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VULNERABILITY ASSESSMENT OF EASTERN UKRAINIAN FORESTS TO CLIMATE CHANGE: CASE STUDY ON THE BASE OF GIS TECHNOLOGY USE

The results of assessment of main peculiarities of forest at the territory of Kharkiv, Sumy and Lugansk regions of Ukraine in present climate and future climate scenarios are presented. On the base of GIS technology the maps of present climate (average data on 1950–2000) and future climate scenarios (RCPs forecasts by years 2050 and 2070) in terms of De Martonne index were created for territory of the north-eastern part of Ukraine. Zones of De Martonne indexes was mapped with thematic forestry maps to determinate possible changes in site condition index, tree species composition and growing stock. All of RCPs forecasts sufficient warming in the second half of XXI century on the north-east part of Ukraine with decreasing of precipitations during vegetation period that will strongly influence on forest ecosystems.

Key words: Climate Change, Vulnerability of Forests, Representative Concentration Pathways (RCPs), Ukraine, De Martonne Index, GIS.

Introduction. In conditions of global climate change there is a risk of subsequent impact on ecosystems. Climate of Ukraine as well as global climate becomes warmer during the whole period of instrumental measurements. For Ukraine during the last hundred years the average annual air temperature increased by 1°C [15].

Climate changes directly and indirectly affect the growth and productivity of forests: directly due to changes in atmospheric carbon dioxide and climate and indirectly through complex interactions in forest ecosystems. But one of main driver of negative impact on forests is drought which often leads to start of negative processes in forest ecosystems which affects the frequency and severity of many forest disturbances as fires, pests and diseases [3, 13].

The forecasted changes in temperature and precipitation may have severe economic consequences. According to recent investigation [7] the value of European forest land will decrease owing to the decline of economically valuable species in the absence of effective countermeasures. By 2100 – depending on the interest rate and climate scenario applied this loss varies between 14 and 50% (mean: 28% for an interest rate of 2%) of the present value of forest land in Europe, excluding Russia, and may total several hundred billion Euros.

Developing adaptive forest management strategies is essential to maintain the provisioning of forest goods and services under future climate change. But such

adaptive forest management strategies need to base on the assessment of vulnerability of forests [5].

Broad scale investigations in Europe show that responses of forest ecosystems to climate changes will be different in different climate zones [10]. For Ukraine such investigations was done by prof. Stoyko S.M. who assessed the potential ecological consequences of global climate warming in forest ecosystems of Ukrainian Carpathians [18]. For forests in the north-eastern part of Ukraine still assessment of their vulnerability due to impact of climate change up to now hasn't been done. This part of country consists of several natural zones – Forest zone (Polissya), Forest steppe zone and Steppe zone which are different in terms of forest growth conditions. The preliminary investigation shows that forests will be vulnerable especially on the borders of zones [16], but for discovering of vulnerable areas it is necessary to apply the mapping of climate indices and put the results on the map of forests distribution.

For the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) [9] four new scenarios – Representative Concentration Pathways (RCPs) were developed. RCP's are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 W m⁻² for RCP2.6, 4.5 W m⁻² for RCP4.5, 6.0 W m⁻² for RCP6.0, and 8.5 W m⁻² for RCP8.5. RCP2.6 is mitigation scenario leading to a very low forcing level, two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions

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(RCP8.5). For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100.

The RCP's are used in this study which was carried out in cooperation with the Integrated drought management programme in Central and Eastern Europe which is one of directions of activity the Global Water Partnership (GWP) Central and Eastern Europe [8]. This activity has been launched jointly GWP and World Meteorological Organization (WMO) to improve the monitoring and prevention of one of the world's biggest natural hazards which are the droughts linked to climate change.

Our study was done for preliminary assessment of vulnerability of forest in future climate scenarios at the north-eastern part of Ukraine, namely to assess of main peculiarities of forest at the north-eastern part of Ukraine in present climate and future climate in terms of de Martonne index and calculation of changes in forest areas with different indexes of de Martonne on the base of GIS technology.

Material and methods. The north-east of Ukraine is the plain part and includes three regions: Sumy, Kharkiv and Lugansk. The territory is rather heterogeneous by natural climatic conditions, forest cover and tree species composition. There are three natural climatic zones: Forest zone (Polissya) (northern part of the pilot territory – at the north of Sumy region), Forest steppe zone (central part of pilot territory – part of Sumy and north-west part of Kharkiv regions) and Steppe zone (zone of ravine forests) (at the south-east of pilot territory – part of Kharkiv and whole territory of Lugansk region). Climate is temperate continental, but in Lugansk region it is dryer, with warmer and dryer summer, and cooler winter. The total area of the pilot territory is about 8.2 mln. ha, the forest area is 1.095 mln.ha. The forest cover in Sumy region is 17,8%, in Kharkiv region is 12% and in Lugansk is 11%.

