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Assessment of carbon emissions due to landscape fires in Ukraine during war in 2022

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Abstract. The Russian military aggression and the related socio-economic and environmental consequences have significantly affected the climate and production of ecosystem services through damage to forests, ecosystems, landscape fires and emissions of gases into the atmosphere. The study aims to estimate carbon dioxide emissions due to landscape fires in Ukraine during the year 2022. The OroraTech wildfire monitoring technology was used to detect fires, while perimeters of burned areas were delineated with Sentinel 2 time series. The Copernicus Dynamic Land Cover map was used to extract burned land covers. Emissions were calculated based on the intensity of fires (dNBR) with the share of burned biomass in different types of land cover. Biomass models were selected considering the dominant tree species within a specific region and the species structure of the sown areas of croplands. The volume of biomass losses was estimated as a result of fires of different severities. It was estimated that during in 2022, landscape fires burned 749.5 thousand hectares thereof: croplands – 419.1 thousand hectares; other natural vegetation – 273.8 thousand hectares; conifer forests – 31.1 thousand hectares; other forests – 25.5 thousand hectares. The impact of the war on landscape fires is confirmed by the large proportion of fires in the 60-kilometre buffer zone along the frontline – 68.9% of the total area of fire. Among all fires, 42.5% of fires occurred in the occupied territory. Total CO₂ emissions from all types of landscape fires reached 5.20 million tons and other greenhouse gases – 0.28 million tons. It is the first detailed mapping of landscape fires with an analysis of each polygon for the whole territory of Ukraine. The results provide important information for assessing the loss of ecosystem services and estimating carbon dioxide emissions as well as for confirming the impact of hostilities on landscape fires

Keywords: wildfires; burned area; CO₂ emissions; land cover type; biomass; mapping

Introduction

An unprovoked Russian full-scale military invasion that started on February 24, 2022, resulted in unprecedented consequences for people, infrastructure, and environment. In particular, disturbances related to battles, shelling, military vehicles and infantry activities, and fortification facility establishment occurred on areas of millions of hectares, including protected areas. Landscape fires, i.e., forest fires, intentional but uncontrollable burning of vegetation residues on cultivated lands (croplands, pastures), uncultivated grasslands or degraded lands, and associated greenhouse gas emissions, became one of the most essential and wide-scale consequences of the war.

Carbon emission assessment of wildfires is an important part of the development of a new green climate global policy and action

plan similar to Green Deal or others. L. Volkova *et al.* (2022) found that a loss of just 1% biomass could be detected between low- and high-severity fires with foliage and partial bark combustion and unburned stem wood. Carbon emissions from forest fires in 2020 across the western United States were in a range from 18.60±1.04 Mg C·ha⁻¹ to 29.70±1.66 Mg C·ha⁻¹ (Bartowitz *et al.*, 2022). According to S. Germand *et al.* (2021) average tree C losses were 114.0 Mg C ha⁻¹ (std. dev. ±9.9 Mg C ha⁻¹) in wet riparian sites and 86.9 Mg C ha⁻¹ (std. dev. ±13.5 Mg C ha⁻¹) in the dry valley site of the southern Canadian montane valley ecosystem, in Waterton Lakes National Park, Alberta Canada.

As a result of high-intensity fires, high tree mortality converts live trees to deadwood, which gradually decomposes. J.E. Stenzel *et*

al. (2019) found that high-intensity fire combusts less than 5% of live tree biomass in mature stands. The regional emissions estimates using widely implemented combustion coefficients are 59%-83% higher than emissions based on field observations.

Despite a significant number of publications on carbon emissions after fires (Zheng *et al.*, 2021), this issue has been researched fragmentarily in Ukraine. Assessment of carbon losses using remote sensing methods in Ukraine was implemented for the Chernobyl Exclusion Zone (CEZ) (Matsala *et al.*, 2023). In this publication, post-fire carbon stock on training forest polygons was calculated by applying local combustion factors within the CEZ. The relative carbon loss was derived using the stand-alone delta of backscatter at vertical-horizontal polarisation or based on the model calibrated with four SAR-based predictors. The total loss of carbon stock resulting from the 2020 catastrophic wildfire was estimated at 156.3 Gg C. Carbon loss in Scots pine stands was 7.4 ± 2.8 Mg C·ha⁻¹. The estimated average carbon loss based on inventory data is $9.3 \pm 5.1\%$ and the mean predicted carbon loss was $11.0 \pm 4.1\%$. According to L.A. Pysarenko & M.V. Savanets (2020), the average long-term values of carbon emissions for the territory of Ukraine vary within the limits of 0.2-1.0 g·m⁻²·month⁻¹. For dry particle flows, the average values are mainly 1.0-3.0 g·m⁻²·month⁻¹. According to the 2023 National Inventory Report (NIR) (2023), the CO₂ emissions from forest fires were 5.75 kt in 2021.

