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NATURAL RESOURCES OF UKRAINE: CONSEQUENCES AND RISKS OF RUSSIAN AGGRESSION

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Abstract. *The natural resources of Ukraine are suffering from russia forces. Ukraine is known as one of Europe's largest grain producers. Ukraine is a major exporter of wheat (accounts for 10% of world exports), corn (15%), barley (15%), and sunflower (especially oil – 50%). The ongoing the Russian-Ukrainian war strengthens the unstable economic system in country. Military actions influence the environment of Ukraine in terms of climate change, soil and impact on agriculture, water security and supply. According to this, grain production in Ukraine decreased by 40%, and structure of crop losses due to war: wheat – 39%, sunflowers – 17%, corn – 12%, barley – 8%, fruits and berries – 3%, other crops – 21%. In addition, the Russian-Ukrainian war has impacted water availability and quality (risk for water resources), soil quality and degradation (risk for soil resources), forest health and productivity and habitat of species (risk for biological resources). For instance, the description of sewage treatment plants (the sewage treatment facilities were shelled in the city of Mykolaiv city, the sewage treatment facilities in the village of Novotroitske, Volnovasky district, Donetsk oblast were damaged etc.), disruption of water supply to the crop production (damaged irrigation systems in Ukraine: 94% in the Kherson region, 74% in the Zaporizhia region, 30% in the Dnipropetrovsk region), pollution of the surface and underground waters (massive flooding of military equipment and ammunition in reservoirs, leaks of oil products and other chemical compounds).*

In this article, we analyzed of the environmental situation under the impact of russian aggression on the state of natural resources of the country and justification of the consequences of this impact; identified the determination of the main risks for providing the country with food and the branches of the national economy with water supply, as well as the preservation of environmental components; proposed the development of proposals for the assessment of environmental damage to the environment as a result of the military aggression of the russian federation against Ukraine. We have identified the main risk: for food safety (the impact of military actions on soil resources – a risk of reduced food provision potential due to the loss of land productivity, since up to 30% of agricultural land is mined and according to the results of 2022, the crop yield losses has reached 17%); for environmental safety (the impact on military actions on water resources – damaged the dams and drainage systems, destruction of sewage treatment plants, seizure of hydroelectric power plants, and mining of coastline caused bacterial (oil products, lubricants) and organic (biogenic substances) pollution of water

bodies and water shortages for the population (complete absence of water supply in temporarily occupied territories) and agriculture (irrigation networks were affected)); for protection of ecosystems (up to 20% of the reserve fund has already been affected, 600 species of fauna and 750 species of flora, including those listed in the Red Data Book, are threatened with extinction).

Keywords: *biological resources, water resources, soil resources, the impact of Russian-Ukrainian war, risks, implications.*

Introduction.

The beginning of the Russian-Ukrainian war, which is ongoing today, should be considered from 2014, namely since the capture Autonomous Republic of Crimea. Scientists note that after the russian federation's full-scale military invasion of Ukraine (from February 24, 2022), the war became the most prominent conflict in Europe since the Second World War (Rawtani et al., 2022; Kireitseva et al., 2023) and caused negative environmental consequences in the form of "ecocide" (Averin et al., 2022; Hrytsku & Derii, 2022; Ladyka & Starodubtsev, 2022; Makarenko et al., 2022; Pereira et al., 2022; Strokal & Kovpak, 2022; Kireitseva et al., 2023). For more than a year, the confrontation has been going on, in which the russian federation is unsuccessfully trying to seize new territories of the country, using for this purpose various military activities that cause a negative environmental impact. For example, the use of explosive weapons has damaged civilian and industrial infrastructure and led to air, soil, and water pollution (CEOBS & Zoï Environment Network, 2022a; Cottrell, Darbyshire, & Holme Obrestad, 2022; Strokal & Kovpak, 2022; Weir & Darbyshire, 2022; Shor, 2023).

According to the data of the Ministry of Environmental Protection and Natural Resources of Ukraine, for the period from February 24, 2022 to March 30, 2023, environmental damages caused by the russian aggression were estimated at UAH 1.9 trillion (EcoZagroza, 2023b; Shor, 2023). Among them, the damages to the air (burning of petroleum products, wildfires, ignition of other objects) were estimated at UAH 988,951 billion, the soil (pollution) – UAH 12 billion, waste generation (soil contamination by waste) – UAH 855 billion, water resources (spill of oil products and toxic substances) – UAH 19 million, biological resources in the nature reserves (fires, destruction of objects in the nature reserve fund, deforestation) – UAH 223 million (EcoZagroza, 2023b).

As of March 22, 2023, according to the International Coordination Center for Humanitarian Demining at the State Emergency Service of Ukraine, 30% of the country's total area belongs to potentially dangerous territories that require the disposal of explosive objects (EcoZagroza, 2023a). As a result, agricultural crops grown on soils with military-induced technogenic pollution can cause the appearance of malignant tumors in the population or disrupt the human nervous system activity (Broomandi et al., 2020; EcoZagroza, 2023a; Holubtsov et al., 2023). It should be noted that the long-term consequences of war-induced environmental damage can vary from persistent pollution (Averin et al., 2022; Rawtani et al., 2022), loss of

ecosystems and chernozems (Dmytruk et al., 2022; Makarenko et al., 2022; Holubtsov et al., 2023), and water quality degradation (Ladyka & Starodubtsev, 2022; Strokal & Kovpak, 2022; Shumilova et al., 2023) to large-scale and regional consequences of industrial disasters (Kireitseva et al., 2023). For this reason, the impact of military aggression on the state of the environment has negative consequences both on ecosystems and the country's natural resources (Makarenko et al., 2022; Strokal & Kovpak, 2022), and human health (UNEP, 2022).

The assessment of the consequences of russian aggression for natural resources is a complex and under-estimated issue, since military activities continue and cause irreparable damage to the environment and threaten the country's environmental security. The cause-and-effect relationship of this impact of military activities on natural resources in Ukraine is the emergence of risks that, first of all, threaten to ensure the implementation of the global Sustainable Development Goals (SDGs) and can cause poverty in the country and the world (SDG 1), hunger (SDG 2), deterioration of the quality of water resources and the threat of the epidemic situation (SDG 6), causing the death of the aquatic biota of the seas (SDG 14), the destruction of biological resources of ecosystems (15 SDG), and in general – creating a threat to peace and justice on the entire planet (SDG 16).

Material and methods.