During the first step of the study the maps of present climate (average data on 1950-2000) and future climate in terms of De Martonne index were created for the pilot territory with help of open-source GIS technology QGIS.

The source of climate data was web-site World Climate (IPCC) [14], where present climate data (average for 1950-2000) and simulated climate model according to the recent IPCC Fifth Assessment [9] are located. In study global climate model (GCM – HadGEM2-AO) was used [6]. The variables included monthly minimum and maximum temperature, precipitation, and 'bioclimatic' variables. Future climate is represented by four greenhouse gas scenarios: four representative concentration pathways (RCPs: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) for two time periods 2050 (average for 2041-2060) and 2070 (average for 2061-2080).

The De Martonne aridity index [12] was calculated on the base of climatic data as ratio of the main climate elements precipitation and temperature in each grid element: $J = P/(T+10)$;

where: P is total annual precipitation, mm;

T is average annual air temperature.

Climate data expressed in De Martonne index was classified by climate classification (Tab.1) for evaluation of the suitability of a certain climate to forest vegetation.

Table 1

Vulnerability zones by De Martonne classes

IDM*	Climate classification	Vulnerability zones		
		Name	Color	Vulnerability level
10–25	Semiarid	A	Red	Very high
25–30	Moderately arid	B	Orange	High
30–35	Slightly humid	C	Yellow	Medium
35–40	Moderately humid	D	Green	
40–50	Humid	E	Light blue	Low
50–60	Very humid	F	Blue	
> 60	Excessively humid	G	Dark blue	from Medium to Very high

*IDM – De Martonne index values range.

GIS-methods were used for determination of climatic factors influence on forests vulnerability. On the base of GIS the maps of present and modeled climate by De Martonne index were created. The GIS of present climate (1950-2000) and modeled climate by De Martonne index (by climate classification) was combined with borders of state forestry enterprises of the Sumy, Kharkiv and Lugansk regions of Ukraine. The climate and climate scenarios data were generalized at level of state forestry enterprises. Forest inventory (forest taxation) data base on 2011 (generalized at level of forest compartments) was used as forestry data source. It is necessary to note that forest taxation data base is available only for state forestry enterprises subordinated to State Agency of Forest resources of Ukraine that makes approximately 70% of total area of forests in the pilot territory – Sumy, Kharkiv and Lugansk regions [17].

The unit of data analysis was forest compartment, contained IDM values and classes of climate (in present climate and modeled) and present forestry characteristics as forest area, tree species composition, main tree species, protection status, average age, total and average growing stock, average change of stock, average site index and average density of stocking. Zones of De Martonne index was mapped with thematic forestry maps to determine possible changes in site condition indexes, tree species compositions and growing stocks.

Results and discussion. In present climate on the pilot territory there are three climate conditions: moderately humid on the north, slightly humid in center and moderately arid on the south-east, that

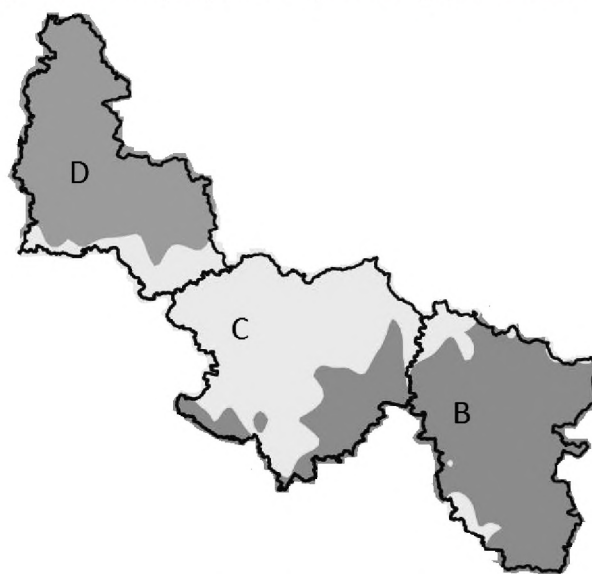
is corresponded to vulnerability classes D, C and B classes (high and medium vulnerability level) (fig. 1).

