Asian Journal of Water, Environment and Pollution, Vol. 18, No. 1 (2021), pp. 7-14.
DOI 10.3233/AJW210002

Development of Forest Shelterbelts Considering Statistical Forecasts Modelling of Local Weather

Irina Volkova*, Kseniia Pitulko[1], Anzhelika Sergeeva[1] and Saida Pshidatok[2]

Institute of Geography RAS, Moscow, Russian Federation
[1]Saint Petersburg' Institute of the All-Russian State University of Justice (Russian Law Academy of the Ministry of Justice of Russian Federation), Saint Petersburg, Russian Federation
[2]Kuban State Agrarian University, Krasnodar, Russian Federation
✉ volin511@yandex.ru

Received October 20, 2020; revised and accepted November 16, 2020

Abstract: This work aims to study the effect of high temperatures and phytopathogenic bacteria on different types of trees in the forest shelterbelts. Therefore, in 2018, 17 tree species were studied from 50 sample sites in the Moscow oblast (Russia). Leaf scorching, diseases caused by phytopathogenic bacteria, and heat damage to the crowns were examined in 5224 tree species. Based on the degree of crown damage, the studied tree species were divided into four classes. It was found that the heat damage to tree crowns was identical between the three sampling aspects (correlation coefficient 0.99). The plant species composition must be considered when developing forest shelterbelts. A long-term forecast on structural changes of planted areas is possible, considering the species composition and climatic characteristics of the region. Class 5 includes only chestnut; class 4 includes three species; class 3 is represented by seven species. Class 2, includes six species, and is the most suitable in developing forest plantations. No tree species in class 1 were found (trees with no damage). There is a connection between pathologies and heat injuries in trees from classes 4 to 5 (correlation 0.89).

Key words: Forest shelterbelts, phytopathogenic bacteria, heat injuries, chlorosis, necrosis.

Introduction

The main function of forest shelterbelts is to prevent soil erosion caused by wind and precipitation (Safonov, 2020; Volodchenkova, 2010). Moreover, the crops are protected from desertification by tree shelterbelts. Currently, there is a tendency for forest shelterbelts planting, based on their types, design, layering, planting time, considering the time spent on growing seedlings and the nature of their subsequent placement (Grigorieva et al., 2016). Important factors such as edaphic (soil composition of a region) and climatic are also considered. The latter implies an integrated approach for developing forest shelterbelts, considering the long-term climatic characteristics of the region (Bennett et al., 2018). Long-term forecasting of the forest shelterbelts growth also includes the height of trees, as well as the possibility of soil deflation (Jespersen, 2020).

The Russian Federation, the largest country in the world by area, has 2.8 million hectares of forest shelterbelts so far and half of them (1.2 million ha) protects fields (Zolotukhin, 2015).

The influence is generally negative leading to the degradation of forest belts, mass drying of trees, and xylophagous insect mass outbreaks (Llorens et al., 2020). It should be noted that climatic changes will differ in various regions, and at first, maintaining the

*Corresponding Author

general trend, they will be characterised by uneven temperature and humidity between different years (Parvathi et al., 2020). Thus, the yield of agricultural crops of plants, even in the same small area, will differ by 30-80% (Akatov, 2016). The influence of forest belts on the productivity of agricultural crops can manifest indirectly, through the difference in soil moisture, which decreases with distance from the trees. It has been established that the yield of agricultural crops can be differentiated by diminution up to 25 m, up to 200 m and up to 400 m. This means that the distance between each side of the forest belt should not exceed 400 m in order to maintain the maximum yield of agricultural crops (Kravets et al., 2016).

Steppe regions in Russia, therefore, consider preserving the existing and planting of new forest belts. The measure is followed by other countries with a climate similar to Russia.

The average temperature in Russia is growing 2.5 times faster as compared to the global scale and 1.5 times faster than over landmasses (Kravets et al., 2016). Not all plants and animals can adapt to such rapid changes in temperature, which is causing variation in the degree of adaptability in different plant species (Garrett et al., 2011). Changes also apply to various types of fungi and bacteria that damage trees (Dukes et al., 2009). Damage caused by phytopathogenic bacteria has significantly increased in the past 10 years, in particular, the southern regions. There are studies on the structure and organisation of forest belts, their impact on crop yields, the biodiversity of animal and plant within forest belts in comparison with the surrounding territories (Körner, 2012; O'Sullivan et al., 2013; Vitasse et al., 2014). Thus, forest belts are characterised by increased humus in the soil, as well as an increase of such elements as nitrogen, phosphorus, and potassium important for the activity of biochemical soil processes (Aidosov et al., 2019; Olson et al., 2018). Meanwhile, the impact of forest belts on agricultural crops will largely depend on their species composition, as well as stress resistance to increasing temperature. At the same time, an integrated approach is required for developing and conducting such research as determined by the relevance of the study.