The purpose of this paper is to determine the main cause-and-effect relationships of the consequences and risks for natural resources as a result of the impact of military activities on them, as well as to substantiate the legal and methodological aspects of the assessment of natural resources in conditions of war. The research methodology included analysis and synthesis of scientific, research, and journalistic literature on this issue. Based on the analysis of literary data, we developed a concept of scientific research that took into account the cause-and-effect relationships of the impact of military aggression on natural resources and provided for three stages of research, which included relevant tasks: Stage 1 – analysis of the environmental situation under the impact of russian aggression on the state of natural resources of the country and justification of the consequences of this impact; the Stage 2 – the determination of the main risks for providing the country with food and the branches of the national economy with water supply, as well as the preservation of environmental components; the Stage 3 – the development of proposals for the assessment of environmental damage to the environment as a result of the military aggression of the russian federation against Ukraine. An important aspect of the principle of scientific research is a comprehensive approach to the assessment of natural resources affected by the Russian-Ukrainian war.

Results.

As a result of the russian military aggression, natural resources underwent significant changes, in particular water, land, forest, and objects of the nature reserve fund (Averin et al., 2022; Ladyka & Starodubtsev, 2022; Makarenko et al., 2022; Strokal & Kovpak, 2022; Weir & Darbyshire, 2022). Over 2,300 crimes against the environment were documented (EcoZagroza, 2023b; Shor, 2023). According to the concept of our

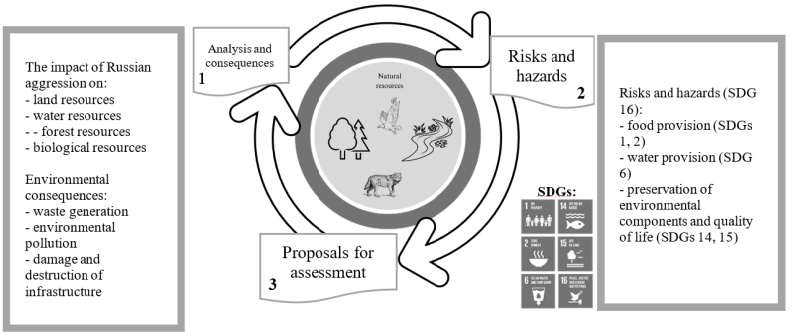

Figure 1. Concept of scientific research (SDGs – global Sustainable Development Goals)

scientific research, the Stage 1 involved the analysis of the impact of military activities on the state of natural resources (land, water, forest, and biological) and the determination of their environmental consequences (Fig. 1).

Analysis of the impact of military activities on the state of natural resources (Stage 1: support information in Table 1). Land resources. At the European level, Ukraine is considered the "breadbasket of Europe", as it is among the five largest grain exporters in the world due to its fertile soils – chernozems, which are ideal for growing grain crops (Ben Hassen & El Bilali, 2022; FAO, 2022; Knox, 2022; Pereira et al., 2022). As a result of the damage caused by military activities to agricultural landscapes, the crop yield losses for 2022 were up to 17% (Deininger et al., 2023). The impact of military activities inflicts irreparable damage on land resources, causing mechanical, physical, and chemical soil contamination (Pereira et al., 2020; Cottrell, Darbyshire, & Holme Obrestad, 2022; Dmytruk et al., 2022).

Military and technogenic contaminants (radioactive elements, heavy metals, pesticide-derived dioxides, nitrate and organophosphorus compounds, polycyclic hydrocarbons) enter the soil in the form of residues or particles due to various types of military activities, which during the Russian-Ukrainian war led to significant negative consequences (Broomandi et al., 2020; Pereira et al., 2020). We note: a) the movement of military equipment: caused a decrease in soil water permeability and disruption of soil biochemical and microbial processes in the areas of active military activities, in particular, Donetsk, Luhansk, Kherson, Mykolaiv, and Sumy Oblasts (Omelchuk & Sadohurska, 2022); b) explosions (missiles, different types of artillery shells, high-explosive aerial bombs, drones, different types of MLRS rockets, vacuum bombs, etc.): provoked the destruction of a sequence of soil horizons; 16 million hectares of country's land are contaminated with ammunition, which poses a threat to food security and water quality, and the fields in the combat zones are solid bursts from shells, scorched earth (Pereira et al., 2020; Cottrell, Darbyshire, & Holme Obrestad, 2022; Kireitseva et al., 2023); c) mining of fields: led to the destruction of the humus horizon of the soil and the formation of craters and pits in demining areas; as of February 2023, 30% of the territory is mined (Shypulia, 2022) and only up to 20% of

the territory was demined (EcoZagroza, 2023a); d) destruction of infrastructure facilities and structures: fires and explosions of different objects occurred as a result of russian airstrikes (fertilizer (ammonium nitrate) explosions in the agricultural warehouse of the farm, village of Dovhenke, Kharkiv oblast, May 2022; fuel burning at the Aistra petroleum storage and reserve, Chernihiv Oblast, March 2022; destruction of the waste management facility, Liubotyn, Kharkiv Oblast, March 2022 (Cottrell, Darbyshire, & Holme Obrestad, 2022)), which caused persistent soil pollution with combustion products, agrochemicals, and fuel (Makarenko et al., 2022; Holubtsov et al., 2023); e) the construction of fortified buildings (blindage, trenches, tunnels, fuel and lubricant storage facilities, and ammunition storage facilities): caused a violation of the soil water balance, which led the degradation of vegetation and increased wind and water erosion, especially in the areas of active military activities (Makarenko et al., 2022; Omelchuk & Sadohurska, 2022; Pereira et al., 2022; Holubtsov et al., 2023). The largest military and technogenic burden on landscapes is typical for the Luhansk (Northern Luhansk), Severodonetsk-Lysychansk, and Toretsk-Horlivka-Yenakiieve industrial agglomerations, where the areas are characterized by a significant increase in the level of mercury, arsenic, and cadmium in the soil, which exceeded the maximum permissible concentrations and background values (Holubtsov et al., 2023). Most of the Kherson Oblast (up to 70%) and a third of the territories of the Mykolaiv Oblast (up to 30%) have disturbed agricultural lands due to the constant movement of heavy russian military equipment (Hurricanes, Urals, Kamaz, etc.), which caused the emergence of the so-called "soil trampling" effect, already massive. Land resources have become almost unusable (EcoZagroza, 2023b; Shypulia, 2023). After the russian airstrike by cruise missiles on March 25, 2022, 10 tanks with oil products and most of the pipelines were destroyed in the village of Kriachky, Fastiv district, Kyiv Oblast. As a result of pipeline damage, the total area of contaminated land amounted to almost 9,000 sq. m and soil contamination with oil products exceeded the maximum permissible concentration by 17 times. The amount of the damage to the land amounted to UAH 41,981 million (Makarenko et al., 2022; Maps of Greenpeace and CEE, 2023).