B – zone of moderately arid climate is located on the south-east of the pilot area – in Balacleya and Izum forestries of Kharkiv region, and almost all territory of Lugansk region (except northern part). This climate zone is characterized by high vulnerability level for forest growth. In these conditions 308.3 thous. ha of forests are growing that makes almost 39% of all forests of the pilot territory, 130 thous. ha of them are coniferous forest stands (mainly scotch pine), and 177,1 thous. ha – deciduous forests.

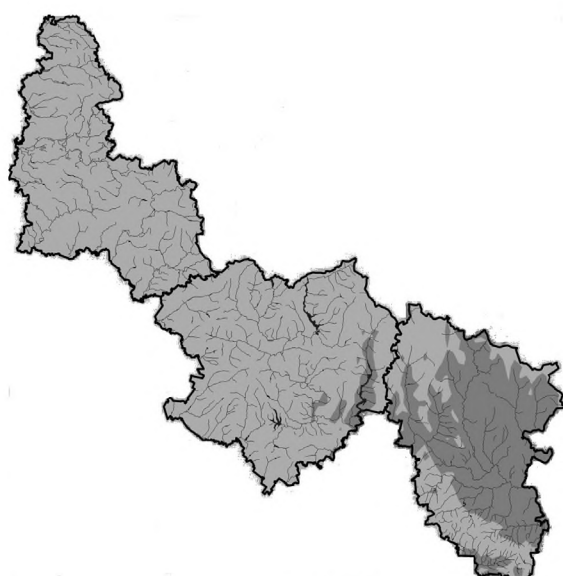
C – zone of slightly humid climate is located in central part of the pilot territory – at the major part of

Kharkiv region (except Balacleya and Izum districts) and southern district of Sumy region (Ohtyrka district) and at northern part of Lugansk region. This climate zone has medium vulnerability level for forests vegetation. The total area of forests amounts 247.2 thous. ha (31%), including 711.6 thous. ha of conifers and 175.4 thous. ha of deciduous forest stands.

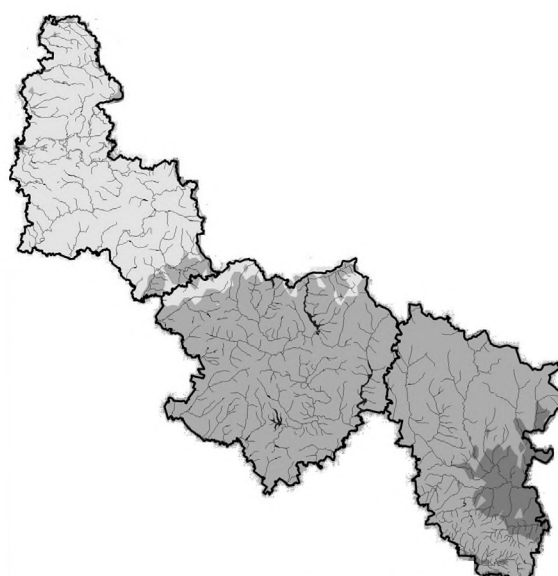
D – zone of moderate humid climate in present is located at the northern part of pilot territory on the major part of Sumy region (except Ohtyrka district) and it is characterized by medium vulnerability level for forest growing. 238.4 thous. ha of forests are located (30%) in this conditions, coniferous stands are slightly prevailing (124 thous. ha).



Present climate (1950-2000)



