DESTRUCTION OF THE KAKHOVKA RESERVOIR: ENVIRONMENTAL CONSEQUENCES

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This is a full translation of the January 2025 publication "Destruction of the Kakhovka Reservoir: Environmental Consequences" (ISBN 978-617-8501-02-0). The publication summarizes information on the environmental, economic, and social consequences of the destruction of the Kakhovka HPP dam in June 2023 as documented by the end of 2024. It analyzes the impacts on protected areas, biodiversity, soils, water resources, and climate and presents the first evidence of ecosystem recovery within the area of the former reservoir.

The team of authors comprises leading ecologists, botanists, and zoologists who analyzed the available information on the consequences of the destruction of the Kakhovka Reservoir and complemented this assessment with the results of their own field expeditions, analyses of bottom sediments, and remote sensing data. This publication is intended to serve as a valuable resource for researchers, environmental professionals, students, and everyone interested in the consequences of anthropogenic disasters and ecosystem recovery

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INTRODUCTION

The area occupied by the Kakhovka Reservoir was once the largest complex of floodplain forests and wetlands in Ukraine's steppe zone, known as Velykyi Luh. The construction of the reservoir in 1956 fundamentally transformed the region. Villages were flooded, irrigated agriculture replaced livestock farming as the dominant agricultural activity, and capture fisheries gave way to aquaculture. The cities that developed in subsequent decades came to depend on water supplied from the Kakhovka Reservoir, and the northern part of the Crimean Peninsula was extensively cultivated and settled only after the North Crimean Canal was built.

On 6 June 2023, Russian forces destroyed the Kakhovka HPP dam, causing the reservoir to drain completely over the subsequent 14 days. The terrorist attack undoubtedly had military motives, but it failed to achieve any obvious military objectives that would have benefited Russia[1]. The destruction of the dam also led to the collapse of southern Ukraine's established economic system. The disaster resulted in the loss of water supplies for numerous settlements and industrial enterprises, the destruction of irrigation systems, the loss of substantial fish stocks, and the disruption of shipping and navigation.

In addition to its profound economic consequences, this catastrophe became one of the most severe environmental disasters in Ukraine's history. Many of its environmental consequences are short-term in nature, and these are the primary focus of this review. Analysis of the environmental impacts makes it possible to assess the scale of the damage caused by the destruction of the dam and to regard this case as an example for studying the consequences of anthropogenic disasters and planning ecological restoration, both in Ukraine and in other countries.

METHODOLOGY

This review was prepared to summarize, verify, and update current knowledge of the consequences of the disappearance of the Kakhovka Reservoir one year after the destruction of the Kakhovka HPP dam. It is primarily focused on analysing environmental changes and their implications for biodiversity conservation, ecosystems, and the condition of protected areas. It is important to note that the authors of this review support the restoration of natural ecosystems in place of the former Kakhovka Reservoir, which makes their perspective on the consequences of the destruction of the Kakhovka HPP dam somewhat subjective.

1 In the Ukrainian original text throughout this publication, the names Russian Federation and Russia are written in lowercase, in accordance with the decision of the National Commission on Language Standards adopted on 15 September 2023 (Minutes No. 83) [https://mova.gov.ua/news/napysannia-nazv-rosiiska-federatsiia]).

To overcome this limitation, the authors compiled a review of literature on the Kakhovka Dam destruction consequences published from June 2023 to June 2026, which shows the full spectrum of expert opinions over a longer time period. This review of more than 100 sources is available as an additional volume of the Metamorphoses of Velykyi Luh series.

The authors deliberately did not focus on the consequences for housing, infrastructure, the energy sector, or agriculture. These issues have already been extensively covered in numerous publications and analytical reports. However, it should be noted that many of these publications speculate on the need to restore the reservoir by presenting arguments that substantially exaggerate its role. This review also does not examine the significance of the event for Russia's military objectives or for Ukraine's counteroffensive and the liberation of occupied territories.

Field expeditions

The preparation of this review also included six field expeditions to the area formerly occupied by the Kakhovka Reservoir. These were carried out on 30 June and 19 October 2023, and on 11 and 29 April and 30 October 2024 within Kamianska Sich National Nature Park in Kherson Region, at two former bays of the Kakhovka Reservoir – Mylivska Bay and Kamianska Bay, now the Mylivska Ravine and the Kamianka River, respectively. An additional expedition was conducted on 21-22 May 2024 on Khortytsia Island and in the vicinity of the villages of Malokaterynivka (left bank) and Kanivske (right bank) in Zaporizhzhia Region. During these field studies, twelve permanent monitoring plots were established to investigate vegetation recovery on the bed of the former reservoir. The permanent monitoring plots were established according to the methodology developed by the Eurasian Dry Grassland Group (EDGG), which, in addition to standard geobotanical data, includes analyses of the species–area relationship, soil parameters, and a range of other variables[22]. All species of vascular plants and bryophytes were recorded both within the monitoring plots and in adjacent areas of the former reservoir bed. Morphometric parameters were measured for young individuals of hybrid crack willow (*Salix × rubens*) and black poplar (*Populus nigra*). At the same time, soil samples were collected for comprehensive analyses, together with samples of soil algae, fungi, and viruses.

Analysis of Bottom Sediment Samples

Laboratory analyses of the 119 samples discussed in this review were carried out at Canterbury Christ Church University (United Kingdom) as part of the Global Food and Water Security (GFWS) project. Concentrations of heavy metals were determined using a PerkinElmer Optima 8000 inductively coupled plasma optical emission spectrometer (ICP-OES).

Sampling Methods

To determine the distribution of potentially toxic chemical elements in soils, samples were collected from the surface soil horizons (0-5 and 5-10 cm) using the envelope sampling method. Each sample weighed 0.5-0.7 kg. The samples were air-dried, gently disaggregated, and sieved through a 2 mm mesh. They were then quartered and divided into laboratory subsamples.

Maps showing the distribution of individual toxic elements in soils were produced using modern GIS methods in ArcGIS Online. Geochemical data were processed and quantitatively interpreted using Microsoft Excel and STATISTICA 6.0.

Soil contamination was assessed using the concentration coefficient (K_c) and the integrated pollution index (Z_c):

$$K_c = C_i/C_{\text{ф}},$$

where C_i is the concentration of the ith element in the sample (mg/kg), and C_{bg} is the background concentration of that element

$$Z_c = (\Sigma\ C_i/C_{\text{ф}}) - (n - 1),$$

where C_i is the anomalous concentration of a chemical element in the assessed sample, C_{bg} is the background concentration of that element, and n is the number of chemical elements included in the association under investigation. According to the Z_c values, soil contamination is classified as follows: permissible: ⩽16; moderately hazardous: 16-32; hazardous: 32-128; extremely hazardous: ⩾128.

Remote Sensing

The dynamics of vegetation recovery were investigated using remote sensing. Changes in water extent and vegetation development on the bed of the former reservoir were analyzed using Sentinel-2 Level-2A remote sensing data with a spatial resolution of 10 m (Copernicus Sentinel data, European Space Agency). The analysis included true-color imagery as well as two spectral indices: the Normalized Difference Water Index (NDWI) and the Normalized Difference Vegetation Index (NDVI). The indices were calculated using the Raster Calculator in QGIS 3.4.5-Madeira. The monitoring plots established in different habitat types served as ground-truth data. A more detailed description of the methodology is provided in a separate publication by the authors[71].

Sources

This review is based on numerous sources that directly or indirectly address the consequences of the loss of the Kakhovka Reservoir. Most of these sources are difficult for the international research community to access and include news reports (particularly from social media), media articles, scientific publications (predominantly in Ukrainian and published in lesser-known journals), transcripts of scientific conferences and seminars, responses to information requests submitted to public authorities, and the authors' own data. In total, the authors reviewed at least 4,000 online sources. Particularly valuable was the analysis of presentations delivered by specialists at conferences and seminars that contained unpublished information and expert opinions. Only key verified sources are cited in this review, although the total body of information examined was considerably larger. For example, during the year following the destruction of the Kakhovka Hydropower Plant dam, more than 150 scientific publications and 10 major analytical reports prepared by international organizations were published.

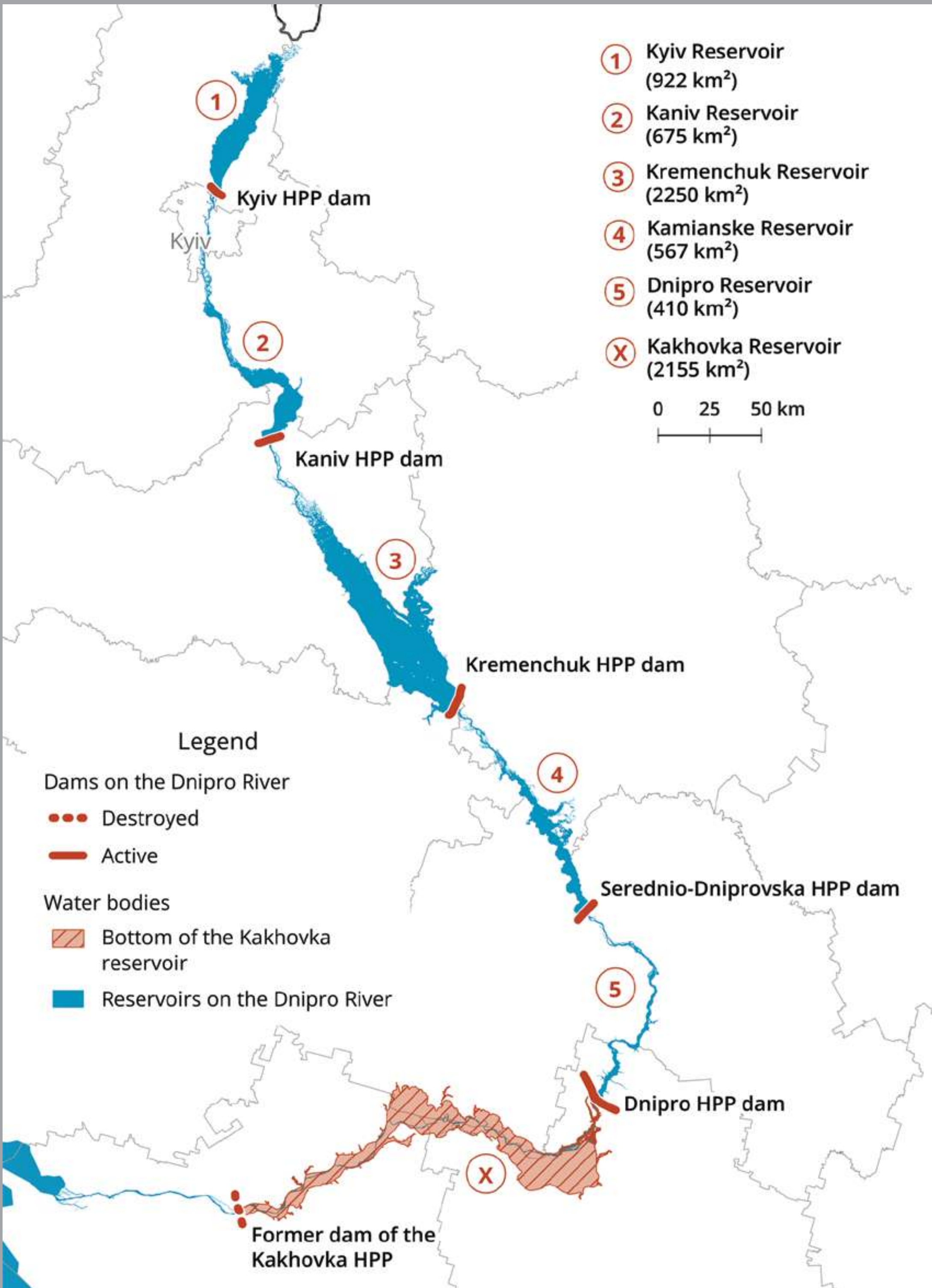
CHRONOLOGY OF EVENTS

During the Soviet period, a cascade of six large reservoirs with associated hydropower plants (HPPs) was constructed on the Dnipro River within the territory of Ukraine. Consequently, all reservoirs of the Dnipro Cascade are, at least formally, regarded as components of HPP infrastructure.

The Kakhovka Reservoir was the largest reservoir in the cascade by storage volume and the second largest, after the Kremenchuk Reservoir, by surface area. Its water surface covered 2,117.35 km² (31% of the total surface area of the Dnipro Cascade reservoirs), its shoreline extended for 931.3 km, and its storage volume was 18.19 km³ (41.5% of the total storage volume of the cascade)[215]. It was constructed between 1952 and 1955 on the site of former wetlands, forests, and settlements, and was filled to its design water level between 1956 and 1958. Until 2023, the Kakhovka Reservoir was the last reservoir in the Dnipro Cascade. Downstream lay the Dnipro Delta with its archipelago of islands.

In 2022, the Kakhovka HPP dam was a strategically important facility in the conduct of military operations. On the first day of the full-scale invasion[179], 24 February 2022, Russian forces captured the city of Nova Kakhovka and the Kakhovka HPP. From then until the destruction of the dam, the Kakhovka HPP remained entirely under their control. Ukrainian personnel continued operating the plant until autumn 2022[100], after which Ukraine lost any influence over it. In November 2022, Russian forces withdrew from the right bank of the Dnipro but retained control of the Kakhovka HPP because the hydropower plant is located immediately adjacent to the left bank. Following the destruction of the Antonivskyi Bridge on 11 November 2022[176], the Kakhovka HPP dam became the only crossing over the Dnipro within the combat zone. Thereafter, the Kakhovka HPP was placed under particularly heavy military guard[102]. Whether Russian forces would be able to prevent Ukrainian troops from crossing the Kakhovka HPP dam during the counteroffensive was considered a decisive factor in the subsequent course of military operations in the region[97].

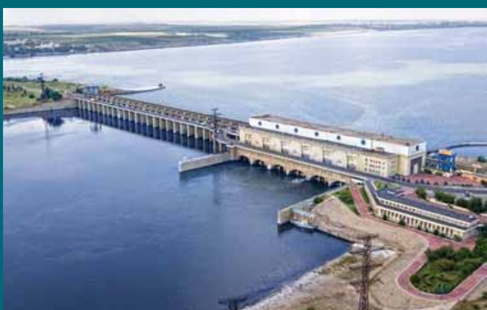
At approximately 02:50 on 6 June 2023, Russian forces blew up the structures of the Kakhovka HPP from within the dam. Ukrainian Prime Minister Denys Shmyhal described the incident as a terrorist act committed by Russia (it was later clarified that responsibility was attributed to the 205th separate motor rifle brigade of the armed forces of the Russian federation)[197]. Ukraine has characterized the destruction of the Kakhovka HPP not only as a terrorist act but also as an act of ecocide[161]. The same position was subsequently expressed by representatives of the United Nations[82], the Council of Europe[7], and the European Commission[3]. On the day of the destruction of the Kakhovka HPP, the Office of the Prosecutor General of Ukraine opened a criminal investigation under the charges of ecocide and violations of the laws and customs of war[194].



1 Kyiv Reservoir (922 km²)
2 Kaniv Reservoir (675 km²)
3 Kremenchuk Reservoir (2250 km²)
4 Kamianske Reservoir (567 km²)
5 Dnipro Reservoir (410 km²)
X Kakhovka Reservoir (2155 km²)
0 25 50 km
Kyiv HPP dam
Kyiv
Kaniv HPP dam
Kremenchuk HPP dam
Serednio-Dniprovska HPP dam
Dnipro HPP dam
Former dam of the Kakhovka HPP
Legend
Dams on the Dnipro River
Destroyed
Active
Water bodies
Bottom of the Kakhovka reservoir
Reservoirs on the Dnipro River

The Russian side also attempted to blame Ukraine for the destruction of the dam (as might have been expected given Russia's conduct of the war), disseminating this narrative through its information space in the form of news reports[6, 203] and even articles published in scientific journals[2]. Claims that Ukraine was responsible for the destruction of the Kakhovka HPP were made not only by representatives of the occupation authorities but also by Russian president Vladimir Hutin himself[75], who described the explosion at the Kakhovka HPP as "Kyiv's barbaric act." In addition, the Russian federation accused Ukraine of destroying the Kakhovka HPP during a meeting of the United Nations[191].

Ukraine's involvement in the explosion at the Kakhovka HPP dam is difficult to envisage even for those unfamiliar with the details of the case. At the time of the explosion, the Kakhovka HPP had been under Russian control for 468 days[23]. The dam was destroyed by an explosion from within[93]; explosives had been placed inside the concrete dam tunnel and in the powerhouse of the hydropower plant[108]. The NORSAR seismic stations in Ukraine and Romania recorded explosions at 02:35 and 02:54[95]. The same timing was reported by other sources[93, 197].



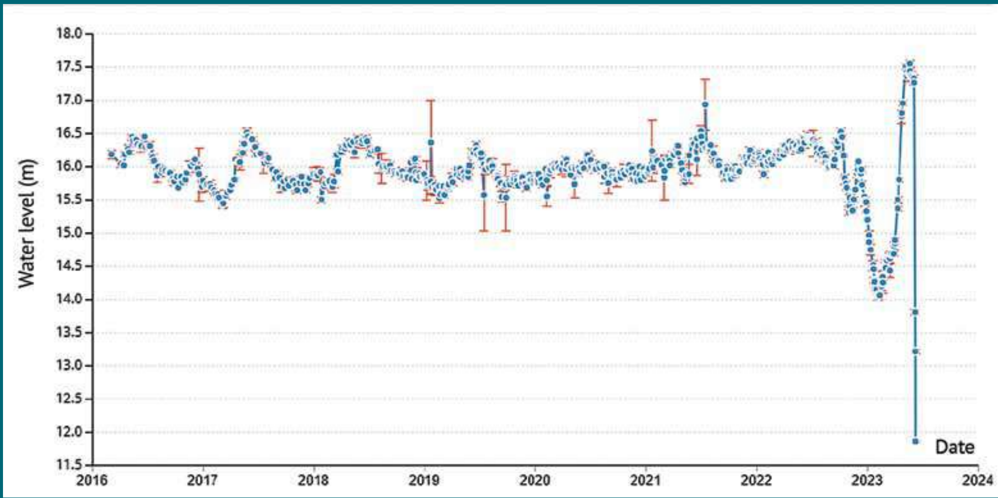
Kakhovka HPP before its destruction (2021)[212]

Kakhovka HPP after its destruction by Russian forces (2023)[2]

At present, substantial evidence indicates that the dam could only have been destroyed in this manner by an explosion originating from within the structure[94, 97, 198]. Videos published during the first hours after the attack clearly show intact sections of the HPP structure collapsing into the cavity created by the explosion deep beneath the water surface.

Hydropower dams are designed with substantial safety margins and are therefore virtually impossible to destroy by external shelling or aerial bombardment. Damage on the scale observed at the Kakhovka HPP dam could not have been caused by any form of external attack. Other major hydropower plants in Ukraine have

2 Particularly noteworthy are articles published in the journal Nature, in which authors from the United States, China, and the Netherlands argue that the destruction of the dam was caused not by an explosion but by inadequate maintenance of the hydropower plant by Ukraine[87, 119]. However, the authors of these articles do not have a professional background in hydropower engineering.



Water Level Dynamics in the Kakhovka Reservoir from 2016 to 9 June 2023[61]

been subjected to missile strikes, yet the resulting damage has not been comparable to the destruction of the Kakhovka HPP.

It should also be noted that Russia appears to have anticipated public dissatisfaction among residents of the occupied territories following the destruction of the dam. On 30 May 2023, the government of the Russian federation adopted Resolution No. 873[193], which stipulated that, until 1 January 2028, no technical investigations would be conducted into accidents at hazardous industrial facilities or hydraulic structures in the territories of the so-called “Donetsk People’s Republic” and the Zaporizhzhia and Kherson regions if such accidents resulted from hostilities, acts of sabotage, or terrorist attacks[3]. During the period when the dam was under Russian military control, the reservoir’s water level fluctuated considerably. However, it rose sharply immediately before the explosion and, by 20:00 on 5 June 2023, had reached a historic maximum of 16.77 m in the Baltic Height System (BHS), which was 0.77 m above the reservoir’s normal water level[61, 213].

Following the destruction of the Kakhovka HPP dam, approximately 14.4 km^3 of water stored in the reservoir was released. This volume corresponds to 35% of the Dnipro River’s mean annual discharge. Before the attack, the Kakhovka Reservoir contained approximately 20 km^3 of water. By 5 July 2023, the remaining volume had declined to 5.5 km^3[218]. As a consequence of the destruction of the dam, all the water (except that remaining in the main channel of the Dnipro River) flowed into the Dnipro River and subsequently into the Black Sea, while some water spread across the flooded areas.

3 At the same time, Russia initiated what it presented as an investigation into Ukraine’s alleged destruction of the Kakhovka HPP. The witnesses selected for the investigation were military personnel responsible for guarding the HPP, that is, most likely the very individuals who had been involved in the dam blasting[199, 206].

As a result of the rapid release of water from the Kakhovka Reservoir, a total of 612 km^2 of land was flooded, including 554.6 km^2 in Kherson Region and 57.8 km^2 in Mykolaiv Region. By the morning of 8 June, according to data from the Kherson hydrological station, the water level in the lower Dnipro had risen by 5.37 m compared with its level at 20:00 on 5 June, and subsequently reached a peak of 5.68 m. In the city of Nova Kakhovka, the total rise in water level exceeded 12.0 m[213].

