Cent. Eur. J. Geosci. • 6(3) • 2014 • 293-307
DOI: 10.2478/s13533-012-0189-5

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Central European Journal of **Geosciences**

The climate of Carpathian Region in the 20th century based on the original and modified Holdridge life zone system

Research Article

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Received 14 February 2014; accepted 27 May 2014

Abstract: The Holdridge life zone system has already been used a number of times for analysing the effects of climate change on vegetation. But a criticism against the method was formulated that it cannot interpret the ecotones (e.g. forest steppe). Thus, in this paper transitional life zones were also determined in the model. Then, both the original and modified life zone systems were applied for the climatic fields of database CRU TS 1.2. Life zone maps were defined in the Carpathian Region (43.5-50.5° N, 15.5-28° E) for each of five 20-year periods between 1901 and 2000. We estimated correctness of the result maps with another vegetation map using Cohen's Kappa statistic. Finally, temporal changes in horizontal and vertical distribution of life zones were investigated. The coverage of boreal region decreased with 59.46% during the last century, while the warm temperate region became almost two and a half larger (257.36%). The mean centres of those life zones, which were not related to mountains, shifted northward during the investigation period. In case of the most abundant life zone types, the average distribution elevation increased. Using the modified model, the potential distribution of forest steppe could be also identified.

Keywords: Holdridge life zone system • transitional life zone • forest steppe • mean centre shift • Kappa statistic

1. Introduction

Alexander von Humboldt [1, 2] recognized that widely separated regions have structurally and functionally similarities in vegetation if their climates are similar, too. Thus, the major vegetation groups and the vegetation boundaries could be applied to classify climates. Those methods, which are based on relations between vegetation and climate, are termed bioclimatic classification methods. One of the best known bioclimatic classification methods is the Holdridge life zone system [3, 4].

Holdridge supposed that textural and structural characteristics of vegetation are basically determined by qualitative and quantitative characteristics of ecological processes. Furthermore, he found that obvious separation of these characteristics appears in biome level, so he chose the life zones as base units of his classification. Life zone and biome are very similar notions. According to Holdridge [4], the life zone is determined only by the climate. At length Holdridge [3, 4] developed a geometric model which de-

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clares the relationship between classes (life zones) and climate indices (mean annual biotemperature, average total annual precipitation, potential evapotranspiration ratio).

Holdridge tried to develop a simple method, which takes into account the effects of cold and heat stress on vegetative growth and quantitative laws of plant physiology, Liebig's law of the minimum [5] and Mitscherlich's law of diminishing returns [6]. Numerous ecological and climatological aspects are not applied in the life zone system which is criticized by some studies, e.g. [7, 8]. The four most important criticisms are the following: a. the seasonality of meteorological variables is not taken into account; b. the transitional life zones (≈ ecotones) are not defined; c. the succession (temporal changes in species composition) is ignored; d. soil physical properties, soil salinity, limit factors of nutrient uptake are not included.

The absence of transitional life zones (e.g. forest steppe) was a known problem for Holdridge as well, but no recommendations were made. Though, in our previous investigation [9] it was shown that in regional studies the use of transitional life zones can be justified. The exact definition of these transitional life zone types can be found in Fan *et al.* [10]. Two criticisms were formulated by us: a. the correlations of new units with vegetation types were not analysed; b. their denominations are also complicated. In this study these problems addressed.

The life zone system was basically developed for defining the spatial differences in climate. After recognizing the climate change, the field of application of the model has changed significantly. Analysing the effects of possible climate change on vegetation based on life zone maps was first done by Emanuel *et al.* [11]. Even though the change in precipitation was not considered, in the mid 1980s they showed that the most drastic changes in vegetation will probably be in higher latitudes.

Then the life zone system was more and more often applied to model ecological effects of climate change, e.g. in different parts of China in the second half of the 20th century [12–15]. In these investigations the horizontal/vertical distribution and diversity of life zones and their temporal changes, shifts of mean centres of life zones, change in patch connectivity were analysed. Fan *et al.* [15] found that the area of the humid/perhumid life zones decreased significantly in the Loess Plateau of China, whereas the extent of warm temperate desert scrub and warm temperate thorn steppe increased considerably. Also Zhang *et al.* [14] observed that in most cases the mean centres of life zones shifted northeast in the Inner Mongolia of China, resulting a decrease in the steppe and forest area and an increase in the desert area.

In spite of the previously formulated criticisms, it seemed to us that the life zone system can be used for model of effects of climate change on vegetation. Thus, in this paper two purposes were formulated: a. to determine potential distribution of forest steppe based on defining of transitional life zones; b. to show the climate change for the last century in the Carpathian Region using the original and modified models. The aspects of investigation of the climate change were the following: spatial distributions, relative extents, mean centres and average distribution elevations of life zones. Because the life zone system has been developed during the exploration of the tropical areas, it was necessary to estimate correctness of the results obtained by the model. So our life zone maps were compared with another vegetation map; the degrees of agreements were determined using Cohen's Kappa statistic [16].

2. Datasets

2.1. Climate dataset

Holdridge life zone system requires daily or monthly time series of temperature and precipitation. In this paper the monthly time series of the gridded database CRU TS 1.2 [17] were used, developed by the Tyndall Centre for Climate Change Research and the Climate Research Unit (CRU) of the University of East Anglia. The dataset covers Europe (34° N to 72° N, 11° W to 32° E) and valid for the period 1901-2000. The dataset was constructed with the anomaly approach [18, 19] interpolating station data with a procedure that considers latitude, longitude and altitude as parameters. The density of the climate station network was insufficient and many of stations have been added to the network only recently. Consequently, the interpolation procedure could include some errors and biases in the gridded data, especially in areas with topographic singularities and low station density. However, the advantage of this interpolation method is that the long and uninterrupted time series of the climate variables was produced for all Europe. The spatial resolution of 10 minute was used, so the grid spacing is about 20 km. The dataset also includes a digital elevation map which was used to define the average distribution elevation of life zones.

In this paper, the target area is the Carpathian Region (43.5-50.5° N, 15.5-28° E). The mean fields of monthly mean temperature and monthly total precipitation were created for each of five 20-year periods (1901-1920, T1; 1921-1940, T2; 1941-1960, T3; 1961-1980, T4; 1981-2000, T5). Holdridge original and modified life zone systems were applied for these mean fields.

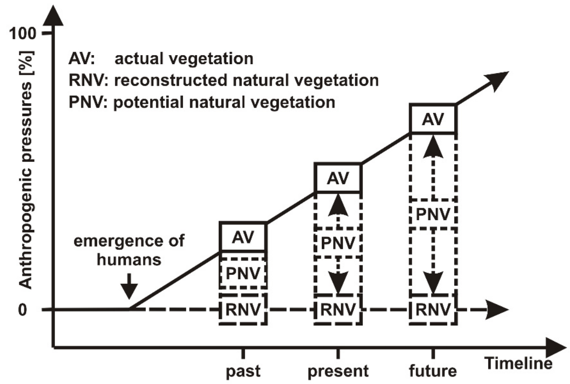


Figure 1. Vegetation states in the function of time and anthropogenic pressures (assuming linear degradation) (adapted from Bartha [20]).