RCP 2,6 2050



RCP 2,6 2070

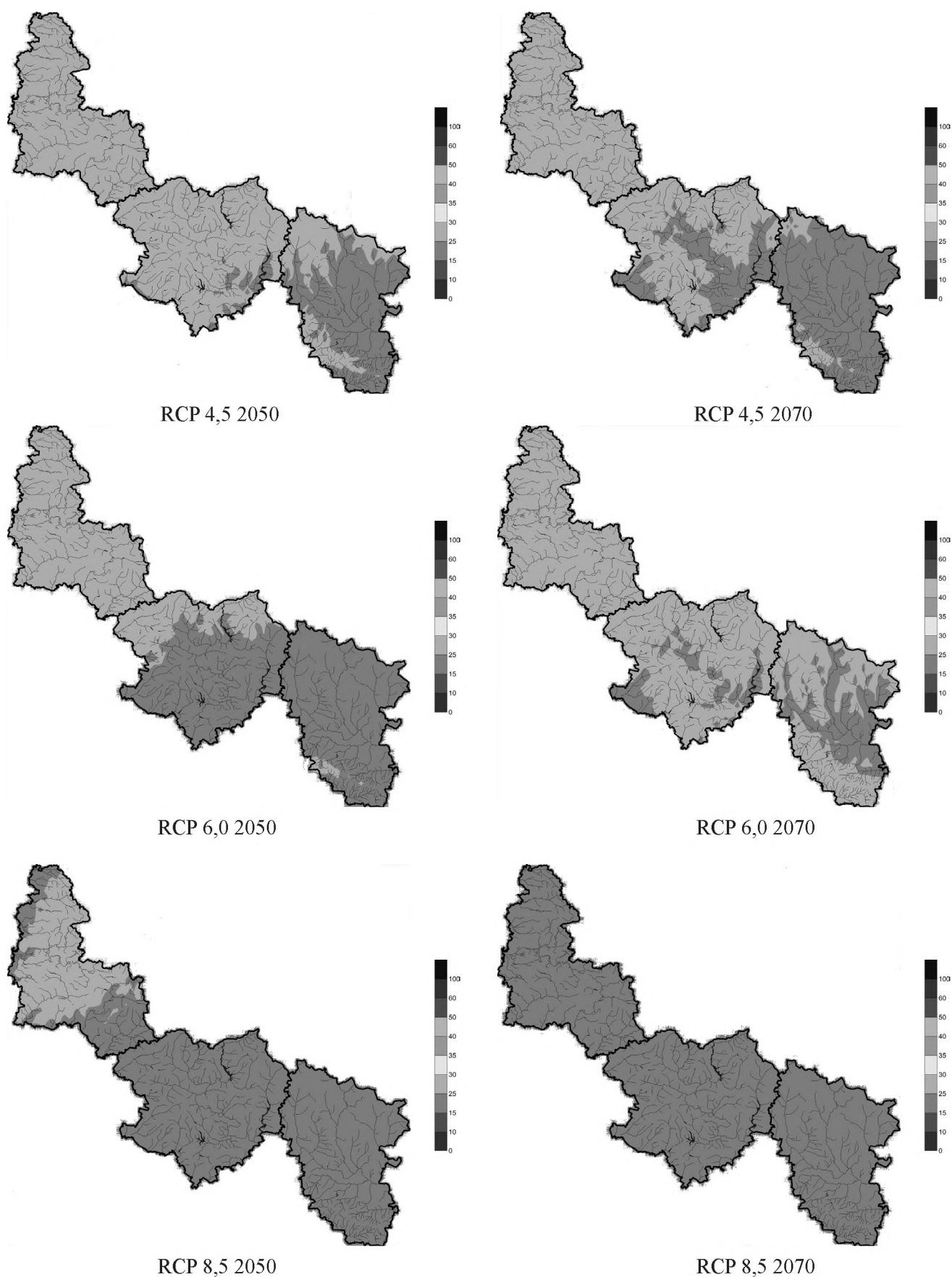


Fig. 1. De Martonne index in 2050 (left column) and 2070 (right column) according to different scenarios: RCP2.6, 4.5, 6 and 8.5 (light-grey – C zone, grey – B zone, dark grey – A zone). (at present climate map zones are indicated)

At figures 1-2 total forest area distribution by zones of vulnerability according to different climatic scenarios is presented.

All climatic scenarios forecast sufficient aridization of climate on the whole pilot territory by 2050 and 2070 years that is unfavorable for forest vegetation. All scenarios forecast significant aridization in northern part of the pilot territory (Polissya and northern forest-steppe) and disappearance of moderately humid climate (D-zone), with the most productive forests. At the same time in all RCP's the new climate – semiarid (A zone of very high level of vulnerability) appears at the pilot territory in varying degrees. In Ukraine in present climate semiarid climatic conditions are observed only outside the pilot territory at southern regions of the country: southern part of Zaporiggya, Dnepropetrivsk, all Kherson, southern Mykolayv and Odessa regions and steppe Crimea, so forest taxation database from these regions will be used for modeling of forest growing at the pilot territory in semiarid climate conditions. For example, forest cover in these zones varies from 3,9 to 4,8% while at the pilot territory this index value is 11-17.8%, so climate aridization will cause significant decreasing of forest areas.

