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V. M. Skrobala[1],
orcid.org/0000-0002-0606-8079,
V. V. Popovych[2],
orcid.org/0000-0003-2857-0147,
P. V. Bosak[2],
orcid.org/0000-0002-0303-544X,
T. I. Shuplat[2],
orcid.org/0000-0003-3497-2636

1 – National University of Forestry of Ukraine, Lviv, Ukraine
2 – Lviv State University of Life Safety, Lviv, Ukraine, e-mail: popovich2007@ukr.net

PREDICTION OF CHANGES IN THE VEGETATION COVER OF UKRAINE DUE TO CLIMATE WARMING

Purpose. To study ecological regularities of the formation of vegetation cover in Ukraine depending on the climatic conditions and analyze its possible changes due to global warming.

Methodology. The research methodology involves the following: differentiation of the climatic conditions and evaluation of the significance of climatic indices at the level of territorial units of a geobotanical zoning based on variance analysis; multiple ordering of the geographic locations in terms of climatic indices basing on the analysis of main components (Principle Component Analysis); development of a typological scheme of the vegetation cover relying upon a discriminant analysis; statistic processing of the climatic parameters.

Findings. Modelling of spatial differentiation of climatic indices depending on the location latitude and longitude as well as altitude above the sea level helped analyze the connection of vegetation cover and climate. It has been determined that peculiarities of the vegetation cover formation according to a scheme of geobotanical zoning is characterized in the most accurate way by the difference of such climatic indices as: air temperature in January, July, and August; monthly precipitation amounts during June-September; duration of a frost-free period; and hydrothermal coefficient of T.G. Selianinov. The main regularity of the formation of Ukrainian vegetation cover has been defined. The regularity means the following structure of interrelation between the climatic indices: along with the growing average monthly temperatures of June-September and decreasing precipitation amounts from April to September, the indices of climatic water availability decrease along with the increasing heat availability indices (duration of an active vegetation period and total of temperatures per that period, average annual temperature). This regularity represents a gradient of climatic indices from the Ukrainian Carpathians towards the southern Crimean coast. It has been determined that during some years of the early *21st* century, the conditions peculiar for a steppe area were formed for the forest and forest steppe areas.

Originality. The vegetation cover of Ukraine is characterized by the ecological range, which is evaluated basing on ordering of the geographical locations in terms of coverage of complex climatic environmental gradients. A typological scheme of the Ukrainian vegetation cover can be represented in a two-dimensional space in the form of square parabola, whose left branch shows a gradient of climatic factors and changes in vegetation cover from the west to the north-east and right branch indicates it from the north-east to the south. Graphic visualization of climatic information on the basis of ecograms and typological schemes of vegetation cover can be used to predict the vegetation cover dynamics due to certain climatic changes.

Practical value. While understanding the climatic conditions of geographic locations during certain periods of time, one can identify their location in the ecological and coenotic range of Ukrainian vegetation and predict their stability and possible changes in the vegetation cover due to global warming.

Keywords: *climate changes, typology of the vegetation cover, vegetation changes, mathematical modelling*

Introduction. Global climate change has become one of the burning ecological problems, solution of which attracts attention of the whole humanity. It results in dangerous weather disasters, abrupt weather changes, floods, strong winds, rainfalls, hails, and draughts causing considerable environmental and economic damages worldwide.

In their paper [1], scientists state that the strategies of reacting to climatic changes can be freely divided into fighting, stage-by-stage adaptation or transformational adaptation requiring increased human contribution and system reorganization. As a rule, transformational adaptation that changes completely the systems and eliminates the causes of problems has six characteristics: restructuring, innovative, changing, multiscaled, system-wide, and stable. Transformational adaptation can be a corresponding reaction to some climatic change when it is expected that severity of climatic change effects will be intensified greatly when current adaptations reach their boundaries or when radical climatic changes have already happened.

According to the research results [2], it is determined that climatic changes have influenced the vegetation phenology in Ethiopian ecoregions. The vegetation beginning has shifted to much earlier periods; and a growing period has prolonged in most ecoregions. This shift is the result of changes in both precipitations and temperature conditions; however, the temperature depends proportionally on the vegetation. The temperature in this region is controlled by the inclination angle of the sun and altitude differences. Right from the beginning of a vegetation period up to ripening, CO_2 absorption has a tendency to increase at the expense of growing photosynthetic activity. This period coincides with the decreasing sun angle.

Paper [3] represents the results of studies concerning analysis of soil cover changes due to human activities within the technogenically disturbed soils at the territories near enterprises of natural gas processing; paper [4] represents topicality of protecting natural fresh water resources as a global problem. This problem is of special significance in the context of activities of various industrial enterprises [5]. It is no doubt that human activities result in negative impact on the ecosystem. That concerns especially the deposit development with the formation of technogenic territories [6] with the formation of mine dumps [7], which can even have toxic effect on the environment [8]. To reduce the environmental load, the authors of paper [9] specified ecological regularities of the formation of vegetation covers for mine dumps basing on the analysis of floristic composition of ecotypes of recultivated and non-recultivated terricones.

The objective of research [10] is to assess the environmental effect of 18 biomass processing factories located in the Alpine region by evaluating the lifecycle and analysing current market purpose of wooden waste. The results can be used to expand scientific knowledge on the environmental impact due to biomass processing technologies and to emphasize soft spots in the supply chain of wooden raw materials. Moreover, these results can help the ones who make decisions concerning the strategies for mitigating climatic changes at regional and local levels. The environmental effect of mine closures is studied in detail in paper [11], while paper [12] represents and tests an analytical model of water influx and water level rise in the mine under flooding.

An NPP model was defined for quantitative evaluation of the contribution of climate changes and human activities to the vegetation changes; the model suits for Chinese Loess Plateau grasslands by observing biomass from the field studies and literature [13].

The results of research [14] demonstrate that a vegetation period in the Yangtze River basin has grown by 0.09 % within the 34-year period. The changes indicate a considerable tendency of vegetation growth with annual change rates of 0.09 % during the period of 1982–2015. Especially after 1994, the vegetation cover has grown considerably. Temperature is a control factor determining the plant vegetation; and vegetation reaction to precipitations is relatively lower due to a great amount of water. At the same time, changes in land management caused by the project of ecological restoration are the basic driving factor to improve vegetation conditions in the Yangtze River basin. In addition, spatial divisions between the tendencies of a vegetation period increase caused by human activities and regions with growing number of forests are in strong relation in the north of the basin.

While modelling [15], 19 bioclimatic variables and topographic elevation changes were used; the variables were obtained from the monthly data in 30 Turkish provinces where *Fraxinus excelsior* L. was found. The results show that *Fraxinus excelsior* L. is influenced greatly by precipitations during the driest month, driest quarter, and hottest quarter. According to the reaction curve of *Fraxinus excelsior* L. in Turkey, it is observed that it prefers growing within the area with a low amount of precipitations being 22 mm during the driest month, average amount of precipitations being 100 mm during the driest quarter, and more than 70 mm of precipitations during the hottest quarter. Climatic scenarios SSP 245 and SSP 585 demonstrate respectively that geographical expansion of *Fraxinus excelsior* L. will be reduced by 7.58 and 6.28 % in 2100. The results demonstrate that the species react to both individual and civil influence as well as the influence in terms of ecosystems due to climate changes by alternating their climatic niches.

Climate changes along with land management and alternating land cover affect significantly the water accessibility in the Mediterranean ecosystems. In paper [16], an instrument for evaluating land and water was being implemented within the period of 2006–2018 in terms of catchment of the central part of Chile (36°) to test the hypothesis on the fact that adaptive plantation strategies can mitigate climatic influences and increase the river flow. It is assumed that exotic tree afforestation will reduce water accessibility in the Mediterranean Sea basins acting in synergy with climate change. Afforestation with exotic pines intensifies water yield reduction while conservative scenarios focused on the protection and restoration of primary forests can partially mitigate the effect of climatic changes.