2.2. Vegetation map

In some aspects the life zone system is a simple potential vegetation model, so its validation may also be based on vegetation maps. Two aspects must be considered for selection of the reference map of validation: a. investigation period; b. target area. Basically three types of vegetation states - and therefore three types of vegetation maps - exist: a. actual vegetation (AV); b. reconstructed natural vegetation (RNV); c. potential natural vegetation (PNV). The states of vegetation can be determined by the function of time and anthropogenic pressures [20] (Figure 1).

By definition the PNV is a hypothetical natural state of vegetation that shows nature's biotic potential under the given climate conditions in the absence of human influence and disturbance [21]. As long as Holdridge's model is applied to observational database, we can determine such a state of vegetation which is akin to the PNV. Namely, the interpretation of the succession is completely absent from the Holdridge life zone system, similarly to the definition of PNV. For this reason, only climatic conditions of the habitat can be determined using life zone system.

Considering all these, we used the natural vegetation map of Europe [22] as a reference map for validation. This map shows a theoretical, constructed, current natural vegetation state. In this case the "current" attribute does not mean a 30-year reference period defined by the World Meteorological Organisation (WMO), but a longer period which began at the end of the last glacial period (Flandrian interglacial). From Hungary the most important contributions to this pan-European natural vegetation map were maps of Zólyomi [23, 24]. These maps present such a reconstructed vegetation state which could exist before age of deforestation, mechanized agriculture, river control and drainage. In consideration of reference map's vegetation definition and the available climate dataset, the period 1901-1920 (T1) was selected as a validation period.

Table 1. The occurring formation and/or formation complex types in the target area based on vegetation map of Bohn *et al.* [22] [C-M: zonal vegetation (determined mainly by macro climate); P-U: azonal vegetation (determined mainly by soil and hydrological conditions)].

	Code	Formations and/or formation complexes
Zonal	C	Subarctic, boreal and nemoral-montane open forests, as well as subalpine and oro-Mediterranean vegetation
	D	Mesophytic and hygromesophytic coniferous and mixed broad-leaved coniferous forests
	F	Mesophytic deciduous broadleaved and mixed coniferous-broadleaved forests
	G	Thermophilous mixed deciduous broadleaved forests
	J	Mediterranean sclerophyllous forests and scrub
	L	Forest steppes (meadow steppes or dry grasslands alternating with deciduous broadleaved forests or xerophytic scrub)
	M	Steppes
Azonal	P	Coastal vegetation and inland halophytic vegetation
	R	Tall reed vegetation and tall sedge swamps, aquatic vegetation
	T	Swamp and fen forests
	U	Vegetation of floodplains, estuaries and fresh-water polders and other moist or wet sites

In the target area 7 zonal and 4 azonal formations and/or formation complexes were registered (Table 1). The reference map [22] was converted to the grid of the climate database [17] using ESRI ArcGIS^{TM} 9.3.1 software. During the conversion the "dominant method" was used to assign values to cells. Azonal formation types were found in 12.13% of the target area which are not defined by the macro climate. These areas were eliminated from validation procedure.

3. Methods

3.1. The original life zone system

Holdridge [4] defined climate types based on potential vegetation types. The conditions for the characteristic ecological processes of each vegetation type were determined using the following climate indices: mean annual biotemperature (*ABT*), total annual precipitation (*APP*), potential evapotranspiration ratio (*PER*).

While defining the *ABT*, Holdridge recognized that the vegetative growth and thus the net primary productivity are possible only in a certain temperature range. First, only the frost's negative effects on plants were recognized, so on his recommendation values less than 0°C were substituted by 0°C [3]. Later he realized that the heat stress inhibits the plant growth in the same way as the cold stress. Consequently, all temperatures higher than 30°C were considered as 0°C for calculation of the *ABT* [4]. First, Holdridge [3] had suggested using the values of monthly mean temperature to compute *ABT*; later the daily values were preferred [4]. In this study monthly values were used for calculation of the *ABT* (1):

$$ABT = \frac{1}{12}\sum_{i=1}^{12} T(i) \qquad 0^{\circ}C \leq T(i) \leq 30^{\circ}C \qquad (1)$$

where *T(i)* is the monthly mean temperature of the *i*th month [°C]; *ABT* is the mean annual biotemperature [°C]. The potential evapotranspiration ratio (*PER*) expresses how much part of the precipitation (*APP*) can be utilized as evapotranspiration (*APE*) which is important characteristic of ecological processes (2). In this paper the *APP* was calculated based on values of the monthly total precipitation (3). The *APE* was determined by multiplying the *ABT* by the constant 58.93 [25] (4). The *APE* is the theoretical quantity of water which would be transferred to the atmosphere within a zonal climate by the natural vegetation of the area, if sufficient, but not excessive water was available throughout the growing season [4].

$$PER = \frac{APE}{APP}, \qquad (2)$$

$$APP = \sum_{i=1}^{12} P(i), \qquad (3)$$

$$APE = 58.93 \times ABT, \qquad (4)$$

where *PER* is the potential evapotranspiration ratio [dimensionless]; *APE* is the annual potential evapotranspiration [mm]; *APP* is the annual total precipitation [mm]; *P(i)* the monthly total precipitation of the *i*th month [mm]. The Holdridge life zone system is one of the best methods, which uses only temperature and precipitation data for description of the terrestrial ecosystem complexes. Each life zone type has exact definition based on the three climate indices (*ABT, APP, PER*). Holdridge developed a geometric model which declares the relationship between life zones and climate indices. This geometric model - so-called the life zone chart (Figure 2) - is a triangular coordinate system, in which the climate indices are depicted on logarithmic axes in recognition of Mitscherlich's law of diminishing returns [6]. The *ABT* of ≈ 17°C ($2^{(log_2 12+0,5)}$ °C ≈ 16.97°C) was defined as a critical temperature line - so-called the frost line - which separates the warm temperate region from the subtropical region [3]. The frost line represents the dividing line between two major physiological groups of evolved plants. On the warmer side of the line, the majority of the plants are sensitive to low temperatures [4].

The life zone chart consists of 37 hexagons. Each hexagon defines a life zone which is named to indicate a vegetation association. Hexagons and triangles were defined in the chart using guide lines of *ABT, APP* and *PER* which are denoted in Figure 2 by dashed lines. Hexagons determine core life zones; while the equilateral triangles can be termed as transitional life zones. Holdridge [4] considered also the determination of the transitional life zones, but taking into account of the large number of classes would be excessive. For this reason, each triangle was divided into three equal parts using straight lines which connect the centre of triangle to all three vertices. Then these smaller triangles were annexed to the adjacent hexagons which determine core life zones. As a result, larger hexagons, whose contours were denoted in Figure 2 by solid lines, appeared around the former hexagons (core life zones). These larger hexagons are the units of the original Holdridge life zone system, so-called life zones.

