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I. M. KOVAL[1, 2], DSc (Agriculture), Senior Researcher
[1]Leading Researcher, of the Forest Ecology Sector, Department of Forestry and Forest Economics
[2]Professor, Department of Environmental Monitoring and Protected Areas Management
e-email: Koval_Iryna@ukr.net ORCID ID: https://orcid.org/0000-0001-6328-1418
[1]*Ukrainian Research Institute of Forestry and Agroforestry Reclamation named after G M. Vysotsky*
86 Hryhoriy Skovorody St., Kharkiv, 61024, Ukraine
[2]*V. N. Karazin Kharkiv National University*
4, Svobody Sq., Kharkiv, 61022, Ukraine

M. O. CHERMNYKH,
Bachelor of the Karazin Institute of Environmental Sciences
e-email: chermnykh2021.9512117@student.karazin.ua ORCID ID: https://orcid.org/0009-0008-5346-8551
V. N. Karazin Kharkiv National University
4, Svobody Sq., Kharkiv, 61022, Ukraine

V. V. GOLOLOBOV,
Postgraduate Student of the Department of Environmental Monitoring and Protected Areas Management
e-mail: vadim.gololobov@gmail.com ORCID ID: https://orcid.org/0009-0009-0086-0303
V. N. Karazin Kharkiv National University
4, Svobody Sq., Kharkiv, 61022, Ukraine

RADIAL GROWTH OF COMMON HORSE CHESTNUT IN GREEN PLANTINGS OF LVIV AND KHARKIV

Purpose. to identify the consequences of climate change and the invasion of the horse chestnut leaf miner on the radial growth of horse chestnut in green plantings of the cities of Lviv and Kharkiv.

Methods. System analysis, dendrochronological and statistical methods were used.

Results. The radial growth of trees in middle-aged plantings was compared for the period before the outbreak of the horse chestnut leaf miner (1982-2001) and after it (2002-2021) for Lviv and for 1990-2006 and 2007-2023 for Kharkiv. The temperatures for the hydrological year for these periods were also compared according to data from the Lviv and Kharkiv weather stations. It was found that in the second period Kharkiv was a decrease in growth by 57%. For the first period (before the outbreak), deviations from the norm of radial growth of common horse chestnut in the green plantation of Lviv were 12-23%, the corresponding values for the second period – 17-72%. It was found that in the second period in the Lviv plantation, the influence of temperatures on the radial growth of horse chestnut, in general, became more positive for different periods of the hydrological year. The number of positive correlation coefficients between radial growth and climatic factors also increased, which indicates an increase in the sensitivity of trees. In the green plantation of Kharkiv, when comparing the influence of climate on the radial growth of horse chestnut in 1986-2004, and 2005-2022 it was found that precipitation had a positive effect on growth, unlike temperature, which had a negative effect on radial growth. This is characteristic of both periods.

Conclusions. When comparing the radial growth of horse chestnut for the periods before the beginning of the chestnut miner invasion (1982-2001) and after it (2002-2021) in Lviv and, respectively, for Kharkiv for 1986-2004 and 2005-2023, the decrease in growth was half as much in the second period compared to the first, despite the fact that the chestnut leaf miner arrived in Kharkiv 5 years later than in Lviv. Despite the significant decrease in radial growth due to climate change and the impact of the chestnut miner invasion, the radial growth of horse chestnut in the Lviv plantation stabilized during 2017–2021 and in the Kharkiv plantation – during 2016–2023. This indicates the adaptation of the horse chestnut to environmental changes at this stage.

KEYWORDS: *Aesculus hippocastanum* L., *radial growth of tree, precipitation, temperatures, invasion, Cameraria ohridella Deschka & Dimic 1986*

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Introduction

Horse chestnut (*Aesculus hippocastanum* L.) is an important part of urban green plantings. In order to establish the ability of horse chestnut to adapt to climate change and the impact of the chestnut leaf borer (*Cameraria ohridella* Deschka & Dimic (*Lepidoptera: Gracillariidae*) invasion, it is necessary to conduct studies of the radial growth of trees, which is a measure of cambial activity and indicates the state of the tree and depends on the influence of environmental conditions. These relationships can change with the age of the tree, as well as with changes in climatic conditions. In dendroclimatic studies, two main climatic elements are most often considered – air temperature and precipitation [1-6]. Using measurements of the width of annual rings, it is possible to assess the response of individual tree species in urban green plantings to climatic factors at the present time, as well as in the past [7].

The chestnut leaf miner crossed the border of Ukraine in 1998, appeared in Lviv in 2002, and reached Kharkiv in 2007 [8-11]. The global temperature of the Earth has already increased by 0.8 °C compared to the pre-industrial period, which has led to numerous problems - mass outbreaks of pests, increased weather variability, increased frequency of heat waves, floods, fires in ecosystems, water shortages, changes in precipitation patterns, etc. [1, 12-15].

The first invasion of the chestnut leaf miner was recorded in Europe in 1984 in the area of Lake Ohrid in Macedonia. This pest species has spread to most European countries, migrating at a speed of approximately 60 km/year. In Poland, this species was first recorded in 1998 near Wrocław. In 1998, the chestnut leaf miner crossed the border from the Hungarian side, so its first foci were recorded in Transcarpathia, and in 2002 in Lviv [12, 16, 17,]. The caterpillar, which feeds on leaf parenchyma, causes browning and dehydration of the leaves, which can be shed in summer. As a result of the chestnut leaf miner feeding on horse chestnut leaves, which lasts from May to September, up to 98% of the photosynthetic area can be lost, as the moth reduces the green, photosynthetic area of the leaves and causes them to dry out and fall off early [18, 19].

It has been established that due to warming, in the green plantings of Kharkiv, the chestnut leaf miner develops in three generations per year. At the same time, given the changes in the dates of the beginning and end of the seasonal development of the chestnut miner, it can be expected that a certain proportion of the population will develop in an additional generation [14, 20].

Pests cause the suppression of radial growth of trees, the formation of pale late wood, etc. Dendrochronological methods allow for highly accurate reconstruction of the timing of extreme events. This is especially important in cases where there are no direct long-term observations of individual trees or forest stands [5, 21].

