Application of digital elevation model for mapping vegetation tiers

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ABSTRACT: The aim of this paper is to explore possibilities of application of digital elevation model for mapping vegetation tiers (altitudinal vegetation zones). Linear models were used to investigate the relationship between vegetation tiers and variables derived from a digital elevation model – elevation and potential global radiation. The model was based on a sample of 138 plots located from the 2nd to the 5th vegetation tier. Potential global radiation was computed in r.sun module in geographic information system GRASS. The final model explained 84% of data variability and employed variables were found to be sufficient for modelling vegetation tiers in the study area. Applied methodology could be used to increase the accuracy and efficiency of mapping vegetation tiers, especially in areas where such task is considered difficult (e.g. agricultural landscape).

Keywords: altitudinal vegetation zones; digital elevation model; linear models; vegetation tiers

In the Czech forest typology and geobiocoenology, the term vegetation tier has been introduced as an analogue of more general terms altitudinal vegetation zone or vegetation belt (see Zlatník 1976a). Altitudinal zonation of vegetation has been known for a long time (Huggett, Cheesman 2002). Altitudinal vegetation zones (or belts) have been recognized and studied in many regions in the world (Ellenberg 1986; Hegazy et al. 1998; Hemp 2006; Zhang et al. 2006). Vegetation tiers represent superstructural units in both typological systems for forest and landscape classification in the Czech Republic. The first one, the typological system of Forest Management Institute (FMI) (Randuška et al. 1986; Viewegh et al. 2003), finds its use mainly in forestry. The second one is the system of geobiocoenological typology (Buček, Lacina 2007) which is used to classify the whole landscape. Both systems characterize potential vegetation rather than the actual one.

Zlatník (1976a) defined vegetation tiers as "the connection of the sequence of differences in vegetation with the sequence of differences in the climate of different altitude and exposure climate". Ten vegetation tiers were distinguished in the former Czechoslovakia (Zlatník 1976b). The first eight tiers (1–8) were named after main woody species growing naturally in particular tiers under normal soil water content (oak, beech-oak, oak-beech, beech, fir-beech, spruce-fir-beech, spruce and dwarf mountain pine vegetation tier). Vegetation tiers are mapped based on the occurrence of plant bioindicators, site altitude, slope orientation, and terrain relief. The characteristics of vegetation tiers used in geobiocoenological typology were described by Buček et al. (2005), Buček and Lacina (2007). Differences in the typological system of FMI were described by Randuška et al. (1986). Holuša and Holuša (2008) described the detailed character-

Supported by the Higher Education Development Fund, Project No. 1130/2008/G4, and by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648902.

istics of the 3rd and the 4th vegetation tiers of the north-eastern Moravia and Silesia. Air and soil temperature, precipitation amount and its distribution are considered to be the main direct factors influencing the altitudinal vegetation zonation (Zlatník 1976b; Randuška et al. 1986).

Digital Elevation Model (DEM) contains information both on altitude and topography. DEM is considered to be the main prerequisite map for spatial modelling in ecology (Guisan, Zimmermann 2000). It determines the spatial resolution of all derived maps, such as a map of slope, aspect, and curvatures. DEM has been used as a source of variables in numerous vegetation studies (e.g. Del Barrio et al. 1997; Gottfried et al. 1998; Guisan et al. 1998).

Three types of environmental variables or gradients can be recognized: indirect gradients, direct gradients, and resource gradients (Austin 1980). Elevation, slope, and aspect represent indirect environmental gradients. The derivation of variables which have a more obvious influence on vegetation may help to elucidate the relations studied (Austin et al. 2006). The aspect is a typical example which is inapplicable to some analyses in its original expression (359° and 1° are far outlying values albeit the real difference in exposure is only slight). The aspect can be substituted by radiation which has a more obvious impact on vegetation, and in addition, it includes the influence of slope steepness and possibly other variables (terrain shading, latitude). Relatively simple formulae for radiation have been introduced e.g. by McCune and Keon (2002). More sophisticated models are incorporated in geographic information systems (Šúri, Hofierka 2004; Pierce Jr. et al. 2005).

