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# Pyrological Characteristics of Forest Edges under Intensive Recreational Loads

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**Abstract**. The increase in fires in urban landscapes causes adverse and sometimes irreversible changes in forest ecosystems. The modern solution is to find the places of primary fires and the most dangerous areas. The purpose of this study was to find dependences between the forest typological features of forest stands and their fire danger. To fulfil this purpose, a systematic analysis of forest fire danger and phytoindication were performed. The composition of the flora of edge biotopes was figured out using the route geobotanical method. The article analyses forest fires that occurred in urban forests of Kyiv during 2014-2021. Primary ignition locations have been identified. It was proved that fires often occurred on the forest edges, as well as along highways and railways. Among the standard indicators of fire danger (number and area of forest fires), the method makes provision for establishing the fire frequencies in the same forest area. This indicator allows figuring out the most dangerous areas from the pyrogenic standpoint. It was found that the simple edge is characterised by a minimal taxonomic composition in the ground vegetation and its projective cover of up to 20%. The grass tier stabilises the environment and mitigates the effects of extreme natural phenomena. The vegetation cover of an elementary and multicomponent edge is one of the barriers that can stop surface fires. Taxonomic diversity, especially of deciduous species, determines the pyrological features of forest edges. Analysis of the flora of marginal biotopes showed that oligotrophs, xerophytes, and xeromesophytes predominate among the species of simple edges. The share of ruderal elements in the ground vegetation was 36%, which indicates a significant anthropogenic impact and synanthropisation of the flora of the edges. These processes adversely impact the conservation of typical species but have a fire-retaining effect. Analysis of forest fires dynamics under intensive recreational loads allows substantiating the vectors for fire safety improvement, choosing a strategy for ensuring fire safety, and increasing the economic and social efficiency of fire prevention measures. It is proved that the forest edge is one of the decisive factors in the fire behaviour arising from a nonwooded area. The formation of multicomponent edges will help minimise the risks of fires

**Keywords**: fire safety, forest edge biotopes, ground vegetation, biodiversity, conditions of intensive recreational loads on forest stands

## Introduction

Extreme weather events that humanity has observed over the past 30 years pose a threat to the world's forests due to the increased probability of forest fires. Every year, up to 400 thousand cases of fires are recorded in the forests of our planet, which damage about 0.5% of the total area of forest areas [1]. An analysis of the world's forests affected by fires has shown that about 67 million hectares of forest are burned annually in the world [2]. It is expected that in the future, climate change will lead to longer fire seasons, more intensive fires around the globe, including areas where fires were previously absent [3; 4]. It is possible to prevent the occurrence of fires or localise them on a small area, provided the understanding of the causes of the fire and the ecology of the fire sites.

In Ukraine, most fires occur for social reasons [5]. In recreational forests, the anthropogenic factor of promoting the spread of fire occurs in almost 100% of cases. Preventing the occurrence and spread of forest fires is one of the most urgent and important tasks of forestry in Ukraine. Anthropogenic forest landscapes are of particular importance, given the probability of fires. Most often, forest fires are recorded near settlements, roads, and recreation

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areas. On the territory of the forest fund of Ukraine, the risk of forest fires directly depends on the recreational load on forest stands, and with an increase in the recreational development of forest areas, the number of forest fires increases. Careless handling of fire under favourable natural and weather conditions causes most fires. Urbanised landscapes are exposed to anthropogenic impact, which is often accompanied by fires of varying intensity. Forest flammability analysis allows setting up fire highs and lows. Prevention of forest fires under intensive anthropogenic stress should also include research on the ecological structures of forest stands. A separate task of the forest sector is to create fire-resistant landscapes that include natural barriers that can limit the spread of fire in the forest.

