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Degradation and restoration of forest ecosystems in the context of war: Environmental and economic challenges to Ukrainian national security

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Abstract. The study aimed to identify the effects of military operations on forest ecosystems and find effective approaches to their restoration in the face of environmental and economic

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challenges. The methodology used was to analyse the impact of military operations on forest ecosystems, assess the economic consequences of forest degradation, and develop a restoration strategy through demining, reclamation and the implementation of monitoring systems. The study analysed the extent of destruction of forest ecosystems as a result of the war, including loss of tree cover, damage caused by fires, mining and mechanical damage. The study established that most forest areas have lost their ability to regenerate themselves due to changes in the hydrological regime and biodiversity. The data on soil contamination with heavy metals are summarised: lead 450 mg/kg and cadmium 6.5 mg/kg were detected in Izium forest; lead 390 mg/kg and cadmium 5.2 mg/kg in Sviatohirsk forest; lead 280 mg/kg and cadmium 3.8 mg/kg in Chernihiv forest; lead 320 mg/kg and cadmium 4.1 mg/kg in Kherson forest. The economic losses from the decline in forest resources, reduction in forest industry revenues and job losses were estimated. The impact on agriculture was analysed, including a decrease in soil productivity, erosion and changes in microclimate. Social consequences, including population displacement and increased unemployment, were identified. Threats to national security due to environmental destabilisation were outlined. The necessity of an integrated approach to restoration, including demining, soil treatment, reforestation with adaptive species and satellite monitoring to prevent illegal logging, was substantiated. The findings of this study can be used to develop strategies for restoring forest ecosystems, planning environmental policy, as well as to attract international assistance and implement sustainable forestry practices in Ukraine

Keywords: soil contamination; mining; biodiversity; phytoremediation; state policy

Introduction

Ukrainian forest ecosystems perform important functions for maintaining ecological balance, supporting biodiversity, regulating climate conditions and ensuring economic stability. However, the ongoing war in the country is having a devastating impact on these natural systems. As a result of the hostilities, the area of forests has significantly decreased, soil and water pollution are increasing, and the ability of ecosystems to recover is deteriorating. Physical destruction of trees, fires, mining, and negative impacts on flora and fauna have become some of the main consequences of military conflicts. This process not only threatens natural resources but also creates serious economic challenges. Restoration of forest ecosystems in the wake of war requires new approaches and strategies that combine environmental initiatives with economic sustainability.

The problem of degradation of forest ecosystems during military conflicts is a relevant topic for research, as war significantly affects the state of natural resources, including forests. Z. Krajnović & A. Smolek (2024) noted that the war caused serious destruction of forests due to hostilities, including artillery shelling and air strikes. The study also emphasised the importance of establishing a monitoring system for rapid response to forest fires. A.B. Tarnavskyi & V.V. Rykhva (2024) highlighted the significant pollution of soil and water in the Donetsk region as a result of hostilities. This has severely complicated the restoration of ecosystems, as toxic substances have greatly reduced the natural ability to self-healing. S. Löfqvist *et al.* (2022) highlighted the need for a comprehensive approach to forest restoration, including environmental,

social and economic factors. The role of international assistance in the implementation of restoration programmes was particularly emphasised. J. Castro *et al.* (2021) noted that military operations contributed to the growth of illegal deforestation due to the lack of control in the conflict zone. To address this issue, the study proposed an enhanced system of monitoring and punishment for violations. R.Y. Zakari *et al.* (2024) emphasised the importance of introducing modern forest monitoring technologies, in particular satellite systems, to detect violations and pollution. The need to respond to illegal logging was noted.

A.K. Priya *et al.* (2023) proposed the use of phytoremediation to clean up soils after they were contaminated as a result of military operations. This method restored environmental conditions in areas affected by toxic substances. T.T. Nguyen *et al.* (2023) noted that climate change, exacerbated by the war, has a negative impact on forest restoration. Extreme weather events complicate the stability of forest ecosystems and their ability to recover. A.M. Tedesco *et al.* (2022) emphasised the importance of international cooperation and funding for the restoration of forest ecosystems. The study proposed the creation of financing mechanisms through green bonds and environmental funds to support restoration activities. R.L. Chazdon *et al.* (2020) emphasised the importance of local communities in the process of forest restoration, as it helps not only to restore ecosystems but also to strengthen social resilience at the local level. F. Hua *et al.* (2022) noted that for forest restoration, it was necessary to adapt new approaches to forestry that combine environmental and economic interests. The development of incentive systems for the sustainable use of forest resources was emphasised.

Despite significant advances in research on the effects of war on forest ecosystems, some gaps require further study. In particular, the long-term economic impact of the loss of forest resources on local economies, as well as the effectiveness of phytoremediation and other soil remediation methods, remain understudied. The impact of climate change, exacerbated by military operations, on forest ecosystems needs to be investigated in more detail and effective adaptation strategies need to be identified.

The study aimed to analyse the impact of the war on Ukraine's forest ecosystems and develop possible ways to restore them, as well as to examine the environmental and economic challenges facing the country. The objectives of the study were to examine the extent of physical destruction of Ukraine's forest ecosystems as a result of hostilities, including landmines, artillery shelling, air strikes and fires, and to assess the economic impact of forest degradation, including loss of forest resources, reduced agricultural productivity and impact on tourism and recreational potential. The study also included consideration of strategic approaches to restoring forest ecosystems, including demining, land reclamation, reforestation, establishing an environmental monitoring system and attracting international support.

Materials and Methods

The analysis covered the territories of Ukraine affected by the war, in particular Donetsk, Luhansk, Kharkiv, Zhytomyr, Dnipro, Zaporizhzhia, Kherson, Chernihiv and Sumy regions. The study considered the period from 2020 to 2024 and analysed the situation for 2028 as a post-war period, which is important for interpreting forecasts of forest resource recovery and economic impacts. For this purpose, a forecasting method was used based on current trends in ecosystem degradation, which assessed the probable changes in the ecological and economic state of the territories after the end of the war.

