Project Title:
Nature Conservation and Conflict in Ukraine: Identifying War Damage to Nature Reserves in Ukraine

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Projekt-Akronym:

(Ukraine-Nature)

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List of abbreviations

ACLED – armed conflict location and event data project

AOP – advanced oxidation process

CMC – confirmed mine-contaminated

FIRMS – fire Information for resource management system

GIS – geographic information system

MPC – maximum permissible concentrations of pollutants

NNP – national nature park

PMC – potentially mine-contaminated

REBR – radiation and ecological biosphere reserve

UXO – unexploded ordnance

VIIRS – visible infrared imaging radiometer suite

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1.Executive summary

This report describes the results of the project “Nature Conservation and Conflict in Ukraine: Identifying War Damage to Nature Reserves in Ukraine” (Ukraine-Nature) that was implemented by the Research and Transfer Centre “Sustainable Development and Climate Change Management” at the Hamburg University of Applied Sciences and supported by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt).

Within this project the Ukraine-Nature team and partners from Ukraine, Poland and Switzerland conducted ecological research on the consequences of armed conflict in four protected nature reserves that are part of The Emerald Network – Chornobyl Radiation and Ecological Biosphere Reserve (REBR); Desniansko-Starohutskyi National Nature Park (NNP); Holosiivskyi National Nature Park (NNP), and Hetmanskyi National Nature Park (NNP). The war has made it difficult to maintain and protect these areas and has put additional pressure on ecosystems that are already threatened by human activities. Ukraine-Nature project delved into the significant yet often neglected environmental repercussions of the Russian invasion of Ukraine, highlighting the adverse effects on soil, biodiversity, and forests. In this context, this research aimed to provide an overview of the impacts of the war on the environment in four Ukrainian protected areas, namely the Chornobyl REBR, Holosiivskyi NNP, Desniansko-Starohutskyi NNP, and Hetmanskyi NNP. To address these aspects, the Ukraine-Nature team relied on several methods including bibliometric analysis, key informant interviews, GIS analyses based on satellite pictures as well as secondary data gathered by experts from the Ukraine Nature Project in two stages: during the expedition and extracted from databases (ACLED, FIRMS, Ministry of Defence of Ukraine and State Emergency Service of Ukraine) and processed by QGIS software.The obtained values were used to assess the level of damage for soil, forests, and biodiversity within the grids of 1*1 km2 by the degree of disturbance: absent, low, medium, above average, high, extremely high. All the results were mapped for each of the researched territories.

It was discovered that habitats and biodiversity in these reserves are endangered by landmines, wildfires caused by artillery shelling and purposeful setting of fires in forested areas, armed clashes between opposing armed forces, military occupation of the land, and the movement and maintenance of military vehicles and machinery. Damages to forested areas in each reserve are extensive and soil sampling in the combat damaged zones conducted in October 2022 indicate that the impact of military activities on soils in the studies areas was found to be particularly significant, requiring special management and monitoring measures when peace returns to these reserves. The current evidence suggests ecological recovery of these nature reserves will be challenging, and some post-conflict restoration work may not be possible. In some cases, it is increasingly likely that some indigenous wildlife species and portions of the landscape will not recover and are likely to be gradually lost completely over time.

The research also explored various methods as well as sustainable-oriented solutions aimed at mitigating these effects on the environment. Furthermore, it discusses the immediate and long-term challenges Ukraine faces in its recovery efforts, emphasizing the need for environmentally conscious approaches to address these issues. One of the main recommendations, for example, would be to ensure legal accountability for environmental war crimes and to intensify the efforts to stop the war. The limited access to the territories due to the mining and shelling, restricts researchers and society in acting towards recovery, and the main activities would rely in constant monitoring and assessment of environmental damages caused by the war. The results of the project were discussed with well-known media like 2DF, Die Zeit, 3SAT, etc. and presented at numerous conferences in Germany.

2. Objectives of the project

Since Russian forces invaded Ukraine in February 2022, the world's attention has focused on the country's heavily shelled cities. But Ukraine, which is located in an ecological transition zone, is also home to vibrant wetlands and forests, as well as a large area of pristine steppe.

Russian troops have conducted military operations in more than a third of the country's protected natural areas, damaging ecosystems or negatively impacting the livelihoods of many animal and plant species.

Reports from the field and research on past armed conflicts suggest that the ecological impacts of conflict could be profound. Wars destroy habitats, kill wildlife, cause pollution and damage and degrade ecosystems at a high rate, with consequences that last for decades. The environment is a silent victim of conflict here.

The national parks, nature reserves and other protected areas in Ukraine provide important ecosystem services. The war threatens natural resources. Soldiers dig trenches, tanks flatten vegetation, bombs scar the landscape and explosives start fires. The weapons spew toxic gases and particles into the air, and heavy metals enter the soil and water.

The military activities have sparked fires in some areas so large that they can be seen from space, raising concerns about the destruction of critical breeding habitats for birds. Some of the administrative offices of the occupied reserves have been ransacked and many staff have been evacuated. There is evidence that environmental destruction is currently an explicit military tactic.

There was therefore a need for a project that examines the extent to which the war is damaging protected areas and that can document this damage and provide a solid basis for future restoration measures. Against this background, the project "Conservation and Conflict in Ukraine: Profiling the War Damages to Protected Areas in Ukraine" (Ukraine-Nature) was proposed.

Usefulness of the project

Our findings will guide future policy measures to address the problems identified in nature reserves. They will highlight the damage done to them during the conflict. They will also support the international efforts and investments needed to repair the damage to conservation gen areas caused by the war.

Goals

The aim of the Ukraine-Nature project is to research and profile damage to protected areas (e.g. national parks, biological reserves) and the natural resources they host, and to map the extent of damage. The aim is to generate valuable data that will be useful for future recovery efforts. This is a pilot project focusing on protected areas in 2 regions: Sumy Oblast Hetmanskiy NNP (50.4867°N 34.9831°E) and Desniansko-Starohutskyi NNP (52°9′57″N 33°24′59″E), Kiev Oblast Chornobylskiy REBR (51°24'14 "N, 30°3'1 "E) and Holosiivskyi NNP (50°17′50″N 30°33′37″E).

Methods

The project was planned to be implemented over a period of 18 months and divided into 3 phases:

Phase 1- Month 1 to 3 (introduction and analysis phase)

In addition to handling the contractual formalities with the Ukrainian partners, the development of relations between the project partners takes place. In the first phase, the
details of the tasks and the time and work plan are agreed upon in a binding manner.

Phase 2 - Month 3 to 16 (Implementation Phase)

This phase includes the implementation of the studies and analyses. A robust information and communication strategy will be planned throughout the period to ensure the visibility of the project activities and their results in Germany and Ukraine. An expert event on the topic of conflicts and nature conservation organised in Hamburg.

Phase 3 - Month 17-18 (Final Phase)

This phase includes dissemination and upscaling activities. The inclusion of an upscaling component in the project will support the relevant actors on the ground in transferring our methods and results to other parts of the country. The project results was planned to be presented at an event in Kyiv.

The main outcome of the project was planned to be the document "Supporting the Restoration of Protected Areas in Ukraine: An Action Plan", which describes the damage to a number of protected areas in the above-mentioned regions, and propose some policy measures to support future restoration efforts in protected areas throughout the country.

3. Steps and methods

Ukraine-Nature project activities were organised according to the developed structure, which contains four working packages (WP). In each working package, different tasks and actions were planned. According to the developed structure of the project, the road map was elaborated and updated monthly. For the "coordinating working group", weekly group meetings were held and documented with follow-ups. All documents and deliveries were organized at the HAW online drive.

Table 1. *Description of actions and the methods used according to the working plan*

Actions	Methods used	Duration, Months
WP1 (project management and partner coordination)		
T1.1 Establishing the Management and partners structure.	Engagement of various partners through newsletters, e-mail, social media and online meetings. Signing agreements. Working groups development and coordination.	M1-M2
T1.2. Internal monitoring of the project´s progress:	Data collection, Gantt chart,analysis of the results, internal reports	M1-M20
T1.3. External monitoring and reporting of the progress of the project.	Intermediate report for the period 01.07.2022 - 31.03.2023 was delivered	M9
T1.4. Final Report	Analyses of the project results presented in this document	M21
WP2 (impact assessments)		
T2.1. Literature review to understand what researchers had explored regarding the environmental impacts of war on water, soil, air and biodiversity on the nature preservation lands.	The investigation was performed using the VOSviewer software with 1714 peer-reviewed documents. The research also considers a set of 48 case studies on the environmental impact assessment of war: 29 from all over the world and 19 from Ukraine.	M1
T2.2.Quantitative and qualitative analyses of research methods and models in order to assess the environmental impacts of the war on ecosystems.	Based on the results of bibliometric assessment of the literature, methods to assess the environmental impacts of the war were explored. The results are presented in attachments in the Table 1. Summary of Methods to Identify the Environmental Impacts of the war in Ukraine.	M1-M2
T2.3. Creation and design of a research model to develop recommendations for the reconstruction and investment based on assessment of impacts of the war on ecosystems	Based on the results of the analyses of the advantages and disadvantages of research methods, a research model was designed to develop recommendations for the reconstruction based on assessment of impacts of the war on ecosystems, and the damages caused on the nature preservation lands	M1-M3
T2.4. Identification of the types of pollution and their potential impacts on the environment.	Questionnaires for the key informant interviews were developed, completed, and analyzed. At the same time, the authors relied on several methods including GIS analyses based on satellite pictures as well as secondary data gathered by experts from the Ukraine Nature Project in two stages: during the on-side expedition and extracted from databases (ACLED, FIRMS, Ministry of Defence of Ukraine, and	M4-M8

	State Emergency Service of Ukraine). Information extracted from databases and satellite images was processed by QGIS software **(**http://qgis.org**)** and presented in Figure 2. Soil sampling was conducted in October 2022 by Dr. Anastasia Splodytel. Together with the preservation areas' representatives and the security service, she travelled to the parks to collect soil and water samples and examine the territories in order to evaluate environmental damages, particularly to the soil. During these expeditions to the four protected nature reserves, 63 samples were collected from the combat damage zones and 20 background samples from the study areas.	
T2.5. Assessing the environmental damages caused by the war in Ukraine for the preservation areas	The content of heavy metals was determined using the ICP-OES method (Inductively Coupled Plasma – Optical Emission Spectrometry) at the Lodz University of Technology. To assess the level of pollutants in the soils of the protected areas, the values of maximum permissible concentrations of pollutants (MPC) were used. Based on the data from ground observations and information extracted from databases and satellite images the map of burned areas was developed. The forest management map, combined with the produced map of losses, enabled the estimation of the volume of tree cover losses by area and stock and classified it using the rating evaluation method by the degree of impact on forests: None, Low, Medium, Above Medium, High, or Extremely High. Maps of the territories of the researched areas were divided using a regular grid of 1*1 square kilometers, each cell containing a unique identifier. The assessment method of rating evaluation with the same grids and unique identifiers, as well as, with the same degrees of impacts (from none to Extremely High) was also used for the soil and biodiversity impacts assessment. The soil criteria were the density of mining and fire intensity. For the biodiversity, the rating assessment was based on the potentially existing rare species and natural habitats and the degree of soil disturbance. A combinative matrix of the military action's impact on biodiversity was formed. The results of the impact assessment on forests, soil, and biodiversity are presented for each researched nature preservation area in Figures 3,4,5 and 6.	M9-M18
WP3 (recommendations for reconstruction and conservation of nature)		
T3.1.Literature reviewing and analysing of the best practices to resolve ecological damages caused by the war.	The best practices to resolve ecological damages caused by the war were discovered by using the VOSviewer software. At the same time, 24 case studies of the business methods to resolve environmental impacts were identified.	M1-M2
T3.2. Preparation of recommendations which will assist in the reconstruction efforts.	Data analyses based on literature review and case studies. The results are presented in attachments in the tables 2/3/4 "Examples of measures to address military actions impacts on soil/forests/biodiversity"	M19-M20
T3.3. Delivering the document "Support in restoration of	Based on the results of WP2 and WP3 (T3.1. and T3.2.) document "Support in restoration of nature reserves in Ukraine: an action plan" was developed.	M21

nature reserves in Ukraine: an action plan".		
WP4 (dissemination and upscaling activities)		
T4.1. Development of robust information and communication strategy to ensure visibility of the project activities and their results in Germany and Ukraine.	Based on the identification of internal and external stakeholders of the Ukraine-Nature project, communication strategy was developed	M1-M3
Task 4.2. Project logo and templates	Based on the projects aim and objectives the logo and templates were produced	M1-M2
Task 4.3 Flyer for the website and social media.	A project flyer based on objectives, methodology and logo was developed	M2
Task 4.4 Networking, Dissemination and Promotion events	According to the developed communication strategy, dissemination, networking, and promotion activities were taken.	M2-M21
Task 4.5 Scientific publications	Based on the project results 3 scientific papers were delivered.	M5, M18, M21

4. Results:

The natural landscape in Ukraine, particularly in the Emerald Network of protected nature reserves, is changing as a result of armed conflict with Russia. Information on the transformation of the landscape and, in some locations, the complete degradation of unique areas is lacking. This lack of comprehensive research documenting the ecological changes caused by military activities occurring in protected nature reserves is a significant data gap and could affect the success of postconflict restoration work in the future and actual conservation activities.