In the complex of fire prevention, restrictive measures occupy a prominent place and allow creating a system of barrier strips that prevent the rapid spread of fires, as well as simplifying their extinguishing. Fire curtains are arranged using the fire-resistant properties of deciduous tree species. Forest edges can serve as a natural barrier that can protect forest landscapes from fires and stop their spread deep into the forest. In this case, the forest edges perform regulatory functions, which lie in changing the behaviour of fires. Forest edges of the desired structure and composition can be formed artificially. At the edge of the forest, the density and biomass of individual species is higher compared to the neighbouring forest and open space. According to their morphology, the edges of the forest can be of three types [6]: simple, elementary, and multicomponent. In the simple edge of the forest, trees differ slightly in height, diameter, and crown size from those that grow deep in the forest. The simple edge is unstable to the negative influence of external factors. An elementary edge of the forest has a distance to the depth of the forest less than the average height of the trees. The elementary edge of the forest does not differ in species diversity. The multi-component forest edge has a depth of 1.5 or more heights of the tree stand. The composition of trees and bushes forming it can be more than 6-10 species.

The multidimensional nature of the fire regime includes fire frequency, interval, seasonality, intensity, spatial aspects (size, configuration), and the study of the relationship between fire danger and biodiversity [7]. In the context of forest fires, the importance of restoring biodiversity from fires also remains relevant.

In terms of their pyrogenic properties and influence on the spread of fires, forest edges were investigated by the authors of [8] using remote sensing methods. Considerable attention is paid to the investigation of the impact of fires on forest fragmentation and changes in the tax characteristics of trees [9]. Scientists pay special attention to studying the structure of forest stands covered by fires [10]. Mensuration of stands revealed that the edges can have a unique composition, structural features, and accumulate dry wood [11].

It is proved that in most cases fires were caused by critical weather conditions [3; 5; 12]. Fires often occurred regardless of the excessive cost of extinguishing forest fires and the level of preparedness in the countries where they occurred. Therefore, some scientific publications specifically investigate the influence of temperature and other conditions on the occurrence and spread of forest fires. The area of fires depends on weather conditions – wind strength, stocking, spacing of trees by area, humidity of combustible materials [12].

Pyrological characteristics and specific features of forest edges associated with recreational load have not been previously studied. In addition, the scientific literature holds no information on the relationship between the type of forest edge and the probability of fires. The originality of the results obtained lies in the justification of the pyrological properties of the forest edges that have undergone changes from recreational loads. This study is the first to compare the pyrological characteristics of forest edges of different forest types.

*The purpose of this study* was to find dependencies between the forest typological features of forest stands and their fire danger. Forest combustible materials are an essential factor in the spread of fires. The sanitary condition of forest stands also serves as one of the pyrological characteristics of forest stands. The results of pest activity and the impact of forest diseases contribute to the accumulation of forest combustible materials on the edges. To fulfil this purpose, the qualitative and quantitative indicators of the components of edge biotopes that determine their pyrogenic features were analysed and generalised. The research objectives included statistical analysis of the number of cases and areas of fires, distribution of fires depending on the types of forest edges, phytoindication and assessment of the systematic structure of the flora of anthropogenically modified edges.

## Materials and Methods

The study was conducted in the urban forests of Kyiv based on Darnytsia Communal Forest-Park Enterprise, Sviatoshino Communal Forest-Park Enterprise and Koncha Zaspa Communal Forest-Park Enterprise. According to physical and geographical zoning, the territory of enterprises belongs to Kyiv Polissia. The initial data for system analysis were obtained from the "Forest fire accounting books" of forest park enterprises in Kyiv [13-15]. The research period was eight years (2014-2021). In each of the forest park enterprises, more than 10 plots were surveyed by the route method, and a forest description was carried out. Biometric indicators, species composition, and sanitary condition of the tree stand were investigated using well-known methods in forestry [16].

Forest types were figured out according to Professor B. Ostapenko's method [16]. The grass tier and its biomorphological structure are presented using the reconnaissance method of geobotanical studies [17]. The composition of the flora of marginal biotopes was performed using the route geobotanic method, with identification of species and estimation of the projective cover of ground vegetation on the Braun-Blanquet scale [17]. Ukrainian names are given according to Yu. Kobiv [18], and Latin names are given according to S.L. Mosyakin, M.M. Fedoronchuk [19; 20]. Established trophomorphs: oligotroph (OgTr); mesotroph (MsTr); megatroph (MTr). Hygromorphs were also diagnosed: hygrophiton (Hg); mesophiton (Ms); xerophiton (X). To find the degree of anthropogenic transformation, a five-point scale of stages of recreational digression was used [7].