An integrated approach should include long-term climate monitoring, highlighting the main trend, the selection of the most drought-tolerant trees, capable of renewal and preservation of vitality in high temperatures, considering also the main pathologies of plant species, mainly fungal and bacterial diseases, and damage caused by xylophages and phyllophages. Moreover, it is necessary to consider the leaf scorching due to high temperatures. An attempt to implement this approach was made by the authors of this work. The authors admit that high temperatures can lead to higher bacterial and fungal diseases. However, certain species of woody plants can show high resistance to these factors.

The purpose of this study is to carry out a comparative analysis of the impact of high air temperatures on different types of trees in the forest belt. The data obtained can be used as recommendations for developing forest shelterbelts.

Material and Methods

Material

The studies were carried out during May-September, 2018, in the Moscow oblast (Russian Federation). A total of 50 plots were selected with various parameters for 5224 trees. The sites were located on the three regions of the oblast, 16 in the Istrinsky, 15 in the Klinsly and 19 in the Zaraysky (Figure 1) in which 1734, 1496 and 1994 trees were examined, respectively.

At least 100 trees were examined for leaf scorching, the presence of phytopathogenic bacteria, and heat damage to the crowns at each site. A total of 17 species of trees and shrubs were examined. Data on average monthly weather conditions were taken from the Archive of actual weather data (Meteonovosti.ru, 2020).

Research Methods

The degree of leaf damage due to prolonged and constant exposure to high temperatures was visually assessed. The degree of crown damage was assessed according to the proposed scale, including 5 classes and 5 points. The changes in the crown's morphological structure, associated with drought and high air temperatures were analysed. Class 1 included trees with minor damage to the crown (from 0 to 2 points), up to 15%. Trees with more pronounced, but weak crown with damage upto 25% and from 2.1 to 3.0 points were included in class 2. Trees with moderate crown damage - up to 50% and up to 4.0 points were categorized in class 3. Class 4 was characterised by severe damage to the crown - up to 75%, and up to 4.5 points on the scale. Finally, class 5 had practically dead trees, the degree of crown damage in which reaches from 75 to 100%, or up to 5 points on a scale.

The mean damage score was calculated individually for each of the tree species, after site examination. The prevalence and frequency of infectious diseases in trees