The life zone system was developed for the tropical regions' investigation [4]. The main purpose of that investigation was to better understand the relation between climate and vegetation in both mountains and lowlands. So Holdridge defined not only latitudinal regions but also altitudinal belts based on the values of *ABT*. He found it necessary to determine which the more important limit factor of the *ABT* (and thus the vegetative growth) is: a. elevation; b. distance from the Equator. On global scale the model is inapplicable for classification, when the altitudinal belts are used too, because of the number of classes would already be 117. For this reason, most studies [12–15], which use Holdridge life zone model for climate classification, neglect the altitudinal belts.

3.2. The modified life zone system

The life zone system has been criticized that life zones don't always coincide with observed vegetation (i.e. often the grasslands are classified as forests). One reason for this probably is that transitional life zones had not been determined by Holdridge [3, 4]. The model had been optimized for global scale. If transitional life zones were defined too, 89 life zone types (38 core life zones + 51 transitional life zones) would be determined. Namely, this large number of classes would make it impossible to visually represent the life zones.

In this paper regional scale analysis was performed, so it has been considered appropriate to determine transi-

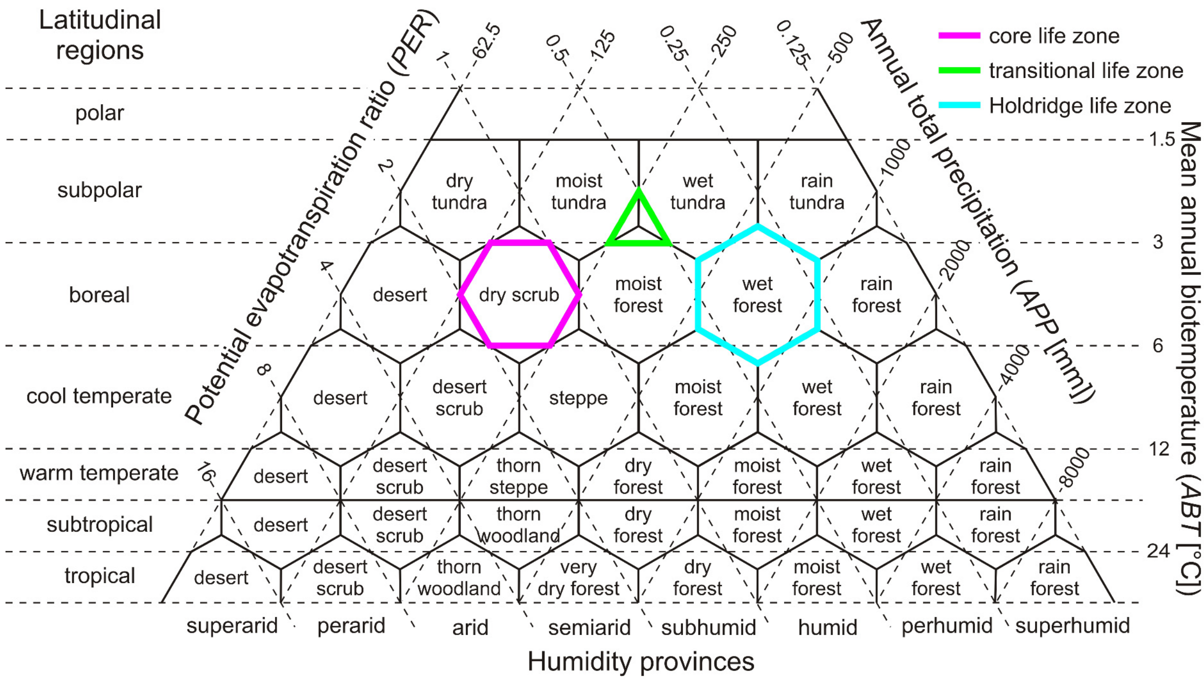


Figure 2. The original life zone chart of Holdridge [4].

Table 2. Latitudinal regions according to Holdridge [4] (*ABT* - mean annual biotemperature).

Latitudinal regions	*ABT* [°C]
polar	0-1.5
subpolar	1.5-3
boreal	3-6
cool temperate	6-12
warm temperate	12-17
subtropical	17-24
tropical	24-30

Table 3. Humidity provinces according to Holdridge [4] (*PER* - potential evapotranspiration ratio).

Humidity provinces	*PER*
superhumid	0.125-0.25
perhumid	0.25-0.5
humid	0.5-1
subhumid	1-2
semiarid	2-4
arid	4-8
perarid	8-16
superarid	16-32

tional life zones. These new units of model have been defined based on latitudinal regions (Table 2) and humidity provinces (Table 3).

Transitional life zones were not distributed among life zones in contrary of the original model, but these were determined as separate units. These new classes were named according to the following steps: a. latitudinal belts and humidity provinces were determined; b. names of vegetation associations were defined as combination of two adjacent core life zones from the same latitudinal belts. The new classes' list can be found in the legend of Figure 3. Each of transitional life zones was not defined which has got only one adjacent core life zone. Thus, only 43 transitional life zones were determined. Every transitional life zone which verges on one of the forest types (e.g. dry forest) and one of the steppe types (e.g. thorn steppe) were defined as forest steppe. The forest steppe is defined as a separate vegetation belt developed in the transitional climate between the zones of closed forests and steppe grasslands, in which more or less closed forests alternate with closed grasslands, forming a landscape of mosaic appearance [26]. One of the main reasons for the defining of transitional life zones was specifically to determine this ecotone and estimate changes in its spatial characteristics.

Each life zone's criteria are shown by Figure 3. For example, the criteria of "boreal dry scrub" core life zone are the followings: a. 3°C < *ABT* < 6°C; b. 125 mm < *APP* < 250 m; c. 1 < *PER* < 2. The climate/vegetation can be identified as "subpolar subhumid moist-wet tundra" transi-

Table 4. The contingency table.

			Map B categories				Total
			1	2	...	c	
Map A	categories	1	p_{11}	p_{12}	...	p_{1c}	p_{1T}
		2	p_{21}	p_{22}	...	p_{2c}	p_{2T}
		...	...	...	...	...	...
		c	p_{c1}	p_{c2}	...	p_{cc}	p_{cT}
	Total		p_{T1}	p_{T2}	...	p_{Tc}	1

tional life zone, if the following three criteria are fulfilled simultaneously: a. $ABT < 3°C$; b. $250 \text{ mm} < APP$; c. $0.5 < PER$.

3.3. The Kappa statistic

For the validation of classification methods the Kappa statistic [16] was used. This method has been commonly applied for comparing two vegetation maps [7, 27, 28]. The Kappa statistic (κ) is determined according to the following formula:

$$\kappa = \frac{p_o - p_e}{1 - p_e}, \quad (5)$$

where p_o is the probability of agreement, p_e is the hypothetical probability of chance agreement. First, the so-called contingency table (Table 4) has to be defined in order to determine the variables of the formula. In this table, it has to be displayed what is the probability that the x category on map A agrees with the y category on map B, and conversely. In Table 4 p_{1T} is the marginal probability of A_1 (category 1 on map A), p_{T1} is the marginal probability of B_1 and p_{11} is the joint probability of A_1 and B_1 (its probability that one point of the category 1 on map A falls also into the category 1 on map B).
The p_o and p_e are calculated using the contingency table according to the following formulas:

$$p_o = \sum_{i=1}^{c} p_{ii}, \quad (6)$$

$$p_e = \sum_{i=1}^{c} p_{Ti} \times p_{iT}. \quad (7)$$

The κ value can vary between 0 and 1, with 0 representing totally different patterns and 1 indicating complete agreement. The threshold values used in this paper for separating the different degrees of agreement for the Kappa statistic (κ) followed those of Monserud and Leemans [27] (Table 5).