Water resources. Water is an indispensable life resource and plays an important role in the Sustainable Development Goals, providing equilibrium between the natural resource use and balanced development of the country (Shumilova et al., 2023). A significant factor for Ukraine's balanced development is water quality, which depends on human activity and point and diffuse sources of pollution (Strokal, M., Strokal, V. & Kroeze, 2022). However, besides these factors, military activities are necessarily involved in the conditions of war in the country. This creates risks that can cause the deterioration of water quality, the emergence of dangerous epidemic situations, and the death of the aquatic biota (Makarenko et al., 2022). Ever since russia's annexation of Crimea (2014) and the occupation of a large area of the Donetsk and Luhansk Oblasts, military activities had a significant impact on water supply of the population and sectors of the national economy, in particular by destroying water treatment facilities in the occupied territories (the pumping station in

the village of Yasynuvate in Donetsk Oblast; treatment plants in the cities of Bakhmut and Shchastia), damaging or using water supply systems for their purposes (the Siverskyi Donets-Donbas canal shutdown; arbitrary withdrawal of the Dnipro River water from the North Crimean Canal) (Khilchevskyi, 2022; Strokal & Kovpak, 2022; Water Conflict Chronology, 2022). The aggression of the russian federation continues to cause damages to the country's water resources by destroying reservoirs and dams (Ladyka & Starodubtsev, 2022), undermining bridges (Khilchevskyi, 2022; Shumilova et al., 2023), and destroying sewage treatment systems and irrigation systems for watering plants (CEOBS & Zoï Environment Network, 2022b). It should be noted that military activities cause irreparable damage to water resources. Only in May 2022, the following were recorded on the territory of the country: 8 cases of termination of water supply; 6 cases of surface water pollution (4 cases – due to the flooding of military equipment; 2 cases – due to the release of chemical substances as a result of shelling); 5 cases of dam damage (4 cases – at reservoirs; 1 case – along the North Crimean Canal); 6 cases of mine flooding; 1 case of bacterial contamination due to mass death of poultry; 1 case of disruption of the hydroelectric power station working (Kakhovka Hydroelectric Power Plant) (CEOBS & Zoï Environment Network, 2022b; Shumilova et al., 2023). During the year of the russian federation's full-scale military invasion of Ukraine, the Ministry of Environmental Protection and Natural Resources of Ukraine recorded spills of more than 11,000 tons of oil products into the water, resulting in damage to the state in the amount of UAH 106,347 million (EcoZagroza, 2023b).

It is worth highlighting the main types of military activities that significantly affect the state of water resources (Table 1): a) seizure of water infrastructure (canals, hydroelectric power plants, and reservoirs): taking the North Crimean Canal and the Siverskyi Donets-Donbass Canal under the control of the russian federation led to water shortages in their regions and caused mass diseases of the population; the occupation by russian troops of the Kakhovka Hydroelectric Power Plant and its reservoir caused huge problems for the agriculture of the Kherson and Zaporizhzhia Oblasts, since the main pumping station of the Kakhovka canal, which supplies water for irrigation, is now located in uncontrolled territory (Shumilova et al., 2023; Strokal & Kovpak, 2022); b) destruction of water infrastructure (reservoirs, dams, canals, and water treatment facilities/stations): caused inflow of return waters into rivers without any treatment (Strokal & Kovpak, 2022), in particular, an 8-fold increase in mercury concentration and up to 3-fold increase in ammonium nitrogen and nitrite concentrations was recorded in the mouth of the Sukhyi Torets River (in the area of the Siverskyi Donets River) due to the destruction of water treatment facilities and pumping stations in eastern Ukraine (Shumilova et al., 2023); the explosion of the sluice of the pumping station at the Kozarovychi Dam (Irpin River, Kyiv Oblast) led to the flooding of about 2.5 thousand hectares of land on the Irpin River floodplain and adjacent territories – the villages of Kozarovychi and Demydiv, Kyiv Oblast (Ladyka & Starodubtsev, 2022), in winter, the territory of these villages turned into an "ice village", creating real threats to the local population and arable land (Smyk & Tymchenko, 2023); c) mining

and explosions of coastlines and water bodies (water area of seas and rivers): led to the threat of contamination of water bodies with oil products and dangerous substances, usually it is observed in those water bodies near which active military activities took place; demining was carried out on the area of 93.5 sq. km of the water surface of the Dnipro River, the Irpin River and the Kyiv Reservoir; d) the presence of military equipment in water bodies: caused chemical pollution of water bodies, oil stains appeared in the place of flooding, in particular, two rotorcraft, 11 enemy combat vehicles, and 21 anti-tank mines were pulled from the Dnipro River and Irpin River in Kyiv Oblast and two russian tanks were pulled from the Desna River in Chernihiv Oblast (CEOBS & Zoï Environment Network, 2022b; Matiash, 2022).

The consequences of these military activities are long-lasting and are a manifestation of water-related terrorism. In the occupied territories, the local population still remains without proper access to water and is deprived of basic sanitary conditions. It should be noted that the quality of water and land resources was affected by factors such as the de-energization of territories, including those used by agricultural holdings. For example, the occupation of the Kherson Oblast led to the de-energization of many settlements, including local farms. In particular, 4.4 million chickens died at a poultry factory in Chornobaivka, and the mass death of birds caused bacterial soil contamination, creating an environmental disaster for natural resources (Belousova, 2022). The discharge of untreated wastewater due to the destruction of drainage systems leads to organic pollution of water bodies since untreated wastewater contains a large number of organic compounds, helminth eggs, pathogenic bacteria, sulfates, and chlorides. This type of pollution can lead to large-scale water blooms, such as in the Dnipro River and the Black Sea (Strokal, M., Strokal, V., & Kroeze, 2022). Examples of the negative impact of military activities on the state of land and water resources are given in Table 1.