The increased vulnerability of trees to stress factors can be expressed in the increase in the significant effects of temperature and precipitation on the radial growth of trees [17]. The study of the dynamics of radial growth of horse chestnut growing under climate change is of great importance for assessing the condition and productivity of stands. Changes in temperature and precipitation and the rate of these changes are among the most important factors of climate change [22].

Studies of horse chestnut in the urban plantation of Poltava and in the arboretum before the invasion of the horse chestnut leaf miner (1992–2007) and after its beginning (2008–2023) have shown that in the second period the radial growth of horse chestnut near the road decreased by 40%, and in the arboretum – by 25%. Under the additional influence of transport emissions, a trend of a steady decrease in the growth of horse chestnut was detected in the plantations near the road, and in the arboretum, fluctuations in growth over the years occurred in accordance with weather conditions, which is confirmed by significant correlation coefficients. In the plantations near the road (against the influence of transport emissions and damage by the horse chestnut miner) for the period 2008–2022 significant positive correlation coefficients of average strength were obtained between the radial growth indices of horse chestnut near the road and climatic factors: the amount of pre-cipitation per hydrological year, average winter temperatures, forest aridity index (FAI), and a negative correlation coefficient with minimum temperatures per hydrological year [17].

Currently, there are not enough scientific works that would reveal the mechanism of adaptation of common bitter chestnut to climate change and the impact of the chestnut borer invasion, so this study is timely and relevant.

Purpose: to identify the consequences of the impact of climate change and the horse chestnut leaf miner invasion on the radial growth of horse chestnut in green plantings of the cities of Lviv and Kharkiv.

Methods of the research

Object of the study: radial growth of horse chestnut in green plantings of Lviv and Kharkiv (Fig. 1, 2). The following methods were used: comparative analysis, dendrochronological – to assess the dynamics of radial growth of common bitter chestnut trees under the influence of climatic factors and chestnut borer invasion; statistical methods – for data analysis and correlation – to establish the dependence of radial growth of trees on climatic factors [2, 7, 8, 23, 24].

Fig. 1 – Sates of core sampling from horse chestnut trees in green plantings of the cities of Lviv (1) and Kharkiv (2)

Fig. 2 – Core sampling location in the alley planting of Kharkiv

Sampling. Cores were taken with a Pressler borer from tree trunks at a level of 1.3 m from the ground surface [2, 7]. 11 cores were taken from each stand. Then the cores were placed in paper containers on which the sample number, their location and the date of collection were recorded.

Office processing of the material and its analysis. Meteorological databases on temperature, precipitation and relative humidity were created for the Lviv and Kharkiv weather stations [24, 25].

The cross-dating method was used to establish the date of formation for each annual tree ring. First, the cores were air-dried, and then the size of the annual rings was measured with an accuracy of 0.01 mm using a device for measuring annual tree rings "HENSON" and a binocular microscope MBC - 9. Before measuring the cores, for greater clarity of the boundaries of the annual rings, a thin (1-2 mm) upper layer of wood was removed with a blade across the fibers and, if necessary, treated with chalk in order to identify clearer boundaries between the annual layers of wood [25].

During cross-dating of tree rings by the method of "skeletal graphs" (graphic method), the exact dates of formation of each ring were determined and based on this, tree-ring chronologies were obtained.

The magnitude of the current radial increment has a significant variation. In order to exclude the individual characteristics of individual trees, the average of individual series of radial increment of pine was carried out. The main statistical characteristics of tree-ring chronologies were calculated [23].

The hydrological year is the period from October 1 of the previous year to September 30 of the current year. The first half of the hydrological year is the period of autumn-winter moisture accumulation, from October 1 of the previous year to April 1 of the current year. The period of intensive tree growth is May, June, July of the current year [25].

The next step is to carry out standardization, i.e. indexing of tree-ring chronologies in order to extract the age (biological trend), which is a low-frequency component of the studied time series. Indexing was carried out by 3-year smoothing of the time series of radial growth of trees [7, 25]. Next, a correlation analysis was carried out, the essence of which is to identify positive or negative relationships between radial growth indices and climatic factors before the onset of damage to the common bitter chestnut by the chestnut miner and after it in green spaces of Lviv and Kharkiv.

Results and discussion

Dynamics of radial growth of horse chestnut in green spaces of Lviv. A local tree-ring chronology of horse chestnut was constructed, which was developed on the basis of 11 cores. The years of minimum tree growth were identified (1985, 1989, 1994, 1999, 2009, 2012, 2016 and 2019). The radial growth rate was calculated as the average value of the annual ring width for the period 1982-2020. Compared with the norm, deviations from the norm ranged from 12 to 71%). At the same time, for the first period (before the outbreak), these deviations were 12–23%, the corresponding values for the second period were 17-72%. Years of maximum tree growth: 1984, 1988, 1991, 2002. An increase in the size of annual rings from 14 to 52% was noted compared to the norm in these years (Fig. 3). Radial growth of horse chestnut in Lviv stabilized during 2016–2021 despite the increase in temperatures and the invasion of the chestnut miner.

The radial growth of trees in middle-aged stands was compared for the period before the outbreak of the horse chestnut miner (1982-2001) and after it (2002-2021). The temperatures for the hydrological year for these periods were also compared according to Lviv data. It was found that in the first period For Lviv, in the first period, the radial growth was 2.57±0.16 mm, and in the second - 1.30±0.14. That is, the growth decreased in 2007-2023 compared to 1990-2006 by 49% (Table 1). The weakening of trees during 2002–2021 is evidenced by cores, half of which have rot and a coefficient of variation that is significantly higher in the second period.

Thus, after the outbreak of the horse chestnut leaf miner, the radial growth of the horse chestnut decreased almost by half. During this period, the resistance of trees also decreased, as evidenced by an increase in the coefficient of variation for the tree-ring chronology.

Average temperatures and precipitation for the hydrological year were calculated. As noted above, the hydrological year is the period from October 1 of the previous year to September 30 of the current year. The first half of the hydrological year is the period of autumn-winter moisture accumulation, from October 1 of the previous year to April 1 of the current year. The period of intensive growth is May, June, July of the current year [25]. Years of minimum growth are mainly characterized by a deficit of precipitation and maximum temperature, and years of maximum growth are characterized by acceptable temperatures and precipitation (Fig. 3, 4).

