COMPARATIVE LANDSCAPE TYPOLOGY OF THE BOHEMIAN AND BAVARIAN FOREST NATIONAL PARKS

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ABSTRACT

Landscape typologies provide their users with a spatial framework, which could be used for management, assessment of landscape changes and monitoring of biodiversity or natural processes. The aim of this article is to distinguish and compare landscape types across the largest natural area within Central Europe. Cluster analysis based on physical-geographical data was used to differentiate particular types of environmental conditions. The results are suitable for comparing both national parks and their management.

Keywords: landscape typology, Bohemian Forest NP, Bavarian Forest NP, cluster analysis

Introduction

The Bohemian and Bavarian Forests make up the largest wilderness area in Central Europe (Křenová and Hruška 2012) and is extensively protected by two transboundary national parks of the same name. Dynamic changes in landscape caused by bark beetle outbreaks across the whole area call for appropriate management of the forest ecosystems. However, the management differs greatly in the two national parks. This inconsistency in the management is often justified by different natural conditions on the German and Czech side (Křenová and Hruška 2012; Bláha et al. 2013). Therefore, a comparative study such as a landscape classification is urgently needed if we want to describe similarities or differences within this region.

Methods

Study Area

Focal area of the landscape classification is defined by the boundaries of both national parks, which together cover about 1,000 km². The physical-geography of the Bohemian and Bavarian Forests are similar, but there are several important differences (Fig. 1). The Bohemian and Bavarian Forests, belong to the same geomorphologic unit and together form the largest and oldest mountain system in Central Europe (Czech Geological Survey 2012). There is a typical relict high mountain plateau in the central part of the area, where there is a mosaic of long flat forested ridges and a high number of peat bogs, especially on the Czech side (Spitzer and Bufková 2008). On the edges of this high mountain plateau are deep brook and river valleys with rocky slopes. The mean altitude of the whole mountain range is about 922 m, the highest peak is 1457 m (Křenová and Kiener 2012). Vertical heterogeneity is much greater on the Bavarian side due to the steep gradients of the slopes. The topography was shaped by glaciers and there are eight glacial lakes and several other glacial features in the area. The mean temperature depends on altitude and varies from 6.0 °C at 750 m to 3.0 °C at 1300 m (Tolasz et al. 2007). The mean annual precipitation varies from 800 to 900 mm in the foothills to 1600 mm in the central area (Dohnal et al. 2011). Soils are mainly cryptopodzols and cambisols, and are generally acidic (Jonášová and Prach 2004; Babůrek 2006).

The forest cover in the whole area is ca. 60%, but reaches 90% in the central parts of the national parks. Vast areas of original mixed forests have been changed into Norway spruce plantations. The remains of the native forest ecosystems have survived as a network of islands of natural climax spruce forests (*Picea abies*), mixed beech-fir-spruce forests (*Fagus silvatica*, *Abies alba*) and relict pine forests (*Pinus silvestris*) (Dohnal et al. 2011). The wetlands, namely raised mires and bottom-valley peat bogs, are valuable natural stands in this area. Big parts of the forests and some secondary forestless areas (especially on the Czech side of the mountains) are currently left to develop spontaneously without human intervention (Dohnal et al. 2011).

The whole region has been influenced by human activities since the Iron Age and later period of Celtic settlements. Slavic tribes came in the 7th and 8th century (Řezníčková in Anděra 2003). The most important period of colonization started in the 16th century when timber extraction needed for mines and glass manufacture led to extensive deforestation and changes in forest structure. In the 19th century, at the time of the highest population density, the mountain plateau was afforested with spruce and several large-scale bark beetle outbreaks occurred in the region (Jonášová and Prach 2004). The most significant event that resulted in a separate land-