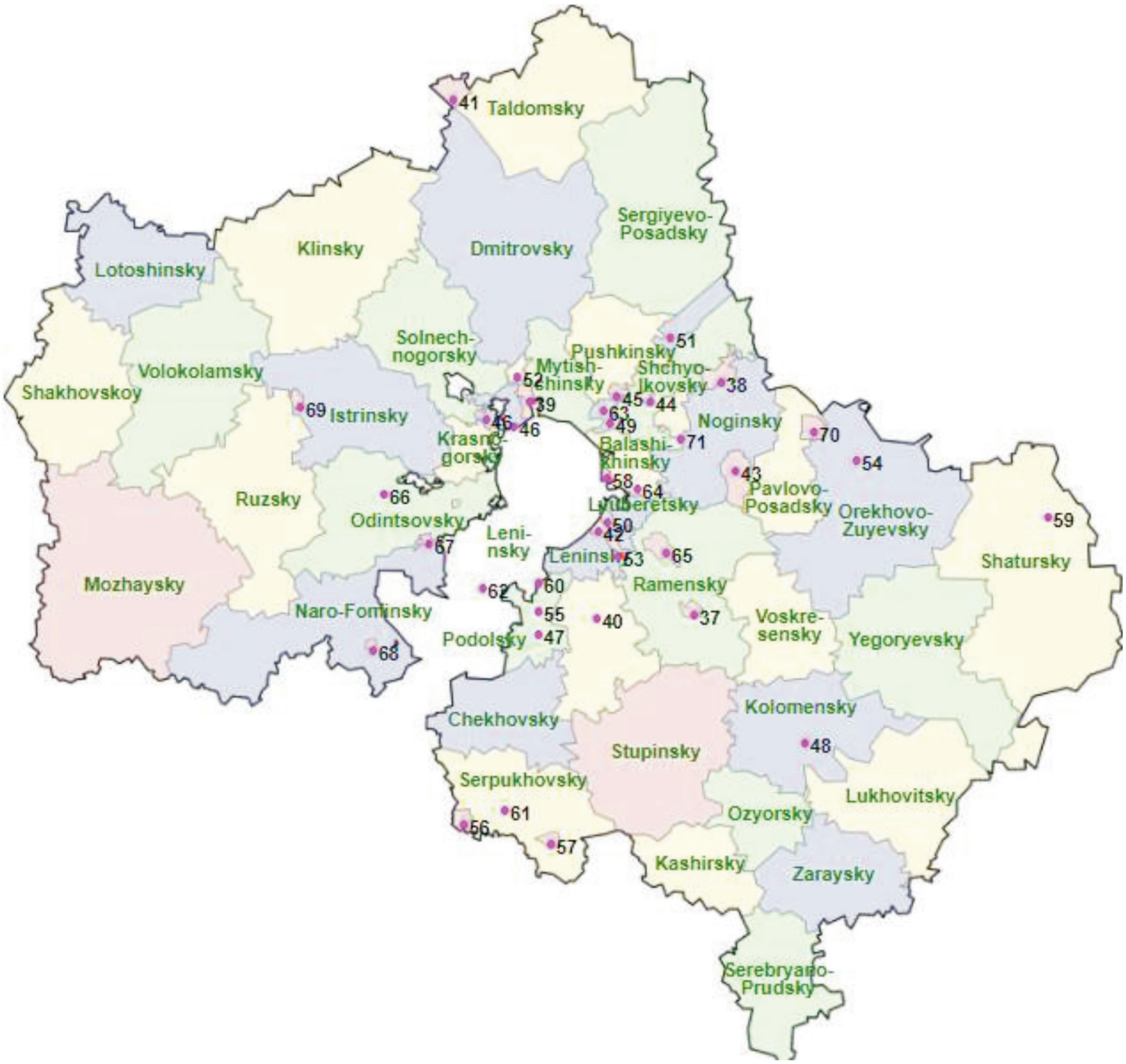

Figure 1: Map of Moscow oblast showing the location of Istrinsky, Klinsly and Zaraysky regions (Moscow map, 2020).

were assessed according to standard phytopathological methods, considering the climatological characteristics of the study region. Particularly, pathogenic bacteria were identified by sowing on nutrient media containing extracts from host plants. The microscopy was carried out to study the features of bacteria sporulation.

Statistical Analysis

Statistical processing was carried out using the Statistica v. 6.0 (StatSoft Inc., USA). The arithmetic means of the sign, the frequency of the sign (in %), as well as the reliability of differences according to the two-sample Fisher t-test for independent samples were calculated. The severity of diseases was also estimated in %. Differences were considered significant at the minimum $p \leq 0.05$. Pearson's correlation was calculated between the occurrence of phytopathogenic bacteria on trees and heat injuries to the crown, in connection with the distributions of signs close to normal. Cluster analysis by Ward's method was carried out between tree species according to the average scores of heat injuries.

Results

Climatological Data

The average values of temperature, humidity and precipitation in the Moscow oblast were approaching extreme during the research period in 2018 (Table 1).

Table 1: The average monthly temperature, humidity and precipitation in the Moscow oblast (Russian Federation) during May-September, 2018

Month	*Tempera-ture, °C*	*Humidity (in %)*	*Precipitation (in mm)*	*Number of days with precipitation*
05	19.7	55.5	1.8	7
06	22.4	44.9	0.7	6
07	25.6	37.8	0.4	6
08	27.0	42.9	0.7	5
09	18.9	50.2	1.2	7

The temperature was above normal (from 2.5 to 18.0ºC), even during the spring months (March - April), which led to the rapid germination of fungi spores parasitising plants. This was also facilitated by sufficient air humidity. The number of days with precipitation was minimal from May to the end of September, as well as the average amount of precipitation. The humidity ranged from 15 to 96% in May, then the precipitation decreased by the summer that led to a moisture deficit in the soil, an increase in tree transpiration, and leaf turgor decrease. These processes led to leaf scorching, in particular, chlorosis. Chlorosis reaches the maximum in the second half of July when the temperature is about 34.5ºC in the shade and up to 51ºC in open areas. To a somewhat lesser extent, this trend continued in August.