The flooded area included approximately 80 settlements in the Kherson and Mykolaiv regions, inhabited at that time by about 40,000 people (before the full-scale invasion, the population had been several times larger), as well as 48 protected areas and numerous environmentally hazardous facilities. The floodwaters flooded industrial sites, farms, warehouses, and retail outlets storing fertilizers, pesticides, and household chemicals, approximately twenty filling stations, several oil depots, sewage pumping stations, cesspits serving private households, several cemeteries, livestock burial sites, private garden plots, and agricultural land (1,300 ha in Kherson Region and 750 ha in Mykolaiv Region[99]), among other sites.

During the first six days after the disaster, approximately 72% of the Kakhovka Reservoir's water volume (14 km^3) flowed into the Black Sea. Neither the magnitude nor the rate of this flood wave had any precedent during the existence of the reservoir. During the decades of the reservoir's operation, ecosystems of standing and slow-flowing waters had developed downstream of the Kakhovka HPP dam. These ecosystems were not adapted to rapidly flowing water. Consequently, even aquatic plants and animals suffered catastrophic losses, although, at first glance, the expansion of the aquatic environment might have seemed beneficial to them. It is reasonable to assume that the greatest losses, not only of infrastructure but, above all, of wildlife, occurred within the zone of catastrophic flooding.

At the same time, while the water level downstream of the destroyed Kakhovka HPP dam was rising rapidly, the water level upstream was falling, exposing the land that had been flooded during the creation of the reservoir.

ECONOMIC CONSEQUENCES OF THE DESTRUCTION OF THE KAKHOVKA HPP

The destruction of the Kakhovka HPP resulted in profound changes to the economic system of southern Ukraine. In addition to its impacts on biodiversity and ecosystems, it has also had a wide range of economic consequences. These affect (or, will affect after deoccupation) various sectors of the economy, not only within the area that was temporarily flooded but also far beyond the reservoir itself.

Until 2023, water abstracted from the Kakhovka Reservoir was used to irrigate agricultural land in southern Ukraine (including Crimea) and to support the operation of industrial facilities and major power generation infrastructure, including the Kakhovka HPP, the Zaporizhzhia Nuclear Power Plant, and the Zaporizhzhia Thermal Power Plant in Enerhodar.

It is also important to note that water from the reservoir was used for water supply to settlements, commercial fisheries, and recreational activities. Owing to its depth and the dimensions of the lock at the Kakhovka HPP, the reservoir also determined the parameters of water transport along the Nova Kakhovka-Zaporizhzhia section of the Dnipro River.

Because the economies of southern Kherson Region, Crimea, and parts of Zaporizhzhia and Dnipropetrovsk regions depended heavily on the operation of the Kakhovka HPP and the reservoir, their “status quo” was maintained at the political level both during the Soviet period and after Ukraine regained its independence. Rather than planning the rational use of water resources and adapting to climate change, all efforts were directed towards preserving the principles of Dnipro water use established during the middle Soviet period.

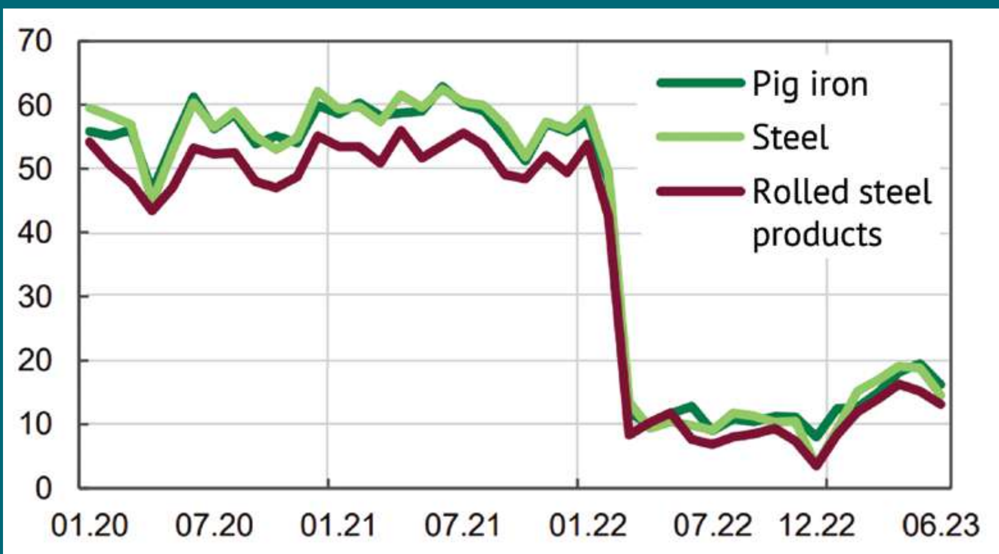
At the same time, the territories under Ukrainian control that previously depended on water supplied from the Kakhovka Reservoir are adapting to its absence. For example, the Concept of the State Target Programme for Comprehensive Water Supply to Territories Affected by Military Operations until 2030[164], approved on 30 July 2024, does not address the restoration of the Kakhovka HPP but instead provides only for the restoration of water supply through alternative means. In other words, a different economic system is gradually emerging from the one that existed during the lifetime of the reservoir.

WATER USE

Industrial and Municipal Water Supply

Many resource-intensive enterprises located far from the Kakhovka Reservoir received process water from the reservoir. According to the Ministry of Economy of Ukraine, losses incurred by industrial enterprises as a result of the destruction of the Kakhovka HPP dam amounted to USD 105 million[167]. The shortage of water was felt most acutely by metallurgical enterprises[4] in Dnipropetrovsk Region, located in the cities of Nikopol, Kryvyi Rih, Marhanets, and Pokrov. Following the destruction of the Kakhovka HPP dam, these enterprises had to reconfigure production to reuse process water or secure alternative sources of water supply. In particular, Ukraine's largest metallurgical plant, ArcelorMittal Kryvyi Rih, was forced to suspend steel production completely in June 2023, reducing production to 15-20% of its pre-war level from the 30-40% achieved at the beginning of the year[36]. Water supply problems were overcome by establishing supplies from alternative sources[127]. Other enterprises also adapted to the new conditions by introducing closed-loop water circulation systems or constructing their own water pipelines[200].

The destruction of the Kakhovka HPP led to a decline in Ukraine's production of pig iron, steel, and rolled steel products, which reduced exports and, consequently, GDP. Before the destruction of the dam, the metallurgical sector accounted for 30% of Ukraine's total industrial output and 42% of the country's total exports[166].



Average daily production of steel, pig iron, and rolled steel products by month, thousand tons[187]

4 Before the full-scale invasion by Russia, the mining and metallurgical sector accounted for a substantial share of Ukraine's GDP. In 2022, it contributed 10.3% of Ukraine's GDP, and in 2023, 5.7% (GMK Center data).

ECONOMIC CONSEQUENCES

Drinking water was supplied from water intakes located on the Kakhovka Reservoir to 140 settlements with a combined population of approximately 1 million people (including the occupied territories)[84]. 90% of consumers supplied by water intakes on the Kakhovka Reservoir lived in five cities: Kryvyi Rih (635,000 inhabitants), Nikopol (115,000), Enerhodar (53,000), Nova Kakhovka (45,000), and Marhanets (45,000).

The loss of the reservoir also affected people who relied on groundwater sources. Researchers observed wells drying up and groundwater levels declining by 5-8 m[84, 97] in settlements on the right bank of the Dnipropetrovsk Region, including the village of Katerynivka in Nikopol District, located 7.6 km from the shore of the former reservoir. Some experts predict that, even if the Kakhovka Reservoir were restored, groundwater levels would not recover to their former state for at least 33.5 years[97].

The drying up of wells and boreholes led to a deterioration in water supply not only because of reduced water availability but also because of declining water quality[38]. To preserve groundwater reserves in the city of Kherson, approximately 30 facilities within the water supply network were decommissioned and sealed on the day of the disaster, while several others were taken out of operation[67]. Currently, most boreholes remain sealed because of the continuing shelling of the area. Five of the city's six water pumping stations in the coastal area resumed operation, restoring the water supply from the Dnipro River after the catastrophic flooding had ended.

Restoring water supply for the population became the principal priority for recovery in the affected areas[5]. Immediately after the terrorist attack by Russian forces on the Kakhovka HPP dam, the Government of Ukraine allocated approximately UAH 980.5 million[179] for the transportation of drinking water to the affected regions of Dnipropetrovsk, Zaporizhzhia, Mykolaiv, and Kherson.


Construction of the water pipeline and installation of chambers for the maintenance, inspection, and control of the pipeline network.
Source: Ministry for Communities and Territories Development of Ukraine.

5 As of early 2025, the vast majority of the area formerly supplied with water from the Kakhovka Reservoir remains under temporary occupation or within the active combat zone.

By the end of 2024, three trunk water pipelines had been commissioned[182], transferring water from the Inhulets and Dnipro rivers to settlements in Dnipropetrovsk Region: the Zaporizhzhia-Tomakivka-Marhanets pipeline, the Marhanets-Nikopol-Pokrov pipeline, and the Inhulets River-Pivdenne Reservoir pipeline[1, 147].

The development of this type of water supply, which does not involve water losses through evaporation, is an important component of restoring municipal water supply in the territories after deoccupation. At the same time, these projects were implemented without complying with environmental protection requirements. They were approved under a simplified procedure during martial law and therefore were not subject to Strategic Environmental Assessment (SEA) or Environmental Impact Assessment (EIA), even though the pipelines were constructed within an Emerald Network site.

Consequently, the pipeline from the Inhulets River was constructed within nine months across steppe areas and memorial sites, including locations of mass executions of Jews during the Second World War[30, 137] and a Jewish cemetery.

Irrigation

Agricultural production has become increasingly challenging in recent years because of global warming, the deterioration of irrigation infrastructure, and soil salinization[133]. As a result, increasing pressure was placed on the irrigation systems of southern Ukraine.

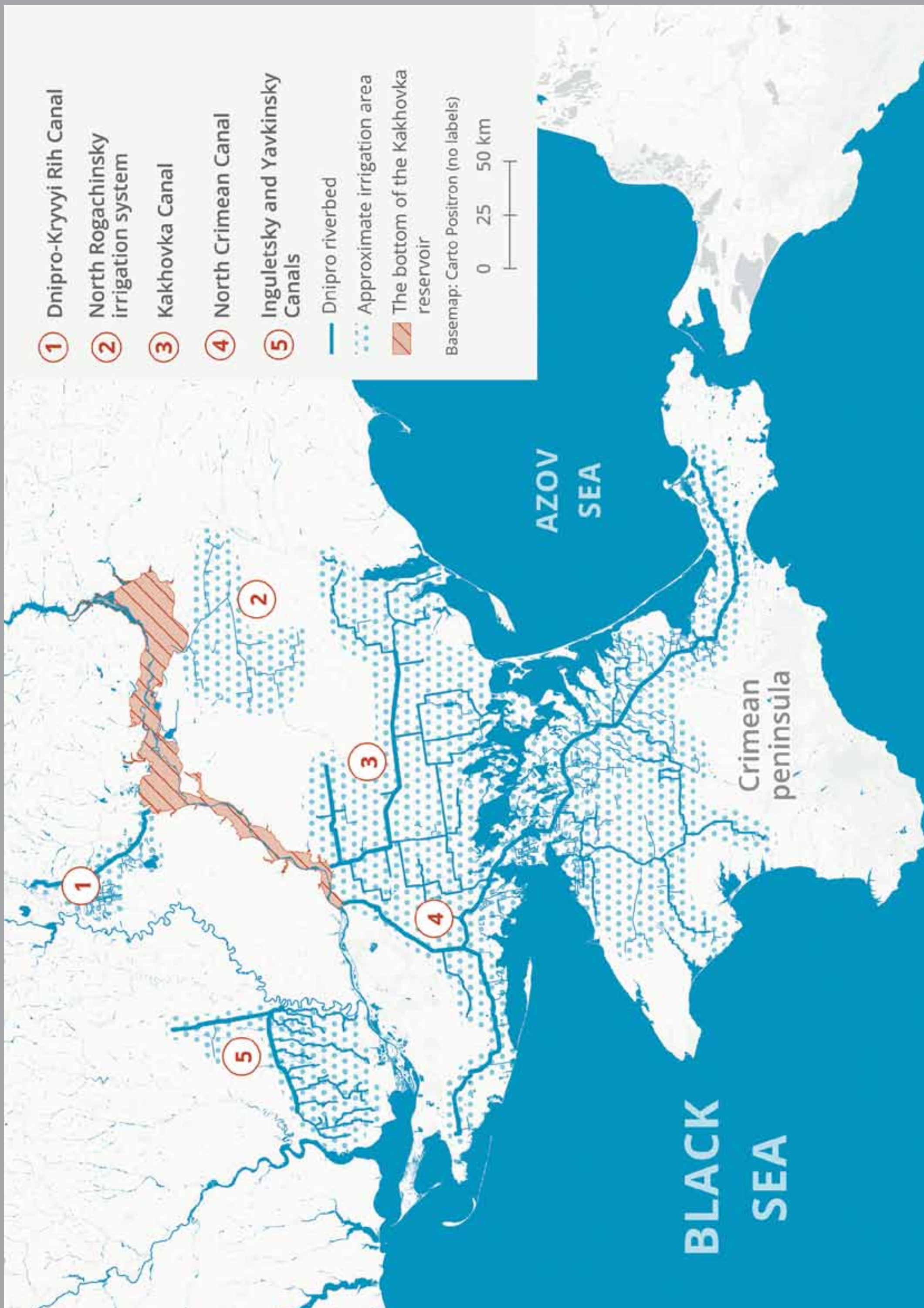
Three main canals originated from the Kakhovka Reservoir: the Dnipro-Kryvyi Rih Canal, the North Crimean Canal, and the Kakhovka Canal. They supplied a number of irrigation systems established between 1957 and 1979: the Kakhovka, North Crimean, Kamianka, Pryazovske, and North Rohachyk systems. Together, during the summer period, these systems were capable of abstracting more than half of the Dnipro River's mean annual discharge (at least 922 of 1,670 m^3/s).

The design irrigated area supplied by the Kakhovka Reservoir was approximately 1.5 million ha[169] (for comparison, this is larger than the area of Montenegro). However, in 2021 the actual irrigated area amounted to only one-fifth of the planned area – 329,000 ha[170] (or 0.8% of Ukraine's total agricultural land[6]) – and was located within Kherson, Zaporizhzhia, and Dnipropetrovsk regions, as well as the Autonomous Republic of Crimea. Consequently, the destruction of the Kakhovka HPP dam left 94% of irrigation systems in Kherson Region, 74% in Zaporizhzhia Region, and 30% in Dnipropetrovsk Region without water[60]. The vast majority of these territories remain under Russian occupation.

It is reasonable to assume that Kherson Region will require the greatest changes in agricultural management as a consequence of the destruction of the Kakhovka HPP dam, since irrigation accounted for 94% of the region's total water use[223]. Both

6 The statistics do not include water supply to the irrigation systems of the Autonomous Republic of Crimea, which has been suspended since the beginning of Russia's occupation in 2014.

Canals Connected to the Kakhovka Reservoir



the extent of irrigation and the irrigated area in the region increased between 2012 and 2018[223]. Nearly half of all oilseed and vegetable crops grown in Kherson Region depended on water supplied from the Kakhovka Reservoir[97].

It should be noted that the reduction in the area sown with agricultural crops in the southern and eastern regions of Ukraine is primarily related not to the loss of the Kakhovka Reservoir but to the hostilities taking place in these regions. Following the start of the full-scale invasion, the area sown with agricultural crops decreased by 92% in Kherson Region, 64% in Zaporizhzhia Region, 19% in Mykolaiv Region, and 2% in Dnipropetrovsk Region[7].

The recovery of agriculture in the deoccupied territories will be delayed. Most agricultural land will require demining and the reconstruction of infrastructure, while part of it will be withdrawn from agricultural use, including areas affected by soil contamination.

Water Supply for the Nuclear Power Plant

The Zaporizhzhia Nuclear Power Plant (ZNPP) is the largest nuclear power plant in Europe, with six operating reactor units that were cooled using water from the Kakhovka Reservoir. The plant's cooling pond is essentially a section of the reservoir separated by a dam.

According to the National Nuclear Energy Generating Company Energoatom, which operates Ukraine's nuclear power plants, the water level in the cooling pond of the Zaporizhzhia Nuclear Power Plant fell from 22 m to 16.66 m between 6 and 8 June[160] because water drained through the sandy dam of the cooling pond into the rapidly receding reservoir[116]. Even this water level was sufficient to ensure the safe operation of the plant, since five of its six reactor units had been placed in so-called "cold shutdown" mode from the beginning of the full-scale invasion, while only one reactor unit remained in operation.

Given that the nuclear power plant was under the occupation of the Russian federation, the Russian state corporation Rosatom had to provide the plant with a backup water supply[159]. The options considered included dredging, the installation of additional pumping stations, and the drilling of new boreholes[113]. Such scenarios had been developed long before the outbreak of the war[159].

Ultimately, the "administration" of the Zaporizhzhia Nuclear Power Plant (established by the occupation authorities of the Russian federation) constructed 11 boreholes with a combined capacity of 250 m^3 of water per hour[63], further increased to 400 m^3/h by April 2024[64]. This adjustment was fully sufficient to cool the operating reactor unit. Therefore, as stated by the International Atomic Energy Agency (IAEA)[62], the loss of the Kakhovka Reservoir does not pose a threat to the operation of the Zaporizhzhia Nuclear Power Plant.

7 For comparison, data from 2021 and 2022 were used, representing the year before the full-scale invasion and the first year following it.

NAVIGATION

The Kakhovka Reservoir formed part of Ukraine's inland waterways and was used for the transport of a wide range of cargoes. The lock at the Kakhovka HPP was the last and southernmost lock in the Dnipro cascade. All river vessels travelling along the Dnipro to load or unload cargo passed through it. For example, in 2021 the total number of lock transits at the Kakhovka lock accounted for one-third of all vessels passing along the Dnipro River[171]. Naturally, this contributed to the wear of the hydraulic structures. In 2020, the technical condition of the Kakhovka lock was assessed as "critical"[55]. At the same time, 2021 was a record year for river transport during the period of Ukraine's independence: 14.4 million tons of cargo were transported along the Dnipro River, of which 43%[172] passed through the Kakhovka lock.

Following the start of Russia's invasion of Ukraine, navigation by small vessels on the Dnipro River was suspended. River vessels became stranded in seaports, where they remain to this day. The river ports of Kherson and Nova Kakhovka, which had provided the link between maritime shipping and river transport on the route connecting seaborne transport with logistics centres in Ukraine, were destroyed.

As of 2024, some river transport companies had begun developing domestic shipping on safe sections of the Dnipro and Desna rivers, while others had relocated their operations to the Danube.

ECONOMIC CONSEQUENCES

Redistribution of Landmines Following the Destruction of the Kakhovka HPP

The catastrophic flooding in June 2023 caused the uncontrolled redistribution of explosive hazards throughout the Dnipro riverbed, the Dnipro-Buh Estuary, and even into the Black Sea. The flood currents carried munitions away from mined riverbanks, after which many became buried beneath thick layers of sediment[109]. Consequently, new minefields formed throughout the flooded area[37, 91, 92, 182]. Potentially, the entire flooded area should be regarded as a zone of uncontrolled dispersal of explosive hazards, since mines can move within sediments and their trajectories cannot be predicted.

Additional challenges arise from the fact that clearance of the riverbed and floodplain wetlands can only be carried out mechanically, including by detonating explosive devices. However, such methods are unacceptable because most of these areas have protected status[40].

Spontaneous minefields in the flooded areas of Kherson Region (Photo: The HALO Trust[91])

At the same time, the fleet that remained upstream of the Kakhovka HPP and was not blocked in ports could, in theory, continue operating. An inland fleet still operates on the Dnipro, without access to the sea, transporting construction materials over short distances[224]. Navigation on the Dnipro from its mouth to the city of Zaporizhzhia will remain impossible until the deoccupation of southern Ukraine. The future restoration of river transport will also require a new approach, as inland water transport may lose its competitive advantage over land transport if bridges are constructed between the cities of Nikopol and Enerhodar. Given that the reservoirs along the Dnipro alternate with free-flowing river sections, the full operation of deep-draught vessels is not feasible. Furthermore, according to river transport operators, the Kakhovka Reservoir was itself unfavorable for small-vessel navigation along the Nova Kakhovka–Zaporizhzhia section because of frequent lock delays lasting several days and storms.

In addition, the Dnipro riverbed and the exposed bed of the former reservoir remain contaminated with landmines, preventing safe navigation.

FISHERIES

Commercial fishing in the Kakhovka Reservoir has always been an important component of Ukraine's fisheries sector. In recent years, annual catches from the reservoir averaged approximately 2,000-3,000 tons of fish and aquatic invertebrates. In 2021, catches from the Kakhovka Reservoir accounted for 7.8% of Ukraine's total fish catch, while catches from the Lower Dnipro and the Dnipro–Buh Estuary accounted for a further 8.4%[35, 146].

In 2022, because of the hostilities and occupation, the Kakhovka Reservoir accounted for only approximately 1.9% of Ukraine's total fish catch[146]. Catches in the Lower Dnipro and the Dnipro-Buh Estuary also declined substantially, accounting for only 1.4% of the country's total fish catch.