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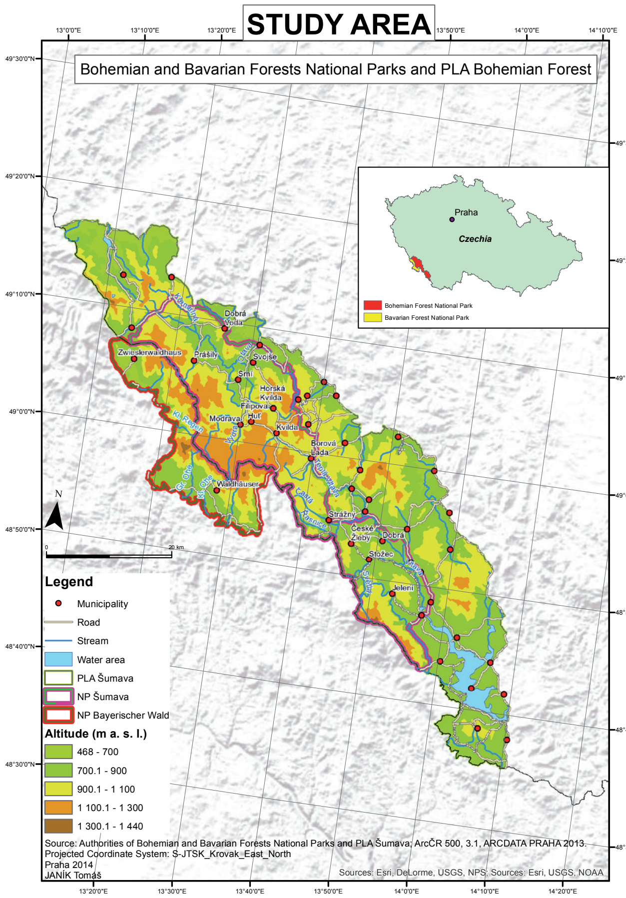

Fig. 1 Map of study area.

scape development was World War II, after which the German residents were expelled and an inaccessible border zone established on the Czech side. The population in the region was reduced to less than a third of what it had been previously, therefore, almost all human activities decreased. Since the 1970s in Bavaria and 1990s in Bohemia, nature protection and tourism have dominated regional development (Perlín and Bičík 2010).

Landscape Typology

Landscape classification provides defined classes, which are described by variables. We can organize environmental gradients into systematically recognized objects (Jongman et al. 2006). Landscape typology and classification are widely used in landscape assessments, evaluation and protection. Typology can characterize a region based on its values and differences (Kolejka and Lipský 2008). Diversity of European cultural landscapes can be expressed by a complex classification using data on both physical (climate, relief, soil, geology) and cultural (land use) features of the environment (Chuman and Romportl 2010).

We used the typological approach (Metzger 2005; Wascher 2005; Chuman and Romportl 2010) based on quantitative statistical methods to identify particular spatial units. Our goal was to carry out classifications, which would provide its users with a spatial framework for assessing differences between both national parks, evaluation of nature conservation, forest management and human activities in general. We used the typological approach (Metzger 2005; Wascher 2005; Chuman and Romportl 2010) to identify particular spatial units. All relevant input data describing the landscape (climate, geology, topography, soils, land cover and land use) were processed within a regular grid covering the area studied.

Physical Landscape Typology

Development of GIS software offered new, easier and better ways of achieving an objective analysis (Chuman and Romportl 2010). We carried out an analysis in STATISTICA 12 and then integrated the data in the software ArcGIS 10.2. We worked with data provided by the authorities of the National Parks (2006–2012) and GEODIS Company (2006).

The area studied, both national parks, was overlaid with a regular grid of 100 × 100 m cells.