There have been only a few studies to estimate carbon emissions from fires during the war in Ukraine, mainly due to data gaps in such assessment. Among them the most completed assessment of the joint team of L. de Klerk *et al.* (2023), who provided the first and second interim assessments. One of the good reviews of the problem of estimating carbon emissions from fires was made by S. Malo (2023). The main

methodological issues of carbon emissions estimation are assessing the burn area, determining the type of affected vegetation, estimating the total biomass, and calculating the proportion of biomass burned. The main research objective of this study is to estimate carbon emissions from landscape fires in Ukraine in 2022.

Materials and Methods

The carbon emissions in 2022 were calculated throughout the entire territory of Ukraine. The research was conducted following the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973). To achieve the aim of the study, it was necessary to calculate the following indicators: burned areas and fire severity; carbon emission from forest fires; carbon emission from cropland burning; and carbon emissions from fires within other natural landscapes.

Burned areas and fire severity

Two remote sensing data sources were harnessed for fire detection and burn area delineation. The special wildfire monitoring service OroraTech was used to detect ignition locations. The system uses aggregated data from over 20 satellites for tracking daily fire. It combines different fire detection approaches provided by more than 20 satellites for the daily identification of fire locations. A time series of Sentinel 2 (Level 2A) surface reflectance data was used for mapping the fire perimeter based on the identified ignition points and corresponding dates. Scene Classification (SCL) band classes were applied to exclude clouds, cloud shadows, and snow. Median image mosaics, generated within a 14-day timeframe, were utilized to manually outline fire perimeters. The Copernicus Dynamic Land Cover 100 m resolution map (2019) was used for land cover type identification within the established fire polygons (Buchhorn *et al.*, 2020). The delta NBR (dNBR,

Normalised Burn Ratio) approach was applied to assess burn severity (Key & Benson, 2006). Pre-fire image mosaics were created by selecting the pixels with the highest NBR values in the 40-day window before the fire. Then, post-fire median mosaics were created from cloud-free images within 5, 10, 15, ..., and 40-day intervals after the fire. The burn severity was mapped using maximum dNBR-value composites obtained for the specified post-fire intervals. This iterative method mitigated the impact of potential vegetation regrowth during the post-fire period and ensured sufficient cloud-free data coverage. The dNBR values were categorized into three discrete burn severity classes: low (0.090-0.179), medium (0.180-0.549), and high (more than 0.550) (Myroniuk *et al.*, 2022). Mean values of burn severity levels were calculated for different land cover types (coniferous forests, broadleaf forests, croplands, other natural vegetation, and urban territories), which were subsequently used in carbon loss assessments. The study primarily focused on the emission of carbon compounds such as CO₂, CO, and CH₄, which constitute 95% of wildfire emissions (Urbanski, 2014).

Carbon emission from forest fires

Species and age structure of forest stands were used for carbon emissions estimation. The age and species structure of forest stands determine the total volume of biomass and the level of biomass losses from fires of different inten-

sity. According to the latest data of the forest assessment in Ukraine (Handbook of the Forest Fund of Ukraine, 2012), the distribution of forested area between coniferous and broadleaved species was estimated for each administrative oblast (region) of Ukraine. Then, their areas were distributed between young, middle-aged and premature, mature and overmature forest stands. Further, the total volume of biomass within the classified forest stands was estimated using mathematical models, compiled by A.Z. Shvidenko *et al.* (2014) and A.M. Bilous (2018). The models were selected considering the dominant tree species within a specific region: coniferous (pine, spruce), broadleaf (oak, beech, birch, aspen, and alder). Different types of forest fires as a surface, canopy (crown) or combined can form different degrees of damage: low (damage to the upper layer of the litter, ground cover, undergrowth and slight burning of the bark of tree stems), medium (damage to the bark of tree stems and lower branches of the crown, destruction of trees of category IV and V according to the Kraft scale) and high (destruction of a significant number of elements of the forest stand). There is lack of scientific publications on forest biomass losses due to different intensities of forest fires in Ukraine. Thus, the study used only limited scientific data (Bartowitz *et al.*, 2022; Matsala *et al.*, 2023) and experts' estimates. Coefficients of forest biomass losses due to forest fires are presented in Table 1.