In response to this crisis, the Ukraine-Nature team has concentrated its research efforts on four areas within the Kyiv and Sumy regions (Figure 1): the Chornobyl Radiation and Ecological Biosphere Reserve, the Desniansko-Starohutskyi National Nature Park, the Holosiivskyi National Nature Park, and the Hetmanskyi National Nature Park. These areas were selected based on information from official sources indicating that they have all suffered from military actions, are part of the Emerald Network, and were not under occupation as of May 2022. This focused approach underscores the critical need for targeted research and restoration efforts to mitigate the environmental impact of the war.

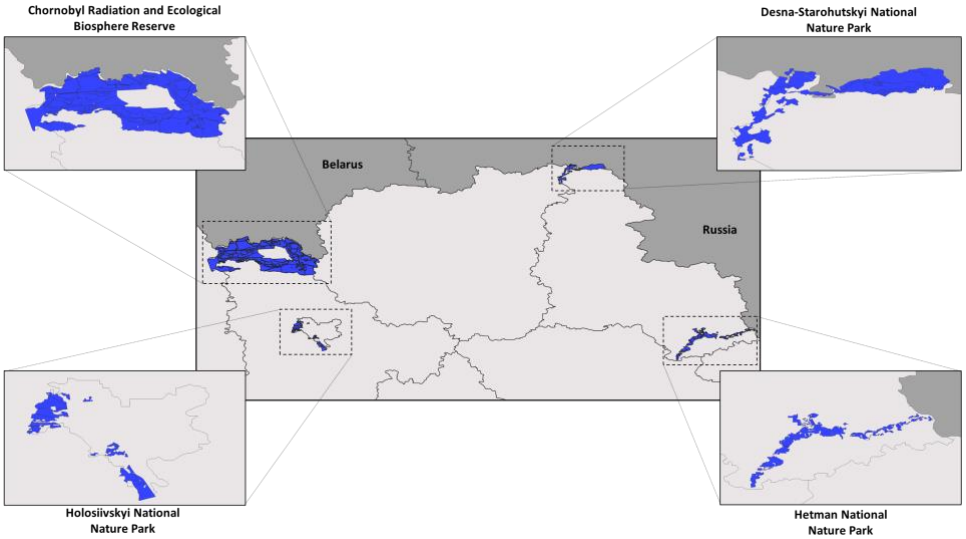

Figure 1. *Selected Ukrainian protected areas.*

To obtain the results, the authors relied on several methods, including bibliometric analysis, key informant interviews, GIS analyses based on satellite pictures and secondary data gathered by experts from the Ukraine Nature Project in two stages: during the expedition (Splodytel, et al. 2023) and extracted from databases (ACLED, FIRMS, Ministry of Defence of Ukraine and State Emergency Service of Ukraine).
Information extracted from databases and satellite images was processed by QGIS software **(**http://qgis.org**)**. Figure 2 shows the spatial dimension of the impacts on the environment in the four PAs. The blue polygons represent areas that experienced occupation by Russian military forces in February-April 2022; the red polygons reveal the burnt areas due to explosions and battles in these regions. The dotted polygons, in turn, indicate areas that potentially contain land mines, and the red dots show the explosions as well as remote violence and battles. A detailed description is provided in the Results section.

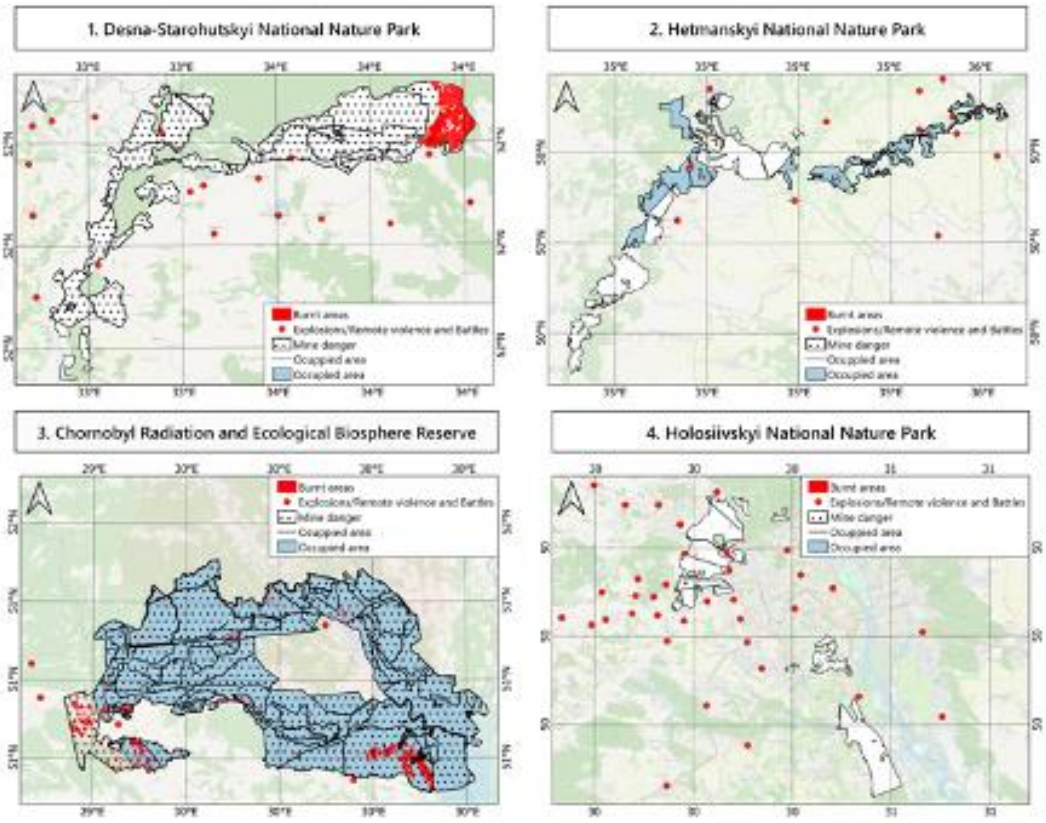

Figure 2. *Distribution of military actions recorded in the studied areas*

4a. Chornobyl radiation and ecological biosphere reserve

Chornobyl REBR was officially established on 26 April 2016, exactly 30 years after the Chornobyl tragedy, by president's decree with the aim of preserving the most typical natural complexes of Polissia in their natural state, ensuring support and increasing the barrier function of the exclusion zone and the zone of unconditional (mandatory) resettlement, stabilizing the hydrological regime and rehabilitating territories contaminated with radionuclides, promoting the organization and conducting of international scientific research. The Reserve is unique and the largest in Ukraine, covering almost 227 thousand hectares, or 2/3 of the exclusion zone territory. On its land, there is a large deal of diversity, including 23 terrestrial, 7 aquatic phytosystems, 5 distinct landscapes, 120 species of lichens, 200 species of mosses, 303 species of vertebrates, and 1256 species of higher plants.
The territory of the Chornobyl REBR borders Belarus. It was through local roads that Russian troops entered Ukraine in the first days of the full-scale invasion. At the end of February 2022, in anticipation of an invasion, the reserve administration pre-evacuated workers, leaving people only in critical positions. Most of the staff, including the scientific department, saw the consequences of hostilities already in April, after the liberation of their territory.

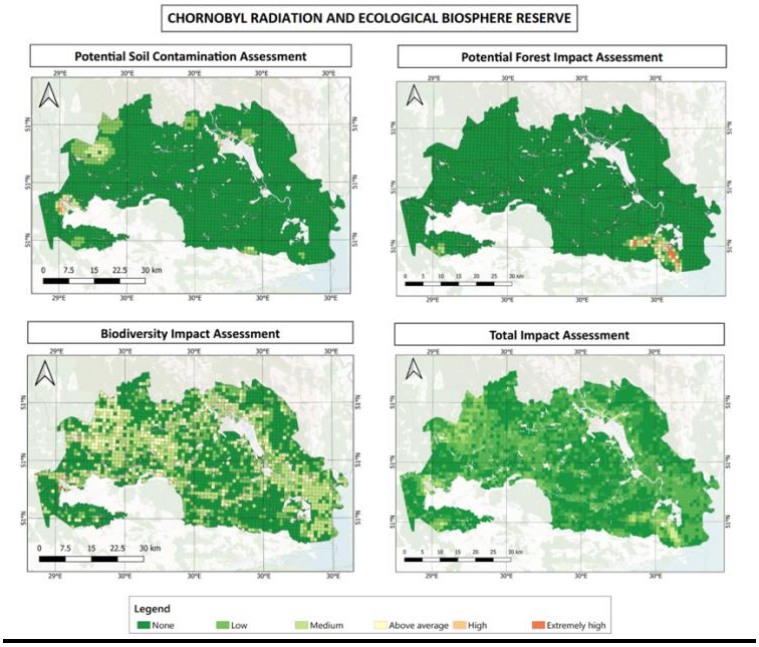

Figure 3. *Chornobyl Radiation and Ecological Biosphere Reserve*

Military actions

Since the beginning of a full-scale invasion in the period 24 February to 11 November 2022 there have been 17 war incidents within the territory of four described in the presented project PAs. That both: on the ground battles (armed clashes) and remote violence (explosions) incidents were included. Four of reported incidents were attributed to the territory of Chornobyl REBR and represent the armed clashes that happened on 4 – 15 March 2022. Chornobyl REBR experienced direct occupation of about 94 % or 213.000 ha by Russian Armed Forces and was out of the area under governmental control between 24 February and beginning of April 2022 (totally about 1.5 months). Recent data showed that almost entire territory of Chornobyl REBR is classified as PMC (potentially mine contaminated), except only 12 ha which is marked as CMC (confirmed mine contaminated). Control over these territories has been lost due to contamination by unexploded ordnance and mines, as well as due to increased security measures along the state border due to the risk of repeated incursions. Computer equipment and research equipment were stolen, as well as cars. Additional research and equipment (camera traps) are needed to study the loss of fauna.