Physical conditions in each cell in the regular grid were described by twelve variables: mean altitude, mean slope, heat load index, incidence of south facing slopes, annual mean temperature, seasonality (the difference between annual min and max temperature), the difference between average temperature in the coldest and warmest month, mean temperature of the warmest quarter of the year, mean temperature of the coldest quarter of the year, annual precipitation, mean precipitation in the coldest quarter of the year and mean precipitation in the warmest quarter of the year. Topography data were provided by the authorities of the Bohemian and Bavarian Forest National Parks; the climatic data were obtained from the WorldClim database (Hijmans et al. 2005). The next necessary step was standardization of the data because we need each variable to be in the same format for the analyses. Classes were identified using k-means cluster analysis in STATISTICA 12. We obtained a class num-

Table 1 Land cover types.

Land cover	LC Code
Without forest	1
Coniferous forest	2
Broad-leaved forest	3
Meadows	4
Peatbogs	5
Rocks	6
Mixed forest	7
Dead-prostrate forest	8
Dead-standing forest	9
Succession	10
Built up areas	11
Water	12

ber for each cell based on a Cluster analysis of the data describing the landscape mentioned above. Classes were visualised in ArcGIS 10.2.

Functional Landscape Typology

We distinguished twelve types of land cover (Table 1) based on the land cover data provided by GEODIS (2008). Land cover typology was used to reduce the input dimensions of land cover data and determine the typical combination of land cover classes within cells in the regular grid. Therefore, k-means cluster analysis was used to identify so called functional types of landscape. Five clusters were identified, for which shares of particular land cover classes were calculated (Fig. 2). This description helps us to understand the distribution of the land cover in both national parks, and provides us with another framework for assessing the landscape in the area studied.

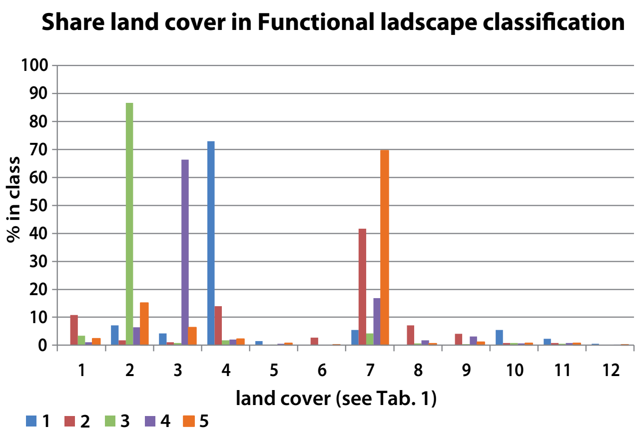

Fig. 2 Share of land cover in Functional landscape classification.

Results

Physical Landscape Typology

First step of the complex landscape classification based on physical-geographical attributes only produced five types of landscape (Fig. 3). Their spatial distribution and calculated characteristics (Table 2) show logical correlations and a continuous gradient in the factors altitude and precipitation. Slope is an important differential variable, helpful for further describing our results. We can distinguish three large scale flat types of landscape and two small scale transitional types of landscape with steep slopes. Names of particular types of physical-landscape are therefore derived from their topographical characteristics.

The largest type of landscape *"high plateaus"* covers the highest parts of the region studied including some mountain peaks. Mean slope is just 6.65°, therefore there are a lot of peat bogs here. High annual precipitation and low temperatures are recorded here. This type of landscape occurs almost only in the Czech part of the area studied, because in the German part of the mountains the slopes are much steeper. This high plateau is usually surrounded by *"edge of plateau"* which is a transitional type of landscape covering the smallest part of the region studied. It includes an enormous number of deep and steep valleys and canyons. Distribution is quite similar in both national parks. Similar types of landforms can be found in another type of landscape named *"mid-slopes"*. The main difference is generally a lower altitude and precipitation and also its spatial distribution as this this type of landscape is widespread in the Czech part of the area studied, especially in regions not connected with the central plateau. *"Higher foothills"* are scattered spatially within the whole area studied and is another transitional type of landscape between other neighbouring levels. Steep slopes and differences in precipitation are typical characteristics of this type. The last type of landscape *"Lower foothills"* occurs in most of the Bavarian national park. In the Czech Republic this type of landscape occurs along rivers, for example, the Vltava River. Despite its name, this type of landscape also includes some flat valleys.