Table 1. Average forest biomass losses coefficients due to forest fires, %

Age group	Fire severity level, dNBR	Component of forest biomass				
		Stem**	Bark	Branches	Undergrowth*	Litter
<i>Coniferous species</i>						
Young (0-20 years)	Low	10	x	10	30	30
	Medium	20	x	30	50	50
	High	40	x	60	100	100
Young (21-40 years)	Low	x	x	10	30	30
	Medium	x	1	20	50	50
	High	x	2	40	95	95

Table 1, Continued

Age group	Fire severity level, dNBR	Component of forest biomass				
		Stem**	Bark	Branches	Undergrowth*	Litter
Middle-aged and premature (41-80 years)	Low	x	x	x	30	30
	Medium	x	1	x	50	50
	High	x	2	5	90	90
Mature and overmature (81 years and older)	Low	x	x	x	30	30
	Medium	x	x	x	50	50
	High	x	1	5	90	90
<i>Deciduous species</i>						
Young (0-20 years)	Low	5	x	10	20	20
	Medium	10	x	20	30	30
	High	30	x	40	80	70
Young (21-40 years)	Low	x	x	x	20	20
	Medium	x	1	10	30	30
	High	x	x	30	70	70
Middle-aged and premature (41-100 years)	Low	x	x	x	20	20
	Medium	x	x	x	25	30
	High	x	1	x	65	70
Mature and overmature (101 years and older)	Low	x	x	x	15	20
	Medium	x	x	x	25	30
	High	x	x	x	65	70

Note: * Undergrowth (living ground cover, young trees, and brushwood); ** – Stem with bark

Source: K.J. Bartowitz et al. (2022), M. Matsala et al. (2023)

The carbon emissions as a result of forest fires were calculated using the following equation:

$$C_{em} = M_{fr} \cdot K_{cf} \cdot K_{lf}, \quad (1)$$

where C_{em} – volume of carbon emissions, t; M_{fr} – dry matter mass of individual components of biomass, t; K_{cf} – coefficient of carbon content in a component of biomass (bark, branches – 0.5; leaves, living ground cover, litter – 0.45); K_{lf} – coefficient of forest biomass losses due to forest fires of different severity (Table 1).

Carbon emission from fires on cropland

Dominant crop species within the sown areas were determined using the crop area distribu-

tion in different regions of Ukraine. According to the Ministry of Agrarian Policy and Food of Ukraine, in 2022, wheat, barley, sunflower, and corn dominated among crops, covering almost 85% of the sown areas. The following ratios of the mentioned crops were used: wheat – 37.3%, barley – 10.8%, sunflower – 26.1%, and corn – 25.8%. Yields of the crops (in t·ha⁻¹) within each region was determined based on national statistics data (Verner, 2021). Biomass volume was determined by the coefficients of the total yield of surface and root crop residues (Table 2) with the yields of crop species considered (Kokhana & Glushchenko, 2015).

Table 2. Coefficients of yield residues depending on crop harvests

Crops	Coefficient of the total yield of by-products, stubble, and root residues	Non-marketable biomass remaining on field, %	
		by-products	stubble and root residues
Wheat	1.5	53	47
Barley	1.3	52	48

Table 2, Continued

Crops	Coefficient of the total yield of by-products, stubble, and root residues	Non-marketable biomass remaining on field, %	
		by-products	stubble and root residues
Sunflower	3.5	50	50
Corn	1.4	58	42

Source: A.V. Kokhana & L.D. Glushchenko (2015)

