IMPACT OF DROUGHT ON THE FOREST VEGETATION IN NORTH-EASTERN UKRAINE: THE LONG-TERM PROGNOSES AND ADAPTATION MEASURES

Igor Buksha, Tatiana Pyvovar, Maksym Buksha, Volodymyr Pasternak
Ukrainian Research Institute of Forestry and Forest Melioration, named after G.M. Vysotsky, Kharkiv

Abstract

This paper focuses on the impacts of expected climate change according to scenarios of the IPCC Fifth Assessment Report (2014) on forests distribution in the north-eastern part of Ukraine in the 21st century. De Martonne aridity index was used for determination of vulnerability level. Ranges of temperature, precipitation and de Martonne index for main tree species were determined. Main tree species’ distribution and forest health condition (defoliation and trees mortality) were assessed by vulnerability zones.

In the 21st century, significant climate warming (by 3–6º C) in the north-eastern part of Ukraine will cause increasing of drought risk, that will be unfavourable for forest vegetation. At present, 61.2% of forests grow on the southern limit of their natural range at moderately and slightly humid climate. Significant deterioration of forest health condition is expected. Forest and forest-steppe zones shifting to the north and replacement by steppe are highly probable, as well as shifting of natural ranges of main tree species. Some tree species probably will disappear and will be replaced by more xeric ones, including introduced. According to our models, the flatland part of Ukraine probably will gradually become forestless, while forests will be preserved only at sites with available soil moisture. We propose to implement adaptation measures based on the best practices for sustainable forest management, as well as improvement of technologies for forest cultivation and control of forest fires.

The study was carried out in the frame of the Integrated drought management program in Central and Eastern Europe supported by the Global Water Partnership.

Key words: climate change, IPCC AR5, forests, de Martonne aridity index

INTRODUCTION

In the last one hundred years, the mean air temperature in Ukraine increased by 1 ºC (Adamenko, 2014). One of the main environmental factors that affect forests is drought (Williams et al., 2013.), that often launches a negative process in forest ecosystems, like forest fires, pests and deceases outbreaks. During the last two decades in Ukraine, there were 11 drought periods (Savchuk, 2015). For the last 30 years, the number of forest fires increased 2.6 times (Environment of Ukraine, 2015). Outbreaks of foliage browsing insects, bark beetles, as well as pathogens, has become more frequent and severe at large territories (Meshkova, 2018) and has resulted in a significant increase of areas of dead forests.

Potential climate effects on forests were studied for different countries (Boczoń et al., 2015, Hlásny et al., 2014, Pravalie et al., 2014). In Ukraine, such study was carried...
out using CCCM, GGFDL, GISS and UKMO models and a first adaptation strategy for the Ukrainian forestry sector has been developed on the base of climate change scenario modelling (Buksha et al. 1998). A recent study of the A1B scenario from IPCC (Shvidenko et al., 2017) showed that conditions will become unfavourable for forest vegetation. The preliminary study (Buksha et al., 2014) according to the newest climate models from Assessment Report 5 of the Intergovernmental Panel on Climate Change (IPCC AR5) (2014) showed a significant increase of droughts frequency in Ukraine.

The southern border of the temperate forests is located in the flatland of Ukraine (Gensiruk, 2002). Forests here are very vulnerable (Shvidenko et al., 2017) due to their high fragmentation and anthropogenic loading. The threat of forest transition to open woodland and non-forest vegetation under a changing climate is very high in this region.

This paper focuses on the assessment of the drought effect on the forest distribution in north-eastern Ukraine. Additionally, we propose measures, aimed at adaptation of forests to climate change, based on the principles of sustainable forest management and world best practices.

**MATERIAL AND METHODS**

This work was a part of an international study conducted in Bulgaria (Raev et al., 2015), Lithuania, Slovenia and Ukraine (Buksha et al., 2014) within the international project “Integrated drought management programme in Central and Eastern Europe”, one of the activities of the Global Water Partnership (GWP) and World Meteorological Organization (GWP CEE, 2015).

Because of the large area of Ukraine (602 thousand km²), the study was performed at a pilot territory (81.9 thousand km²), located at the flatland north-eastern part of the country (at Kharkiv, Sumy and Lugansk regions; (Fig. 1-3), 13.4% (10.96 thousand km²) of it is covered by forests (Forest Fund of Ukraine, 2012). Three natural climate zones are represented there: forest (Polissya), forest-steppe (transition zone) and steppe (Gensiruk, 2002).