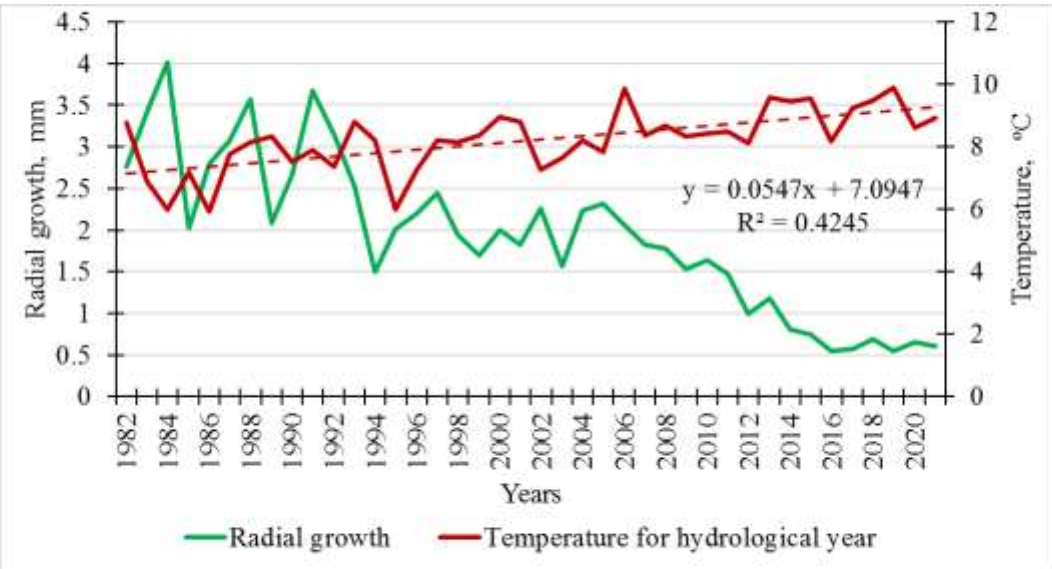


Fig. 3 – Dynamics of radial growth of horse chestnut in green planting of Lviv and temperature of the hydrological year according to data from the Lviv meteorological station (49°50′33″ пн. ш. 24°01′56″ сх. д.)

Table 1

Descriptive statistics of radial growth of common horse chestnut in green planting of Lviv

Indicators	**Periods**	
	1982-2001	**2002-2021**
Mean, mm/error	1,57±0,10	1,34±0,12
Standard deviation	0,35	0,44
Variance	0,52	0,41
Minimum value, mm	1,49	0,55
Maximum value, mm	4,01	2,31
Coefficient of variation	28,14	49,08

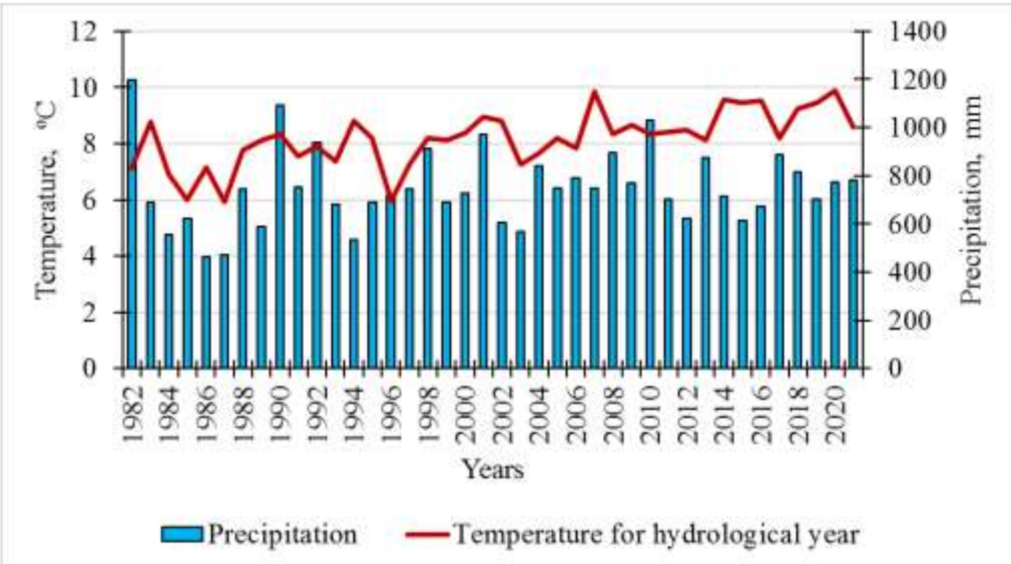


Fig. 4 – Dynamics of temperature and precipitation indicators for the hydrological year according to data from the Lviv Meteorological Station

Based on 11 individual tree-ring chronologies, a local chronology was constructed, from which low-frequency fluctuations, i.e., the age trend, were removed. The radial increment rate was calculated as the average value of the annual ring width for the period 1982–2020. Compared to the norm, the deviations from the norm ranged from 12 to 71%. At the same time, for the first period (before the outbreak), these deviations were 12-23, the corresponding values for the second period were 17-72%. An increase in the sizes of annual rings compared to the norm in these years was noted from 14 to 52%. As already noted, in the second period, the radial increment decreased compared to the first by almost half (Fig. 5).