The study examined several sources and initiatives that contribute to the restoration and conservation of forest ecosystems, as well as monitoring their condition. In particular, the study analysed the activities of the State Environmental Inspectorate of Ukraine (2025), which monitors compliance with environmental standards in the forest sector and performs the functions of identifying violations and taking appropriate measures to eliminate them. The role of the State Agency of Forest Resources of Ukraine (2024), which coordinates and manages the national forest resources, organising measures for sustainable use and restoration of forests, was also considered. An important element of the study was the audit report on forestry and hunting (Accounting Chamber, 2024), which is used for assessing the effectiveness of forest management, identifying problems and providing recommendations for their solution. In addition, the United Nations Decade on Ecosystem Restoration (2021-2030) (2019), which provides financial and technical assistance for the restoration of natural ecosystems, including forests affected by environmental disasters, was analysed. The article also examined the activities of the Global Environment Facility (2024) as a source of funding for international environmental projects, including forest restoration and climate change. The Regulation (EU) 2024/1991 of the European Parliament and of the Council "On Nature Restoration" (2024), which implements ecosystem restoration projects on a global scale, was also considered separately. Particular attention was paid to the methodology of satellite forest monitoring using Sentinel-2A/B satellite data (Mozghovyi *et al.*, 2024), which can be used for the efficient detection of illegal logging and changes in forest cover. Volunteer initiatives are also analysed, including the Million Trees for Ukraine project (The "Million Trees..., 2020), which brings together various organisations to plant trees on a massive scale in the areas of Ukraine affected by environmental disasters. In addition, the effectiveness of the FOREST RECOVERY project (Forest of Ukraine, 2023), which aims to restore forest ecosystems in contaminated areas and bring them out of critical condition through reforestation, soil treatment, and the use of phytoremediation technologies, is investigated. The report by Kyiv School of Economics (2024) was an important source of information

To study the impact of artillery shelling, air strikes, land mines and forest fires on ecosystems, a method of integrated environmental analysis was applied, including analysis of drone photography and satellite monitoring data. This assessed the extent of forest damage, classified types of degradation and pollution, including explosions, soil and water contamination with toxic substances, and assessed illegal logging. The analysis covered the Izium forest (Kharkiv oblast), Sviatohirsk National Park (Donetsk oblast), forests around Chernihiv and forests near Kherson (after the flood). This approach identified the main factors of forest ecosystem degradation and problems related to the weakening of environmental protection structures during the war.

Risk analysis assessed the environmental threats arising from the degradation of forest ecosystems. This method determined the impact of the decline in forest cover on water and air pollution, as well as on public health. In addition, threats to social stability were assessed, including forced resettlement of people due to the destruction of natural areas and environmental pollution. Economic analysis was used to develop a strategy for the restoration of forest ecosystems, including research into international financial initiatives such as UN, EU and World Bank programmes. In addition, this method addressed the need to introduce environmental insurance instruments for forestry

enterprises, as well as to create economic mechanisms to support the restoration process.

Results

Impact of hostilities on forest ecosystems. Forest ecosystems are key in maintaining ecological balance, conserving biodiversity, regulating climate and meeting the economic needs of society. They are not only a source of timber, but also a natural barrier against soil erosion and a habitat for many species of animals and plants. However, during military conflicts, forests become one of the most vulnerable natural areas. Military actions cause significant damage to forest ecosystems, which is manifested in their physical destruction and contamination with toxic substances such as lead, uranium, fuel residues, chemical compounds contained in ammunition, as well as combustion and explosion products. Other major negative factors include large-scale fires, mining, artillery shelling, air strikes, and uncontrolled use of natural resources, including illegal deforestation and disturbance of the natural landscape. The peculiarity of the war's impact on forests is that the consequences of the destruction can last for decades. Even after the end of hostilities, areas remain dangerous due to mining, pollution and disruption of the natural balance. In addition, during periods of instability, the risk of illegal deforestation increases, which only deepens the environmental crisis. According to the State Ecological Inspectorate of Ukraine (2025), in 2024, 2.4 thousand cases of illegal logging (16.1 thousand cubic metres) were detected, with the highest rates in Zhytomyr (39.8%), Kharkiv (12.2%) and Dnipro (8.0%) regions. More than 80,000 km² of Ukraine's territory is contaminated with mines and ammunition. The problem is especially acute in Donbas, Luhansk, Kharkiv and southern regions of Ukraine, where weakened control over forests is accompanied by an increase in demand for timber. Table 1 shows the main quantitative indicators of the physical destruction of forest ecosystems as a result of the war.

Table 1. Physical destruction of forests as a result of the war in Ukraine (2020-2028)

Metric	2020 (before the war)	2024 (during the war)	2028 (after the war) forecast
The total area of forests affected by the war	0 million ha	3.5 million ha	2.0 million ha
Area of forests destroyed by fires	0 km² (0 ha)	1,150 km² (115,000 ha)	30,000 km² (3,000,000 ha)
Area of forest fires	0 km² (0 ha)	320 thousand ha	50,000 km² (5,000,000 ha)
Forests contaminated with mines and ammunition	0 km² (0 ha)	450 thousand ha	50,000 km² (5,000,000 ha)
Forests affected by artillery shelling and explosions	0 km² (0 ha)	more than 160 thousand ha	30,000 km² (3,000,000 ha)
Biodiversity loss as a result of war	none	significant decline in populations of rare species	gradual recovery of biodiversity, but several species may remain under threat
Damage to forestry infrastructure	0 objects	more than 120 forest roads and facilities	10-20% of restored facilities
Total number of forest areas where restoration will take time	0 ha	more than 2.2 million ha	1.5 million ha

Source: compiled by the authors based on Kyiv School of Economics (2024)

The indicators reflect the damage to Ukraine's forest ecosystems as a result of the war. They cover the total area of forests affected by hostilities, as well as areas destroyed by fires and contaminated by mines and ammunition. In addition, data is provided on forest areas damaged by artillery shelling and explosions. The report also highlights the serious consequences for biodiversity, forestry infrastructure and the need to restore large areas of forests where the recovery process will take a long time.

The war has caused major losses for forests located in eastern and southern Ukraine, where active hostilities are taking place. The forests in the immediate combat zone suffered the greatest losses. Artillery shelling, fires and mines were the main factors that led to the destruction of forests. In regions such as Donetsk, Luhansk and Zaporizhzhia, large areas of forests were not only damaged but also made dangerous for recovery due to mining (Barker *et al.*, 2020). This seriously hampers the natural recovery of forest ecosystems in these areas. Destroyed forests often lose their fertile soil layer, which is the basis for the further growth of new plants. Environmental pollution and tree damage also significantly slow down the recovery process. Restoration of such areas requires a holistic approach, including demining, soil clean-up and planting new trees.

The war not only destroyed natural habitats but also directly affected rare and endangered species of animals and plants. These species include the black stork, lynx, marsh reed and white lily (Soils and war..., 2024). As a result of the hostilities, populations of local species that were previously characteristic of certain ecosystems have declined or even disappeared. For instance, the reduction in the number of wild animals due to the mining of territories and destruction of their natural habitats has led to the complete disappearance or substantial reduction in the number of some species, such as wild animals that lived in forests. What is particularly important is that the disappearance of certain species can have long-term consequences for ecosystems. For instance, the disappearance of predatory animals such as lynx can lead to the overpopulation of their prey, causing an imbalance in ecosystems.

