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RESILIENCE OF URBAN TREES TO EXTREME WEATHER IN BUCHAREST, ROMANIA

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Abstract

In the last years, Europe has experienced extreme weather conditions with significant impact on vegetation. Extremely warm summers and poor rainfall in all seasons transformed Bucharest (Romania) into one of the hottest and driest cities in Europe. In this research, more than 190 trees species, hybrids and cultivars present in the green spaces of University of Agronomical Sciences and Veterinary Medicine Bucharest were investigated for their resistance to extreme weather. The results showed that trees from 24% of the existent species, hybrids and cultivars were affected and lost in the last two years. Over 55% of the dead trees were native species. In 2024, when summer temperatures exceeded 35ºC for 28 days, all of the lost trees were placed in areas without irrigation. Monitoring tree under extreme weather conditions can provide essential information for resilient plantations and sustain biodiversity in cities.

Key words: *drought, heatwaves, native and non-native species, resistance.*

INTRODUCTION

Urbanization was proved to be close linked to climate change (Chapman et al., 2017; Khosia & Bhardwaj, 2019; Sarvari, 2019; Xu et al., 2021). Yet, it has been found that thermal comfort in cities is getting worse and extreme events are occurring mainly due to climate change and less due to increased urbanization (Argüeso et al., 2014; Oleson et al., 2015; Ren et al., 2022). Green areas play a key role in ensuring thermal comfort in cities. The cooling effect of vegetation is greater during summer than winter (Hamada & Ohta, 2010). Also, the cooling effect depend on the size of green areas (Aram et al., 2019) and their design and composition (Jaganmohan et al., 2016; Wu et al., 2021; Gallay et al., 2023). For this reason, green areas in cities are now critically needed in the fight against climate threats. Appropriate green areas can solve not only thermal comfort of the urban population but also limiting the flood risks (Kim et al., 2016; Zimmermann et al., 2016; Green et al., 2021; Zia et al., 2022), reduce winds velocity (Rafael et al., 2018; Feitosa et al., 2021) or the impact of air pollutants (De la Sota et al., 2019). In this context, cities need more green areas but in recent years, heatwaves and droughts, two major events associated with climate change, have affected more frequently woody species (Marchin et al, 2022; Wang et al., 2023). Tree species are impacted differently by these events. Symptoms can vary from leaf damage to tree death, depending on the species (Teskey et al., 2015; Percival, 2023), age (Lucas-Borja et al, 2021; Haase & Hellwig, 2022), phenophase (Geng et al., 2022) and duration of exposure (Teskey et al., 2015; Kunert et al., 2022). In Central European cities, for species such as *Acer platanoides*, *Tilia cordata* and *Quercus robur*, drought stress caused a significant negative response in terms of trees growth, but not for *Robinia pseudoacacia* and *Platanus* x *acerifolia* (Dervishi et al., 2022; Franceschi et al., 2023). Some species have ability to recover fast after the drought event, such as *Aesculus hippocastanum*, *Quercus nigra*, *Acer campestre* and *Tilia tomentosa* (Stratópoulos et al., 2019; Dervishi et al., 2022).

Extreme high temperatures over a prolonged period often combine with drought to impact trees. Marchin et al. (2022) showed that in urban conditions, heat stress presents a greater risk to tree survival than drought stress. However, in green areas without irrigation, trees death can occur faster when these two stress events are combined (Percival, 2023). A recent study about the future intensity of heat in European cities estimated that the greatest increase is expected in Central Europe, but also in South-East

Europe, in cities such as Bucharest and Sofia (Smid et al., 2019). Bucharest is also known as a city located in a region frequently affected by drought (Mihailescu et al., 2009; Grigorescu et al., 2021). In episodes of severe drought, the law imposes water preservation and green areas are the first deprived of water.
For these reasons, studies about impact of extreme weather on tree species are very important for the future green spaces. The aim of this study was to identify resistant and sensitive species to heatwaves and drought, for future more resilient plantations and to sustain biodiversity in cities.