On 6 June 2023, the day of the terrorist attack, and during the following several days, the vast majority of the reservoir's fish populations were washed downstream into the Lower Dnipro and the Black Sea. As a result of the hydraulic shock, fish mortality was recorded along the stretch from Kherson to the Dnipro-Buh Estuary, including large numbers of juvenile fish that were unable to withstand such extreme conditions[134]. At the time of the terrorist attack, the Kakhovka Reservoir supported at least 39 fish species, including 20 species of commercial importance[80]. Annual catches amounted to up to 2,200 tons in 2021[146] and 2,800 tons in 2020[146]. The commercial catch in the reservoir consisted predominantly of non-native fish species. In 2021, catches of PRussian carp (*Carassius gibelio*) amounted to 1,462 tons, representing 61.6% of the total catch from the reservoir. Silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*) and their hybrids, as well as grass carp (*Ctenopharyngodon idella*), also accounted for a substantial share of the catch. These species were stocked annually to replenish commercial fish stocks.

Among native species, the most abundant catches were common roach (*Rutilus rutilus*), accounting for 14.7% (350 tons) of the total catch, and common bream (*Abramis brama*), accounting for 9.3% (221 tons). Large catches of pikeperch (*Sander lucioperca*), common carp (*Cyprinus carpio*), and wels catfish (*Silurus glanis*) were also recorded.

As a result of the terrorist attack, not only natural populations of rare fish species were affected, but also aquaculture facilities maintaining sturgeon broodstock at a specialized hatchery. Grow-out ponds and broodstock ponds within the zone of catastrophic flooding were flooded by nearly four meters of contaminated water containing high concentrations of suspended particles, including toxic substances[128]. As a result, the entire sturgeon broodstock maintained at the Dnipro Experimental Sturgeon Hatchery named after Academician S. T. Artiushchyk was lost.

In addition to freshwater fish-farming, harvesting of freshwater crayfish was an important component of the use of aquatic biological resources in the region. An analysis of freshwater crayfish catches in Ukraine during 2017-2023[174] shows that catches increased until the beginning of the full-scale invasion and then declined by almost 30-40%. As a result of the destruction of the Kakhovka HPP dam, a large proportion of the shoreline that had provided habitat for freshwater crayfish was lost, leading to the loss of the reservoir's commercial crayfish stock.

Overall, the losses to fish populations are substantial for Ukraine's inland fisheries sector. They have caused significant damage to fisheries enterprises and contributed to a decline in the region's socio-economic indicators. The loss of rare fish species and the sturgeon broodstock will significantly reduce the effectiveness of measures aimed at maintaining populations of species protected at both the national and international levels.

ELECTRICITY GENERATION

The Kakhovka HPP generated an average of 1,420 million kWh of electricity per year[136]. With the loss of the reservoir, Ukraine also lost a source of electricity generation with an installed capacity of 334.8 MW. On average, the pumps supplying the irrigation canals consumed about 15% of the electricity generated by the HPP each year. During dry summer months, however, almost all of the electricity generated could be used to pump water into the canals. In terms of land-use efficiency, the Kakhovka HPP ranked last among the hydropower plants of the Dnipro cascade, generating 6,590 kWh of electricity per hectare.

The Kakhovka HPP has not been operating within Ukraine's power system since October 2022. Although it had previously played an important role in balancing renewable energy generation, its complete loss did not cause the collapse of Ukraine's power system[95]. Nevertheless, interruptions to electricity supply affected up to 140,000 people[110]. As a result of the disaster, nearly 130 electrical substations and two solar power plants were flooded[4].

RECREATION

The recreational sector associated with the Kakhovka Reservoir was an important component of leisure and tourism in Ukraine, primarily as a center for water sports, recreational fishing, and beach tourism. Recreational activities organized by institutions within Ukraine's protected areas network[183] were also focused on the reservoir's shoreline, including organized tourism, excursions, and recreation at countryside leisure complexes.

From a historical and cultural perspective, Khortytsia Island and its monuments associated with the period of the Ukrainian Cossack State were particularly attractive to visitors from other regions of Ukraine. The disappearance of the reservoir did not affect their state of preservation.

The transformation of the Dnipro River valley into a theatre of war temporarily brought all recreational activities in the area to a halt. According to the World Bank, losses to Ukraine's culture and tourism sector as a result of the armed aggression of the Russian federation amounted to USD 19.6 billion[104]. It should therefore be remembered that recreational activities changed not only because of the destruction of the reservoir but, above all, as a consequence of the war.

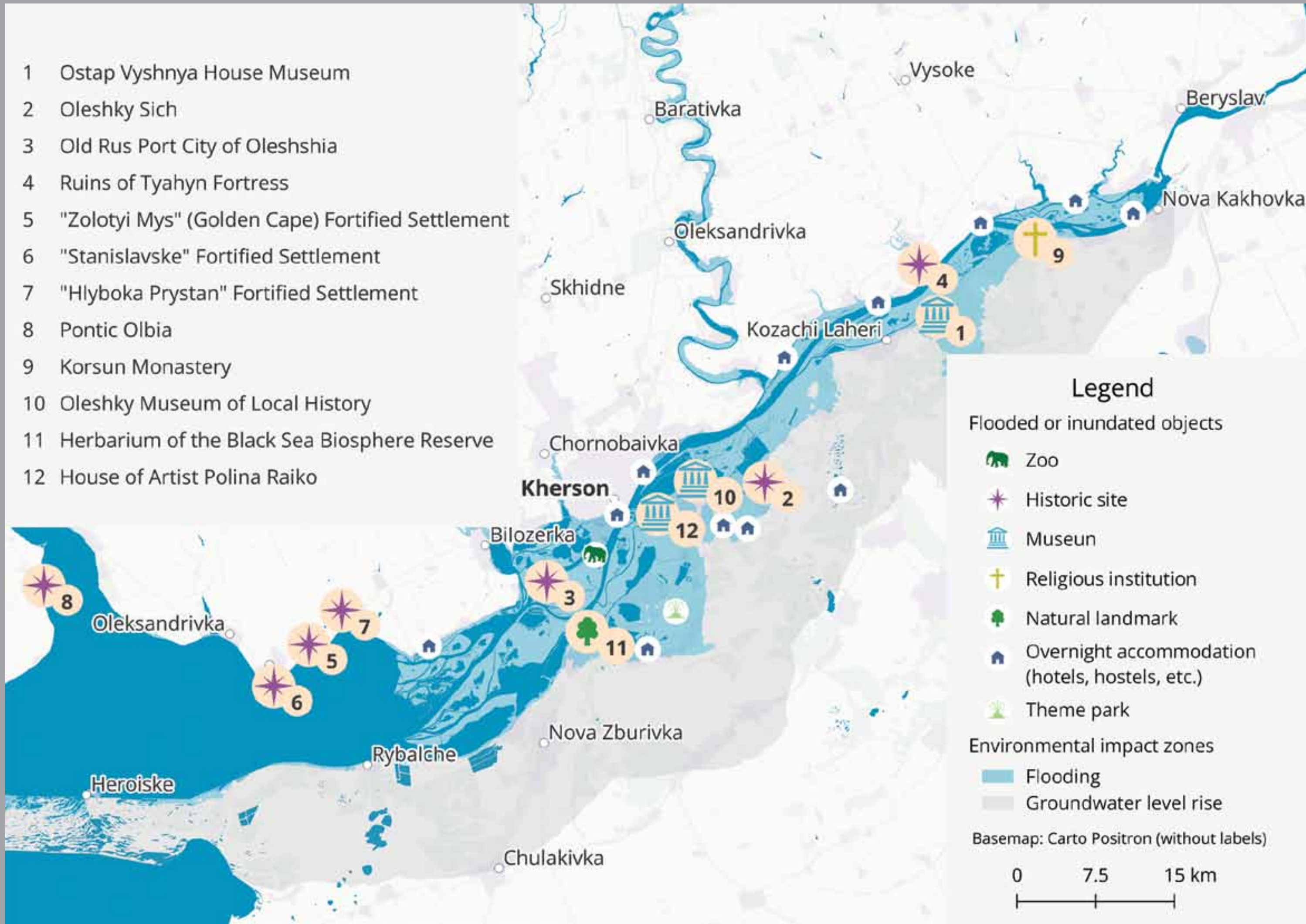
Changes Caused by the War	Changes Caused by the Destruction of the Reservoir
• Suspension of recreational activities for the duration of the war • Landmine contamination • Destruction of recreational facilities and sites of historical, cultural, and natural heritage as a result of shelling • Loss of access to beach and recreational areas in southern Ukraine • Withdrawal of investment from Ukraine's tourism sector • Restrictions on recreational fishing along the Dnipro River	• Recreational infrastructure located along the former shoreline has become separated from the present course of the Dnipro River • Physical destruction of recreational facilities within the flooded area • Pollution, resulting in further adverse impacts on the protected areas network • Increase in illegal archaeological excavations at sites dating from different historical periods • Exposure of contaminated sands that now form the banks of the present-day hydrographic network of the Velykyi Luh

The recreational sector suffered its greatest losses within the flooded area, where not only infrastructure but also more than 120 monuments[148] of history, urban planning, architecture, science and technology, and monumental art of national and local significance were destroyed. Among the sites flooded by the Dnipro were the Ostap Vyshnia House Museum[8] in the village of Krynky, restored only in 2021; the medieval

8 Ostap Vyshnia (1889–1956) was a Ukrainian humorist and the founder of the usmishka ("smile"), a distinctive genre of humorous short prose in Ukrainian literature.

Tourist Infrastructure Sites Flooded in Kherson Region

1 Ostap Vyshnya House Museum
2 Oleshky Sich
3 Old Rus Port City of Oleshshia
4 Ruins of Tyahyn Fortress
5 "Zolotyi Mys" (Golden Cape) Fortified Settlement
6 "Stanislavske" Fortified Settlement
7 "Hlyboka Prystan" Fortified Settlement
8 Pontic Olbia
9 Korsun Monastery
10 Oleshky Museum of Local History
11 Herbarium of the Black Sea Biosphere Reserve
12 House of Artist Polina Raiko



Interior of Polina Raiko's House Before and After the Flooding (photos by I. Moisiienko and the Polina Raiko Charitable Foundation, respectively)

port city of Oleshshia[9]; and the Oleshky Sich. The flooding also affected the remains of the Tyahyn Fortress[10], the hillforts of Zolotyi Mys, Stanislav, and Hlyboka Prystan, the Korsun Monastery[11], the Oleshky Museum of Local History, the Suziria House of Culture Museum in Hola Prystan, the Zoological Museum and Herbarium Collection of the Black Sea Biosphere Reserve, and the house[155] of the renowned Ukrainian folk artist Polina Raiko[12]. This list of outstanding cultural and historical monuments affected by the Kakhovka disaster is far from exhaustive.

The disaster also had negative impacts far beyond the immediate area, reaching the Black Sea coast, which has traditionally been one of Ukraine's most popular seaside recreation areas. The Black Sea shoreline was littered with masses of plant debris, dead fish, and even household items carried downstream from the Lower Dnipro and destroyed settlements[219].

Large parts of the Black Sea coastal waters and the Dnipro floodplain remain contaminated with landmines, while the soils along the Dnipro shoreline (the former bed of the reservoir) are unsuitable for the development of recreational areas because of heavy metal contamination (see the chapter **"Soils and sediments"**). The outflow of water from the Kakhovka Reservoir washed anti-personnel landmines out of their original locations and carried them to the Black Sea coast, creating an additional obstacle to the recovery of recreation and tourism. This is likely to continue affecting the region's attractiveness for tourism for many y ears to come. As this area played a key role in the formation of the Ukrainian state, it has long attracted visitors not only because of its picturesque landscapes but also because of its historical significance. This is precisely why it deserves to be restored in the future.

9 Oleshshia was a medieval port city and an important commercial and strategic center of Kyivan Rus.

10 The surviving defensive structures of Tyahyn Fortress date back to the fourteenth century.

11 Korsun Monastery was founded in 1784 near the present-day city of Nova Kakhovka. It remained active until the 1930s and was almost completely destroyed in the 1950s.

12 Polina Raiko (1928–2004) was a Ukrainian artist best known for her works in the style of naïve art.

ENVIRONMENTAL CONSEQUENCES OF THE DESTRUCTION OF THE KAKHOVKA HPP

The destruction of the Kakhovka HPP dam caused not only direct damage to the environment but also constituted a crime that, under Ukrainian legislation, is classified as ecocide[13] [157]. On the day of the terrorist attack (6 June 2023), the Ukrainian authorities initiated a pre-trial investigation into the destruction of the Kakhovka HPP[194]. The disaster, deliberately planned by the Russian side, resulted in the large-scale destruction of flora and fauna and the contamination of water resources.

Chronology of the Environmental Consequences of the Destruction of the Kakhovka HPP Dam

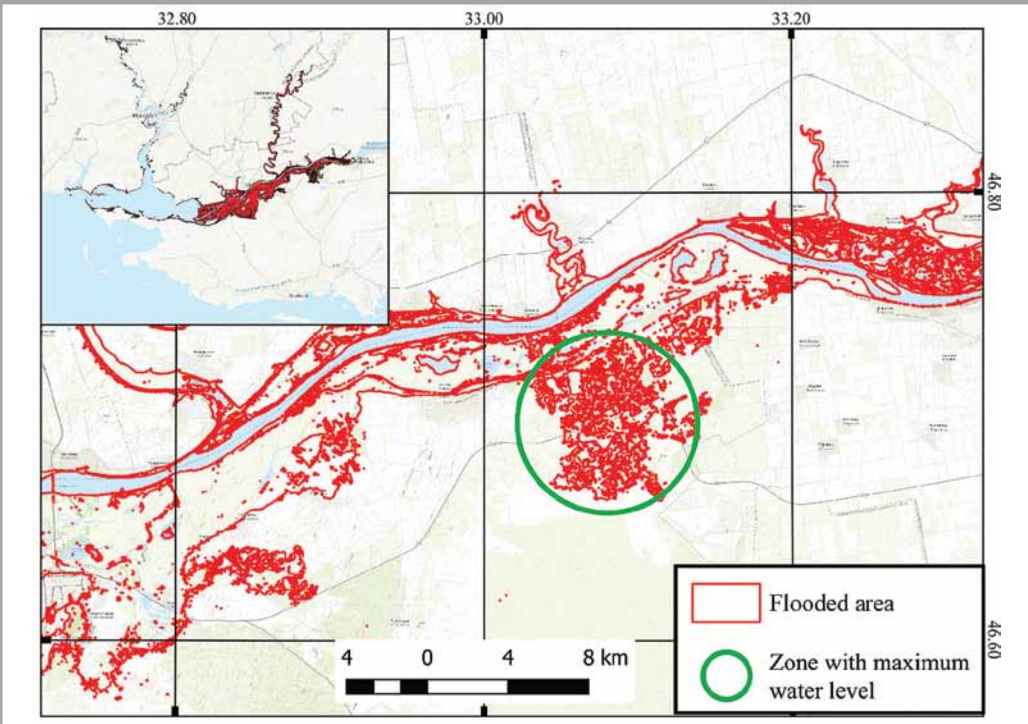
On the eve of the disaster, the Kakhovka Reservoir contained a record volume of water – 19.9 km^3 [111, 117, 214]. Following the explosion, water rapidly drained from the reservoir, increasing pressure on the damaged dam and ultimately leading to its almost complete destruction.

Surface runoff developed across the newly exposed reservoir bed, flowing from elevated areas into depressions and then into the main channel of the Dnipro River. The rapid drainage of water was facilitated by the network of channels and distributaries of the Dnipro that had remained preserved from the period before the reservoir was created.

At the same time, settlements, agricultural land, and natural areas downstream, primarily on the left bank of the Dnipro, were flooded. The extent of flooding depended on elevation above sea level, backwater effects, and other factors. The depth of flooding generally ranged from 20 cm to 8 m[24], reaching a maximum of 12.5 m[116]. Temporary flooding caused groundwater levels to rise on the left bank of the Dnipro. This bank consists of extensive sandy deposits formed by the river in the past. In some places, the momentum of the floodwaters carried them over natural river levees, flooding areas located even higher than any natural river's water level[24]. Once the flow weakened, however, the water was no longer able to overtop the levees and return to the river channel. Consequently, flooding persisted for several months in low-lying areas, particularly near the village of Krynky.

13 In 2001, the term ecocide was introduced into the Criminal Code of Ukraine (Article 441) as a separate criminal offence, defined as *"the mass destruction of flora or fauna, poisoning of the atmosphere or water resources, as well as any other acts capable of causing an environmental catastrophe"*.

Flooded Area Beyond the Natural River Levee[24]



Flooding of settlements, farms, and summer cottage communities added debris from buildings, trees, soil, and other solid materials to the floodwaters, greatly increasing their destructive force. Numerous facilities containing chemical pollutants (warehouses and stores selling mineral fertilizers, pesticides, and other chemicals) and organic pollutants (livestock farms, cesspits, and sewage collectors) were flooded. In addition, organic sediments and living organisms inhabiting the water column were carried away by the floodwaters.

The organic sediments washed out of the reservoir posed a particular hazard because they contained large quantities of pollutants that had accumulated over many years as a result of discharges of untreated industrial and municipal wastewater from the cities of Zaporizhzhia, Dnipro, Kamianske, and other settlements[129, 205].

Equally important was the flooding of numerous protected areas of national and international importance, as well as natural habitats[14] protected under the Bern Convention.

On the fourth day after the disaster (9 June 2023), water levels in the Lower Dnipro began to decline gradually. By 10-11 June 2023, the total flooded area had decreased

14 Here and throughout this book, the authors use the term natural habitat as a synonym for biotope, following the approach whereby habitat is used in the context of protected habitat types, whereas biotope is used in a broader, more general sense.

by almost half and subsequently returned to its original extent[99]. Water remained for a longer period only in isolated depressions. For example, the areas surrounding Lake Soliane in the city of Hola Prystan remained flooded for several months[5]. Thus, across most of the affected area, the impacts of flooding were both catastrophic and short-lived.

The Bern Convention on the Conservation of European Wildlife and Natural Habitats

The Bern Convention is the principal international legal instrument for nature conservation in Europe. It establishes priorities for the conservation of species and natural habitats and provides the basis for the designation of new protected areas, as well as for the protection and funding of existing ones.

As a Contracting Party to the Bern Convention and a country developing the Emerald Network on its territory, Ukraine has undertaken to implement measures to conserve the populations of these species and habitats and to prevent the deterioration of their conservation status across all four biogeographical regions represented in the country. The destruction of the Kakhovka HPP dam caused irreversible damage to populations of these species in the Steppe biogeographical region and undermined many years of efforts to establish protected areas and achieve progress in species conservation along the Lower Dnipro.

In practice, the reservoir continued to drain until the water levels upstream and downstream of the destroyed dam equalized (**23 June**). This date may therefore be regarded as the beginning of the restoration of the former Dnipro River channel along a 250 km stretch.

Upstream of the dam, the once continuous expanse of the reservoir became fragmented, forming a series of isolated water bodies in low-lying areas[192]. The size and number of these isolated water bodies gradually decreased as groundwater levels in the drained reservoir declined. As water levels fell during the draining of the reservoir, fish and other aquatic animals trapped in these isolated water bodies died from oxygen depletion and the physical drying out of the pools. In many places, the retreating water left behind thick layers of fish and molluscs, which subsequently died after being exposed to the open air.

The overwhelming majority of fish (in terms of abundance) that became trapped in isolated water bodies after 6 June had died by **20 June 2023**. A further episode of fish mortality occurred in **February-March 2024**, when shallow residual water bodies froze. These water bodies also warm rapidly, and many of them persisted even during the exceptionally hot summer of 2024.

The release of organic pollutants resulting from the decomposition of dead animals and plants effectively created a source of secondary water pollution, posing a long-term threat to the environment.

BIODIVERSITY

All terrestrial and aquatic areas affected by the destruction of the Kakhovka HPP dam can be divided into three zones with similar consequences for biodiversity:

a) the territory of the former Kakhovka Reservoir (the drained zone), together with the canals and irrigation systems dependent on it;

b) the zone of temporary catastrophic flooding;

c) the biologically productive shallow-water zone in the northwestern Black Sea.

A zone of elevated groundwater levels was also recorded during the period of catastrophic flooding, extending southward from the flooded area across the Lower Dnipro Sands massifs.