The aim of presented paper is to explore possibilities of using DEM for mapping vegetation tiers. DEM is considered to be a useful tool for transferring the knowledge of vegetation tiers from easily classifiable sites to the sites that are not easily classifiable (e.g. large areas of non-native spruce monocultures, agricultural land).

MATERIAL AND METHODS

Study area

The study area is located in the Zlín Region, around the towns of Valašské Klobouky and Brumov-Bylnice, and between the towns of Uherský Brod, Luhačovice, and Bojkovice. Both sites cover an area of approximately 10,000 ha in total. The area lies within the Natural Forest Area Bílé Karpaty and Vizovické vrchy (Plíva, Žlábek 1986). The altitude ranges from 250 to 835 m a.s.l., with Průklesy being the highest point. The soil parent material is sandstone and claystone of flysch layers (Chlupáč 2002). The main soil type is Cambisol (Czech Geological Survey 2003). Mean annual temperature (for the period 1961–2000) ranges from 6 to 9°C, depending on the altitude; mean annual precipitation varies from 650 to 1,000 mm (Tolasz 2007).

Data collection

Phytosociological relevés were recorded in 2007 to 2008 using standard methods. Relevés were recorded in square geobiocoenological plots (20 × 20 m), located in 2007 in various forest stands so as to capture the variability of vegetation. In 2008, the plots were supplemented by plots selected by a stratified random sampling design, in which altitude, aspect, predominant tree species, and historical land-use were considered. Trees were classified into several vertical strata using Zlatník's adjusted scale; the cover for each species in the layer was determined using the abundance-dominance scale (Zlatník 1976b). A total of 200 relevés were recorded. All relevés were classified into the system of geobiocoenological typology (Buček, Lacina 2007). The relevés from the nutrient-poor soils were excluded (trophic range A and AB according to Buček, Lacina 2007), as well as the relevés from the tufa mounds and waterlogged sites.

The locations of phytosociological relevés were determined by GPS. In 2007, GPS receiver Garmin GPSMAP 76S was used; recorded data were transferred to GRASS GIS (GRASS Development Team 2009). In 2008, Trimble Juno ST GPS receiver with ArcPad 7.1.1 (ESRI) software and Trimble GPSCorrect 2.40 (Trimble) extension was employed. Data were transferred to ArcGIS 9.2 (ESRI) with Trimble GPS Analyst 2.10 (Trimble) extension. Phytosociological relevés were stored in TURBOVEG 2.75 program (Hennekens, Schaminee 2001).

Determining vegetation tiers

Geobiocoenological plots were classified into vegetation tiers of the geobiocoenological classification system (Buček et al. 2005; Buček, Lacina 2007) while the species combination of herb-, shrub- and tree-layer, altitude and aspect were taken into account. Bioindicator values of plant species associated with vegetation tiers were used according to Zlatník (1963) and Ambros and Štykar (2001). At low altitude sites, relatively few relevés were recorded, therefore 7 supplementary plots were established. Supplementary plots were similarly classified into vegetation tiers although no phytosociological relevés were performed.

Digital elevation model and derived maps

DEM was interpolated from contour lines using the RST (regularized spline with tension) method. Contour line data were obtained from the Fundamental Base of Geographic Data of the Czech Republic (ZABAGED) provided by the Czech Office for Surveying, Mapping and Cadastre. Klimánek (2006) found ZABAGED as the best generally available source of elevation data in the Czech Republic. Maps of slope, aspect, and annual sum of potential global radiation (hereinafter referred to as potential global radiation) were derived. All the above-mentioned calculations were processed within GRASS GIS environment. Potential global radiation was calculated in r.sun module. This module can be used to compute direct, diffuse and reflected solar radiation for a particular day in the year, based on latitude, type of surface and atmospheric conditions (Hofierka, Šúri 2002; Neteler, Mitasova 2008). For the purposes of analysis, global radiation was calculated as the sum of direct and diffuse radiation; impact of atmospheric conditions was omitted from the calculation, while the effect of terrain shading was included. The resolution of raster maps was 5 m, except for the maps of potential global radiation (10 m resolution).