MATERIALS AND METHODS

The studies were conducted between 2022 and 2024 at the University of Agronomic Sciences and Veterinary Medicine of Bucharest (USAMV), Romania (44°24'N, 26°05'E). Climate of Bucharest is temperate continental with hot and dry summers, followed by cold and humid winters. In 2023 and 2024, Bucharest was listed among the hottest and driest cities of Europe and with the warmest summer on record (NMA, 2025), exceeding 39ºC for a week in July 2024 (Figure 2). Therefore, in order to assess the impact of extreme weather on the tree species, data recorded in 2022 were taken as reference for comparison.
Campus university where the investigations were carried out is located in the northern part of the city and cover an area of 38 ha (Figure 1).

Figure 1. Map of the USAMV campus

Various categories of green areas of campus, such as Dendrological Park, Botanical Garden, those around buildings, green parking lots and circulation paths, include over 4700 specimens of ornamental trees and shrubs. At the beginning of 2022, a total of 2891 trees from 115 species, 73 cultivars and 6 hybrids grew in the campus' green areas. This diversity of trees from 27 botanical families has been maintained without irrigation in most of the area, except for those covered with lawn. For the present study, trees in these areas were excluded.
During study, the dead trees were recorded annually at the end of vegetation period in terms of species, dimensions (height and DBH at 1 m) and the area in which they grew.
Chi-squared tests were applied to compare native vs. non-native species and conifers vs. broadleaves affected by extreme weather. Also, differences between conifer and broadleaf cultivars were examined with Chi-squared test. Data on the origin and type of dead trees species (conifers or broadleaves) in the reference year 2022 and the extreme weather years, 2023 and 2024, were statistically analysed using one-way ANOVA test and significance of the difference among means was estimated with LSD (Least Significant Difference) Post Hoc Test at 5% level of significance. Data on the size (height and dbh) of dead trees in the reference year 2022 and the extreme weather years 2023 and 2024, were examined by F-test at $p<0.05$.

RESULTS AND DISCUSSIONS

The extreme weather has had an important impact on trees. During the three years of observations, more than 30% of species, 10% of cultivars and 30% of hybrids were affected by heatwaves and drought (Table 1).

Table 1. Dead trees by plant taxonomy and number

	Total no. in campus	Dead trees			Total of dead trees
		Year 2022	Year 2023	Year 2024	
Species	115	7	23	26	
No of trees	2221	13	62	86	161
Cultivars	73	0	4	5	
No of trees	397	0	4	9	13
Hybrids	6	0	1	2	
No of trees	272	0	1	11	12

Compared to the reference year 2022, in which no extreme weather events were recorded, it was observed a tripling of the number of species, from 7 species, to a total of 36 species affected by extreme weather in 2023 and 2024. Annual losses were observed in four species: *Acer platanoides*, *Juglans regia*, *Prunus cerasifera* and *Tilia platyphyllos*, including in the reference year 2022 (Table 2). However, for these species, the number of dead trees also increased in 2023 and 2024.

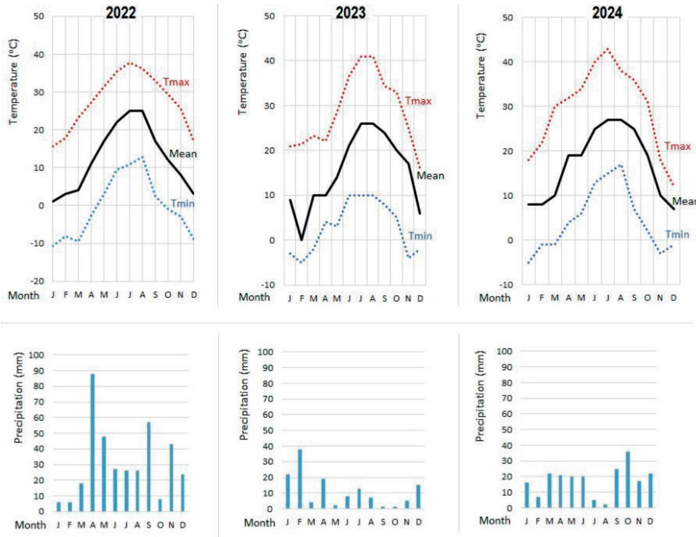

Figure 2. Mean monthly temperatures and precipitations during studied period (2022-2024)