Impacts on soil

Due to the military impact, there were observed mechanical and chemical pollution of soils of the Chornobyl REBR (Fig. 3). Chemical pollution is mainly caused by fires resulting from the use of weapons systems. According to the data of Chornobyl REBR, during the occupation of the Chornobyl NNP Exclusion Zone (in the period from February 24, 2022 to May 1), 2022, fires caused by the occupiers damaged soil cover on the area of 31,760 hectares. After the liberation of the Exclusion Zone, due to the effect of explosive objects, fires were recorded on the area of 18,132 hectares.

As a result of pyrogenic impact, the physical and chemical properties of the soil cover have changed. A change in acid-alkaline conditions toward a neutral pH reaction was quite expected for the soils of the areas affected by fires. On the burned areas, humus substances disappear and a hydrophobic layer, which limits water infiltration, is formed. Reducing the content of water-soluble compounds and neutralizing the pH contribute to the mineralization of organic matter and differentiation of the soil profile under conditions of increased exposure to metals. E.g., an increase in the calcium content by 4.3 times and a decrease in magnesium by 2 times were detected.

Heavy metal pollution is a consequence of artillery shelling and other military activity. Our results showed that concentrations of gross forms of all studied elements in soil samples from the burning area (as a result of a fire provoked by shelling) have many times higher values compared to the background soil. In particular, an increase in potassium by 3.5 times, magnesium by 1.3 times, nickel by 3 times, and vanadium by 4 times was

recorded (Table 2). In contrast to the background samples, the presence of lead and zinc was detected in the range of 8 – 12 mg/kg.
According to the additional results of the ICP analysis with inductively coupled plasma, in soil samples from the burner (Kupovate village), the concentrations of gross forms of all studied anthropogenic metals were several times higher to compare with the background soil.

Table 1. *Gross content of heavy metals in the background and pyrogenically degraded soils of the Chornobyl Radiation and Ecological Biosphere Reserve (mg/kg)*

Soil	Ni	Co	V	Cr	Cu	Pb	Zn
Conflagration	75,0	1,7	28,0	17,0	32,0	45,0	52,0
Background	15,0	0,8	12,0	8,0	10,0	12,0	20,0
MPC	20	-	-	100	33	32	55

In addition to chemical pollution, soils of Chornobyl REBR suffered from mechanical pollution. In the burned areas there is a removal of humic substances and the formation of a hydrophobic layer, which limits the infiltration of water. Mechanical disturbance of the soil cover (tunnels, dugouts, etc.) accounted for about 6% of the Reserve's territory and wasn't pose significant threats to the territory's landscapes.

Impacts on forests

In 2022 in Chornobyl radiation and ecological biosphere reserve biodiversity was damaged in an area of 49892 hectares out of 227 thousand hectares as a result of fires(Table 3). In the Chornobyl REBR, pine coniferous plantations suffered extensive damage as a result of fires. Notably, large annual fires are typical for these areas and occurred even without the impact of military operations. During the Russian occupation, the REBR faced massive fires of high fire hazard class vegetation, such as young pine forests, fallows, meadow waste grounds, and wetlands with dry reeds and wetland grasses.

Table 2. *Volume of trees damaged or lost (cubic meters, m3) as result of armed conflict in the Chornobyl Radiation and Ecological Biosphere Reserve*

Tree species	Opachycke Forests	Kotovske Forests
	Current estimate of lost timber volume (m^3)	Current estimate of lost timber volume (m^3)
Pine (*Pinus silvestris*)	562,258	84,122
Pine (*Pinus* spp.)	12,957	-
Birch (*Betula pendula*)	9,536	831
Acacia (*Robinia pseudoacacia*)	418	-
Oak (*Quercus rubra*)	47	-
Pine (*Pinus bancsiana*)	445	-
Aspen (*Populus tremula*)	366	4
Oak (*Quercus robur*)	1,105	290
Adler (*Alnus glutinosa*)	1,032	24

Impacts on biodiversity

Estimated impacts on natural habitats and rare biota ranged here from None to Hight. The following types of natural habitats of Resolution 4 of the Berne Convention were marked for areas with a level of damage to

biodiversity from above average to extremely high moderate negative and negative impact: Inland surface waters: C1.2. Permanent mesotrophic lakes, ponds and pools; Mires, bogs and fens: D5.2 Beds of large sedges normally without free-standing water; Grasslands and lands dominated by forbs, mosses or lichens E1.9 Open non-Mediterranean dry acid and neutral grassland, including inland dune grassland, E3.4 Moist or wet eutrophic and mesotrophic grassland; Woodland, forest and other wooded land: G1.5 Broadleaved swamp woodland on acid peat; G1.8 Acidophilous Quercus-dominated woodland.
All these biotopes have been affected to varying degrees by military operations. In these territories, a moderately negative, negative and highly negative impact on habitats, places of migration, reproduction and feeding of a number of species that are included in national and international natural lists was indicated, among which birds, reptiles, bats and other mammals. It is interesting to note that no rare representatives of the flora were recorded in the affected area, but this does not rule out the high probability of their presence within the identified natural habitats of Resolution 4 of the Berne Convention. There have been detonations of animals caused by explosive objects. Due to the limited access, it is impossible to effectively control the territory and protect biodiversity (poaching, illegal logging, etc.). Contamination by mines and explosive objects, disturbance of soil cover, and contamination by heavy metals still affect the ecosystems and will affect them in the future.

Action plan:

I. Before the end of military actions

1. Monitoring and risk assessment should include state of soil, habitats, forests and biodiversity. As far as a lot of equipment was stollen during the occupation, international support and cooperation in the monitoring and risk assessment of these territories is needed. Considering that there is limited access to the territory of Chornobyl REBR due to the mined areas, a satellite-based approach to map soil, forest, and biodiversity disturbances is highly prospected. Satellite data should be supplemented by the results of recent observations of the territory (where it is possible) and key informant interview databases.
2. Constant digitalization and mapping of the processes of monitoring
3. Emergency stabilization treatments. Unfortunately, limited access to the territory of Chornobyl REBR makes it almost impossible to carry out measures that prevent forest fires and protect against pests and diseases
4. Restoration measures planning

II. After the end of military actions

1. Demining and ensuring the safety of the territory

As access to the territories is crucial in order to develop a system of restoration measures, the first stage of active restoration is demining and ensuring the safety of the territory. Responsible mining clearance conducted by experts and military personnel can protect the population and preserve the park's biodiversity.

2. Military waste removal by specialised organisations and military personnel.
3. Monitoring of territories that were inaccessible for various reasons, including mined areas.
4. Development of complex restoration measures and its implementation

Soil restoration. Restoration of the soils of the territories that have undergone military actions, involves the development of complex restoration measures by reclamation of destroyed soil cover (where it is possible), followed by the establishment of vegetation cover and ***rewilding*** through the process of natural colonization of species. In some cases, conservation of the most polluted soils. ***Active soil recovery is limited*** by the radiation hazard.

Reforestation. Traditionally, restoration of forest landscapes after fires involves several sequential phases: planning, design, implementation, monitoring and evaluation. A key approach to reforestation is natural succession, which is considered the most desirable path to reforesting forests of naturally protected areas. Complementing these stands with valuable forest-forming species will allow the formation of mixed semi-

natural forests, which is a highly stable forest ecosystem. Controlling tree density and forest edges could be important elements of new management policies. Rehabilitation for broken crowns and tree falls.

Biodiversity restoration. As the main war impact in Chornobyl Radiation and Ecological Biosphere Reserve was fires, biodiversity restoration here associated with after fires ecosystem recovery. Fires in forest landscapes significantly impacted both structural and functional diversity, as habitats formed by perennial biomorphs, such as trees, were destroyed. The loss of these habitats primarily affects forest biota, particularly saproxylic and xylobiont animals and fungi. Restoring forest ecosystems' structure and functionality will take several decades and involve serious successional changes on the damaged territory. Forest fragmentation caused by war-related disturbances leads to the loss of biodiversity and ecosystem services.

Developing crisis response plans for wildlife is highly important for mitigating the impact of emergencies and ensuring prompt and effective actions to protect and preserve vulnerable species and their habitats. It should include the ***restoration of habitats*** to support ***populations of aboriginal, valuable, and rare species.***

4b. Desniansko-Starohutskyi National Nature Park (NNP)

This park was founded on 23rd February 1999, and is situated in the Sumy region's Seredno-Budsky district, which is in the far north of Ukraine. 16214.36 hectares make up the area. The protected area, 2547.40 hectares, includes Lakes Greater and Small Bugs in the Desna floodplain and a sizeable part of the Starogutsky woodland. In general, on its territory and adjacent regions of Novgorod-Seversky Polissya, there are now 340 species of 37 rows of 6 classes. The habitats of boreal species (crane-like, diurnal birds of prey, owls, woodpeckers, passerines, insectivores, rodents, hare-like, carnivorous mammals, ratic, etc.), the majority of which are designated in the Red Book of Ukraine, are preserved in the protected area (2357.4 hectares), which makes up a sizeable portion of the Starogutsky forest (2317 hectares).

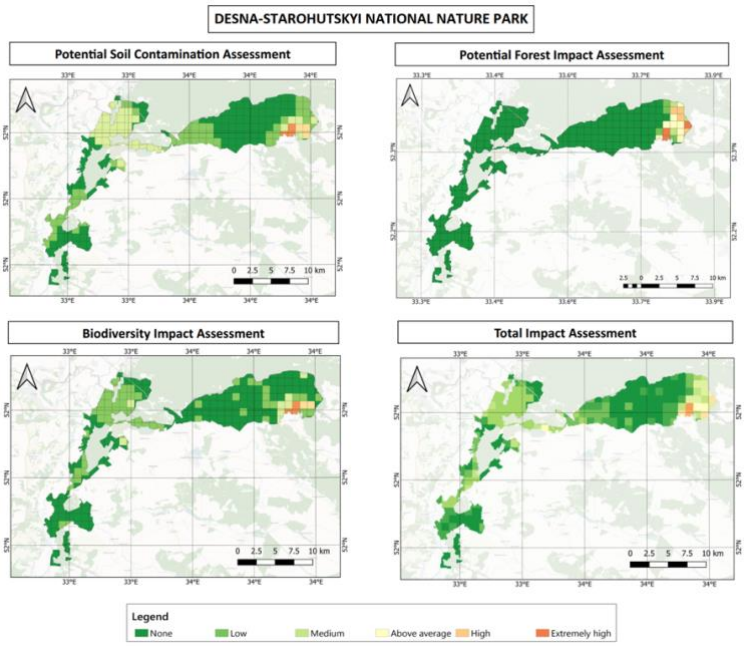

Figure 4. *Desniansko-Starohutskyi National Nature Park*

Military actions

The case of the Desniansko-Starohutskyi NNP vividly demonstrates the challenge of bordering a significant part of the Nature Reserve Fund object with the aggressor country. The length of the common border with Russia in the north and east reaches 30 km. The national park was not under occupation, but every day – starting from February 24, 2022 – it suffers from Russian shelling. The whole park was under regular artillery fire even after the liberation of the terrain. There were 13 war incidents within Desniansko-Starohutskyi NNP (Znob-Novhorodska hromada) in the form of explosions due to shelling, artillery or missile attacks from 16 July to 9 November 2022. The central building of the park is located 400 m from the border with Russia. Every day, either the park itself, or the town of Seredyna-Buda, or the village of Stara Huta, where the

institution's buildings are located are under regular artillery fire. So, on July 31, 2022, the Russians fired a mortar and damaged the new building of the Starohutske Nature Conservation Research Department, a forest fire monitoring tower, garages, a car, etc. After regaining governmental control, almost the entire area of Desniansko-Starovytskyi NNP (about 98 %) was recognized as the PMC zone (potentially mine contaminated) which stretches along the state border with the Russian Federation. In Desna-Starohutskyi NNP military artillery and missile attacks continue to affect the reserve. Part of the employees have been granted the right to work remotely, some are on layoff and on unpaid leave abroad, also there are mobilized workers.