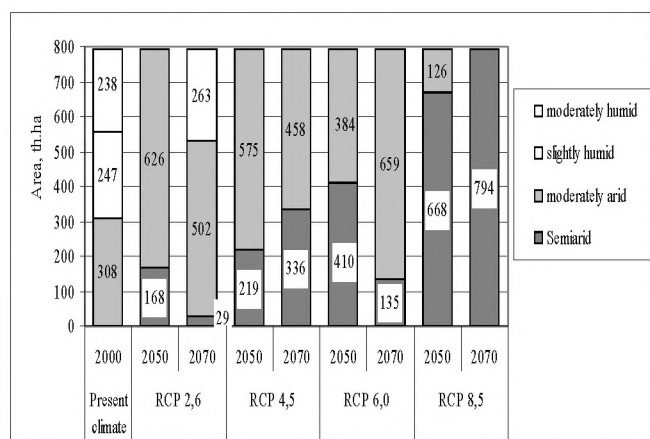


Fig. 2. Total forest area in present climate and in future climate scenarios (thous. ha)

RCP 2,6 is the most “optimistic” scenario that is characterized by aridization of climate on the pilot territory by 2050, more significant on the north (in Sumy region) where climate will change from moderately humid to moderately arid, less in Kharkiv – (change from slightly humid to moderately arid) and appearance of semiarid climate on the south in Lugansk region. By 2070 this scenario provides slight more humid climate comparing to 2050 but not to the present climate values: in Sumy region – slight humid climate is expected, in Kharkiv and Lugansk – moderately arid (only in Stanichno-Lugansk district of Lugansk region semiarid climate will remain).

RCP 4,5 is characterized by gradual climate aridization on the whole territory by 2070: all territory of Lugansk region and southern and central districts of Kharkiv region will become semiarid, and all remaining

part of the pilot territory will become moderately arid.

According to RCP 6,0 sufficient aridization of climate is expected: by 2050 Sumy and northern part of Kharkiv region will become moderately arid, while on the remaining part of Kharkiv and all Lugansk the climate will be semiarid. By 2070 the large part of the territory will become moderately arid, only in eastern and central districts of Lugansk region it will be semiarid climate.

The worst climatic conditions for forest vegetation are expected according to RCP8.5 scenario: by 2050 the large territory (all Lugansk, all Kharkiv regions and southern districts (Lebedin, Trostynets and Ohtyrka) and northern districts (Seredino-Buda and Shostka) of Sumy region will become semiarid; than climate will become more arid and by 2070 the whole pilot territory will have semiarid climate.

In present forests of the pilot territory are mainly represented by protective forests (Fig.3) that cover almost 38% (300.4 thous.ha), and recreational forests (275 thous.ha, or 35%), only 16% (127.thous. ha) make commercial forests mainly located in moderate humid climate.

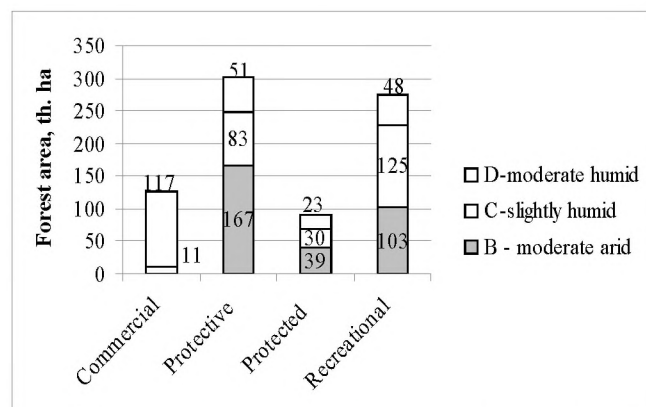


Fig 3. Present forest area (thous. ha) distribution by protective status (protective, protected, recreational and commercial forest) in different climate conditions by IDM on the pilot territory of Ukraine

In moderate arid climate all forests are not-commercial. In future due to sufficient climate aridization all forests will fulfill mainly protective functions so it is possible to forecast change of commercial status to non-commercial.

Forest stands of the pilot territory amount 35 main forest tree species (Tab. 2), but only two main forest forming species as *Quercus robur* and *Pinus sylvestris*, are dominating that cover 83% of all forest area. The large part of forest stands (especially pine) is artificial. About one third of pine forests is pure (116070 ha). Comparatively big area is covered by *Fraxinus excelsior* forest stands (6.4%) and introduced *Robinia pseudoacacia* (3%) (mostly in moderately arid climate).