Table 2. Species affected by extreme weather

Scientific name	Percent of dead trees (from total no. in campus) Year 2022	Year 2023	Year 2024
Conifers			
Abies lasiocarpa	-	-	100
Chamaecyparis lawsoniana	-	16.7	50.0
Picea abies	-	7.7	-
Pinus nigra	-	1.2	2.3
Pinus strobus	-	5.3	10.5
Pinus sylvestris	-	11.1	-
Pseudotsuga menziesii	12.5	-	50.0
Taxus baccata	-	-	13.6
Thuja occidentalis	2.7	-	-
Thuja plicata	-	-	6.2
Broadleaves			
Acer campestre	-	6.5	7.8
Acer negundo	-	-	8.3
Acer platanoides	0.6	1.3	5.7
Acer pseudoplatanus	-	5.3	5.2
Acer tataricum	-	-	4.3
Aesculus hippocastanum	-	-	40.0
Ailanthus altissima	-	1.9	16.7
Carpinus betulus	-	-	1.8
Castanea sativa	-	-	25.0
Catalpa speciosa	-	-	20.0
Celtis occidentalis	-	4.3	7.5
Fagus sylvatica	-	-	100
Fraxinus excelsior	-	4.0	3.0
Gleditsia triacanthos	-	2.7	-
Juglans regia	4.6	6.4	6.4
Malus baccata	-	7.7	-
Morus alba	-	-	8.3
Phellodendron amurense	-	100	-
Populus nigra	-	5.9	-
Prunus avium	-	8.3	-
Prunus cerasifera	0.9	7.0	2.6
Quercus rubra	0.7	1.3	-
Robinia pseudoacacia	-	-	2.6
Scandosorbus intermedia	-	100	-
Tilia platyphyllos	3.0	1.0	1.0
Tilia cordata	-	100	-
Ulmus minor	-	13.3	6.7

Extreme weather killed all trees of *Abies lasiocarpa*, *Fagus sylvatica*, *Phellodendron amurense*, *Scandosorbus intermedia* and *Tilia cordata* and more than 50% of *Chamaecyparis lawsoniana* and *Pseudotsuga menziesii*. Important tree losses associated with drought and hot temperatures were recorded in other 13 species: 40% in *Aesculus hippocastanum*; 25% in *Castanea sativa*; 20% in *Catalpa speciosa*; 20.0% in *Ulmus minor*; 18.6% in *Ailanthus altissima*; 17.4% in *Juglans regia*; 15.8% in *Pinus strobus*; 14.3% in *Acer campestre*; 13.6% in *Taxus baccata*; 11.8% in *Celtis occidentalis*; 11.1% in *Pinus sylvestris*; 10.5% in *Acer pseudoplatanus* and 10.5% in *Prunus cerasifera*. This also had an important impact on the campus green areas, with a total tree loss of 6.84% in years with extreme weather, compared to 0.57% in the reference year 2022.

The loss of non-native tree species was significantly lower than that of native species (Figure 3) in years with extreme weather ($\chi^2 = 17.175$; $p = 0.0003$). More than half of these are native to North America (Figure 4).

Most of the lost native species are known in Romania as highly adaptable to various temperatures and precipitations regimes. However, native species may be more vulnerable in urban conditions than in their natural habitat (Roloff et al., 2009; Stratópoulos et al., 2019). On the other hand, some non-native species have proved high plasticity that allows them to adapt to a range of conditions, other than those in their natural habitat (Sjöman et al., 2016; Kendal et al., 2018; Schlaepfer et al., 2020).

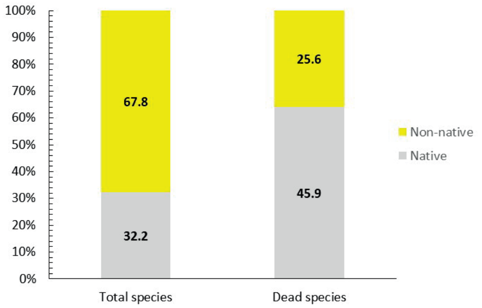

Figure 3. Differences between the loss of native and non-native species from total species