Impacts on soil

Desniansko-Starohutskyi NNP faced mechanical and chemical pollution of the soil cover (Fig. 5) caused by constant enemy bombardment involving the 122-mm howitzer D-30, 2S1 Gvozdika and 152 mm gun-howitzer D-20, SO-152 barrel artillery (a projectile weighs 21.76 – 43.56 kg), which causes the formation of craters. All types of ammunition used in combat operations (high-explosive, fragmentation, armor-piercing, cumulative shells and mines) are characterized by the formation of a shock wave and explosion products that spread in the environment. When a projectile reaches an obstacle, the explosion and the formation of a shock wave occurs instantly in 10^{-4} to 10^{-5} seconds. The destruction radius increases with the mass of explosive in the projectile. For 122-mm and 152-mm shells with explosive weights of 4.5 kg and 8.4 kg, the radius of destruction in medium-density soil is 1.65 and 2.03 m respectively.

Explosive waves lead to the destruction of the sequence of soil horizons with an obvious disruption in the air-water regime. The soil at the impact site becomes turbulent, subjected to dynamic compaction, and contains numerous metal debris with remnants of explosive toxic substances. The main source of pollution during firing is explosion products, which are fine particles and ions of heavy metals that penetrate the soil.

The most common elements of military-technogenic origin in the study area were lead, zinc, vanadium, manganese, aluminum, iron and sporadically copper. The total series of accumulation of gross forms of heavy metals in the interval of 0 – 10 cm was as follows: Zn > Pb > V > Mn > Cu. Zinc exceeded by 1.4 times is typical for the epicenters of artillery strikes, which is confirmed by the results of studies of paired sampling points. The zinc content in most of the samples exceeded the background by 13 times and the MPC by 6.4 times. The lead content exceeded the background by 1.3 – 5 times and the MPC by 1.7 times at the site of the air strike on the Desna children's camp. A third of the samples collected showed an increased manganese content of 1.1 times.

Impacts on forests

The overall damage, considering all types of military damage, affects more than 63% of the total grids analyzed (Fig. 4). Desniansko-Starohutskyi NNP also suffered significant losses of pine plantations as a result of arson on the Russian side of the border (Table 3). The statistics indicate that biodiversity as well as soil damage were the most widespread, affecting over 40% of the grids. In Desna-Starohutskyi NNP in May 2023 939.6 hectares 10% out of 16214.36 hectares in general was burned as a result of setting fire on the Russian border.

Table 3. *Area of forest loss in the Desniansko-Starahutskiy NNP*

Tree species	Area, ha	N, compart.	Timber volume, m3
Pine (*Pinus silvestris*)	816,751	377	307915,127
Birch (*Betula pendula*)	53,402	119	6354,838
Mixed forest	46,47	256	11896,32
Spruce (*Picea abies*)	2,338	400	935,2
Adler (*Alnus nigra*)	0,118	216	25,488

Impacts on biodiversity

Regarding biodiversity, the park's administration did not provide precise data on the inventory of natural habitats and distribution of rare biota due to the lack of databases; therefore, the analysis used public data from biodiversity databases and standard data form of the Emerald Network, to which the park belongs (Site code: UA0000031).

Based on the results of the analysis, it can be assumed that the following natural habitats of Resolution 4 of the Berne Convention may have been adversely affected: D - Mires, bogs and fens: D5.2 -Beds of large sedges normally without free-standing water; E - Grasslands and lands dominated by forbs, mosses or lichens: E2.2 - Low and medium altitude hay meadows, E3.4 - Moist or wet eutrophic and mesotrophic grassland; G - Woodland, forest and other wooded land: G1.8 -Acidophilous Quercus-dominated woodland. The habitats, places of residence and migration and nesting places of a large number of species of rare avifauna and some mammals were affected. A number of insects, amphibians and fish were affected indirectly.
It should be noted that part of the park's land is subject to withdrawal of a 2 km zone along the border to organize a border strip. Restricted access as a result of the protection of the border zone, the organization of minefields will have a negative impact on the biodiversity, especially on large carnivores and ungulates. On the other side, due to the lack of economic activity in the recreational and economic zone, rare species, such as bears, are recorded more often. Detonations of animals using explosive devices were recorded. Due to the ban on hunting in the hunting grounds around the Desna-Starohutskyi park, there is an increase in ungulates both on the territory of the NPP and in the adjacent areas. The main threat to biodiversity is possible due to the occurrence of fires, which cannot be extinguished until the territory is cleared of mines
Military activities in Desniansko-Starohutskyi NNP led not only to the death of forestry workers and destruction of the park's infrastructure, but also to a serious negative impact on natural complexes, especially forest habitats. In turn, significant military activities, partially limited access to park territories, and lack of monitoring data on biodiversity and natural habitats considerably underestimate the possible negative impact on the park's ecosystems.

Action plan:

I.Before the end of military actions

1.Monitoring and risk assessment should include state of soil, habitats, forests and biodiversity. Due to the limited access to the territory of Desniansko-Starohutskyi NNP due to various reasons, including mined areas, a satellite-based approach to map soil, forest, and biodiversity disturbances is highly prospected. Satellite data should be supplemented by the results of recent observations of the territory (where it is possible) and key informant interview databases.
2.Digitalization and mapping of the processes of monitoring
3.Emergency stabilization treatments
4.Restoration measures planning
One of the most important primary steps in the restoration of ecosystems affected by war is the planning – creation of a strategy for their restoration with a scheme of restoration measures and their phased implementation.

II. After the end of military actions

1. Demining and ensuring the safety of the territory.
2. Military waste removal can help to mitigate the possible long-term impacts of military waste.
3. On-field Monitoring of territories (that were inaccessible for various reasons, including mined areas).
4. Regaining financial stability by the rebuilding of infrastructure and development of ecological tourism and recreational use of forests. With the support of international cooperation and attraction of investments in fields of forest restoration.
5. Development of complex restoration measures and its implementation:

<u>Soil restoration</u>

Soil erosion caused by fires in Desniansko-Starohutskyi NNP is the most obvious environmental disturbance because by reducing or eliminating vegetation and ground cover, fires increase the susceptibility of soil to raindrop impact, reducing aggregate stability and promoting sediment detachment (Vieira, et al., 2018). There are several emergency stabilization treatments, such as mulching and seeding, that provide immediate ground

cover to reduce soil erosion and preserve nutrients. For long-term soil treatment, it is necessary to conduct ***soil erosion rate assessments*** (Depountis, N., et al. 2020; Vetrita & Cochrane,2019; Syaufina, L.2018) to determine the right methods for soil remediation. ***Anti-erosion measures,*** including replant vegetation suited to site conditions. Restoration of vegetation cover is best achieved through natural processes of colonization of species from surrounding ecosystems.
According to the field expedition to the Desniansko-Starohutskyi NNP, soil found in hollows/ funnels made by explosions is compacted, perturbed, and contaminated by metallic fragments.
Therefore, ***loosening compacted soil is needed***: eration and gypsum (clay) loosen the soil, allowing water, air, and nutrients to reach the roots and be absorbed. ***Detoxification*** of soil can make the environment cleaner and safer for plant, animal and human life by removing harmful contaminants. ***Biological, chemical and physical treatments*** can bring back nutrients and the soil biodiversity.

Reforestation through planning, design, implementation, monitoring, and evaluation. One of the key strategies for restoring forest landscapes in Desniansko-Starohutskyi NNP could be ***active, passive, or mixed forest management.*** Development of ***forests monitoring system*** (field inventories combined with remote sensing). Computer modelling of forest restoration.
Restoring of forests that were damaged in Desniansko-Starohutskyi NNP could be done by the:
1) ***Shift to more structurally diverse and less flammable forests c***ould be a crucial solution. 2) ***Establish of mosaic plantations*** (widely spaced structures). 3) ***Rehabilitation for broken crowns and tree falls***.

Biodiversity

- ***Habitat restoration and conservation***.
- ***Support of populations of aboriginal, valuable and rare species.*** It is important to ensure the support of populations of aboriginal species, especially valuable and rare ones. Other important measure – control the spread of invasive species.
- ***Monitoring and assessment of biodiversity dynamics after restoration***. Studying the impact of war on plant and animal populations and monitoring and assessing the dynamics of biodiversity after recovery.

4c. Hetmanskyi National Nature Park (NNP)

Hetman National Nature Park was established on April 27, 2009. Hetman National Nature park is situated in Okhtyrka district land in the southeast corner of the Sumy area. The Hetmansky NNP covers an area of 233.6 km² and stretches from the border with Russia to the borders of the Poltava region. During the first five weeks of Russia's full-scale invasion of Ukraine, the territory of the Hetman NPP was the scene of fierce fighting between the Russian troops advancing on Kyiv through the Sumy Oblast and the Defense Forces of Ukraine. The large part of it, including the administration in Trostyanka, was under occupation. Even after the liberation of the park, part of its territory near the border with Russia is under regular shelling. All this led to the damage of thousands of hectares of forests and other ecosystems within this NNP.

Military actions

About 46.3 % of Hetmanskyi NNP, which is ~ 11.000 ha were under occupation between 24 February and beginning of April 2022. The most active fighting took place in the eastern part, and the territories close to the border with Russia suffered the most negative impact. Areas bordering the settlements of Trostyanets, Okhtyrka, and Velika Pisarivka were particularly affected, where there were active hostilities, direct clashes, artillery fire, aerial bombardment and rocket attacks, resulting in fires occurring both directly on the territory of the park and secondarily spreading to the forest lands of the park from settlements. According to official data, the territory of the park was completely liberated on April 1, 2022. Nearly 15 % of the reserve was classified as potentially contaminated with land mines (PMC). In addition, an area of 12 ha within Hetmanskyi NNP is defined as CMC (confirmed mine contaminated) according to official data. According to our results

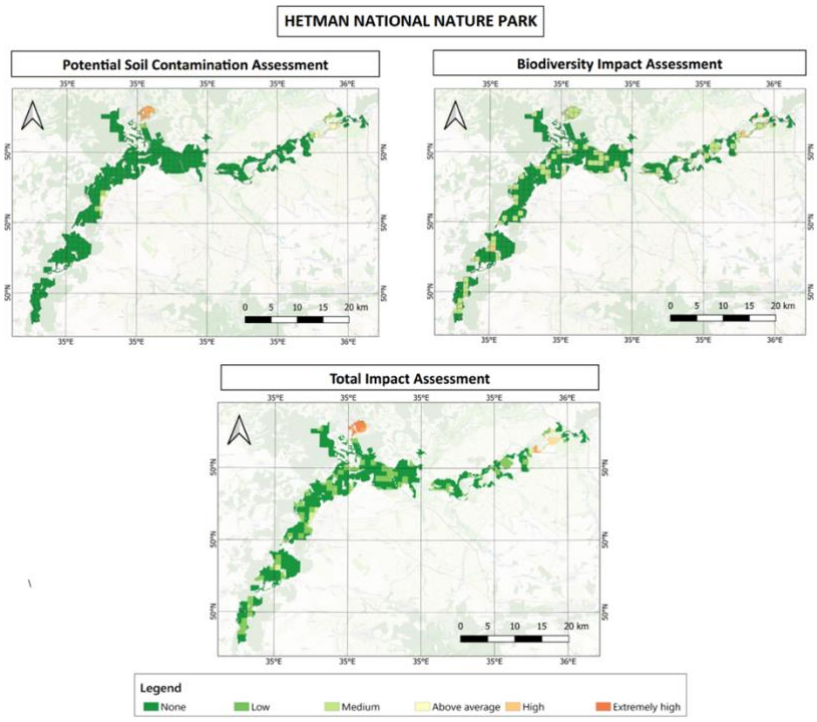

Figure 5. *Hetmanskiy National Nature Park*

Impacts on soil

Similar to the other researched protected nature reserves mentioned above, for the Hetmansky NNP is typical the formation of the craters, due to ammunition explosions and formation of pits and mound landforms due to the fortification.