The study included materials from the latest state forest accounting in the specified region. Statistical data was processed using the Microsoft Excel computer program.

## Results and Discussion

On the territory of urban forests in Kyiv during the fire-hazardous period, forest fires occur with different frequency [21]. According to official statistics, during the audit period, over 8 thousand cases of forest fires were registered in pine forest stands with a total area of more than 1.5 thousand hectares. The average area of the plot covered by the forest fire was 0.86 hectares. Within the fire hazard period, the fire maximum (according to the number of fires) was observed in June, and the fire minimum – in October. The time of detection of fires was mostly between 1200 and 1600. All the fires found were surface fires. The area under study is characterised by a relatively high average class of natural fire danger – II,27 [13-15]. The probability of a forest fire is quite high. The analysis of annual preventive and restrictive measures confirms the elevated level of readiness of enterprises for the fire-hazardous season. Therewith, areas where the probability of fires is elevated require added research.

Places of primary ignition were as follows: edges, unfurnished recreation areas, territories along highways and railways, agricultural land, as well as, directly, forest areas. The span diagram (Fig. 1.) presents the quantitative characteristics of fires for the period under study.

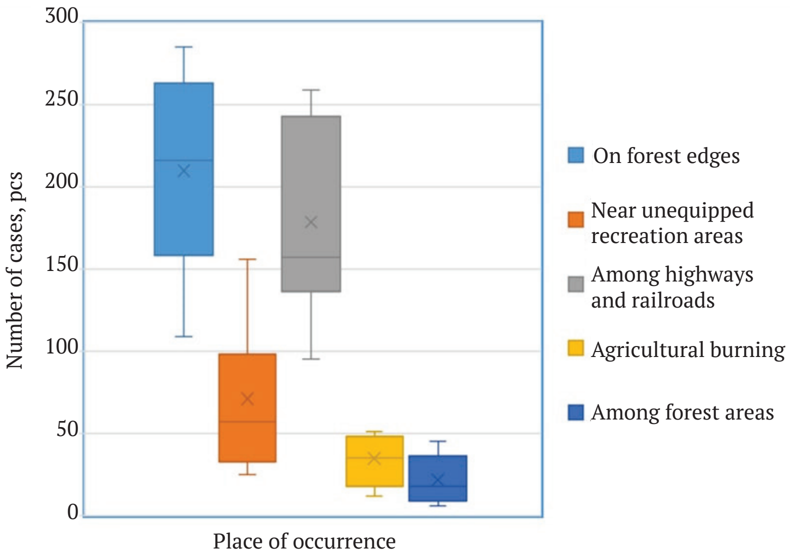


**Figure 1**. Statistical data on the number of cases of forest fires

The distribution of the number of fire cases is uneven and focuses mainly on the forest edges (34%) and along highways and railways (26%), the lowest number of cases was recorded among forest areas (7%). Fires near recreation areas were found only in places that were not properly equipped. Studies have also proved [12] that due to the considerable number of visitors to forests during the fire-hazardous period, conditions of elevated risk of fire are created on dry days. It is during such periods that sources of controlled fire often turn into fires. Due to the small areas of agricultural lands near the urban forests of Kyiv, the number of fires that have moved from these lands is relatively lower.

The average number of cases of forest fires can be figured out from the median. The highest median was recorded at the edges. The scale of the number of detected fires also falls on the territory of the forest edges (from 109 to 285 cases).

Depending on the type, the edge of the forest may be the place where forest fires occur, or the place where they stop. Figuring out the features and pyrological characteristics of firebreak edges will help combat fires by limiting their spread. The main indicators for assessing forest fires are their number, area, and average repeatability in the same location (Table 1).

**Table 1**. Distribution of fires depending on the type of forest edge

| Edge type | Share of forest fires by number, % | Share of forest fires by area, % | Average repeatability, times |
|---|---|---|---|
| Simple | 76 | 89 | 6 |
| Elementary | 21 | 8 | 2 |
| Multicomponent | 3 | 3 | – |

**Source:** developed by the authors

As Table 1 shows, most often forest fires occur in simple edges (76% of the total number), where they occupy the largest area (89% of the area of all fires on the forest edges). The average frequency of fires is also highest in the simple edge of the forest. Thus, from a pyrogenic standpoint, the most dangerous is a simple edge.