The average monthly temperatures from April to September steadily increased during the past years (Figure 2).

The hottest months were in 2007 (May), 2012 (June), 2011 (July), 2010 (August and September). Thus, since 2007, the region under study has experienced warming, which reached its maximum in 2018.

Trees Heat Injuries

Only chestnut was assigned to the 5th class among the studied tree species (Table 2). All trees samples of chestnut were dry or with the most damage to crown.

Birch, as well as pear and apple trees, were mostly with dry tops, classified as weakly resistant species. Most (seven tree species) were medium-resistant species with partially damaged crowns. This group includes all maple species, among which one (*A. negundo*) is invasive. Locust tree also belongs to invasive plants. Thus, invasive tree species have an average degree of resistance to heat, which may provide them with an advantage over some natural species.

The six species with a high resistance include elm, English oak, white and black poplars and ash. These trees are characterised by slight damage to crowns. The above classification generally coincides with the results of cluster analysis (Figure 3).

For cluster analysis, the average score for each tree species was calculated between three aspects. Meanwhile, a correlation coefficient of 0.99 was obtained from the average points of heat injuries in different aspects. This indicates the simultaneity of the heat injury onset between trees growing in different parts of the region, even though the cases themselves

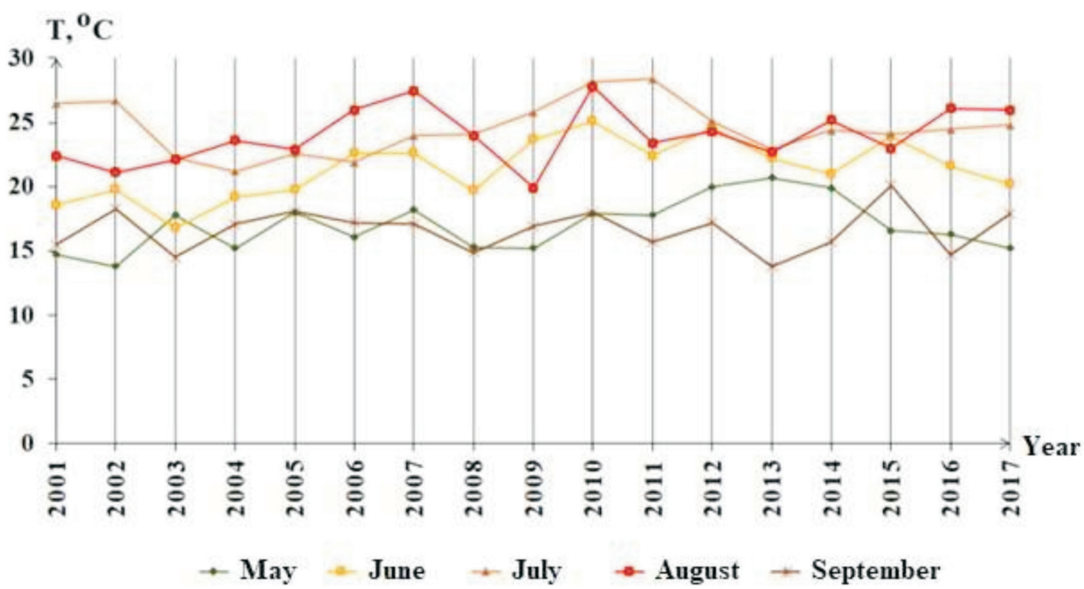

Figure 2: Average monthly temperature (in °C) during May-September, 2001-2017, in the Moscow oblast (Russian Federation).