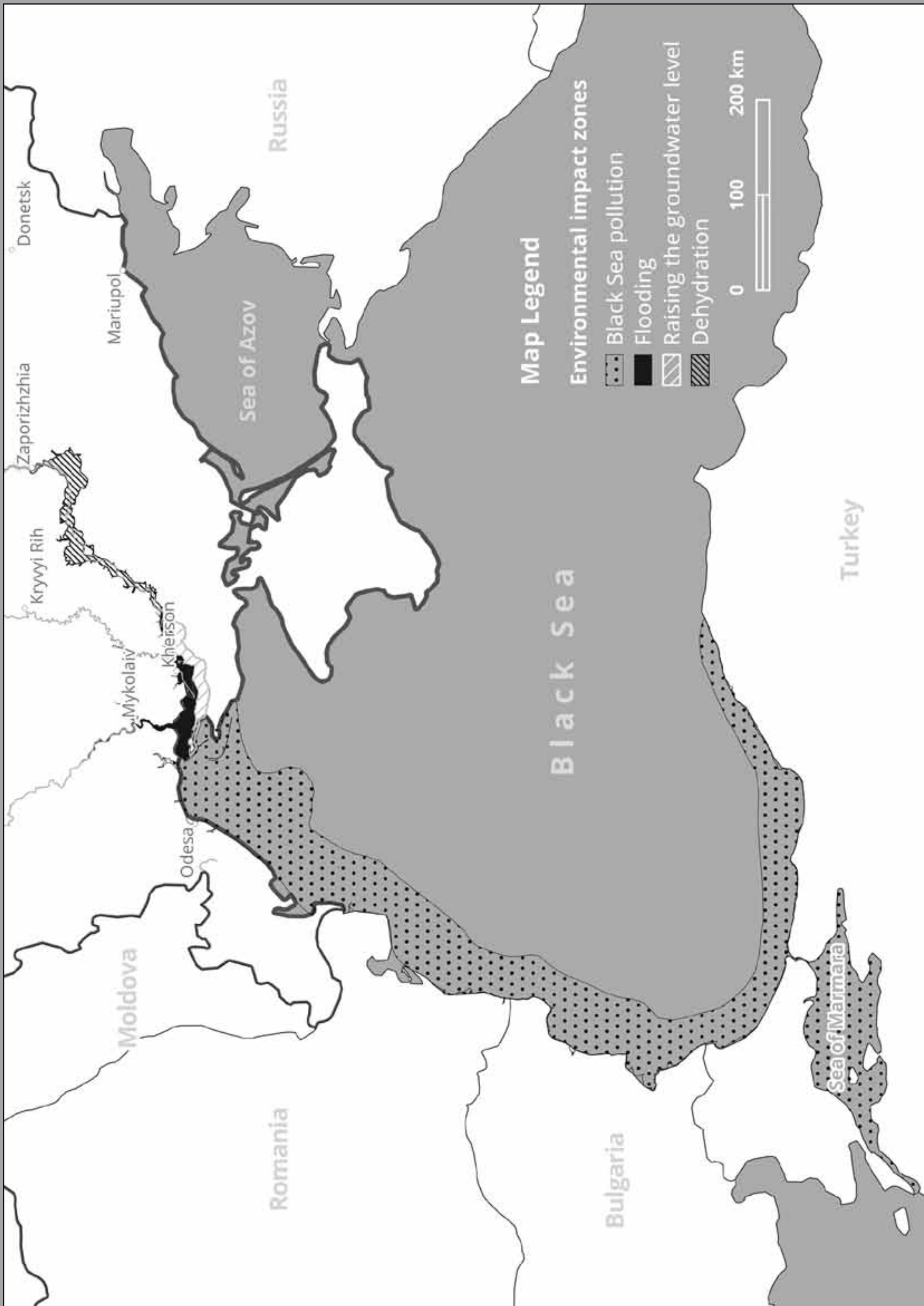
By the end of 2024, active hostilities were continuing across most of the drained zone, while the frontline passed through other parts of it. The same applies to the flooded zone. Because of landmine contamination along the shoreline and other factors, even the Black Sea coast remains difficult to access, while conducting research in the marine environment is even more challenging.

Whereas biodiversity within the former reservoir was completely lost, making it possible to obtain absolute estimates of biodiversity loss, losses in the other affected zones are not as readily apparent (for example, in the flooded zone, most plants survived, whereas terrestrial and aquatic animals perished). The mass loss of fauna caused by the destruction of the Kakhovka HPP dam affected both large and small groups of animals, including insects, aquatic invertebrates, and soil invertebrates. The formation of soils in southern Ukraine and the maintenance of the food web of the Lower Dnipro ecosystem depend on the activities of the latter.

At the time of the destruction of the dam, many groups of animals, both terrestrial and aquatic, were in their breeding season or had already produced their 2023 offspring. Because of the sudden and rapid course of events, during the first minutes after the disaster most animals had no chance of escaping the several-meter-deep torrent of water. The situation was further aggravated by the fact that the disaster occurred at night, when animals were disoriented, and by the absence of natural mechanisms for coping with such events in species of the steppe zone adapted to arid conditions. It is also reasonable to assume that there was mass mortality among aquatic animals inhabiting the Lower Dnipro that were washed into the saline waters of the Black Sea or buried beneath thick layers of contaminated silt. These included many species of molluscs, crustaceans, insects, worms, and vertebrates, including fish, amphibians, and mammals that typically inhabit aquatic environments, such as beavers and otters.

Unfortunately, Ukraine has never carried out a comprehensive biodiversity inventory or biodiversity monitoring in accordance with modern standards[106], except for species studied for the assessment of their resource potential, such as commercially important fish species. Consequently, it is impossible to determine the exact numbers of plant and animals that were lost, since even after deoccupation it will no longer be possible to establish what existed before the dam's blasting.

Zones Affected by the Disaster



Another reason why the losses cannot be accurately assessed is the rapid recovery of the landscape and biodiversity within the former reservoir. It is likely that similar processes are occurring just as rapidly in the area that was temporarily flooded. By the time research in these areas becomes possible, several years from now, the results will no longer reflect the losses caused by the disaster but rather the state of nature's recovery at that time. This will become a new baseline for future studies of biodiversity in these areas.

Plants

The area formerly occupied by the Kakhovka Reservoir did not support particularly rare flora. The only notable exception was floating watermoss (*Salvinia natans*)[15]. This aquatic fern floats on the water surface, forming the rare habitat "floating *Salvinia* mats", which is protected under the Bern Convention. Within the reservoir itself, however, floating *Salvinia* mats were relatively uncommon, as they typically develop in sheltered bays and river branches where the plants are not carried away by the current. The main population of this species in southern Ukraine occurred not in the reservoir but within the Dnipro Delta.

In addition to floating watermoss, the free-floating plant communities of the Lower Dnipro that were affected by the flooding included such rare species as Don's hornwort (*Ceratophyllum tanaiticum*), waterwheel plant (*Aldrovanda vesiculosa*)[42], fringed water-lily (N*ymphoides peltata*), Sarmatian pondweed (*Potamogeton sarmaticus*), common bladderwort (*Utricularia vulgaris*), and white water-lily (*Nymphaea alba*), among others[185]. In particular, the waterwheel plant (*Aldrovanda vesiculosa*) is classified as Endangered on the IUCN Red List[66]. Only a very small number of Ukrainian plant and animal species have this conservation status.

The Lower Dnipro is of much greater conservation value at the phytocoenotic and ecosystem levels. In particular, it contains rare associations belonging to ten formations included in the Green Book of Ukraine, as well as nearly thirty habitat types listed in Resolution No. 4 of the Bern Convention (**Appendix 4**). Among the affected habitats were aquatic plant communities and aquatic habitats, although at first glance one might expect them to benefit from an increase in water. In reality, however, they were exposed to a different kind of water. Owing to the absence of natural floods for many decades as a result of river regulation, extensive areas of the Lower Dnipro became occupied by aquatic communities characteristic of standing and slow-flowing waters. These include, among others, the Submerged Hornwort Formation (*Ceratophylleta submersi*), the Waterwheel Plant Formation (*Aldrovandeta vesiculosae*), and the Floating Watermoss Formation (*Salvinieta natantis*). A number of habitat types listed in Resolution No. 4 of the Bern Convention have similar ecological characteristics (e.g. C1.222 Floating *Hydrocharis morsus-ranae* rafts, C1.225 Floating *Salvinia natans* mats, and C1.32 Free-floating vegetation of eutrophic waterbodies), which, like the rare plant communities, are not adapted to life in fast-flowing water.

15 Removed from the Red Data Book of Ukraine in 2021.

The destructive floodwave generated by the breach of the Kakhovka HPP dam washed away most of these plants, plant communities, and habitats into the Dnipro-Buh Estuary and the Black Sea, where they perished in the saline waters.

The flooded zone, with its steppe slopes and sands of the first above-floodplain terrace, was of exceptional biological value. It supported numerous species with highly restricted distributions, occurring only in this region. These include the Lower Dnipro Sands endemics short-headed knapweed (*Centaurea breviceps*), lax jurinea (*Jurinea laxa*), and Dnipro thyme (*Thymus borysthenicus*), as well as the Buh-Dnipro endemics Savran alyssum (*Alyssum savranicum*), downy hawthorn (*Crataegus alutacea*), Helen's hawthorn (*Crataegus helenolae*), woolly-flowered wheatgrass (*Agropyron dasyanthum*), and grass-leaved sea lavender (*Goniolimon graminifolium*), among others[185]. It is reasonable to assume that the flooding killed hundreds of thousands of individuals of these species, representing a substantial proportion of their total populations.

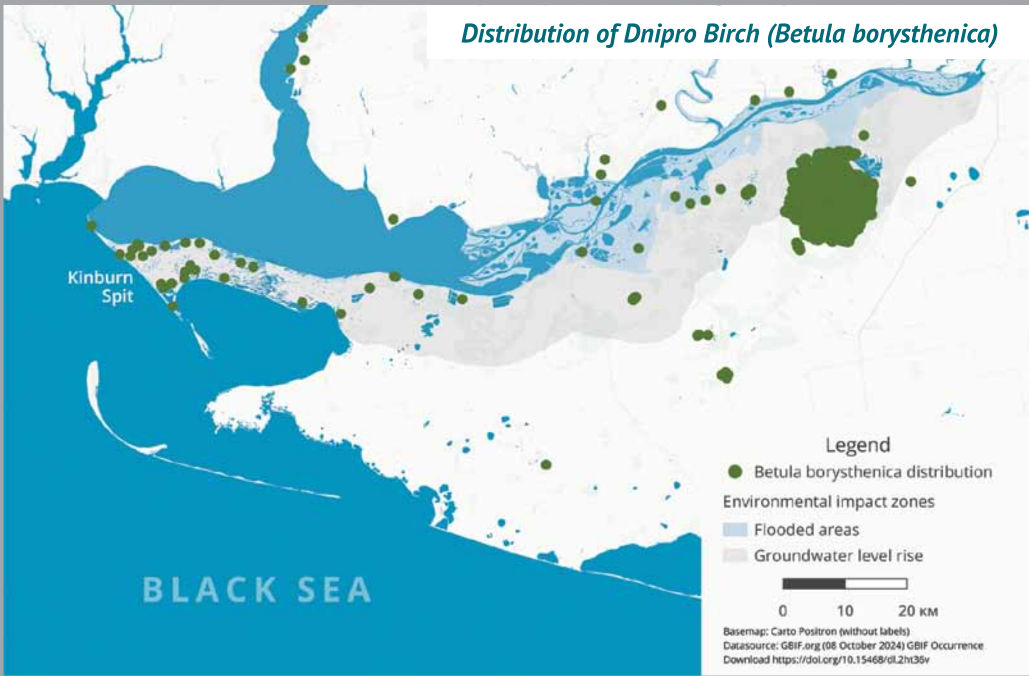
Excessive flooding may also have caused the loss of populations of rare meadow plant species, particularly orchids, including Buh orchid (*Anacamptis coriophora*), variegated orchid (*Anacamptis picta*), marsh orchid (*Anacamptis palustris*), early marsh orchid (*Dactylorhiza incarnata*), and marsh helleborine (*Epipactis palustris*), all of which are listed in the Red Data Book of Ukraine[185].

Similarly to plants, flooding may also have had a devastating impact on populations of local fungi and lichens adapted to arid conditions. It is likely that the flooding destroyed the only known population of a lichen species first described in 2021. It was discovered during an expedition of the Eurasian Dry Grassland Group in the "Sagy"Landscape Wildlife Reserve. In 2022, its status as a distinct species was confirmed by molecular genetic studies, and it was given the provisional name Ukrainian circinaria (*Circinaria ucrainica*)[68]. Only a year later, however, the site was flooded.

Because water spread rapidly through the soil horizons, vast expanses of dry sandy habitats with their characteristic unique vegetation quickly became waterlogged. Exceptionally high groundwater levels persisted in this area for several months. Consequently, approximately 11,000 ha of planted forests died[107], and natural forests and steppe vegetation also probably underwent significant changes. These changes involved not only altered environmental conditions for native vegetation but also created new opportunities for the spread of invasive species. This posed a threat to the remaining relict birch and oak forests, including some of the largest oak trees in Kherson Region, located in the Zburivske Forestry near the bank of the Dnipro River. These oaks are remnants of the legendary Hylaea described by Herodotus. Most of them had the status of protected natural monuments.

Particular concern also surrounds the condition of the Dnipro birch forests, which are included in the Green Book of Ukraine. These forests are formed by the subendemic Dnipro birch (*Betula borysthenica*), a plant species listed in the Red Data Book of Ukraine.

Distribution of Dnipro Birch (Betula borysthenica)



Typical Habitat of Dnipro Birch (Betula borysthenica) on the Sands of Left-bank Kherson Region (photo by I. Moisiienko)

Under natural conditions, these forests occur as small groves surrounding mires and lakes, in places where groundwater lies very close to the surface (0.5-2 m). Even in years with only slightly elevated groundwater levels, widespread waterlogging and mortality of Dnipro birch have been observed. It is therefore expected that the exceptional flooding caused by the destruction of the Kakhovka HPP dam resulted in extensive waterlogging and mortality of this rare plant species. Future rises in groundwater levels may expand the area affected by flooding by a further 15,000-20,000 ha.

→ Natural habitat types listed in Resolution No. 4 of the Bern Convention that were affected by the destruction of the Kakhovka H PP are presented in **Appendix 4**.

→ Plant, fungal, and lichen species listed in the Red Data Book of Ukraine that had previously been recorded within the zone of catastrophic flooding are presented in **Appendix 5**.

→ Plant communities included in the Green Book of Ukraine that had previously been recorded within the zone of catastrophic flooding are presented in **Appendix 6**.

Risk of the Spread of Invasive Plant Species

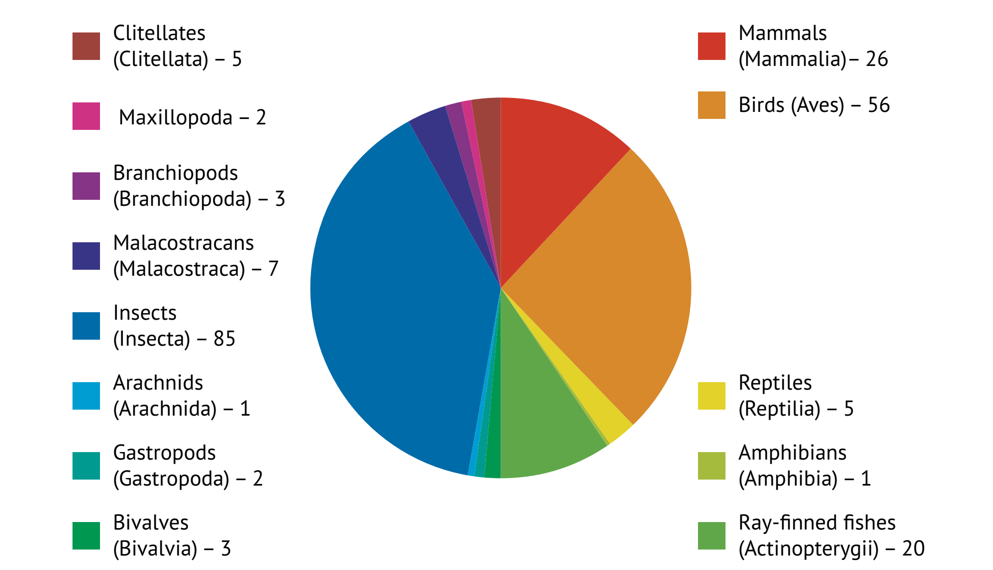
When assessing the consequences of the exposure of the Kakhovka Reservoir bed during the first days after the terrorist attack, some experts suggested that the drainage of the reservoir would lead to the rapid spread of invasive plant species. At the time, this assumption was based on the belief that the former reservoir was not surrounded by natural or semi-natural ecosystems with a sufficient seed reserve (seed bank) of native plants capable of providing a source of seeds for the newly exposed area. In addition, invasive species generally spread much more rapidly and aggressively colonize newly available habitats. The species expected to spread included the widespread invasive annuals Canadian fleabane (*Erigeron canadensis*), common ragweed (*Ambrosia artemisiifolia*), and giant goldenrod (*Solidago gigantea*), as well as perennial species, shrubs, and trees such as false indigo-bush (*Amorpha fruticosa*), Siberian elm (*Ulmus pumila*), black locust (*Robinia pseudoacacia*), Russian olive (*Elaeagnus angustifolia*), and others[185]. However, these predictions were not confirmed. On the contrary, the first botanical expeditions recorded a gradual increase in the proportion of native perennial species and a decline in invasive and annual species characteristic of the habitat types that had formed on the former reservoir bed (see the section **"Beginning of the Recovery of the Natural Ecosystems of Velykyi Luh"**).

Animals

Drawing conclusions about the consequences of the destruction of the Kakhovka Reservoir for wildlife is considerably more difficult than in the other sections of this study, although there is no doubt that these consequences are catastrophic. Many factors make it impossible to provide even approximate estimates of the losses suffered by individual animal groups, especially in quantitative terms.

Nevertheless, the available evidence allows absolute assessments of losses to the fauna of the flooded zone and the aquatic fauna of the former Kakhovka Reservoir, even in the absence of quantitative data. This is because:

- A large proportion of the fauna inhabiting the water column (fish and planktonic organisms) was carried downstream and was also exposed to pollution. At the same time, organisms from the Dnipro Delta and the estuaries were washed into the Black Sea, where they died because of salinity levels unsuitable for freshwater species[184]. This also applies to the planktonic larvae of benthic organisms[207], which may additionally have experienced larval abortion as a result of pollution and other stress factors.
- Virtually all organisms inhabiting the bottom of the drained area (molluscs, crustaceans, and various groups of worms) perished.
- Part of the benthic fauna within the flooded zone was affected by the cumulative stress of pollution and siltation and, in some areas, by abrupt changes in temperature, salinity, or oxygen content, resulting in the mass mortality of certain species and a general deterioration of environmental conditions.



Rare Animal Species Threatened by the Kakhovka Disaster

- Most terrestrial non-flying animals perished in the floodwaters. Those inhabiting reed beds and other dense vegetation were carried into the sea on floating islands of vegetation torn away by the flood.

Although these assessments are likely to be close to reality, they cannot be supported by quantitative estimates because no biodiversity monitoring data were available before the events of 2023. Currently, it is possible to speak with confidence about threats to, and substantial declines in the abundance of, most animal species within the area affected by the disaster, but not about species extinctions. At this stage, it is possible only to identify species that may be at risk of disappearing.

At least 249 species listed in the Red Data Book of Ukraine have been recorded within the affected areas during different seasons and in different years. The overwhelming majority of these species were affected by the flooding, while only a small number were affected in the other impact zones.

→ Animal species listed in the Red Data Book of Ukraine and previously recorded within the zone of catastrophic flooding are presented in **Appendix 7**.

Invertebrates

A large proportion of the organisms inhabiting freshwater ecosystems live in the littoral zone and within the bottom mud or sand of shallow waters. This distinctive habitat on the bed of the former reservoir underwent fundamental transformation.

Most organisms characteristic of these specific conditions have no mechanisms for surviving desiccation other than burrowing into mud or sand. It is therefore evident that many benthic organisms were either carried away by the current together with the riparian vegetation of the delta, died as the reservoir dried out, or were affected by the deterioration of water quality. The sediments transported by the current were deposited in the Lower Dnipro and in the bottom brackish-water zone of the Dnipro-Buh Estuary, creating atypical conditions both for the native fauna and for the animals transported with the vegetation and floodwaters.

Freshwater Invertebrates

Together with the freshwater discharged into the sea, much larger numbers of riverine planktonic organisms than under normal conditions were also carried into marine waters. Thus, on 9 June 2023, an outbreak of the cladoceran (*water flea*) *Podonevadne trigona* (27,400 individuals/m^3) was recorded off the coast of Odesa Region[190], and on 11 June an outbreak of the larvae of the zebra mussel *Dreissena polymorpha* was recorded. Both species are characteristic of the freshwater and brackish waters of the Dnipro River[184].

As for the benthic fauna of the Lower Dnipro and the Dnipro-Buh Estuary, it remains unknown to what extent bottom sediments were washed away before this area became a site of deposition for sediments transported from the reservoir. This zone is distinguished by a high diversity of rare and endemic species.

Not only rare species are important, but all freshwater invertebrates, as they perform numerous essential ecological functions in freshwater ecosystems: they decompose dead organic matter, filter the water, and provide a food resource for fish, amphibians, and birds. According to UNEP[107, p. 21], sediments deposited within the flooded zone covered approximately 31,000 ha, of which 12,000 ha consisted of coarse sediment fractions. At present, quantitative estimates of losses are available only for certain groups of benthic invertebrates. This is particularly true for zebra mussels of the family Dreissenidae (*Dreissena polymorpha* and *Dreissena bugensis*), which constituted the main component of the animal biomass of the Kakhovka Reservoir. Before the destruction of the dam, the biomass of these mussels ranged from several grams to several kilograms per square meter of the reservoir bottom, while locally it reached several tens of kilograms per square meter[128]. The so-called "zebra mussel beds", where biomass was highest, were located mainly at depths of 2-6 m, and all of them perished when the reservoir was drained[128].

Protected Species

A number of benthic aquatic invertebrates are listed in the Red Data Book of Ukraine. Some of these are narrow-range endemic species, while the populations of others are endemic to Ukraine.

Most belong to very rare and poorly studied animal groups, known only from isolated records in the past, making it extremely difficult at present to predict the impact of the disaster on their populations (for the complete list of species, see **Appendix 7**).

<u>Maxillopoda</u>. Two species have been recorded within the zone affected by the destruction of the Kakhovka HPP dam: *Colpocyclops longispinosus* and *Colpocyclops dulcis*, both inhabitants of estuarine waters.

Zebra Mussel Colonies on the Bed of the Former Reservoir

In the future, the deposits of dead zebra mussels will play an important role in determining possible future uses of this area. On the one hand, these mussels were highly efficient water filter feeders (1 kg of zebra mussels can filter more than one ton of water per day). On the other hand, they accumulated pollutants within their tissues, which may be released over time if a new reservoir is created[140]. In addition, their shells form extensive colonies that may cover areas of tens of hectares, potentially creating a physical obstacle to the future use of the former reservoir bed.