Table 2

Forest area distribution by main forest tree species in present climatic conditions (ha) (Forest inventory (taxation) data base on 2011)

Main tree species	Moderately arid	Slightly humid	Moderately humid	Total
<i>Quercus robur</i>	103419,2	155819,9	75150,6	334389,7
<i>Pinus sylvestris</i>	128478,2	71665,8	126449,8	326593,8
<i>Fraxinus excelsior</i>	24356,5	8971,1	17261,1	50588,7
<i>Robinia pseudoacacia</i>	21338	2100	264	23702
<i>Alnus glutinosa</i>	3070,6	1718,7	5776	10565,3
<i>Betula pendula</i>	2018,3	295,7	2888,6	5202,6
<i>Populus tremula</i>	637,5	984,8	3479,1	5101,4
<i>Picea abies</i>	-	-	1224,5	1224,5
Other coniferous	2724	172	-	2896
Other deciduous	22304,3	5520,1	5876,2	33700,6
Total	308346,6	247248,1	238369,9	793964,6

Present tree species composition of forests on the pilot territory is rather vulnerable to climate change: comparatively high percent of pure pine stands that have a big risk of fires or insects outbreaks, so there is a big threat of loss of these forests.

Another problem is in low diversity of forests – a significant percentage of oak and pine stands. It is possible that in new climatic conditions main forest species will be substituted by secondary. These changes in forest tree species composition will cause decreasing of forest biodiversity and productivity of stands.

There is a significant probability of increasing of areas of introduced species, as *Robinia pseudoacacia*, *Fraxinus lanceolata*, *Quercus rubra*, as well as invasive *Acer negundo*, that will also cause losses in biodiversity and stand productivity.

In present climate spruce forest stands are growing only in moderately humid climate so future aridization of climate will cause degradation of these forests.

Table 3

Total growing stock of forests by main forest tree species in present climatic conditions, thous. m³ (Forest inventory (taxation) data base on 2011)

Main tree species	Moderately arid	Slightly humid	Moderately humid	Total
1	2	3	4	5
<i>Quercus robur</i>	15381,08	36541,07	19539,43	71461,58

End of Table 3

1	2	3	4	5
<i>Pinus sylvestris</i>	27070,28	20393,46	38501,66	85965,4
<i>Fraxinus excelsior</i>	4154,56	2156,64	5009,8	11321
<i>Robinia pseudoacacia</i>	1636,32	237,47	47,09	1920,88
<i>Alnus glutinosa</i>	443,77	434,49	1150,48	2028,74
<i>Betula pendula</i>	80,11	47,95	549,54	677,6
<i>Populus tremula</i>	81,57	231,19	784,62	1097,38
<i>Picea abies</i>	-	-	301,22	301,22
Other coniferous	203,5	15,45	-	218,95
Other deciduous	2385,17	901,01	1423,63	4709,81
Total	51436,36	60958,73	67307,47	179702,6

Total growing stock in forests of the pilot territory is 179702.6 thous. m³ (Tab. 3). The average growing stock is 226.3 m³ per ha, that varies from 261 m³ ha⁻¹ at coniferous stands to 201 m³ ha⁻¹ in deciduous (Fig.4).

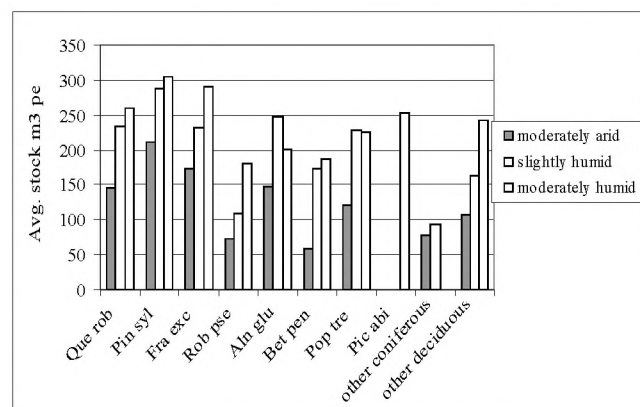


Fig 4. Average growing stock per hectare by main forest tree species in present climate (Que rob – *Quercus robur*, Pin syl – *Pinus sylvestris*, Fra exc – *Fraxinus excelsior*, Rob pse – *Robinia pseudoacacia*, Aln glu – *Alnus glutinosa*, Bet pen – *Betula pendula*, Pop tre – *Populus tremula*, Pic abi – *Picea abies*)

In present climate the most favorable climate conditions for timber productivity are in moderately humid climate almost for all forest tree species. Productivity of Oak, Pine and Ash decrease on 40% in moderately arid climate comparing to moderately humid (Fig.4).