The structure of flora and fauna populations has undergone significant changes in the areas of active hostilities. Soil degradation and environmental pollution have become the main factors affecting the flora. Plants are either dying or spreading to areas with more favourable growth conditions. For animals, the biggest threats are the destruction of nesting sites and deaths from explosions and landmines. This has resulted not only in a decline in the number of individual species but also in the disruption of natural food chains and ecological interactions. For instance, the disappearance of certain animal species that were an important part of the food chain can affect other species that used them as food or competitors (Can soil be cured..., 2023).

Explosions, artillery shelling and the use of ammunition have caused significant soil and water contamination. Toxic substances, such as heavy metals, nitrates and organic toxins, are accumulating in the soil and water resources, posing a threat to human and animal health. This pollution makes it difficult to restore ecosystems, as toxic substances can kill plants and animals trying to settle in these areas. Poor water and soil quality also make it difficult to restore natural resources. Statistics show that the level of water pollution in the combat zones in Ukraine far exceeds the permissible standards. For instance, as of the end of October 2022, Russian troops illegally used about 410 million m^3 of water, causing damage worth almost UAH 15.5 billion. In addition, damage to hydraulic structures, such as the Oskilske Reservoir, has led to significant environmental losses, including the death of about 2 million

fish worth UAH 883.7 million. This data confirms that the level of water pollution in the war zones exceeds the permissible standards by several times (Munitions and chemicals..., 2022). This creates serious environmental problems, as contaminated water can lead to diseases in animals and people who depend on this water for their needs.

One of the most evident problems associated with the war is the physical destruction of forests as a result of hostilities. Artillery shelling, air strikes, use of armoured vehicles and explosive devices lead to massive destruction of tree cover. Forests that have long formed unique ecosystems can be destroyed in a short period as a result of intense hostilities. In addition, shell and rocket explosions create craters that disrupt the structure of the soil. This leads to soil erosion, making it impossible for vegetation to regenerate naturally. The loss of fertile soil becomes an obstacle to forest regeneration even after the hostilities stop. Restoration of such lands takes decades and, in some cases, even special environmental programmes. Another threat is the mining of territories. Forests are often used as a natural barrier during hostilities, which leads to the massive installation of minefields. This makes the area unsuitable not only for economic activity but also for natural ecosystem recovery. Wildlife migrating through such dangerous areas can become victims of mines, which negatively affects populations of many species. Mine action also hampers the efforts of ecologists and foresters who could be involved in restoring destroyed ecosystems. Another consequence of war is forest fires caused by explosions, shelling or the use of incendiary munitions. In contrast to natural fires, which can be part of the natural process of forest regeneration, military fires are uncontrollable and destroy large areas of ecosystems. They cause a loss of biodiversity, as fire destroys not only trees but also the habitats of many species of animals and plants. In addition to physical destruction, war causes large-scale environmental pollution. As a result of hostilities, heavy metals, fuel residues, and toxic substances from ammunition and explosives get into the soil and water bodies. For example, lead, mercury and cadmium contained in munitions fragments can persist in the soil profile for a long period, inhibiting plant growth and making it difficult for plants to grow (Table 2). Water contamination is another serious problem (Review of the year..., 2023). Explosions and the destruction of infrastructure cause toxic substances to enter rivers and lakes, which negatively affects the state of aquatic life. As a result, many natural water sources become unfit for human consumption, affecting both human and animal populations that depend on these ecosystems.

Table 2. The destruction of Ukrainian forest ecosystems as a result of the war and the level of their pollution

Location	Lead (Pb) concentration, mg/kg	Cadmium (Cd) concentration, mg/kg	Other pollutants
Izium Forest (Kharkiv region)	450 (at the rate of 32)	6.5 (at the rate of 0.5)	Mercury, copper, tin
Sviatohirsk National Park (Donetsk region)	390 (at the rate of 32)	5.2 (at the rate of 0.5)	Arsenic, uranium
Forests around Chernihiv	280 (at the rate of 32)	3.8 (at the rate of 0.5)	Petroleum products
Forests near Kherson (after flooding)	320 (at the rate of 32)	4.1 (at the rate of 0.5)	Heavy metal salts

Source: developed by the authors based on the Nature Reserve Fund of Ukraine (n.d.)

In times of war, control over the use of natural resources is significantly weakened. This creates ideal conditions for illegal deforestation. Due to economic instability and reduced government control, many people are forced to engage in illegal logging as a means of survival. In addition, the destruction of environmental protection institutions and their archives makes monitoring and conservation of forests much more difficult. Uncontrolled deforestation leads to further deterioration of ecosystems. Forests that were already damaged by the hostilities are under additional pressure from illegal logging. This not only reduces the total area of forests but also accelerates soil degradation and upsets the natural balance of the region. The destruction or weakening of environmental protection institutions also means that ecosystem restoration will be difficult after the end of hostilities. The lack of adequate funding and expertise makes it difficult to implement environmental programmes aimed at preserving and restoring forests.

The war negatively affects forest ecosystems, which is manifested in the physical destruction of tree cover, environmental pollution, forest fires and uncontrolled use of natural resources. Restoration of such areas is a complex and long-term process that requires significant financial, technical and human resources. To minimise the effects of the war, it is necessary to develop comprehensive forest restoration strategies, including mine clearance, clean-up of contaminated soils, restoration of biodiversity and strengthening of control over the use of forest resources. International cooperation in the field of environmental security is also important, as the war affects not only individual regions but also the global ecosystem.

Economic consequences of forest degradation. Forest ecosystems are substantial not only in the ecological balance but also in shaping the economic stability of regions. Forests provide timber and non-timber resources, perform protective functions for agricultural land, and are an important factor in the development of tourism. However, as a result of the war, forests are being significantly degraded, which negatively affects the national economy. Reduced forest resources, deteriorating soil quality and loss of recreational potential cause financial losses at both local and national levels. Economic losses include the direct loss of timber, losses of companies involved in the harvesting and processing of forest resources, and a drop in timber exports. In addition, forest degradation leads to a significant reduction in agricultural yields due to deteriorating soil quality, increased erosion and increased drought risk. This requires additional costs for land reclamation. Damage to forest plantations and a decline in forest resources have also resulted in a decline in budget revenues from the forestry sector, which has a significant impact on the financing of local administrations and infrastructure projects. Table 3 shows the main quantitative indicators of economic losses caused by the degradation of forest resources as a result of the war.