Forest and biological resources. The natural forest resources of the country, which are the "lungs" of our daily life, the Emerald Network sites such as Kinburnska Kosa, Oleshkivski Pisky, Kakhovske Reservoir, Lower Dnipro, and Dniprovsko Buzkyi Lyman, and Ramsar Wetlands such as Dnipro River Delta and Yagorlytska Bay suffer from mining, constant shelling, and bombings (Sadogurskaya, 2022; Virlych, 2022); the construction of fortified buildings goes through the valuable territories of the Black Sea Biosphere Reserve, Oleshkivski Pisky and Lower Dnipro National Parks, Saga Landscape Reserve, Berezovi Kolky Forest Reserve, Korsunskyi General Zoological Reserve, Shaba Botanical Reserve, and Khrestova Saga Botanical Reserve and others (UNCG, 2022; Virlych, 2022). These military activities are the causes of fires and the destruction of the country's biological resources (Makarenko et al., 2022). Since the russian federation's full-scale military invasion of the country (February 24, 2022), 20% of the nature reserves and 3 million hectares of forests in Ukraine were affected by the war as of December 2022 (UNCG, 2022). During the year of the full-scale war, 2 biosphere reserves (the Black Sea Biosphere Reserve and the Askania Nova Biosphere Reserve named after Friedrich Falz-Fein), 10 national nature parks, and 8 nature reserves

(Velikyi Lug (Zaporizhzhia Oblast), Pryazovskyi (Zaporizhzhia Oblast), Charivna Gavan (Crimea), Meotyda (Donetsk Oblast), Biloberezhzhia Svyatoslava (Mykolaiv Oblast), Dzharylgatskyi (Kherson Oblast), Lower Dnipro (Kherson Oblast), Oleshkivski Pisky (Kherson Oblast), Kremin Forests (Luhansk Oblast), Azov-Syvash (Kherson Oblast)), as well as about 600 species of fauna and 750 species of flora were under threat of extinction, including Red Data Book species (Ministry of Environmental Protection and Natural Resources of Ukraine, 2023).

It should be noted that as of February 2023, deforestation and forest toppling were recorded on the area of 281,223 hectares, which, according to expert assessments, caused environmental damages in the amount of UAH 6,521 million; wildfires were identified on the area of 60,269 hectares and environmental damages due to this type of violation was estimated at UAH 166,870 million; violations of the objects of the nature reserve fund were recorded on the area of 1,240,113 hectares, which was estimated at UAH 102,309 million in environmental damage (EcoZagroza, 2023b). According to preliminary calculations of the Ministry of Environmental Protection and Natural Resources of Ukraine, as of March 1, 2022, russia has already conducted military operations on the territory of 900 objects of the nature reserve fund with an area of 12,406.6 sq. km, which is about a third of the area of the reserve fund of Ukraine. It should be noted that about 200 territories (2.9 million hectares) of the Emerald network are under threat (Omelchuk & Sadohurska, 2022). The first cases of wildfires were recorded as early as March 12–14, 2022, when russians deliberately set fire to forests in the Exclusion Zone of the Chornobyl Nuclear Power Plant. The fire, which destroyed 15,000 hectares of forests (including those contaminated by radiation) in the area from Irpin to Chernobyl, caused air quality deterioration and animal migration (UNCG, 2022). In the Drevlyanskyi Nature Reserve (Zhytomyr Oblast), 22 fires were recorded, where forests and peatlands were burning with a total area of about 2,120 hectares, which caused the migration of animals to the Republic of Belarus and the destruction of rare species of flora (EcoZagroza, 2023b). As a result of the sinking of watercraft (private and utility boats, cutter) in the occupied territory of the Kherson Oblast, more than 10 tons of fuel and lubricants leaked into the Dnipro River, which caused oil pollution and the death of river flora and fauna (Virlych, 2022). Also, the occupation of the Zaporizhzhia NPP is a war crime against nature, which has caused great environmental damage to biological resources. Besides the threat to the radiation safety of Ukraine and other countries of the world, at least 30 detonations of dogs, foxes, and wild boars on mines were recorded during the autumn months of last year due to the mining of the perimeter around the Zaporizhzhia NPP by russian occupiers (Ecobusiness group, 2022).

The military activities in Ukraine threatened three migratory wildlife corridors of international importance, causing a loss of biodiversity and a threat to the existence of the Red Data Book species: a) the southern wildlife corridor (the Sea of Azov–Black Sea latitudinal route): the largest in terms of concentration of migratory birds in Ukraine; it is a kaleidoscope of unique coastal and marine habitats, primarily estuaries, islands, salt flats, lakes, and

flatlands, which are home to hundreds of rare bird species (Omelchuk & Sadohurska, 2022); plays a significant role in the conservation of populations of many migratory bird species (Makarenko et al., 2022); the Black Sea Biosphere Reserve (wildfires, which were recorded due to persecution of the reserve's workers, affected the nesting of birds) and the Askania Nova Biosphere Reserve named after Friedrich Falz-Fein (the territory is completely under temporary occupation, constant flights of aviation equipment have created a stress factor for animals, the collection of valuable animals such as Kaffir buffalo, Przewalski's horses, and others, remains under threat of extinction), the Azov-Syvash National Nature Park, the Dzharylgatskyi National Nature Park, the Meotyda National Nature Park (in the parks, the occupiers created conditions for the provision of fishing services, clay and salt mining, construction, transportation of passengers by water transport, excursion services, and restaurant business services), and the Oleshkivski Pisky National Nature Park (some part of the park occupiers turned into a military training area) (Sadogurskaya, 2022; UNCG, 2022; Virlych, 2022); the extermination of dolphins occurs due to explosions in the sea and mining of the marine environment, which causes disorientation of cetaceans, the formation of wounds and large burns in their bodies, as a result of which they die (for example, dead dolphins were found on the coast of the Tuzlivski Lymany National Nature Park in April 2022 (Sadogurskaya, 2022)); b) the northern wildlife corridor (Polyskyi latitudinal): located along the forest belt of Polissia and in the north of the Forest Steppe; during the occupation of the Chernobyl Radiation and Ecological Biosphere Reserve (February–March 2022), animals were forced to migrate to the Republic of Belarus due to fires and constant shelling, in particular, Przewalski's horses, lynxes, and birds were under threat (Makarenko et al., 2022; Sadogurskaya, 2022; UNCG, 2022); c) the wildlife corridor of the Dnipro meridian migration route: used by waterfowl and coastal birds (geese, ducks, loons, waders, martins, terns, and others), the territory of this route, which runs along the Dnipro River and its tributary the Desna River, constantly suffers from bombings, shelling, and fires in the nature reserve fund (Makarenko et al., 2022).

It should be noted that all international wildlife corridors have transboundary significance and are important for the conservation of the Earth's biodiversity (Makarenko et al., 2022). Currently, most of the migratory wildlife corridors pass over the war zone, which is the reason for the anxiety in birds, their exhaustion due to changing flight routes, lack of opportunity to rest, and coming under shelling (Omelchuk & Sadohurska, 2022). Also, some areas of wetlands of international importance, which are protected in accordance with the requirements of the Ramsar Convention, are in the zone of negative impact (Virlych, 2022). Military aggression creates risks for bird migration, the functioning of landscapes of migratory wildlife corridors, and contributes to the destruction of rare and endemic species' ranges and natural habitats.