Data analyses

The influence of the variables on the herb layer species composition was evaluated by indirect ordination method – non-metric multidimensional scaling (NMDS; using 2 dimensions) and by fitting the variables as vectors to the ordination plot. The influence of DEM-derived variables (elevation, potential global radiation, and slope steepness), vegetation tiers and percent tree canopy cover was assessed. The smooth surface for vegetation tiers was also fitted to the ordination plot (using generalized additive models – GAM). Before the analyses, data were edited using the JUICE 6.5 (Tichý 2002) program – the nomenclature was unified and the data set was divided into 3 subsets for analyses. The first subset contained all relevés in which at least 2 species per plot occurred in the herb layer (188 relevés), the second subset consisted of all records with at least 8 herb-layer species (170 relevés), and the third subset included all records with at least 14 herb-layer species (131 relevés). The species cover values were transformed using square root transformation; data were standardized; Jaccard index of dissimilarity was used for the purposes of NMDS. Statistical significance of the impact of each variable was tested by permutation tests; the impact of variables was compared using the coefficient of determination (R^2).

A linear model for vegetation tiers was developed, using vegetation tiers determined by a field survey as dependent variables, and elevation and potential global radiation as independent variables. The model was based on data from geobiocoenological plots in which more than 14 herb layer species were found and from supplementary plots (in total 138 plots). The cross-correlation between elevation and potential global radiation was weak ($R = -0.1471$). Vegetation tiers represent an ordinal variable (values 2, 3, 4 and 5 in model area). However, when developing the model they were considered as a continuous variable. Model values are therefore continuous and the limits between vegetation tiers had to be set for them. The limits were set so as to achieve the minimum number of plots differently classified by the model.

Comparison of model vegetation tiers and vegetation tiers obtained from the Regional Plans of Forest Development (RPFD)

The map of model vegetation tiers was compared with the map of vegetation tiers classified by the typological system of FMI obtained from the Regional Plans of Forest Development (RPFD, Forest Management Institute in Brandýs nad Labem 2003). The comparison was carried out only for forest land within the boundaries of the study area. Error matrix and the percentage of correctly classified pixels were calculated in the GRASS GIS environment (about error matrix e.g. in Campbell 2002).

RESULTS

Classification of plots into vegetation tiers based on a field survey

Out of 131 geobiocoenological plots in which at least 14 herb layer species were found, 5 were classified into the 2nd vegetation tier, 50 into the 3rd, 62 into the 4th, and 14 into the 5th tier. All supplementary plots were classified into the 2nd vegetation tier. The second vegetation tier is found at the lowest elevations (240–380 m a.s.l.), the 3rd tier at elevations of 330–550 m, the fourth at 500–740 m, and the fifth above 650 m (Fig. 1). Plots located in the third and fourth tiers are evenly distributed along the gradient of potential global radiation, plots in the fifth

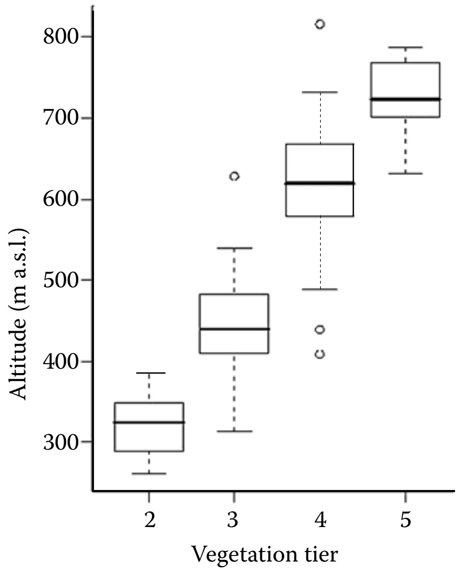

Fig. 1. Box-and-whisker plots showing the distribution of elevation in vegetation tiers determined through field survey. Center line and outside edge (hinges) of each box represent the median and range of inner quartile around the median; vertical lines on the two sides of the box (whiskers) represent values falling within 1.5 times the absolute value of the difference between the values of the two hinges; circle represents outside values