Geographical location of Ukraine and features of its climate favour almost yearly origin and formation of draughts of different intensities and coverage areas on its territory. Over the recent years, repetition of the days with maximum summer temperatures being more than +35 and +40 °C, belonging to the extreme weather phenomena, has increased by almost two times [17]. One can observe intense processes of drying and dying of pine plantations on the even Ukrainian areas as well as the secondary fir forests in the Carpathians growing under the improper vegetational conditions [18]. This process is especially notable within the southern regions of Ukraine where recent satellite observations has demonstrates loss of about 20–30 % forest-covered lands almost in all steppe areas [19].

Objective of our research is to study ecological regularities of the formation of vegetation cover in Ukraine depending on climatic conditions and analyze its possible changes due to global warming.

Objects and methods of the research. The considered region is represented by the Ukrainian territory. Ukraine is located in the central part of European continent. Eastwards from the west (22–40 °E), its territory expands for 1,300 km; southwards from the north (45–52 °N) – for almost 900 km. The area of Ukraine is 603.7 thousand km^2. Ukrainian climate is moderately warm with excessive watering in the northern-western and western part and insufficient watering in the southern steppe areas. The climate continentality increases from the west to the east. The relation between the vegetation cover and climate was studied by modelling spatial differentiation of climatic indices depending on the area latitude and longitude as well as altitude above the sea level. Taking into consideration a long-term period of forest vegetation development, a period of 1881–1960 was taken as the standard of climatic conditions. The data sources were represented by different reference materials as well as open-access electronic archives.

The significance of climatic indices for the vegetation cover formation was examined by means of a dispersion analysis, where a geobotanical region was a level of the vegetation cover differentiation.

Each elementary area of the land surface can be represented in the form of a point in a 24D space of signs, whose coordinates meet the values of average monthly temperatures and average monthly precipitations. The space dimensionality was reduced basing on a canonic discriminant analysis. A method for predicting changes in the vegetation cover can be formulated as "transformation of the time coordinates into the spatial ones": which vegetation was peculiar in the past for today's specific climatic conditions. The calculations were performed with the help of statistic package "Statistica".

Research results. Ukrainian territory covers four geobotanical regions: the European broad-leaved forest, European-Siberian Forest steppe, European-Asian steppe, and Mediterranean forest ones. In terms of Ukrainian vegetation cover, forest vegetation is of the main significance. The largest forest areas are found in the mountainous regions of the Ukrainian Carpathians and Mountainous Crimea as well as in the forest and steppe-forest areas. The south of Ukraine contains mostly pine and oak-pine forests; the north shows mostly hornbeam-oak and hornbeam-beech; the west demonstrates mostly maple-linden-oak forests. During the pre-agricultural period, the north was covered with the forb-fescue-feather grass steppes (Fig. 1), where such gramineous plants as *Stipa capillata* L., *S. lessingiana* Trin. et Rupr., *Festuca rupicola* Heuff, *F. valesiaca* Gaud., *Koeleria cristata* (L.) Pers., *Agropyron pectinatum* (Bieb.) Beauv., *Poa angustifolia* L., *Phleum phleoides* (L.) Karst. dominate; the characteristic forbs are *Salvia nutans* L., *Phlomis pungens* Willd., *Ph. tuberosa* L., *Filipendula vulgaris* Moench. The driest southern conditions of the steppe region (Fig.1) form the desert-like wormwood-grass steppes, which are specific with their great amount of *Artemisia boschniakiana* (Bess.) DC., *A. taurica* Willd., *A. austriaca* Jacq., *Kochia prostrata* (L.) Schrad., *Agropyron pectinatum* (Bieb.) Beauv. in the grass stand [19, 20].

Latitudinal and vertical zonalities are the determining factors of the vegetation cover formation. Minimal average monthly temperatures in January (–8– –7 °C) are peculiar for the high-mountain part of the Carpathians and northern-eastern part of Ukraine while at the southern Crimean coast the temperatures do not go below 0 °C (Table 1). During the year, the highest temperature values are recorded in July. In case of broad-leaved forest and forest steppe regions, the temperature reaches 18–20 °C; in terms of steppe and sea coasts, it reaches 21–24 °C (Table 1).

Regularities of spatial-time distribution of the quantitative indices of thermal conditions in Ukraine can be characterized

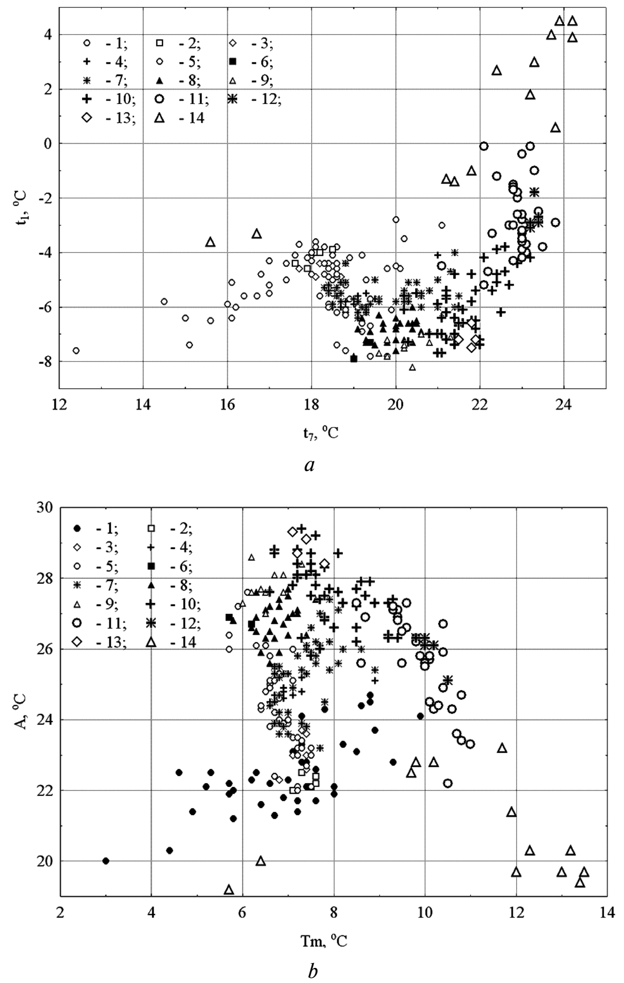

Fig. 1. Ecograms of the vegetation cover of Ukraine:

A — in the coordinate system of the average monthly temperatures of January t_1 and July t_7; °C; B — in the coordinate system of the average annual temperature Tm, °C, and annual range of temperatures, A °C; Numeric ordering of subprovinces: 1. The Eastern Carpathian mountainous subprovince. 2. The Baltic subprovince of the Central European subprovince. 3. The Western Ukrainian subprovince. 4. The Podilia-Bessarabia subprovince. 5. The Polissia subprovince. 6. The Mid-Russian subprovince of the Eastern European province of the European broad-leaved region. 7. The Podilia and Mid-Dnieper subprovince. 8. The Left-Bank Dnieper subprovince. 9. The Mid-Russian forest steppe subprovince of the Eastern European province of the European-Siberian forest steppe region. 10–12. The Pryazovia-Black Sea steppe subprovince. 10. A zone of forb-fescue-feather grass steppes. 11. A zone of fescue-feather grass steppes. 12. A zone of wormwood-grass steppes. 13. The Mid-Don subprovince of the Black Sea coastal (Pontic) steppe province of the European-Asian steppe region. 14. The Mountainous Crimean subprovince of the Mediterranean forest region