Table 3. Economic consequences of forest degradation in Ukraine (2020-2028)

Metric	2020 (before the war)	2024 (during the war)	2028 (after the war) forecast
Amount of forest fires	2,000 cases	3,500 cases	2,000 cases
Area of forest plantations lost	1,500 ha	3,200 ha	1,000 ha
Damage caused by forest fires	UAH 10 million	UAH 30 million	UAH 10 million
Share of forests affected by the war in the total area of the forest fund of Ukraine	0%	approximately 35%	15%

Table 3, Continued

Metric	2020 (before the war)	2024 (during the war)	2028 (after the war) forecast
Losses for the forest industry from the loss of forest resources	UAH 10 million	over UAH 55 million in 2023	UAH 30 million
Costs of reforestation after fires	UAH 5 million	approximately UAH 12 million per year	UAH 6 million
Economic losses from the loss of biodiversity and ecosystem services	UAH 5 million	more than UAH 18 million per year	UAH 8 million
Decrease in forest industry revenues due to damage to forest plantations	0%	by 20% compared to the pre-war level	by 10% compared to the pre-war level
Number of jobs lost due to forest degradation	0 persons	over 6,000 people are employed in the forestry industry	4,000 persons
Investments in reforestation and forest fire fighting	UAH 3 million	UAH 9 million per year	UAH 5 million

Source: compiled by the authors based on Kyiv School of Economics (2024)

The indicators reflect the significant impact of the war on Ukraine's forests, including large-scale fires, degradation of forest ecosystems and economic losses. The hostilities have affected a large part of the forest fund, resulting in a decrease in biodiversity, reduced forestry revenues and job losses. Expenditures on reforestation and firefighting remain insufficient to compensate for the damage, which requires increased attention to reforestation and natural resource protection.

Forests are an important source of resources used in various sectors of the economy. The war has led to a reduction in timber harvesting due to the physical destruction of forests, contamination of territories with explosives, and the impossibility of safe business operations. According to the State Agency of Forest Resources of Ukraine (2024), illegal deforestation increased significantly during the war, especially in areas where active hostilities were taking place. The overall reduction in timber harvesting as a result of the war is estimated at 30-40% compared to pre-war levels. Many forests are becoming dangerous due to mines, making logging and access to natural resources impossible. In addition to timber, forests provide significant amounts of non-timber resources, including mushrooms, berries, and medicinal plants. Their collection is an important source of income for the local population, especially in rural areas. The war has made some of these areas inaccessible or environmentally hazardous, reducing opportunities for collecting and selling these products. Mine action has particularly affected the availability of forest resources in eastern and southern regions of Ukraine, such as Donetsk, Luhansk and Kherson oblasts, where the fighting has been ongoing for a long time (Yutilova *et al.*, 2025). This limits not only timber harvesting but also access to forest resources for the population engaged in collecting non-timber products. The loss of forest resources directly affects the country's economic security. The forestry sector suffers significant financial losses, which affects local budget revenues. In particular, as a result of the decline in timber harvesting, which fell by 40-50% compared to pre-war levels, revenues from logging fell by 22%. In addition, a drop in exports of forest products resulted in losses of over UAH 60 million. The decline in revenues

from logging and related industries has also led to the loss of more than 6,000 jobs in forestry. This leads to a decrease in tax revenues and weakens the economies of regions dependent on forest resources, creating additional social and financial difficulties. In the context of military instability, this further weakens the economy of these regions (Accounting Chamber, 2024).

Forests fulfil an important function in preserving soil fertility and regulating the water balance. Deforestation or damage to forests changes the hydrological regime, leading to a decrease in the water table. This, in turn, increases the risk of droughts, negatively impacting agriculture. The absence of forests also contributes to soil erosion. Forest roots hold the soil cover in place, preventing it from eroding and losing its fertile layer. Forest degradation increases the risk of dust storms, which reduce soil quality and worsen conditions for growing crops. The degradation of forest ecosystems has affected large areas of agricultural land (Rybalova *et al.*, 2023). In the regions that have suffered the greatest forest losses, such as Donetsk, Luhansk and Kherson oblasts, the area of degraded land reaches more than 150,000 hectares. This has led to a significant drop in groundwater levels, which is confirmed by hydrological observations. In these regions, the water table has dropped by 15-20%, which increases the risk of droughts and decreases agricultural productivity. The decline in soil quality has a negative impact on yields, particularly for grains and oilseeds. In the areas with the greatest forest losses, such as Luhansk and Donetsk regions, yields can drop by 30-40% compared to pre-war levels. This is caused by soil erosion, reduced organic matter content and degradation of water supply, which worsens the conditions for growing crops. The decline in agricultural productivity leads to higher food prices, which creates an additional economic burden on the population. In addition, the war causes soil contamination with toxic substances, such as explosive remnants, heavy metals, fuel and chemical compounds. This worsens the environmental condition of the land, making it unsuitable for agricultural use. Restoration of such areas requires significant financial investments, and their productivity may remain low for a long time.

Due to the war, the Ukrainian forestry sector has suffered major financial losses, which has a negative impact on local budget revenues. In total, more than 60,000 hectares of forests were destroyed as a result of hostilities in the temporarily occupied territories, which is estimated at least UAH 14 billion (Vedmedenko, 2024). The destruction of forests has also led to a change in the hydrological regime, a decrease in groundwater levels and an increase in drought risks, which negatively affects agriculture. Forests are an important resource for the development of ecotourism and the recreational economy. However, the war has significantly reduced opportunities for the development of this sector. Destroyed natural areas have lost their attractiveness to tourists, and mined areas have become dangerous, making it difficult to develop green tourism. An example is the Shatsky National Park in Polissia, which has suffered from hostilities and mining. Formerly popular with tourists, in 2025 part of its territory is closed due to the danger of explosive devices. Similarly, the Dermansko-Ostromostianskyi Park in western Ukraine has been destroyed, and some of its natural routes have become inaccessible due to mining. In the Carpathian region, despite the absence of active hostilities, the overall security situation and restrictions on transport accessibility have led to a 50-60% decrease in tourist flows compared to 2021 (Report on the Program..., 2023). The tourist infrastructure in Chernihiv and Sumy regions has also suffered, with numerous tourist bases destroyed, reducing the

attractiveness of recreational areas. Damage to the forestry sector has created additional financial difficulties for local communities that were dependent on tourism and forest resources before the war. In the context of military instability, the economies of these regions are experiencing additional difficulties.

The presence of remnants of military equipment, infrastructure destruction and environmental pollution also have a negative impact on the development of the recreational economy. Sanatoriums, tourist resorts and natural parks that used to bring income to the region may remain abandoned or destroyed. Restoring tourism potential requires significant time and financial resources, which creates additional difficulties for the affected regions. The degradation of forest ecosystems as a result of war has serious economic consequences. The loss of forest resources reduces forest sector revenues and deprives local people of the opportunity to use natural resources. Deteriorating soil conditions negatively affect agricultural productivity, increasing the risks of erosion, drought and pollution. In addition, the destruction of natural areas reduces the country's tourism potential, depriving local communities of the opportunity to earn money from ecotourism. Losses in Ukraine's gross domestic product (GDP) due to forest degradation and the decline in their ecosystem services can reach up to 1.5% annually. Illegal deforestation is also gaining alarming proportions: during the war, its volumes have increased by at least 30%, resulting in annual losses to the state budget of more than UAH 2 billion due to lost tax revenues and shadow timber trafficking (Petrychenko *et al.*, 2022). To reduce economic losses, it is necessary to implement measures to restore forest ecosystems, control illegal logging and minimise the effects of environmental pollution. It is also important to attract investment in restoring tourism infrastructure and cleaning up natural areas. A comprehensive approach to addressing these issues will not only help restore forests but also stabilise the national economy.