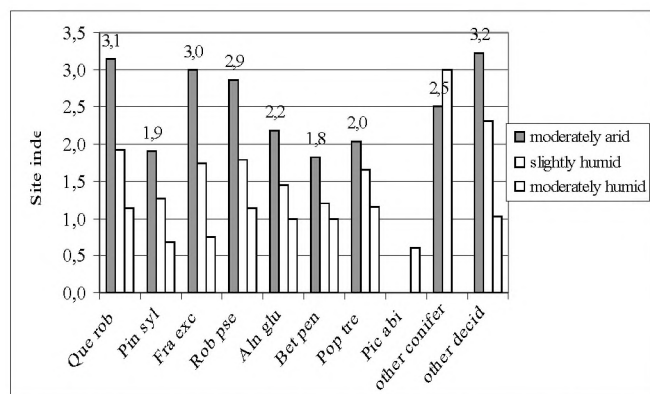


Fig 5. Average site index (bonitet) by main forest tree species in present climate

Another index describing the productivity is site index (bonitet) that shows relation between average age of forest stand and its average height and depends on forest site conditions. The scale includes five main classes: I (the most high productive stands), II, III, IV, V (the less productive stands). The majority of forests in moderately humid conditions have site index values about 1 (high productive), in slightly humid climate productivity decreases (site index varies between 1.2 to 1.9 for main forest forming species and exceeds 2 for other species). In moderately arid climate the site index achieves highest values (varies from 1,8 to 3.1) that means decreasing of productivity.

In future climate even according to the “optimistic” 2.6 RCP scenario expected aridization of climate will cause significant decreasing of productivity of forests in Sumy and Kharkiv regions, while in Lugansk the productivity will remain almost at the same level. Vulnerability of forests in the north-eastern part of Ukraine will increase according to the rest of RCP’s forecasts.

Conclusions. Recent world climate models forecasts sufficient warming in the second half of XXI century on the north-east part of Ukraine with decreasing of precipitations during vegetation period that will strongly influence on forest ecosystems.

In present climate the high vulnerable zone is on the south-east of the pilot territory (Lugansk and part of Kharkiv region) where there is moderately arid climate, while the remaining territory has medium vulnerability level (moderately and slightly humid climate). Forests in moderately humid climate are characterized by high productivity.

All RCP’s forecast significant climate aridization that cause disappearance of moderately humid climate and appearance of semiarid climate (very high vulnerability level for forest growth). Large territories will become moderately arid. Expected climate will cause significant decreasing of forest cover, forest sustainability, productivity and biodiversity, changes in tree species composition.

RCP 2,6 is the most “optimistic” scenario that is characterized by drier climate on the pilot territory by

2050, and by 2070 climate will be slight humid in the north and moderately arid on the rest of territory (except one district of Lugansk region with semiarid climate).

RCP 4,5 and 6,0 are characterized by gradual aridization of climate on the whole territory: by 2070 climate will be semiarid and moderately arid.

The worst climatic conditions for forest vegetation are expected according to RCP8.5 scenario: by 2070 the whole pilot territory will have semiarid climate.

Development of strategies for adaptive regulation of forest stands should be based on regional and local vulnerability assessment, the proper forest maps and quantitative indicators of forest inventory, including changes in forest cover, condition, productivity and biodiversity. Continue of research activity needs to predict and assess by quantitative indicators the impact of climate change on forest at the north-eastern part of Ukraine.

REFERENCES

1. Adams, H. D. et al. Temperature sensitivity of drought-induced tree mortality portends increased regional die-off under global change-type drought. *Proc. Natl Acad. Sci. USA* 106, 7063-7066 (2009).
2. Allen, C. D. & Breshears, D. D. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. *Proc. Natl Acad. Sci. USA* 95, 14839-14842 (1998).
3. Allen, C. D. et al. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecol. Manage.* 259, 660-684 (2010).
4. Breshears, D. D. et al. Regional vegetation die-off in response to global-change-type drought. *Proc. Natl Acad. Sci. USA* 102, 15144-15148 (2005).
5. Christian Temperli, Harald Bugmann, and Ché Elkin 2012. Adaptive management for competing forest goods and services under climate change. *Ecological Applications* 22:2065-2077.
6. Climate change in the 21st century simulated by HadGEM2-AO under representative concentration pathways Hee-Jeong Baek, Johan Lee, Hyo-Shin Lee, et al. *Asia-Pacific Journal of Atmospheric Sciences*. November 2013, Volume 49, Issue 5, pp. 603-618 – <http://link.springer.com/article/10.1007%2Fs13143-013-0053-7#page-1>.
7. Hanewinkel Marc et al. Climate change may cause severe loss in the economic value of European forest land. *Nature Climate Change* 3, 203-207 (2013).
8. Integrated Drought Management Programme in Central and Eastern Europe // Global Water Partnership Central and Eastern Europe. – 2 p.
9. IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, et al. (eds.)]. Cambridge University Press, United Kingdom and

New York, USA. – http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

10. Marja Kolström, Terhi Vilén, Marcus Lindner. Climate Change Impacts and Adaptation in European Forests. EFI Policy Brief 6, 2011. – 16 p.