Table 1

Distribution of climate types in terms of heat availability conditions

Total of the temperatures above +10 °C	Climatic zone	Number of meteorological stations, pcs/%
1,400–1,800	cool	4/1.4
1,800–2,200	cool-moderate	13/4.6
2,200–2,800	moderate	144/51.1
2,800–3,400	warm-moderate	99/35.1
3,400–4,000	moderate-warm	19/6.7
> 4,000	warm	3/1.1

basing on their dependence on geographical latitude φ and longitude λ as well as on the altitude above the sea level h (1° of latitude is equal to 111.2 km, 1° of longitude at 49° latitude is equal to 73.2 km)

$$t_1 = 40.43 - 0.756 \cdot \varphi - 0.254 \cdot \lambda - 0.0055 \cdot h, \quad R^2 = 0.829;$$

$$t_2 = 45.23 - 0.802 \cdot \varphi - 0.316 \cdot \lambda - 0.0049 \cdot h, \quad R^2 = 0.878;$$

$$t_3 = 46.33 - 0.748 \cdot \varphi - 0.281 \cdot \lambda - 0.0049 \cdot h, \quad R^2 = 0.906;$$

$$t_4 = 29.43 - 0.378 \cdot \varphi - 0.073 \cdot \lambda - 0.0055 \cdot h, \quad R^2 = 0.764;$$

$$t_5 = 22.09 - 0.174 \cdot \varphi + 0.066 \cdot \lambda - 0.0059 \cdot h, \quad R^2 = 0.834;$$

$$t_6 = 32.96 - 0.342 \cdot \varphi + 0.094 \cdot \lambda - 0.0067 \cdot h, \quad R^2 = 0.936;$$

$$t_7 = 42.55 - 0.514 \cdot \varphi + 0.130 \cdot \lambda - 0.0071 \cdot h, \quad R^2 = 0.952;$$

$$t_8 = 45.29 - 0.581 \cdot \varphi + 0.116 \cdot \lambda - 0.0069 \cdot h, \quad R^2 = 0.955;$$

$$t_9 = 45.35 - 0.612 \cdot \varphi - 0.001 \cdot \lambda - 0.0064 \cdot h, \quad R^2 = 0.931;$$

$$t_{10} = 50.04 - 0.760 \cdot \varphi - 0.120 \cdot \lambda - 0.0057 \cdot h, \quad R^2 = 0.928;$$

$$t_{11} = 45.54 - 0.731 \cdot \varphi - 0.220 \cdot \lambda - 0.0058 \cdot h, \quad R^2 = 0.869;$$

$$t_{12} = 43.64 - 0.766 \cdot \varphi - 0.261 \cdot \lambda - 0.0053 \cdot h, \quad R^2 = 0.830;$$

$$Tm = 40.78 - 0.598 \cdot \varphi - 0.093 \cdot \lambda - 0.0059 \cdot h, \quad R^2 = 0.936,$$

where t_1–t_{12} are average monthly temperatures, °C; *Tm* is average annual temperature, °C; R^2 is coefficient of determination.

Along with the increasing latitude of some area by 1°, the average monthly temperature for most months decreases by 0.5–0.8 °C. This effect is the weakest one during the period of April – June; it is 0.2–0.4 °C. On average, the year-long increase of the geographical latitude by 1 °C is equivalent to the temperature drop by 0.6 °C. Along with the growing geographical longitude, the average monthly temperatures rise from May to August by 0.1 °C and drop from September to April mostly by 0.2–0.3 °C; in September this effect is the least noticeable one. On average, the year-long growth of the geographical longitude by 1 °C is equivalent to the temperature decrease by 0.09 °C. Along with the increasing altitude above the sea level by 100 m, the air temperature decreases on average by 0.59 °C.

Climate continentality influences considerably the vegetation formation. Along with distancing towards the inland, a temperature in winter decreases; in summer it increases. Air difference between the eastern and western regions is 2–3 °C in winter and 3–4 °C in summer. A degree of climate continentality can be characterized by the annual range of air temperature of the warmest and coldest months. Annual range A grows from the east to the west by 0.39 °C on average per 1° of the longitude. In the west, the annual air range is 22–24 °C; in the east, it grows up to 28 °C. Annual range of the air temperature A decreases by 0.24 °C along with the increasing latitude by 1°, by 0.17 °C with the increasing altitude above the sea level by 100 m.

$$A = {*}2.12 - 0.242 \cdot \varphi + 0.385 \cdot \lambda - 0.0017 \cdot h, \quad R^2 = 0.848,$$

where * is coefficients with a raw error.

Gorczyński continentality index *Kg* is tightly connected with the annual air range *A* (correlation coefficient is $r = 0.96$). Moderate sea climate ($Kg = 26.2$–30.0 %) is peculiar for 9.2 % of the Ukrainian settlements (coasts of the Mountainous Crimea, the Ukrainian Carpathians, and the Carpathian region). Major part of the Ukrainian area is characterized by continental climate ($Kg = 30.1$–48.0 %). On average, Gorczyński continentality index Kg increases from the west to the east on average by 0.88 % per 1° of the longitude, and decreases by 0.35 % along with the latitude growth by 1° and by 0.42 % along with the increasing altitude above the sea level by 100 m. In the east of Ukraine, Gorczyński continentality index *Kg* is 45–48 %

$$Kg = 29.1 - 0.35 \cdot \varphi + 0.88 \cdot \lambda - 0.0042 \cdot h, \quad R^2 = 0.866.$$

General regularity of spatial distribution of the annual precipitation amounts is in their gradual decrease from the west and the northern west to the south and southern east. Within the western Ukrainian regions, the precipitation amounts are 600 mm and more; within the northern east the figure is 500 mm. At the southern steppe, there is 400 mm of precipitations while in the Carpathians the amount is more than 100 mm. Along with the growing altitude above the sea level by 100 m, the annual precipitation amount increases by 60 mm. The annual amount of precipitations rises by 15 mm along with the latitude increase by 1° and decreases by 11 mm per 1° of the longitude.

The regularities of spatial-time distribution of monthly precipitation amounts within the Ukrainian area on the basis of their dependence of geographical coordinates and altitude above the sea level have become possible to identify only for a warm season. They represent the increase of monthly precipitation amounts by 5–10 mm per 100 m of altitude and 1–4 mm per 1° of the latitude; their decrease is shown by 1–2 mm per 1° of the longitude.

$$p_4 = 36.6 + {*}0.47 \cdot \varphi - 0.81 \cdot \lambda + 0.051 \cdot h, \quad R^2 = 0.615;$$

$$p_5 = 62.1 + {*}0.34 \cdot \varphi - 1.17 \cdot \lambda + 0.078 \cdot h, \quad R^2 = 0.810;$$

$$p_6 = 120.9 - {*}0.17 \cdot \varphi - 1.85 \cdot \lambda + 0.105 \cdot h, \quad R^2 = 0.786;$$

$$p_7 = -95.6 + 4.28 \cdot \varphi - 1.90 \cdot \lambda + 0.102 \cdot h, \quad R^2 = 0.844;$$

$$p_8 = -90.2 + 4.15 \cdot \varphi - 2.05 \cdot \lambda + 0.077 \cdot h, \quad R^2 = 0.849;$$

$$p_9 = {*}7.0 + 1.66 \cdot \varphi - 1.67 \cdot \lambda + 0.047 \cdot h, \quad R^2 = 0.720;$$

$$P = {*}153.1 + 14.57 \cdot \varphi - 11.38 \cdot \lambda + 0.597 \cdot \mathrm{h}, \quad R^2 = 0.629,$$

where p_4–p_9 are average monthly amounts of precipitations per April-September, mm; P is average annual amount of precipitation, mm; * is coefficients with a raw error.