The calculations considered that not only by-products but also the main crop would be lost due to fire in the 60-km buffer zone during May and July 2022, as a high density of shelling was observed. Volumes of carbon emissions as a result of fire on croplands were calculated by the following equation:

$$C_{em} = B_{pl} \cdot K_{cf} \cdot K_{pf}, \quad (2)$$

where C_{em} – volume of carbon emissions, t; B_{pl} – plant biomass in a completely dry state, t; K_{cf} – coefficient of carbon content in a unit of biomass (0.45); K_{pf} – coefficient that considers the fire severity (low – 0.9; medium and high – 1.0). *Carbon emission from fires on other natural landscapes*

Using the Official website of the State Statistics Service of Ukraine (n.d.) for geodesy,

cartography, and cadastre, the regional structure of other landscape types was determined. In 2020, the regional structure of landscapes, in addition to forest areas and arable land, also includes hayfields, fallows, and pastures. According to the Land Directory of Ukraine (2020), the share of each of the listed types of agricultural landscapes within each region was calculated. Productivity and biomass volumes were determined by types of landscapes. The productivity of the mentioned types of landscapes (in t·ha⁻¹) within each region is estimated following scientific data from numerous botanical and ecological publications and grouped by natural zones of Ukraine (Table. 3). Biomass losses are differentiated depending on the level of site damage and the type of landscape. Equation 2 was used to estimate carbon emissions from fires within other natural landscapes.

Table 3. Productivity of certain types of landscapes within natural zones

Natural zone	Dry matter yield, t·ha ⁻¹		
	Hayfields	Pastures	Fallows
Steppe	2.7	2.4	1.8
Forest steppe	4.2	3.8	2.8
Ukrainian Polissya	3.8	3.4	2.5
Ukrainian Carpathians	3.2	2.8	2.1

Source: M.I. Stakal (2020), V.I. Grigoriev et al. (2021)

As a result of applying the described algorithm by category (forest fires, fires on cropland, fires on other natural landscapes) burned areas by burn severity classes, biomass and carbon losses and greenhouse gas emissions were determined.

Results and Discussion

The total area of landscape fires in Ukraine in 2022 reached 749.5 thousand hectares. The majority of the affected territories were agricultural lands (croplands), accounting for 419.1 thousand hectares, and other natural vegetation

(abandoned lands) amounting to 273.7 thousand hectares. Forest fires burned 56.7 thousand hectares. In total, about 20 thousand fires were detected in 2022. A significant proportion of these fires occurred within a 60-kilometer buffer zone along the frontline, comprising 69% of the total fire-affected area, and 43% of all fires occurred in occupied territories (Zibtsev *et al.*, 2023). The territories most affected by fires are those where

active military operations were ongoing in the eastern, southern, and northern parts of Ukraine. Specifically, the most significantly impacted regions were Donetsk (146.3 thousand hectares), Kherson (84.1 thousand hectares), Kyiv (70.9 thousand hectares), Zaporizhia (65.6 thousand hectares), Luhansk (65.6 thousand hectares), Mykolaiv (47.7 thousand hectares), and Kharkiv (42.6 thousand hectares) (Fig. 1).

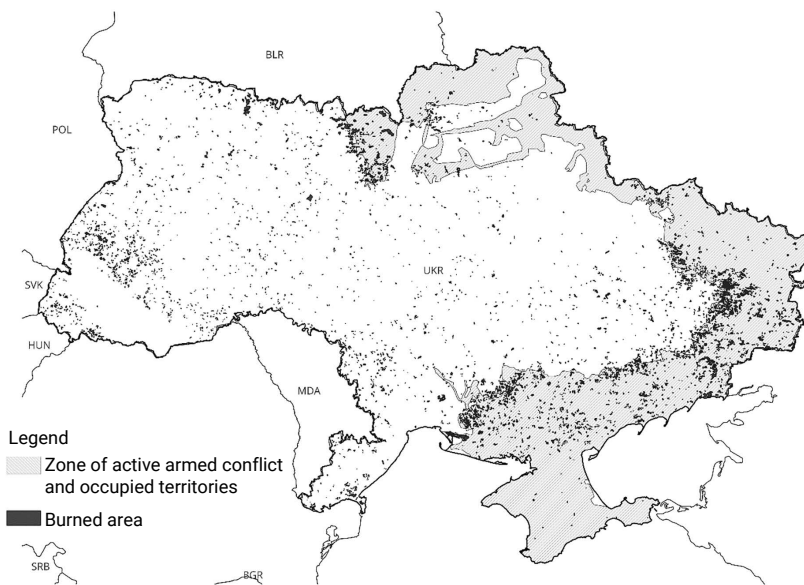


Figure 1. Distribution of fire perimeters in 2022 over the territory of Ukraine

Source: S. Zibtsev *et al.* (2023)