Threats to national security due to forest degradation. War not only causes direct human losses and destruction of infrastructure but also poses serious threats to national security due to environmental degradation. In this context, environmental security is seen as an integral part of national security, as environmental degradation directly affects public health, food stability, economy and territorial governance. Forest ecosystems, which perform key ecological, economic and social functions, are undergoing significant destruction, which has long-term consequences for the country. The loss of natural resources, environmental pollution and climate change are making it harder for the economy to recover and exacerbating social problems. The decline in forest cover also reduces nature's ability to regenerate itself, making it more difficult to overcome the environmental crisis. Environmental experts estimate that the total area of forests damaged or destroyed by the hostilities is over 3.5 million hectares, of which a significant portion needs to be fully restored. More than 450,000 hectares of forests are contaminated with mines and ammunition, making it impossible to use them and restore natural processes. As a result of the hostilities, the level of soil contamination with heavy metals and toxic substances has increased 5-10 times compared to the pre-war period. In addition, more than 320,000 hectares of forests have burned due to massive fires caused by shelling, which has led to a significant loss of biodiversity and disruption of ecosystem links (Melnykovych *et al.*, 2025).

One of the main challenges to national security is the deterioration of the country's environmental situation. Hostilities cause massive pollution of water resources, soil and air with

toxic substances. Rivers, lakes and groundwater are at risk of being contaminated by explosive residues, heavy metals (lead, cadmium, mercury, copper, nickel) and oil products. In particular, as a result of the destruction of fuel storage facilities and military equipment, benzene, toluene and polycyclic aromatic hydrocarbons with carcinogenic effects are released into water bodies. In some regions, such as Donbas, Luhansk and Kharkiv, the concentration of nitrates and sulphates in groundwater has been recorded as exceeding the norms by 5-10 times, which poses a threat to the health of the population, which may consume contaminated water or be exposed to toxic substances through food. In addition to water pollution, the destruction of forests has a significant impact, as they play an important role in maintaining air quality. Forests absorb carbon dioxide and filter out harmful substances, but their destruction significantly reduces this natural ability. Explosions and fires release large quantities of fine dust, dioxins, nitrogen oxides and heavy metals into the air, which increases air pollution (Bayegizova *et al*., 2024). There is a 30-50% increase in the concentration of harmful substances in the air in areas of active hostilities. This has serious consequences for public health. There has been an increase in cases of respiratory diseases, asthma and bronchitis, and a rise in cancer rates, especially in regions with significant chemical pollution. In the areas of environmental disaster, the number of respiratory diseases and cardiovascular pathologies has increased by 20-25%, which underscores the need for urgent measures to restore the affected areas to a healthy state (Kolawole & Iyiola, 2023).

Forest degradation affects not only the ecological state but also the social situation in the country. A large part of the population, especially in forested regions, depends on forestry for jobs and income. Deforestation, landmines and environmental pollution lead to job losses in the forestry sector and related industries such as wood processing, tourism and agriculture. Rising unemployment is exacerbating social tensions and increasing the risk of economic instability. In addition to economic difficulties, forced displacement is a serious problem. Environmental pollution and the destruction of forest ecosystems can make some areas uninhabitable. Due to water pollution, soil degradation and landmines, the number of internally displaced people has exceeded 150,000 in the war-affected regions. The situation is most critical in the frontline areas, where large areas of forest remain unsafe for living and business. Lack of clean water, soil contamination and risks from mines are forcing people to leave their homes and seek safer places to live. This creates an additional burden on other regions and exacerbates the problem of internal displacement (Pandya & Didwania, 2021).

Forests are key in climate regulation, and their loss has serious consequences for the ecological balance. Destruction of forest cover contributes to rising temperatures, as fewer trees can absorb carbon dioxide and reduce the greenhouse effect. This can exacerbate global warming, increase the frequency of droughts and alter precipitation levels, which negatively impacts agriculture and water supplies. In some regions, such as Donbas and Luhansk, where forests have been heavily damaged by the hostilities, climate conditions are changing, including an increase in average annual temperature by several degrees and a decrease in precipitation, which is exacerbating water shortages. In addition to the impact on climate, the decline of forest ecosystems leads to the loss of ecosystem services that ensure the natural resilience of the environment. Forests help to retain moisture, prevent soil erosion and maintain biodiversity, which is essential for maintaining the natural balance. War destroys

ecosystem functions such as water conservation, dust storms and soil erosion protection. This leads to increased erosion of forests and adjacent lands, more dust storms and deterioration of water quality, which creates additional challenges for local communities, agriculture and ecosystems in general. The destruction of these ecosystems reduces resilience to climate change and complicates recovery from environmental disasters (Ma *et al.*, 2022).

The degradation of forest ecosystems as a result of the war poses serious challenges to Ukrainian national security. Water, air and soil pollution threatens public health, while the loss of forest cover increases climate risks and reduces the natural capacity for self-healing. Social problems related to unemployment in the forestry sector and forced resettlement increase tensions in society and hinder economic recovery. To mitigate these threats, it is necessary to develop comprehensive measures for forest restoration, environmental monitoring and climate change adaptation. It is particularly relevant to control pollution, demining and support the socio-economic development of war-affected regions. Only a combination of environmental, economic and social initiatives will ensure the country's long-term stability and security. International initiatives aimed at restoring the natural environment after the war include the United Nations Decade on Ecosystem Restoration (2021-2030) (2019). This initiative provides technical and financial assistance to countries affected by conflicts to restore forest ecosystems and contaminated areas, including through tree planting, demining, and sustainable forestry practices. Another important initiative is the Global Environment Facility (2024) fund, which finances ecosystem restoration projects, including reforestation, water conservation and climate change mitigation measures. One example of the implementation of this programme in Ukraine is the support of projects to restore forest ecosystems in areas affected by military operations, as well as measures to improve resilience to environmental disasters. Regulation (EU) 2024/1991 of the European Parliament and of the Council (2024) supports countries in restoring biodiversity and forest ecosystems after conflicts. In Ukraine, this programme has funded projects aimed at de-mining forest areas and cleaning up pollution, particularly in regions affected by the fighting, such as Donbas. Thus, the integration of international assistance and national efforts is key to the effective restoration of the natural environment and ensuring stability in Ukraine after the war.

Key strategies for restoring forest ecosystems in Ukraine. The war has severely damaged Ukrainian forest ecosystems, making it difficult for them to recover naturally and requiring comprehensive restoration measures. In addition to physical destruction, the environmental crisis is caused by landmines, soil and water pollution, and uncontrolled logging. Forest restoration requires a systematic approach that combines environmental, technological, economic and social initiatives. Effective strategies need to be developed to clean up the areas, reforest, strengthen control and attract investment.