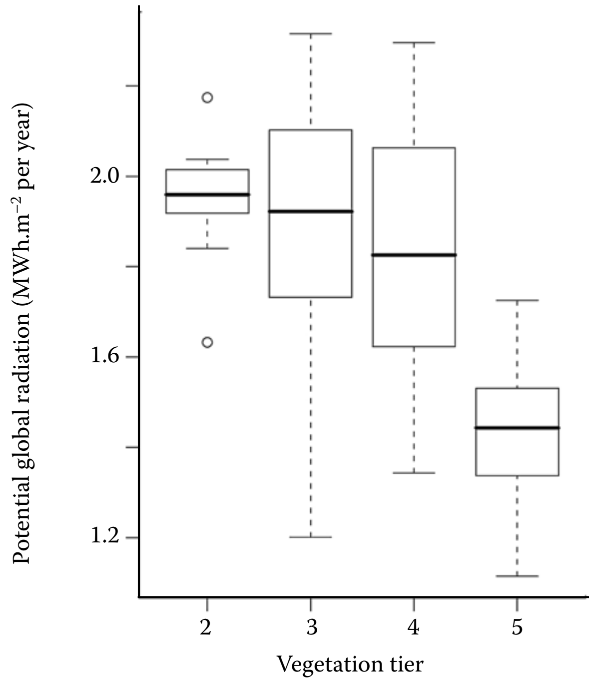

Fig. 2. Box-and-whisker plots showing the distribution of potential global radiation in vegetation tiers determined through field survey. Center line and outside edge (hinges) of each box represent the median and range of inner quartile around the median; vertical lines on the two sides of the box (whiskers) represent values falling within 1.5 times the absolute value of the difference between the values of the two hinges; circle represents outside values

tier have mainly shady aspect with lower potential global radiation, while plots in the second tier have mainly sunny aspect (with higher potential global radiation) (Fig. 2).

Variability of vegetation

Phytosociological relevés were classified into 9 groups of geobiocoene types after removing those from the nutrient-poor soils, tufa mounds and waterlogged sites. In the 2nd vegetation tier there were *Fagi-querceta typica*, *Fagi-querceta aceris, Fagi-querceta tiliae*, in the 3rd vegetation tier *Querci-fageta typica*, *Querci-fageta aceris*, *Querci-fageta tiliae*, in the 4th ve-getation tier *Fageta typica*, *Fageta aceris* and in the 5th vegetation tier *Abieti-fageta typica* and *Abieti-fageta aceris inferiora*. Phytosociological relevés were re-

Table 1. Coefficients of determination (R^2) and significances based on permutation tests (1,000 permutations) for variables fitted as vectors to the NMDS ordination. (The analysis was performed for 3 subsets of data: subset I included all phytosociological relevés in which at least 2 species per plot occurred in the herb layer, subset II (at least 8 herb-layer species per plot) and subset III (at least 14 herb-layer species per plot))

Variable	R^2 (significance)		
	subset I (≥ 2 species)	subset II (≥ 8 species)	subset III (≥ 14 species)
Cover of tree layer	0.0898 (***)	0.2210 (***)	0.3335 (***)
Elevation	0.2457 (***)	0.3247 (***)	0.4062 (***)
Slope	0.0638 (**)	0.0551 (**)	0.0391 (.)
Radiation	0.1706 (***)	0.1487 (***)	0.1486 (***)
Vegetation tiers	0.2380 (***)	0.3168 (***)	0.4670 (***)