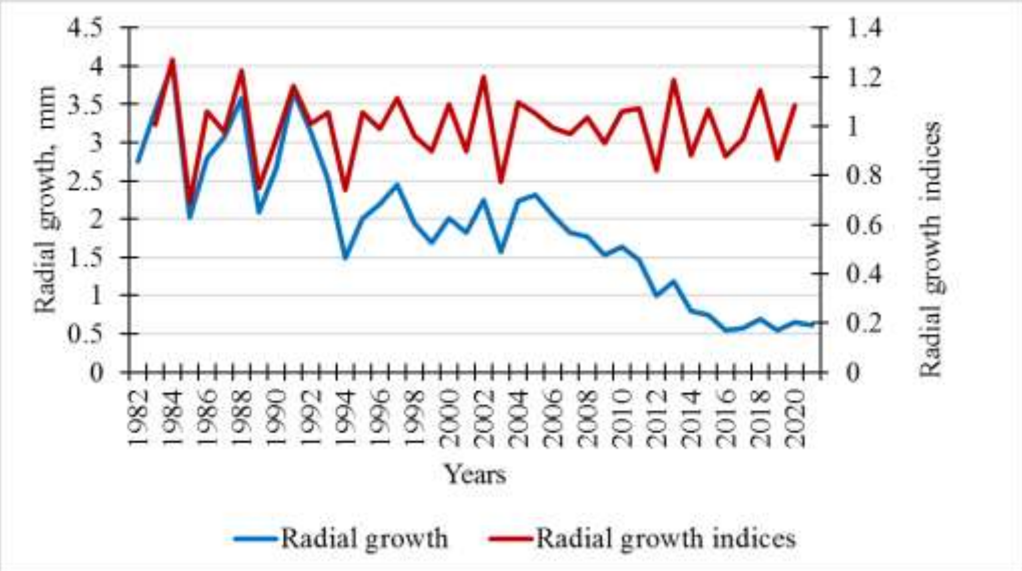


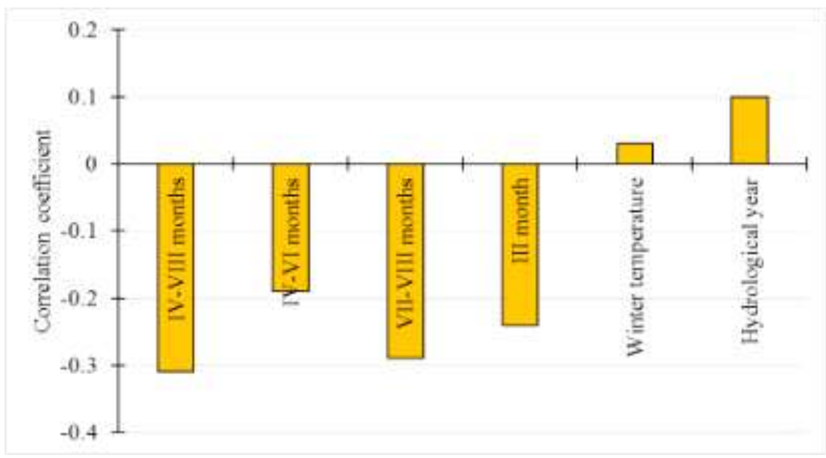
Fig. 5 – Dynamics of radial growth and indices for common horse chestnut in green spaces of Lviv [3]

A correlation analysis was conducted between radial growth indices and climatic factors for different periods of the hydrological year. It was found that the negative impact of temperatures was mitigated in the second period compared to the first. In the temperate zone, it is difficult to detect significant relationships between tree-ring chronologies and climatic factors because in these climatic conditions, the factors limiting tree growth change throughout the year.

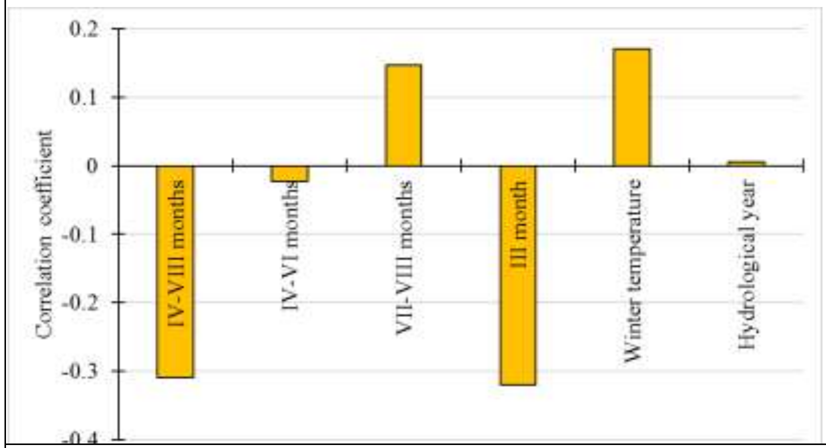
A correlation analysis was conducted between radial growth indices and temperature factors for different periods of the hydrological year for 1983–2001 and for 2002–2020. It was found that the negative impact of temperatures on radial growth, which was observed in the first period during the growing season, was somewhat weakened in the second period, which can be explained by the fact that the common bitter chestnut is a thermophilic plant native to the Balkan Peninsula and at this stage the temperature could have a positive effect on growth. But March temperatures began to have a more negative impact on growth in the second period (Fig. 6).

Correlation analysis between radial growth indices and precipitation showed that in the second period precipitation began to limit the formation of tree rings more. The effect of precipitation per hydrological year on growth was significantly positive (r=0.57 at the 0.05 level). That is, the sensitivity of growth to precipitation increased after the onset of the chestnut leafminer outbreak. In addition, recreation and pollution from transport could also have a negative effect on radial growth of trees (Fig. 7).

Dynamics of radial growth of horse chestnut in green plantations of Kharkiv. The radial growth of trees in middle-aged plantations was compared for the period before the outbreak of the chestnut borer (1982-2001) and after it for 1990-2006 and 2007-2023 for Kharkiv. The temperatures for the hydrological year for these periods at the Kharkiv weather station were also compared. It was established that in the first period for Kharkiv the radial growth was 2.57±0.19 mm, and in the second period – 1.10±0.06, that is, there was a decrease in growth by 57%. The temperatures for the hydrological year for the period before the invasion of the

