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Dynamics of forest dieback in the green zone of Kyiv in the context of climate change

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Abstract. Forest ecosystems of megacities, in particular Kyiv, are under the influence of intense anthropogenic pressure and global climate changes, the rapid increase in the average annual temperature, and increased aridisation of the region lead to a massive weakening of forest stands and requires a detailed analysis of the dynamics of sanitary conditions for the development of adaptive strategies for managing forest park landscapes. The purpose of the study was to comprehensively analyse the dynamics of dieback in pine stands managed by the Municipal Enterprise "Sviatoshyn Forest and Park Economy" during 2020-2025, identify relationships between meteorological factors, the intensity of forest pathological processes, and assess the role of stem pests in the degradation of pine stands based on detailed surveys conducted in 2025. The study was based on the analysis of literature data, basic forest management materials, and weather monitoring using the Meteoblue service. A detailed study on model trees revealed the species composition, colonisation density, and production of young xylophagous beetles by the number of maternal galleries and emergence holes per 1 dm² of the trunk surface. It was found that the volume of selective sanitary cutting is a direct response to climate stress; peak indicators of measures correlate with periods of extreme temperatures and moisture deficiency. Most stands have a low Class 3 resistance rating and a substantial proportion of deadwood (5-20% of standing volume). A complex of xylophagous insects was identified in the dieback centres: *Ips acuminatus*, *Ips sexdentatus*, *Phaenops cyanea*, and also *Tomicus piniperda* and *Tomicus minor*, which exhibited

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the highest colonisation density and production of young beetles. Mass infection by the pine polypore (*Phellinus pini*) was also recorded, along with deterioration of the aesthetic condition due to the accumulation of debris. The data obtained confirmed the high vulnerability of pure pine mono-specific forests to contemporary hydrothermal stresses within urban green-belt forests. The necessity of transition to the development of biologically stable mixed plantings and introduction of adaptive management methods that combine the principles of sanitary rehabilitation with support for the recreational potential of suburban forests was substantiated

Keywords: stem pests; pathogens; plant viability; hydrothermal stress; selective sanitary cutting

Introduction

The importance of urban green infrastructure in mitigating the effects of climate change, adapting urban ecosystems, and improving the quality of life of the population comes from ecosystem services provided by urban vegetation (Kong *et al.*, 2021), through the combination of shading and transpiration, vegetation cools both surfaces and air (Wong *et al.*, 2021; Alonzo *et al.*, 2025). Urban forests reduce the "urban heat island" effect, create shade during heat waves, retain and filter rainwater, and preserve biodiversity (Shannon *et al.*, 2021; Lüttge & Buckeridge, 2023). However, according to P.C. Ibsen *et al*. (2024), due to adaptive closure of plant stomata to prevent dehydration, conventional climate models overestimate the actual cooling effect of trees by approximately 60%. Kyiv, as a major metropolitan area, is characterised by high population density and intensive economic activity, placing considerable pressure on forest ecosystems Uncontrolled recreation, air and soil pollution, and forest fragmentation weaken trees and increase their vulnerability to harmful insects and pathogens. Global warming causes extreme weather events such as droughts, heat waves, and strong winds that negatively affect the state of forests. L. Portoghesi *et al*. (2023) noted that despite the significant ecosystem services of urban green spaces, extreme weather conditions can cause massive trees and large branches to fall, resulting in infrastructure damage, blocking of transport routes, injury and death, and the loss of the most ecological potential of plantings.

Climate change is also contributing to the spread of invasive species that pose a threat to local forest ecosystems. The deterioration of the sanitary condition of forests leads to the loss of biodiversity and disruption of environmental ties. As the forest-park landscapes of Kyiv's green belt provide a range of ecosystem services, including environmental regulation, microclimate regulation, sanitary and hygienic functions, and recreation, disturbance of these natural complexes reduces the quality of the urban living environment. A key indicator of climate change in the region is the rapid growth of temperature indicators. Since the end of the 20th century, the average annual air temperature in Kyiv has consistently exceeded the climatic norm. The study by I.F. Viksha (2022) outlined common threats and trends towards aridisation of Polissia. Especially critical is the increase in the number of days with extreme temperatures above +30°C and the fixation of new absolute highs in the summer period, which creates a long-term thermal stress for forest vegetation. According to the researcher, thermal stress provokes a "hydrological shock" in forest vegetation. Due to excessive transpiration and a critical drop in the ground water level, trees (in particular, *Pinus sylvestris* and *Betula pendula*) catastrophically lose turgor, which leads to the destruction of their water supply system (xylem). In addition, I.F. Buksha (2022) reported a change in the nature of precipitation: although the total annual amount may remain relatively stable, it becomes heavy or falls during atypical periods, which increases the summer hydrological deficit.