Table 5. The relation between the Kappa statistic (κ) and the degree of agreement according to Monserud and Leemans [27].

Degree of agreement	Kappa statistic (κ)
no	0.00-0.05
very poor	0.05-0.20
poor	0.20-0.40
fair	0.40-0.55
good	0.55-0.70
very good	0.70-0.85
excellent	0.85-0.99
perfect	0.99-1.00

3.4. Spatial characteristics of the life zones

During our investigation the following parameters were analyzed: spatial patterns, relative extents, mean centres and average distribution elevations of life zones. The mean centre and average distribution elevation of life zones can be calculated using the following formula:

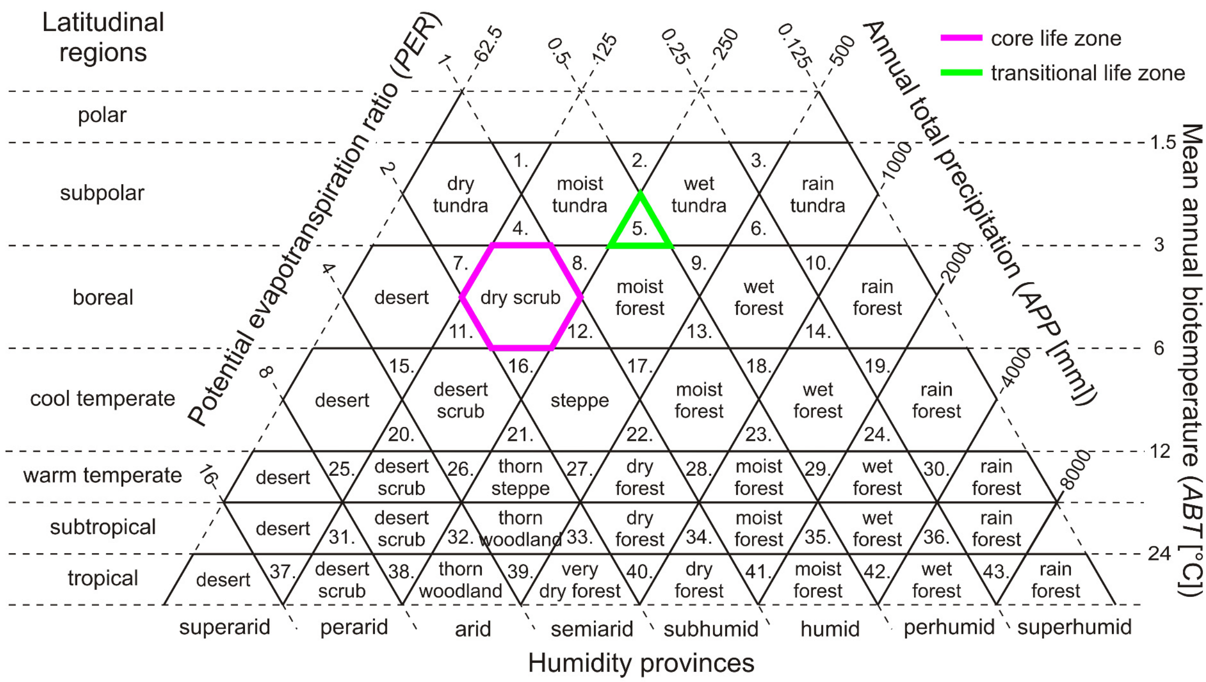
$$q_j(v,t) = \frac{\sum_{i=1}^{N_j(v,t)} Q_{ij}(v,t)}{N_j(v,t)}, \quad (8)$$

where v is the variable (1: longitude, 2: latitude; 3: altitude); t is the time; $N_j(v,t)$ is the number of grid points of the jth life zone type in t; $q_j(v,t)$ is the average value of the variable v of the jth life zone type in t (($q_j(1,t)$, $q_j(2,t)$) coordinates of the mean centre of the jth life zone type in t, $q_j(3,t)$ average distribution elevation of the jth life zone type in t); $Q_{ij}(v,t)$ is the variable v of the ith grid point of the jth life zone type in t.

4. Results

4.1. The validation of classification methods

According to Berényi [29], the quality of a bioclimatic classification method depends on its ability to identify relations between vegetation and climate. Thus, as a first step the validation of models (original and modified) was performed. Our life zone maps were compared with a vegetation map [22] using the Kappa statistic (κ).
First, the maps were reclassified. For the original model two large classes were defined: a. steppe; b. forest. For the modified model the forest steppe was determined as a separate class. For the original model the "forest steppe" formation was identified as (α.) forest and (β.) steppe. Further categorization was obviously based on the separation of woodlands and grasslands. Finally, three experiments were made (Table 6).
Our results were compared also to other similar investigations [7, 13]. The most important characteristics of these validations are summarized in Table 7.



1. subpolar humid dry-moist tundra
2. subpolar perhumid moist-wet tundra
3. subpolar superhumid wet-rain tundra
4. subpolar subhumid dry-moist tundra
5. subpolar humid moist-wet tundra
6. subpolar perhumid wet-rain tundra
7. boreal subhumid desert – dry scrub
8. boreal humid dry scrub – moist forest
9. boreal perhumid moist-wet forest
10. boreal superhumid wet-rain forest
11. boreal semiarid desert – dry scrub
12. boreal subhumid forest steppe
13. boreal humid moist-wet forest
14. boreal perhumid wet-rain forest
15. cool temperate semiarid desert – desert scrub
16. cool temperate subhumid desert scrub – steppe
17. cool temperate humid forest steppe
18. cool temperate perhumid moist-wet forest
19. cool temperate superhumid wet-rain forest
20. cool temperate arid desert – desert scrub
21. cool temperate semiarid desert scrub – steppe
22. cool temperate subhumid forest steppe
23. cool temperate humid moist-wet forest
24. cool temperate perhumid wet-rain forest
25. warm temperate arid desert – desert scrub
26. warm temperate semiarid desert scrub – thorn steppe
27. warm temperate subhumid forest steppe
28. warm temperate humid dry-moist forest
29. warm temperate perhumid moist-wet forest
30. warm temperate superhumid wet-rain forest
31. subtropical perarid desert – desert scrub
32. subtropical arid desert scrub – thorn woodland
33. subtropical semiarid thorn woodland – dry forest
34. subtropical subhumid dry-moist forest
35. subtropical humid moist-wet forest
36. subtropical perhumid wet-rain forest
37. tropical perarid desert – desert scrub
38. tropical arid desert scrub – thorn woodland
39. tropical semiarid thorn woodland – very dry forest
40. tropical subhumid very dry – dry forest
41. tropical humid dry-moist forest
42. tropical perhumid moist-wet forest
43. tropical superhumid wet-rain forest

Figure 3. The modified life zone chart.