Significance levels: ***α = 0.001. **α = 0.01. *α = 0.05. (.) α = 0.1

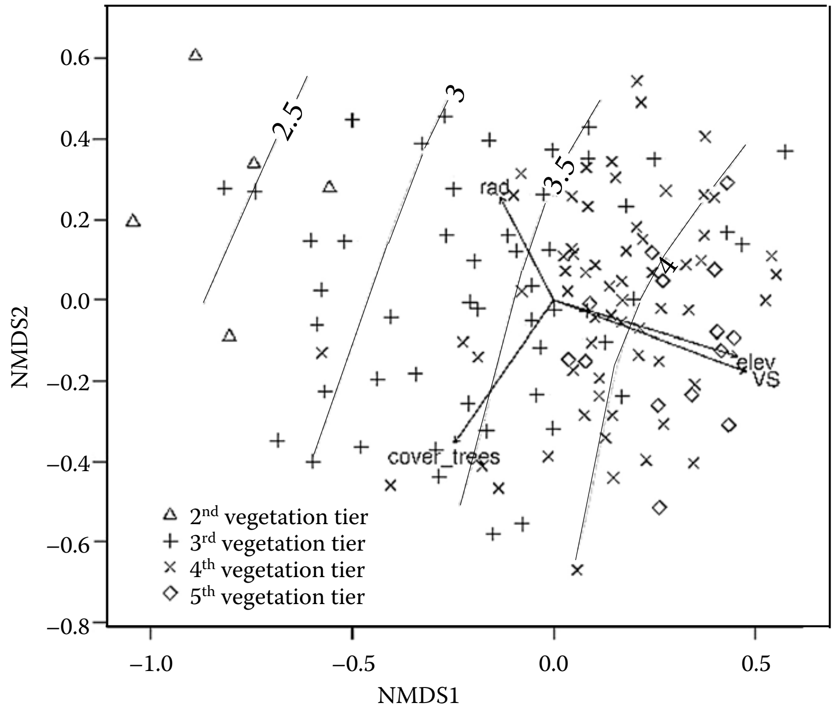

Fig. 3. NMDS ordination plot for subset of phytosociological relevés with more than 14 species. Only species from herb layer are used for ordination. Environmental variables (rad – potential global radiation, elev – elevation), cover of tree layer (cover_trees) and vegetation tiers (VS) are fitted as vectors on the ordination. Vegetation tiers are fitted also as surface using GAM (grey isolines)

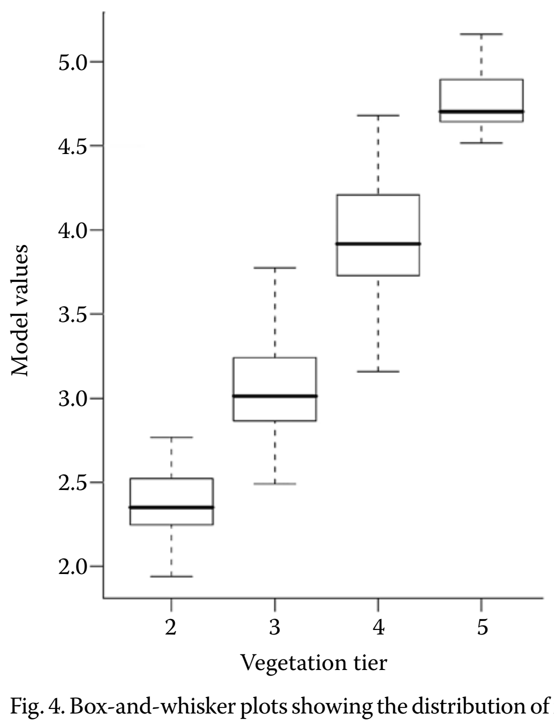

Fig. 4. Box-and-whisker plots showing the distribution of model values of vegetation tiers in vegetation tiers determined through field survey. Center line and outside edge (hinges) of each box represent the median and range of inner quartile around the median; vertical lines on the two sides of the box (whiskers) represent values falling within 1.5 times the absolute value of the difference between the values of the two hinges; circle represents outside values

corded in forest stands with the near natural tree species composition (mainly with *Quercus petraea*, *Fagus sylvatica*, *Carpinus betulus* and *Abies alba*) as well as in forest stands hardly influenced by human activities (*Picea abies* and *Pinus sylvestris* monocultures).

Influence of variables on vegetation

Elevation, potential global radiation, tree canopy cover and vegetation tiers are variables which significantly influence the herb layer species composition. Significances and coefficients of determinations (R^2) for variables fitted to NMDS ordination for all subsets of plots are shown in Table 1. Elevation and potential global radiation fitted as vectors to NMDS ordination are significant with P value < 0.001. R^2 for elevation is highest in the subset of plots with at least 14 species of herb layer (R^2 = 0.4062) and lowest in the subset of plots with at least 2 species of herb layer (R^2 = 0.2457). R^2 for potential global radiation is almost the same for all 3 analyzed subsets. Another DEM-derived variable is slope. Its influence on the herb layer species composition is lower; it is not statistically significant (at α = 0.05) for the subset of records with at least 14 herb layer species per plot. The variable 'tree canopy cover' is significant with P value < 0.001 and it has the highest influence in the subset of records with at least 14 herb layer species per plot.