O.Y. Chornobrov (2025) investigated the disruption of seasonal cycles, which leads to an imbalance of natural processes and a shift in phenological phases. The winter period in Kyiv has become much milder, the duration of stable snow cover and periods of stable frosts has decreased. The growing season begins 2-3 weeks earlier, but is accompanied by sharp temperature fluctuations and spring frosts that damage young tree shoots. The duration of summer has effectively increased due to September, shifting the onset of biological autumn to late October. Such changes disrupt the state of winter dormancy of tree species and make them more vulnerable to pathogens at the beginning of the growing season. Despite the fact that the total annual precipitation varies within the normal range, the nature of their distribution has changed dramatically. Against the background of high temperatures, there is an acute shortage of moisture in the second half of summer (July – August). Precipitation during this period is increasingly heavy in nature and falls in the form of short-term intense thunderstorms. Such moisture does not have time to penetrate into the deep layers of the soil, draining superficially, which leads to rapid drying of the root layer of the root zone. The Selyaninov's hydrothermal coefficient for Kyiv in July and August is increasingly falling below 0.6, which is classified as a period of severe drought (SEA, 2025). A severe lack of moisture combined with high solar insolation leads to hydrological depletion of woodlands, a critical decrease in ground water levels, and deterioration of growth conditions, a decrease in biological resistance, weakening of trees and, as a result, to the activation of the harmfulness of insects and diseases. A. Zhezhkun & I. Porohnyach (2020) focused on the physiological weakening of tree species and changes in forest inventory and stands parameters under the influence of prolonged droughts. The researchers proved that chronic lack of moisture in summer limits radial growth and reduces the intensity of photosynthesis, which makes trees defenceless against abiotic factors. N. Puzrina *et al*. (2022) found that hydrological depletion and reduction of resin release in conifers creates optimal conditions for mass reproduction of xylophages (stem pests). It was emphasised that harmful insects and concomitant infections attack physiologically weakened trees, which promotes the transformation of isolated dieback centre into large-scale epiphytotics.

The purpose of this study was to comprehensively investigate the dynamics of pine stand dieback in the Municipal Enterprise "Sviatoshyn Forest and Park Economy" (ME Sviatoshyn FPE) during 2020-2025, establish the relationship between meteorological factors, and the intensity of forest pathology processes, and assess the role of stem pests in the degradation of pine stands based on the results of detailed surveys conducted in 2025.

Materials and Methods

The study was performed by analysis and synthesis materials of basic forest management (Kyiv City State Administration, 2020) of Municipal Enterprise "Sviatoshyn Forest and Park Economy". The volume of selective sanitary cutting for the period 2020-2025 was analysed, followed by field surveys in Scots pine dieback areas. During the reconnaissance survey, a general inspection of the sites was carried out (Goychuk *et al*., 2012), in the examined stands, visual inspection revealed a significant weakening (yellowing of needles, falling bark, dryness). Detailed surveys of the sites were accompanied by the determination of the species composition of xylophagous insects. Detailed forest pathology surveys were conducted in 2025 within pine dieback areas by establishing temporary sample plots (five in each forest district) around active group dieback centres, in accordance with established methodologies (Meshkova, 2020; Puzrina *et al.*, 2021) and relevant regulatory and reference materials (Resolution of the Cabinet of Ministers of Ukraine No. 756, 2016; Kyiv City State Administration, 2020).

Population indicators of insects that inhabited trees in dieback centres were determined on model Scots pine trees (Meshkova, 2020; Puzrina *et al.*, 2021). The state of the population and its impact on forest stands allowed assessing the quantitative characteristics of the insect population, in particular, the number, prevalence, production of young beetles (the number of emergence holes), and the colonisation density. When studying the settlement density, model trees were cleaned of knots, and a 10 cm wide part of the bark was removed from the base to the top (Fig. 1).

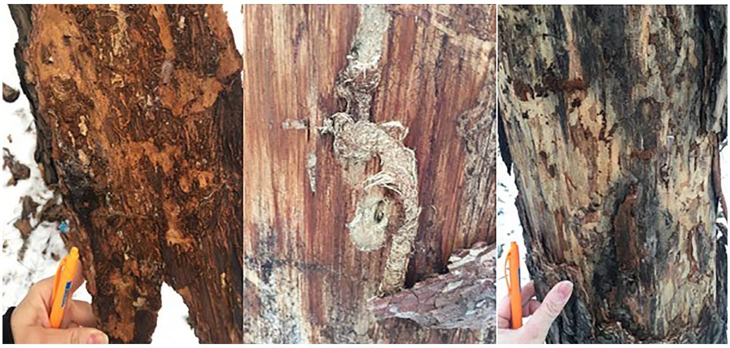

Figure 1. Galleries and emergence holes of xylophagous insects

Source: photo by the authors

To determine the colonisation density by the number of maternal galleries per 1 dm^2 and production of young beetles by the number of emergence holes per 1 dm^2 (Table 1), the sampling-plot method was used, with two plots established on each tree at sites colonised by each insect species of the subfamily *Scolytinae*.