Ammunition with gunpowder and explosives of different composition were used, and their combustion produced such substances as nitrogen, soot, hydrocarbons, lead, manganese dioxide, and other derivatives, which negatively affect environment. In the areas of bombardment of Hetmanskyi NNP, isolated exceedances of zinc by 1.4 times, vanadium by 1.9 – 2.5 times and lead by 1.5 to 6.3 times were detected. The copper content exceeds the background by 2 times in the areas of air bombardment. For the areas of artillery shelling, the copper content was recorded within the background values. In some samples, the cadmium content is close to the MPC (0.5 mg/kg) but does not exceed it.

Disturbance of the soil and vegetation cover in some places was also significant because of the use of weapons and military equipment movement. Such military disturbances were most evident on dry sod-podzolic sandy soils of leveled terraces. Tracks and multi-track paths of significant depth were formed on the routes of military equipment movement; these often became filled with water, causing waterlogging of the terrain. Maintenance and repair of military equipment in field camps led to the area's pollution with fuels and lubricants, used oils, and antifreeze and organic solvents, Most often, in the places of significant spills of petroleum products in field filling stations, the soils lost its essential property - the ability to self-recover - while microorganisms were completely destroyed.

Impacts on biodiversity

Data on the inventory of natural environments habitats and distribution of rare biota were not provided by the park administration due to the lack of databases, so we used public biodiversity and the standard data form of the Emerald network, to which the park belongs.

Based on the results of the analysis, it could be assumed that the following natural habitats may have been affected. The natural habitats of the Resolution 4 of Bern Convention: Mires, bogs and fens: D5.2 – Beds of large sedges normally without free-standing water; Grasslands and lands dominated by forbs, mosses or lichens: E2.2 – Low and medium altitude hay meadows, E3.4 – Moist or wet eutrophic and mesotrophic grassland; Woodland, forest and other wooded land: G1.8 – Acidophilous Quercus-dominated woodland,

G1.A1 – Quercus – Fraxinus – Carpinus betulus woodland on eutrophic and mesotrophic soils, G3.4232 – Sarmatic steppe Pinus sylvestris forests. Also, ichthyofauna of the Vorskla River was likely to be indirectly affected, namely species included in the Red Data Book. Within the meadow and forest habitats, the habitats were negatively affected on insect species.
Despite the complete de-occupation of the park's territory under the influence of mass mining, artillery and rocket attacks, the deployment of the Armed Forces of Ukraine and a possible re-invasion, the eastern part of the park, close to the borders, remains under attack.
The level of damage to the park ranged from none to extremely high.
If soil damage was evident in 9.15% of grid areas surveyed in this study, the damage of the biodiversity was found in 24.89% of grid areas (fir. 6). The extent of damage in the Hetmanskyi NNP, considering any type of damage, affected more than 27% of grid areas surveyed in this study.

Action plan:

I. Before the end of military actions

1. Monitoring and risk assessment.

Due to the existing dangers like constant shelling and mining of the Hetmanskyi NNP, on-field monitoring and any recovery measures is impossible for the most of the territory. Therefore spatial data and key informant interviews databases could be used for monitoring and risk assessment before the end of military actions.

2. Digitalization and mapping of the processes of monitoring
3. Emergency stabilization treatments such as mulching and seeding, that provide immediate ground cover to reduce soil erosion and preserve nutrients.
4. Restoration measures planning

II. After the end of military actions

1. Demining and ensuring the safety of the territory.

As the access to the territories is crucial in order to develop a system of restoration measure, first stage of active restoration is demining and ensuring the safety of the territory. Responsible mining clearance conducted by experts and military personnel can protect the population and preserve the park's biodiversity.

2. Military waste removal by specialised organisations and military personnel.
3. Monitoring of territories (that were inaccessible for various reasons, including mined areas).
4. Regaining of financial stability
5. Rebuilding of infrastructure
6. Development of complex restoration measures and its implementation

Soil restoration based on soil analysis.

Maintenance and repair of military equipment in field camps in Hetmanskyi NNP led to the area's pollution with fuels and lubricants, used oils, and antifreeze and organic solvents. The main petroleum products that have entered the ecosystem because of military operations are diesel fuel, heating oil, lubricants and others. A particularly difficult contaminant to address is diesel oil, as it consists of many compounds with different chemical structures and biodegradability. Compared with other petroleum derivatives, diesel oil is characterized as a low evaporation rate liquid with slow degradation rates. Diesel oil compounds have different impacts on soil microorganisms. All petrochemicals have strong toxic, carcinogenic and mutagenic properties. For environmental remediation, many remediation technologies have been developed and applied—biodegradation, advanced oxidation process (AOP) and many combined methods (Rakowska, 2020; Sivagami et al., 2019). One of the promising technologies with many advantages, such as suitability for various types of pollutants, a short treatment period, high efficiency, and technical simplicity, is the process of thermal desorption. However, in comparison with physicochemical methods (application of skimmers, booms, barriers and sorbents, dispersants, and controlled in situ burning), bioremediation is a more effective approach without disrupting polluted environments.

Bioremediation, as an economical and environmentally friendly approach, is based on microorganisms' ability to degrade petroleum hydrocarbons. This method aims at biostimulation and bioaugmentation of the natural attenuation of contaminants with indigenous microorganisms (Baniasadi & Mousavi, 2018). Novel approaches for bioremediation, including the addition of novel materials, the use of GEMs, and the integration of electrochemical strategies with biological methods, could be very effective for remediating damaged areas.

Biodiversity

- ***Monitoring*** of local species populations and ***collecting biodiversity data***. Monitoring system and data collection of the biodiversity of the protected areas should be carried out. Organization of monitoring of alien species and ruderal flora.
- ***Habitat restoration and conservation***. Restoration of habitats, with a focus on particular taxonomic and ecological groups of the biota. If necessary, conservation with subsequent restoration of especially destroyed dwellings. If possible, the implementation of artificial breeding and the return of war-affected species to their natural habitats.
- ***Support of populations of aboriginal, valuable and rare species.*** It is important to ensure the support of populations of aboriginal species, especially valuable and rare ones. Other important measure – control the spread of invasive species.
- ***Monitoring and assessment of biodiversity dynamics after restoration***. Studying the impact of war on plant and animal populations and monitoring and assessing the dynamics of biodiversity after recovery.
- ***Developing crisis response plans for wildlife*** is highly important for mitigating the impact of emergencies, ensuring prompt and effective actions to protect and preserve vulnerable species and their habitats. Based on research results, the development of measures to restore disturbed populations which affected by military action.
- ***Conducting environmental protection and educational activities*** with the involvement of local communities, development ecological tourism.
- ***Rehabilitation for broken crowns and tree falls***.
- ***Expansion of the territories of the protected area.***

4d. Holosiivskyi National Nature Park (NNP)

Holosiivskyi NNP is the only one in Ukraine and one of the few national parks in the world located entirely within the boundaries of megacities. It is located in the city of Kyiv, in its southern and western parts and, hence, with a high pressure of recreational activities in pre-war period.. This park was established on 27.08.2007 according to the decree of the president of Ukraine with The total area of 10,988.14 hectares. On the territory of Holosiivskyi NNP there are 23 endangered natural habitats requiring specific conservation measures. It is divided into several relatively small, mostly wooded, areas. At the same time, the park has highly studied natural habitats and rare biota. Due to its bordering with settlements and frequent city dwellers' visits, there were a lot of amateur observations, and, therefore, the total number of observations for the NNP's territory in the Global Biodiversity Information Facility (GBIF) database accounts for about 15.000 records.

Military actions

The northwestern part of the park suffered the greatest negative impact during the occupation of the cities of Hostomel, Bucha, and Irpin, which directly borders the park's territory. As part of the offensive on Kyiv, Russian troops tried to surround and besiege the Ukrainian capital Kyiv from the west. Columns of Russians moved from the territory of Belarus through Chornobyl. As a result, areas on the border of the park were most affected. It was revealed the significantly high war incident density values for Holosiivskyi NNP. On the other side, only 0.3 % of entire territory of Holosiivkyi NNP (equal to 34 ha) was PMC (potentially mine contaminated), which is the lowest level among all reserched protected nature reserves.

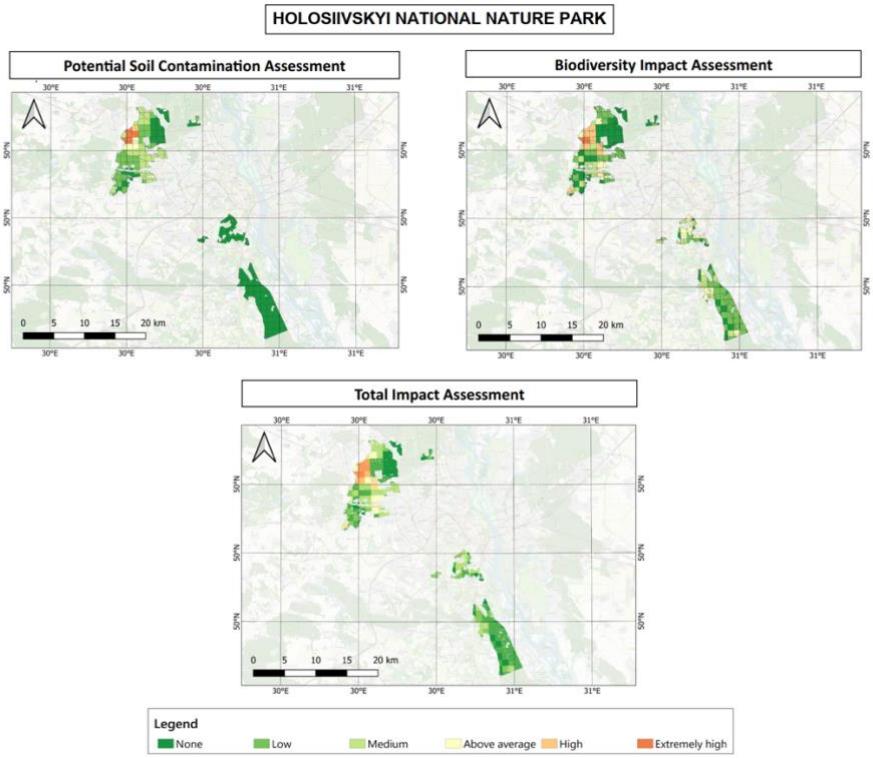

Figure 6. *Holosiivskyi National Nature Park (NNP)*

Impacts on soil

Along with mined territory, the Holosiivskyi NNP faced a mechanical impact, namely deformation of the soil cover due to the construction of defense infrastructure. During the battles, the 85-mm divisional gun D-44, 122-mm howitzer D-30, and 152 mm gun-howitzer D-20 weapons were used for direct fire artillery, involving high-explosive incendiary and high-explosive anti-tank projectiles weighing from 6.5 to 43.56 kg.