Colonies of Dreissenid Mussels on the Reservoir Bottom and on Flooded Trees (photos by S. Skoryk and I. Moisiienko, respectively, 2023)

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Branchiopoda. Three species are known from the affected area (*Branchinecta orientalis*, *Branchinectella media*, and *Tanymastix stagnalis*), all characteristic of the water bodies of the sandy terraces that were flooded.

Malacostraca. Populations of six species listed in the Red Data Book of Ukraine have been recorded within the affected area. These species are characteristic of both the Dnipro–Buh Estuary and the floodplains of the Lower Dnipro. Of particular importance are *Lanceogammarus andrussowi*[52] and *Shablogammarus shablensis*[43], both endemic to the Ponto-Caspian region, as well as *Pontastacus pachypus* – the rarest crayfish species in Europe, whose entire population known outside the Caspian Sea basin is concentrated within the disaster area.

Gastropoda. The Red Data Book of Ukraine includes *Laevicaspia lincta*[44] and *Clathrocaspia knipowitschii*[45], both characteristic of the floodplains of the Lower Dnipro and several other areas of the Northern Black Sea region.

Bivalvia. Three species listed in the Red Data Book of Ukraine are known from the affected area: *Hypanis plicata relicta*[47], Adacna fragilis (listed in the Red Data Book of Ukraine as *Hypanis laeviuscula*[103]), and *Anodonta cygnea*[46]. Recent records of *Hypanis plicata relicta* are known only from the Dnipro Estuary, making this species a priority target for surveys following the deoccupation of the territory.

Clitellata. Three rare species of this group – *Hirudo verbana*, *Archaeobdella esmonti*, and *Trocheta danastrica* – are characteristic of the floodplains of the Lower Dnipro.

Marine Invertebrates

From June to mid-July, mass mortality of Black Sea and Mediterranean mussels was recorded in the Black Sea at depths of up to 3 m[184], corresponding to the zone affected by freshwater inflow. Under unfavorable conditions, these mussels normally close their valves and survive until conditions improve. In this case, however, the adverse conditions persisted for an extended period. As a result of the wedge of warm, desalinated water (salinity 8‰) discharged into the sea from the Dnipro River, approximately 3,680 tons of mussels died in the northwestern Black Sea[184]. Most of the dead individuals exceeded 20 mm in length, indicating the loss of the most reproductively valuable part of the population.

At the same time, meiobenthic organisms (e.g. nematodes) and detritivores feeding on decomposing organic matter proved resistant to these stressful conditions[121]. As a result, the abundance of detritivorous and herbivorous-detritivorous invertebrates increased by 660% and 1,400%, respectively, compared with pre-disaster levels[184]. This was due to the large volume of organic matter that served as a food resource during their reproductive period[184].

Within the area affected by the disaster, there are also risks to a number of planktonic and neustonic species of small crustaceans included in the Red Data Book of Ukraine. These species inhabit the surface layers of the open sea, into which the desalinated and polluted waters were displaced from the coast following wind-driven offshore transport.

Terrestrial Invertebrates

Within the flooded zone, insects represent the most species-rich group of animals. Although most species are associated with terrestrial habitats, some groups also depend on aquatic environments for larval development.

The area affected by the terrorist attack on the Kakhovka HPP includes habitats supporting a total of 84 insect species rare in Ukraine (**Appendix 7**). Most are characteristic of steppe and sandy habitats. The flooding affected the only known locality in Ukraine of the rare ant *Liometopum microcephalum* and most known localities of *Tapinoma kinburni*[53]. The islands inhabited by *Liometopum microcephalum* were among the first to be struck by the floodwaters. It is therefore reasonable to conclude that this species became extinct in Ukraine during the first hours after the breach of the Kakhovka HPP dam.

Fish

Fish of the Dnipro River

One of the most visible consequences of the destruction of the Kakhovka HPP dam was the mortality of large numbers of freshwater fish, including juveniles, inhabiting the Kakhovka Reservoir and the floodplains of the Lower Dnipro. In particular, many fish became trapped as the reservoir water level declined and numerous isolated, non-draining water bodies were formed. Water levels in these water bodies continued to fall as water filtered through the layer of bottom sediments. By the beginning of autumn 2023, five to eight large water bodies remained connected to the Dnipro River channel, 15-20 medium-sized and large water bodies that had lost their direct connection with the river, and a large number of isolated medium-sized and small water bodies[128]. In most of the smaller water bodies, the principal components of the aquatic ecosystem had probably already perished[128].

Formation of Isolated Water Bodies During the Decline in Water Level in the Kakhovka Reservoir (photo by M. Bronziuk)

Working under emergency conditions during active hostilities, staff of national nature parks and fisheries enterprises, together with volunteers and local residents, rescued fish by reconnecting isolated lakes with channels so that the fish could at least reach the main river channel instead of being left stranded on the drying bed[76]. In some cases, fish were even transported by hand back to the river.

At the time of the June 6 terrorist attack, between 39[80] and 54 species of fish inhabited the Kakhovka Reservoir, of which 20 were commercially important[80]

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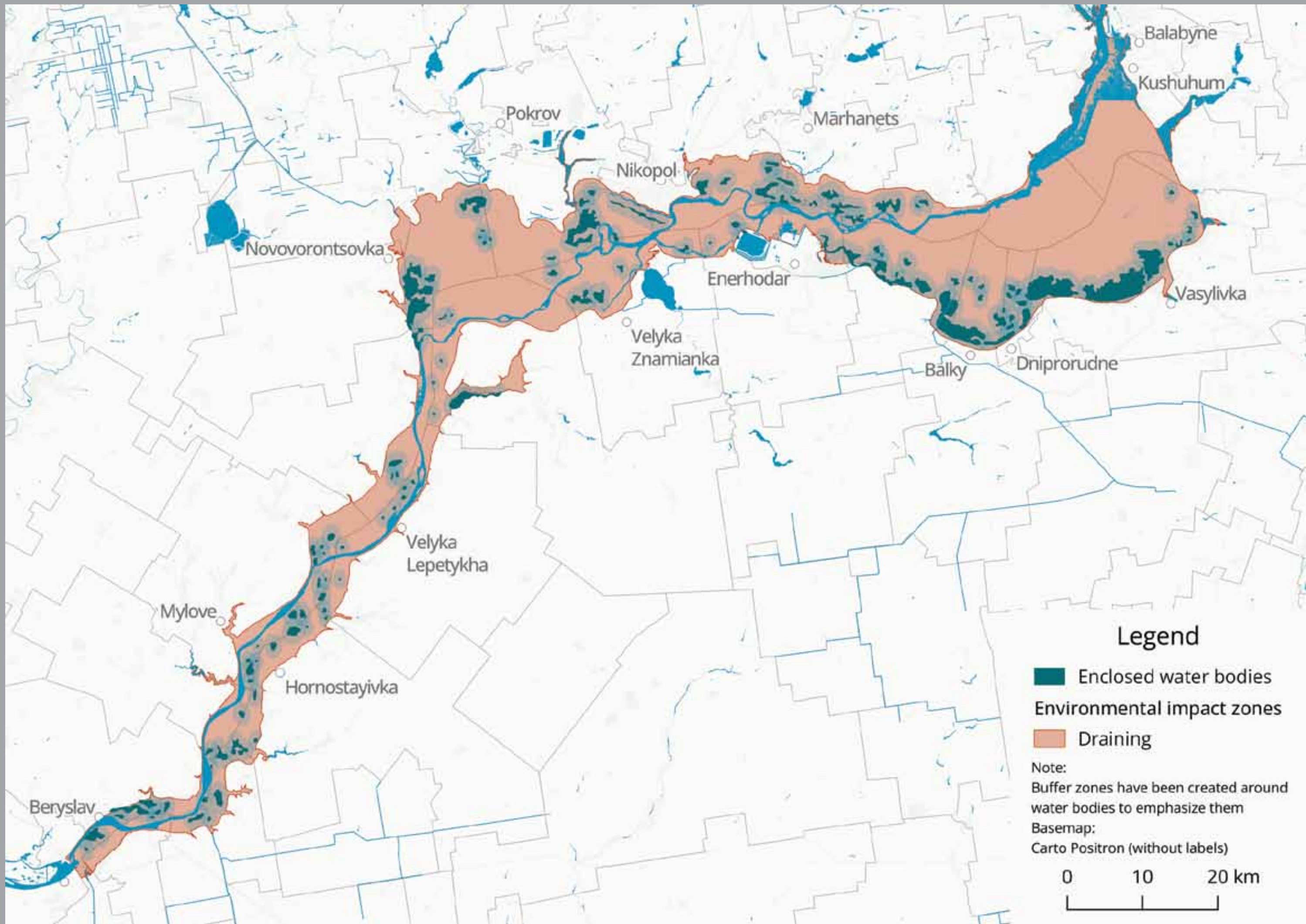
Fragmentation of the Reservoir Bed Resulting in the Formation of Isolated Water Bodies Acting as Ecological Traps, as of 30 June 2023[192]



(annual catches ranged between 2,000 and 3,000 tons). It should be noted, however, that throughout the existence of the Kakhovka HPP dam the reservoir was inaccessible to anadromous fish species. Therefore, many native species adapted to flowing-water conditions disappeared or experienced substantial population declines.

Fish Rescue Operation in the Kakhovka Reservoir (photo by M. Bronziuk[76])

Artillery strike by Russian forces on the evacuation point at Korabelna Square, 8 June 2023 (photo by S. Yurchenko[97])

At the time of the disaster, most fish species had already produced that year's juveniles, which perished during the catastrophe.

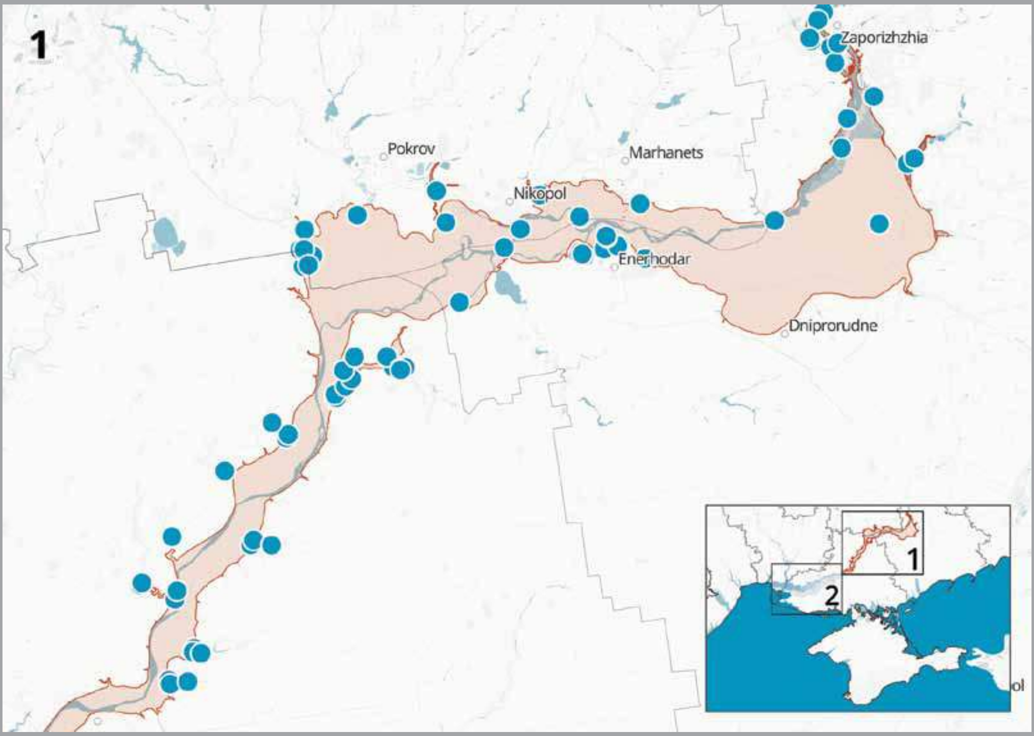
In Odesa Region, dead fish continued to wash ashore for a month after the disaster[184]. Among the freshwater fish found dead in the sea, the most abundant were silver carp (*Hypophthalmichthys* spp.), common roach (*Rutilus rutilus*), PRussian carp (*Carassius gibelio*), common carp (*Cyprinus carpio*), and pumpkinseed (*Lepomis gibbosus*).

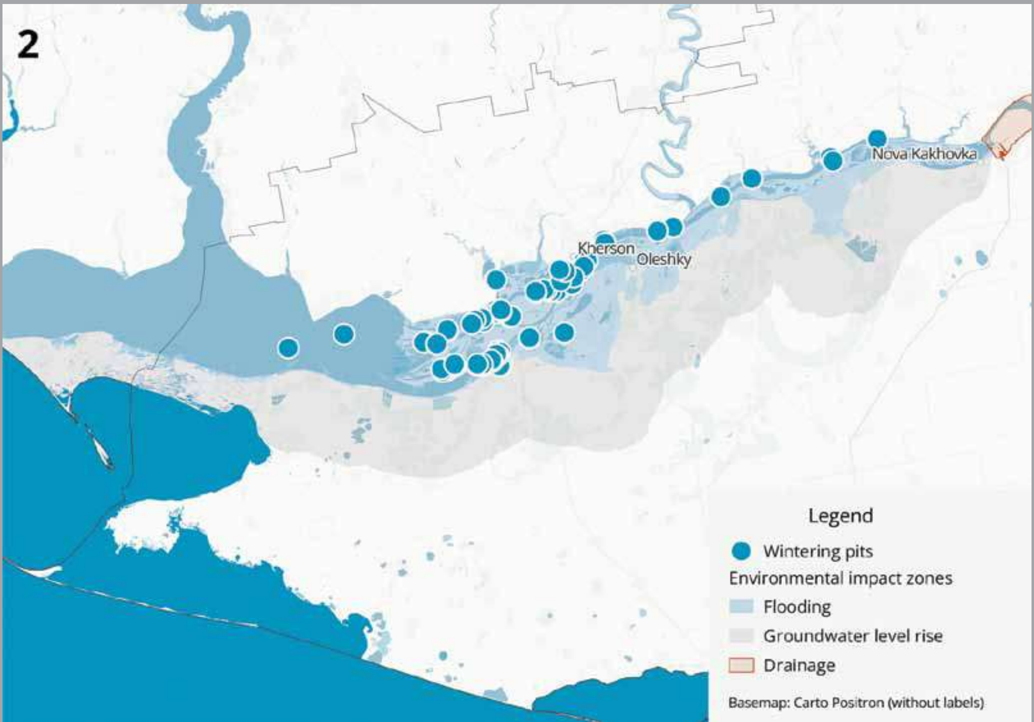
Populations of more than 60 fish species in the flooded zone (the Lower Dnipro) were also affected by the destruction of the dam. Many wintering pits were threatened with being filled by secondary deposits of silt[3, 57].

Other negative factors affecting the fish of the Lower Dnipro included the hydraulic shock caused by the powerful floodwave released from the Kakhovka Reservoir, as well as artillery shelling. As reported by numerous sources, Russian forces deliberately shelled the flooded areas and people during evacuation[185]. According to official estimates, approximately 11,400 tons of fish were killed[158]. Currently, however, the consequences for biodiversity remain difficult to assess, as comprehensive field studies are still impossible.

At the same time, these catastrophic changes have created opportunities for the return of anadromous fish species to this section of the river and for an increase in the proportion of native species. In the near future, spawning grounds on the shallow floodplain areas may also recover during spring floods. As early as 2024, the first records of sturgeon catches in the city of Zaporizhzhia had already been reported[85].

Wintering Pits within the Kakhovka Reservoir and the Area Flooded by Its Waters





Fish of the Black Sea

No studies of marine fish populations have been conducted to date because the marine area has remained inaccessible under martial law. Consequently, no reliable conclusions can yet be drawn regarding the impact of the disaster on these populations.

Populations of several fish species listed in the Red Data Book of Ukraine occurred within the area affected by the catastrophic discharge of water from the Kakhovka Reservoir. According to a widely accepted hypothesis[135], the Ukrainian population of *Sander marinus,* which inhabited the Dnipro-Buh Estuarine Area, was probably driven to extinction.

Amphibians and Reptiles

The drainage of the former reservoir undoubtedly resulted in the mortality of large numbers of amphibians dependent on aquatic environments. Both suitable breeding sites and the moisture necessary for their survival disappeared. The species most affected include the green frog complex (*Pelophylax esculentus* complex – *Pelophylax ridibundus* and *Pelophylax esculentus*), fire-bellied toad (*Bombina bombina*), eastern tree frog (*Hyla orientalis*), great crested newt (*Triturus cristatus*), and smooth newt (*Lissotriton vulgaris*).

The decline in moisture levels may also have negatively affected reptiles that are closely associated with aquatic habitats, including the European pond turtle (*Emys orbicularis*), grass snake (*Natrix natrix*), and dice snake (*Natrix tessellata*).

The present-day course of the Dnipro River does not coincide with the former shoreline of the reservoir, and in some places the two are separated by several kilometers. At the time of the reservoir's destruction, the former shoreline consisted of shallow waters formed along banks that had been eroded by reservoir waves. These areas were among the first to dry out, leaving amphibians and reptiles isolated within a narrow strip of riparian vegetation. Unlike reptiles, amphibians find it difficult to move across hot, dry sand. The only exceptions were the floodplains around Khortytsia Island and isolated bays of the reservoir, where access to water remained. However, most of the former reservoir bed lacked suitable habitats with aquatic and riparian vegetation for a prolonged period. It is therefore reasonable to assume that amphibians either perished or migrated downstream during this time.

The wetlands of Velykyi Luh will clearly provide more suitable conditions for amphibians than the narrow strip of habitats that formerly existed along the reservoir shoreline. Nevertheless, the recovery of amphibian populations will take time, as terrestrial animals will only be able to recolonize the former reservoir once suitable habitats have developed there.

Combined with the powerful current, flooding of the riparian areas downstream of the Kakhovka HPP dam effectively washed amphibians and reptiles into saline waters into the Black Sea, where they are unable to survive. Consequently, hundreds of dead Danube crested newts (*Triturus dobrogicus*), a species listed in the Red Data Book of Ukraine, were found along the coasts of Odesa Region and Romania. These individuals belonged to a relict population inhabiting the Dnipro Delta[112].

Rescue of Danube Crested Newts

Following the breach of the Kakhovka Reservoir dam, individual Danube crested newts were rescued by local residents of Odesa Region and staff of national nature parks[204]. At least 149 newts were saved. This represents only a very small fraction of the population that had inhabited the Lower Dnipro region[181]. After rehabilitation at Odesa Zoo, specialists from the Ukrainian Herpetological Society released the rescued animals back into the Dnipro River[34, 209]. There are also reports that some surviving animals were taken by local residents as pets, while others that had dried out in the sun after dying were collected as souvenirs commemorating this tragedy[181].

Dead Danube Crested Newts (Triturus dobrogicus) on a Beach in Odesa Region[203]

Rescued Danube Crested Newts Before Their Release into the Wild[34]

Large numbers of dice snakes (*Natrix tessellata*) and grass snakes (*Natrix natrix*) from Kherson Region were also washed ashore along the coast of Odesa Region, together with occasional individuals of the Sarmatian rat snake (*Elaphe sauromates*), a species listed in the Red Data Book of Ukraine. Dead European pond turtles (*Emys orbicularis*), marsh frogs (*Pelophylax ridibundus*), and edible frogs (*Pelophylax kl. esculentus*) were also recorded[185].

Protected Species

Among amphibians, only one species listed in the Red Data Book of Ukraine has been recorded within the area affected by the terrorist attack on the Kakhovka HPP dam – the Danube crested newt (*Triturus dobrogicus*). Among reptiles, four species listed in the Red Data Book of Ukraine occur within the affected area. All inhabit terrestrial habitats and, under natural conditions, are commonly found along the shoreline: European green lizard (*Lacerta viridis*), Sarmatian rat snake (*Elaphe sauromates*), Caspian whipsnake (*Dolichophis caspius*), and steppe viper (*Vipera renardi*).

In the case of the European green lizard, it is likely that not only adult individuals perished, but also shoreline egg-laying sites and burrows were destroyed, which may adversely affect the recovery of the population in the future.

All of the reptile species listed in the Red Data Book of Ukraine are characteristic of the rare steppe habitats and sands of the Lower Dnipro[74]. Among the species listed in Resolution No. 6 of the Bern Convention whose populations were affected are the fire-bellied toad (*Bombina bombina*), European pond turtle (*Emys orbicularis*), steppe viper (*Vipera renardi*), Sarmatian rat snake (*Elaphe sauromates*), and the Danube crested newt (*Triturus dobrogicus*), mentioned above.

Birds

Birds are the most mobile group of vertebrates and, potentially, suffered the least from the destruction of the Kakhovka Reservoir, as they are the only vertebrates capable of leaving areas that underwent catastrophic changes following the destruction of the dam. Naturally, this applies only to flying adults, since nestlings and eggs, which were present in most species at the time of the destruction of the dam, had no opportunity to escape.

The flooded area included important nesting sites for colonial wetland birds and riparian bird species. One such site was Kardashynske Mire in the Dnipro floodplain near the village of Kardashynka in Kherson Region. In particular, the Kardashynske Mire Wildlife Reserve supported breeding colonies of nine bird species that have been monitored over many years: pygmy cormorant (*Phalacrocorax pygmeus*), black-crowned night heron (*Nycticorax nycticorax*), glossy ibis (*Plegadis falcinellus*), ruddy shelduck (*Tadorna ferruginea*), squacco heron (*Ardeola ralloides*), purple heron (*Ardea purpurea*), grey heron (*Ardea cinerea*), great egret (*Ardea alba*), and little egret (*Egretta garzetta*)[50].