Table 1. Criteria for assessing the colonisation density of xylophagous insects and the abundance of the new generation

Species	numerator: density of the colonisation (maternal galleries), for jewel beetles – the number of larvae under the bark; denominator: number of the new generation (emergence holes), units·dm^{-2}		
	low	average	high
Large pine shoot beetle *Tomicus piniperda*	0.7 or less 3.0 or less	0.8-1.5 3.1-5.0	1.6 or more 5.1 or more
Small pine shoot beetle *Tomicus minor*	2.9 or less 6.0 or less	3.0-5.0 6.1-10.0	5.1 or more 10.1 or more
Sharp-dentated bark beetle *Ips acuminatus*	2.0 or less 6.0 or less	2.1-5.0 6.1-10.0	5.1 or more 10.1 or more
Six-toothed bark beetle *Ips sexdentatus*	0.5 or less 2.0 or less	0.6-1.2 2.1-4.0	1.3 or more 4.1 or more
Blue pine jewel beetle *Phaenops cyanea*	0.4 or less -	0.5-0.8 -	0.9 or more -

Source: developed based on V.L. Meshkova (2020) and N. Puzrina *et al.* (2021)

Archived data on weather conditions in the study region from 2020-2025 were analysed based on Meteoblue materials (n.d.). Under laboratory conditions, the work involved processing the collected materials and analysing the results obtained. Such a set of methods helped to assess the sanitary condition of pine stands and the specifics of the development of their dieback centres. The combination of forest pathology studies with the determination of population indicators of xylophagous insects provided a comprehensive assessment of their role in stand degradation processes. The analysis of meteorological data for the study period allowed considering the influence of weather conditions on the dynamics of the sanitary conditions of pine stands. The obtained field and archival materials were used to further compare the dieback intensity with the indicators of tree colonisation by xylophagous insects and weather conditions. This created a methodological basis for assessing the main factors associated with the development of Scots pine dieback centres within the Municipal enterprise "Sviatoshyn Forest and Park Economy".

Results and Discussion

Analysis of basic forest management inventory materials and meteorological data for 2020-2025 was used to determine the dynamics of areas subjected to selective sanitary felling and to characterise the weather conditions during the study period. Based on the materials of detailed forest pathological surveys in 2025, the sanitary condition of the surveyed pine stands, the species composition of xylophagous insects, the density of their settlement, and the number of the younger generation were established. The obtained experimental data allow estimating the scale of pine dieback, the dynamics of sanitary and health measures, and to determine the species structure and population indicators of the complex of xylophagous insects that act as catalysts for the degradation of suburban forests. Dynamics of air temperature and precipitation volumes in Kyiv during 2020-2025 (Fig. 2) allowed tracking weather changes and characteristic meteorological trends, in particular, clear seasonality and certain variations in the distribution of precipitation. According to regional reports on the state of the natural environment in Kyiv (2021 and 2023) and the SEA report (2025), real indicators of atmospheric pollution and hydrological regime of the capital and confirmed that the forests of the green zone are under the influence of climate aridisation (drought) and significant anthropogenic and recreational load. The complex interaction between abiotic factors, host trees, insects, and their natural enemies makes it very difficult to predict the overall impact of climate change on forest health and requires analysing the dynamics of pest populations in climate change scenarios (Jactel *et al.*, 2019).

The graphs show a typical temperate continental climate with clearly defined seasonality, but there are noticeable interannual fluctuations and signs of general warming. The most mild winters were in 2020 and 2025, when temperatures almost did not fall below 0°C in the daytime, and periodic cold snaps were insignificant. But during the winter of 2021, 2023, and 2024, temperatures dropped to -10°C, especially in 2021, a particularly severe January-February was observed. Consistently hot summers were noted in 2021 and 2022, when the temperature peaks in July-August crossed the mark of +30°C, in 2023-2025, summer highs also remained high in the range of +25...+30°C, but with a more undulating character, which indicates the alternation of heat and cooler fronts. There is a tendency for a rapid transition from winter to summer, especially noticeable in 2024 and 2025, where April-May have a rapid increase in temperature. Autumn periods are long, with a gradual decrease in temperatures until December. Every year, summer temperature peaks are observed, reaching or exceeding +30°C. Winters range from mild (in 2020) to more severe with sharp short-term cold snaps (in 2021). The distribution of precipitation during the study period was uneven, which indicates a change in the nature of moisture in the region from moderate to periodically dry or abnormally wet. In 2020, precipitation was distributed relatively evenly, the largest amount was recorded in late spring and in the first half of summer (May-July). However, starting in 2021, peak fluctuations in precipitation were noted, for example, the extreme June maximum of precipitation (2021) and the critically dry average part of the year 2022 (June-August with almost no precipitation). In 2025, the overall precipitation level was the lowest compared to previous years. The wettest month for Kyiv is most often June. Moreover, consistently high precipitation rates are observed in mid-autumn (October) and early winter (December), the driest periods often occur in August or early spring. Given the substantial recreational pressure on the forests managed by the forest park enterprise, and in order to assess their sanitary condition, the dynamics of a set of measures aimed at improving forest health was analysed. These measures were intended to ensure that pine stands continued to perform their protective, water-regulating, aesthetic, and sanitary-hygienic functions, with particular attention paid to selective sanitary felling carried out during 2020-2025 (Fig. 3).