Besides the mentioned factors of the impact of military aggression on natural resources (land, water, forest, and biological), hazardous waste (generated as a result of explosions and, accordingly, fires in industrial and radiation facilities) and livestock waste (generated as

a result of the detonation of warehouses with agrochemicals and waste, as well as the destruction of livestock enterprises), the largest number of which is concentrated in the zones of active military activities (Kyiv, Chernihiv, Kharkiv, Kherson, Zaporizhzhia, Donetsk, and Sumy Oblasts), also have a significant impact. For the year of the full-scale war in Ukraine, 3,500 sq. m of the territory is contaminated with hazardous waste and 683,382 sq. m of the territory is contaminated with other waste were recorded (EcoZagroza, 2023b).

Justification of risks and hazards (Stage 2: support information in Figure 2). Based on the analysis of the environmental state of natural resources (Stage

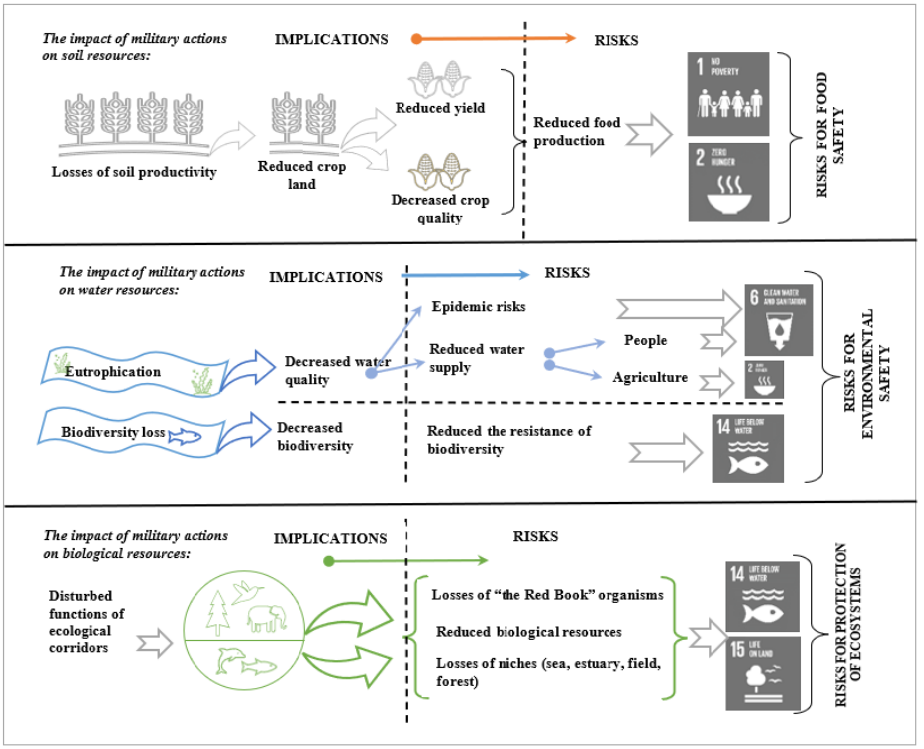

Figure 2. Cause-and-effect relationships of the impact of military aggression on natural resources, which created risks for food and environmental security of the country and the world as a whole (developed according to information and analytical materials: land resources (CEOBS & Zoï Environment Network, 2022a; Dmytruk et al., 2022; Makarenko et al., 2022; Omelchuk & Sadohurska, 2022; Shypulia, 2022; EcoZagroza, 2023b; Holubtsov et al., 2023), water resources (CEOBS & Zoï Environment Network, 2022b; Khilchevskyi, 2022; Ladyka & Starodubtsev, 2022; Strokal & Kovpak, 2022; Water Conflict Chronology, 2022; Shumilova et al., 2023), biological resources (Makarenko et al., 2022; Sadogurskaya, 2022; UNCG, 2022; EcoZagroza, 2023b; Maps of Greenpeace and CEE, 2023; Ministry of Environmental Protection and Natural Resources of Ukraine, 2023))

1), which developed as a result of the military aggression of the russian federation and the justified consequences of the impact of military activities on the natural resources of the country, we have identified the main cause-and-effect relationships of the emergence of risks that can become a threat to the deterioration of food and water provision of the population, the spread of infectious diseases, and the impoverishment of the country's biodiversity (Fig. 1). First of all, there is a risk of reduced food provision potential due to the loss of land productivity, since up to 30% of agricultural land is mined and according to the results of 2022, the crop yield losses has reached 17%. Active military activities taking place in the northwestern part of the Black Sea are blocking the seaports of Ukraine, creating a risk of hunger for the entire civilized world. This, in turn, can cause hunger and poverty in those countries to which Ukraine exports grain and oil crops, which can lead to a global food crisis.

The impact of the war on water resources and related infrastructure is quite noticeable. Damage to dams and drainage systems, destruction of sewage treatment plants, seizure of hydroelectric power plants, and mining of coastline caused bacterial (oil products, lubricants) and organic (biogenic substances) pollution of water bodies and water shortages for the population (complete absence of water supply in temporarily occupied territories) and agriculture (irrigation networks were affected). The negative consequences of these events were the reduction of water supply and the real probability of the emergence of the epidemic situation, which in general poses a threat to the environmental security of the country. The environmental sustainability of ecosystems has also been significantly affected by military activities.

Biological resources are also strongly affected, especially by mining, constant shelling and bombing, and in general from the occupation. Up to 20% of the reserve fund has already been affected, 600 species of fauna and 750 species of flora, including those listed in the Red Data Book, are threatened with extinction. According to operational data, active military activities are taking place in the territories belonging to the nature reserve fund, which is about 900 various objects. The main risks as a result of this should include the mass destruction of valuable natural species and communities that perform important biosphere ecosystem services and the loss of habitats for transboundary bird species. Also, as a result of constant military activities, migratory wildlife corridors of international importance are being violated. Only in the southern wildlife corridor, environmental crimes were recorded at each object of the nature reserve fund (for example, 30% of the territories were burned in the Black Sea Biosphere Reserve and part of the territory in the Oleshkivski Pisky National Nature Park was turned by the occupiers into a military training area). This situation created a threat to the conservation of biodiversity and ecosystem sustainability as a whole.

Challenges regarding the assessment of natural resources for the impact of military activities (Stage 3: support information in Table 2). Assessment of natural resources for the impact of military activities involves, first of all, the determination of environmental damage. It is important to take into consideration the systemic and integral approaches in assessing environmental damage and determining their scale.