Currently, a great number of the parameters and empiric formulas are used to characterize climatic conditions of the areas: length of periods with the temperature above 0 °C (warm period), +5 °C (vegetation period), +10 °C (period of active vegetation), +15 °C (summer period), total of the average daily temperatures per these periods, coefficients of water availability and continentality. Characteristic of these climatic parameters at the subprovince level of geobotanical zoning indicates great variety of the conditions of vegetation cover formation at the Ukrainian territory (Table 1).

Beginning of the warm period coincides with the end of winter and its end coincides with its beginning. Duration of a warm period $d_{t>0}$ varies from 230–235 days in the north and in the Carpathians up to 360 days in the south; the average total of positive temperatures per warm period $\sum t_{>0}$, is from 2,130 up to 4,960 °C. Duration of a vegetation period $d_{t>5}$ increases from 178–205 days in the Carpathians and eastern forest steppe up to 310 days in the Crimea. The temperature total per that period $\sum t_{>5}$ is less than 2,585 °C in the Ukrainian Carpathians and rises up to 3,895–4,730 °C in the Crimea. The average duration of active vegetation period $d_{t>10}$ varies within the range of 4–7 months, and a total of active temperatures $\sum t_{>10}$ – from less than 2,300 °C in the Carpathian region up to 4,060 °C in the Crimea.

Duration of the periods with average daily temperature being more than 0, +5, +10, and +15 °C shortens by 4–9 days with the latitude increase by 1° and by 4–6 days with the increase in the altitude above the sea level by 100 m. The longitude effect on the duration of the indicated periods is not so clearly seen. The total of the average daily temperatures per indicated periods decreases by 131–147 °C along with the latitude growth by 1°, by 72–86 °C along with the increasing altitude above the sea level by 100 m. The total of the average daily temperatures increases from the west to the east by 10–28 °C on average per 1° of the longitude.

$$d_{t>0} = 775.8 - 8.7 \cdot \varphi - 2.7 \cdot \lambda - 0.058 \cdot h, \quad R^2 = 0.816;$$

$$d_{t>5} = 556.5 - 5.9 \cdot \varphi - 1.6 \cdot \lambda - 0.057 \cdot h, \quad R^2 = 0.882;$$

$$d_{t>10} = 412.7 - 4.5 \cdot \varphi - 0.5 \cdot \lambda - 0.060 \cdot h, \quad R^2 = 0.884;$$

$$d_{t>15} = 294.9 - 4.4 \cdot \varphi + 1.3 \cdot \lambda - 0.041 \cdot h, \quad R^2 = 0.544;$$

$$\sum t_{>0} = 10{,}268.9 - 147.3 \cdot \varphi + 9.9 \cdot \lambda - 0.84 \cdot h, \quad R^2 = 0.743;$$

$$\sum t_{>5} = 9819.9 - 141.6 \cdot \varphi + 11.7 \cdot \lambda - 0.84 \cdot h, \quad R^2 = 0.732;$$

$$\sum t_{>10} = 8779.7 - 130.8 \cdot \varphi + 17.8 \cdot \lambda - 0.86 \cdot h, \quad R^2 = 0.718;$$

$$\sum t_{>15} = 8003.5 - 135.2 \cdot \varphi + 28.3 \cdot \lambda - 0.72 \cdot h, \quad R^2 = 0.538,$$

where $d_{t>0}$, $d_{t>5}$, $d_{t>10}$, $d_{t>15}$ are durations of the periods with the temperatures more than 0, 5, 10, and 15 °C, days; $\sum t_{>0}$, $\sum t_{>5}$, $\sum t_{>10}$, $\sum t_{>15}$ are totals of the daily temperatures per periods with the temperatures more than 0, 5, 10, 15 °C.

Most part of the Ukrainian territory belongs to the moderate and warm-moderate climatic zones (51.1 and 35.1 % of the considered geographical locations, respectively); a cool climatic zone is represented by the Ukrainian Carpathians (Table 1).

Peculiarities of the vegetation cover formation depend greatly on the water availability conditions. Arid zone (HTKS = = 0.7–1.0) covers the northern steppe (a zone of forb-fescue-feather grass steppes) and the southern-western forest steppe. A zone of insufficient watering (HTKS = 1.0–1.3) includes almost all broad-leaved forest region and a forest steppe area except its western part. A very arid zone (HTKS = 0.5–0.7) covers the southern part of a steppe area (zones of fescue-feather grass and vermouth-gramineous steppes); and a zone of extra watering (HTKS > 1.3) involves the western parts of the forest and forest steppe regions as well as the Ukrainian Carpathians. G. T. Selianinov hydrothermal index is closely connected with De Martonne aridity index (correlation coefficient is $r = 0.93$). Distribution of these parameters as for the number of geographical locations represents approximately the ratio of territories with different water availability conditions (Table 2).

Selianinov G. T. indices increase by 0.04 along with the latitude growth by 1°, by 0.2 along with the rising altitude above the sea level by 100 m, and decrease from the west to the north on average by 0.03 per 1° of the longitude. De Martonne aridity index *Ia* grows by 1.71 along with the latitude increase

Table 2

Distribution of climate types in terms of water availability conditions

Index	Climatic zone	Number of meteorological stations, pcs/%
HTKS	G. T. Selianinov Hydrothermal index	
0.3–0.5	dry	13/4.6
0.5–0.7	very arid	30/10.6
0.7–1.0	arid	88/31.2
1.0–1.3	insufficient watering	80/28.4
1.3–1.6	sufficient watering	39/13.8
>1.6	extra watering	32/11.4
Ia	De Martonne aridity index	
10–20	semi-arid	5/1.8
20–24	Mediterranean	26/9.2
24–28	semi-humid	30/10.6
28–35	humid	75/26.6
35–55	very humid	128/45.4
>55	extremely humid	18/6.4

by 1°, by 4.9 along with the rising altitude above the sea level by 100 m, and decreases from the west to the east on average by 0.44 per 1° of the longitude

$$HTKS = *{-0.40} + 0.043 \cdot \varphi - 0.032 \cdot \lambda + 0.0022 \cdot h, \quad R^2 = 0.884;$$

$$Ia = -42.78 + 1.71 \cdot \varphi - 0.44 \cdot \lambda + 0.049 \cdot h, \quad R^2 = 0.716,$$

where * is coefficients with a raw error.

Geobotanical zoning of the Ukrainian territory makes it possible to identify which climatic indices represent peculiarities of the vegetation cover formation in the most accurate way. A subprovince, a geobotanical region, or other territorial units of a geobotanical zoning are characterized by different values of climatic indices. Testing of the significance of these indices basing on a disperse analysis relies on the comparison of dispersion stipulated by the inter-group spread (mean square effect, MS Effect) and dispersion stipulated by the intra-group spread (mean square error, MS Error). A zero hypothesis is in the insignificant difference between the average values in the groups due to insignificant variability of a parameter. In terms of zero hypothesis, the intra-group dispersion will coincide practically with a general dispersion calculated without consideration of a group belonging. The obtained intra-group dispersions were compared with the help of F-criterion.

Low values of F-criterion are peculiar for the monthly amount of precipitation of a cold season (p_{11}–p_3), average monthly air temperature of April t_4. The greatest difference for such climatic indices is as follows: air temperature of January, July, and August, monthly precipitation amounts during June-September (p_6–p_9), length of a frost-free period $d_{t>0}$, and hydrothermal coefficient of G. T. Selianinov HTKS.