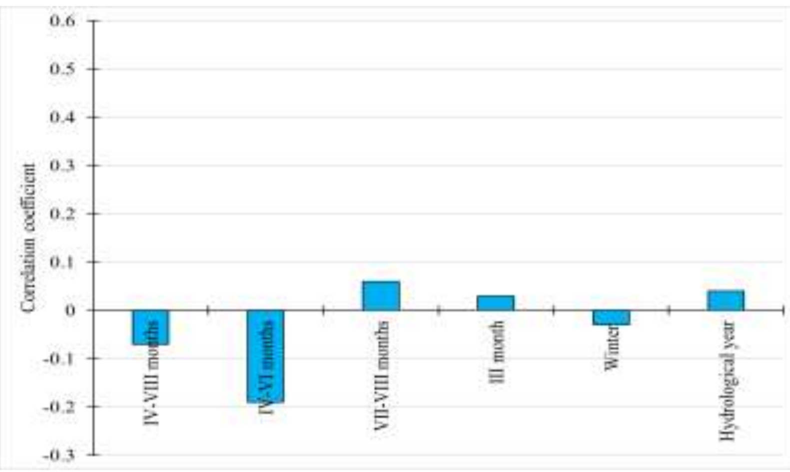


a)1983–2001

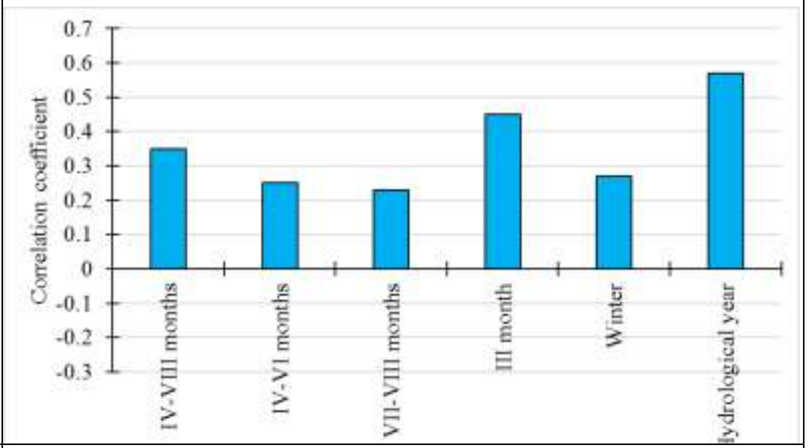


b) 2002–2020

Fig. 6 – Correlation analysis between radial growth indices of common horse chestnut in the Lviv stand and temperature indicators for different periods of the hydrological year



a) 1983–2001



b) 2002-2020

Fig. 7 – Correlation analysis between radial growth indices of horse chestnut in stands in Lviv and precipitation for different periods of the hydrological year

chestnut borer were 7.73±0.21 and 8.70±0.17 for Lviv. The radial growth trend of horse chestnut decreased until 2023. During 2005–2006, this decline was rapid, and after this period, the decline in growth slowed down (Fig. 8).

Statistical analysis of the radial growth of horse chestnut for 1986-2004 and 2005-2023 showed that the radial growth in the second period decreased by more than half (by 56%), which is probably caused not only by age reasons, but also by climate warming and related biotic factors, such as outbreaks of the wood-mining moth (*Cameraria ohridella*), which is an invasive species, so it is difficult to combat it. The variability of tree ring sizes decreased by almost half in the second period, as evidenced by the standard deviation and variance (Table 2).

Average temperatures and precipitation for the hydrological year were calculated according to data from the Kharkiv Meteorological Station. The years with the maximum temperatures for the hydrological year were established: 1990, 2008, 2009, 2016, 2017, 2018, when temperatures ranged from 8.9 to 10.5 ºC. The years with the minimum amount of precipitation for the hydrological year, when the amount of precipitation ranged from 417 to 521 mm. The years with the maximum amount of precipitation for the hydrological year: 1988, 1991, 1996, 2000, 2006, 2010, 2016. In these years, the amount of precipitation ranged from 653 to 782 mm (Fig. 9).

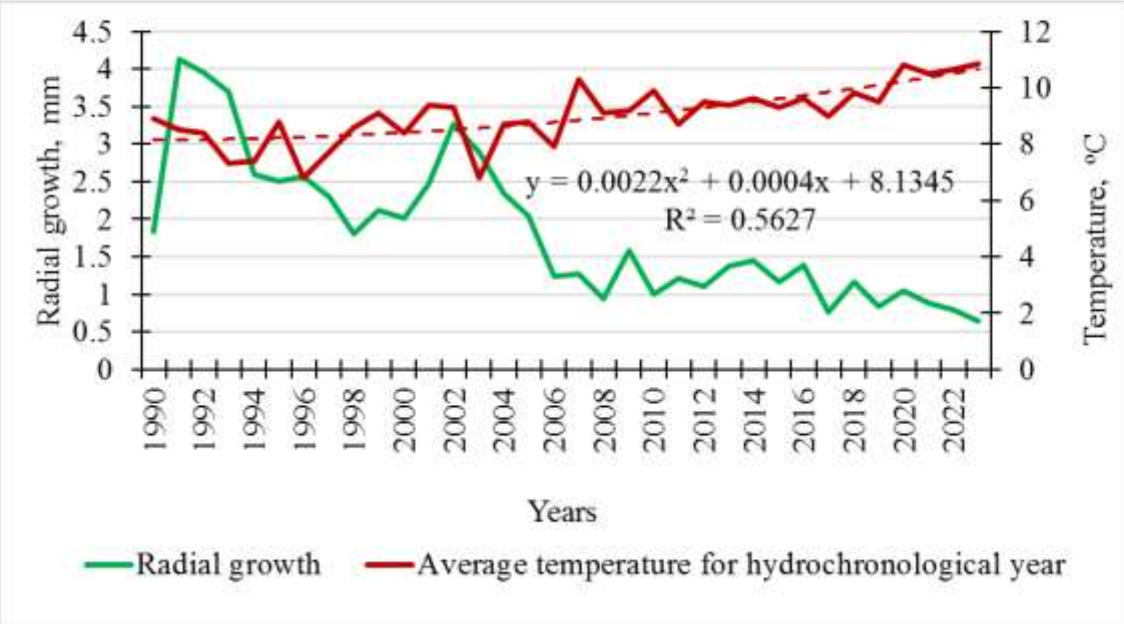


Fig. 8 – Dynamics of radial growth of horse chestnut in green plantings of Kharkiv and temperatures of the hydrological year according to data from the Kharkiv meteorological station

Table 2

Descriptive statistics of radial growth of horse chestnut in green planting of Kharkiv

Indicator	1986–2004	2005–2023
Mean/ error	2.65±0,15	1.15±0,08
Standard deviation	0.68	0.33
Sample variance	0.47	0.11
Minimum	1.80	0.65
Maximum	4.13	2.04
Coefficient of variation	26	29