At the depth of up to 1.5 m on the military operations territories, soil homogeneity disturbance was recorded. Followed the disturbance of genetic horizons of the soil cover, plants' adaptation to climate change weakens, arid conditions worsening, and the lack of moisture is stronger. This intensified a number of hazardous geomorphological processes: landslides, soil subsidence, etc. When constructing fortifications, the Ukrainian military disregarded the groundwater depth and soil moisture conditions, which negatively affected the landscapes of the nature conservation area. Part of the NNP, (Pushcha-Vodytsia Forest), was shelled, which caused soil deformation in all directions of the shock wave propagation. As for the heavy metals pollution of soil, only manganese exceeded the background level by 1.5-2.1 times, while the rest of the studied elements are within the background values.

Impacts on biodiversity

For sites with above average to extremely high biodiversity damage the following types of natural habitats were affected by moderate negative and negative impacts (Resolutions 4 of the Bern Convention): Inland surface waters: C2.33 Mesotrophic vegetation of slow flowing rivers, Woodland, forest and other wooded land: G1.1, Riparian and gallery woodland, with dominant Alnus, Betula, Populus or Salix; G1.7 Thermophilous deciduous woodland.

These areas were moderately adversely and negatively affected on habitats for migration, breeding and feeding grounds of a number of species included in national and international nature lists.

Overall damages, considering all type of damage, affects more than 72% of the grids surveyed in the reserve (Fir.7). Soil quality was affected in ca. 60% of surveyed grids. Biodiversity was affected in ca. 40% of survey grids. The damage levels for soil and biodiversity range from 0 to 5. The mean values for damage_bio and damage_soil are 0.73 and 1.17, indicating damage was more significant to biodiversity than soil damage.

There was a moderate positive correlation (around 0.53) between soil and biodiversity damage. This suggests that areas with higher soil damage were likely to have higher biodiversity damage as well.

Action plan:

II. Before the end of military actions

1.Monitoring and risk assessment.

Holosiivskyi NNP has highly studied natural habitats and rare biota. Due to its bordering with settlements and frequent city dwellers' visits, there are a lot of amateur observations, and, therefore, the total number of observations for the NNP's territory in the Global Biodiversity Information Facility (GBIF) database accounts for about 15,000 records. On-side monitoring is also possible as far as there is vary small area mined. However, Holosiivskyi NNP is still suffering due to constant avia bombing and drone attacks, therefore constant monitoring of impacts on the environment with the consolidation of databases is needed.

2. Digitalization and mapping of the processes of monitoring

3. Emergency stabilization treatments

4.Restoration measures planning

II. After the end of military actions

1. ***Ensuring the safety of the territory, demining***
2. ***Fast soil analysis and military waste removal*** can help to mitigate the possible long-term impacts of military waste.
3. ***Regaining of financial stability***
4. ***Rebuilding of infrastructure***
5. ***Development of complex restoration measures based on monitoring and its implementation:***

Soil restoration. Restoration of the soils of Holosiivkyi NNP involves the development of complex restoration measures by reclamation of craters, ditches, followed by the establishment of vegetation cover and rewilding.

- ***Detoxification***
- Covering trenches and damage caused by bombing
- ***Loosening compacted soil***: aerator; gypsum (clay); introducing organic matter. aeration and gypsum (clay) loosen the soil, allowing water, air, and nutrients to reach the roots and be absorbed.
- ***Anti-erosion measures***, including replant vegetation suited to site conditions.

Biodiversity

- ***Habitat restoration and conservation***.
- ***Rehabilitation for broken crowns and tree falls***.
- ***Support of populations of aboriginal, valuable and rare species.***
- ***Monitoring and assessment of biodiversity dynamics after restoration***.
- ***Conducting environmental protection and educational activities*** with the involvement of local communities, development ecological tourism.
- ***Expansion of the territories*** of the protected area.

5.Discussion

5.1. To what extent were the objectives achieved?

The main aim of the Ukraine-Nature project was fulfilled, particularly to provide an overview of the impacts of the war on the environment in four Ukrainian protected areas, namely the Chornobyl RABR; Desniansko-Starohutskyi NNP; Holosiivskyi NNP, and Hetmanskyi NNP. The difficulty in assessing environmental impacts caused by military actions was due to the environmental data scarcity on the state of pre-war, at the same time there was limited access to the territories.

The project duration was extended for three months due to the new big military events occurring in the studied areas during the data collection phase, therefore it was needed additional time to process them.
The main outcome of the project was also delivered, particularly the document "Supporting the Restoration of Protected Areas in Ukraine: An Action Plan", which describes the damage to four researched protected nature reserves and proposes measures to support future restoration and actual conservation efforts. It was translated into Ukrainian and delivered to preservation areas management, Ministry of Environment of Ukraine and State Enterprise Biological Resources of Ukraine.
This interdisciplinary approach of the project offers valuable insights into environmental degradation, proposing actionable measures for recovery and sustainability not only in the post but also during the war. In this regard, the Ukrainian government and the international community need to prioritize environmental protection in the country, even during conflict, since the Russian war in Ukraine can put the natural ecosystems in danger and generate long-lasting damage to preservation areas that belong to the European Emerald Network and influence the well-being of the European ecosystems. The Ukraine-Nature project budget was not exceeded.

5.2.Deviations from the results obtained via planned

The Ukraine-nature team managed to accomplish all the planned tasks and deliver results despite all the challenges.
There is still heavy shelling in the Sumy region, particularly in Desniansko-Starohutskyi NNP and Hetmanskiy NNP. At the same time, most of the territories of the research areas are mined, as a result, access to it is very limited. Therefore, examination of the territories was limited as well as soil and water samples collection was very dangerous. However, one of the partners, Dr. Anastasia Splodytel, managed to collect the samples.
Soil and water samples were delivered to the project partners at the Lodz University of Technology since there were problems with electricity in Ukrainian laboratories. To have permission to cross the border with samples, specific documentation for the border officials was formulated.
Considering that examination of the territories was limited due to constant shelling and mined territories, the Ukraine-Nature team relied except satellite pictures and databases also on key informant interviews. Despite the difficulties with electricity and internet connection in Ukraine, answers from the key informants were collected. They were translated, analysed, and presented in the table “Actual situation on the Preservation areas”. It gave valuable information about the damaged areas in our research preservations, biodiversity loss, risks for biodiversity if any consequences of combat operations still affect the ecosystems or will affect them in the future, and also how the war affected the ability to perform the duties of the employees (including scientists). At the same time, administrations of preservation areas also provided us with different maps of their territories. They were needed to proceed with the satellite analyses of the territories.
Despite the difficulties with electricity and internet connection in Ukraine, the Ukrainian partners, who are satellite imagery and GIS experts, continued to work and assess the impacts of war. Their contribution was very relevant since they were conducting screening and mapping of fires, missile attacks, and military waste. To have a complex holistic assessment of environmental impacts, experts in soil, forests, and biodiversity kindly volunteered to collaborate with satellite analyses.
The project results were planned to be presented at an event in Kyiv, however, due to the ongoing military activities the place was changed to the Ivano-Frankivsk city (west of Ukraine).

5.3.Partners cooperation processes

Cooperation between partners was organised according to the developed Ukraine-Nature communication strategy. It describes not only publications in media about the project but also the interaction between partners, DBU project officers, stakeholders, decision-makers and policymakers. The communication with internal and external stakeholders of the Ukraine-Nature project was based on regular online conferences, emails, face-to-face project meetings and workshops. The administrations of the researched preservation areas have been engaged since the inception of the project by signing agreements with them.

According to the developed communication strategy, the communication with internal and external stakeholders of the Ukraine-Nature project was based on regular online meetings, emails, face-to-face project meetings and workshops.
The communication of Ukraine-Nature project was happening at four distinct levels:

1. **Specific communication activities towards the DBU**, e.g. emails, meetings and phone calls with the DBU project officer, regular reports, deliverables, etc.;
2. **Communication with stakeholders closely involved with the project** (Preservation areas management, NGOs and ukrainian and international scientific community) within open stakeholder meetings, workshops, seminars and development of joint tasks.
3. **Communication with decision-makers and policymakers** (Miministry of Environment of Ukraine, State Enterprise Biological Resources of Ukraine) via meetings, workshops, presentation of results and delivering document "Support in restoration of nature reserves in Ukraine: an action plan".
4. **Communication with other parties of interest** (general public) via different communication channels, especially social media, media (newspapers, TV channels, online platforms) and the HAW website.

The coordination procedure for the project working groups consisted of the development of working documents (outputs, roadmap, and protocols) as well as regular personal and group online meetings.
Every two weeks, representatives of the Ukraine-Nature team took part in the Ukrainian environmental working group organized by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA).
The project team also constantly used newsletters within our two big networks European School of Sustainability Science and Research (ESSSR) and the Baltic University Programme (BUP) in order to inform the members about new project's events or important news.

6. Public relations:

6.1. Communication and Dissemination of the results

According to the developed communication strategy the logo of the Ukraine-Nature project was produced, and templates were used in numerous presentations, publications, and official documents. They combine the colours of Ukraine and Germany at the same time, promoting projects moto: "Ecosystems have no borders". It underlines the cooperation between two countries (Germany and Ukraine) towards a clean and healthy environment for all living beings. A project flyer Ukraine-Nature in English, German and Ukrainian was done and used in numerous correspondence with potential partners, media and other stakeholders closely involved with the project. It includes details about the project's objectives, methodology and logo.
Based on the developed Ukraine-Nature communication strategy the following communication and dissemination actions were taken:

- Reports in media: ZDF; 3SAT; Die Zeit ; TAZ.DE; Bergedorfer Zeitung; Nachrichten.idw; Ukrainian media
- Publications in:
  - Social media: Twitter, Linkedin, Facebok
  - DAAD annual report
  - BUP online platform
  - HAW web page
- Presentation of the results on events:
  - Peilung #4 by DAAD on June 9th, 2023, at the daadgalerie, Berlin;
  - die Zukunft im Land, Projektmöglichkeiten, Anschlussförderung nach dem Fellowship und über den Wiederaufbau by DBU on June 29th, 2023, Osnabrück;
  - Institut für Friedensforschung und Sicherheitspolitik, Universität Hamburg on October 25, 2023, Hamburg;

  - Stimmen aus der Ukraine! By Württembergischen Landesbibliothek on February 8th, 2024 , Stuttgart;
  - “Cafe Kyiv. The Future of Ukraine in Europe” by Konrad Adenauer Foundation on February 19th, 2024, Berlin.
- Lectures for German and Ukrainian students
- Two Seminar that presented the midterm and final results of the project were held in Hamburg (Germany) and Ivano-Frankivsk (Ukraine)
- Two workshops one online and one in Hamburg
- 3 Scientific articles
- Planned presentations: Woche der Umwelt 2024 by DBU on June 4-5th, Berlin; Congress of Central and East European Studies (ceecon24) on 7-8 October, Berlin.

The project team took part in creating a documentary video for the ZDF channel. One of the biggest German TV channels " Zweites Deutsches Fernsehen", made a documentary video about environmental damages caused by the war in Ukraine and our project was also included in this material. Around half a million German citizens could see it broadcasted on TV and it is also available through the link.
General information about the project was posted in the HAW website in both English and German. Also, materials with the interview were published in the Die Zeit newspaper, “Bergedorfer Zeitung” newspaper and online media TAZ.DE. Video material about the Ukraine-Nature project supervised by Martin Rosefeldt was broadcast by 3 Sat in Kulturzeit on the 15th of January. The list of publication about the project Ukraine-Nature is presented in the Table 5.