Table 6. Reclassification of formations and life zones in the target area [capital letter (formations): notation according to Table 1; Roman numerals (α., β. Holdridge life zones, γ. core life zones): I. - boreal rain forest, II. - boreal wet forest, III. - cool temperate wet forest, IV. - cool temperate moist forest, V. - cool temperate steppe, VI. - warm temperate moist forest, VII. - warm temperate dry forest; Arabic numerals (transitional life zones): notation according to Figure 3].

Class	Formations			Life zones (original model) (α., β.)	Life zones (modified model) (γ.)
Forest	C, D, F, G, J			I., II., III., IV., VI., VII.	I., II., III., IV., VI., VII.
	α. L	β. -	γ. -		10., 14., 18., 23., 28.
Steppe	M			V.	V.
	α. -	β. L	γ. -		
Forest steppe	α. -	β. -	γ. L	-	17., 22.

Table 7. Main characteristics of life zone system's validations.

	Lugo *et al.* (1999)		Zheng *et al.* (2006)	This study		
				original		modified
				α.	β.	γ.
Kappa statistic (κ)	0.39	0.43	0.43	0.31	0.41	0.37
Degree of agreement	poor	fair	fair	poor	fair	poor
Location	Conterminous United States		Xinjiang Uygur Autonomous Region	Carpathian Region		
Area	8 080 464 km^2		1 660 001 km^2	716 390 km^2		
Spatial resolution	2.5 minute		0.5 minute	10 minute		
Investigation period	1961-1990		1971-1980	1901-1920		
Vegetation map	Bailey (1976)	Küchler (1964)	Hou *et al.* (1982)	Bohn *et al.* (2000/2003)		
Definition of vegetation	potential natural	potential natural	actual	(potential/reconstructed) natural		
Number of classes	4		12	2		3

Zheng *et al.* [13] had validated the life zone model for the Xinjiang Uygur Autonomous Region for the 1970s based on the actual vegetation (AV) map of the People's Republic of China [30] (Table 7). The AV map was reclassified. Each AV type was identified as a life zone type, so 12 classes were established. Strict conditions were determined for validation using lot of classes, but it could be equilibrated at a high spatial resolution (0.5 minute). Yue *et al.* [31] found that the scale and spatial resolution of used database has an important role in vegetation studies (e.g. ecological diversity, vegetation dynamics). This effect is also visible in Table 7. Eventually Zheng *et al.* [13] had diagnosed "fair" agreement between the maps.

Lugo *et al.* [7] had investigated in the conterminous United States for the period 1961-1990 at a spatial resolution of 2.5 minute (Table 7). Vegetation maps of Bailey [32] and Küchler [33] were used for validation. Four classes were defined for reclassification: forest, grassland, shrubland and non-vegetated. In spite of the relatively high spatial resolution and the small number of classes only "poor" and "fair" agreements were found for comparison of maps.

In this paper the used spatial resolution (10 minute) was relatively poor considering experiences of the former investigations, so it was found appropriate to use few classes. Another problem was that majority of azonal formations were observed in the central part of the Carpathian Basin in which majority of transitional life zones were also found. It is totally unambiguous that the life zone model is most sensitive to transitional life zones. Thus, this had also hampered model validation.

For the original model we found "poor" (α. $\kappa = 0.31$) and "fair" (β. $\kappa = 0.41$) agreement. After an extra class was defined, degree of the agreement was still only "poor" (γ. $\kappa = 0.37$). Because of the more strict conditions it can be understood as a development that this value is more than mean of two former values. Considering all these, the reference investigations' results and ours were very similar. Thus, the models were also used rightly in the Carpathian Region.

4.2. Spatial pattern of life zones

4.2.1. Holdridge original life zone system

The observed climate change can be detected based on the changes in spatial pattern of life zones. In Table 8 the relative extent of life zones is shown for the previously defined 20-year long periods. The spatial distribution of life zones for the periods 1901-1920 (T1) and 1981-2000 (T5) can be seen in Figure 4. In all periods 7 life zone types can be registered (Table 8).

The characteristic life zone of the Carpathian Region in T1 was the "cool temperate moist forest", covering almost 70% of the total area (Table 8). The second most abundant life zone coverage was around 10% related to "cool temperate steppe". About one-third of this was found in the centre of the Carpathian Basin (Figure 4), where the precipitation was the lowest. The remaining part was situated east of the Carpathians. A small patch of the "cool temperate steppe" can also be observed in the centre of Wallachia. The third most extensive life zone type was the "cool temperate wet forest", covering ca. 8% of the target area which is shown in higher mountains. The characteristic life zone type of Wallachia and North of Serbia was the "warm temperate dry forest"; the relative extent of this life zone type was little more than 6%. In Eastern and Southern Carpathians the climate conditions were suitable for "boreal wet forest", covering ca. 5% of the total area. The characteristic life zone type was the "boreal rain forest" in the highest peaks of the Carpathians which was the rainiest and coolest part of the target area.

Comparing the two maps, it is evident that for the end of the century (T5) the climate of the Carpathian Region changed substantially, the spatial pattern of life zones altered. It is also important to analyse what kind of changes occurred between T1 and T5. However, in case of the original life zone system, the latitudinal and humidity changes cannot be properly addressed because each life zone type extends to three latitudinal regions and three humidity provinces.

Table 8. Ratio of each life zone type's area and total target area (%) for the periods 1901-1920 (T1), 1921-1940 (T2), 1941-1960 (T3), 1961-1980 (T4) and 1981-2000 (T5).

Life zone type	T1	T2	T3	T4	T5
Boreal wet forest	5.07	3.32	3.10	3.44	2.64
Boreal rain forest	0.43	0.18	0.06	0.18	0.09
Cool temperate steppe	9.58	8.44	10.96	5.83	13.02
Cool temperate moist forest	69.91	70.00	67.49	70.86	61.56
Cool temperate wet forest	8.01	8.17	5.34	8.93	5.86
Warm temperate dry forest	6.23	9.00	12.34	9.98	15.60
Warm temperate moist forest	0.77	0.89	0.71	0.77	1.23