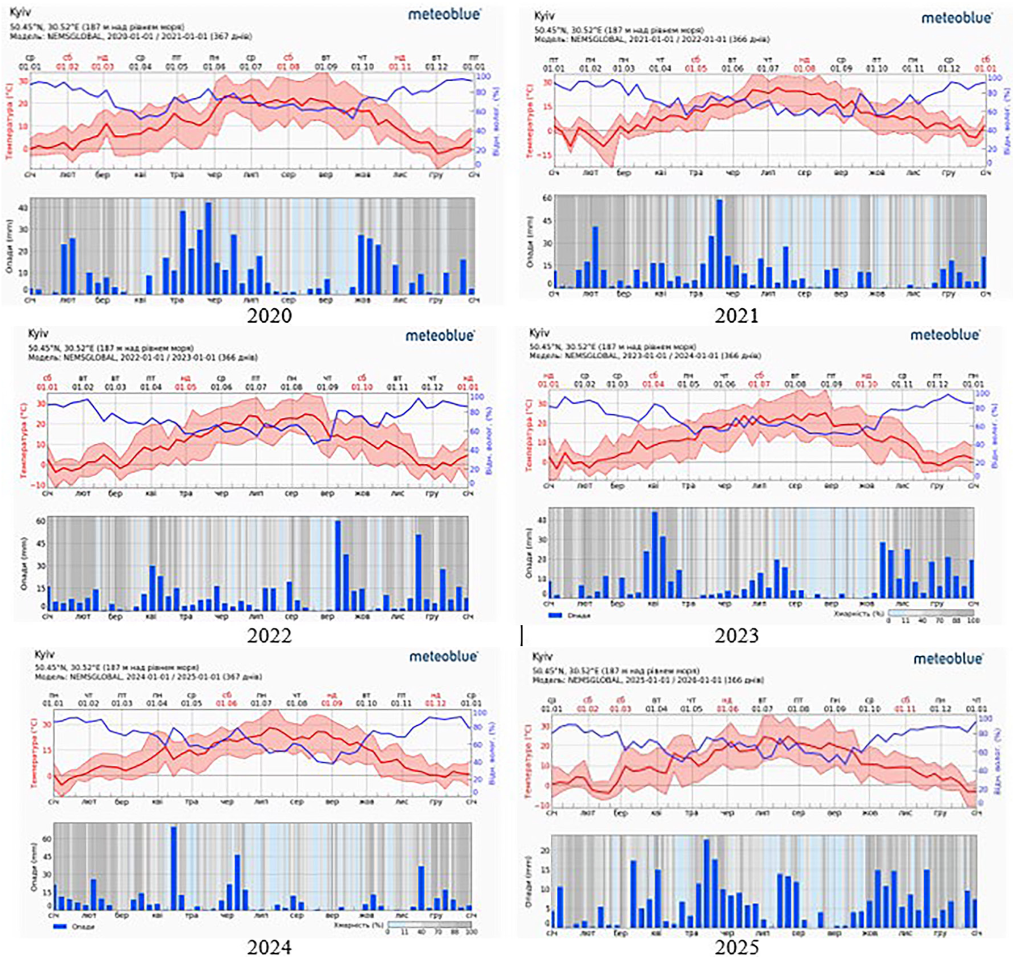

Figure 2. Indicators of temperature and precipitation in Kyiv for 2020-2025
Source: developed by the authors based on materials from Meteoblue (n.d.)