The floodplains in the lower part of the Dnipro Delta also served as important breeding habitats for various duck species and other wetland birds. The destruction of the Kakhovka HPP dam occurred during the breeding season, when most birds had nestlings. In particular, it may have resulted in the loss of young from the small local population of common goldeneye (*Bucephala clangula*)[65, 115]. Most species probably had no opportunity to breed again, as migration begins as early as August. It is therefore reasonable to conclude that the 2023 generation was lost.

The Role of the Dnipro Delta During Seasonal Bird Migration

For migratory birds, the Dnipro Delta plays a special role during seasonal migrations. It is here that the river section of their migration route ends, after which they continue their journey across the sea. Therefore, at least for some species[39], the delta serves as an important stopover and feeding area.

Another important factor is the persistent fires in the floodplains of the Dnipro Delta, caused by a combination of factors associated with the frontline passing through the area. Together with the consequences of the destruction of the Kakhovka HPP dam, these fires make the area less suitable for birds to rest before their long migration. Nevertheless, observations from 2024 indicate that birds continue to stop in large numbers in the Dnipro Delta[16].

16 Personal communication from members of the Special Operations Forces stationed on Travnevyi Island in the Dnipro-Buh Estuary.

European roe deer drifting on a floating vegetation mat comes ashore near Odesa[123].

European fallow deer (Dama dama) near Odesa (introduced species)[77].

Mammals

The consequences of the destruction of the Kakhovka HPP for mammals were distributed very unevenly. They were much less severe within the drained reservoir area but extremely significant in the zone of catastrophic flooding. The open waters of the reservoir were of little importance to mammals, as water bodies of this size do not constitute suitable habitats for this group of animals.

The situation was entirely different in the flooded zone, which was inhabited by numerous terrestrial mammal species. These became one of the groups most severely affected by the disaster. Most of the flooded area consists of an archipelago of islands in the Dnipro Delta. As a result, even large predators and ungulates that would normally escape by fleeing were trapped on the islands. Some species that are strong swimmers, such as beavers, muskrats, and otters, managed to survive for several days in the open sea and reached the coast of Odesa Region alive[213]. However, these were exceptional cases. It is therefore likely that, in addition to pollutants and debris, the carcasses of many animals drifted in the marine waters. Evidence of this remains fragmentary[77], largely because the coastline has been inaccessible for field research.

Protected Species

Among the mammal species protected in Ukraine, only occasional records of the Eurasian beaver (*Castor fiber*) and the Eurasian otter (*Lutra lutra*) are known from the former Kakhovka Reservoir, mainly in the floodplains near Khortytsia Island.

Overall, 26 mammal species listed in the Red Data Book of Ukraine have been recorded within the area affected by the destruction of the Kakhovka HPP dam. Of these, 23 inhabit primarily terrestrial habitats, while only three are aquatic marine species (cetaceans). The overwhelming majority are characteristic of the steppe habitats and sands of the Lower Dnipro region. Among terrestrial mammals, three species appear to be particularly vulnerable: the sandy mole-rat (*Spalax arenarius*)[39], Nordmann's birch mouse (*Sicista lorigera*), and Falz-Fein's three-toed jerboa (*Stylodipus telum falzfeini*)[51]. The sandy mole-rat is an endemic species occurring exclusively in the Lower Dnipro region, ranging from

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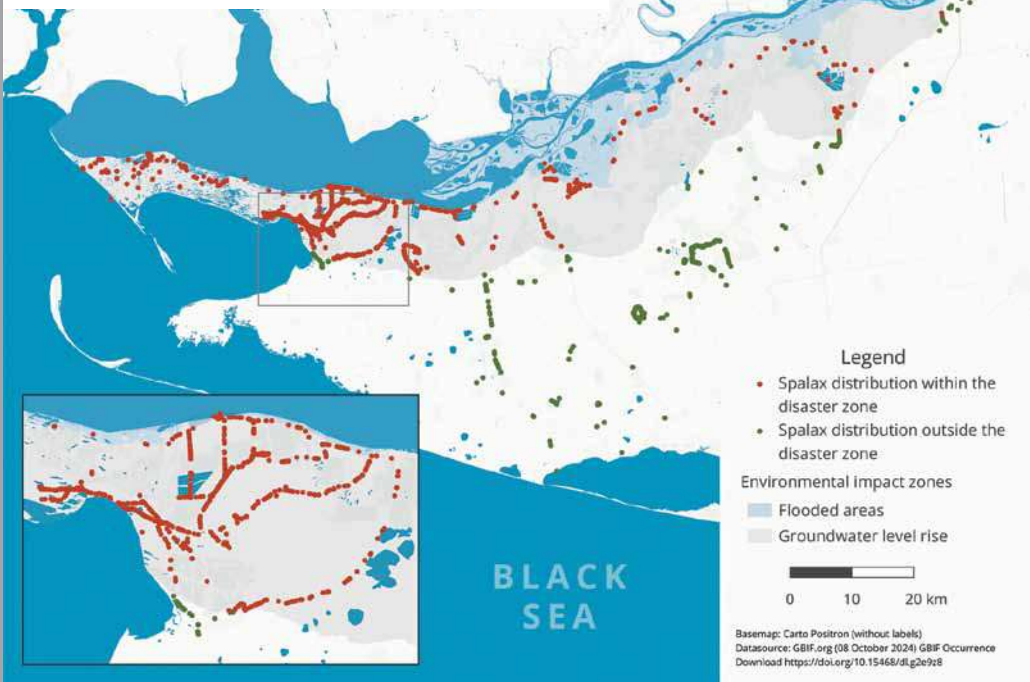
the city of Kakhovka in the north to the Kinburn Peninsula and the village of Lazurne on Dzharylhach Bay in the south. There is a high probability that populations occurring along the banks of the Dnipro River (near Krynky, Oleshky, Hola Prystan, and the villages of Stara Zburivka, Rybalche, and Heroiske) became extinct. There is, however, hope that populations in the southeastern part of the species' range were less severely affected. Mole-rat mounds are visible on some aerial and satellite images, indicating that at least part of the population survived the flooding. The Lower Dnipro Sands constituted the most important part of the range of Nordmann's birch mouse, supporting up to 70% of the known global population. The population in the Sagy Tract[217] lay directly within the flood-risk zone. Other populations, including those in the Black Sea Biosphere Reserve and Oleshkivski Pisky National Nature Park, were outside the area of direct flooding but may have been affected by the rise in groundwater levels. Falz-Fein's three-toed jerboa is an endemic subspecies that also occurs exclusively in the Lower Dnipro Sands. However, unlike the sandy mole-rat and Nordmann's birch mouse, which are associated with lower-lying and more humid habitats, this jerboa inhabits the driest and highest sand dunes. It can therefore be considered the least affected of the region's endemic mammals following the destruction of the Kakhovka HPP dam.

All of these species are globally threatened, and the sandy mole-rat is found nowhere else except within the flooded area and the adjacent zone affected by the rise in groundwater levels. Until hostilities have ended, it is virtually impossible to assess the actual losses of rare species populations. Of greatest importance will be assessing the condition of populations inhabiting sandy areas, where the rise

Distribution of the Sandy Mole-rat



in groundwater levels and flooding of sandy steppes may have caused both the direct mortality of burrowing mammals and substantial degradation of their habitats.

In 2024, a new edition of the European Red List was published under the auspices of the International Union for Conservation of Nature (IUCN). For the first time, this authoritative publication identifies the consequences of the war and the destruction of the Kakhovka HPP dam as threats to the survival of six mammal species. In particular, the sandy mole-rat (classified as *Endangered*) and Nordmann's birch mouse (classified as *Critically Endangered*) have not only been assigned a higher threat category, but have also become the first species whose decline has been officially associated with the war and the destruction of the Kakhovka HPP dam[105].

Natural Habitats

Southern Ukraine is rich in natural habitats that are unique on a European scale, including those listed in Resolution No. 4 of the Bern Convention. To ensure their international protection, Emerald Network sites were established. Virtually the entire flooded area, as well as the territory of the former reservoir, formed part of this network. Overall, the Kakhovka disaster affected two Emerald Network sites upstream of the dam and eleven downstream. Together, these sites protected 21 valuable natural habitat types, ranging from steppes and forests to aquatic ecosystems[185].

When the Kakhovka Reservoir still existed as a continuous water body, these unique habitats occupied only a small proportion of its total area – 2.5%[17], or approximately 53 km². They consisted primarily of aquatic and riparian habitats: former Dnipro floodplain landscapes that remained above the reservoir water level, as well as shallow-water floodplain habitats.

With the loss of the reservoir, a substantial proportion of the aquatic ecosystems disappeared. At the same time, however, the area of riparian wetlands increased considerably as the floodplain was restored, with its numerous channels and distributaries. As a result, the length of the shoreline has increased, together with the extent of riparian habitats.

By the end of 2024, unique wetland habitats and shallow waters occupied approximately the same area as before the reservoir was created[131] – about 60% of its former extent. The natural hydrological regime of these habitats is being restored. As early as the year following the disaster, the area was flooded during the spring flood[90] (see the section **Beginning of the Recovery of the Natural Ecosystems of Velykyi Luh**).

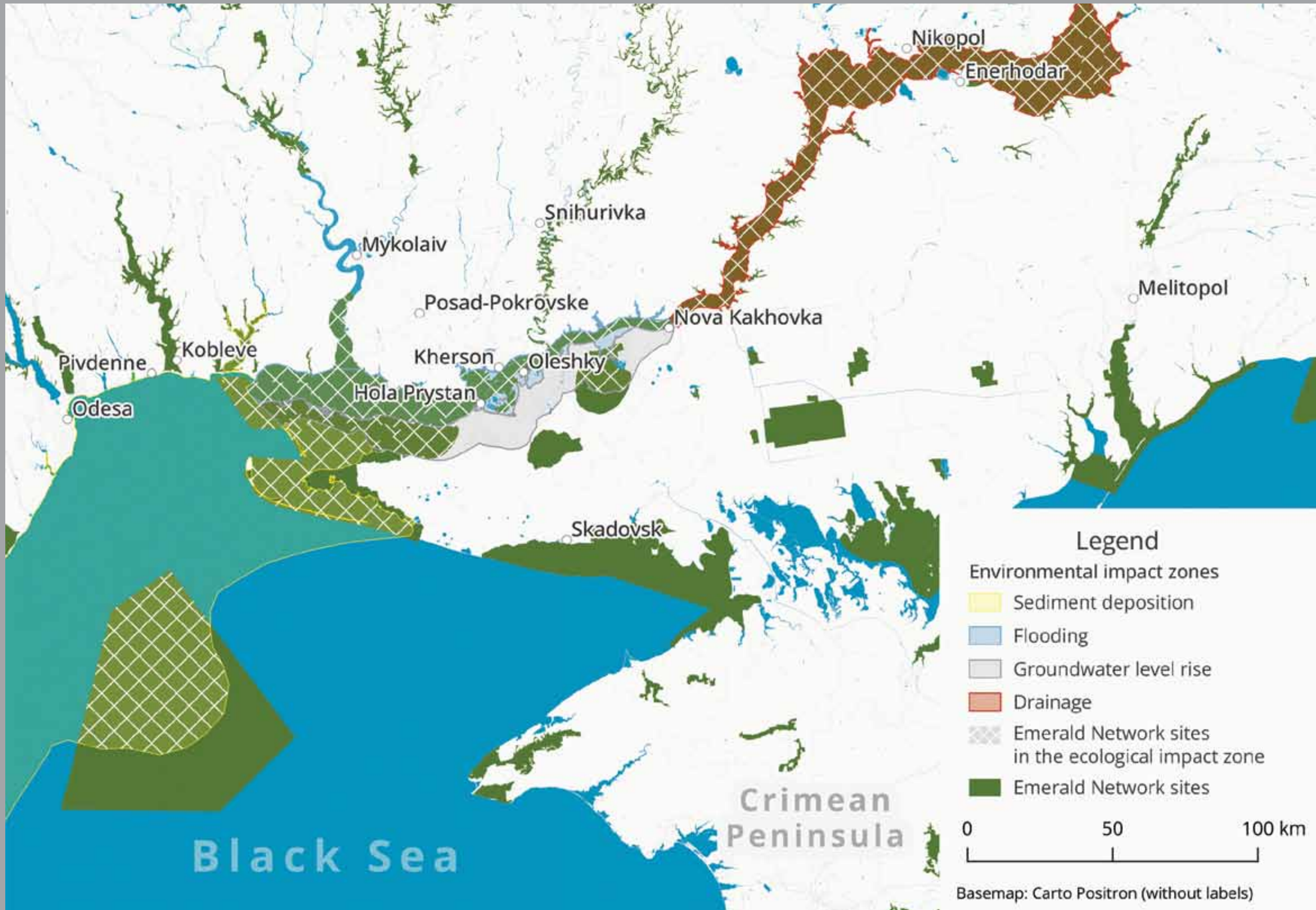
Thus, the restoration of the natural topography of the Dnipro Valley will increase the area of habitats of international importance in the zone upstream of the former HPP dam.

Within the zone of catastrophic flooding downstream of the dam, however, the situation is different. Much of the vegetation associated with aquatic habitats was washed into the sea by the floodwaters, while terrestrial and freshwater habitats were affected by the contaminated silt carried by the flood (see the section **Soils and sediments**).

→ Types of natural habitats listed in Resolution No. 4 of the Bern Convention that were affected by the destruction of the Kakhovka HPP dam are presented in **Appendix 4**.

17 Excluding habitats along the shoreline, the extent of which changes due to shoreline erosion.

Emerald Network Sites within the Area Affected by the Disaster



PROTECTED AREAS

Ukraine protects areas of exceptional natural value that have been designated at both the national and international levels. Protected areas of international importance are established under international conventions. In Ukraine, these include Emerald Network sites (Bern Convention), Wetlands of International Importance (Ramsar Convention), and biosphere reserves (UNESCO Man and the Biosphere (MAB) Programme).

Within the ***drained area***, both locally and nationally designated protected areas, as well as internationally recognized sites, were affected. Estimating their total area is difficult because many of these areas have multiple protection designations and overlap spatially. In addition, the Khortytsia Historical and Cultural Reserve, which also contributes to the conservation of natural ecosystems, is not part of Ukraine's protected areas network.

Overlap of Protected Area Boundaries

Velykyi Luh National Nature Park includes Panai Regional Landscape Park and three wildlife reserves. At the same time, the national park itself is designated as an Emerald Network site, while parts of it are also recognized as Wetlands of International Importance under the Ramsar Convention, namely Archipelago Velyki and Mali Kuchuhury and Sim Maiakiv Floodplain. If all of these protected areas are shown on a single map, they collectively encompass almost all natural areas within the Dnipro Valley, adjacent coastal areas, and shallow marine waters – from the city of Zaporizhzhia to the Dnipro-Buh Estuary.

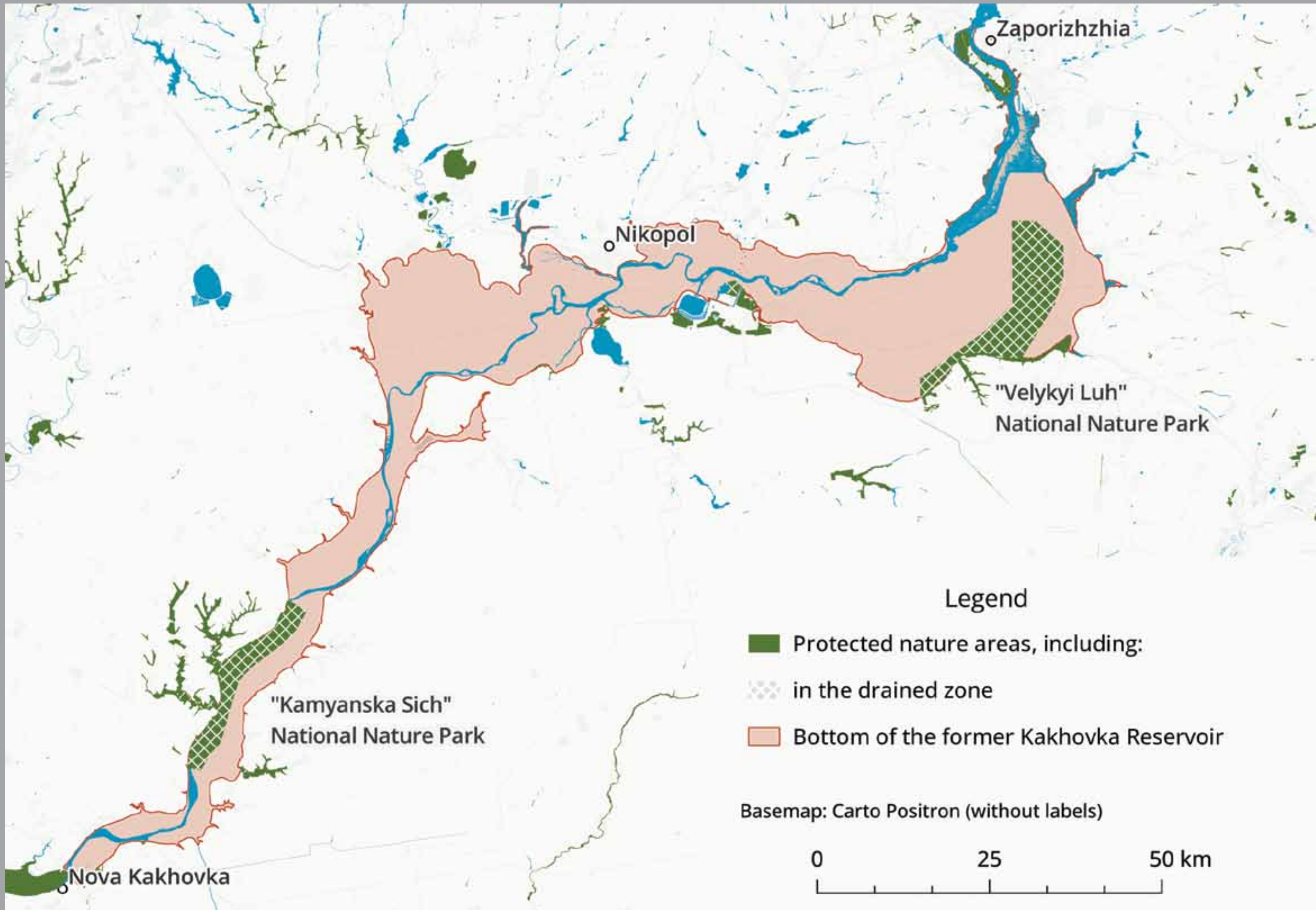
Protected areas affected by the drainage of the reservoir were established while the Kakhovka Reservoir still existed. Its water area was included within their protected boundaries, not so much to conserve the open waters of the reservoir itself as to protect its shallow waters, where floodplain forests, wetlands, meadows, ravines, sandy and true steppe slopes of the Dnipro, rock outcrops, and other natural features occurred.

The Kakhovka Reservoir occupied 44% of the area of Velykyi Luh National Nature Park. It connected the shoreline with the sandy islands of the Archipelago Velyki and Mali Kuchuhury. Today, wetlands are being restored there, and they may ultimately prove to be of greater value for biodiversity.

Within Kamianska Sich National Nature Park, the reservoir, together with its bays, accounted for more than 65% of the park's area. The primary purpose of estab-

Kamianska Sich National Nature Park Immediately After the Draining of the Reservoir (photo by S. Skoryk[107])

Protected Areas Affected by the Draining of the Reservoir



lishing the park was to conserve the steppe ecosystems of the right bank of the Dnipro rather than the reservoir itself, although the reservoir was undoubtedly an important component of the landscape at that time.

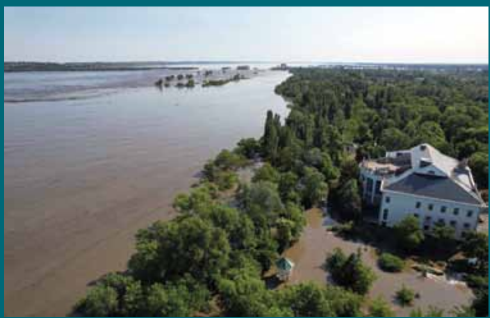
Among the internationally designated protected areas within the drained zone are two Emerald Network sites (Kakhovske Reservoir UA0000106 and Velykyi Luh National Nature Park UA0000037) and two Wetlands of International Importance: Archipelago Velyki and Mali Kuchugury and Sim Maiakiv Floodplain.

The Wetlands of International Importance Archipelago Velyki and Mali Kuchugury and Sim Maiakiv Floodplain formed a unique complex providing favorable conditions for migratory birds across southern Ukraine. Numerous bays and inland lakes with extensive reed beds provided shelter, while abundant food resources enabled birds to gather in large numbers and remain within this relatively small wetland complex for extended periods.

Overall, **protected areas of national and international importance account for more than 80% of the total flooded area, including UNESCO biosphere reserves**.

According to expert estimates, 47 protected areas were affected to varying degrees by the flooding. These included the Black Sea Biosphere Reserve (protected since 1927 and designated as a UNESCO Biosphere Reserve)[18], four national nature parks, and Kinburn Spit Regional Landscape Park. Some protected areas were affected by the rise in groundwater levels rather than direct flooding, including the "Sagy" Landscape Wildlife Reserve, Korsunskyi Forest Wildlife Reserve, Shaby Wildlife Reserve, and others.