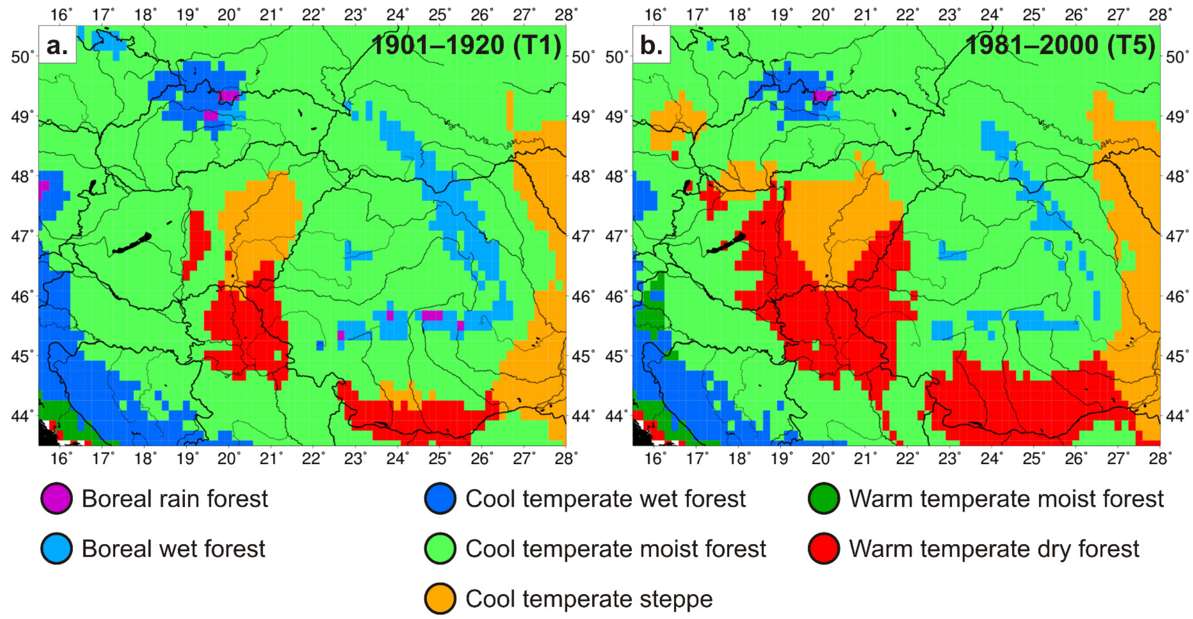


Figure 4. Spatial distribution of life zones for the periods (a.) 1901-1920 (T1) and (b.) 1981-2000 (T5)

We felt it necessary to investigate what life zone type transitions occurred from T1 to T5. A transition matrix can be defined in which the ratios of life zone transition affected areas are indicated (not shown). Life zone transition was observed over 19.86% of the target area in the last century. The two greatest changes were attributed to transition from "cool temperate moist forest" to "warm temperate dry forest" (8.2%) and to "cool temperate steppe" (4.51%) (Figure 4).

4.2.2. *Holdridge modified life zone system*

Modifying the life zone system those ecotones which are important in the view of Carpathian Basin can be determined. With use of the transitional life zone types, the depiction of climate is more detailed. The new life zones for the periods 1901-1920 (T1) and 1981-2000 (T5) are shown in Figure 5, while the corresponding table with area ratios in Table 9. In the investigation period 7 core and 7 transitional life zone types were registered in the region. By the end of the century 1 core and 2 transitional types became completely extinct (Table 9).

Even after the introduction of transitional life zones, the most abundant life zone type in T1 was the "cool temperate moist forest" core type (58.8%). The second in the ranking became the "cool temperate subhumid forest steppe" transitional type (19.9%), covering the Great Hungarian Plain, the Wallachia and in small patches along the Hungarian upper section of the Danube (Figure 5). The third place belonged to the "cool temperate wet forest" (5.53%) found in the Dinaric Alps, the Alps and the North Carpathians. However in the Eastern and Southern Carpathians the "boreal wet forest" was the characteristic life zone type (3.25%). The "cool temperate perhumid moist-wet forest" covered most of the other transitional types in Figure 5 in mountainous areas (4.39%). In T1 another life zone type, the "cool temperate steppe" had a relative extent over 3%

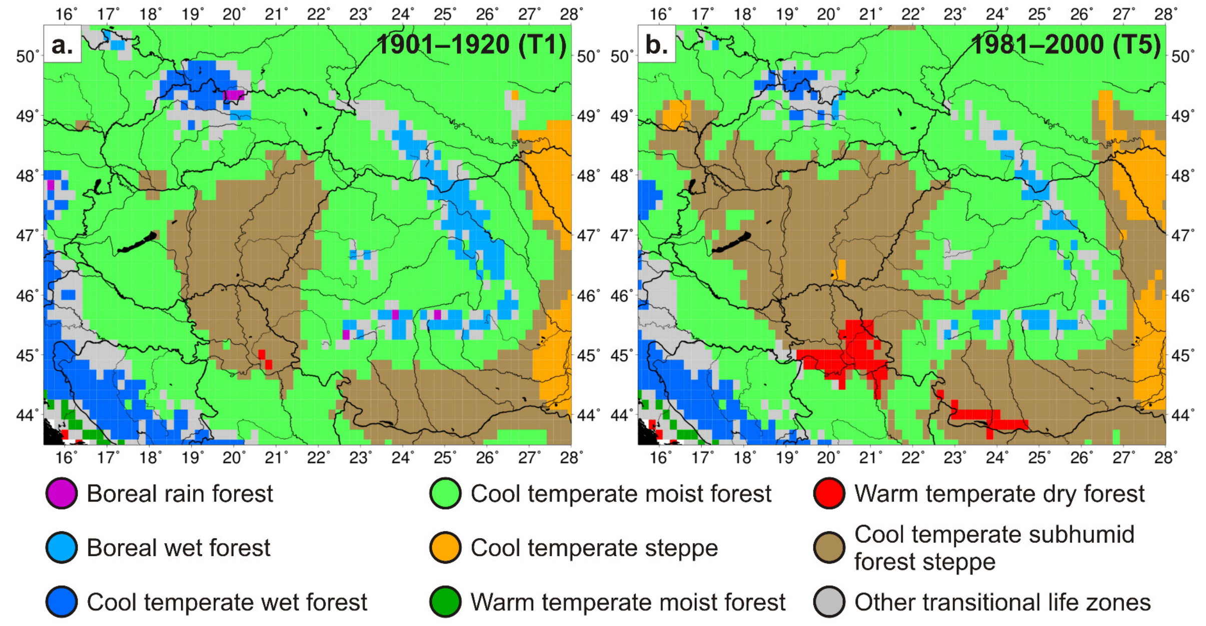


Figure 5. Spatial distribution of core and transitional life zones for the periods (a.) 1901-1920 (T1) and (b.) 1981-2000 (T5).

Table 9. Ratio of each core/transitional life zone type's area and total target area (%) for the periods 1901-1920 (T1), 1921-1940 (T2), 1941-1960 (T3), 1961-1980 (T4) and 1981-2000 (T5) (-: indiscernible in the actual period).

	Life zone type	T1	T2	T3	T4	T5
Core life zones	Boreal wet forest	3.25	1.90	1.57	1.60	1.47
	Boreal rain forest	0.21	0.09	-	0.15	-
	Cool temperate steppe	3.87	5.83	6.85	0.89	4.33
	Cool temperate moist forest	58.80	58.83	56.13	58.27	50.63
	Cool temperate wet forest	5.53	5.56	3.53	6.54	4.02
	Warm temperate dry forest	0.12	0.40	2.00	0.18	1.97
	Warm temperate moist forest	0.40	0.46	0.12	0.46	0.31
Transitional life zones	Boreal superhumid wet-rain forest	0.09	0.03	-	-	-
	Boreal perhumid wet-rain forest	0.52	0.46	0.34	0.71	0.18
	Cool temperate humid forest steppe	0.21	-	0.18	-	-
	Cool temperate perhumid moist-wet forest	4.39	4.18	4.30	4.67	3.44
	Cool temperate subhumid forest steppe	19.90	19.40	21.98	24.26	30.27
	Cool temperate humid moist-wet forest	2.43	2.61	2.43	2.06	2.79
	Warm temperate humid dry-moist forest	0.28	0.25	0.58	0.21	0.58

but this was only found east to the Carpathians. The remaining 7 life zone types were spread over 4.26% of the target area, mostly outside the Carpathian Basin.