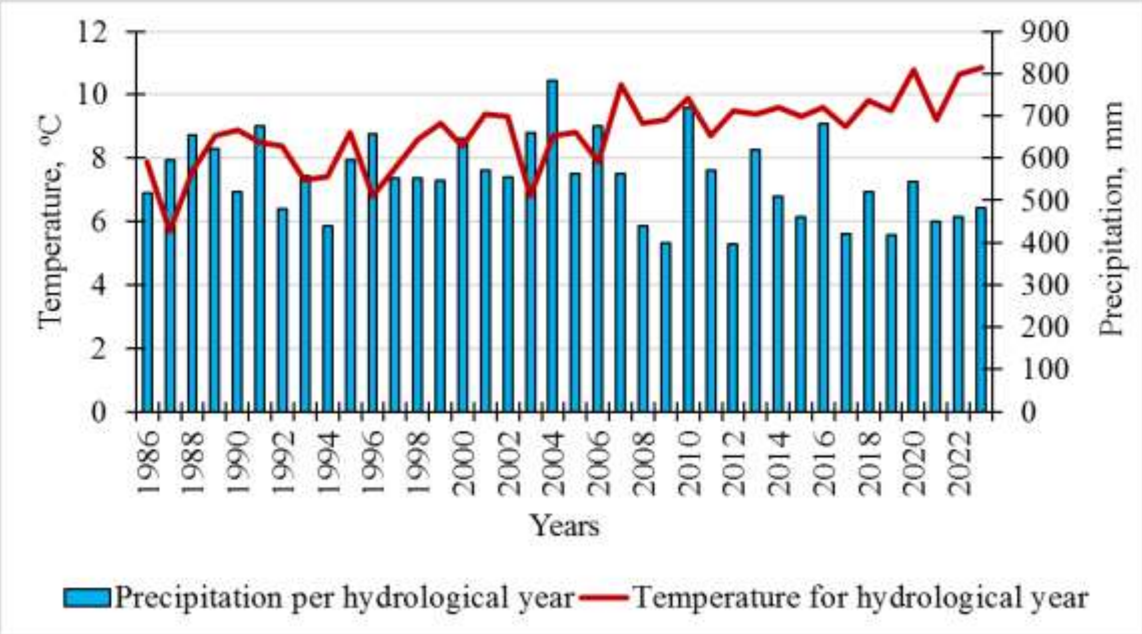


Fig. 9 – Dynamics of temperature and precipitation indicators for the hydrological year according to data from the Kharkiv Meteorological Station

Periods of increased growth are highlighted: 1977-1985, 2002-2003 and its decrease: 1986–1991, 1994–2001. Since 2004, a sharp decrease in radial growth of trees has begun, which continues to this day. The years of minimum (1978, 1981, 1983, 1986, 1990, 1994, 1998, 2006, 2008, 2010, 2012, 2015, 2017, 2019) and maximum growth (1979, 1982, 1985, 1987, 1991, 2002, 2009, 2014, 2016, 2018) were established. Based on 11 individual tree-ring chronologies, a local chronology was constructed (Fig. 10).

In recent decades, there has been a steady increase in temperature. So, in 2005–2023, compared to 1986–2004, the temperature for the hydrological year increased by 1.49 °C, for April–August – by 1.52 °C. That is, in the first period, the average temperatures for the hydrological year and April–August in the first period were 8.1 and 17.0 °C, respectively, and in the second – 9.6 and 18.5 °C. That is, the temperature increases in the second period compared to the first was 16% for the hydrological year and 9% for the growing season.

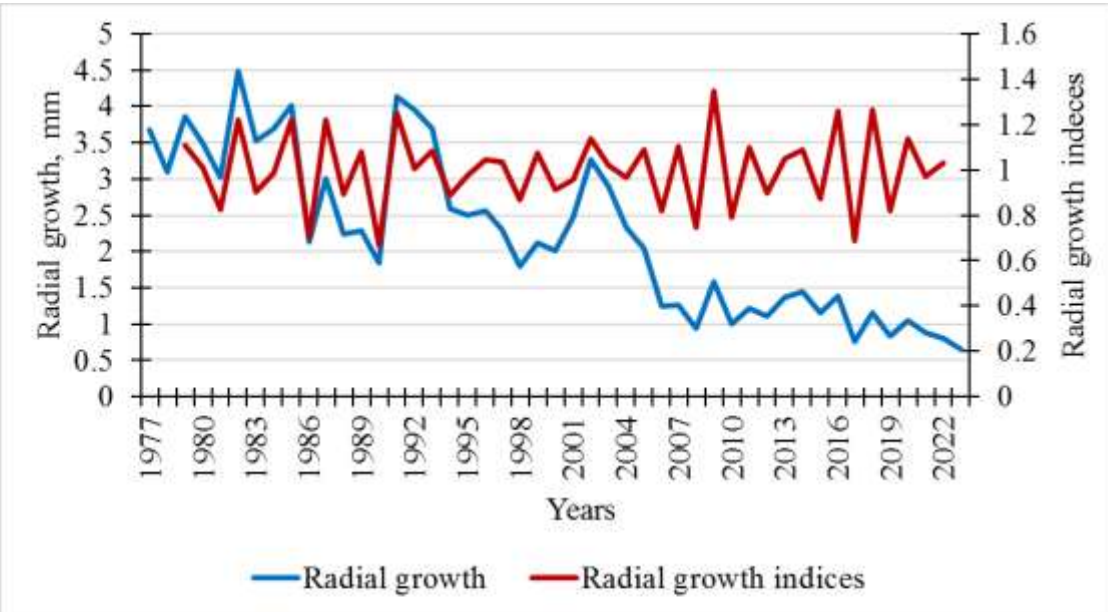
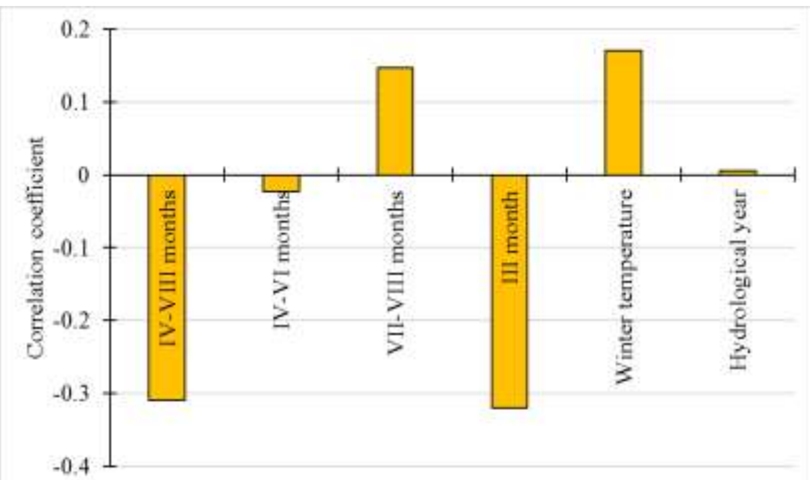
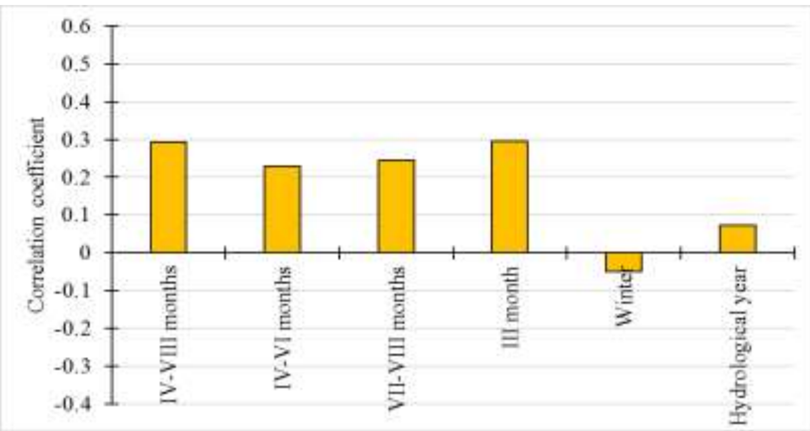