1. Basic provisions regarding environmental damage assessment

Title of the document	Branch	Main provisions
International level		
Geneva Conventions of 12 August 1949	Refers to the protection of victims of international armed conflicts	Article 35, Paragraph 3 of the Protocol – "It is prohibited to employ methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment…"
Convention on the Prohibition of Military or any Hostile Use of Environmental Modification Techniques	Refers to the environmental protection from the use of hostile means	Article 1, Paragraph 1 – «States party to the Convention undertake "not to engage in military or any other hostile use of environmental modification techniques …»
United Nations General Assembly Resolution ES-11/5. Furtherance of remedy and reparation for aggression against Ukraine. Adopted by the General Assembly on November 14, 2022	Refers to the mechanism of legal protection	Paragraph 3 – General Assembly "Recognizes also the need for the establishment, in cooperation with Ukraine, of an international mechanism for reparation for damage, loss or injury, and arising from the internationally wrongful acts of the Russian Federation in or against Ukraine"
National level		
Law of Ukraine On Environmental Protection	Refers to general indemnification provisions	Section 1, Article 69 – "Damage caused as a result of violation of environmental legislation is subject to compensation in full"
Civil Code of Ukraine	Refers to damages due to the violation of civil law	Section 1 – "Person to whom losses as a result of violation of its civil law are caused has the right to their compensation"
Criminal Code of Ukraine	Refers to criminal law	According to Article 441, "Ecocide" – "Mass destruction of flora and fauna, poisoning of air or water resources, and also any other actions that may cause an environmental disaster, – shall be punishable by imprisonment for a term of eight to fifteen years". At the same time, it should be noted that there is no similar norm on ecocide in international law

The assessment of environmental damage caused by the armed aggression of the russian federation against Ukraine is one of the first, mandatory, and most important stages of the entire procedure for compensation for war damage. Since Ukraine is trying to join the European Union in the near future, in this case, the implementation and approximation of European Directives to ensure the global Sustainable Development Goals are strong arguments. Therefore, we consider it expedient to take into account the legal norms and rules at the international and national levels (Table 2). In particular, it should be noted that

the provision of the Geneva Convention stipulates that the use of methods or means of warfare that may harm the environment is prohibited. The prohibition of the use of any means of the impact on the natural environment by states participating in a military conflict is stipulated in the Convention on the Prohibition of Military or any Hostile Use of Environmental Modification Techniques. Within the framework of the national level (in the Criminal Code of Ukraine), the definition of the term "ecocide" is specified, which clarifies that the deliberate or mass destruction of natural resources, which led to an environmental disaster, is punishable by criminal law.

A comprehensive methodology for environmental assessment for the impact of military activities on natural resources has not been developed, and there are only some fragmentary approaches and methods. Thus, Hardashchuk (2022) proposes to conduct the assessment in the following directions: 1) direct destruction of landscapes, ecosystems, natural habitats, and plant and animal populations; 2) threats and risks of technogenic disasters caused by military activities (destruction of industrial facilities, infrastructure, etc.); 3) destruction and pollution of agricultural landscapes, withdrawal of agricultural land from circulation, and disruption of natural systems of life support and natural services, which directly results in risks for food security, etc.; 4) threats to human life and health arising both from the destruction of natural ecosystems and as a result of technogenic disasters, limited access to natural resources, atmospheric air and water pollution, and threats of epidemic outbreaks.

Under the auspices of the Ministry of Environmental Protection and Natural Resources of Ukraine, methods were developed for determining the amount of environmental damage caused to natural resources as a result of emergency situations and/or armed aggression and hostilities during martial law: a) land resources – damaged land and soils (Zakon.rada.gov.ua, 04/04/2022 No. 167); the land fund of Ukraine (Zakon.rada.gov.ua, May 18, 2022, No. 295); b) water resources – as a result of water pollution and/or clogging, arbitrary use of water resources (Zakon.rada.gov.ua, July 21, 2022, No. 252); within the territorial sea, exclusive economic zone, and internal waters of Ukraine in the Sea of Azov and Black Sea (Zakon.rada.gov.ua, 19.08.2022 No. 309); c) forest resources – forest fund (Zakon.rada.gov.ua, October 5, 2022, No. 414); d) nature reserve fund – territories and objects of the nature reserve fund (Zakon.rada.gov.ua, October 13, 2022, No. 424).

All of the above methods include forecasting national and sectoral recovery costs; determine the amount of compensation to the state for environmental damages, as well as to the national property of the state, which includes territories and objects of the nature reserve fund.

Systematic research on environmental assessment should become the basis for the development of scientifically based recommendations for the restoration of natural resources, ecosystems and complexes at the local and regional levels. We suggest that when determining the consequences and risks caused by military aggression, a systematic approach and an integrated analysis of the situation assessment should be taken into account, which in combination will create a comprehensive assessment of the real situation of the impact on natural resources. As a next stage, we propose to include methodological and

legal aspects of the national level in the evaluation, as well as take into account all provisions of legal norms and rules of the international level.

Discussion.

Discussion connects with two aspects. The first aspect identifies the limitations of the study, second – is implications for the environmental management. In this article, we explored the consequences of the Russian-Ukrainian war and their impacts on the natural resources of Ukraine which related to data from 24 February 2022 – 01 May 2023. We emphasized the main implication of military action. We did not include all local threats for specific natural resources in local territories which are occupied by russian troops. This aspect requires more in-depth research experiments. However, we established the main risks for food and water supply and for protecting the environmental state. These risks depend on exploring the mined fields, burned forests, polluted water bodies, dead animals and birds, and destroying their habitats. These are all the consequences of conducting military activities on the territory of Ukraine.

According to the second aspect, we searched how the consequences of war can influence environmental systems management. In this article, we highlighted the agricultural position of Ukraine in Europe focusing on the world's largest exporter of grains. However, due to the Russian-Ukrainian war, agricultural lands are suffering from military actions (phosphorus bombs, weapons, shelling, mining) that led to soil degradation and pollution, description of the hydrological regime of the soil, etc. According to this, Ukraine has lost over 50% of suitable agricultural land (Angurets O., 2023). A lack of productive soil can lead to a decreased food supply in global and regional areas (Fig. 2). We identified the cause-and-effect relationships of the impact of military aggression on natural resources, which created risks for the food and environmental security of the country and the world as a whole. During the Russian-Ukrainian war, environmental management require to involve scientists, international organizations, and economists who can promote the elimination of consequences. Also, environmental systems need to combine international and national methodologies (Table 2) to solve ecological problems of protecting natural resources in Ukraine.

Conclusion.