11. McDowell, N. G. et al. The interdependence of mechanisms underlying climate-driven vegetation mortality. Trends Ecol. Evol. 26, 523-532 (2011).

12. Oliver, John E. (2005). The Encyclopedia of World Climatology. Springer Publishing. p. 90. ISBN 978-1-4020-3264-6. Retrieved 5 March 2013.

13. Williams A. Park. et al. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change 3, 292-297 (2013).

14. World Clim – Global climate data <http://www.worldclim.org/>

15. Адаменко Т.І. Агрокліматичне зонування території України з врахуванням зміни клімату / Адаменко Т.І. – К.: ТоВ «РІА»БЛІЦ. – 2014 – 16 с.

16. Букша І.Ф. Україна та глобальний парниковий ефект. Вразливість і адаптація екологічних та економічних систем до зміни клімату. Кн. 2.: Монографія. / І.Ф. Букша, П.Ф. Гожик, Ж.Л. Ємельянова та ін. – К.: Вид-во Агентства з раціонального використання енергії та екології, 1998. – 208 с.

17. Довідник з лісового фонду України за матеріалами державного обліку лісів станом на 01.01. 2011р. – Ірпінь, 2012. – 132 с.

18. Стойко С.М. Потенційні екологічні наслідки глобального потепління клімату в лісових формаціях Українських Карпат / С.М. Стойко // Науковий вісник Нац. лісотех. ун-ту України : зб. наук.-техн. праць. – 2009. – Вип. 19.15. – С. 214-224.

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ОЦЕНКА ВРАЗЛИВОСТИ ЛІСІВ СХІДНОЇ УКРАЇНИ ДО ЗМІН КЛІМАТУ: ДОСЛІДЖЕННЯ НА ОСНОВІ ЗАСТОСУВАННЯ ГІС-ТЕХНОЛОГІЙ

Представлені результати аналізу основних лісово-лісогосподарських показників лісових насаджень у сучасних та майбутніх кліматичних умовах на території Харківської, Сумської та Луганської областей України. Для північно-східної частини України на

основі ГІС технології були створені карти сучасного клімату (середні показники за 1950–2000 рр.) і прогнози для майбутнього клімату на 2050 р. і 2070 р., які ґрунтуються на показниках індексу Де Мартона. Визначені зони Де Мартона були накладені на лісові тематичні карти для оцінювання можливих змін типів умов місцезростання, видового складу деревних порід та запасів деревостанів. У північно-східній частині України за усіма розглянутими прогнозами передбачається істотне потепління у другій половині ХХІ століття та зменшення опадів впродовж вегетаційного періоду, що буде суттєво впливати на лісові екосистеми.

Ключові слова: зміна клімату, вразливість лісів, траєкторії концентрації парникових газів, Україна, індекс Де Мартона, ГІС

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ОЦЕНКА УЯЗВИМОСТИ ЛЕСОВ ВОСТОЧНОЙ УКРАИНЫ К ИЗМЕНЕНИЯМ КЛИМАТА: ИССЛЕДОВАНИЯ НА ОСНОВЕ ИСПОЛЬЗОВАНИЯ ГИС-ТЕХНОЛОГИЙ

Представлены результаты анализа основных лесоводственно-таксационных показателей лесных насаждений в современных и будущих климатических условиях на территории Харьковской, Сумской и Луганской областей Украины. Для северо-восточной части Украины на основе ГИС технологии были созданы карты современного климата (средние показатели за 1950–2000 гг.) и прогнозы для будущего климата на 2050 и 2070, основанные на показателях индекса Де Мартона. Определенные зоны Де Мартона были наложены на лесные тематические карты для оценки возможных изменений в типах условий местопроизрастания, видовом составе древесных пород и запасах древостоев. Для северо-восточной части Украины все рассмотренные прогнозы предусматривают потепление во второй половине ХХІ века и уменьшение осадков на протяжении вегетационного периода, что будет существенно влиять на лесные экосистемы.

Ключевые слова: изменение климата, уязвимость лесов, траектории концентрации парниковых газов, Украина, индекс Де Мартона, ГИС