Table 5. *The list of publication about the project Ukraine-Nature*

№	Title of the publication	Media	Link to the publication
1	Naturschutz und Konflikt in der Ukraine: Ermittlung der Kriegsschäden an Naturschutzgebieten in der Ukraine	HAW web page	https://www.haw-hamburg.de/forschung/forschungsprojekte-detail/project/project/show/ukraine-nature/
2	Invitation to attend the workshop “Ukraine Nature”	Ternopil National Med. Uni	https://www.tdmu.edu.ua/en/invitation-to-attend-the-workshop-ukraine-nature/
3	Kriegsopfer Natur	TAZ.DE	https://taz.de/Forschung-ueber-Kriegsschaeden/!5890269/
4	Wie die Lohbrugger Hochschule der Ukraine in Krieg hilft	Bergedorfer Zeitung	https://www.abendblatt.de/hamburg/bergedorf/article236684289/forschung-natur-wie-die-lohbruegger-hochschule-der-ukraine-im-krieg-hilft.html?service=amp
5	Today is the day to prevent the exploitation of the #environment in #war and armed conflict.	Twitter	https://twitter.com/ftz_nk_hamburg/status/1589317211230912512?s=48&t=Vyw8gf1bJU52CjwOl_HCVg&fbclid=IwAR1p8jj6ZELxotLz_6aQTxN5jW1NVE3rWRXRdoFMWz5p-Ivq0fxLlh1Rnik
6	We are in our local #newspaper!	Twitter	https://twitter.com/ftz_nk_hamburg/status/1581910217888911360?s=48&t=hVqb2N1KVzkclLNzZNJ8yw&fbclid=IwAR1wnVbyioLjbNTEmpYvPqBdZVVnuKKF3cOHtx1e2SWiS_aYzKcUg37RODg
7	FTZ-NK comes on TV.	Twitter	https://twitter.com/ftz_nk_hamburg/status/1600852491733594112?s=48&t=Ts04MkTraNMImAUewzWTHA
8	Research project examining impact of war on nature in Ukraine	Hamburg news	https://hamburg-business.com/en/news/research-project-examining-impact-war-nature-ukraine

9	Seminar "Nature conservation and conflict in Ukraine" with public hour for journalists	Nachrichten.idw	https://nachrichten.idw-online.de/2023/04/21/seminar-nature-conservation-and-conflict-in-ukraine-with-public-hour-for-journalists
10	Invitation to attend the workshop “Ukraine Nature”	BUP platform	https://bup.fi/invitation-to-attend-the-workshop-ukraine-nature/
11	Umwelt unter Beschuss. Wie der Krieg die Ukraine zerstört	ZDF	https://www.zdf.de/dokumentation/planet-e/planet-e-umwelt-unter-beschuss-100.html
12	BUP Sustainability Report	BUP platform	https://www.balticuniv.uu.se/digitalAssets/1031/c_1031784-l_1-k_bup-sustainability-report.pdf
13	Ein interessanter Beitrag des ZDF zu den dramatischen Umweltschäden des Kriegs in der Ukraine.	Linkedin	https://www.linkedin.com/posts/hawhamburg_planet-e-umwelt-unter-beschuss-activity-7032363227632005121-KHA8?utm_source=share&utm_medium=member_desktop
14	Wie wirkt der Krieg auf Ökosysteme der Ukraine?	HAW web page	https://www.haw-hamburg.de/detail/news/news/show/projekt-untersucht-kriegsschaeden-in-oekosystemen-der-ukraine/
15	Ukraine-Nature: ecosystems have no borders	Linkedin	https://www.linkedin.com/posts/research-and-transfer-center-sustainable-development-and-climate-change-management_ukraine-nature-war-activity-7061247604239552512-7jij?utm_source=share&utm_medium=member_desktop
16	Nature conservation and war in Ukraine	Linkedin	https://www.linkedin.com/posts/research-and-transfer-center-sustainable-development-and-climate-change-management_natureconservation-warinukraine-ukrainenature-activity-7064182056712327168-9rkU?utm_source=share&utm_medium=member_desktop
17	Verbrechen gegen die Natur	Die Zeit	https://www.zeit.de/2023/45/ukraine-krieg-umweltschutz-biodiversitaet-waldbraende
18	German national newspaper Die Zeit wrote about the results of our “Ukraine-Nature” project	Linkedin	https://www.linkedin.com/posts/research-and-transfer-center-sustainable-development-and-climate-change-management_dbu-ukraineabrnature-activity-7126260318393024512-EMRG?utm_source=share&utm_medium=member_desktop
19	Russlands Verbrechen gegen die Natur im Ukraine-Krieg	3sat Kulturzeit	https://www.youtube.com/watch?v=kj-j62D1BXk
20	Nature is a silent victim of the war until we speak for it.	Linkedin	https://www.linkedin.com/feed/update/urn:li:activity:7158433755852881921/
21	We warmly invite you to join our seminar	Linkedin	https://www.linkedin.com/feed/update/urn:li:activity:7158380197497450496/
22	Projekt „Ukraine-Nature“ vom "Nachhaltigkeit und Klimafolgenmanagement" (FTZ-NK)	Linkedin	https://www.linkedin.com/feed/update/urn:li:activity:7165335366621773827/

23	Ausmaß der Kriegsschäden in ökologischen Schutzgebieten	HAW web page	https://www.haw-hamburg.de/detail/news/news/show/ausmass-der-kriegsschaeden-in-oekologischen-schutzgebieten/
24	Вплив війни на природу: у Франківську розповіли, як досліджують деокуповані природоохоронні зони	galka.if.ua	https://galka.if.ua/vplyv-viyny-na-pryrodu-u-frankivsku-rozpovily-iak-doslidzhuiut-deokupovani-pryrodookhoronni-zony-foto/?fbclid=IwAR0lFLbU8GkPCwVAzWw_bFGvZh1wwuwFGrcSKajt9-MwhGypgSTqHt97vss_aem_AU-l7KFvwj_MMfNpylrXR1czzhS8tCLH0aUgx9BBqUEZUwMnf-3yLGTjZ0fiBcSby1QALQYaYJfI3CHv1UISSAen
25	У Франківську ділилися дослідженнями, як війна вплинула на довкілля деокупованих природничих парків	report.if.ua	https://report.if.ua/socium/u-frankivsku-dilylysya-doslidzhennyamy-yak-vijna-vplynula-na-dovkillya-deokupovanyh-pryrodnychyh-parkiv/
26	В рамках проєкту “Ukraine-Nature” за сприяння німецького екологічного фонду DBU	Facebook	https://www.facebook.com/golospark/posts/pfbid02hjYdENdHABtdtTpSFAabYmSPKM3yTeVhvCTb3XWiv3BjFChd3hXF4CoEJP8z1Vsbl

In order to share the results of the project, two lections for students of Christian-Albrechts Universität zu Kiel, Institute of Natural Resource Conservation were delivered within the topic "SDG 15 life on land and effect of wars (Ukraine)". And for the students of the Department of Biology and Ecology in Vasyl Stefanyk Precarpathian National University, Ukraine.
Seminar that presented the midterm results of the project was held in Hamburg and online on 22-23.05.2023. The Ukraine-Nature team and partners from Ukraine and Poland presented their midterm research results and shared valuable information about the damaged areas in research preservations, biodiversity loss, and consequences of combat operations that still affect the ecosystems or will affect them in the future. The event also explored how the war affected the ability to perform the duties of the employees (including scientists) as well as its effects on human health. There were 16 offline and 65 online participants.
On February 12th, 2024, Ukraine-Nature team and partners from Ukraine, and Switzerland presented the final results of the Ukraine-Nature project. During the seminar held in Ivano-Frankivsk (Ukraine), project experts from academia, preservation areas management, and NGOs together with online participants from all over the EU discussed soil and forest degradation, biodiversity loss, and consequences of combat operations that still affect the ecosystems or will affect them in the future. The event also explored the researched methods used and recommendations for the conservation and restoration efforts. There were 18 offline and 56 online participants.

6.2. International partnership

In order to establish the partners' structure, an online workshop with 54 participants was held on 13.09.20222. The project presentation was followed by a discussion regarding possible opportunities for collaboration. After the event, numerous offline and online personal meetings were held. As a result, four working groups were created to conduct the research: 1) a coordinating working group, 2) preservation areas management, 3) a satellite imagery, GIS working group, and data analyses 4) soil and water samples analyses. For this purpose, four agreements between nature preservation areas and FTZ-NK were signed. Together with the Ukraine-Nature team from HAW in the project also took part folowing partners:

1.Oleh Chaskovsky,National forestry university of Ukraine, Ukraine
2. Oleh Hodyna, Holosiivskyi National Nature Park, Ukraine
3. Sergiy Kubrakov, Desna-Starohutskyi National Nature Park, Ukraine
4. Oleksandr Borsuk, Chornobyl Radiation and Ecological Biosphere Reserve, Ukraine

5. Reto Burch, Suena GmbH, Germany
6. Oleksii Maruschchak, Ukrainian Nature Conservation Group, Ukraine
7. Anastasia Splodytel, National Academy of Sciences of Ukraine, Ukraine
8. Anatoliy Smaliychuk, Ivan Franko National University of Lviv, Ukraine
9.Serhiy Panchenko, Hetmanskii National Nature Park, Ukraine
10. Oleksandr Kvarta, Hetmanskii National Nature Park, Ukraine
11. Andrii Zamoroka, Vasyl Stefanyk Precarpathian National University, Ukraine
12. Viktor Shparyk, Vasyl Stefanyk Precarpathian National University, Ukraine

In order to enrich the results with interdisciplinary expert knowledge and narrow it down to the Ukrainian context, a workshop with Ukrainian professors was held at the Hamburg University of Applied Sciences (HAW-Hamburg).
The workshop, which involved 15 professors from 3 Ukrainian universities (Ivano-Frankivsk National Medical University, National Forestry University of Ukraine, and the Ivan Franko National University of Lviv), was held in Hamburg on 25.08.2022. As a result, the project team formed answers into the table considering four dimensions (water, soil, biodiversity and air) and answering the following questions: Impacts, Consequences to public/human health, Possible post-war solutions and policies to tackle the impacts, which stakeholders should be involved in the process.

6.3. Continuation of the project

A proposed system of measures includes consistent and constant monitoring of affected areas, prioritizing critical sites for immediate post-conflict intervention, and developing a "Marshall Plan for Environmental Reconstruction" to guide restoration efforts with national and international support.
Future studies could extend this research by monitoring environmental variables over the long term, employing qualitative analyses to understand the extent of environmental damage, and leveraging satellite imagery for comprehensive damage assessments. Understanding social implications of environmental degradation also warrants further research.
Moreover, given the wide variety of initiatives and efforts concerned with natural resources conservation and recovery during the war, it is suggested that a project be undertaken that can congregate information on different projects, connect various stakeholders, and act as a “hub” in the dissemination of events, publications, study reports, and funding opportunities to support current and on-going initiatives. The staff at the project Ukraine Nature will in the coming months engage in actions with the objective of setting up the “Ukraine Nature Network”, hence continuing the work initiated as part of this project.
Given the scarcity of data on post-war environmental restoration and nature conservation during the war, this project findings are invaluable, highlighting the urgent need for targeted restoration and preservation efforts in the face of ongoing military threats. The results will inform future management decisions, legislative initiatives, and international awareness regarding the environmental consequences of war. Additionally, the findings will be further shared through scientific conferences, publications, and discussions with experts to foster a collaborative approach to "green recovery".