Based on our results, topography is the most important factor, when describing differences within both national parks. These differences are nicely shown in the form of an irregular and patchy distribution of all the physical types of landscape mentioned above.

Functional Landscape Classification

The second step in the complex classification was run only using land cover characteristics. Based on the distribution of land cover classes, five functional types of landscape were identified. A *"Disturbed forest landscape"* is typical of the region studied and consists of large ar-

Table 2 Average values for Physical landscape typology.

Type	Mean altitude (m a. s. l.)	Slope (°)	Precipitation (mm/year)	Area (km^2)
Mid-slopes	932.22	7.67	1090.1	229.3
Edge of plateaus	1048.90	14.32	1139.5	126.1
Higher foothills	845.76	12.27	1025.4	127.4
Lower foothills	778.94	4.21	1016.5	190.5
High plateaus	1141.30	6.65	1187.1	255.9

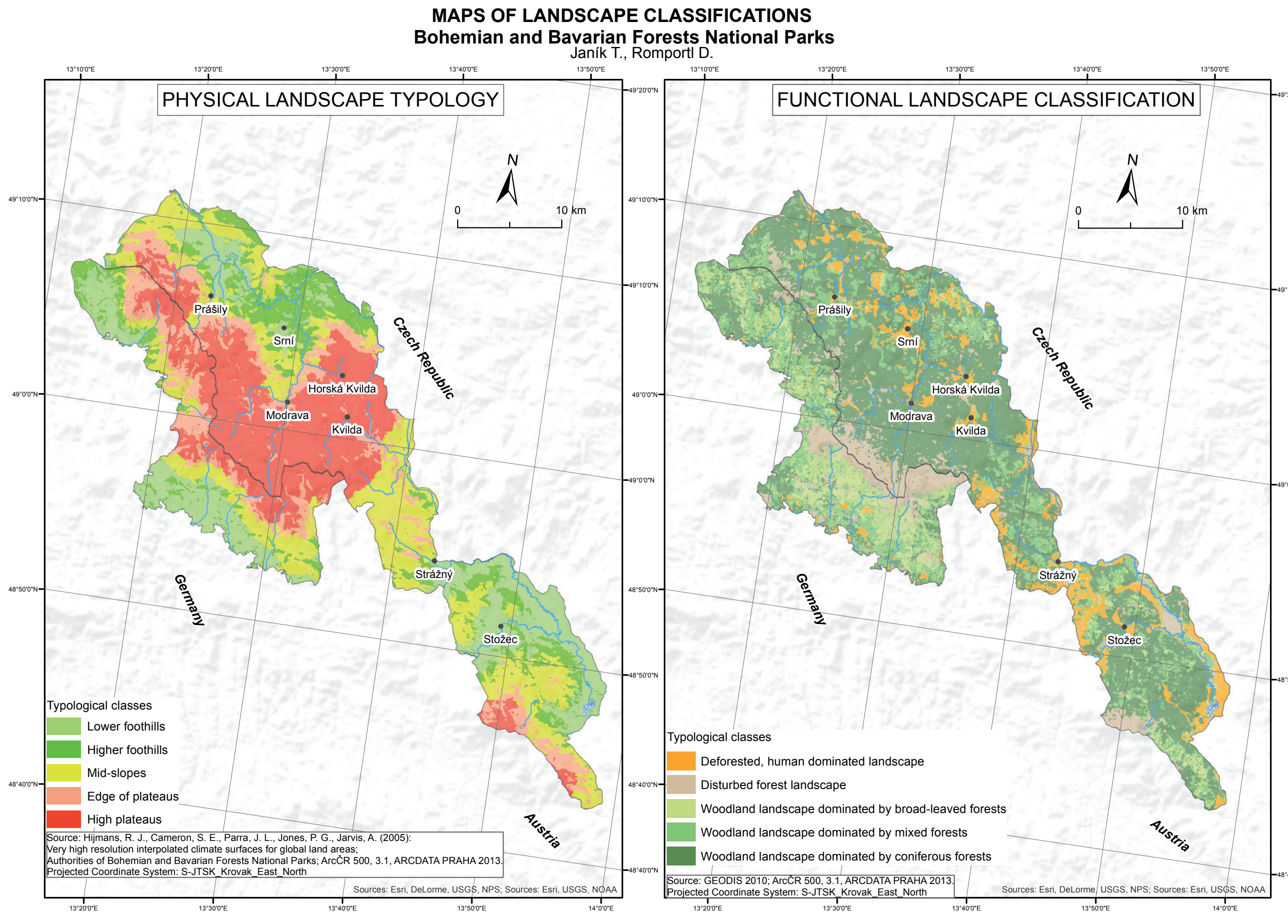

Fig. 3 Maps of landscape classifications.

eas of dead-standing spruce trees resulting from wind storms and bark beetle attacks. This type of landscape occurs widespread along the borders of both national parks, however larger areas occur on the Czech side. The main difference between the national parks is in the distribution of forest types of landscape. The Czech side is dominated by *"woodland landscape dominated by coniferous forests"*, whereas in Germany *"woodland landscape dominated by broad-leaved forests"* and *"woodland landscape dominated by mixed forests"* are much more wide spread. In addition, in particular on the Czech side, the *"deforested, human dominated landscape"* includes meadows, settlements and other deforested areas subject to human activity (Fig. 3). For a correct interpretation it is necessary to know the percentage of land cover in each class (Fig. 2).

Discussion

We can distinguish two types of conditions based on our typologies. Physical abiotic conditions determined by natural long-term processes, connected to climate and geomorphological conditions have resulted in the physical landscape typology. It is a convenient framework for evaluating the processes occurring in the area studied (Kolejka and Lipský 2008; Chuman and Romportl 2010) and for determining the differences among the classes, which can be useful for obtaining a more accurate picture of the landscape.