Table 2: Heat injuries of different tree species in the examined area

Tree species	*Degree of damage, Istrinsky region (in points)*	*The same, Klinsly region*	*The same, Zaraysky region*	*Degree of resistance*
Aesculus hippocastanum	4.8	4.7	4.9	Class 5, weakly resistant
Betula pendula	4.4	4.2	4.4	Class 4, medium-resistant species
Malus sylvestris	4.2	4.1	4.3	
Pyrus pyraster	4.1	4.2	4.1	
Caragana arborescens	4.0	4.0	3.9	Class 3, species with average resistance
Acer platanoides	3.9	3.8	3.7	
A. negundo	3.7	3.7	3.7	
A. tataricum	3.5	3.4	3.3	
Robinia pseudoacacia	3.4	3.4	3.4	
Fraxinus pubescens	3.2	3.2	3.1	
Ulmus laevis	3.1	3.1	3.0	
U. pumila	2.8	2.6	2.7	Class 2, highly resistant species
Quercus robur	2.8	2.6	2.6	
Populus nigra	2.7	2.5	2.6	
Fraxinus lanceolata	2.5	2.5	2.4	
Fraxinus excelsior	2.3	2.2	2.2	
Populus alba	2.7	2.5	2.5	

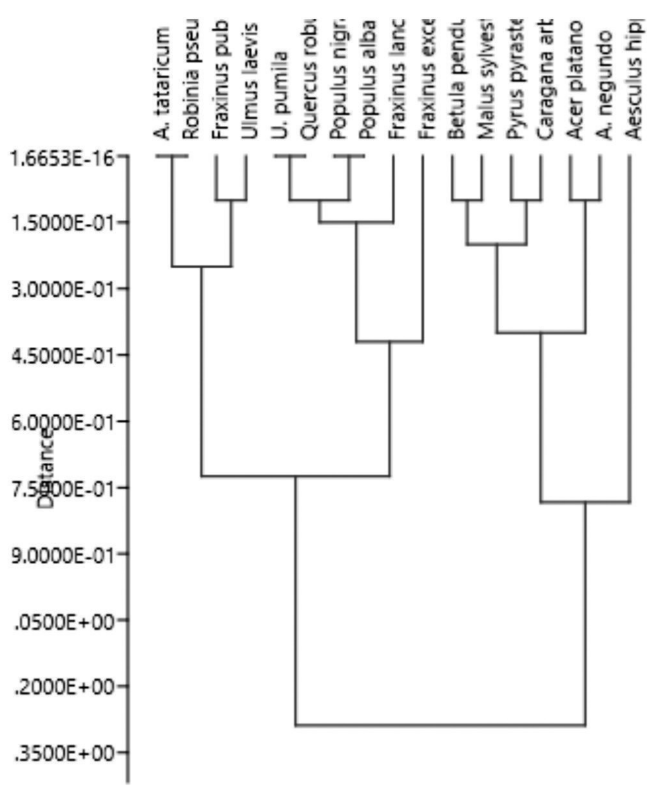

Figure 3: Cluster hierarchical analysis according to Ward's method between tree species with the damage degree.

vary. No significant differences were found for mean scores within each species between the three aspects. This also indicates the similarity of the damage processes occurring as a result of long-term exposure to high temperatures.

There are significant differences between the classes of heat damage to tree crowns. Thus, trees of class 5 are damaged slightly more than trees of class 4 (by 1.1 times, the differences are unreliable), 1.4 times more than trees of class 3 ($p \leq 0.05$), 1.9 times more than trees of class 2 ($p \leq 0.01$). There were no trees of class 1, which is uninjured one. This indicates a generally negative effect of high temperatures on trees in shelterbelts.

The high temperature is no less influenced by the leaves (Figure 4).

The maximum damage to leaves was recorded for birch, Norway maple, chestnut and American maple, to a lesser extent for oak and elm, and minimal for ash (Figure 4). Thus, trees with the damaged crown (birch, chestnut, American maple) will be characterised by insufficient photosynthesis as a result of damage to the leaves, which, can also lead to death.

Phytopathogenic Damage to Trees

The increase frequency in phytopathogenic bacteria occurrence was noted in forest plantations under prolonged exposure to high temperatures (Table 3).

Table 3: The degree of phytopathogenic infection of trees depending on the heat damage level, average for all three regions

The heat damage level, points	*Type of infection*	*Disease frequency, %*
1-3, slight damage	1	15.0 – 57.5
	2	9.0 – 16.0
	3	6.0 – 16.0
	4	19.5 – 25.0
	5	11.0 – 28.0
	6	7.0 – 28.0
	7	6.0 – 19.0
	8	2.0 – 10.0
	9	1.0 – 4.0
	10	3.5 – 19.5
3.1-5.0, severe damage	1	11.0 – 34.0
	2	8.0 – 10.0
	3	4.0 – 11.0
	4	28.5 – 35.5
	5	19.0 – 36.0
	6	18.0 – 35.5
	7	12.0 – 26.0
	8	6.0 – 15.5
	10	8.0 – 20.0
	11	6.0 – 10.0

Note: 1 - diseases caused by powdery mildew, 2 - rust on the leaves, 3 - leaf spot; 4 - tracheomycosis; 5 - graphiasis; 6 - necrosis; 7 - bacteriosis; 8 - maple wilt; 9 - endoxylin cancer; 10 - transverse cancer; 11 - the presence of tinder fungi on the trunks and branches.