Analysis of the dependences between the climatic parameters indicates the availability of strong connection between certain variables. Thus, in terms of average monthly temperatures of June and August, a correlation coefficient is $r = 0.99$; for the August temperature and temperature totals being more than +10 °C, it is $r = -0.98$; in case of average monthly temperature of August and amount of precipitation in August, it is $r = -0.89$ as well as G. T. Selianinov hydrothermal coefficient and monthly amount of precipitations of July, it is $r = 0.96$.

Since climatic parameters of the vegetation cover are correlated with each other, it can be concluded that the observation data can be explained by the insignificant number of new variables, being not measured immediately but which can be obtained by means of linear combination of the output data. That helps reduce dimensionality of the observation space. The results of the main component analysis basing on the correlation matrix demonstrate that two main components provide 81.5 % of the overall dispersion; consequently, it is sufficient for most analysis purposes to use two-dimensional projection of the data matrix. The main regularity of the formation of the Ukrainian vegetation cover, represented by the first main component Factor$_1$, is in the following structure of interrelations between climatic indices: along with the growing average monthly June-September temperatures (coefficient of correlation is $r = 0.91$–0.93), a decreasing amount of precipitations from April to September ($r = -0.85$– -0.91), indices of climatic water availability decrease ($r = -0.93$), indices of heat availability increase (length of the active vegetation period $d_{t>10}$ ($r = 0.87$) as well as the temperature total per this period $\sum t_{>10}$ ($r = 0.93$) and the average annual temperature Tm ($r =$ 0.82). This regularity represents a gradient of climatic indices from the Ukrainian Carpathians towards the southern Crimean coast.

The second axis of maximum variation of vegetation Factor$_2$ explains 25.4 % of the general data dispersion. Values of the second main component depend on the average monthly November-March temperature t_{11}–t_3 ($r = 0.76$–0.81), duration of a frost-free period $d_{t>0}$ ($r = 0.77$), and duration of a vegetation period $d_{t>5}$ ($r = 0.70$).

Scatter diagrams, whose axes are represented by climatic factors correlated maximally with the main components, make it possible to assess the ecological vegetation space in a simplified way (Fig.1). Moreover, graphic visualization of the climatic information on the basis of ecograms can be used to predict the vegetation cover dynamics due to certain climatic changes.

The main disadvantage of numerous indices and empiric formulas used to characterize climatic conditions of the territories is that they do not consider variability (dispersion) of the climate elements. Our studies were based on the idea of mathematical modelling of a typological scheme of vegetation cover in the coordinate system of average monthly temperatures and average precipitation amounts taking into account the available information on the belonging of geographical locations to a certain type of geobotanical regions. To do that, we have calculated optimal combinations of climatic parameters that will help determine the boundaries of vegetation cover types at the level of geobotanical zoning areas of Ukraine.

The mathematical modelling results (Table 3, Fig. 2) can be represented by the following equations

$$Root_1 = 1.617 \cdot t_1 - 1.051 \cdot t_2 - 1.720 \cdot t_3 + 0.093 \cdot t_4 - 0.776 \cdot t_5 - 0.744 \cdot t_6 + 1.727 \cdot t_7 + 1.256 \cdot t_8 - 0.609 \cdot t_9 - 0.724 \cdot t_{10} + 0.394 \cdot t_{11} + 0.792 \cdot t_{12} + 0.053 \cdot p_1 - 0.085 \cdot p_2 + 0.032 \cdot p_3 - 0.042 \cdot p_4 + 0.071 \cdot p_5 - 0.011 \cdot p_6 - 0.012 \cdot p_7 - 0.087 \cdot p_8 - 0.011 \cdot p_9 - 0.011 \cdot p_{10} + 0.048 \cdot p_{11} + 0.003 \cdot p_{12} - 11.404; \quad \lambda_1 = 27.344;$$

$$Root_2 = 0.726 \cdot t_1 - 0.766 \cdot t_2 + 1.416 \cdot t_3 - 0.097 \cdot t_4 - 2.215 \cdot t_5 + 0.485 \cdot t_6 - 0.556 \cdot t_7 + 1.189 \cdot t_8 - 0.605 \cdot t_9 + 0.214 \cdot t_{10} + 0.086 \cdot t_{11} + 0.846 \cdot t_{12} + 0.019 \cdot p_1 + 0.005 \cdot p_2 - 0.021 \cdot p_3 + 0.007 \cdot p_4 + 0.056 \cdot p_5 + 0.009 \cdot p_6 + 0.046 \cdot p_7 - 0.055 \cdot p_8 - 0.053 \cdot p_9 + 0.024 \cdot p_{10} - 0.019 \cdot p_{11} - 0.000 \cdot p_{12} + 19.105; \quad \lambda_2 = 23.259;$$

$$Root_3 = 1.435 \cdot t_1 + 0.552 \cdot t_2 - 2.832 \cdot t_3 + 1.250 \cdot t_4 + 1.332 \cdot t_5 - 0.931 \cdot t_6 - 0.002 \cdot t_7 - 2.017 \cdot t_8 + 0.463 \cdot t_9 - 0.203 \cdot t_{10} - 1.032 \cdot t_{11} + 1.423 \cdot t_{12} - 0.074 \cdot p_1 + 0.055 \cdot p_2 - 0.011 \cdot p_3 - 0.007 \cdot p_4 - 0.046 \cdot p_5 - 0.039 \cdot p_6 + 0.031 \cdot p_7 - 0.052 \cdot p_8 + 0.032 \cdot p_9 - 0.080 \cdot p_{10} + 0.091 \cdot p_{11} + 0.016 \cdot p_{12} + 43.497; \quad \lambda_3 = 5.728,$$

where $Root_i$ is canonic discriminant functions, axes of a typological scheme of the vegetation cover; t_i is average monthly

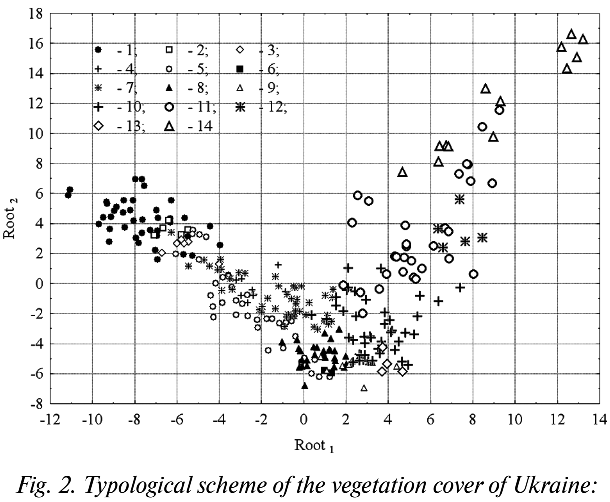

Fig. 2. Typological scheme of the vegetation cover of Ukraine:

1–14 — numerical ordering of the subprovinces is represented in Fig. 1; Root$_{1–2}$ — axes of a typological scheme

Table 3

Geographic coordinates, climatic parameters, and typological-scheme location of the vegetation cover of the Ukrainian settlements