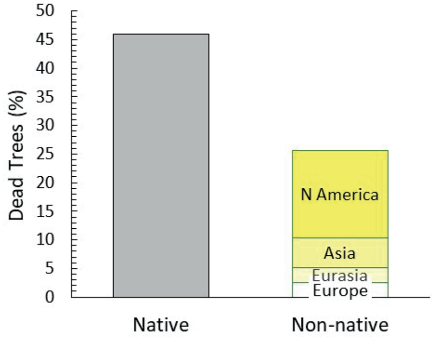

Figure 4. Share of lost species, by their origin

In urban conditions, Esperon-Rodriguez et al. (2021) observed that heatwaves have less impact on native trees species than non-native species. Comparing 806 woody species, Niinemets & Valladares (2006) reported that non-native species have better resistance to drought than native ones. However, trees vulnerability to dieback in extreme weather conditions may be influenced by factors other than genetic resistance of the species, such as: soil type (Karimian et al., 2020; Dervishi et al., 2022; Haase & Hellwig, 2022) or type of plantations (Vogt et al., 2017).

In terms of number of dead trees, significant differences (LSD = 2.33; $p = 0.043$) were observed between native and non-native species lost in extreme weather years, compared to the reference year 2022 (Figure 5). However, there were no significant differences between the two years with extreme weather (2023 and 2024).

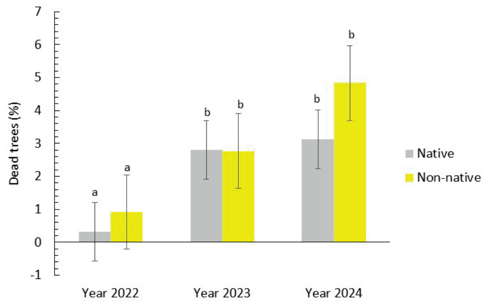

Figure 5. Differences between the loss of native and non-native species in the reference year 2022 and the extreme weather years, 2023 and 2024 (Error bars indicate SE. Data with the same letter are not statistically different at p<.05)

Tree mortality was significantly different ($\chi^2 = 21.948$; $p = 0.00001$) between conifers and broadleaves species (Figure 6).

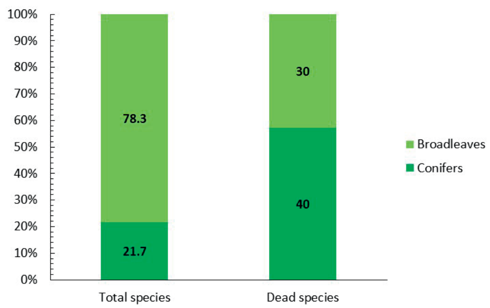

Figure 6. Differences between the loss of conifers and broadleaves species from total species

Also, the number of individuals lost in years with extreme weather was significantly higher (LSD = 9.65; $p = 0.020$) in conifers species compared to broadleaves ones (Figure 7).

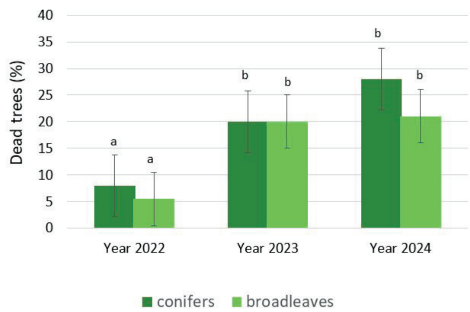

Figure 7. Differences between the loss of conifers and broadleaves species in the reference year 2022 and the extreme weather years, 2023 and 2024 (Error bars indicate SE. Data with the same letter are not statistically different at p<.05)

Some of the cultivars of species were also affected in the years with extreme weather (Table 3).