In particular, an increase in the incidence of diseases affecting vascular system (tracheomycosis, graphosis, wilt) was found among trees with moderate and severe heat damage. Necrosis, bacteriosis and cancer were more common. Meanwhile, diseases associated with powdery mildew, rust and leaf spot were less common.

Trees with a strong and moderate heat damage level have a significant difference between infections with phytopathogenic bacteria (Pearson's correlation coefficient 0.89). Trees with a low level of damage have a lower coefficient (0.55). The stronger is the heat injury, the greater possibility of infecting with phytopathogenic bacteria, which can lead to the death of the plant.

Discussion

Modern science emphasises the continuity of the adaptive processes of living organisms when the environment changes (O'sullivan et al., 2017). Adaptation includes two types of reactions of organisms (including plants): nonspecific stress response and processes aimed at adapting to changes in specific abiotic factors (Bita and Gerats, 2013). Plants, including trees, are the first to have a stress response (change in turgor, defoliation, and growth arrest) (Körner, 2016). As a response, shock proteins and enzymes are formed in the plant, which mobilise the body's defenses (Nievola et al., 2017). However, such a reaction cannot provide long-term protection from adverse environmental conditions (Moles et al., 2014).

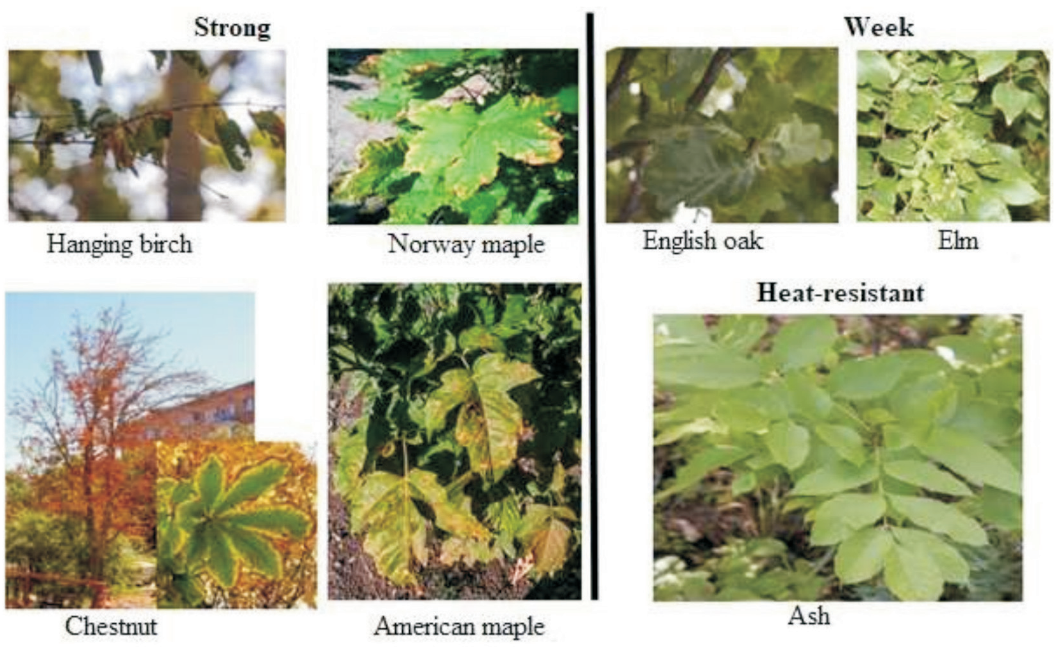

Figure 4: The degree of heat damage to leaves in different tree species.