Downstream of the dam, protected areas in the marine waters and in the valleys of the Inhulets and Southern Buh rivers were also affected. These included the nationally important wildlife reserves Zernov's Phyllophora Field and Snake Island, as well as Tuzlivski Lymany National Nature Park (located approximately 220 km and 160 km from the Dnipro-Buh Estuary, respectively).

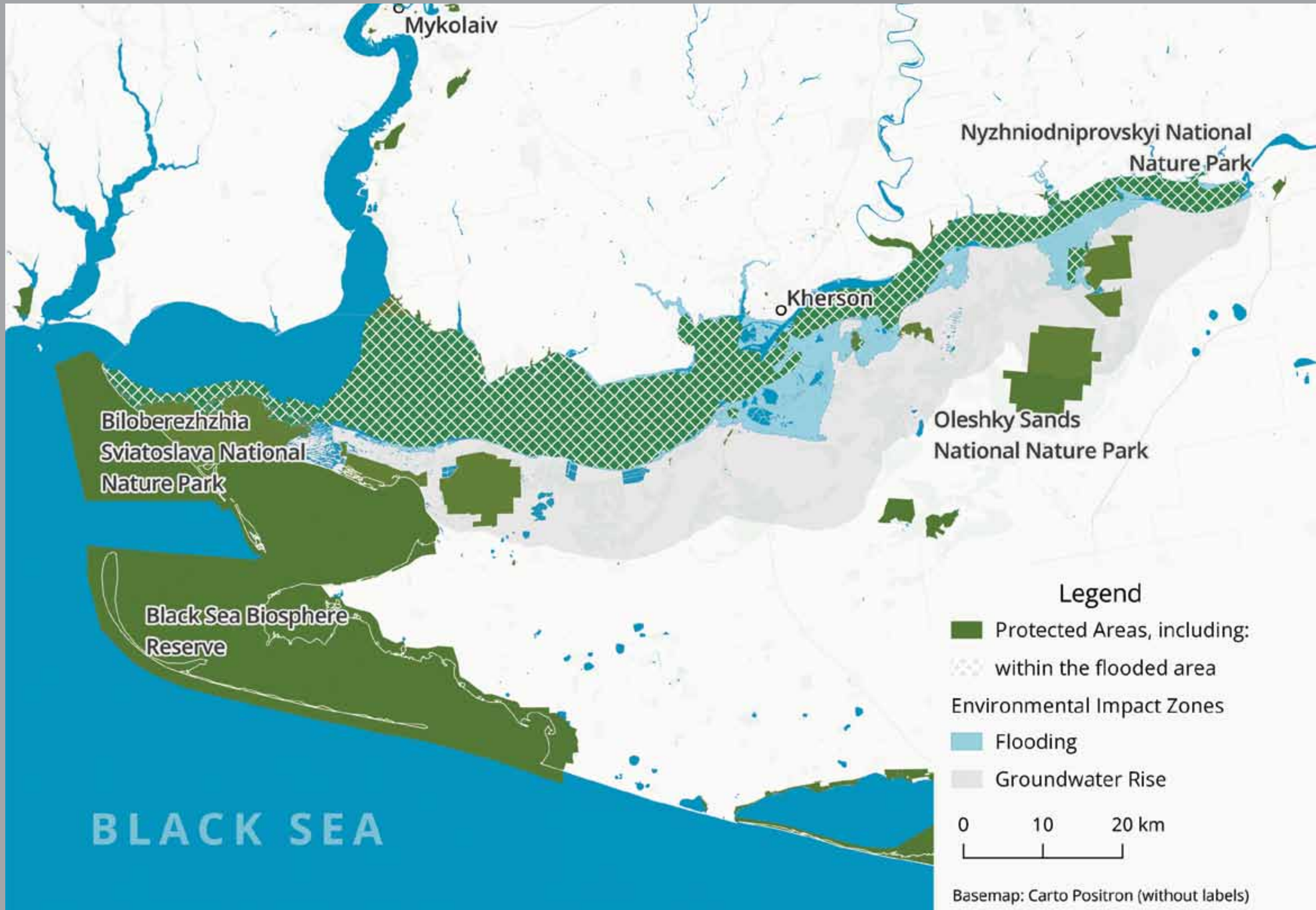


Flooded Area of Lower Dnipro National Nature Park (photo courtesy of the archive of Lower Dnipro National Nature Park)

The area most severely affected by the flooding was Lower Dnipro National Nature Park, where the water level rose by 3.5 m and remained at that level for more than ten days. The park was established to protect the Dnipro Delta as one of the most valuable floodplain and riparian complexes in Europe, which was completely flooded by the waters of the Kakhovka Reservoir[188].

18 The administrative headquarters of the Black Sea Biosphere Reserve was also located within the flooded area. The floodwaters destroyed administrative buildings and a museum. As a result, in addition to the damage to the natural heritage, the scientific legacy of a century of research was lost forever, including field notebooks, observation records, the collections of the environmental education center, herbarium collections, photographic archives, educational materials, and a library containing 3,480 volumes (authors' own information).

Protected Areas Affected by the Flooding



Oleshky Sands National Nature Park was also affected by the flooding. Its territory comprises a landscape unique in Europe, consisting of sandy steppes, sand dunes, and groves of broadleaved forest in the depress ions between the dunes. In June 2023 this complex was threatened by rising groundwater levels (see the section **Environmental Consequences of the Destruction of the Kakhovka HPP. Biodiversity**). Biloberezhzhia Sviatoslava National Nature Park faced the same threat.

Important Bird Areas

An additional conservation designation is the inclusion of sites in the international network of Important Bird Areas (IBA). This inventory is maintained by BirdLife International[16]. Five IBAs are located within the former Kakhovka Reservoir: Knyazhe-Hryhorivka Village[17], Kajiry Village[9], Enerhodar[10], Vasylivka Village[11], and the Konka River Mouth[12]. Two additional IBAs are located within Lower Dnipro National Nature Park: the Dnipro Delta[13] and Kozats'ki Islands[14]. According to BirdLife International, these sites are important habitats for approximately 700,000 birds each year[15].

Areas Proposed for Protection

In addition to the existing protected areas, Ukraine had been working to expand its protected areas network. Within the flooded zone, 22 areas had been identified as priorities for future protection, each of which was of considerable importance for nature conservation in the region.

Active work was underway to establish the Dolyna Kurhaniv Landscape Wildlife Reserve[19] in Hola Prystan District, Kherson Region. This area represents a former channel of the Dnipro – a flat landscape that is periodically flooded by seawater during wind-driven storm surges. Such habitats are known internationally as salt marshes, because they are regularly flooded by saline seawater during tidal cycles. This phenomenon is unique in Ukraine, as the Black Sea does not experience regular tides.

Indirect Impacts

Protected areas located far from the Kakhovka Reservoir were also affected indirectly. For example, the operations of the Askania-Nova Biosphere Reserve, located in the southern part of Kherson Region, depended on irrigation water supplied from the Kakhovka Reservoir. Following the destruction of the dam, the reserve was forced to switch to groundwater extracted from artesian aquifers, the long-term availability of which cannot be assessed under the current conditions of occupation[138].

Most of the protected areas affected by the destruction of the Kakhovka HPP dam are also located within active combat zones. Consequently, these territories are subject to the cumulative impacts of the war[138] and the destruction of the Kakhovka HPP dam.

→ Protected areas affected upstream and downstream of the Kakhovka HPP dam are listed in **Appendix 1**.

19 Proposed area: 3,870 ha [186].

→ Proposed protected areas in Kherson Region affected by the destruction of the Kakhovka HPP dam are listed in **Appendix 2**.

→ Emerald Network sites affected upstream and downstream of the Kakhovka HPP dam are listed in **Appendix 3**.

SOILS AND SEDIMENTS

During its nearly 70 years of operation, the Kakhovka Reservoir accumulated a substantial volume of bottom sediments on its bed. The sediment layer averaged 17.6 cm in thickness, although its depth varied depending on the bottom topography and water movement. In some locations, the sediment deposits reached a thickness of up to 1 m.

Downstream Transport of Sediments

Currently, there is no reliable information on what proportion of the bottom sediments was washed away during the drainage of the reservoir and subsequently deposited on the flooded areas. It is known, however, that the slight differences in depth and the presence of the former hydrographic network, including the original river channel, caused water to drain rapidly from shallower areas towards deeper ones. This resulted in the sheet erosion of sediments into deeper depressions, channels, and distributaries, followed by their transport into the main channel of the Dnipro and further downstream to the river's lower reaches and the Black Sea. Another portion of the sediments accumulated more intensively within the wetland area in the eastern part of the former reservoir, where the largest isolated waterbody formed during the drainage of the reservoir. Sediments were also transported there by the moving water masses.

Contamination of the bottom sediments of the Kakhovka Reservoir has had adverse impacts not only on the area formerly occupied by the reservoir itself but also on the territories where these sediments were deposited as the water flowed out through the destroyed Kakhovka HPP dam. From the very first day after the dam's destruction, a distinct plume of sediment-laden water was visible along the main channel of the Dnipro, extending downstream along the navigation channel.

View of the Kakhovka Reservoir after the Water Receded in June 2023 (photo by Ukrinform[220])

As the force of the water flow and the extent of flooding gradually decreased, the concentration of suspended sediments and pollutants continued to increase[96]. At this stage, sediments that had accumulated on the bed of the Kakhovka Reservoir over decades, together with debris from destroyed infrastructure and waste disposal sites (including biological waste), became incorporated into the suspended load. Consequently, the most heavily contaminated deposits are likely to be the uppermost sediment layers – those deposited during the final stage of the flood.

As the flow slowed in the expanding Dnipro Delta, sediment began to settle and became visible after the water level receded. In some places, these deposits reached a thickness of up to 70 cm, for example on the flooded streets of the city of Kherson[86].

Downstream of the dam, the transported sediments altered local ecosystems. Upstream, the reservoir bed was exposed, and most of its surface became completely dry within just 17 days after the destruction of the Kakhovka HPP dam. Immediately after the water receded, the exposed bed was entirely devoid of vegetation. It was compared to a desert, while the Kakhovka disaster itself was likened to the situation in Salt Lake City, where the drying of the Great Salt Lake created a basin of "toxic dust"[78]. Concerns about the risk of dust storms were expressed by officials of the Ministry of Agrarian Policy and Food of Ukraine[177], the Ministry of Defence of Ukraine[221], the National Police of Ukraine[220], and experts from UNEP[109].

During the first days after the emptying of the Kakhovka Reservoir, desiccation cracks began to develop across the exposed bed, forming characteristic five- and six-sided polygons. The deepest recorded cracks reached 128 cm[73].

Desiccation Cracks on the Bed of the Former Reservoir

Primary cracks typically branched at right angles where the texture of the bottom sediments was heterogeneous. Secondary cracks curved and joined previously formed cracks at nearly right angles[41]. As a result, the entire drying surface became covered by a uniform network of cracks, dividing it into distinct polygonal plates.

In June 2023, the depth of cracks in the moist sediments ranged from 3 to 25 cm, while their width varied from 0.5 to 4 cm. Both depth and width increased towards the center of the former reservoir bed, where the sediment layer was thickest. The polygonal plates formed by the cracked sediments averaged 43 cm in width. During expeditions conducted by the Ukrainian Nature Conservation Group, experts observed that after 3.5 months the average depth and width of the cracks had increased approximately sevenfold, whereas the average width of the polygonal plates had decreased by only half. This pattern indicates intense desiccation of a dense, cohesive substrate under conditions of insufficient precipitation throughout the season.

Despite the cracked surface of the exposed reservoir bed and early predictions of desertification, the former reservoir is being naturally recolonized by vegetation. In areas where vegetation has not yet become established, the cracks facilitate soil formation by trapping windblown organic matter and plant debris, including leaves, twigs, and the remains and feces of detritivorous animals.

Desiccation Cracks on the Bed of the Kakhovka Reservoir, 19 October 2023 (photo by O. Khodosovtsev)

Soil Formation Processes Triggered by the Destruction of the Dam

Following the destruction of the reservoir and the downstream transport of a large proportion of its bottom sediments, intrazonal soils characteristic of river floodplains began to develop across the former reservoir bed. These soils are forming on a heterogeneous mixture of sandy, loamy sand, and silty bottom sediments, and their properties depend on the composition of the parent material, the morphology of the former reservoir bed, and the velocity of the water flow. Consequently, fluvial deposits (alluvium) are coarser in the upper part of the former reservoir, whereas further downstream, where flow velocity decreases, waterlogging processes become more pronounced[201]. The soil horizons are still poorly developed and consist primarily of layers of alluvial sediments differing in particle-size composition and organic matter content.

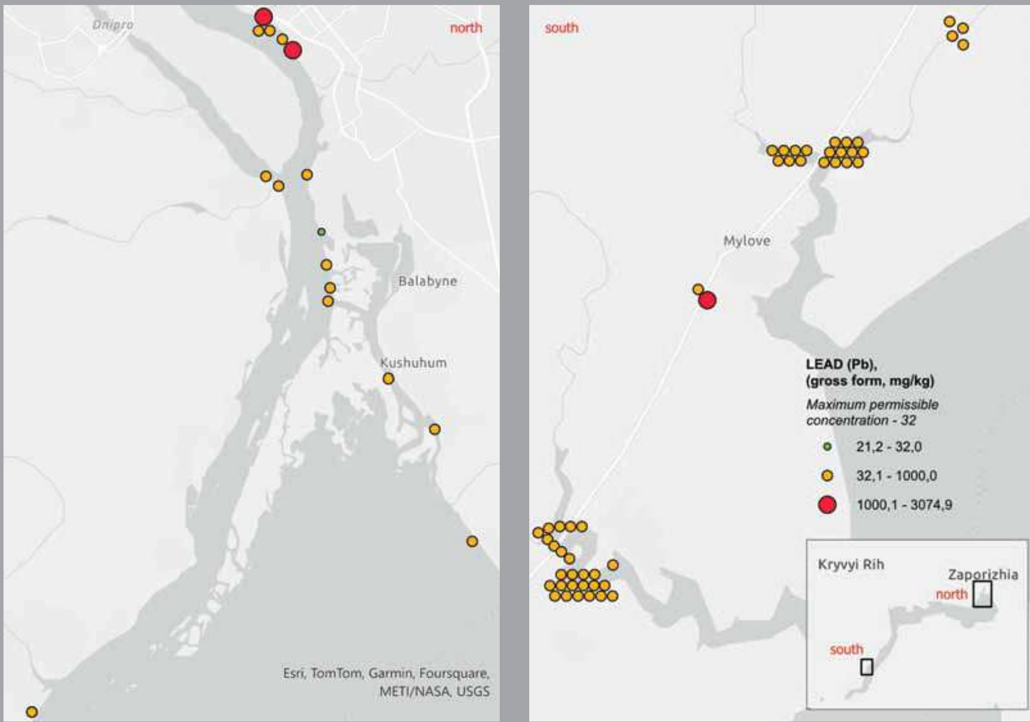
The most favorable substrates for the initiation of soil formation and the development of terrestrial habitats are the clay-rich sediment layers found within the former reservoir bed. These contain the highest concentrations of organic matter among all sediment types analyzed during the study, reaching up to 16%. Their elevated organic matter content most likely reflects the redistribution of sediments from deeper layers that were rich in sedimentary organic material. As vegetation continues to develop, the organic matter content of these soils is expected to increase further[72].

Soil formation is still at an early stage. Owing to the diversity of sediment types and the processes occurring within them, a complex mosaic of soil types and habitats is expected to develop across the former reservoir bed.

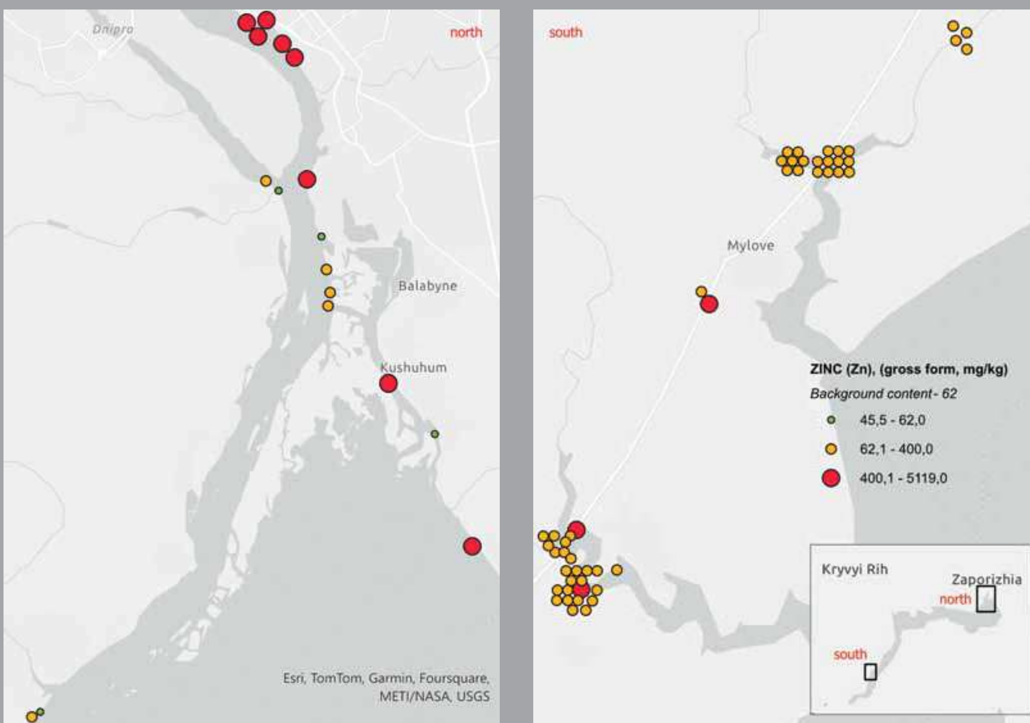
Soil Contamination Following the Destruction of the Kakhovka HPP Dam

During the summer of 2023, the authors collected and analyzed 119 soil samples. Although full access to the study area was not possible, the sampling strategy was designed to represent a wide range of landscape-geochemical conditions. The analyzed samples therefore provide representative information on different parts of the former reservoir bed.

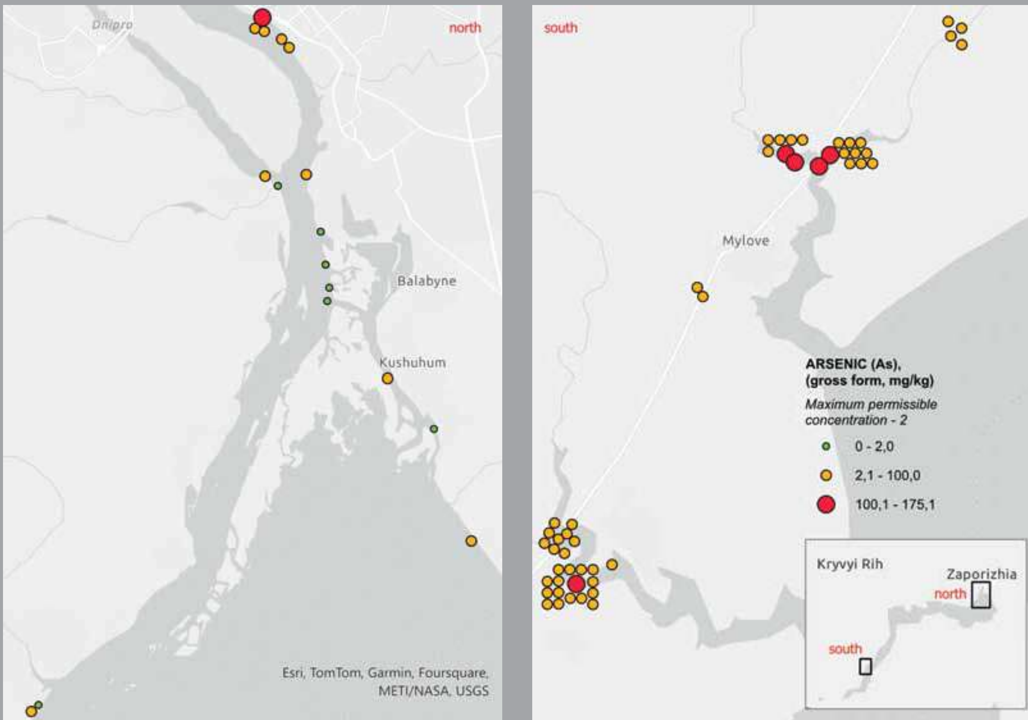
Distribution of Lead (Pb) in Bottom Sediments



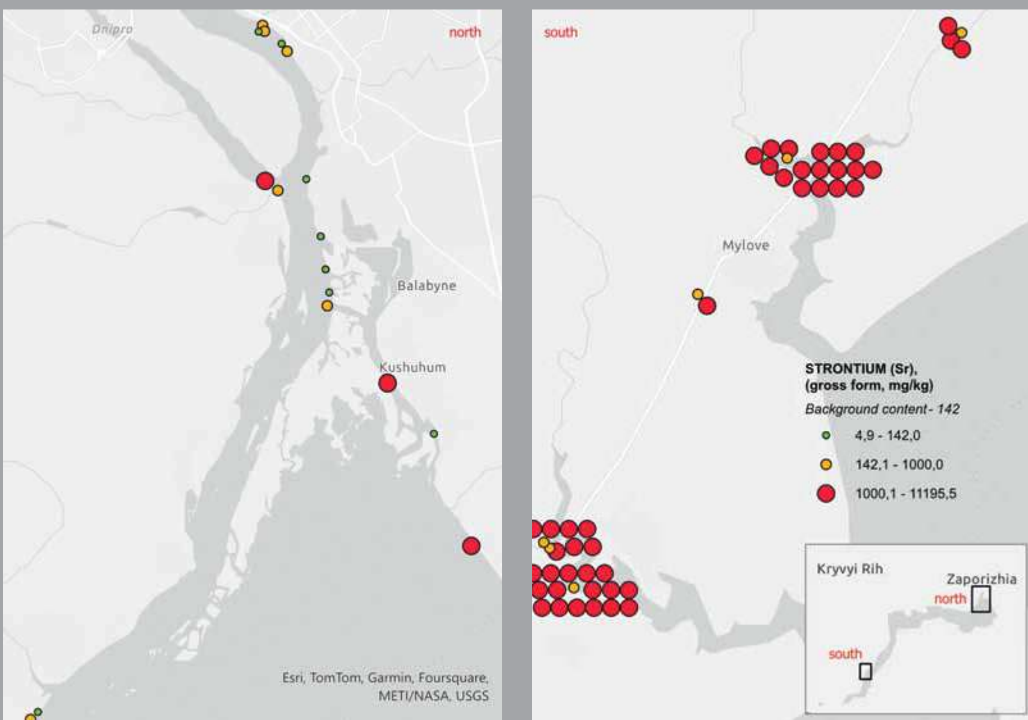
Distribution of Zinc (Zn) in Bottom Sediments



Distribution of Arsenic (As) in Bottom Sediments



Distribution of Strontium (Sr) in Bottom Sediments



In 94% of the analyzed soil samples, concentrations of toxic substances exceeded either the maximum permissible concentrations (MPCs) or natural background concentrations[20]. Several general patterns were identified:

- The pH of all sediment types was alkaline (7.0-8.6), indicating low mobility of toxic elements and the formation of poorly soluble compounds[204]. As a result, toxic substances tended to accumulate in the bottom sediments of the former reservoir rather than being transported downstream.
- Concentrations of contaminants generally followed the sequence: As–Pb–Sr–B–Zn–Cu–Co–Mo–Mn–Ni–P–V–Ba. The highest concentrations were recorded for arsenic (As), lead (Pb), strontium (Sr), and zinc (Zn). Concentrations of Cu, Co, Mo, Mn, Ni, P, V, and Ba showed considerable variation; however, for all of these elements, average concentrations exceeded both MPCs and background values by approximately 7-17 times. Cadmium (Cd) was the only exception, with concentrations corresponding to the natural geochemical background at all sampling sites.
- In some of the analyzed samples, zinc (Zn), vanadium (V), and nickel (Ni) exhibited the greatest mobility. Their highest average concentrations were recorded at depths of 25-35 cm, suggesting lateral[21] migration of contaminants, a process that has not yet been investigated in detail within the study area.
- The close similarity between metal concentrations in the redeposited bottom sediments of the catastrophic flooding zone and those in the soils of the former reservoir bed indicates a common source of contamination associated with industrial activities around the Kakhovka Reservoir, primarily from enterprises located in the cities of Zaporizhzhia, Dnipro, Kamianske, Nikopol, Marhanets, and Pokrov. This finding is of particular concern because increasing concentrations of mobile forms of chemical elements raise the risk of pollutants entering food webs.