Name	φ, °N	λ, °E	h	t_1	t_7	Tm	p_1	p_7	P	$Root_1$	$Root_2$	$Root_3$
European broad-leaved forest region												
Vinnytsia	49.23	28.48	285	–6.0	18.7	6.7	34	77	621	–2.36	–0.74	0.72
Zhytomyr	50.27	28.67	224	–5.7	18.9	6.8	46	83	666	–2.19	–2.44	2.90
Ivano-Frankivsk	48.92	24.72	270	–4.9	18.4	7.3	35	98	683	–6.92	1.58	–0.45
Kyiv	50.43	30.52	150	–6.1	19.9	7.1	46	74	649	–0.39	–3.52	1.53
Lutsk	50.73	25.33	192	–4.9	18.6	7.2	42	84	666	–3.56	0.56	2.49
Lviv	49.83	24.00	326	–5.0	17.4	6.7	52	106	798	–6.05	1.97	2.58
Rakhiv	48.05	24.20	430	–4.8	18.0	7.3	76	134	1,221	–8.95	4.84	–3.30
Rivne	50.62	26.25	230	–5.4	18.5	6.9	50	83	683	–3.41	–0.24	2.46
Slavsk	48.83	23.45	592	–6.5	15.6	5.2	71	128	1,036	–9.68	3.95	–2.45
Stryi	49.25	23.85	294	–4.1	18.5	7.6	41	107	764	–6.32	4.05	–1.49
Uzhhorod	48.62	22.30	115	–2.8	20.0	9.3	65	82	841	–6.31	4.30	–2.05
Chernivtsi	48.30	25.93	239	–5.0	19.3	7.8	39	95	712	–5.69	1.94	–2.43
Chernihiv	51.50	31.30	113	–6.7	19.4	6.5	44	72	639	–0.10	–5.23	3.96
European-Siberian forest steppe region												
Kamianets-Podilskyi	48.68	26.60	224	–5.0	19.5	7.8	33	86	621	–3.91	0.94	–0.89
Poltava	49.58	34.57	160	–6.9	20.6	7.0	41	70	585	1.46	–4.48	–0.85
Sumy	50.92	34.75	126	–7.8	19.8	6.2	44	81	633	1.11	–5.83	0.10
Ternopil	49.57	25.60	334	–5.4	18.4	6.9	40	93	678	–4.05	0.89	0.90
Kharkiv	50.00	36.25	138	–7.3	20.8	6.9	47	69	609	3.07	–5.22	–0.59
Khmelnytskyi	49.42	27.00	297	–5.6	18.6	6.8	41	91	654	–3.37	–0.40	2.12
Cherkasy	49.43	32.07	80	–5.8	20.0	7.2	37	69	564	0.97	–2.51	1.29
European-Asian steppe region												
Henichesk	46.17	34.78	14	–2.9	23.4	10.0	41	37	417	8.46	3.07	–1.74
Dnipro	48.45	34.98	145	–5.4	22.3	8.5	48	56	558	3.84	–2.69	–2.33
Donetsk	48.00	37.80	192	–6.6	21.6	7.5	45	60	563	4.31	–4.40	–0.18
Zaporizhzhia	47.83	35.17	107	–5.2	22.7	8.8	42	51	515	4.11	–3.26	–2.02
Kerch	45.37	36.45	32	–1.0	23.3	10.6	48	43	496	8.92	6.68	–0.24
Kropyvnytskyi	48.50	32.30	171	–5.6	20.2	7.5	41	70	561	1.09	–2.36	1.54
Luhansk	48.57	39.33	40	–7.2	22.0	7.6	32	57	506	4.65	–5.21	–3.08
Mykolayiv	46.97	32.00	14	–3.6	23.0	9.6	34	42	444	3.91	0.64	–3.30
Odesa	46.47	30.73	54	–3.3	22.3	9.5	47	38	477	4.86	2.47	–1.50
Starobilsk	49.27	38.93	61	–7.2	21.9	7.4	43	57	546	3.93	–5.33	–1.92
Kherson	46.63	32.58	18	–3.2	23.0	9.8	36	38	419	5.08	1.51	–2.11
Mediterranean forest region												
Yalta	44.50	34.17	41	4.0	23.7	13.0	88	44	623	12.19	15.78	4.19

Notes: φ, λ – geographic latitude and longitude; h – altitude above the sea level; $Root_{1-3}$ – axes of a typological scheme, discriminant functions

temperature of the i^{th} month; p_i is an average monthly amount of precipitations; i is the sequence number of the month; λ_{1-3} is eigen values of the vectors.

Representation of the elementary areas according to the vegetation cover signs in the system of geographic coordinates is a scheme of a geobotanical zoning of the territory. Information content of this scheme is explained by the available correlation between the climatic parameters and geographic coordinates. Comparing with the scheme of a geobotanical zoning of Ukraine, a multidimensional typological scheme is characterized by greater information content. The first axis of a typological scheme $Root_1$ (Fig. 2) explains 38.5 % of the overall dispersion. Maximal value of a canonic discriminant function $Root_1$ is peculiar for the region of Mountainous Crimean subprovince of the Mediterranean forest area, first of all it is Southern Crimean Coast (Gurzuf, Alushta, Yalta, Simeyiz, Alupka), where natural vegetation cover is formed by downy-oak and Crimean-pine forests. Minimum values of $Root_1$ are peculiar for the Eastern Carpathian mountainous subprovince of the European broad-leaved forest area (Fig. 2).

The values of the first discriminant function $Root_1$ depend mostly on the average monthly June-September temperatures and average April-September precipitations (Table 3). This function is special in its close connection with G. T. Selianinov hydrothermal coefficient ($r = -0.86$), total of annual precipitations ($r = -0.73$), average annual temperature ($r = 0.62$), total of monthly temperatures of an active vegetation period ($r = 0.78$), and De Martonne aridity index ($r = -0.72$).

The second axis of a typological scheme (Fig. 2) explains additionally 32.8 % of the overall dispersion. The values of function $Root_2$ depend mostly on the average monthly November-March temperatures ($r = 0.83–0.91$), temperature ranges ($r = -0.82$), duration of the frost-free ($r = 0.85$) and vegetation periods ($r = 0.71$).

Two discriminant functions explain 71.3 % of the overall dispersion stipulated by the differences in climatic conditions at the level of geobotanical regions. As for the third axis of a typological scheme $Root_3$, that explains only 8.0 % of the overall dispersion, the greatest coefficients of correlations in terms of module are peculiar for Gorczyński continentality index of ($r = -0.48$), average monthly temperatures of April ($r = -0.42$) and May ($r = -0.38$).

The regularities of spatial differentiation of the vegetation cover according to climatic conditions of certain Ukrainian regions make it possible to analyze dynamics of vegetation changes due to climate changes. In this context, three variants of studies should be considered. Prediction on the basis of two-dimensional diagrams (Fig. 1), where axes are represented by climatic indices, represents an open system. Inclusion of additional objects (geographical locations) does not require additional calculations. Thus, for Kyiv, located within the broad-leaved forest area, indices $t_1 = -6.1$ and $t_7 = 19.9$ °C are the climatic standard (Table 4).

Within the period of 2011–2019, the mentioned parameters were demonstrating their growth up to the values of $t_1 = -3.7$ and $t_7 = 21.6$ °C, which corresponds to the town of Ananiev, Odesa Oblast (47.67 °N, 29.92 °E) located in the south-west of the forest steppe area (Podilia and Mid-Dnieper subprovince) at the boundary with Steppe. The vegetation cover of this territory shows meadow steppes as well as forest plantations of rock oak (Quercus petraea (Mattuschka) Liebl.) and common oak (Quercus robur L.) on the podzolized black soils. Under such temperature conditions, pine forests near Kyiv will lose their stability due to changes in the water conditions of soils. Climate warming for Kyiv is similar to the displacement southwards by 2° of the latitude. In case of Uzhhorod for the period of 2011–2019, the average monthly temperatures of January and July are close to Budapest (Hungary) of the period of 1960–1990 (Table 4). For Odesa of the period of 2011–2019, the average monthly temperature of January and July are close to the climatic standard of Ankara of the period of 1960–1990 (Turkey, 39.95 °N, 32.88 °E, 894 m above the sea level) (Table 4).

