree species like a silver fir. Stand variables were collected in sample plots. Plot basal area ($G$) was calculated as a sum of basal areas of individual trees (excluding those with DBH smaller than 10 cm) in a circular plot with a radius of 12.5 m. Tree age (above breast height) was calculated from long tree cores taken at breast height.

2.4. Models

A general linear modelling method was applied where square terms and interaction terms (multiplication products) of original independent variables were treated as independent linear predictors (Ott, 1993) of fir damage estimation. The ‘Backward Stepwise’ method (Ott, 1993) was used for model optimization (selection of a subset of linear predictors entering the final model). All statistical processing retained the significance level of $p = 0.05$.

During modelling, care was taken that the total number of estimators in the model (including all original variables, their squares and interactions) satisfies the condition: $2P + 1 < N$ (Ott, 1993), where $P$ is the number of parameters (estimators) in the model, and $N$ is the sample size (number of trees).

Twenty-seven separate models (see also Table 1) were developed regarding the different subsets of input data (all trees, trees with diameter over 40 cm and trees with diameter below 40 cm), different subsets of independent variables (limited number of DEM-based variables presumed as the most important estimators of tree damage, all DEM-based variables, all variables without age, all variables) and different model design (with and without square terms).

3. Results and discussion

Modelling results are summarised in Table 1. Parameters’ estimations for particular models were omitted and they are available on request. All models explain significant part of variability of damage status of silver fir at the research area. Both models developed from separate data sets with regard to diameter of 40 cm (presumed a boundary between dominant trees and suppressed or young trees) explained a significantly larger part of total variability (in all combinations of other mentioned model characteristics) in relation to the respective models developed for all trees together. Consequently, models developed for all trees were not examined any further, presuming that processes leading to forest dieback are significantly influenced by the social position of a tree.

All the remaining models were preliminarily used for the construction of hypothetical spatial distributions of fir damage for the entire fir area in Croatia. The criteria for the final selection of models potentially applicable to spatial prediction of fir damage was combination of: (1) total variability explained by the model ($R^2$) and (2) a portion of predicted values within the range of input data on fir damage (0–100%).

The selected models were applied to entire Dinaric part of Abieti-Fagetum area (Trinajstić et al., 1992), aiming at constructing a hypothetical spatial distribution of silver fir health status. This was done within the frame of raster geographic system (raster-GIS) using all geomorphological and climatic estimators in the spatial resolution of 200 m x 200 m.

For raster pixels without actual data for stand variables, mean values were used in those models that use these variables. Fig. 2 shows spatial distribution of estimated silver fir health status for two developed models (with and without stand factors included as estimators). Without more data from the field it is hard to tell whether obvious differences between two models presents better prediction with stand structures data included in the model (that higher $R^2$ suggest—Table 1) or drawback of using mean values for pixels without ground truth data. Answering that question will be one of the directions in our future research on the topic.

The interpretation of unexplained variability and a portion of predicted values in the expected range in all developed models (Table 1) could be addressed to: (1) the static nature of the model (the registered damage did not occur at once; climatic aberrations from the average were not included in the...
model (see, e.g. Zierl, 2004); (2) mechanically incurred damage (damage due to falling, tree logging, wind and snow impacts); (3) damage resulting from primary and secondary pest outbreaks (insects, see e.g. Androč and Klepac, 1969; Klepac, 1972 or fungi). (4) regularly applied management procedures (removing more severely damaged trees (Pripić et al., 1994; see also Oszlany, 1997) in some localities, which may decrease the mean tree damage in a plot (see, e.g. Pernar and Kutan, 2001; Seležko-Maletić and Škrlj, 1990); (5) the impacts of local pollutant sources, for example, along the roads (see, e.g. Ekstrand, 1994); (6) level to which sampled plots represents whole modelled area as observed in Köhl and Gertner (1997); (7) insufficient model complexity.

The six finally selected models (all with a reduced set of DEM-based variables and square terms; models 22–27) were tested on the independent data set collected within the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects (ICP on Forests (Anon., 1989). It has to be emphasized that ICP data cannot be interpreted in this research as fully reliable ground truth, due to the known problem of visual interpretation (especially in a case of larger number of field observers, which took a place here), highlighted by a number of authors (Bednarová, 2001; Dobbertin and Brang, 2001; Wilk et al., 1998; Wohlfahrt et al., 1998). Beside those limitations, ICP data remains only existing field data, hence, acceptable for model validation.

A significant correlation between model results was obtained only for trees thinner than 40 cm (Table 2). Absence of significant correlations for trees thicker than 40 cm can be explained by the impact of forest management that favours the removal of damaged mature trees, which is additional reason for partial unreliability of ICP data, as well for fm damage data collected in this research. This could be important input for future collecting of data in the dependence of forest management practice.

### 4. Conclusions

The obtained results could be preliminarily used for spatial prediction and mapping of fm damage within GIS for the entire area of Abieti-Fagetum in Croatian karst. Future research should focus on: (1) completing a larger field sample so that more plastic prediction models can be provided (e.g. developed by neural networks); (2) integrating spatial forest health prediction models with spatial models of air/pollutant immisions (Antonič and Legović, 1999) and other relevant factors, e.g. impact of pests and mechanically incurred damage; (3) including the temporal aspect of forest health; (4) using of more reliable ground truth data; (5) using of more advanced modelling techniques such as Neural Networks, Support Vector Machines and Naïve Bayesian Classifiers.

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### References