The distribution of the area affected by fires of different severity levels (based on dNBR values) showed that natural landscapes were mostly affected by medium burn severity (43.6-47.7%

of total area). High fire severity ($dNBR \geq 0.550$) observed on a small proportion of forested areas and, among all other land categories, high fire severity prevailed on croplands (Table 4).

Table 4. Assessing the condition of woody plants

Land category	Proportion of fire severity classes, %		
	Low	Medium	High
Coniferous forest	51.9	43.6	4.5
Other forest	46.8	44.4	8.8
Other natural vegetation	34.0	47.7	18.3
Cropland	22.7	45.9	31.4
Total	29.1	46.3	24.6

Source: calculated by the authors

Emissions of carbon dioxide from landscape fires in Ukraine reached 5.20 million tons in 2022 (Table 5). Carbon emissions were largest from fires on croplands (59%) and on uncultivated land (24%). Forest fires emitted over 16.9% of total carbon emissions (12.6% from fires in pine forests and 4.3% in broadleaf and mixed forests). Average carbon losses per 1 hectare during fires in coniferous forests were more than 2 times higher compared to other landscape types and broadleaf forests. Such

high carbon losses are associated with significant fuel load in pine forests and higher fire intensity. In broadleaf prevailing fires of low intensity burning dry surface fuel.

Results of the assessment done by L. de Klerk *et al.* (2023) showed a significantly different distribution of areas of fires by land cover types in comparison with current results (Table 6): 11.3% less area of fires on agricultural lands and 78.6% less area of fires in other landscapes (abandoned lands).

Table 5. Burned area, biomass and carbon losses, CO₂ emission by land category

Land category	Burned area, thous. ha	Biomass loss, Mt	Biomass loss, t·ha ⁻¹	Carbon loss, Mt	Carbon loss, t·ha ⁻¹	CO ₂ emission, Mt	Other greenhouse gases, Mt
Coniferous forest	31.1	0.33	10.66	0.14	4.59	0.53	0.05
Other forest	25.5	0.17	6.49	0.07	2.69	0.25	0.02
Other natural vegetation	273.8	0.78	2.83	0.35	1.28	1.28	0.06
Cropland	419.1	1.90	4.54	0.86	2.05	3.14	0.15
Total	749.5	3.18	4.33	1.42	1.89	5.20	0.28

Source: calculated by the authors

Table 6. Comparison of areas of fire on land categories in L. de Klerk *et al.* (2023) report and current study

Land category	Area of landscape fires, thous. ha (de Klerk <i>et al.</i> , 2023)	Area of landscape fires, thous. ha (current study)	Difference	
			Hectare	%
Forests	58.9	56.7	2215	3.9
Agricultural lands	371.7	419.1	-47409	-11.3
Other landscapes	58.6	273.7	-215167	-78.6

Source: prepared by the authors based on L. de Klerk *et al.* (2023)

Even though in our assessment the area of fires on croplands and grasslands was more than 262.6 thousand ha, the calculated carbon emissions from such types of lands in the study of L. de Klerk *et al.* (2023) were 11.69 million tons higher (Table 7). The reason for such difference is a peculiarity of the methodology for calculating biomass burned during fires for different types of natural and cultural landscapes. The

release of carbon during forest fires according to L. Klerk *et al.* (2023) is 210.8 t·ha⁻¹, while in our study this indicator is on average 13.7 t·ha⁻¹ (15 times lower). Among all landscape fires in 2022 in Ukraine, only a small share are forest crown fires that result in immediate biomass burning and carbon release. Fire weather during the fire season of 2022 was rather safe in the northeastern and eastern regions of Ukraine

and close to pretty safe in the 2013 year. More complete burning of biomass was typical for open types of landscapes (agricultural lands and other landscapes). Another source of differences with the report of L. de Klerk *et al.* (2023) is

methodological approaches in assessing the productivity of biomass on agricultural lands and other landscapes, which also contributed to an overestimation of 49.6-50.3% for CO₂ emissions in the L. de Klerk *et al.* (2023) report (Table 7).