We used data on temperature and precipitation from the WorldClim dataset (2014) on the current climate and projected them using the global climate model HadGEM2-AO (Baek et al., 2013) for four representative greenhouse gas concentration trajectories (RCP’s) (IPCC AR5, 2014). RCP 2.6 is an “optimistic” scenario, RCP4.5 and RCP6 are two stabilisation scenarios and RCP 8.5 is a very high GHG-emission scenario (“pessimistic”). Zones of vulnerability for forests were defined according to the classification of De Martonne aridity index (IDM; Fig.3) (De Martonne, 1926).

By means of GIS, the climate data for the pilot territory of Ukraine were isolated using methods of generalisation of climate layers and data. We used the mapping software Surfer 12, the GIS layer for present climate (1950-2000) and modelled climate with the De Marton index (classified, see Fig.3) were combined with forest enterprises borders on the pilot territory of Ukraine and with coordinates of forest monitoring plots. Climate data were generalised at forest enterprise level. Forest taxation data based on
2011 (generalised at level of forest compartments) were used as data source. The unit of data analysis was forest compartment, contained IDM values and classes and forest characteristics, such as forest area, species composition, main tree species. Each forest monitoring plot got a relevant IDM value.

Maps of current (1950-2000) and modelled climate (for 2050 and 2070) were elaborated. Tree species composition and area of 18649 forest compartments (forest taxation database) were analysed. Ranges of precipitation, temperature and IDM were defined for main tree species for the current climate for the flat part of Ukraine and for modelled climate (2070) for the pilot territory. Forest health condition (crown defoliation and trees mortality) was assessed from the forest monitoring database (1298 plots in the flatland part of Ukraine, including 227 at the pilot area). Defoliation data were averaged for the period 2001-2013 at plot and species level. Statistical analysis was carried out with the program Past 2.17. Single factor analysis of variance (ANOVA) and a chi-squared test were used.

Fig. 1. Scenarios of changes in annual mean air temperature (°C) in the current climate in Ukraine (top map); in 2050 (middle row) and 2070 (bottom row) at the pilot territory.
RESULTS

At present, there is a temperate continental climate at the pilot territory of Ukraine, with an average annual air temperature between 5.7 – 9.1 °C (Fig. 1) and an annual amount of precipitation 472 – 623 mm (Fig. 2). Significant climate warming was projected till 2070: according RCP 2.6 the temperature would increase by 3.1 °C and according RCP 8.5 – by 6.4 °C. The expected warming in cold months of the year could change the boundaries of climate seasons, the mean monthly temperature in summer would increase by more than 5 °C. Under RCP’s 2.6, 4.5 and 6.0 projections precipitation amount would not change significantly. As it was forecasted by RCP 8.5, precipitation would considerably decrease: approximately by 59 mm (11%) by 2070, with the whole territory, with an increase in winter and reduction during the vegetation period.

*Fig. 2.* Annual precipitation (mm) in Ukraine in the current climate for 1950-2000 (top) and in 2050 (middle) and 2070 (bottom row) at the pilot territory
Fig. 3. Vulnerability zones identified using De Martonne aridity index (IDM) in Ukraine in the current climate for 1950–2000 (top map); in 2050 (middle row) and 2070 (bottom row) in the pilot territory.
In the current climate, de Martonne index ranged from 20.1 to 45.7 for the flatland part of Ukraine and from 25.6 to 40 for the pilot territory (Fig. 3). Three zones B, C and D were represented in it. Zone D of moderately humid climate located in the north, almost coincided with the forest zone (Polissya), which had the highest forest coverage (17.8%). It is located in the Polesian Lowland with alluvial sandy soils. Highly productive forest stands of *Pinus sylvestris* L. (238.4 thousand ha; Buksha et al., 2014) grew there. Deciduous forests with dominance of *Quercus robur* L., *Betula pendula* Roth, *Populus tremula* L. and *Alnus glutinosa* (L.) Gaertn were less represented.