Fig. 10 – Dynamics of radial growth and indices for horse chestnut in Kharkiv [10]

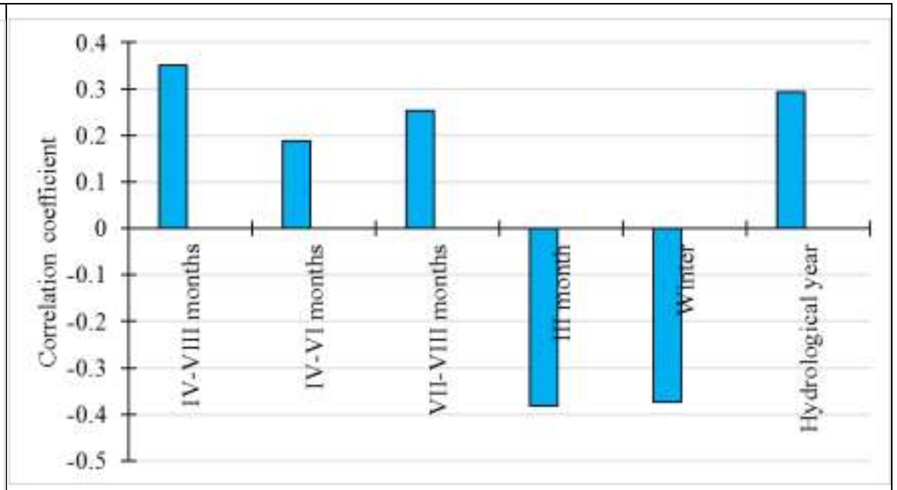


a)1986–2004

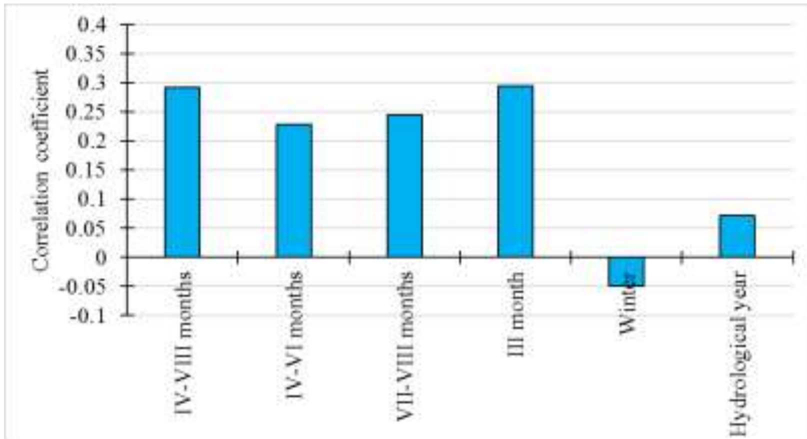


b) 2005–2022

Fig. 11 – Correlation analysis between radial growth indices of horse chestnut in green plantations of Kharkiv and temperatures for different periods of the hydrological year.
Note: * – significance of the correlation coefficient at the 0.05 level



a) 1986–2004



b) 2005-2022

Fig. 12. – Correlation analysis between radial growth indices of horse chestnut in stands of Kharkiv and precipitation for different periods of the hydrological year

The influence of climatic factors on the radial growth of trees in 1986–2004 and 2005–2023 was compared. It was found that the average temperature for the hydrological year in the second period increased by 1.49 ° C compared to the first, and the corresponding value for the growing season was 1.52 ° C. The amount of precipitation for both the hydrological year and the growing season decreased by 83 mm and 36 mm in the second period. By conducting a correlation analysis between the radial growth indices of trees and the average temperatures and precipitation amounts for different parts of the hydrological year for 1986–2004 and 2005–2023, it was found that the relationships between precipitation, temperatures and hydrothermal coefficients are weak and medium. A significant positive effect of winter temperatures on the radial growth of common horse chestnut in 1986–2004 was established. ($R=0.52$, $t_{fact.} = 2.55$, $t_{theor.} = 2.11$ at the 0.05 level of significance). In the second period, this effect became negative. In general, in the second period, the effect of temperatures had a more positive effect on growth than in the first (Fig. 11).

Correlation analysis between radial growth indices of horse chestnut and precipitation for the period before the beginning of the horse chestnut leaf miner invasion (1986–2004) and after it (2005–2022) showed that March precipitation in the second period had a positive effect on growth in the second period, unlike the first period, where this effect was negative. However, in the second period, winter precipitation limited radial growth of trees to a lesser extent. During April-August, precipitation had a positive effect on growth during both periods (Fig. 12).