Secondly the classification goes further in revealing the functional types of landscape. Land cover is the variable most affected by humans. There are differences between the German and Czech parts caused by different forest management, in particular that which occurs during and after the most common disturbances in mountain forests in Central Europe, wind throws and subsequent bark beetle outbreaks (Jonášová and Prach 2004; Nováková and Edward-Jonášová 2015). Many studies in both national parks conclude that the forest is able to regenerate after disturbances (Fischer et al. 2002; Jonášová and Prach 2004; Jonášová at al. 2010; Nováková and Edward-Jonášová 2015). On the German side the forests regenerated without human help after the wind throw in 1983. The Czech side was affected by a wind throw in 2007 and its management is very unclear (Křenová and Kiener 2012). Our typology reveals larger areas of dead forest in the central area of the national park on the Czech side.

Conclusion

These classifications provide users with an objective spatial framework for further investigation. It is easy to determine similarities and differences in physical conditions and reveal uniqueness, rareness or threats to particular types of landscape within both national parks. Moreover, it is possible to evaluate the effect of human activity, level of nature protection and efficiency of landscape management in both national parks. Such transboundary classifications help us to better understand the geographical conditions and provide valuable information about the spatial distribution of the different types of landscape.

On the other hand, processes are very dynamic and therefore it important to have more than a spatial perspective. We need to analyse temporal changes, which are associated with human activity, because on the Czech side, in particular, the interested parties have discussed its future management for a long time. It depends on the representatives of the national park, municipality, industry and region, and politicians at the national level, agreeing.

Software and Map Design

Software STATISTICA 12 was used for the statistical analyses and ESRI ArcGIS 10.2 for all spatial analyses and visualisation.

Main output of our study are two maps that visualize the spatial distribution of both clusters analyzed. For particular types of landscape we chose colour to express gradual change in an understandable way by representing instinctive similarities between colours and classes.

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