Zone C of the slightly humid climate located in the centre, almost matched with the forest-steppe zone and was characterised by medium forest cover (12% of the territory) and productivity. Forests in this zone (247.2 thousand ha; Buksha et al., 2014) were mostly represented by acidophilus temperate oak (*Quercus robur* L.), forests with *Tilia cordata* Mill., *Acer platanoides* L. and *Fraxinus excelsior* L. and artificial Scots pine forests (*Pinus sylvestris* L.). Climate conditions in zones C and D were favourable for forest vegetation, the risk of droughts was evaluated as medium.

At the south-east of the region, zone B (moderately arid climate) characterised by high drought vulnerability was presented. It almost coincided with the northern part of the steppe zone. It had the lowest forest coverage (11% of the territory) and the lowest productivity (Buksha et al., 2014). At this zone, forests were distributed mostly in hilly elements of the relief and along water sources (floodplain forests). Deciduous forests were formed mainly by stands with dominance of *Quercus robur* L., *Fraxinus excelsior* L. and of *Robinia pseudoacacia*. Coniferous stands were represented by artificial stands of Scots pine and *Pinus nigra* Arn. *ssp. pallasiana* (Lamb) Holmboe. According all scenarios, a significant decrease of IDM values could be expected throughout the country, particularly at the pilot territory (in 2070 at RCP2.5 IDM would range from 23.5 to 32.5; at RCP 8.5 – from 17.7 to 23.5; Fig. 3), so intensification and duration of droughts would likely be the main climate change driver for this territory. Significant shifting of climate zones could be expected: moderately and slightly humid climates (D and C zones) would shift beyond the pilot territory, the area of moderately arid climate (zone B) would spread to the north, while the semiarid climate (A zone) would appear in the south (Buksha et al., 2014). By 2070, the climate in north-eastern Ukraine would become similar to current conditions in the forestless southern steppe of Ukraine, where forest cover is about 3.9 – 4.8%. By the end of the century, all forests within the studied area would become highly and very highly vulnerable (Buksha et al, 2014).

Our results for the current composition of tree species on the pilot area showed that *Quercus robur* L. and *Pinus sylvestris* L. were the key forest species, dominating at 83% of forest area (Table 1). They have been also the most economically important and fulfilled multiple ecological functions (Buksha et al., 2014). Scots pine stands occupied 41% of the total forest area. Pine is characterised by high drought tolerance and undemanding to soil condition (San-Miguel-Ayanz et al., 2016). In the current climate, forests in zone D (38.7%) grow on the southern border of their natural range, while in zones C and B pure forest plantations prevailed, created for afforestation at poor sandy soils in forest-steppe and steppe. There is a high risk of forest fires and biotic damage in these forests.
European oak stands grow within their natural range (San-Miguel-Ayanz et al., 2016) in zones D and C. The species prefer fertile and moist soils but it can tolerate mild drought, as well as flooding. However, its ability to natural regeneration at forest-steppe zone without silvicultural support is very poor (Didenko, Borysova, 2017), while natural regeneration of the common ash (*Fraxinus excelsior* L.) and *Acer* spp. is good. A relatively large area belonged to the common ash stands, which tolerated limited water availability (Table 3) (San-Miguel-Ayanz et al., 2016).

<table>
<thead>
<tr>
<th>Species, (area)</th>
<th>Year, RCP</th>
<th>A***</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>**%(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coniferous, (330.7 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>131.2</td>
<td>71.8</td>
<td>127.7</td>
<td>38.6</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>72.9</td>
<td>257.8</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>265.6</td>
<td>65.1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><em>Pinus sylvestris</em> L., (326.6 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>128.5</td>
<td>71.7</td>
<td>126.4</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>71.5</td>
<td>255.1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>262.4</td>
<td>64.2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other coniferous, (4.1 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>2.7</td>
<td>0.2</td>
<td>1.2</td>
<td>29.7</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>1.4</td>
<td>2.7</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>3.2</td>
<td>0.9</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Deciduous, (463.3 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>177.1</td>
<td>175.4</td>
<td>110.7</td>
<td>23.9</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>94.9</td>
<td>368.3</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>401.9</td>
<td>61.3</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><em>Quercus robur</em> L., (334.4 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>103.4</td>
<td>155.8</td>
<td>75.2</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>55.7</td>
<td>278.7</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>296.9</td>
<td>37.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><em>Fraxinus excelsior</em> L., (50.6 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>24.4</td>
<td>9.0</td>
<td>17.3</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>10.4</td>
<td>40.2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>40.7</td>
<td>9.9</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><em>Robinia pseudoacacia</em> L., (23.7 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>0.21</td>
<td>0.021</td>
<td>0.003</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>0.10</td>
<td>0.14</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>0.23</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Other deciduous, (54.6 10^3 ha)</td>
<td>2000</td>
<td>0</td>
<td>0.28</td>
<td>0.09</td>
<td>0.18</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td>2050, RCP 2.6</td>
<td>0.19</td>
<td>0.36</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2050, RCP 8.5</td>
<td>0.41</td>
<td>0.14</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