During the war, russia not only kills Ukrainians and destroys the country's infrastructure, but contemporarily commits environmental crimes and destroys Ukraine's environment every day. As a result of the war, the environmental situation is deteriorating catastrophically. Mined fields, burned forests, polluted water bodies, dead animals and birds, and destroyed their habitats – these are all the consequences of conducting military activities on the territory of Ukraine.

We note that although chernozems have extraordinary resilience and self-healing capacity, negative impact of military activities on land resources will have a long-term effect, which will be manifested directly in a decrease in soil water permeability, disruption of biochemical and microbial processes, deterioration of water and air conditions, nutrient cycles, and root nutrition of plants. The restoration of land resources is an integral part of the post-war recov-

2. The impact of war on natural resources

Environmental impact of war	Implications	Risk
Land resources		
Movement of military equipment (physical impact)	Soil compaction, pollution of the territory with products of military activities	Loss of soil fertility and decrease in land productivity
Explosions (chemical impact)	The explosive wave provokes the destruction of the sequence of soil horizons, which leads to a violation of the air-water regime. It changes the natural physicochemical properties of the soil cover (pH, cation exchange, and humus content), and various local landscape geochemical anomalies are formed, which leads to a decrease in land productivity in the long-term perspective. Compounds of explosive substances, which enter into the soil solution, are absorbed by the root systems of plants and agricultural crops, freely move between tissue membranes and, ultimately, are completely deposited in plants.	Violation of the melioration systems Hazardous waste generation Product contamination and crop yield reduction
Field mining (chemical and physical impact)	Demining territories leads to the destruction of humus horizons, there are changes in the granulometric, structural and aggregate state, and physicochemical properties of soils.	
Destruction of infrastructure facilities and warehouses with fuel and lubricant materials (chemical impact)	Causes fires and explosions, which is an indirect impact on land quality. Induce persistent soil pollution with combustion products, agrochemicals, and fuel. The highest concentration of petroleum products is observed in the places where fuel and lubricants are spilled. Most often, an important property of the soil is violated – the ability to self-healing, and the biological activity of the soil decreases due to changes in the chemical composition of the soil in places of significant oil spills.	
Construction of fortified buildings (mechanical impact)	Violation of the water balance in the soil, the development of wind and water erosion. Increases the number of dangerous geomorphological processes: landslides, waterlogging, and soil subsidence.	Decrease in land productivity Waterlogging of the territories
Water resources		
Seizure of water infrastructure (canals, hydroelectric power plants, and reservoirs)	Caused the risk of water shortage in the Kherson and Mykolaiv Oblasts (Strokal & Kovpak, 2022). In the Kherson Oblast, 106 cities remained without water, which is at least 64,700 inhabitants, in the Mykolaiv Oblast – 40 cities (Shumilova et al., 2023). The seizure of the Kakhovka Hydroelectric Power Plant and reservoir led to a delay in water supply in the irrigation system, which caused severe problems in the agricultural sector in the Kherson and Zaporizhzhia Oblasts.	Water shortage Threat of the epidemic situation Crop yield losses through the damage to irrigation systems

Environmental impact of war	Implications	Risk
	This is because the main pumping station of the Kakhovsky Canal which supplies water for irrigation, is now located in an uncontrolled territory (Shumilova et al., 2023). The Luhansk and Donetsk Oblasts were left without water supply due to the seizure and later shutdown of the Siverskyi Donets-Donbas Canal (Shumilova et al., 2023).	
Destruction of water infrastructure	The occupation of the territories of Donetsk Oblast led to the seizure of water treatment plants, and subsequently to significant violations of their functioning (Strokal & Kovpak, 2022). As a result of the destruction of water treatment facilities and pumping stations in eastern Ukraine, an 8-fold increase in mercury concentration and a 3-fold increase in ammonium nitrogen and nitrite concentrations were recorded in the mouth of the Sukhyi Torets River (in the area of the Siverskyi Donets River) in July 2022 (Shumilova et al., 2023). The inflow of return waters into rivers without any treatment occurred due to the damage to the treatment facilities (Strokal & Kovpak, 2022). The explosion of the sluice of the pumping station at the Kozarovychi Dam (the Irpin River, Kyiv Oblast) led to the flooding of about 2.5 thousand hectares of land in the Irpin River Floodplain and adjacent territories – the villages of Kozarovychi and Demydiv, Kyiv Oblast (Ladyka & Starodubtsev, 2022). In particular, during the winter period, the territory of these settlements turned into an "ice village" since the water, although the flooding occurred in March 2022, remained at almost the same level, creating real threats for the local population and arable land (Smyk & Tymchenko, 2023). As a result of the missile strike, the dam of the Karachuniv Reservoir near the city of Kryvyi Rih was damaged, which caused the water level in the Ingulets River to rise to 2 m. This led to the flooding of a large part of the city of Kryvyi Rih and agricultural land. In this regard, the content of nitrogen-containing compounds and other chemical elements doubled in the Ingulets River (Ladyka & Starodubtsev, 2022). Damage to the dam at the Oskil Reservoir in the Kharkiv Oblast led to the flooding of the reservoir area (Strokal & Kovpak, 2022). The shelling that took place on March 14, 2022 at the water treatment facilities of the Vasylivka water supply and drainage facility (the village of Verkhnia Krynytsia, Zaporizhzhia Oblast) led to the destruction of sewage pumping station	Water pollution Flooding Threat of the epidemic situation Decrease in land productivity and crop yield

Environmental impact of war	Implications	Risk
	No. 1, which supplies wastewater from the city of Vasylivka to the treatment facilities. As a result, return water from the city now enters the Dnipro River without any treatment (CEOBS & Zoï Environment Network, 2022b; Strokal & Kovpak, 2022). Untreated wastewater contains a large number of organic compounds, helminth eggs, pathogenic bacteria, sulfates, and chlorides. Such pollution can lead to an increase in the area of water blooms in the Dnipro River and the Black Sea with the onset of warming (Strokal & Kovpak, 2022).	
Mining and explosions of coastlines and water bodies	In the summer period, demining was carried out on the area of 93.5 sq. km of the water surface of the Dnipro River, the Irpin River, as well as the Kyiv Reservoir, as they were the site of active military activities (Matiash, 2022). Mining of the coastlines of the Black Sea and the Sea of Azov caused chemical and acoustic pollution, physical damage to natural habitats of birds, and the decline of environmental protection activities (CEOBS & Zoï Environment Network, 2022b).	Loss of aquatic biota Violation in the functioning of the water ecosystem An increase in the temperature of the reservoir Pollution of the reservoir with dangerous substances (petroleum products, heavy metals)
Presence of military equipment in water bodies	In the summer period, two rotorcraft, 11 enemy combat vehicles, and 21 anti-tank mines were pulled out of the Dnipro and Irpin rivers (Kyiv Oblast), and two Russian tanks were pulled from the Desna River in Chernihiv Oblast (Matiash, 2022). The sinking of the russian warship Moskva (depth 45–50 m) by the Armed Forces of Ukraine caused chemical pollution of the water body, oil spills appeared at the site of the sinking (CEOBS & Zoï Environment Network, 2022b).	Water pollution with heavy metals, radionuclides, oil products
Other impact	The use of sonar systems by the naval forces to detect submarines may be the cause of marine animal stranding, such as porpoises and common dolphins (CEOBS & Zoï Environment Network, 2022b).# As a result of the sinking of watercraft (private and utility boats, cutter) in the occupied territory of the Kherson Oblast, according to preliminary calculations, more than 10 tons of fuel and lubricants leaked into the Dnipro River. This leads to the destruction of the river flora and fauna, poisoning the area for many years. There is a possibility that dangerous substances can reach the Black Sea (Virlych, 2022).	Physical damage to natural habitats