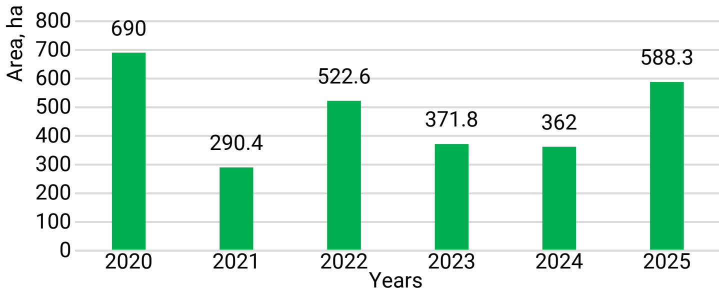

Figure 3. Volumes of selective sanitary cutting for the period 2020-2025, ha
Source: compiled by the authors

At the beginning of the study period, the highest rate of sanitary cutting area of 690.0 hectares was recorded, which indicates the presence of large-scale forest dieback centres, which required prompt and extensive forest protection measures. In 2021, there was a rapid decrease in the area of cutting to the minimum value of 290.4 hectares for the entire period, which may be due both to the successful elimination of the main dieback centres in 2020, and to the climatic features of that year. In 2022, the area subjected to selective sanitary cutting increased substantially again, reaching 522.6 ha, indicating another wave of stand weakening and the formation of new dieback centres in 2025, there is a noticeable tendency to increase the volume of sanitary and health measures, the selective sanitary cutting area increased to 588.3 hectares. Analysis of the areas of selective sanitary felling in the forest districts of the Municipal enterprise "Sviatoshyn Forest and Park Economy" indicates the substantial scale of planned measures aimed at improving forest health, particularly in pine stands, which frequently form dieback centres (Fig. 4).

a b

Figure 4. Areas of intensive dieback
Note: a – Kyiv Forestry Unit, b – Sviatoshyn Forestry Unit
Source: photo by the authors

Uneven precipitation and periodic abnormal temperatures lead to fluctuations in the dieback centres, which is reflected in the annual dynamics of the areas covered by sanitary measures during the study period. Analysis of cutting volumes by year allows tracing the dynamics of the sanitary state of forests. For carrying out selective sanitary cutting by removing dead trees and their groups, cleaning up debris in stands where it is several times higher than the natural level, soil trophicity increases, conditions for root nutrition of plants, and the general sanitary condition improve, the stability of the ecosystem's biological diversity and its balance are restored. It should be noted that the largest area of pine stands passed through selective sanitary cutting (690.0 ha) was in 2020, which can be explained by the influence of negative factors of a reversible and irreversible nature.

Analysis of the dynamics of selective sanitary cutting in the context of climate change (for the period 2020-2025) allowed identifying the relationship between meteorological anomalies and the sanitary condition of pine stands. According to Figure 2, there is a trend towards general warming, a rapid transition from winter to summer (especially in 2024-2025), and regular summer heat peaks over +30°C, such an increase in temperature combined with an uneven distribution of precipitation creates conditions for physiological weakening of trees. There is a change in the nature of moisture from moderate to periodically dry, in particular, the extreme drought in the summer of 2022 (June-August with almost no precipitation) and the lowest overall precipitation level in 2025 are among the determining factors for the drying of plantings. Volumes of selective sanitary cutting (Fig. 3) reflect the deterioration of pine stands under the influence of these changes. Since forests perform protective and water-regulating functions, cutting is aimed at improving the sanitary condition and minimising the consequences of climate stress and recreational stress.

The main reason for the appointment of selective sanitary cutting is the presence of dead wood, the share of which ranges from 5% to 20% of the stand. Most forests have a high recreational rating and a low (Class 3) level of stability. Selective sanitary cutting in all forest districts is caused by massive dieback of pine trees. The most intensive cutting rates were determined in the Kyiv and Sviatoshyn Forestry Units, where the largest areas in need of sanitary measures are concentrated. The composition of stands is mainly pure Scots pine (10Sp), which make up a significant share of the area, especially in over-ripe stands (Fig. 5). Therefore, this explains the biological instability of pine mono-specific forests in current climatic conditions. The analysis of the data presented in Figure 5 shows a relatively stable structure for the distribution of selective sanitary cutting volumes between forest districts during the study period.

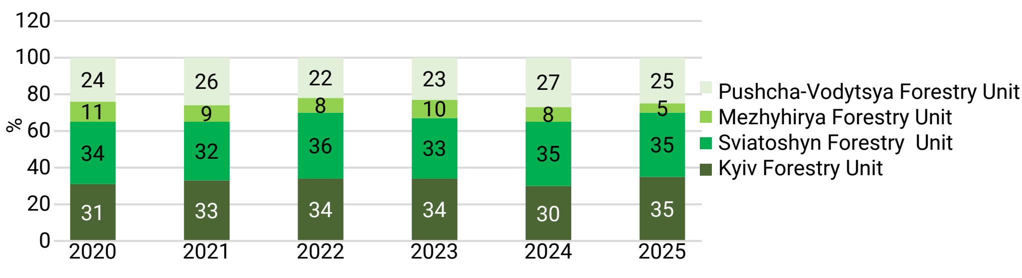

Figure 5. Distribution of the volume of selective sanitary cutting in forest districts (2020-2025)
Source: compiled by the authors