Due to the considerable proportion of forest fires on the edges, it is important to form multicomponent edges, by planting deciduous tree species and cutting down to improve the quality composition of forests. Such edges should become a barrier to the spread of fire, curbing the spread of fire from the forest to the locality and vice versa.

The realisation that forest fires are an integral part of many ecosystems encourages the study of fire-resistant forest areas compared to more sustainable ones [22]. The floral composition of edge biotopes is usually typical and has a set of common species. This is especially true for the living ground cover, which includes ruderal and synanthropic species. Plants of living ground cover perform many functions in the landscape, including the formation of primary biomass, regulation of land runoff, and the formation of a local microclimate. Thus, land cover stabilises the environment and mitigates the effects of extreme natural phenomena. Currently, land cover is one of the barriers that can stop forest fires. The floral structure is an indicator not only of taxonomic richness, but also of pyrological characteristics of the edges (Table 2).

**Table 2.** Floral structure of ground vegetation in diverse types of forest edges

| Edge type | General projective cover<br>moss tier<br>shrub tier, % | Most common plant species | Taxonomic diversity, species |
|---|---|---|---|
| Simple | 0-5<br>15 | *Pinus sylvestris* L.<br>*Centaurea Marschalliana* Spreng.<br>*Chamaecytisus singeri* (Nenuk.) Klaskova<br>*Euphorbia seguierana* Neck.<br>*Festuca ovina* L.<br>*Helichrysum arenarium* (L.) Moench<br>*Keleria glauca* (Spreng.) DC.<br>*Veronica incana* L.<br>*Dicranum polysetum* Sw.<br>*Cladonia mitis* Sandst. | up to 15 |
| Elementary | 0-5<br>35–110 | *Pleurozium Schreberi* (Brid.) Mitt.<br>*Urtica dioica* L.<br>*Viola arvensis* Murr.<br>*Veronica chamaedrys* L.<br>*Stellaria graminea* L.<br>*Sedum telephium* L.<br>*Hieracium pilosella* L.<br>*Impatiens parviflora* DC.<br>*Geranium robertianum* L.<br>*Festuca ovina* L.<br>*Dactylis glomerata* L.<br>Carex *ericetorum* Poll.<br>*Berberis vulgaris* L.<br>*Betula pendula* Roth.<br>*Acer tataricum* L.<br>*Crataegus monogyna* Jacq.<br>*Pinus sylvestris* L.<br>*Pyrus communis* L. | up to 37 |
| Multicomponent | 0<br>15–70 | *Populus tremula* L.<br>*Quercus robur* L.<br>*Quercus borealis* Michx.<br>*Prunus spinosa* L<br>*Sambucus racemosa* L.<br>*Spiraea media* Franz Schmidt.<br>*Sorbus aucuparia* L.<br>*Achillea submillefolium* Klok. et Krytzka<br>*Festuca pratensis* Huds.<br>*Geum urbanum* L.<br>*Impatiens parviflora* DC.<br>*Poa trivialis* L.<br>*Rubus caesius* L.<br>*Sedum telephium* L.<br>*Stellaria media* (L.) Vill.<br>*Polygonatum odoratum* (Mill.) Druce. | up to 58 |

**Source:** developed by the authors

The simple edge is characterised by a minimal taxonomic composition, especially in the ground vegetation, as well as a low projective cover of the grass tier. Lichens and mosses are most often burned by surface fire [8], and the grass layer of the ground vegetation is more resistant to fire. In the areas of the forest edges where the highest species richness of fires was recorded, there were no fires, while the territories covered by surface fires have almost equally low rates of the number of species [9]. We confirmed the study of the above-mentioned works and found that the taxonomic richness of forest edge biotopes and projective cover define the probability of forest fires and contribute to its localisation.