Table 7. CO₂ emissions in the different land categories

Land category	CO ₂ , Mt (current study)	CO ₂ , Mt (de Klerk <i>et al.</i> , 2023)	CO ₂ , t·ha ⁻¹ (current study)	CO ₂ , t·ha ⁻¹ (de Klerk <i>et al.</i> , 2023)
Forests	0.78	12.41	13.7	210.8
Cultivated lands	**3.14	*4.19	7.5	11.3
Other landscapes	1.28	0.41	4.7	7.0
Total	5.20	17.01	-	-

Note: *all agricultural lands included croplands, pastures, and haymakers; **croplands

Source: developed by the authors based on L. de Klerk *et al.* (2023)

L. de Klerk *et al.* (2023) used data on fires (number of fires, fire start and end time, coordinates of the boundaries of each fire, land categories for each fire) from fire prevention information systems: Fire Information for Resource Management System (FIRMS) (n.d.) and the European Forest Fire Information System (EFFIS) (n.d.). Following the data given by L. de Klerk *et al.* (2023), 75% of forest fires in 2022 occurred in coniferous forests, 21% in broadleaf forests, and 4% in mixed forests. It is assumed that 75% of fires are canopy (crown), 25% – surface.

According to current research data, 55% (31.1 thousand hectares) of forest fires occurred in coniferous forests, mostly pine stands while 45% (25.5 thousand hectares) – in broadleaf and mixed forests. Analysis of the dNBR index showed that 30% of the fire areas are of low severity – weak or average surface fires. At this level, only the upper layer of the forest litter, the living above-ground forest grasses and, partially, undergrowth burns out. The bark of trees can be burned up to 1 meter in height with some temperature impact on external live layers of stems. More heavy impact on stands occurred with intensive ground fires (up to 1.5 flame length) that were a case in 46% of areas of fires, while severe impact (crown fires) occurred

in 24% of all fires. In the L. de Klerk *et al.* report (2023), it is assumed that 70% of forest biomass is lost due to the impact of crown fires that resulted in carbon emissions in the year of fires according to the Tier 1 approach of the Intergovernmental Panel on Climate Change (IPCC) guidelines. The average stock of wood was taken at the level of 233 m³·ha⁻¹. The same approach was used when estimating emissions from forest fires in the 2023 National Inventory Report (NIR) (2023).

L. de Klerk *et al.* (2023) considered emissions of other greenhouse gases: carbon monoxide (CO), methane (CH₄), non-methane volatile organic compounds (NMVOC) and nitrogen compounds (N₂O, NO_x). According to S. Urbanski (2014), emission factors are 1600-1641 (wildfire), 1705 (grassland) g/kg CO₂; 95-135 (wildfire), 61 (grassland) CO; 3.38-7.38, 1.95 (grassland) CH₄; 23.15-33.87 (wildfire), 16.87 (grassland) NMOC; 1.0-2.0 (wildfire), 2.18 (grassland) NO_x, the share of others is insignificant. According to H. Keith *et al.* (2014) in temperate Australian forests, 6-7% of biomass is lost as a result of low-severity wildfires and 9-14% as the result of high-severity wildfires. Direct emissions occurring during forest fires are caused by the burning of such forest

combustible materials as leaves, branches, woody debris, and other organic material on the soil surface. The proportion of the total carbon stock burned was relatively small (more than half of the stock losses from burning came from short-lived biomass components). A significant proportion of biomass, although not burned, is redistributed to dead components. The decomposition of these components and new recovery have the largest impact on carbon stocks in the coming decades. M.D. Hurteau & M.L. Brooks (2011) noted that long-term effects of fire are manifested in indirect fire emissions from the long-term decomposition of trees that have dried up, but not consumed by fire; this source can be as much as three times the size of direct carbon emissions. Established carbon dioxide emissions for forests during fires were 13 times lower compared to the data of L. de Klerk *et al.* (2023). Such differences were caused by significant differences in calculation methods: this article considered carbon emissions directly during a fire without addressing long-term changes in the redistribution of carbon in fire-damaged forests caused by post-fire tree mortality.