In Sviatoshyn Forestry Unit, selective sanitary cutting covers significant areas, especially in pine stands aged 60-110 years and older. The main cause of cutting is a high proportion of dead wood and damage by pine polypore (in some secretions, the degree of damage reaches 40-60%). Kyiv Forestry Unit located in the National Nature Park. This imposes strict restrictions on forestry, so most allocations have a sustainability Class 2 (sometimes Class 3) and a stage 1-2 of recreational digression. This indicates that natural ecosystems are already partially disrupted due to excessive human visits (soil compaction, undergrowth damage). The stands of the Kyiv Forestry Unit are mature and over-mature (age 60-100 years), which makes pine more susceptible to climate change. The natural decline with the development of dead wood in such plantings is high, so the appointment of selective sanitary cutting is biologically justified. The volume of cutting in the Pushcha-Vodytsya Forestry Unit is also significant, given the preservation of the recreational potential of nature reserves and the national park, but it covers a significant number of compartments in regulated recreation areas and nature reserves. A significant amount of cutting is combined with clearing forests of debris, which is important for regulated recreation areas. Damage caused by stem rot diseases, particularly pine stem rot, was also recorded, affecting up to 50-70% of the trees. In the Mezhyhirya Forestry Unit, cutting is more mosaic in nature, covering plantings that are diverse in composition. In addition to pure pine stands, cutting is often carried out in areas with a high proportion of black alder and common oak in protected areas and economic parts of the national park. All surveyed pine stands exhibited visible signs of decline (Fig. 6).

a  b 

Figure 6. Detailed survey of dieback centres (2025)

Note: a – Kyiv Forestry Unit; b – Sviatoshyn Forestry Unit

Source: photo by the authors

During the 2025 survey in the Kyiv and Sviatoshyn Forestry Units, it was revealed that weakened and severely weakened trees predominate in these stands, a significant number of dead trees (up to 60% of the stand) were noted, and the spread of stem pests, including the six-toothed bark beetle, the lesser pine bark beetle, and the blue jewel beetle, was also recorded. In the most weakened areas, the nature of tree death has a dispersed-group character. To determine the degree of colonisation by xylophagous insects, model trees were used, where the average number of species of the subfamily *Scolytinae*, families *Curculionidae*, and families *Buprestidae* per square decimetre of the barrel surface was determined (Table 2).

Table 2. Degrees of tree colonisation by xylophagous insects (2025)

Species	Colonisation density, galleries per 1·dm^{-2}		Production of stem pests, emergence holes per 1·dm^{-2}	
Kyiv Forestry Unit				
Ips acuminatus	0.2±0.1	low	1.1±0.2	low
Ips sexdentatus	0.6±0.2	average	3.1±0.3	average
Tomicus piniperda	1.0±0.2	average	4.2±0.3	average
Tomicus minor	5.2±0.4	high	7.5±0.4	high
Phaenops cyanea	0.6±0.3	average	0.3±0.1	average
Sviatoshyn Forestry Unit				
Ips acuminatus	0.4±0.1	low	0.8±0.3	low
Ips sexdentatus	0.1±0.1	low	0.6±0.2	low
Tomicus piniperda	2.3±0.3	high	6.8±0.6	high
Tomicus minor	6.3±0.4	high	10.6±0.7	high
Phaenops cyanea	1.2±0.4	high	1.1±0.3	high

Source: compiled by the authors

Notably, the identified populations of xylophagous insects are characterised by different degrees of colonisation, they are also noted on trees of different categories, but only very weakened Scots pine trees contained *Ips acuminatus*. Despite the low density of the settlement, *Ips acuminatus* has the ability to attack almost healthy trees and form continuous mass populations in the surveyed stands together with *Ips sexdentatus* (Fig. 7).

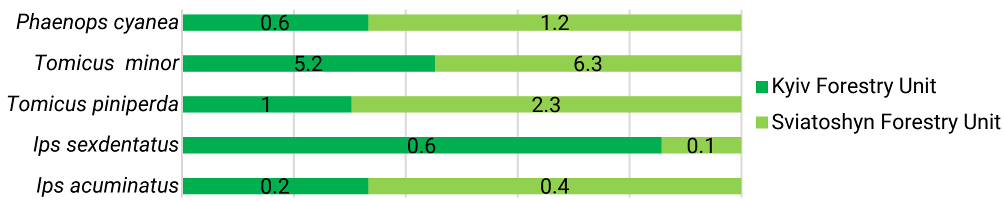

Figure 7. Average values of population colonisation density (according to 2025 records), maternal galleries per 1·dm^{-2}

Source: compiled by the authors

The highest colonisation density was recorded for *Tomicus piniperda* and *Tomicus minor*; however, populations of xylophagous insects differed in the intensity of tree colonisation. This suggests that population density depends on a number of factors and the ecological state of specific areas or individual trees. belonging to different health-status categories; however, there was a clear relationship between colonisation density and the degree of weakening of the host tree (Fig. 8).