Species of ground vegetation on the forest edges that were covered by surface fires were studied. Analysis of the flora of edge biotopes in relation to nutrition showed (Fig. 2) that oligotrophs (69.4%) and mesotrophs (25.3%) predominate among the species, megatrophs are represented by the smallest number (5.3%). Among hygromorphs in the flora of marginal biotopes (Fig. 3), xerophitons (37%), xeromesophitons (26%), and mesophitons (12%) predominate, the lowest number is represented by mesohygrophitons (3%) and hygrophitons (1%).

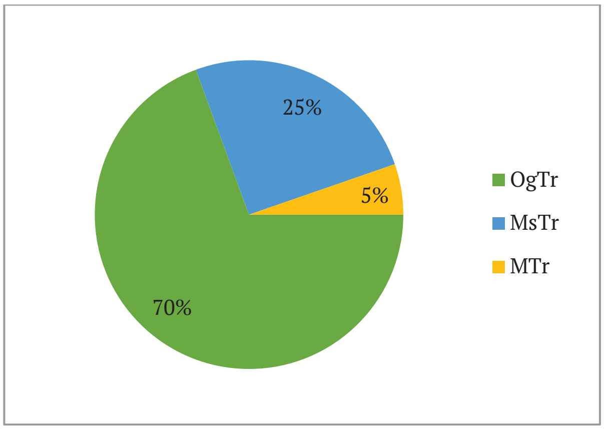


**Figure 2**. Trophomorph species spectrum

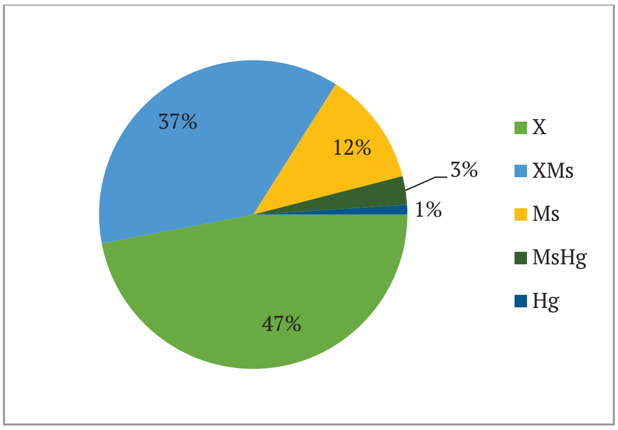


**Figure 3**. Hygromorph species spectrum

The consequences of anthropogenic impact on the herbaceous vegetation lead to changes in the ecotope, cause transformation of the grass tier with changes in the systematic structure, invasion of meadow species, synanthropisation, and also inhibit the natural renewal and development of trees [17; 23]. A study of edge species of ground vegetation showed that the share of ruderal elements is 36%. This indicates a powerful anthropogenic impact on the research area and diagnoses an elevated level of synanthropisation of the forest edge flora. These processes set back the conservation of typical species but have a fire-retaining effect. Some authors explain the increased fire vulnerability of individual areas by fragmentation of the forest cover, which creates favourable conditions for the spread of fire [10]. In cases where the intensive recreational load leads to a decrease in species diversity, and, accordingly, to fragmentation and increased insolation of the site, it is possible to claim an increase in the fire hazard of the territory.

An important pyrological feature of forest edges is the sanitary condition. Phytophage insects and pathogens adversely affect the sanitary condition of the forest and contribute to the accumulation of forest combustible materials on the forest edges. The most common pathological factors of weakening forest edges in the urban forests of Kyiv are white mistletoe *Viscum album* L., *Phellinus pini* (Thore et Er.) Pil., *and Fomitopsis annosa* (Fr.) Karst. The following pathogens were found in the examined tree stands: *Piptoporus betulinus* (Bull. ex Fr.) Karst., *Phellinus tremulae* (Bond.) Bond. et Boriss., *Inonotus dryophilus* (Berk.) Murr., *Ganoderma applanatum* (Pers. ex Wallr.) Pat., *Pseudomonas quercina* Schem., *Nectria galligena* Bres., *Sphaeropsis malorum* Peck., *Cronartium flaccidum* (Alb. et Schw.) Wint., *Lophodermium pinastri* Chev. Among the harmful insects that often focus on the edges, the most common include *Acrocercops brongniardella* F., *Hyponomeuta rorella* Hb., *Aradus cinnamomeus* Panz., *Argyrestia glabratella* Z. *and Operophthera brumata* L.