The latter also includes long-term exposure to high temperatures and low humidity, according to our study. Initially, the plant species of classes 4 and 5 have an insufficient stress response that lead to an irreversible damage process. The prolonged exposure to high temperatures leads to dehydration, vascular system disorders, leaf scorching, destruction of chlorophyll, and a change in the rate of biochemical cellular processes (Timoshin et al., 2018; Wright et al., 2017). Exposure to air temperatures above 35-40ºC in the shade and up to 50ºC in open areas leads to leaf fall, the death of branches on the crowns and drying out (Bjorkman et al., 2018; Michaletz et al., 2015, 2016).

Conclusion

All the trees can be divided into four classes according to adaptive potential extreme conditions as per the study in 17 tree species. The least resistant species, chestnut belongs to the 5th class where all trees were completely damaged. Class 4 includes three species of heavily damaged trees while in class 3, trees with an average level of resistance, include seven species, three of which are representatives of the Maple genus. Class 2, trees with a pronounced resistance, is represented by six species, namely oak, elm, ash and poplar. Despite the pronounced resistance of class 2, all the trees, except ash, had chlorosis and leaf necrosis caused by prolonged heat exposure. Wilt disease, necrosis and cancer prevailed among the pathologies. There is a connection between pathologies and heat injuries in trees from classes 4 and 5 (correlation 0.89). The correlation is less pronounced (0.55) for trees with less damage (classes 2 and 3). Thus, when developing forest shelterbelts, considering aridification in local regions, the following tree genera can be chosen as the most resistant: *Fraxinus, Quercus, Ulmus*, and *Populus*.

Acknowledgements

The work of Volkova I. was within the framework of the state ordered research theme of the Institute of Geography RAS, no. 0148-2019-0008 (AAAA-A19-119022190170-1) “Problems and prospects of Russia’s territorial development in terms of its unevenness and global instability”.

References

Aidosov, A., Aidosov, G., Zaurbekov, N., Zaurbekova, N., Zaurbekova, G. and I. Zaurbekov (2019). Mathematical modelling of atmospheric pollution in an industrial region with a view to design an information system software for ecological situation. *Ekoloji*, **28(107):** 349-358.

Akatov, P.V. (2016). Global warming and its regional consequences for the European part of Russia. *Living and Bioinert System*, **15:** 14-22.

Bennett, J.M., Calosi, P., Clusella-Trullas, S., Martínez, B., Sunday, J., Algar, A.C. ... and C. Rahbek (2018). GlobTherm, a global database on thermal tolerances for aquatic and terrestrial organisms. *Scientific Data*, **5:** 180022.

Bita, C. and T. Gerats (2013). Plant tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in Plant Science*, **4:** 273.

Bjorkman, A.D., Myers-Smith, I.H., Elmendorf, S.C., Normand, S., Rüger, N., Beck, P.S. ... and D. Georges (2018). Plant functional trait change across a warming tundra biome. *Nature*, **562(7725):** 57-62.

Dukes, J.S., Pontius, J., Orwig, D., Garnas, J.R., Rodgers, V.L., Brazee, N. ... and J. Ehrenfeld (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research*, **39(2):** 231-248.

Garrett, K.A., Forbes, G.A., Savary, S., Skelsey, P., Sparks, A.H., Valdivia, C. ... and H. Eckersten (2011). Complexity in climate-change impacts: An analytical framework for effects mediated by plant disease. *Plant Pathology*, **60(1):** 15-30.

Grigorieva, S.O., Konstantinov, A.V. and I.M. Shkolnik (2016). Influence of climate changes on the composition of forest stands, their stability and areas of the main forest-forming species. *In:* Proceedings of the St. Petersburg Scientific Research Institute of Forestry, **3:** 21.

Jespersen, D. (2020). Heat shock induced stress tolerance in plants: Physiological, biochemical, and molecular mechanisms of acquired tolerance. *In:* Priming-Mediated Stress and Cross-Stress Tolerance in Crop Plants (pp. 161-174). Academic Press.

Körner, C. (2012). Treelines will be understood once the functional difference between a tree and a shrub is. *Ambio*, **41(3):** 197-206.

Körner, C. (2016). Plant adaptation to cold climates. *F1000 Research*, 5.

Kravets, M.V., Bartenev, I.I., Gavrin, D.S. and S.P. Borzenkov (2016). Global warming and peculiarities of climate change in the Central Black Earth region. Actual problems of modern agricultural sciences, **3:** 18-20.