* Forest areas from the Forest taxation database on forest enterprise, subordinated to State Agency of Forest Resources of Ukraine. Data on other forests are not available.
** Percentage (%) of the area of forest tree species over zone D, with medium vulnerability.
*** A – semiarid climate (very high vulnerability level); B – moderately arid (high vulnerability); C – slightly humid and D – moderately humid (medium vulnerability).
Norway spruce (Picea abies Karst.) was recorded only in zone D, outside of its natural range (1.2 thousand ha). Plantations of Crimean pine Pinus nigra Arn. ssp. pallasiana (Lamb), one of the most xeric species, grew only in zone B (2.7 thousand ha).

Among introduced species, the most widespread was Robinia pseudoacacia L., which grew as the main species (23.7 thousand ha, 5% of deciduous) mainly in B
zone and in all other zones in deciduous and pine forests. It had a comparatively high tolerance to air temperature (Table 2) and high resistance to insects and diseases (San-Miguel-Ayanz et al., 2016). Invasive Acer negundo L. was spread on all territories under the canopy of forests (covering an area of 67.5 thousand ha). Due to its high reproductive capacity and wide tolerance (Agishev, 2016.), it could replace native tree species in forests.

Scots pine, European oak and common ash in the flatland part of Ukraine (Table 2) were distributed under a comparatively narrow range of annual precipitation (407-778 mm) and temperature (5.9–10.7 °C; Table 2), black locust grew under the lower values of precipitation and higher values of temperature. Till 2070, due to increasing of air temperature at the pilot territory even under the optimistic scenario RCP 2.6 the range of IDM would shift towards lower possible values for tree species. At RCP 8.5 conditions, it would be at the lower (xerogenic) limits for all studied species.

According to the forest monitoring data at the flatland of Ukraine, the total amount of forest tree species both deciduous and coniferous significantly decreased from zone D (45 and 9, respectively) to zone A (14 and 2, respectively). In the semiarid climate, the most common species were the Scots pine, Crimean pine and the introduced black locust. Predicted climate aridisation could cause significant changes in forest species composition of the region.

The health condition of the main tree species was significantly different in different climate zones (Table 3). The largest mean defoliation was observed at climate zones A and B. Defoliation over 25% (Fischer R, Lorenz M (eds.), 2011) was considered an indicator of tree weakening, so the majority of trees in the semiarid zone were under permanent water stress, which caused decreasing of trees resistance to pests and pathogens. The mortality level of the European oak (2.3%), Scots pine (1.1%) and the common ash (3.4%) in zone B was significantly higher (р<0.05) as compared to zones C (0.2, 0.4 and 0%, respectively) and D (0.2, 0 and 0%, respectively). Therefore, in a new arid climate significant deterioration of forest health condition could be expected.

The decline of oak (San-Miguel-Ayanz et al., 2016), ash (Davydenko, Meshkova, 2017), spruce (Spiecker, 2000, Debrinjuk, 2011) and pine (Pyrohova, 2016) stands were registered in different regions of Ukraine and in Europe. It was associated both with climate-caused changes of natural ranges of pests and pathogens, timing of their development and with the change of trees susceptibility to their damage (Meshkova, 2009). The risk of forest fires and pathogens damage is very high, especially at pure pine stands at dry habitats.