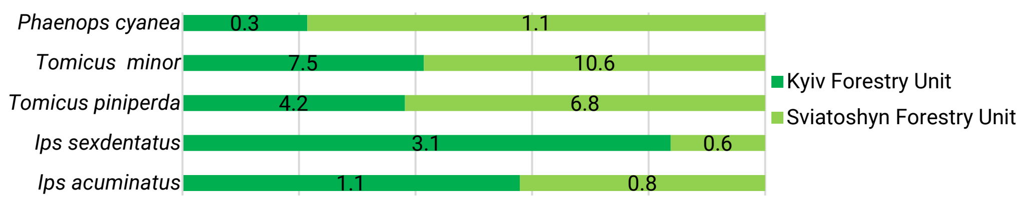

Figure 8. Average values of stem pest production, emergence holes per 1 dm^{-2}

Source: compiled by the authors

Populations of *Tomicus minor* and *Tomicus piniperda* have the highest settlement density and productivity. The success of reproduction of a new generation of insects has a direct linear relationship: the higher the density of maternal galleries, the higher the density of emergence holes, and reproductive ability (in Sviatoshyn Forestry Unit, the production of young beetles was 10.6), which was confirmed by N. Puzrina *et al*. (2022). In Kyiv Forestry Unit, the population density of *Phaenops cyanea* averaged 0.3, representing a low number of emergence holes and indicating high larval mortality during development beneath the bark, possibly due to external factors or tree defence mechanisms.

The surveyed forest areas also contain secondary tree species that, at the time of the survey, exhibited signs of weakening and dieback, including birch canker, thereby contributing to stand debris and reducing the aesthetic condition of the forest stands. Defective and windthrown trees removed during selective sanitary felling provide a substrate for the development of numerous microorganisms and fungi and serve as a reservoir for forest pest colonisation. For allocations of high recreational importance, where semi-open or closed spaces of horizontal or vertical closeness are recorded, measures aimed at forming stable landscapes are introduced. They combine the principles of sanitary selection with improved visibility and alternating open and closed forest spaces.

According to the research by P. Lehmann *et al*. (2020), due to climate change, the distribution of most insect species is determined by temperature-dependent population dynamics and trophic interactions. In a chronic pest focus, insects that attack trees are usually in a phase of increasing or concentrated abundance, due to the development of populations with reduced density. V.L. Meshkova *et al*. (2017) noted that such foci are characterised by a relatively moderate level of insect numbers (although it is increased compared to healthy forests) and a limited number of trees that have withered in the current year. Ephemeral outbreaks, or outbreaks of mass reproduction, are characterised by a short development period (3-5 years), high population densities, and a substantial volume of trees undergoing dieback. In both cases, reversible and irreversible consequences for forest stands are possible, but in the latter case, when mass reproduction of insects occurs, complete destruction of the forest is usually observed. According to C. Bässler *et al*. (2013), rising temperatures cause an imbalance in the ecosystem. Insects (in particular, Coleoptera) respond to warming much faster than plants, showing a non-linear and rapid expansion of their ranges into new ecological niches. A sharp reaction of insects to meteorological factors (warming, droughts) leads to massive outbreaks of stem pests, such as sharp-dentated bark beetle (*Ips acuminatus*) (Porokhnyach, 2019).

X. Morin *et al*. (2018) point out that climate change directly affects ecosystem functioning through impacts on plant physiology, which leads to changes in global productivity and indirectly affects ecosystems through changes in the composition and diversity of plant communities, so forests with high diversity will be more resilient to climate change. The study by H. Pretzsch *et al*. (2017) presented an analysis of the radial growth of trees in different climatic zones, showed that the effect of "urban heat island" accelerates the passage of phenophases, and stimulates the growth of trees at a young age, but leads to their premature ageing and a sharp decrease in adaptive capacity in extreme summer temperatures. X. Kong *et al*. (2021), using remote sensing techniques, found that high urban density and isolation of forest fragments disrupt the natural hydrological regime and degrade the microclimatic buffering of the forest. This leads to the fact that urban pine stands lose their stability much faster than suburban or natural forests. The specific feature of the functioning of forest ecosystems within the urbanised territories of Southern and Central Europe were also investigated by L. Portoghesi *et al*. (2023), who emphasised that anthropogenic pressure (recreational load, soil compaction, chemical pollution) acts as a catalyst for chronic physiological stress of trees.