Prediction of the vegetation cover changes on the basis of discriminant functions is a semi-open system. Relying on the average monthly temperature values and average precipitation amounts per certain period of time (year, decade etc.), each geographic location corresponds to a certain location of the vegetation cover on a typological scheme (Fig. 2). In such a way, location of a typological scheme (–0.39; –3.52) corresponds to the climatic standard of Kyiv; and a point with (0.77; 2.55) coordinates corresponds to a period of 2011–2019. This point occurs at a "while spot" of a typological scheme; however, its closest geographic locations are as follows: a) Ananiev (47.32 °N, 29.92 °E) of the Odesa Oblast with (–0.11; –0.17) climagram coordinates; b) Zatyshshia (47.67 °N, 29.85 °E) of the Odesa Oblast with (1.41; –0.39) climagram coordinates; c) Rozdilna (46.85 °N, 30.08 °E) of the Odesa Oblast with (2.09; 1.04) climagram coordinates. The first two settlements belong to the Podilia and Mid-Dnieper subprovince of a forest steppe area; the third one belongs to a zone of forb-fescue-feather grass steppes of the Black Sea steppe province of a steppe area. Thus, conditions of the Forest steppe and Steppe boundary of the southern-western part of Ukraine correspond to the climatic conditions of Kyiv within the period of 2011–2019.

Kharkiv is located in the east of Ukraine (the Mid-Russian forest steppe subprovince of a forest steppe area). The vegetation cover here is peculiar with meadow steppes and linden-oak forests. Climatic standards of Kharkiv (Table 4) corresponds to the location of a typological scheme (3.07; –5.22); a period of 2011–2019 corresponds to the point with (4.00; –0.36) coordinates. Following geographic locations are the closest ones to Kharkiv of the 2011–2019 period: a) Mykolayiv (46.58 °N, 32.00 °E) of Mykolayiv Oblast with (3.91; 0.64) coordinates on a typological scheme, a zone of fescue-feather grass steppes; b) Huliaipole (47.63 °N, 36.27 °E) of Zaporizhzhia Oblast with (4.07; -2.44) climagram coordinates, a zone of forb-fescue-feather grass steppes.

The semi-open system of prediction allows using the extrapolation results, owing to which "white spots" on a typological scheme can be filled with the points corresponding to the settlements of the neighbouring countries. For instance, low values of the first and second discriminant functions are characteristic for Moscow (–3.99; –5.75), Novgorod (–2.53; –6.48), Pskov (–3.06; –4.37), and Vologda (–4.48; –8.49). Most often, the extrapolation involves the first three discriminant functions; thus, the extrapolation of the years with extreme weather and climatic conditions often gives the results, which are hard to explain basing on a typological scheme. The semi-open system can be improved only in terms of expanded geographic space of the settlements.

A closed system of prediction is developed on the principles of similarity evaluation and determination of the considered object belonging to a clearly defined totality of the objects characterized by the average values and dispersion according to numerous climatic parameters. Each geobotanical region is characterized by a set of settlements with similar structure of vegetation cover and climatic parameters. A degree of vegetation cover changes can be described relying on the changes in predicted coordinates of a geographic location on a typological scheme comparing to their standard values (Table 4). The averaged data per long-term periods of time represent the best results to be compared. Climatic conditions of the vegetation cover formation for the periods of 1881–1960 and 1961–1990 differ insignificantly, e.g. Lviv, Chernivtsi, Uzhhorod (Table 4). Compared with the period of the whole observation period up to 1990, in most cases the average monthly temperature during the period of 1960–1990 varied within the range of 0.1–0.5 °C both towards warming and cooling.

The learning sampling can be used to classify a geographic location with a specific set of climatic parameters. In this context, Lviv of 2002, 2009, 2016 in its totality of climatic parameters can be included into the Danube-Dniester geobotanical region of fescue-feather grass steppes with 45.64 °N, 29.09 °E geographic coordinates. For Poltava location (49.58 °N, 34.57 °E) of the Left-Bank Dnieper subprovince of a forest steppe area, maple-linden-oak forests are peculiar. As for climatic indices of 1986, 1991, 1992, 1999, 2006, 2017, Poltava may be included into the Crimean steppe geobotanical region of the fescue-feather grass and forb-fescue-feather grass steppes (45.31 °N, 34.11 °E). The calculations can be carried out for foreign geographic locations as well. For example, Vilnius (Lithuania) and Riga (Latvia) in their climatic indices of 1960E1990 are similar to the Right-Bank western-northern geobotanical region of hornbeam-oak and oak forests with (49.68 °N, 28.43 °E) coordinates while Sofia (Bulgaria), Bucharest (Romania), Yerevan (Armenia), Tashkent (Uzbekistan) belong to the Danube-Dniester geobotanical region with (45.64 °N, 29.09 °E) coordinates.

Conclusions. Climatic conditions play a determining role in the formation of a vegetation cover of Ukraine. The vegetation cover-climate connection is seen from the results of modelling the spatial differentiation of climatic indices depending on the location latitude and longitude as well as alti-

Table 4

Characteristic of climatic conditions and results of prediction of the vegetation cover changes