It is advantageous also to analyse the dynamics of climate change based on the changes in extent of life zones (Table 9). As it was observed in the original system more than half of the area was covered with "cool temperate moist forest". Furthermore, the extent of "cool temperate subhumid forest steppe" never fallen below 19%. The implementation of transitional life zones allows us to consider the climate change using the latitudinal and humidity properties. In the whole investigation period the cool temperate belt's extent was more than 95%. From T1 to T3 the area of superhumid, perhumid and humid provinces decreased continually, while in consequence the subhumid province gained area. As it was seen the period T4 was more humid than the previous ones. In T4 the relative area of subhumid types was 25.33%, which was the second lowest from the five periods. In T5 the extent of humid, perhumid and superhumid provinces was the lowest (54.31%, 9.11%, 0%), while the subhumid reached its maximum (36.57%). The coverage of boreal region decreased with 59.46% from T1 to T5, while the warm temperate region became almost two and a half larger (257.36%). During the investigation period, the extent of subhumid province grew with 53.08%, and the humid and perhumid provinces decreased by 12.57%, 33.46% respectively (Table 9).

Using transition matrix the changes across types can be assessed (not shown). Life zone transitions were observed in 24.38% of the target area. For more than three quarter of these transitions 4 types were responsible. In about 12% of the total area the "cool temperate moist forest" changed to "cool temperate subhumid forest steppe" by the end of the century. Second greatest change was the transition from "cool temperate perhumid moist-wet forest" to "cool temperate moist forest" (3.25%). The "cool temperate subhumid forest steppe" became "warm temperate dry forest" in 1.69% of the total area. Around the same area transition was observed in case of "boreal wet forest" to "cool temperate perhumid moist-wet forest" (1.47%).

4.3. Mean centre of life zones

The climate change was also investigated based on shifts of mean centres of life zones which are shown for the last century in case of the original model in Figure 6.

The absolute positions of mean centres are not informative and they can be misleading since the mean centres of life zones not necessarily fall into the area of the given life zones because of their fragmentation. For this reason, only the direction and distance of shifts are analysed from 1901-1920 (T1) to 1981-2000 (T5) in this paper (Table 10).

Among the previously observed 7 life zone types, the shifts of the boreal latitudinal belt's types and the "cool temperate wet forest" type were misconceived because they were related to mountains in the last century (Figure 4). In case of 3 out of the remaining 4 types, the average centre shifted northward, and one shifted towards northwest (Table 10). The distance of shift was 23.55 km, 32.41 km and 90.12 km for cool temperate moist forest, warm temperate dry forest and warm temperate moist forest respectively. The mean centre of "cool temperate steppe" had a shift of 132.68 km towards the northwest. In T5 this life zone type appeared in northwest part of the target area but in T1 it could be registered only east of the Danube hence the northwest shift.

Comparing the results of the modified and original models, it was found that the directions of shifts of mean centres are similar from T1 to T5. So these results are not shown for brevity. However, it should be said that when only the south-north shifts are investigated, only 3 out of 11 defined mean centres shifted southward: boreal wet forest, cool temperate wet forest and cool temperate perhumid moist-wet forest. It has to be noted that since there are more categories in the modified model and the life zone areas are fragmented, the mean centres have greater fluctuation.

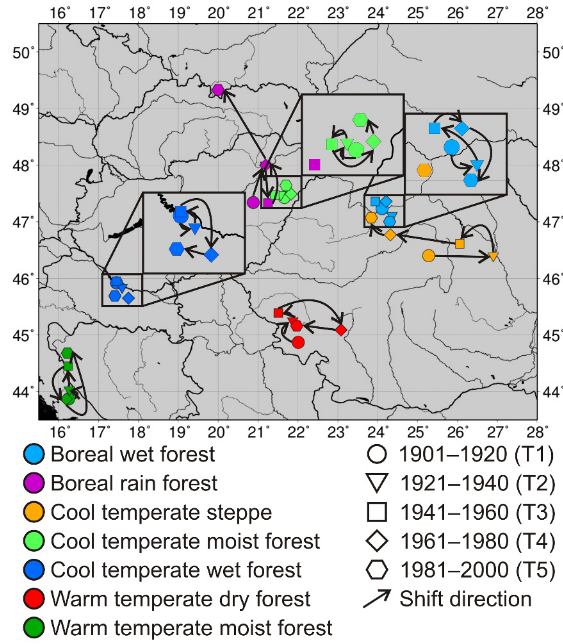


Figure 6. The shifts of mean centres of life zones determined for the target area in the last century.

Table 10. Shift distance [km] and direction of each life zone type from 1901-1920 (T1) to 1981-2000 (T5) in the target area.

Life zone type	From T1 to T5	
	distance [km]	direction
Boreal wet forest	29.35	southeast
Boreal rain forest	230.70	northwest
Cool temperate steppe	132.68	northwest
Cool temperate moist forest	23.55	north
Cool temperate wet forest	25.77	south
Warm temperate dry forest	32.41	north
Warm temperate moist forest	90.12	north

4.4. Average distribution elevation of life zones

4.4.1. Holdridge original life zone system

So far the horizontal distribution of life zones was investigated, further the following characteristics of their vertical distribution are summarized in Table 11: a. average distribution elevation (z_{ave}) in T1 [m]; b. changes in z_{ave} for consecutive periods [m]; c. change in z_{ave} from T1 to T5 [m].

The results in Table 11 confirm our earlier statement that life zones of the boreal latitudinal belt and the "cool temperate wet forest" life zone type were related to mountains. The value of z_{ave} was 716.3 m, 994.2 m and 1304.7 m for cool temperate wet forest, boreal wet forest and boreal rain forest respectively. In most life zones the value of z_{ave} increased in all periods except from T3 to T4. The maximum elevation increase (146 m) was registered in case of the "boreal wet forest" from T1 to T5 and the minimum was 26 m for "cool temperate steppe". Exceptions were found for the elevation decrease in case of "boreal rain forest" (56 m) and "warm temperate moist forest" (43.5 m) from T4 to T5. Also for the latter, the only increment can only be found from T2 to T3. In case of "boreal rain forest" the reason behind the decrease in elevation is that it was superseded from the Southern Carpathians and it could only be found on the northern slopes of the High Tatras. In altogether the elevation of the 5 most abundant life zone types had increased, that is the life zones shifted to higher elevations (Table 11).

4.4.2. Holdridge modified life zone system

The values of average distribution elevation (z_{ave}) of life zones were investigated also for the modified model (Table 12). At the beginning of the last century (T1) 14 core/transitional life zone types were registered in the Carpathian Region, but not all types were observed in the subsequent periods in the target area. Thus, not all elevation changes could be calculated.