According to the Global forest watch, during the previous decade, a decrease in forest area was observed in Ukraine. For the pilot territory, it was reduced by 170 thousand ha (or 13.8%) for the period 2000-2010. The rate of losses was lower in the Lugansk region: 5.7 thousand ha (or 2.4%), while in the Kharkiv region, where mainly transitional forest-steppe zone were located, it was the highest (82.9 thousand ha, or 17.5%).
DISCUSSION

At present, forests in north-eastern Ukraine grow under climate conditions with vulnerability level from medium to high. A considerable increase in temperatures and precipitation reduction in the vegetation period might cause increasing of evaporation and water stress. New climate conditions will be similar to the current climate for the forestless southern steppe of Ukraine. Within the next three decades, all forest ecosystems in the north-eastern part of Ukraine would be vulnerable, due to intensification and duration of droughts.

The process of forest area decreasing at the pilot territories would continue. Due to the relatively narrow margin between forest and steppe zones, the probability of it shifting to the north is very high, even according to the optimistic scenario. The extension of the steppe ecoregion was forecasted. Under new arid climate, shifting of natural ranges of main tree species, e.g. \textit{Pinus sylvestris} L. and \textit{Quercus robur} L., to the north is probable (Brèda et al. 2006; Dyderski et al., 2018), particularly in north-eastern Ukraine, there would be no appropriate climate for these species. Similar results were obtained at the national study (Shvidenko et al., 2017). Significant changes could be expected also for the species composition: many tree species would probably disappear and will be replaced by more xeric ones, including introduced species, such as \textit{Robinia pseudoacacia} L. and \textit{Pinus nigra} ssp. \textit{pallasiana}. At wet sites, \textit{Acer negundo} L. will spread. That would reduce the forest ecosystems biodiversity and stability. The trees would become more susceptible to infection and invasion, so a significant increase of intensity and frequency of biotic (pests and diseases) and abiotic (fires) damage (mostly in pine stands) might be expected. Tree species could lose their productivity (Bukhsa et al., 2014, Shvidenko et al., 2017), reproductive capacity and ability to natural regeneration.

Measures for adaptation of forests in Ukraine to drought were developed using vulnerability zones and taking into account European experience (Hlásny et al., 2014; Kolström et al., 2011; Temperli et al., 2012). The main task is to develop strategic documents and policies in the forest sector that should include implementation of multipurpose management, focused on environmental functions of forests. For its realisation, state information systems on forests and shelterbelts should be developed, as well as monitoring systems for forest vegetation, particularly biodiversity, forest fires and damage.

Very important is to both maintain the existing forests, as well as to create protective forests. Conservation of forests can be fulfilled by complex measures that include silviculture and are directed to decrease of deforestation, maintenance of mixed forest, transformation of coppices into high-stemmed stands, use of higher rotation age, improvement of species composition and take into account species adaptive capacity, support of natural regeneration, conservation of gene fund of native tree and shrub species, growing from drought-resistant seedlings. Using and adapting the best practices for sustainable forest management and exchange of experience with countries with vast semi-arid areas is necessary, as well as improvement of technologies for forest cultivation and control of forest fires.
CONCLUSION

In the 21st century, significant climate warming in the north-eastern part of Ukraine could cause increasing of drought risk that will be unfavourable for forest vegetation. Significant deterioration of forest health condition is expected. Some tree species probably will disappear and will be replaced by more xeric ones, including introduced species, such as Robinia pseudoacacia L. and Pinus nigra ssp. pallasiana.

There is a big risk of forest decline on large territories, partly caused by pests and diseases outbreaks and forest fires. The flatland part of Ukraine will probably gradually become forestless. Forests will remain only locally present, as intrazonal vegetation in wet sites.

The implementation of suggested adaptation measures is expected to increase forest resilience and maintaining of environmental forest functions in the future climate condition and would significantly reduce the consequences of climate change.

REFERENCES

Adamenko, T. I. 2014. Agro-climatic zoning of Ukraine with the account of climate change “RIA” Blitc ltd. 16 pp. (In Ukrainian)


De Martonne, Emm. 1926. Areisme et indice d’aridite. – Comptes Rendus de L’Academie des Sciences de Paris, 182(23), 1393-1398.


Raev, I., V. Alexandrov, G. Tinchev. 2015. Assessment of drought related climate change impacts on forests in Bulgaria. – Silva Balcanica, 16(1), 5-24.


E-mail: pasternak65@ukr.net