ery of natural resources because they are natural components of agricultural landscapes that provide food not only to Ukraine but also to many other countries of the world. The shortage of grain crops can cause hunger and poverty in some importing countries of Europe and Africa. The impact of military activities on Ukraine's land resources will lead to the irreversible degradation of chernozem soils, which will become one of the causes of the expected food security crisis. It is worth noting that causing irreparable damage to land resources, and destroying the integrity of soil profiles and landscapes – all this leads to significant fragmentation of territories, disruption of functioning and destruction of the structure of agricultural landscapes.

The main consequences of the impact of military activities on water resources include water pollution with heavy metals and nitrogen-containing compounds (mining of water bodies, explosions of oil tanks, etc.), flooding of territories and deterioration of their sanitary condition (destruction and detonation of dams), and absence of centralized water supply (destruction of pumping stations). The main risk is the shortage of safe water use for various types of consumption as a result of the seizure of water infrastructure (for example, the North Crimean Canal and the Kakhovka Hydroelectric Power Plant) and the destruction of dams and pumping stations (for example, the dams of the Oskil Reservoir in the Kharkiv Oblast, the detonation of the dam and the pumping station at the mouth of the Irpin River at the confluence with the Kyiv Reservoir in the Kyiv Oblast); as well as the strengthening of eutrophication processes in water bodies due to water pollution with various components and as a result of flooding territories.

The construction of trenches and fortified buildings destroys vegetation and increases soil erosion, and garbage and military waste pollute the soils and groundwater. Following the movement of the front line, the line of physical destruction of natural habitats also shifts, especially where they are subjected to intense shelling. An example of this is the environmentally sensitive wetlands along the Dnipro estuary in the south of the Kherson Oblast, which were used for fortification by Russia after its withdrawal from Kherson.

Regarding the legal aspects of the environmental assessment of the damage caused by military activities, Ukraine should rely on the legal force of paragraph 3 of the UN General Assembly Resolution ES-11/5, according to which an international legal protection mechanism for reparation for losses and consequences arising from the internationally wrongful acts of the russian federation in Ukraine was created. At the national level, in accordance with Article 441 "Ecocide" of the Criminal Code of Ukraine, the perpetrators of the aggressor country must be punished with imprisonment for a term of 8 to 15 years for the mass destruction of natural resources. Besides that, competent professionals in the field of environmental protection and economists should improve the criteria in the methods that must be taken into account for assessing the damage of various natural resources in order to fully compensate the damage caused by the russian federation.

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Анотація. *Від російських військ страждають природні ресурси України. Україна відома як один з найбільших виробників зерна в Європі. Україна є великим експортером пшениці (10% світового експорту), кукурудзи (15%), ячменю (15%), соняшнику (особливо олії – 50%). Російсько-українська війна, що триває, зміцнює нестабільну економічну систему в країні. Військові дії впливають на довкілля України з точки зору зміни клімату, ґрунту та впливу на сільське господарство, безпеку води та постачання. Відповідно до цього, виробництво зерна в Україні скоротилося на 40%, а структура втрат врожаю через війну: пшениця – 39%, соняшник – 17%, кукурудза – 12%, ячмінь – 8%, плоди та ягоди – 3%, ін. культур – 21%. Крім того, російсько-українська війна вплинула на наявність і якість води (ризик для водних ресурсів), якість і деградацію ґрунту (ризик для ґрунтових ресурсів), здоров'я та продуктивність лісів і середовище проживання видів (ризик для біологічних ресурсів). Наприклад, опис очисних споруд (обстріляно очисні споруди м. Миколаєва, пошкоджено очисні споруди с. Новотроїцьке Волноваського району Донецької області тощо), порушення водопостачання до с. рослинництво (пошкоджено зрошувальні системи в Україні: 94% у Херсонській області, 74% у Запорізькій області, 30% у Дніпропетровській області), забруднення поверхневих та підземних вод (масове затоплення військової техніки та боєприпасів у водоймах, витоки) нафтопродуктів та інших хімічних сполук).*

У статті проаналізовано екологічну ситуацію під впливом російської агресії на стан природних ресурсів країни та обґрунтування наслідків цього впливу; визначено основні ризики для забезпечення країни продовольством та водопостачання галузей народного господарства, а також збереження компонентів довкілля; запропоновано розробку пропозицій щодо оцінки екологічної шкоди навколишньому середовищу внаслідок військової агресії Російської Федерації проти України.

Ми визначили основний ризик: для продовольчої безпеки (вплив військових дій на ґрунтові ресурси – ризик зниження потенціалу продовольчого забезпечення через втрату продуктивності землі, оскільки до 30% сільськогосподарських угідь видобувається і за результатами 2022 року втрати врожаю сягнули 17%); для екологічної безпеки (вплив військових дій на водні ресурси – пошкодження дамб і дренажних систем, руйнування очисних споруд, захоплення гідроелектростанцій, мінування берегової лінії, спричинене бактеріальним (нафтопродукти, мастила) та органічним (біогенні речовини) забрудненням водойм і нестача води для населення (повна відсутність водопостачання на тимчасово окупованих територіях) та сільського господарства (постраждали зрошувальні мережі)); на охорону екосистем (уже постраждало до 20% заповідного фонду, під загрозою зникнення знаходяться 600 видів фауни та 750 видів флори, у тому числі занесених до Червоної книги).

Ключові слова: *біоресурси, водні ресурси, ґрунтові ресурси, вплив російсько-української війни, ризики, наслідки.*