City, Geographical coordinates	Years	t_1	t_7	Tm	P	Location on a typological scheme			Predicted geographical coordinates	
						$Root_1$	$Root_2$	$Root_3$	φ, °N	λ, °E
Kyiv 50.26 N 30.31 E	1881–1960	–6.1	19.9	7.1	649	–0.39	–3.52	1.53	50.69	30.09
	1991–2000	–3.1	20.1	8.2	620	–1.01	0.18	4.74	50.06	23.42
	2001–2010	–3.3	22.1	9.0	621	0.73	–0.37	–2.73	46.80	30.30
	2011–2019	–3.7	21.6	9.7	611	0.77	2.55	–1.47	48.35	30.31
	2012	–4.0	23.7	9.1	752	–1.06	–6.06	–13.97	49.25	38.52
	2016	–5.7	22.4	9.5	654	–1.02	7.63	–9.54	45.64	29.09
Uzhhorod 48.37 N 22.18 E	1881–1960	–2.8	20.0	9.3	841	–6.31	4.30	–2.05	48.30	23.29
	1961–1990	–2.8	19.9	9.6	740	–7.72	4.67	–2.56	48.57	22.28
	1991–2000	–1.5	20.7	10.0	738	–5.50	5.26	–0.83	50.06	23.42
	2001–2010	–1.3	21.8	10.5	773	–4.15	3.68	–4.33	48.57	22.28
	2011–2019	–0.9	21.4	11.1	663	–1.53	10.76	–3.23	48.57	22.28
	2012	–0.7	22.8	10.5	657	5.08	14.28	–5.44	45.31	34.11
Chernivtsi 48.18 N 25.56 E	1881–1960	–5.0	19.3	7.8	712	–5.69	1.94	–2.43	48.94	25.55
	1961–1990	–4.9	18.7	7.9	653	–6.37	3.29	0.22	48.94	25.55
	1990–2000	–2.2	19.7	8.6	618	–5.03	5.00	2.16	50.06	23.42
	2001–2010	–3.0	20.8	9.0	669	–6.97	2.23	–7.26	48.65	23.95
	2011–2019	–2.9	21.0	9.8	568	–0.58	7.34	–5.52	48.30	23.29
	2018	–1.7	20.7	9.8	694	4.71	–0.52	17.20	44.99	34.71
Lviv 49.83 N 24.00 E	1881–1960	–5.0	17.4	6.7	798	–6.05	1.97	2.58	50.14	24.44
	1961–1990	–4.6	17.3	7.2	730	–6.72	3.46	2.50	49.49	25.11
	1991–2000	–2.6	18.2	7.7	740	–4.19	5.15	4.87	50.06	23.42
	2001–2010	–3.1	19.4	8.2	817	–2.27	4.38	–2.90	50.14	24.44
	2011–2019	–2.7	19.3	9.0	741	0.12	8.92	–1.39	48.22	24.61
	1988	–1.0	18.9	7.3	782	–0.08	–5.13	19.37	50.17	32.33
	2018	–0.5	19.1	9.2	820	0.98	–0.72	19.59	50.16	33.55
Poltava 49.58 N 34.57 E	1881–1960	–6.9	20.6	7.0	585	1.46	–4.48	–0.85	50.16	33.55
	1991–2000	–4.2	21.0	8.0	538	2.47	–1.01	1.35	48.02	32.54
	2001–2010	–4.1	22.1	8.9	621	4.34	0.60	–4.09	48.44	35.58
	2011–2019	–4.8	22.0	9.4	603	1.20	–2.59	–1.09	50.16	33.55
	2017	–5.9	21.3	9.7	445	3.09	14.49	–10.74	45.31	34.11
Kharkiv 50.00 N 36.25 E	1881–1960	–7.3	20.8	6.9	609	3.07	–5.22	–0.59	50.05	35.83
	1991–2000	–4.5	21.1	7.8	495	1.52	–2.20	2.47	48.02	32.54
	2001–2010	–4.4	22.5	8.8	547	4.40	–0.86	–3.98	47.38	33.19
	2011–2019	–5.2	22.4	9.3	514	4.00	–0.36	–2.01	48.44	35.58
	2017	–5.8	21.5	9.5	421	5.43	14.08	–9.29	45.31	34.11
Dnipro 48.45 N 34.98 E	1881–1960	–5.4	22.3	8.5	558	3.84	–2.69	–2.33	48.44	35.58
	1991–2000	–3.8	22.2	8.7	556	1.41	–1.35	0.88	48.02	32.54
	2001–2010	–3.4	23.0	9.7	601	4.36	1.52	–5.74	47.38	33.19
	2011–2019	–4.0	22.9	10.1	561	4.05	0.01	–4.96	48.44	35.58
	2017	–5.5	21.6	10.2	495	–0.21	13.73	–10.64	45.31	34.11
	2018	–2.9	22.5	10.1	678	13.25	–9.74	18.66	50.16	33.55
Zaporizhzhia 47.83 N 35.17 E	1881–1960	–5.2	22.7	8.8	515	4.11	–3.26	–2.02	48.44	35.58
	1991–2000	–3.3	22.5	9.2	478	2.11	0.73	0.04	48.02	32.54
	2001–2010	–3.0	23.5	10.1	523	6.04	1.96	–7.62	47.38	33.19
	2011–2019	–3.4	23.5	10.6	509	2.90	–0.21	–4.13	47.38	33.19
	2016	–5.2	23.9	10.3	518	1.17	4.49	–18.43	47.38	33.19
Odesa 46.47 N 30.73 E	1881–1960	–3.3	22.3	9.5	477	4.86	2.47	–1.50	46.55	31.63
	1991–2000	–0.8	22.7	10.5	433	3.99	4.40	1.28	46.73	35.71
	2001–2010	–0.3	23.7	11.4	501	5.83	6.37	–3.99	46.73	35.71
	2011–2019	–0.5	23.7	11.8	487	6.09	8.65	–7.96	46.28	32.56
	2018	1.0	23.7	11.9	491	14.95	0.72	13.92	44.99	34.71
	2019	–0.2	23.3	12.8	439	–2.19	14.43	–19.07	45.64	29.09

tude above the sea level. In most cases, along with the growing location latitude by 1°, the average monthly temperature decreases by 0.5–0.8 °C. The annual precipitation amounts increase by 15 mm along with the latitude growth by 1°, by 60 mm along with the rising altitude above the sea level by 100 m, and drop by 11 mm per 1° of the longitude. Specific features of the vegetation cover formation depend greatly on the conditions of water and heat availability. Specific combination of the climatic parameters is peculiar for different territorial units of a geobotanical zoning (areas, provinces, subprovinces, regions).

Numerous climatic indices are characterized by strong connection and ordered structure in a multidimensional space of parameters. The main regularity of the formation of Ukrainian vegetation cover in such structure of interrelations between climatic indices is as follows: along with the growing average monthly June-September temperatures and decreasing amount of April-September precipitations, the water availability indices decrease while the heat availability indices rise.

Graphic visualization of the climatic information basing on ecograms and typological schemes of the vegetation cover can be used to predict the vegetation cover dynamics due to certain climatic changes. During some years of the early *21st* century, the conditions peculiar for a steppe area were formed for the settlements of forest and forest steppe areas.

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Прогнозування зміни рослинного покриву України внаслідок потепління клімату

В. М. Скробала[1], *В. В. Попович*[2], *П. В. Босак*[2], *Т. І. Шуплат*[2]

1 – Національний лісотехнічний університет України, м. Львів, Україна

2 – Львівський державний університет безпеки життєдіяльності, м. Львів, Україна, e-mail: popovich2007@ukr.net

Мета. Встановити екологічні закономірності формування рослинного покриву України залежно від кліматичних умов і проаналізувати можливі його зміни внаслідок глобального потепління.

Методика. Диференціація кліматичних умов і оцінка значущості кліматичних показників на рівні територіальних одиниць геоботанічного районування на основі дисперсійного аналізу; багатовимірна ординація географічних пунктів у просторі кліматичних показників на основі аналізу головних компонент (Principle Component Analysis); побудова типологічної схеми рослинного покриву на основі дискримінантного аналізу; статистична обробка кліматичних параметрів.

Результати. На основі моделювання просторової диференціації кліматичних показників залежно від широти й довготи місцевості, висоти над рівнем моря проаналізовано зв'язок рослинного покриву та клімату. Установлено, що особливості формування рослинного покриву, у відповідності до схеми геоботанічного районування, найточніше характеризуються відмінністю таких кліма-

тичних показників, як: температура повітря січня, липня й серпня; місячна кількість опадів червня-вересня; тривалість безморозного періоду; гідротермічний коефіцієнт Г. Т. Селянінова. Визначена основна закономірність формування рослинного покриву України, що полягає у такій структурі взаємозв'язків між кліматичними показниками: зі збільшенням середніх місячних температур червня-вересня, зменшенням кількості опадів за період із квітня по вересень зменшуються показники вологозабезпеченості клімату, зростають показники теплозабезпеченості (тривалість періоду активної вегетації та сума температур за цей період, середня річна температура). Ця закономірність відображає градієнт кліматичних показників у напрямку від Українських Карпат до південного узбережжя Криму. Установлено, що для населених пунктів лісової й лісостепової областей в окремі роки початку 21 століття формувалися кліматичні умови, характерні для степової області.

Наукова новизна. Рослинний покрив території України характеризується екологічним простором, оцінка якого виконана на основі ординації географічних пунктів на осях комплексних кліматичних градієнтів середовища. У двовимірному просторі типологічну схему рослинного покриву України можна зобразити у вигляді квадратичної параболи, ліва гілка якої відображає градієнт кліматичних чинників і зміну рослинного покриву в напрямку із заходу на північний схід, а права гілка параболи – у напрямку із північного сходу на південь. Графічна візуалізація кліматичної інформації на основі екограм і типологічних схем рослинного покриву може використовуватися для прогнозування динаміки рослинного покриву внаслідок змін клімату.

Практична значимість. Знаючи кліматичні умови географічних пунктів у певний період часу, можна визначити їх положення в еколого-ценотичному просторі рослинності України, прогнозувати стійкість і можливі зміни рослинного покриву внаслідок глобального потепління.

Ключові слова: *зміни клімату, типологія рослинного покриву, зміни рослинності, математичне моделювання*

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