Table 2. Error matrix for the classification of plots into vegetation tiers determined by the model and vegetation tiers determined by a field survey. The number of plots within different categories is shown

Vegetation tiers determined by a field survey	Vegetation tiers determined by the model				
	2nd	3rd	4th	5th	row sum
2nd	10	2	0	0	12
3rd	1	46	3	0	50
4th	0	4	55	3	62
5th	0	0	0	14	14
Column sum	11	52	58	17	138

Vegetation tiers themselves, fitted as vectors, have similar R^2 and similar direction as elevation (Table 1, Fig. 3). They represent the most significant variable ($R^2 = 0.46$) in the subset of records with at least 14 herb layer species per plot. Parameters of the generalized additive model by which the smooth surface of vegetation tiers is fitted are statistically significant; the deviation explained by the model (D^2) is 0.49.

Model for vegetation tiers

The model for vegetation tiers in which elevation was included as the independent variable explains 78% of variability ($R^2_{adj} = 0.7759$, $t_{elev} = 21.805$, df = 136, $P_{elev} < 0.001$). The model with potential global radiation explains much less variability ($R^2_{adj} = 0.1416$, $t_{rad} = -4.858$, df = 136, $P_{rad} < 0.001$). The model in which both variables are included ex-

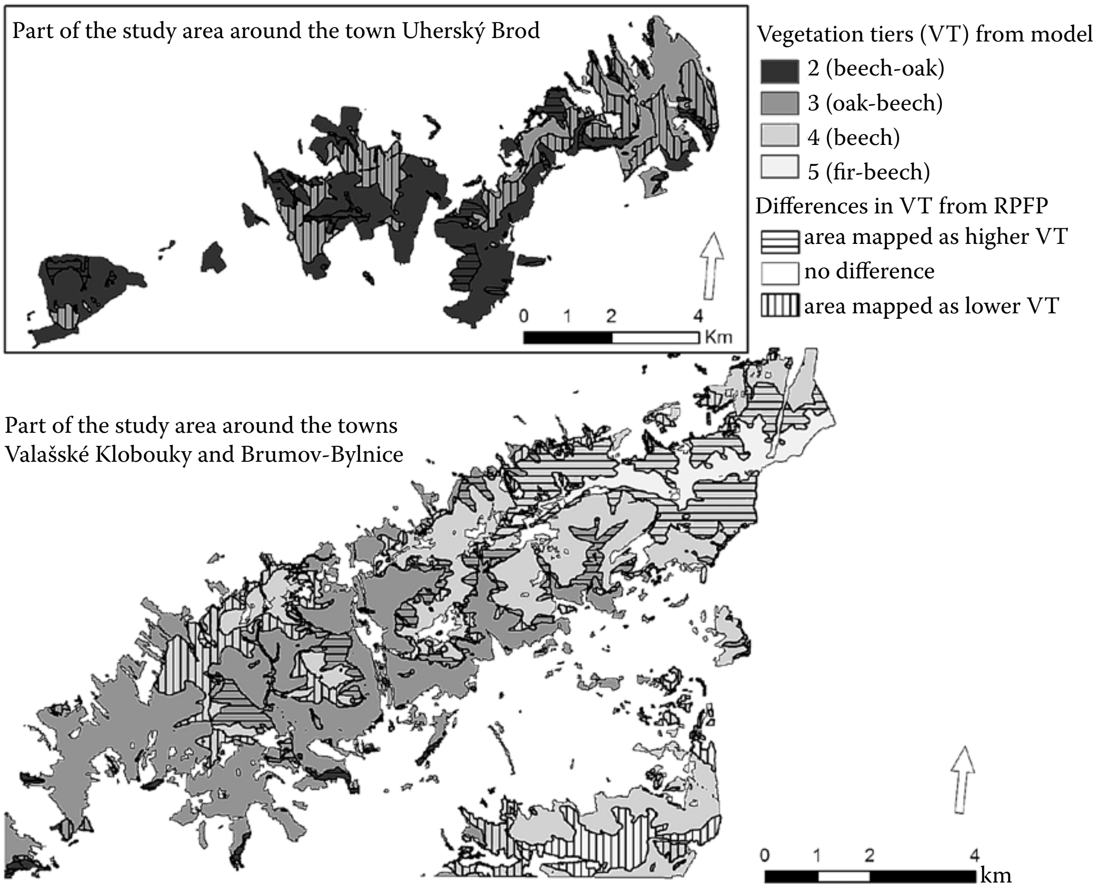

Fig. 5. Map of vegetation tiers derived from the model and its comparison with vegetation tiers from RPFD. Vegetation tiers from model are based on the system of geobiocoenological typology, vegetation tiers from RPFD (Regional Plans of Forest Development) are based on the typological system of FMI. From the map it is possible to see different concept of the 5th vegetation tier in the mapping from RPFD and insufficient incorporation of vegetation inversion by the model especially in lower vegetation tiers

Table 3. Error matrix for vegetation tiers determined by the model and vegetation tiers classified by RPFD

Vegetation tiers by RPFD (area in ha)	Vegetation tiers determined by the model (area in ha)					
	1st	2nd	3rd	4th	5th	row sum
1st	0	5	4	0	0	9
2nd	0	1,043	698	0	0	1,741
3rd	0	292	2,110	508	4	2,914
4th	0	0	341	1,247	204	1,792
5th	0	0	13	507	241	761
Column sum	0	1,340	3,166	2,262	449	7,217

plains 84% of variability, both variables are significant (R^2_{adj} = 0.8366, t_{rad} = –7.172, df = 135, $P_{rad} < 0.001$, t_{elev} = 24.068, df = 135, $P_{elev} < 0.001$).