Consequently, due to rising temperatures and climate aridisation, pine stands in the green zone of Kyiv are experiencing intense weakening and mass drying, which is accompanied by the activation of xylophagous insects and the spread of pathogens. An increase in the volume of selective sanitary cutting is a direct response to climate stress and the deterioration of pure pine stands. To ensure the sustainability and preservation of ecological and recreational functions of suburban forests, it is necessary to switch to the development of biologically stable mixed plantings in compliance with the principles of environmentally oriented forestry.

Conclusions

The study revealed a persistent trend towards climate aridification in Kyiv, manifested in a 1.2-1.5°C increase in mean annual temperature and a rise in the number of days with extreme heat exceeding +30°C. Despite the relative stability of the annual precipitation rate, changes in their nature to storm and long periods of drought lead to hydrological depletion of forests and a decrease in the water table. The combination of climate stress with intense anthropogenic and recreational stress in the metropolis has caused a massive weakening of pine stands. Most forests are characterised by a low Class 3 of resistance, the presence of a significant proportion of dead wood (5-20% of the stand), and the spread of stem rot. In areas affected by dieback, a complex of xylophagous insects was established, dominated by the six-toothed bark beetle and the great spruce bark beetle (*Ips acuminatus*, *I. sexdentatus*), large and small pine shoot beetles (*Tomicus piniperda*, *T. minor*), and the blue pine jewel beetle (*Phaenops cyanea*). The highest colonisation density and reproductive capacity were demonstrated by representatives of the genus *Tomicus*, which indicates their leading role in the degradation processes of weakened trees.

Conducting selective sanitary cutting is a reasonable measure aimed at improving the health of forests by removing dead wood and debris. The dynamics of the volume of these cutting operations directly correlates with meteorological anomalies: the maximum values of the areas of sanitary measures are a reaction to the deterioration of forests after dry periods. To preserve the ecosystem functions of Kyiv's green belt, it is necessary to transition towards the establishment of biologically resilient mixed-species stands, as overmature mono-specific forests have proved particularly vulnerable to contemporary climate-related stresses. Sanitary selection in recreational areas should be combined with landscape planning to maintain the aesthetic appeal and viability of forest parks. Therefore, contemporary management of forest-park landscapes in metropolitan areas cannot be limited to conventional forestry practices. Future research should focus on the implementation of adaptive strategies aimed at enhancing biodiversity and optimising the spatial structure of stands to preserve their sanitary and ecological functions.

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Conflict of Interest

None.

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Динаміка всихання лісів зеленої зони м. Київ в контексті зміни клімату

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Анотація. Лісові екосистеми мегаполісів, зокрема Києва, перебувають під впливом інтенсивного антропогенного тиску та глобальних кліматичних змін, стрімке зростання середньорічної температури та посилення аридизації регіону призводять до масового ослаблення насаджень та вимагає детального аналізу динаміки санітарного стану для розробки адаптивних стратегій управління лісопарковими ландшафтами. Мета роботи полягала у комплексному аналізі динаміки всихання соснових насаджень комунального підприємства «Святошинське лісопаркове господарство» протягом 2020-2025 років, виявлення взаємозв'язку між метеорологічними факторами та інтенсивністю лісопатологічних процесів, а також оцінити роль стовбурових шкідників у деградації соснових насаджень за результатами детальних обстежень 2025 року. Дослідження було засновано на аналізі літературних даних, матеріалів базового лісовпорядкування та моніторингу погодних умов за допомогою сервісу Meteoblue. Детальне обстеження на модельних деревах дозволило визначити видовий склад, щільність поселення та продукцію молодих жуків ксилофагів за кількістю маточних ходів та вильотних отворів на 1 дм^2 поверхні стовбура. Встановлено, що обсяги вибіркових санітарних рубок є безпосередньою реакцією на кліматичний стрес; пікові показники проведення заходів корелюють із періодами екстремальних температур та дефіциту вологи. Більшість насаджень мали низький 3-й клас стійкості та значну частку сухостою (5-20 % запасу). В осередках всихання ідентифіковано комплекс комах-ксилофагів: *Ips acuminatus*, *Ips sexdentatus*, *Phaenops cyanea*, а також *Tomicus piniperda* та *Tomicus minor*, які мають найвищу щільність поселення та продукцію молодих жуків. Також зафіксовано масове ураження сосновою губкою *Phellinus pini* та погіршення естетичного стану через накопичення захаращеності. Отримані дані підтверджують високу вразливість чистих соснових монокультур до сучасних гідротермічних викликів у межах лісів зелених зон. Обґрунтовано необхідність переходу до формування біологічно стійких змішаних насаджень та впровадження методів адаптивного управління, які поєднують принципи санітарного оздоровлення з підтримкою рекреаційного потенціалу приміських лісів

Ключові слова: стовбурові шкідники; патогени; життєздатність насаджень; гідротермічний стрес; вибіркові санітарні рубки