Conclusions

Russian military aggression against Ukraine has caused a drastic increase in the number and area of forest fires in Ukraine. Besides disturbing forests and open natural landscapes, biodiversity and negative social impacts, wildfires also produce large amounts of carbon emissions. Based on the data on wildfires mapped by the authors using remote sensing data of Sentinel 2 satellite images, this paper presents the results of the assessment of carbon emissions from landscape fires that occurred in Ukraine in 2022. The war was found to be a major factor in the fire situation, with 69% of the total area affected by fires in the 60-kilometre buffer zone along the frontline. In general, in 2022, there were about 20 thousand landscape fires on a

total area of 749.5 thousand hectares, with the most affected agricultural land (arable land) – 56%, other natural vegetation (abandoned land) – 37%, and forest fires – 7%.

It was estimated that direct emissions of carbon dioxide due to landscape fires in 2022 amounted to 0.78 million tons (775348.8 tons) on forest lands, on croplands – 3.14 million tons (3142750.8 tons), other landscapes 1.28 million tons (1280089.4 tons). Compared to de Klerk *et al.* (2023), the area of forest fires in our study was smaller by 3.9%, while fires on agricultural lands were higher by 11.3%, and other landscape fires by 78.6%.

To obtain more accurate data on carbon emissions from fires in Ukraine's natural landscapes and to assess the negative environmental consequences caused by the war, it is necessary to conduct massive fieldwork to establish burning intensity (burn severity) for different types of landscapes. The next step to improve the proposed methodology for estimating carbon emissions after a fire is to predict the post-fire dynamics of forest ecosystems, which may include the recovery or degradation of damaged territories. The results also are an important step toward collecting scientifically proven evidence of the ecocide of the Russian war against Ukraine of the war in international courts.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Оцінка викидів вуглецю від ландшафтних пожеж в Україні за період війни у 2022 році

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Анотація. Військова агресія російської федерації та пов'язані з нею соціально-економічні та екологічні наслідки суттєво вплинули на клімат та виробництво екосистемних послуг через пошкодження лісів, екосистем, ландшафтні пожежі та викиди газів в атмосферу. Метою дослідження було оцінити викиди вуглецю внаслідок ландшафтних пожеж в Україні упродовж 2022 року. Для виявлення пожеж використовувалася технологія моніторингу лісових пожеж OroraTech, а периметри пройдених вогнем ділянок окреслювалися за допомогою часових

рядів супутникових знімків Sentinel 2. Для розподілу пройдених пожежами площ за типами земного покриву використовувалася карта Copernicus Dynamic Land Cover. Викиди вуглецю були розраховані за даними інтенсивності пожеж (dNBR) та частки спаленої біомаси в різних типах земного покриву. Моделі біомаси були обрані з урахуванням домінуючих деревних порід у конкретному регіоні та домінуючої видової структури посівних площ сільськогосподарських культур. Обсяги втрат біомаси оцінювалися з врахуванням інтенсивності пожеж. Підраховано, що протягом 2022 року площа ландшафтних пожеж сягнула 749,5 тис. га, з них 419,1 тис. га на орних землях; 273,8 тис. га в інших природних типах рослинності; 31,1 тис. га в хвойних лісах; 25,5 тис. га в інших лісах. Вплив війни на ландшафтні пожежі підтверджується великою часткою пожеж у 60-кілометровій буферній зоні вздовж лінії фронту – 68,9 % від загальної площі пожеж. Серед усіх пожеж 42,5 % пожеж сталися на окупованій території. Сумарні викиди CO₂ від усіх видів ландшафтних пожеж сягнули 5,20 млн тонн, а інших парникових газів – 0,28 млн тонн. Це перше детальне картографування ландшафтних пожеж з аналізом кожного полігону для всієї території України. Результати дослідження надають важливу інформацію для оцінки втрат екосистемних послуг та оцінки викидів вуглецю, а також для підтвердження впливу бойових дій на ландшафтні пожежі

Ключові слова: лісові пожежі; вигоріла площа; викиди CO₂; тип ґрунтового покриву; біомаса; картографування