Limits between vegetation tiers were set for model values at 2.55, 3.5 and 4.5. Model values slightly overlap with vegetation tiers determined by a field survey (Fig. 4). In total 13 plots were classified differently by the model (9% plots). In other words, 91% of plots were classified equally (Table 2).

Comparison of model vegetation tiers and vegetation tiers obtained from RPFD

The resulting map of model vegetation tiers corresponds to the map of vegetation tiers from RPFD in 64%. The lowest difference was found for the 3rd vegetation tier, the highest for the 5th and for the 2nd vegetation tier (Table 3, Fig. 5).

DISCUSSION

Elevation is an important variable affecting the herb layer species composition. Its importance increases as we select the subset of plots with a higher number of species recorded in the plot (Table 1). This may be explained by the higher probability of occurrence of indicator species. However, using only the herb layer species composition is not sufficient for accurate determination of vegetation tiers in the study area (Fig. 3). The herb layer species composition is affected by a number of other variables (e.g. by canopy cover in performed analyses). The effect of some of these variables was excluded in this paper by excluding phytosociological relevés from the nutrient-poor soils (trophic range A and AB according to Buček, Lacina 2007), relevés from the tufa mounds and waterlogged sites where the determination of vegetation tier is less obvious and the impact of vegetation tiers on vegetation composition is overlaid by the impact of these variables (Buček, Lacina 2007). Problems related to the determination of vegetation tiers and the use of bioindication were discussed by Grulich and Culek (2005). Vegetation tiers are often determined in forest stands affected by forest management practices which e.g. alter the tree species composition. These influences can be obvious (such as spruce monocultures at a low altitude) while others may be rather elusive (e.g. former use of the forest as wood pasture allowing more light to reach the forest floor).

The linear model developed for classifying vegetation tiers based on DEM-derived variables (elevation and potential global radiation) was found to be satisfactory, explaining 84% of data variability. The effect of both variables is linear (see Fig. 6 for elevation) in the study area. However, this could not be necessarily valid in the whole gradient of vegetation