One of the most acute problems in forest restoration is mined areas, which makes any environmental protection measures impossible (Fig. 1). Under natural conditions, forest restoration in such areas can take decades. At the same time, the use of adaptive methods such as phytoremediation (soil cleansing by plants) and controlled afforestation with resistant tree species can significantly speed up the process (Guidi Nissim *et al.*, 2023). Effective restoration requires a combination of natural mechanisms and active measures, including ecological demining, improvement of soil characteristics, and the involvement of specialised reforestation programmes.

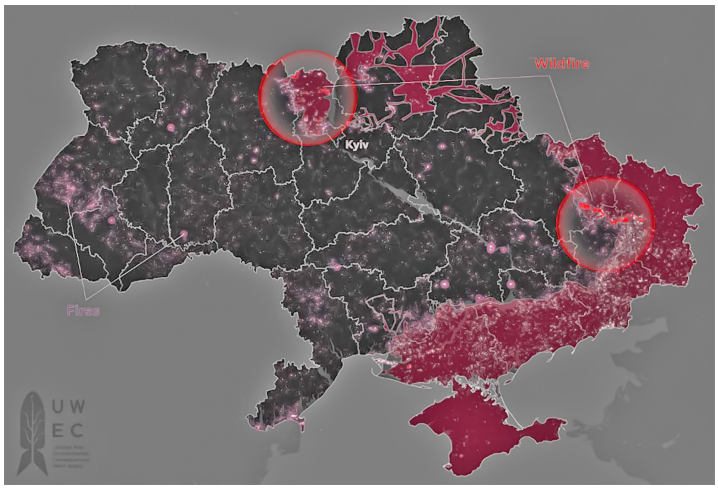

Figure 1. Map of Ukraine showing mined forest areas
Source: O. Vasylyuk *et al*. (2024)

In Ukraine, large areas of forests, particularly in the east and south of the country, are subject to demining due to the hostilities (Flamm & Kroll, 2024). This process takes a long time, which significantly complicates the natural recovery of forest ecosystems. Natural forest regeneration in such regions is ineffective due to physical damage to the soil cover, pollution, and a lack of biodiversity. Destroyed forests do not have the natural conditions for rapid regeneration, as soils lose fertility after hostilities due to explosions and erosion, as well as toxic pollution with heavy metals and chemicals. Natural forest regeneration becomes even more difficult in areas where there is a high concentration of mines and unexploded ordnance, as this is not only dangerous but also makes any environmental initiatives ineffective until the areas are cleared of mines. Therefore, to restore forest ecosystems in the affected regions, it is necessary to implement comprehensive measures, including environmental demining and sustainable forest management. Millions of hectares of forests have been mined, which seriously complicates the restoration of these areas. Effective demining requires the use of modern technology, including the creation of detailed minefield maps and the use of robotic systems to safely dispose of explosive ordnance. In addition to the mine threat, chemical contamination of soils caused by explosions, toxic emissions and other anthropogenic impacts is a serious problem. One of the most effective methods of soil remediation after such contamination is phytoremediation, i.e., the use of plants that can absorb and neutralise toxic substances. For instance, sunflower and mustard are effective at extracting heavy metals, and some tree species can neutralise oil compounds and other chemical pollutants. This method has already been used in other countries, including after military conflicts in the Balkans, where phytoremediation helped restore soils after contamination with explosives and other toxic materials (Kumar *et al.*, 2025). In addition to phytoremediation, other alternative remediation methods can be used to restore soil fertility. For example, mechanical cleaning of contaminated areas, which includes the removal of toxic materials and

restoration of soil structure. The introduction of biofertilisers and organic materials also helps to improve soil conditions, by increasing humus content and improving water permeability. An integrated approach that combines phytoremediation with classical reclamation methods will ensure the effective restoration of forests and soil resources affected by the war.

In the eastern and southern regions of Ukraine, which have become the main areas of hostilities, wetlands have been severely affected. This has resulted in a disruption of the natural water balance, deterioration of water quality, and a decrease in biodiversity, as these areas are important habitats for many species of flora and fauna. Areas belonging to such natural complexes as the Kherson floodplains, the floodplains of the Don and Dnipro rivers, as well as nature reserves and sanctuaries in Donbas have been affected. The loss of wetlands disrupts the hydrological regime, which in turn makes it difficult to restore other ecosystems. Forest restoration should be based on adaptive approaches that consider climate change and the specifics of the affected regions. To this end, it is important to implement massive tree-planting programmes using drought- and disease-resistant species. For example, in the steppe regions, it is advisable to plant acacia and oak, which are better adapted to higher temperatures. In addition to the direct restoration of tree cover, it is important to maintain natural ecosystem processes, including water balance. Restoring wetlands will help to conserve biodiversity, improve water quality, and increase the resilience of forest ecosystems to climate change (Adie & Lawes, 2022).

Conservation and restoration of forests are impossible without effective monitoring of their condition. Satellite technology and drones can be used to quickly detect illegal logging, disease outbreaks and forest fires. Remote monitoring data will help to respond to environmental threats in a timely manner and optimise restoration strategies. Ukraine has already implemented projects that use satellite technology to monitor forests, including projects implemented through cooperation with international partners such as the European Union. One such project is Forest Monitoring using Sentinel satellites, which can be used for monitoring of the state of forests and prompt detection of changes in forest cover (Mozghovyi *et al.*, 2024). In addition to technological control, it is important to increase liability for environmental crimes. Stricter sanctions should be introduced for illegal deforestation and pollution of natural areas. It is advisable to increase penalties for those involved in illegal deforestation and to create a system of compensation for the affected areas, including fines for companies that violate environmental standards. At the same time, it is necessary to introduce measures to encourage businesses to use forest resources sustainably, for example, through tax incentives for companies that implement eco-strategies (Scheper *et al.*, 2021).

Restoration of forest ecosystems requires significant financial expenditures, so attracting international resources is extremely important. One such support mechanism is the introduction of environmental insurance for forestry enterprises. This will help compensate for losses from environmental disasters and promote a more responsible attitude of businesses to natural resources. For instance, Germany and Switzerland have successfully operated environmental insurance systems that insure forestry companies against damage caused by forest fires, pests, or natural disasters (Mansourian *et al.*, 2021). This experience can be adapted in Ukraine, providing compensation for the loss of forest resources and reducing environmental threats. The introduction of environmental insurance in Ukraine will help to create a financial cushion for forestry

enterprises and ensure the sustainable development of the forestry industry.