Studies of radial growth of horse chestnut conducted by scientists in northwestern Poland, which were conducted in 2 periods: before the specified date of invasion of the chestnut miner (until 1999) and after the invasion (2000-2016), found that in 2000, despite favorable weather conditions, 91% of the analyzed trees showed a decrease in growth rates. The period of strong reduction lasted until 2010. Before the invasion, the radial growth rate depended on the temperature and precipitation in May and June of the current year, while after the invasion, the growth and climate response depended on the temperature and precipitation of the previous year, and the correlation was stronger. Surprisingly, in recent years (2011–2016), despite the annual infection of horse chestnut by the the horse chestnut leaf miner, the health of the analyzed trees improved and the width of the annual rings increased [19]. Our studies have obtained similar results: a significant decrease in the radial growth of horse chestnut in urban plantings was established after the onset of the horse chestnut leaf miner impact, which lasted in Lviv and Kharkiv for 12-14 years. Then there was some stabilization of tree growth.

Conclusions

When comparing the radial growth of horse chestnut for the periods before the beginning of the chestnut miner invasion (1982-2001) and after it (2002-2021) in Lviv and, respectively, for Kharkiv for 1986-2004 and 2005-2023, the decrease in growth was half as much in the second period compared to the first, despite the fact that the chestnut leaf miner arrived in Kharkiv 5 years later than in Lviv.

Despite the significant decrease in radial growth due to climate change and the impact of the chestnut miner invasion, the radial growth of horse chestnut in the Lviv plantation stabilized during 2017–2021 and in the Kharkiv plantation – during 2016–2023. This indicates the adaptation of the horse chestnut to environmental changes at this stage.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. Furthermore, the authors have fully adhered to ethical norms, including avoiding plagiarism, data falsification, and duplicate publication.

***Authors Contribution*:** all authors have contributed equally to this work

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І. М. КОВАЛЬ[1, 2], д -р. с.-г. наук, ст. наук. співроб.
[1]Провідний науковий співробітник сектору екології лісу відділу лісівництва та економіки лісового господарства
[2]Професорка кафедри екологічного моніторингу та заповідної справи
e-email: Koval_Iryna@ukr.net ORCID ID: https://orcid.org/0000-0001-6328-1418
[1]Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г. М. Висоцького
вул. Григорія Сковороди, 86, м. Харків, 61024, Україна
[2]Харківський національний університет імені В. Н. Каразіна
Майдан Свободи, 4, м. Харків, 61022, Україна

М. О. ЧЕРМНИХ,
Бакалавр Навчально-наукового інституту екології
e-email: chermnykh2021.9512117@student.karazin.ua ORCID ID: https://orcid.org/0009-0008-5346-8551
Харківський національний університет імені В. Н. Каразіна
Майдан Свободи, 4, м. Харків, 61022, Україна

В. В. ГОЛОЛОБОВ,
аспірант кафедри екологічного моніторингу та заповідної справи
e-mail: vadim.gololobov@gmail.com ORCID ID: https://orcid.org/0009-0009-0086-0303
Харківський національний університет імені В. Н. Каразіна
Майдан Свободи, 4, м. Харків, 61022, Україна

РАДІАЛЬНИЙ ПРИРІСТ КАШТАНА ЗВИЧАЙНОГО В ЗЕЛЕНИХ НАСАДЖЕННЯХ ЛЬВОВА ТА ХАРКОВА

Мета. Виявлення наслідків впливу зміни клімату та інвазії каштанового мінера на радіальний приріст гіркокаштана звичайного в зелених насадженнях міст Львова та Харкова.

Методи. Системний аналіз, дендрохронологічні та статистичні методи.

Результати. Порівняно радіальний приріст дерев в середньовікових насадженнях для періоду перед початком спалаху каштанового мінера (1982-2001 рр.) та після нього (2002-2021) для Львова та для 1990-2006 та 2007-2023 рр. для Харкова. Також порівняно температури за гідрологічний рік за ці періоди за даними Львівської та Харківської метеостанцій. Встановлено, що у другому періоді для Харкова відбулося зменшення приросту на 57%. Для першого періоду (до спалаху) відхилення від норми радіального приросту гіркокаштана звичайного у зеленому насадженні Львова склали 12-23%, відповідні значення для другого періоду – 17-72%. Встановлено, що у другому періоді у Львівському насадженні вплив температур на

радіальний приріст гіркокаштана звичайного, в основному, став більш позитивним за різні періоди гідрологічного року. Також збільшилася кількість позитивних коефіцієнтів кореляції між радіальним приростом та кліматичними чинниками, що свідчить про збільшення чутливості дерев. В зеленому насадженні м. Харкова при порівнянні впливу клімату на радіальний приріст гіркокаштана звичайного у 1986-2004 рр. та 2005-2022 рр. встановлено, що опади позитивно впливали на приріст на відміну від температури, яка впливала на радіальний приріст негативно. Це є характерним для обох періодів.

Висновки. При порівнянні радіального приросту гіркокаштана звичайного для періодів до початку інвазії каштанового мінера (1982-2001 рр.) та після нього (2002–2021 рр.) у Львові та відповідно для Харкова для 1986-2004 та 2005-2023 рр., зниження приросту було удвічі меншим у другому періоді в порівнянні з першим, незважаючи на те, що каштановий мінер прийшов у Харків на 5 років пізніше, ніж у Львів. Незважаючи на значне зменшення радіального приросту внаслідок зміни клімату та впливу інвазії каштанового мінера, відбулася стабілізація радіального приросту гіркокаштана звичайного у насадженні Львова упродовж 2017–2021 рр. та у насадженні Харкова упродовж 2016–2023 рр. Це свідчить про адаптацію гіркокаштана звичайного до екологічних змін на даному етапі.

КЛЮЧОВІ СЛОВА: *Aesculus hippocastanum L., радіальний приріст дерева, опади, температури, інвазія, Cameraria ohridella Deschka & Dimic 1986*

Конфлікт інтересів

Автори заявляють, що конфлікту інтересів щодо публікації цього рукопису немає. Крім того, автори повністю дотримувались етичних норм, включаючи плагіат, фальсифікацію даних та подвійну публікацію.

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