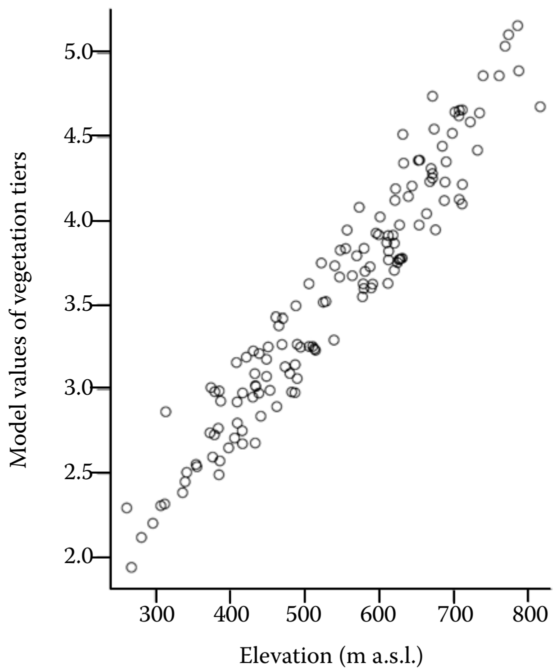

Fig. 6. Scatter plot of model values of vegetation tiers against altitude. Figure shows positive linear relationship of these variables

tiers in the Czech Republic. Only 9% of plots (in total 13 plots) were classified differently by the model than by the field survey, out of them 5 were close to the border of the vegetation tier (less than 20 m), 3 were on the bases of valleys perhaps influenced by vegetation inversion. The classification of the other 5 plots is problematic, 2 plots are in oak stands at higher elevation where probably more light available to the herb layer influences the occurrence of species from lower vegetation tiers, 2 plots are on the south facing slopes of the 5th vegetation tier where only few plots are established and 1 is close to the forest edge.

The model was used to obtain a smooth trend of vegetation tiers, based on variables relevant to the definition of vegetation tiers by Zlatník (1976a). Plots which do not fit into this trend were reclassified into another vegetation tier. Based on the combination of selected variables, the model has further extended the knowledge of vegetation tiers from sample plots to the whole study area. It represents an analogical approach to the site classification which is based on similarity of the site being classified to the analogous easily classifiable site (e.g. with the species composition closer to that of natural conditions). This approach is commonly known and used in mapping not only vegetation tiers but also groups of geobiocoene types (Buček, Lacina 2007). However, the approach presented here allowed us to obtain more accurate and precise results more efficiently.

Elevation and global potential radiation are sufficient variables for the study area. Areas with steep valley slopes would probably require additional variables to characterize inversion areas (slightly missing also in the study area). The effect of vegetation inversion is more important in the lower vegetation tiers (from 1st to 4th vegetation tier) (Buček, Lacina 2007). In future, the model could be improved by a variable derived from DEM that expresses the effect of inversion. For example Antonic et al. (2001) used GIS based depth in sink to estimate the distribution of 6 dominant tree species in karst regions. Similarly to model vegetation tiers in larger areas, more variables would probably be needed (e.g. to express varying amounts of precipitation).

Two thirds of the map of model-determined vegetation tiers are equivalent to the map obtained from RPFD (Table 3, Fig. 5). This result can be considered as satisfactory taking into account differences between vegetation tiers defined by the system of geobiocoenological typology and vegetation tiers defined by the typological system of FMI. The typological system of FMI classifies azonal forest types into lower or higher vege-tation tiers than the surrounding area (Mikeska 2000). Mikeska (2000) proposed geographically zonal vegetation tiers which are more similar to vegetation tiers in geobiocoenological typology. But these are not included in RPFD. This is for example the cause of determination of the 1st vegetation tier in the study area by RPFD. Other differences may be explained by a slightly different approach to the definition of individual vegetation tiers in both systems. The most important differences are in the 5th and in the 2nd vegetation tiers in the study area. Differences in the mapping of the 5th vegetation tier can be explained by a different concept of determination of this vegetation tier. In the mapping for RPFD this tier is mapped from lower altitudes in the north-eastern part of the study area (Fig. 5). Differences in the mapping of the 2nd vegetation tier revealed insufficient incorporation of the effect of vegetation inversion by the model.

CONCLUSION

Vegetation tiers were successfully modelled in the study area using elevation and potential global radiation as independent variables. Both variables have a similar influence on the herb layer species composition. The presented model explains 84% of data variability. Only relatively few plots (9%) were classified differently by the model than by the field survey. The possibilities of using a digital elevation model for the more accurate and efficient mapping of vegetation tiers were explored. The findings may be used e.g. for transferring the knowledge of vegetation tiers from natural forest fragments to the whole landscape in a particular region.

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Received for publication June 22, 2009
Accepted after corrections October 12, 2009

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