From T1 to T2 the second highest of elevation increases (102.3 m) was registered in case of the "boreal perhumid wet-rain forest". In the same period the maximum elevation decrease (90.2 m) was found in case of the "boreal rain forest". The former appeared in the Southern Carpathians, thereby displacing the latter. The humidity characteristic of the former is perhumid, whereas in case of the latter it is superhumid. Thus, the aridity processes are also shown by changes in values of z_{ave}. From T2 to T3 all defined elevation changes was increase apart from the "warm temperate dry forest". In line with previous results the values of z_{ave} decreased from T3 to T4 for all life zone types. In this period the greatest elevation decrease was found for the "warm temperate moist forest" (190 m). Except for one type the values of z_{ave} increased form T4 to T5. On the whole, we could see that the value of z_{ave} had increased in case of the most of the life zone types, that is to say the life zone types moved to higher elevations.

5. Summary

Holdridge had developed the life zone system to define the spatial differences in climate for global scale. This had forced him to make compromises. He had not determined transitional life zone types, because it would have been impossible to visually represent life zones. In our former investigation [9] it was shown that in regional analysis the use of transitional life zones can be justified. In this paper the life zone system of Holdridge was modified; the list of uniform names for the new units was shown.

Because the life zone system has been developed during the exploration of the tropical areas, it was necessary to validate the models for our target area also. Our life zone maps were compared with another vegetation map [22]. The degrees of agreements were determined using Cohen's Kappa statistic. Our results were compared to other similar, extratropical studies [7, 13]. The reference investigations' results and ours were very similar (poor-fair agreement between different vegetation and life zone maps).

Furthermore, in this paper the original and modified models were also applied to estimate the effects of climate change in the Carpathian Region for the last century. During our investigation the following parameters' temporal changes were analyzed: spatial patterns, relative extents, mean centres and average distribution elevations of life zones.

In the target area 7 life zone types were observed using the original model. We found that the characteristic life zone type of the Carpathian Region was the "cool temperate moist forest" during the whole investigation period. This type covered more than 60% of the total area in all periods. In the Carpathian Region 7 core and 7 transitional life zone types could be registered using the modified life zone system. Thanks to the determination of transitional types the spatial pattern of life zones was substantially amended: a. the dominance of the "cool temperate moist forest" reduced; b. the second most abundant life zone type became the "cool temperate subhumid forest steppe" transitional type, covered a significant part of the lowland areas. The relative extent of the latter type was 19.9% in the period 1901-1920 (T1), whereas it was already 30.27% in the period 1980-2000 (T5). The spatial pattern of this transitional life zone type for T5 was compared with the

Table 11. Each of life zones' (a.) average distribution elevation (z_{ave}) in the period 1901-1920 (T1) [m], (b.) changes in z_{ave} for consecutive periods (T2: 1921-1940, T3: 1941-1960, T4: 1961-1980, T5: 1981-2000) [m], (c.) change in z_{ave} from T1 to T5 [m].

Life zone type	a.	r.				c.
	T1	From T1 to T2	From T2 to T3	From T3 to T4	From T4 to T5	From T1 to T5
Boreal wet forest	994.2	+75.9	+32.1	-45.5	+83.6	+146.0
Boreal rain forest	1304.7	+25.0	+38.3	-38.3	-56.0	-31.0
Cool temperate steppe	107.3	+28.6	+2.7	-30.3	+25.3	+26.3
Cool temperate moist forest	326.9	+15.8	+29.4	-36.2	+56.6	+65.5
Cool temperate wet forest	716.3	+17.0	+76.3	-72.4	+64.6	+85.5
Warm temperate dry forest	91.4	+2.6	+17.4	-19.5	+33.9	+34.4
Warm temperate moist forest	416.8	-28.4	+9.3	-11.8	-43.5	-74.5

Table 12. Each of core/transitional life zones' (a.) average distribution elevation (z_{ave}) in the period 1901-1920 (T1) [m], (b.) changes in z_{ave} for consecutive periods (T2: 1921-1940, T3: 1941-1960, T4: 1961-1980, T5: 1981-2000) [m], (c.) change in z_{ave} from T1 to T5 [m] (-:indiscernible in one of actual periods).

	Life zone type	a.	b.				c.
		T1	From T1 to T2	From T2 to T3	From T3 to T4	From T4 to T5	From T1 to T5
Core life zones	Boreal wet forest	1059.6	+54.9	+50.5	-46.3	+65.3	+124.4
	Boreal rain forest	1363.9	-90.2	-	-	-	-
	Cool temperate steppe	115.0	+16.0	+14.3	-37.0	+14.7	+8.1
	Cool temperate moist forest	339.8	+16.0	+27.6	-35.1	+60.8	+69.3
	Cool temperate wet forest	765.7	+32.9	+43.1	-53.8	+80.9	+103.1
	Warm temperate dry forest	102.8	-3.7	-2.4	-36.6	+28.1	-14.5
	Warm temperate moist forest	487.7	-41.4	+167.2	-190.0	+100.9	+36.7
Transitional life zones	Boreal superhumid wet-rain forest	1467.3	+179.7	-	-	-	-
	Boreal perhumid wet-rain forest	1032.3	+102.3	+55.8	-81.4	+140.2	+216.9
	Cool temperate humid forest steppe	295.1	-	-	-	-	-
	Cool temperate perhumid moist-wet forest	785.6	+57.9	+46.7	-43.1	+51.5	+113.1
	Cool temperate subhumid forest steppe	114.4	+8.4	+13.1	-16.3	+37.5	+42.7
	Cool temperate humid moist-wet forest	406.0	-38.2	+78.8	-119.1	+64.1	-14.3
	Warm temperate humid dry-moist forest	206.3	+12.9	+80.8	-94.5	-9.0	-9.8

potential distribution of the forest steppe [26]; a great agreement was found between the two maps.

The aspects of our investigation were also the temporal changes in the mean centres and the average distribution elevations of life zones. Similar tendencies were found in both models, so only the original life zone system's results were summarized. The mean centres of those life zones, which were not related to mountains, shifted northward from T1 to T5. Furthermore, we found that the average distribution elevations of all types increased from T1 to T3 apart from one case, whereas elevation decrease was registered in case of all life zone types between T3 and T4. The reason for this is that T4 was slightly rainier and cooler than T3. In altogether in case of the 5 most abundant life zone types, this parameter had increased during the last century. The registered changes in the spatial pattern of life zones (e.g. northward shift, appearance at higher elevations) fit in with former observations of the natural environment [34].

In summary, the effects of the climate change could be suitably detected in the Carpathian Region for the last century using the life zone system. The climate of the region could be depicted in much more detail using the modified model. We had determined transitional life zone types in the model, so the potential distribution of forest steppe could be also identified which is a very important ecotone of the region. We believe that this relatively simple, suggestive bioclimatic classification method is suited to that its current and later results can be used to communicate climate change to the public. For this reason, our further purpose is to estimate the projected climate change's effects on life zones for the Carpathian Region using these models.

6. Acknowledgements

This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 'National Excellence Program'. The authors gratefully acknowledge the Climatic Research Unit of the University of East Anglia, UK, for providing the monthly high resolution dataset CRU TS 1.2.

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