Forest restoration requires the active participation of society (Tolochko *et al.*, 2024). Environmental education is substantial in this process, helping to shape the environmental culture of the population. Educational campaigns among schoolchildren, students and the military will help to understand the importance of forests and the need to protect them. In addition to education, it is necessary to engage local communities in direct participation in forest restoration. Volunteer initiatives, social projects, and the development of ecotourism can not only help restore nature but also become a source of income for local people. For example, the Million Trees for Ukraine project brought together volunteers, government organisations, and private companies to plant trees in areas affected by environmental disasters. The Forest Recovery project aims to restore forest ecosystems affected by the war by reforesting and cleaning the soil from heavy metal and explosive contamination. Through the implementation of a reforestation programme with adaptive species and the use of phytoremediation technologies, the project helps to restore biodiversity and improve the ecological condition of the affected areas.

Restoration of forest ecosystems in the wartime and post-war period is a complex but necessary task for Ukraine's environmental security. A comprehensive approach, including demining, reforestation, strengthening of control, economic support and public initiatives, will help restore destroyed ecosystems and prevent further forest degradation. International cooperation and investment are particularly important, as only joint efforts can ensure a sustainable and secure future for Ukraine's forests. Restoration of the natural environment is not only an environmental but also a socio-economic process that requires the active participation of all citizens and government institutions.

Discussion

The results of the study demonstrated that the war has a devastating impact on forest ecosystems, causing physical destruction of tree cover, large-scale fires, soil and water pollution with toxic substances, and uncontrolled use of natural resources. The study determined that a significant part of the forests in Ukraine have been damaged, making it difficult for them to regenerate naturally. Thousands of hectares of forests are minefields, rendering them unsafe for any activity, including environmental restoration initiatives. The impact of the war on forests has long-term consequences, as soil damage, pollution and loss of biodiversity can affect ecosystems for decades.

This problem was also studied by P. Pereira *et al.* (2022), confirming that the physical destruction of forests during war is one of the greatest threats to ecosystems. Explosions, artillery shelling and fires caused by hostilities can lead to massive tree destruction, soil disturbance and changes in the hydrological regime. This destroys not only the forests themselves but also the vital ecological functions they perform, including air purification, water protection and biodiversity. R.J. Wenning & T.D. Tomasi (2022) also demonstrated that the effects on forest ecosystems can be long-lasting. In addition to the direct destruction of trees, war also leads to changes in the composition of vegetation and the regeneration of forests after hostilities. Local species of flora and fauna can be drawn into the war zone, putting them at risk of extinction or displacement, and disrupting the natural balance of the ecosystem. Notably, the destruction of forests during the war has far-reaching environmental consequences that can affect the stability of climate conditions and regional hydrological

cycles. Destruction of forests not only reduces carbon dioxide absorption, which increases the greenhouse effect, but can also lead to a decline in water quality due to soil erosion and water pollution (Moroz, 2024). Given that forest ecosystems are critical to maintaining the balance of nature, their destruction in war has the potential for long-term environmental disasters, even after the fighting ends.

One of the most critical problems is the physical destruction of forests as a result of hostilities. Artillery shelling, air strikes and the use of heavy machinery led to the destruction of forests. The explosions create craters that change the structure of the soil, making it unsuitable for vegetation regeneration (Fedoniuk *et al.*, 2024). Affected areas often remain barren for a long time due to the loss of the fertile layer. In addition, mined forests become dangerous for wildlife, leading to a decline in populations of rare species. Such ecological changes can be irreversible, making it difficult to restore forest resources. F. Rodriguez-Jimenez *et al.* (2024) concluded that forest fires caused by military operations are one of the biggest threats to forest ecosystems. Artillery shelling, air strikes, and explosions can not only cause outbreaks but also make them uncontrollable due to the lack of resources for rapid response. In times of war, fire can quickly spread over large areas, making it difficult to extinguish and leading to even greater destruction of forests. X. Meng *et al.* (2023) determined that the uncontrolled spread of fire in wartime often has catastrophic consequences for the environment and people. Fires can destroy large areas of forests, reducing biodiversity and degrading soil conditions. In addition, fire can pollute the air with toxic smoke, exacerbating public health problems and increasing the negative impact on the climate. These results confirm the above study, as they demonstrate a direct correlation between military operations and large-scale forest fires. The use of high-precision technologies, such as satellite imagery, shows that forests in areas of active hostilities are more likely to be affected by fire. In addition, analysis of the situation in conflict zones confirms that the lack of proper fire control combined with aggressive military operations significantly increases the likelihood of large-scale fires.

Forest fires caused by explosions, bombing and the use of incendiary munitions have become another serious problem. Contrary to natural forest fires, which can be part of the ecosystem cycle, military fires are uncontrollable and lead to the destruction of large areas (Krawczyńska *et al.*, 2024). In 2023, almost 298,000 hectares of burnt forests were recorded in Ukraine. This not only contributes to the loss of biodiversity but also worsens the air quality and causes large amounts of carbon dioxide emissions. As entire forest ecosystems are destroyed, biodiversity restoration requires significant resources and time. The study by J. Turunen *et al.* (2021), which also determined that environmental pollution of forest areas during war often has serious consequences for local ecosystems, is noteworthy. The detonation of munitions and chemicals used in hostilities can leave behind toxic residues that contaminate soil, water and air. Substances such as heavy metals, nitrates and toxic gases have long-term effects, poisoning the vegetation and animals living in these areas. In turn, C. Sonne *et al.* (2023) concluded that the toxic impact of munitions on the environment also leads to changes in the chemical composition of soils and water resources. The high concentration of toxic elements in the soil can slow down the recovery of forest ecosystems after war, hindering the process of natural regeneration. In addition, these toxic substances can accumulate in food chains, posing a risk to people and animals that interact with contaminated resources. This data is consistent with the theses presented in the previous section, as it confirms the negative

impact of military operations on the ecological state of forest areas. The survey results demonstrated that the remnants of ammunition and toxic substances significantly contaminate soil and water, making it difficult to restore ecosystems. This is also consistent with previous analysis that demonstrates how long-term contamination can negatively affect biodiversity and the life cycle of forests.

The economic impact of forest degradation is also significant. The war has significantly reduced timber harvesting, which has affected the forestry industry and the incomes of local communities. Soil and water contamination makes it impossible to use forest land for agricultural purposes. Ecotourism has also been significantly affected, as the destroyed forests have lost their attractiveness to visitors and mined areas remain dangerous. Losses from the loss of forest resources and reduced revenues in related industries are estimated at millions of hryvnias annually (Strokal *et al.*, 2024). A. Daiyoub *et al.* (2024) also conducted a study that confirmed that illegal logging during wartime becomes a significant problem due to reduced control over the use of natural resources. In conflict situations, local forests often become targets of illegal exploitation, as the authorities lose the ability to effectively regulate forestry. This leads to the uncontrolled destruction of timber, which not only damages forest ecosystems but also disrupts the ecological balance in the region. L. Xia *et al.* (2023) also found that the reduced control over the use of natural resources during the war also fosters corruption and illegal timber trade. This increases the scale of deforestation, as illegal actions go unnoticed or unpunished due to the lack of appropriate control bodies. Such practices lead to the degradation of forest areas, reducing the ability of ecosystems to regenerate after the end of hostilities.