The results of the study highlight the pyrological features of edge biotopes and are important in detecting direct links between the features of the floral structure and the frequency of forest fires.

## Conclusions

During 2014-2021, a third of fires in urban forests were recorded on the edges (34%) and along highways and railways (26%). Fires near recreation areas were found only in territories that were not properly equipped.

The pyrological features of forest edges in recreational forests directly depend on the type of forest edge and the sanitary condition of the forest stand. An increase in ruderal species positively affects the fire resistance of forest stands. The taxonomic richness of edge biotopes is directly proportional to the probability of forest fires and contributes to its localisation.

Analysis of forest fires dynamics under intensive recreational loads allows substantiating the vectors for the improvement of forest protection systems in Ukraine, choosing a strategy for ensuring fire safety, and increasing the economic and social efficiency of fire prevention measures. The analysis suggests that the edge of the forest is one of the decisive factors in the behaviour of forest fires. The formation of multicomponent forest edges can be one of the strategic directions of forestry development to ensure fire safety, which is aimed at minimising the risks of fires.

Further studies of the pyrological features of the edges allow establishing the optimal composition and structure of the stand in terms of preventing the occurrence and development of forest fires. Identifying the components of stands that affect their pyrogenic features will be of practical importance in the formation of fire-resistant urbanised landscapes.

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## Пірологічна характеристика лісових узлісь за умов інтенсивних рекреаційних навантажень

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**Анотація.** Збільшення пожеж в урболандшафтах спричиняють негативні та інколи незворотні зміни в лісових екосистемах. Сучасне вирішення проблеми, в першу чергу, полягає у виявленні місць первинних займань та найбільш небезпечних ділянок. Мета досліджень передбачала виявлення залежностей між лісотипологічними характеристиками деревостанів узлісь та їхньою горимістю. Для досягнення поставленої мети здійснено системний аналіз горимості лісів та фітоіндикацію. Склад флори узлісних біотопів проводився за допомогою маршрутного геоботанічного методу. У статті проаналізовано лісові пожежі, які виникали в міських лісах Києва упродовж 2014-2021 рр. Визначені місця первинного займання. Доведено, що пожежі часто виникали на узліссях, а також вздовж авто та залізничних доріг. Серед стандартних показників горимості (кількість та площа лісових пожеж) методикою передбачено встановлення повторюваності пожеж в одній і тій самій лісовій ділянці. Даний показник дозволяє виявити найбільш небезпечні з пірогенної точки зору площі. Встановлено, що несправжнє узлісся характеризується мінімальним таксономічним складом у живому надґрунтовому покриві та його проективним покриттям до 20 %. Трав'яний ярус стабілізує стан навколишнього середовища та пом'якшує наслідки екстремальних природних явищ. Рослинний покрив елементарного та багатокомпонентного узлісь є одним із бар'єрів, який здатний зупинити низові пожежі. Таксономічне багатство, особливо листяних видів, визначає пірологічні особливості лісових узлісь. Аналіз флори узлісних біотопів показав, що серед видів несправжніх узлісь переважають оліготрофи, ксерофіти та ксеромезофіти. Частка рудеральних елементів в живому надґрунтовому покриві становили 36 %, що свідчить про значний антропогенний вплив та синантропізацію флори узлісь. Зазначені процеси несуть негативний вплив на збереження типових видів, але мають пожежостримуючий ефект. Аналіз динаміки виникнення лісових пожеж за умов інтенсивних рекреаційних навантажень дає змогу обґрунтувати напрями покращення пожежної безпеки, обрати стратегію забезпечення пожежної безпеки, підвищити економічну і соціальну ефективність протипожежних заходів. Доведено, що узлісся є одним з вирішальних факторів поведінки лісових пожеж, що виникають з безлісної території. Формування багатокомпонентних узлісь сприятиме мінімізації ризиків виникнення пожеж

**Ключові слова:** пожежна безпека, узлісні біотопи, живий надґрунтовий покрив, біорізноманіття, умови інтенсивних рекреаційних навантажень