Table 3. Cultivars and hybrids affected by extreme weather

Scientific name	Percent of dead trees (from total no. in campus)		
	Year 2022	Year 2023	Year 2024
Acer pseudoplatanus 'Erythrocarpum'	-	100	-
Cedrus deodara 'Pendula'	-	-	50
Chamaecyparis lawsoniana 'Ivonne'	-	-	100
Picea pungens 'Argentea'	-	7.2	7.2
Populus nigra 'Italica'	-	-	50
Prunus cerasifera 'Pissardii'	-	3.7	-
Taxus baccata 'Overeyenderi'	-	100	-
Tilia x *europaea*	-	1.7	17.0
Ulmus x *hollandica*	-	-	100

Cultivars such as *Acer pseudoplatanus* 'Erythrocarpum', *Chamaecyparis lawsoniana* 'Ivonne' and *Taxus baccata* 'Overeyenderi' were completely lost. It was remarked that among cultivars of some were vulnerable to drought and heatwaves, while others were not. Consequently, tree cultivars such as: *Cedrus deodara* 'Pendula', *Chamaecyparis lawsoniana* 'Ivonne', *Prunus cerasifera* 'Pissardii' and *Taxus baccata* 'Overeyenderi' suffered losses, while *Cedrus deodara* 'Aurea', *Chamaecyparis lawsoniana* 'Columnaris', *Prunus cerasifera* 'Nigra' and *Taxus baccata* 'Fastigiata', did not.
Also, the cultivar *Picea pungens* 'Argentea' was found susceptible, with a tree mortality of 3,7%, but the other two cultivars, *Picea pungens* 'Glauca', *Picea pungens* 'Hoopsii' or the species *Picea pungens*, were not.
Differences between cultivars resistance have also been reported by other authors. Assessing the drought tolerance of both *Acer saccharum* and *Acer rubrum* cultivars, Sjöman et al. (2015) noted variation among them.
In another research of the drought response of five cultivars of *Spiraea japonica*, Sjöman et al. (2023) observed that cultivar *Spiraea japonica* 'Little Princess' was the most vulnerable and *Spiraea japonica* 'Superstar', the most tolerant, as was the wild-type.
The difference between the mortality of conifers cultivars (6.5%) and broadleaves cultivars (8.9%) was not significant ($\chi^2 = 1.251$; $p = 0.263$).
Regarding hybrids, it was observed that the impact of extreme weather affected 30% of them and 4.4% from the total individuals. Trees of *Ulmus* x *hollandica* were completely lost. Vulnerability of this hybrid to prolonged drought was also reported by Nitschke et al. (2017).
Larger trees were more affected by extreme weather. For 59.3% species, dead trees were taller than those alive (Figure 8).

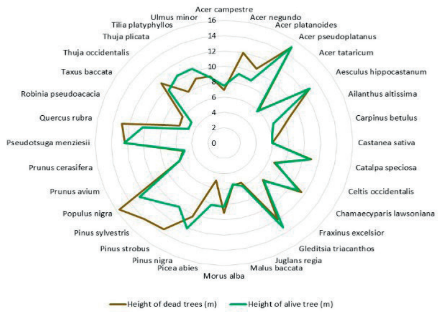

Figure 8. Comparison between mean height of dead and alive trees

Also, for the most of vulnerable species (71.8%), dead trees had a higher dbh than living trees (Figure 9).

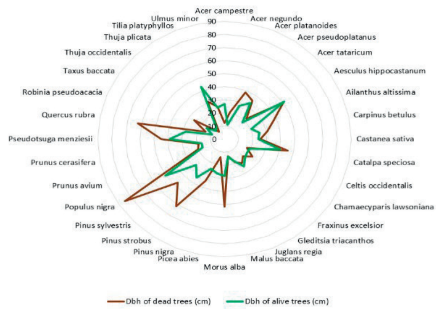

Figure 9. Comparison between mean dbh of dead and alive trees

Most of the individuals lost in extreme weather years were big size trees in some species such as: *Acer platanoides*, *Catalpa speciosa*, *Chamaecyparis lawsoniana*, *Morus alba*, *Pinus strobus*, *Populus nigra*, *Quercus rubra* and *Taxus baccata*. Also, young trees have been lost in some species such as: *Acer campestre*, *Picea abies*, *Tilia platyphyllos* and *Thuja plicata*.
Significant differences were found between the height ($F = 3.327$, $p = 0.008$) and dbh ($F= 2.361$, $p = 0.045$) of dead trees in the reference year 2022, compared to the extreme weather years, 2023 and 2024.