Comparing the data obtained in the course of research, it is possible to conclude that military operations significantly increase the negative impact on forest ecosystems. For instance, the increase in illegal logging in conflict zones is directly correlated with the lack of control and law enforcement that is common during war. In addition, data on toxic soil and water pollution indicate long-term environmental impacts that persist even after the end of hostilities. National security is an important issue, as forest degradation worsens the environmental situation in the country. Air, water, and soil pollution pose a threat to public health, contributing to the spread of disease and a lower quality of life (Matkivskyi & Taras, 2024). In addition, the destruction of forest cover exacerbates climate risks, such as rising temperatures and increased frequency of droughts. This could have global implications, as forests are important climate regulators and sources of oxygen. N.T. Hoang & K. Kanemoto (2021) concluded that economic losses due to forest degradation are a significant problem for countries where forest resources are an important source of income. The destruction of forests during the war leads to a significant reduction in timber production, which has a direct impact on the forest industry and the economy. The loss of ecosystem services, such as water purification and erosion protection, also has financial implications, particularly in the form of costs to restore the natural balance. M. Xie *et al.* (2022) determined that the financial impacts of forest destruction are not limited to losses from the direct destruction of timber. Forest degradation leads to reduced agricultural yields and tourism, as healthy forest ecosystems are essential for maintaining the stability of these industries. In the long term, the economic losses from the disruption of the ecological balance can be significantly greater than the initial losses from deforestation, rendering forest restoration critical to economic stability.

In general, the results of the study are consistent with the findings of other scientific works that confirm the significant and long-term negative impact of military operations on forest ecosystems. The data demonstrate a shared vision of the problem in the academic community, especially in terms of the physical destruction of forests, toxic pollution, biodiversity degradation and economic losses caused by the destruction of natural resources.

Conclusions

A study of the impact of the war on forest ecosystems in Ukraine revealed catastrophic consequences for the environment, including forests. The hostilities led to the physical destruction of forests, large-scale fires, environmental pollution and uncontrolled use of natural resources. The area of forests affected by the war has significantly decreased, with significant losses occurring in forests destroyed by fires. According to the data, the area of dead forest plantations in 2024 is 3,200 hectares, and the area of forest fires reached 3,500 cases. The area of forests destroyed by fires in 2024 was 1,150 km² (115,000 ha), which is significantly higher than before the war. As a result of the hostilities, approximately 3.5 million hectares of forests were affected by the war, and more than 450,000 hectares of forests were contaminated by mines and ammunition.

A substantial consequence is the pollution of the environment, which makes it difficult to restore forests. Much of the forests are contaminated with mines and ammunition, which poses a great danger to people and animals. Even more forest areas have been affected by artillery shelling and explosions, which makes it difficult to restore forest areas for a long time. The area of forests affected by artillery shelling and explosions exceeded 160,000 hectares in 2024, and by 2028, the total area of such forests is projected to reach 3 million hectares.

The war also caused a significant loss of biodiversity, as the destruction of natural habitats and disruption of ecological chains have put many species of animals and plants at risk of extinction. The decline in forest industry revenues as a result of the destruction of forest resources in 2024 is 20% compared to pre-war levels. Losses for the forestry industry due to forest degradation exceeded UAH 55 million in 2024, and biodiversity loss causes economic losses of more than UAH 18 million annually.

Restoration of forest ecosystems requires significant financial expenditures. Approximately UAH 12 million is spent annually to restore forests after fires, while investments in reforestation and forest fire fighting amount to about UAH 9 million per year. More than 2.2 million hectares of forest land require long-term restoration. This requires a comprehensive approach that includes mine clearance, environmental monitoring, phytoremediation, large-scale reforestation programmes, as well as international support and community engagement. Only through such measures can the sustainable development of forest resources in Ukraine be ensured in the future.

The importance of integrating environmental policy into national security and economic recovery strategies is particularly noteworthy, as it will help ensure the sustainability of forest ecosystems and maintain the country's socio-economic stability. The main limitation of the study is the lack of up-to-date data from the temporarily occupied and frontline territories, which makes it difficult to fully assess the extent of forest losses. The long-term environmental impact of hostilities on forest ecosystems, including the impact of soil and water pollution on natural regeneration processes, needs to be further studied.

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Conflict of Interest

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Деградація та відновлення лісових екосистем у контексті війни: екологічні та економічні виклики національній безпеці України

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Анотація. Метою дослідження було виявлення впливу військових операцій на лісові екосистеми та пошук ефективних підходів до їх відновлення в умовах екологічних та

економічних викликів. Використана методологія полягала в аналізі впливу військових операцій на лісові екосистеми, оцінці економічних наслідків деградації лісів та розробці стратегії відновлення шляхом розмінування, рекультивації та впровадження систем моніторингу. У дослідженні проаналізовано масштаби руйнування лісових екосистем внаслідок війни, включаючи втрату деревного покриву, пошкодження, спричинені пожежами, гірничими роботами та механічними пошкодженнями. Дослідження встановило, що більшість лісових масивів втратили здатність до самовідновлення через зміни гідрологічного режиму та біорізноманіття. Узагальнено дані щодо забруднення ґрунту важкими металами: в Ізюмському лісі виявлено свинець 450 мг/кг та кадмій 6,5 мг/кг; у Святогірському лісі – свинець 390 мг/кг та кадмій 5,2 мг/кг; у Чернігівському лісі – свинець 280 мг/кг та кадмій 3,8 мг/кг; у Херсонському лісі – свинець 320 мг/кг та кадмій 4,1 мг/кг. Було оцінено економічні втрати від скорочення лісових ресурсів, скорочення доходів лісової промисловості та втрати робочих місць. Було проаналізовано вплив на сільське господарство, включаючи зниження продуктивності ґрунтів, ерозію та зміни мікроклімату. Було визначено соціальні наслідки, зокрема переміщення населення та зростання безробіття. Окреслено загрози національній безпеці через дестабілізацію навколишнього середовища. Обґрунтовано необхідність комплексного підходу до відновлення, що включає розмінування, обробку ґрунтів, відновлення лісів адаптивними видами та супутниковий моніторинг для запобігання незаконним вирубкам. Результати цього дослідження можуть бути використані для розробки стратегій відновлення лісових екосистем, планування екологічної політики, а також для залучення міжнародної допомоги та впровадження практик сталого лісівництва в Україні

Ключові слова: забруднення ґрунтів; видобуток корисних копалин; біорізноманіття; фіторемедіація; державна політика