Llorens, E., González-Hernández, A.I., Scalschi, L., Fernández-Crespo, E., Camañes, G., Vicedo, B. and P. García-Agustín (2020). Priming mediated stress and cross-stress tolerance in plants: Concepts and opportunities. *In:* Priming-Mediated Stress and Cross-Stress Tolerance in Crop Plants, pp. 1-20. Academic Press.

Meteonovosti.ru (2020). Retrieved from http://www.hmn.ru/index.php?index=16&value=27612

Michaletz, S.T., Weiser, M.D., McDowell, N.G., Zhou, J., Kaspari, M., Helliker, B.R. and B.J. Enquist (2016). The energetic and carbon economic origins of leaf thermoregulation. *Nature Plants*, **2(9):** 16129.

Michaletz, S.T., Weiser, M.D., Zhou, J., Kaspari, M., Helliker, B.R. and B.J. Enquist (2015). Plant thermoregulation: energetics, trait–environment interactions, and carbon economics. *Trends in Ecology & Evolution*, **30(12):** 714-724.

Moles, A.T., Perkins, S.E., Laffan, S.W., Flores-Moreno, H., Awasthy, M., Tindall, M.L. ... and M. Anand (2014). Which is a better predictor of plant traits: Temperature or precipitation? *Journal of Vegetation Science*, **25(5):** 1167-1180.

Moscow map (2020). Districts of the Moscow regionю Retrieved from http://moskva-map.ru/mo-rajony.htm

Nievola, C.C., Carvalho, C.P., Carvalho, V. and E. Rodrigues (2017). Rapid responses of plants to temperature changes. *Temperature*, **4(4):** 371-405.

Olson, M.E., Soriano, D., Rosell, J.A., Anfodillo, T., Donoghue, M.J., Edwards, E.J. ... and A. Echeverría (2018). Plant height and hydraulic vulnerability to drought and cold. *Proceedings of the National Academy of Sciences*, **115(29):** 7551-7556.

O'sullivan, O.S., Heskel, M.A., Reich, P.B., Tjoelker, M.G., Weerasinghe, L.K., Penillard, A. ... and N.H. Bahar (2017). Thermal limits of leaf metabolism across biomes. *Global Change Biology*, **23(1):** 209-223.

O'sullivan, O.S., Weerasinghe, K.L.K., Evans, J.R., Egerton, J.J., Tjoelker, M.G. and O.K. Atkin (2013). High-resolution temperature responses of leaf respiration in snow gum (*Eucalyptus pauciflora*) reveal high-temperature limits to respiratory function. *Plant, Cell & Environment*, **36(7):** 1268-1284.

Parvathi, M.S., Dhanyalakshmi, K.H. and N.K. Nataraja (2020). Molecular mechanisms associated with drought and heat tolerance in plants and options for crop improvement for combined stress tolerance. *In:* Agronomic Crops, pp. 481-502. Springer, Singapore.

Safonov, V. (2020). Assessment of heavy metals in milk produced by Black-and-White Holstein cows from Moscow. *Current Research in Nutrition and Food Science Journal*, **8(2):** 410-415.

Timoshin, A.V., Sevbitov, A.V., Drobot, G.V., Yumashev, A.V. and M.D. Timoshina (2018). Use of bioresorbable plates on the basis of collagen and digestase for treatment of diseases of oral mucosa (review of clinical cases). *International Journal of Green Pharmacy*, **12(S1):** 290-296.

Vitasse, Y., Lenz, A. and C. Körner (2014). The interaction between freezing tolerance and phenology in temperate deciduous trees. *Frontiers in Plant Science*, **5:** 541.

Volodchenkova, L.A. (2010). Crisis ecological situations in the evolution of forest biocenosis [Crisis Ecological Situations in Forest Biocenosis Evolution]. *In:* III All-Russian Scientific-Practical Conference "Biological Systems: Stability, Principles and Mechanisms of Functioning", pp. 137-139. Nizhniy Tagil: NTGSPA.

Wright, I.J., Dong, N., Maire, V., Prentice, I.C., Westoby, M., Díaz, S. ... and M.R. Leishman (2017). Global climatic drivers of leaf size. *Science*, **357(6354):** 917-921.

Zolotukhin, A.I. (2015). Adaptation of woody plants after heat stress. Bulletin of the Saratov University. New series. Chemistry series. Biology. *Ecology*, **1(1):** 93-98.