Studying the damages induced by heatwave-compounded drought events on 35 tree species in peri-urban forests of central Europe, Lyu and Saha (2023) showed that crown dieback is size dependent. More vulnerable in dry and hot climates were found small trees, which require more attention. Although the sensitivity of younger trees to drought episodes is higher, they tend to recover faster comparing with older trees (Au et al., 2022). In urban conditions, trees accumulate different stresses, such as improper soil conditions, air pollution or inadequate light conditions (Czaja et al., 2020). Different studies on urban trees have revealed three main factors for their mortality: species, size or age and site characteristics (Hilbert et al., 2019). In our study, drought and heatwave affected tree species of diverse sizes differently, but mainly older trees for most of them. Haase & Hellwig (2022) studying the effects of extreme weather on street trees in Germany, also reported a significant risk of mortality of older trees and newly planted trees.

In 2024, when summer temperatures exceeded 35ºC for 28 days, all individuals of some species placed in areas without irrigation were able to tolerate the hot drought without any damage (Table 4). These represent 47.8% of the total species on campus. Most of them (69.6%) are non-native species, of various sizes/ages.

These species must be investigated more in the future, to understand their ability to cope with extreme weather events

Table 4. Tree species not affected by extreme weather

Scientific name	Origin	Age range (years)
Conifers		
Abies alba	native	10-80
Abies concolor	N America	12-80
Abies nordmanniana	Eurasia	14-80
Hesperocyparis arizonica	N America	10-20
Juniperus virginiana	N America	15-70
Picea pungens	N America	12-60
Pinus ponderosa	N America	10-70
Pinus wallichiana	Asia	10-30
Platycladus orientalis	Asia	12-60
Broadleaves		
Acer buergerianum	Asia	20-40
Acer rubrum	N America	7-30
Acer ginnala	Asia	7-50
Albizia julibrissin	Asia	10-40
Betula pendula	native	8-50
Catalpa bignonioides	N America	10-80
Catalpa ovata	Asia	12-60
Celtis australis	native	10-70
Cercis canadensis	N America	10-50
Cercis siliquastrum	Eurasia	10-50
Corylus colurna	native	12-60
Crataegus monogyna	native	7-50
Diospyros virginiana	N America	10-40
Elaeagnus angustifolia	Asia	14-35
Eucommia ulmoides	Asia	20-50
Ficus carica	Eurasia	5-20
Fraxinus americana	N America	12-60
Fraxinus angustifolia	native	10-60
Fraxinus ornus	native	10-60
Fraxinus pennsylvanica	N America	12-50
Juglans nigra	N America	10-60
Koelreuteria paniculata	Asia	10-40
Liquidambar styraciflua	N America	8-20
Liriodendron tulipifera	N America	10-50
Maclura pomifera	N America	10-50
Magnolia kobus	Asia	7-40
Malus floribunda	Asia	10-50
Malus sylvestris	native	8-60
Morus nigra	Asia	10-60
Parrotia persica	Asia	7-40
Paulownia tomentosa	Asia	7-60
Populus alba	native	10-50
Prunus mahaleb	native	10-35
Prunus padus	native	7-30
Prunus serotina	N America	10-30
Pyrus piraster	native	10-50
Quercus cerris	native	10-80
Quercus coccinea	N America	10-30
Quercus palustris	N America	10-30
Quercus robur	native	10-80
Robinia hispida	N America	7-30
Styyphnolobium japonicum	Asia	10-60
Tilia americana	N America	10-50
Tilia tomentosa	native	7-80
Ulmus laevis	native	10-60
Ulmus pumila	Asia	7-70

CONCLUSIONS

In recent years, episodes of heatwave combined with drought have significantly affected trees in green areas of campus.

Native trees, previously considered highly adaptable to various weather conditions and therefore recommended for massive plantations, have proven vulnerable in current weather conditions.

Non-native species showed a better resistance to extreme weather.

Tree mortality was associated with their larger size in most species, possibly due to their lower ability to recover after drought events compared to younger trees.

The study also highlighted some conifer and broadleaved species that have proven good resilience to extreme weather.

Monitoring tree plantations can provide essential information about species resilience, but future research will need to consider also other factors such as species association, plantations composition, size, density and management, that could improve plants tolerance to extreme weather and longevity of plantations.

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