7. Conclusion

7.1. Modifications in the project's approach

The project was planned to be implemented over a period of 18 months and divided into 3 phases. However, project duration was extended for three months (until March 2024) for the following reasons:
1. New military events occurred in the studied areas during the data collection phase, so we needed additional time to process them.
2. As a result, the environmental impact assessment required more time than expected
The planned methods to be used included the following techniques:
a) Panel Instrumental Variables Approach, a method for estimating causal relationships when controlled experiments are not feasible (in this case due to the conflict and the current dangers of travelling in the country).

b) The use of spatially explicit data parameters to characterise the heterogeneity of damage in the different areas to be included in the study.
c) Use of current satellite data that can be cross-checked with previous records.
To achieve the objectives of this project, we relied on satellite data as planned and also complimented it with more sources of data: key informant interviews, secondary data gathered by experts from the Ukraine Nature Project in two stages: during the on-side expedition and extracted from databases (ACLED, FIRMS, Ministry of Defence of Ukraine, and State Emergency Service of Ukraine).
Instead of Panel Instrumental Variables Approach it was used soil and water analyses and on-field examination as it considered to be more accurate. Despite current dangers of travelling in the country partner of the project Dr. Anastasia Splodytel managed to collect soil and water samples and examine the territories. The content of heavy metals was determined using the ICP-OES method (Inductively Coupled Plasma – Optical Emission Spectrometry) at the Lodz University of Technology. To assess the level of pollutants in the soils of the protected areas, the values of maximum permissible concentrations of pollutants (MPC) were used.
It was also used the spatially explicit data parameters to characterise the heterogeneity of damage in the different areas as planned and processed it by QGIS software (http://qgis.org). It was complimented with rating evaluation method by the degree of impact on forests, soil and biodiversity: None, Low, Medium, Above Medium, High, or Extremely High. Maps of the territories of the researched areas were divided using a regular grid of 1*1 square kilometers, each cell containing a unique identifier. A combinative matrix of the military action's impact on biodiversity was formed.

7.2. Changes to the objectives

Since in the context of the ongoing war, there is limited access to the territories due to mining and shelling, it restricts researchers and society in acting toward recovery. Therefore, the project objectives were extended to provide recommendations not only for the post-war period but also before the end of military actions, particularly the main activities that would include constant monitoring and assessment of environmental damages caused by the war.
The Ukraine-Nature project aimed to research and profile damage to protected areas (e.g. national parks, biological reserves) and the natural resources they host, and to map the extent of the damage. During the project implementation, it was outlined three groups of soil, forests, and biodiversity to make the research more focused and practical. These groups were chosen based on the results of the identification of military actions and their impacts on the environment. Detailed impacts assessment from the Russian-Ukrainian war on the protected nature reserves as well as recovery recommendations were concentrated within these three groups.

8.References

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9. Attachments

Table 1. Summary of Methods to Identify the Environmental Impacts of the war in Ukraine

Dimension	Main Impacts	Possible Methods to Identify the Impacts	
Soil	Land mines	Military operations Electromagnetic techniques Grounding penetrating radar Nuclear quadrupole resonance/neutron probes	Damage assessment (Semi-quantitative field survey supported by laboratory analyses of soil samples)
	Military waste and contamination	Crowdsourcing data informing the type of military waste and its location (photos, survey, qualitative description)	Experts' involvement in understanding the type of military waste and its environmental consequences. Toxicological soil analysis, biodiversity soil analysis
	Land surface change	Crowdsourcing data can inform the changes in the land surface (photos, survey, qualitative description).	Satellite imagery Expert analysis of the soil.
Air	Wildfires / Intense circulation of heavy military vehicles/ explosions	Measurement of air particles Air Analysis Calculations, indexes Chemical analysis Computational fluid dynamics Computer simulation speculation and projection (to estimate the total amount of pollutants emitted from welt fires) calculations were based on actual average crude oil flow rates).	Concentration analysis Concentration gradients Electronic guidance system Environmental monitoring Explosion testing High-speed photography Numerical simulation
Biodiversity	Biodiversity loss, animal migration, Microbiome compromise,	Chemical analysis Computer modelling Concentration analysis Damage detection Field pictures Ecological risk assessment Ecotoxicity Environmental monitoring Surveying wildlife	Gas chromatography Remote sensing Risk Analysis/Assessment Toxicity testing Vegetation assessment Data about national biocapacity extracted from the Global Footprint Network.
Water	Acid Rain, pH alteration (river and groundwater)	pH measurement Chemical analysis of water and soil samples Biological monitoring Vegetation surveys Water body surveys	Remote sensing and satellite imagery Historical data comparison Atmospheric monitoring Modelling and simulation
	Pollution/contamination	Water Sampling and Chemical Analysis	Soil testing Hydrological studies

Dimension	Main Impacts	Possible Methods to Identify the Impacts	
	(heavy metals, oil): aquifers, rivers, sea, groundwater, wetlands, surface water; estuaries	Sediment Analysis Biological Monitoring Remote Sensing and Aerial Photography	Ecological surveys and habitat assessment Biomarkers and Bioassays Trace Metal Speciation Isotope Analysis
	Flooding: pollution sewage from household latrines, fuel and lubricants from petrol stations, heavy metals and PAHs	Water quality testing Sediment analysis Remote sensing and GIS Mapping Biological Monitoring	Health risk assessments Soil testing Ecotoxicological assessments Drone surveillance Isotope Tracing

Table 2. Examples of measures to address military actions impacts on soil

Methods and Techniques	Advantages and Disadvantages
Land mines: lead to soil contamination and endanger the lives of human beings and animals.	
• Demining/mining clearance: excavators, flails • Mine defusal	**Advantages** Responsible mining clearance conducted by experts and military personnel can protect the population and preserve a park's biodiversity. **Disadvantages** Exploding mines intentionally could lead to increased military waste and soil contamination, compression, and erosion.
Military waste and soil contamination (heavy metals, oil spills, shelling) lead to the loss of nutrients, mineral composition, and soil biodiversity.	

Military waste removal by specialised organisations and military personnel. Soil detoxification Biological treatment/bioremediation Chemical treatment Physical treatment	**Advantages** Fast soil analysis and military waste removal can help to mitigate the possible long-term impacts of military waste. Detoxification of soil can make the environment cleaner and safer for plant, animal, and human life by removing harmful contaminants. Biological, chemical, and physical treatments can bring back nutrients and soil biodiversity. **Disadvantages** Soil detoxification: it could be expensive and take some time to fix the problem, depending on the type of contamination. Bioremediation: after partial biological processing, additional detoxification approaches may be needed due to increased toxicity. Physical treatment: it may involve high investments, destruction of soil structure, risk of secondary pollution, and risk of destruction of nutrients and disturbance of soil properties. Chemical treatment: chemical treatment residues have a significant influence on the ecological system, soil fertility reduction, and underground water contamination, affecting animals and birds and promoting serious environmental pollution.
Land surface change: soil compression, erosion, craters, trenches, construction of bunkers, etc.	
Loosening compacted soil: aeration, introducing gypsum (clay) and organic matter. Trenches and damage caused by bombing: cover Erosion: replanting vegetation suited to site conditions.	**Advantages:** aeration and gypsum (clay) loosen the soil, allowing water, air, and nutrients to reach the roots and be absorbed. **Disadvantages** Aeration: high energy consumption and maintenance costs, can have an erosive effect. Gypsum (clay): may result in decreasing potassium or magnesium levels in the soil. Excessive organic matter can lead to nitrogen tie-up.

Table 3. Examples of measures to address military actions impacts on forests

Methods and Techniques	Advantages and Disadvantages
Forest contamination by mines and explosive objects (UXO)	
Licensed trainings to involve foresters in the demining process. List of detailed recommendations, which should be mandatory and applied on liberated territories.	**Advantages:** Greater awareness among foresters about land-contamination risks. **Disadvantages:** Forests are currently not a priority for demining. Demining in forests is more difficult than in other territories, the usage of special machines is limited.

	Lack of experienced staff and proper equipment for forest demining.
Fires	
Fire suppression operations. Satellite-based approach to map forest disturbances (e.g. fires or tree harvesting). Updated management policies incorporating proactive management of fire risks.	**Advantages:** Lower vulnerability of forests. Satellite data sources sufficiently provide the long-term data on forest disturbance regimes. Forests become less flammable due to more structurally diverse polycultures and mosaic plantations of varying densities. **Disadvantages:** Ongoing battles and mines and UXO contamination make it impossible to restore forests or even prevent forest fires. Difficulties with compiling and comparing forest fires statistics between different actors due to the different techniques used (e.g. satellite vs ground data).
Forest fragmentation caused by war-related disturbances	
Large-scale damaged forest cover mapping. Satellite data for assessment of damaged forests. Restoring of damaged forests. Developing capacities for growing planting forest material.	**Advantages:** Fragmented forests could reduce fuel contiguity that facilitate rapid fire spread. **Disadvantages:** Complex restoration and rehabilitation are needed. Detailed assessment is needed. Some forest ecosystem cannot be restored. Spatial data is not always accurate and up-to-date.
Absence or violation of the monitoring system of damaged forests	
Development of forests monitoring system and assessment methodology (field inventories combined with remote sensing). Digitalization of forest management.	**Advantages:** Remotely sensed data provide strong support to future forest planning in Ukraine. **Disadvantages** Part of the protected territories and objects are still located in the combat zone, while liberated areas face forest contamination; therefore, field inventories are dangerous or impossible.
Damaged forest infrastructure	
Conducting an inventory of destroyed and damaged objects of forest infrastructure. Development of ecological tourism and recreational use of forests.	**Advantages:** Rebuilding of forest infrastructure will support ecosystem restoration, increase financial income from recreation, tourism, and forestry, and support research, monitoring, and climate change adaptation. **Disadvantages:** Ongoing battles, mines, and UXO contamination make it impossible to restore forest infrastructure. Limited financial support from the state budget.

Table 4. Examples of measures to address military actions impacts on biodiversity

Methods and Techniques	**Advantages and Disadvantages**
Ecosystem contamination by mines and explosive objects (UXO)	
Demining/mining clearance. Mine defusal.	**Advantages:** Any work in ecosystems should be conducted only after clearance and demining. **Disadvantages:** Risk of cratering and pollutants released from onsite detonation of mines. The possibility of using special machines for the disposal of explosive devices is limited in some of the ecosystems. Climate change and climate-related hazards should be considered.
Absence or violation of the monitoring system of the damaged ecosystem	
Remote environmental monitoring and assessment in near real-time. Mapping the damage to designated natural areas and reserves. International cooperation.	**Advantages:** Analysis and assessment in line with the needs of the area. Mapping should identify immediate priorities where restoration should be fast-tracked due to the high risks, such as significant threats to biodiversity, climate, or ecosystems, in order to develop a strategic plan to guide overall restoration. Data could be used for international cooperation, technical assistance, and financial support. **Disadvantages:** On-side access is limited due to the presence of UXO or the proximity to frontlines. Remote data has limitations and can both guide and be enhanced by field data collection. Monitoring system needs experts to plan and implement environmental policies.
Biodiversity loss, animal migration, microbiome compromise, and habitat destruction	

Pollution cleanup and prevention. Computer modelling. Habitat restoration and conservation.	**Advantages:** Habitat restoration and conservation support the mitigation of damages and prompt effective actions to protect and preserve vulnerable species and their habitats. **Disadvantages:** Limited on-site access. Lack of knowledge about biodiversity restoration approaches in the special case of war impacts. Habitat restoration projects can be expensive and may take years to show significant results. Restored habitats could be vulnerable to invasion by non-native species. Fragmentation of habitats can limit the effectiveness of restoration efforts, especially for species that require large, interconnected habitats.

Damages from tranches, Holosiivkiy NNP

Source: Ukraine-Nature expedition, Dr. Anastasia Splodytel

Process of samples collection

A crater formed by artillery bombardment with 122 mm ammunition. Sumy region

Source: Ukraine-Nature expedition, Dr. Anastasia Splodytel

Damages from artillery and gun fires

Source: Ukraine-Nature expedition, Dr. Anastasia Splodytel