Overall, soil contamination within the former reservoir poses a high environmental risk. Concentrations of toxic substances indicate that the entire territory of the former Kakhovka Reservoir, as well as the flooded areas downstream, constitutes an environmental disaster zone. However, the available data are insufficient to determine the precise spatial distribution of contamination across the entire area. The preliminary analysis indicates that much of this territory is likely to be unsuitable for many forms of human use, particularly agriculture. In view of these findings, the most appropriate land-use option would be to designate the area as a protected area and establish a long-term soil geochemical monitoring program. In particular, further research is needed to investigate the transfer of mobile forms of metals from soils into plants. The results of such studies will make it possible to assess the potential for the phytoremediation of contaminated land.

20 Natural background concentrations are the characteristic concentrations of chemical elements naturally occurring in a given soil type and landscape.

21 Lateral migration is the horizontal movement of contaminants through soil away from their original point of entry as a result of natural processes.

SURFACE WATER BODIES

City of Oleshky and the Southern Part of the City of Kherson, 10 June 2023 (photo: Keystone / AP Photo[107])

The water released from the Kakhovka Reservoir flowed through the Dnipro delta into the Dnipro–Buh estuary and subsequently into the Black Sea. According to approximate estimates, during the first days after the destruction of the dam, up to 40,000-50,000 m^3/s of water passed through the breach[99]. During this period, the outflow carried away bottom sediments that had accumulated in the reservoir over decades, large quantities of dissolved pollutants, and debris from settlements and industrial facilities. The destruction of the Kakhovka HPP dam alone resulted in the release of at least 150 tons of transformer oil[83] and 300 tons of fuel[195] (according to other estimates, 465 tons[83]) into the water.

Technogenic Facilities Flooded by the Waters of the Kakhovka Reservoir

The flooded area included at least 54 petroleum storage facilities[83], municipal solid waste landfills, cemeteries, wastewater treatment plants, agricultural facilities, petrol stations, chemical enterprises, livestock farms (including manure storage sites), and cesspits[8].

Some of the flooded facilities posed particularly serious environmental risks. These included the Kherson oil refinery (46.600, 32.548), the Glusco fuel storage facility in Oleshky (46.625, 32.789), and a number of petrol stations in the cities of Oleshky, Hola Prystan, and Kherson. In addition, 3,471 tons of fertilizers were washed into the Dnipro from the Polimin-Yuh chemical plant in Oleshky (46.375, 32.455)[156]. According to various estimates, as many as 1,088 such facilities were located within the flooded area, ultimately becoming sources of pollution to the Dnipro[19, 59, 83, 101] and, subsequently, to the Black Sea.

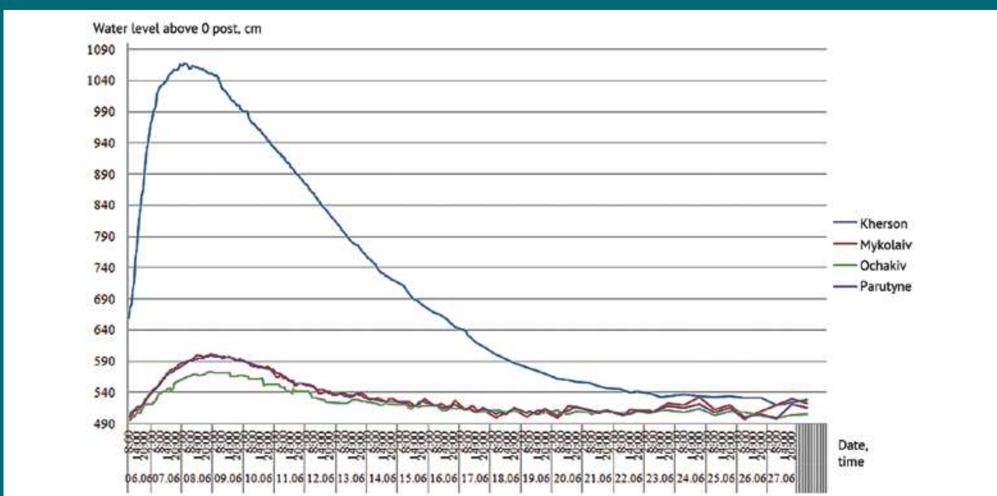
Freshwater Ecosystems

The left bank of the Dnipro lies at a lower elevation than the right bank and therefore experienced more extensive flooding. As Ukraine currently has no access to hydrological stations or surface water quality monitoring sites on the left bank of the basin, the consequences of the disaster for freshwater ecosystems can only be assessed using data collected on the right bank of the Dnipro.

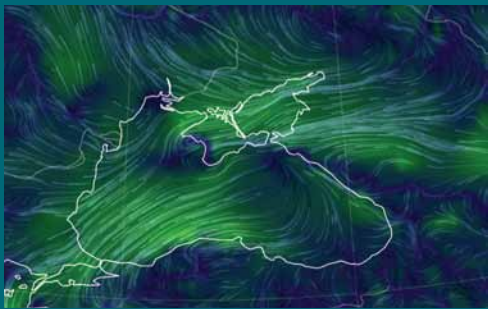
The volume of water flowing from the Dnipro was so great that water levels also rose in its tributaries, the Inhulets and Viryovchyna rivers. Reverse flow was recorded in both rivers[145]. Water levels in the Inhulets River rose as far as 150 km upstream. The average increase in water level was approximately 6 m[88], reaching up to 8 m in some places, while the flooded area covered about 67 km². Because the Inhulets is a regulated river and lacks a well-defined floodplain, valuable steppe habitats on its slopes were affected by the flooding.

Flooded Afanasivka Village, More Than 80 km from the Confluence of the Inhulets and the Dnipro (photo: Suspilne Mykolaiv[122])

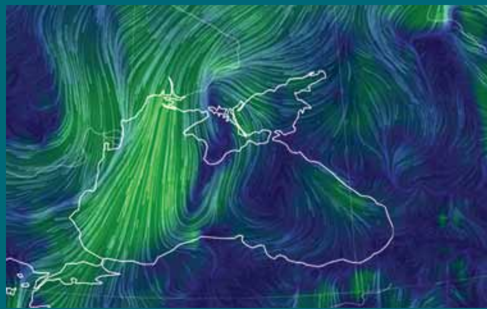
The floodwaters also carried fish from the Dnipro into the Inhulets. The fish fauna of the Inhulets differs substantially from that of the former reservoir, particularly in the composition of cyprinids, gobies, and percids. Species carried into the river included Pontic shad, sabrefish, silver and bighead carps, sand smelt, several species of pipefish, and most goby species. As conditions in the Inhulets were unsuitable for



Changes in Water Levels in the Dnipro, Southern Buh, and Dnipro-Buh Estuary Recorded at Hydrological Stations (source: Mykolaiv Regional Centre for Hydrometeorology)



Winds Driving Water Masses out of the Dnipro–Buh Estuary on 6 June 2023 (source: Earth Nullschool[25])



Winds Driving Waters Released from the Kakhovka Reservoir across the Black Sea on 12 June 2023

species originating from the Kakhovka Reservoir, it is likely that they subsequently returned to the Dnipro.

Rising water levels were also recorded[173] at hydrological stations on the Southern Buh River located more than 100 km from the Dnipro-Buh estuary[22]. Near the city of Mykolaiv, the backwater effect caused the water level in the Southern Buh to rise by 104 cm[32, 89], the highest level ever recorded. Water levels began to decline only on 11-12 June[97].

By the third day after the disaster (9 June 2023), water levels at hydrological stations on all affected rivers had begun to fall, and by the fifteenth day they had almost completely stabilized[173]. This process was facilitated by easterly winds, which reduced the backwater effect in the rivers and, consequently, the extent of flooding.

Water Pollution

Before the destruction of the dam, the Kakhovka Reservoir was the most polluted reservoir in the Dnipro cascade, receiving inadequately treated industrial wastewater and accumulating the largest volume of bottom sediments within the entire cascade[166]. Although pollutants were transported in the water column and absorbed onto suspended particles, the overwhelming majority (99.5%), including Mn, Cu, Zn, and Cr, accumulated in the bottom sediments of the reservoir. This was primarily due to its shallow depth and low flow velocity.

Chemical and Physical Pollution

As the reservoir drained, pollutants stored in its bottom sediments were remobilized and transported with the silt into the Dnipro Delta and the Black Sea.

Because of the sudden and uncontrolled nature of the flooding, it is difficult to estimate the total amount of pollutants released. According to UNEP estimates[109, 94], approximately 1,077,000 m^3 of waste was carried away by the floodwaters, while UNDP estimated this volume at 2,894,000 m^3[109, 47].

22 The maximum water level of 5.93 m (relative to the gauge datum) was recorded on the morning of 9 June 2023 at the Prybuzhany hydrological gauging station (HP-II), Pervomaisk Hydrological Station. However, the water level did not reach the critical threshold of 7.50 m [173].

Water samples[23] collected from floodwaters entering the Inhulets River from the Kakhovka Reservoir in early June revealed concentrations of several hazardous substances far exceeding the maximum permissible concentrations (MPCs). Multiple exceedances were recorded for Class I hazardous substances, including lead, zinc, and cadmium[24], as well as for Class II hazardous substances, including copper, nickel, cobalt, and manganese[25] (Hazard Class III)[140]. It is likely that these pollutants were ultimately transported into the flooded areas on the left bank of the Dnipro as well.

Biological Pollution

In addition to chemical contamination, elevated levels of microbial pollution were recorded in both the Dnipro and the Inhulets rivers. This was most likely caused by the flooding of cesspits, the destruction of livestock burial sites[96], and the mass mortality of animals[178]. Between 9 and 17 June 2023, the maximum concentration of lactose-positive *Escherichia coli* (LPCI)[26] in the Inhulets River and the waters of the Dnipro-Buh Estuary reached up to 240 million units, approximately 48,000 times higher than the established permissible sanitary norm[210].

At the same time, water samples showed increased biochemical oxygen demand (BOD) together with elevated ammonia concentrations, indicating the influx of nitrogen fertilizers, wastewater, and sewage into the aquatic environment[210].

Indicators of microbial contamination began to decline after 17 June 2023. A second peak was recorded in mid-July[210], most likely as a result of increasing water temperatures.

ENVIRONMENTAL CONSEQUENCES

Long-term Consequences for Freshwater Ecosystems

The creation of the Dnipro cascade of reservoirs fundamentally altered the ecosystems of the Lower Dnipro and its delta. The natural hydrological regime was replaced by daily regulated discharges through the hydropower dams. In addition, a deep-water navigation channel was constructed to provide access to the Dnipro ports, allowing denser saline water to penetrate further into the delta. The redeposition of sediments transported from the Kakhovka Reservoir following the 2023 destruction of the dam across the temporarily flooded floodplain has created an additional pressure on the ecosystems of the Dnipro valley. This has occurred both through direct contamination and sediment deposition and through the further deterioration of oxygen conditions in the water, a critical factor for many aquatic organisms.

Changes in the hydrological regime, particularly the absence of daily water-level fluctuations formerly caused by dam releases, have resulted in less predictable water-level dynamics in the Dnipro-Buh estuary, creating new environmental conditions

23 Water samples were collected by the State Environmental Inspectorate of Ukraine and the State Enterprise *Institute for Soil Protection of Ukraine on 7 June 2023* [140].

24 Concentrations exceeded the maximum permissible concentrations (MPCs) by 25-415% for lead, 1.8-100.5% for zinc, and 4-107% for cadmium [140].

25 Concentrations exceeded the maximum permissible concentrations (MPCs) by 3-42% for copper, 1.5-103% for nickel, 0.6–57% for cobalt, and 12-45% for manganese [140].

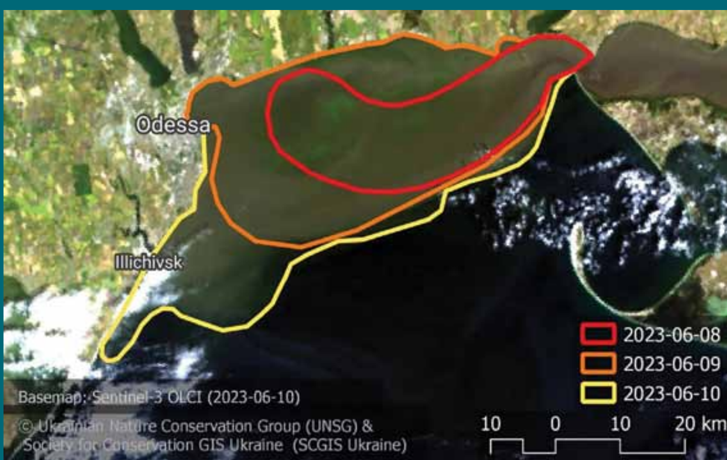
26 Water samples were collected by researchers from the Admiral Makarov National University of Shipbuilding between 9 and 17 June 2023.

for aquatic organisms[70]. Hydrological connectivity between lakes in the delta has decreased by a factor of 7-8, initiating ecological succession towards increased wetland formation. Rising salinity in river water is also likely to reduce dissolved oxygen concentrations in the Dnipro-Buh estuary and the Dnipro delta. This is an important ecological factor that is expected to affect both the composition and abundance of freshwater organisms.

Following the destruction of the Kakhovka HPP, organic matter accumulated in the former reservoir has continued to be washed out from its bed, particularly during the 2024 spring flood[90]. Water samples collected from the lower reaches of the Dnipro[27] showed high concentrations of organic matter and protozoa. In March 2024, an unusually large phytoplankton bloom was recorded in the Dnipro-Buh estuary, particularly involving the diatom *Melosira varians*, which had been transported by water flows from the former Kakhovka Reservoir[84]. Water samples also contained large numbers of ciliates (*Oxytricha fallax*, *Vorticella microstoma*, *Uronella nigricans*, and *Pseudoglaucoma muscorum*), species typically associated with polluted stagnant waters[124]. Consequently, the Dnipro-Buh estuary has become a zone of accumulation for organic matter originating from the former Kakhovka Reservoir. In the future, this may lead to the formation of hypoxic or anoxic bottom waters with elevated concentrations of pollutants and nutrients in the near-bottom layer[69].

Marine Ecosystems

The most intensive impacts of the destruction of the Kakhovka HPP dam on the marine ecosystem persisted for approximately three months after the disaster[184] and unfolded in several stages. The abrupt change in hydrophysical conditions (10-20 June) was followed by a rapid biological response, including the mass mortality of some organisms and simultaneous population outbreaks of others (20 June-10 July)[121].



Distribution of Bottom Sediments in the Black Sea, 8-10 June 2023

27 Water samples were collected by researchers from Kherson State Agrarian and Economic University.

Around 12 June, the wind direction along the western coast of the Black Sea changed. Water movement shifted from north to south, facilitating the transport of pollutants into the open sea. Owing to the enormous volume of water released from the reservoir, seawater salinity declined sharply. The lowest salinity values along the Odesa coast were recorded on 11 June, reaching 3.95‰[28] compared with the normal 14-16‰[139], and remained at this level until 17 June[162].

The freshwater plume extended southwards along the western coast of the Black Sea, following the prevailing marine currents until it reached the shallow Dniester and Danube-Dniester submarine banks, where water depths are less than 20 m. In these shallow areas, freshwater displaced seawater all the way to the seabed, likely causing damage to benthic ecosystems[120].

On 15 June, the polluted waters reached the mouth of the Danube River[216] and then continued southwards along the western Black Sea coast beyond Ukraine's territorial waters. They subsequently reached the Bosporus Strait and entered the Sea of Marmara within the territorial waters of Türkiye[120].

Chemical Pollution

Water samples collected in late June 2023, from Odesa Bay, near the city of Ochakiv, the Dnipro–Buh estuary, and near the city of Kherson showed similar levels of contamination. Concentrations of petroleum products, toxic metals (Zn, Cd, and Pb), and organochlorine compounds (lindane and PCBs[29] [211, 216]) exceeded permissible levels.

Petroleum Products in the Flooded Area near the City of Kherson, 10 June 2023 (photo: Keystone / AP Photo[107])

28 A salinity of 3.95‰ means that each kilogram of seawater contained only 3.95 g of dissolved salts.

29 Polychlorinated biphenyls (PCBs) are highly carcinogenic chemical compounds that were formerly used in industrial and consumer products. Their production has been prohibited internationally since 2001.

"Islands" of Debris Recorded in the Black Sea on 10 June 2023 (source: DeepState)

On the third day after the disaster, when the polluted waters reached the Odesa coastline (9 June), concentrations of petroleum products in the Black Sea near the village of Nova Dofinivka exceeded the permissible level by a factor of 6.6, while iron concentrations were up to 12.4 times above the permissible level. Elevated concentrations of ammonium nitrogen were also recorded[142]. These most likely resulted from the decomposition of organic matter and probably entered the water following the flooding of sewage systems, cesspits, and agricultural facilities.

Petroleum products covering large areas of the sea surface caused oxygen depletion, leading to the suffocation of marine organisms, while elevated nitrogen concentrations accelerated the growth of phytoplankton.

Phosphate concentrations remained high until 10 June and began to decline on 12 June. Nitrate concentrations were also elevated and reached their peak between 10 and 14 June. During this period, floating "islands" of debris measuring up to 1.1 km in length drifted across the Black Sea[143, 150-153].

Pollution levels began to decline after 13 June[142]. However, critically high concentrations of copper (Cu) and cobalt (Co) persisted in the sea until early July[215].

Microbiological Pollution

Between 12 and 26 June 2023, the Odesa Regional Centre for Disease Control and Prevention of the Ministry of Health of Ukraine detected hazardous microorganisms in coastal waters along the Odesa region. Owing to the reduced salinity of seawater following the inflow of freshwater, cholera-like *Vibrio* spp., *Salmonella*, rotavirus, and lactose-positive *Escherichia coli* remained viable in this part of the Black Sea[144]. These microorganisms are capable of causing acute intestinal infections.

Explosive Biotic Response

The influx of large quantities of nutrients into the Black Sea triggered a rapid proliferation of freshwater phytoplankton in the Dnipro-Buh estuary[33, 162], followed by a large-scale bloom in the Black Sea.

Water blooms were first recorded in the coastal waters of Odesa on the eighth day after the disaster, 14 June 2023. Freshwater and brackish cyanobacteria, which are naturally present in Odesa Bay, dominated the bloom; however, their abundance was exceptionally high. Particularly abundant were *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* (3 g/m^3), which formed a green film on the water surface. Phytoplankton biomass increased by 150-300 times[33, 212], and in some areas by as much as 2,000 times[121] compared with normal levels.

Intensive Phytoplankton Bloom in Desalinated Seawater in Odesa Bay, 14 June 2023 (photo by O. Halaiko[222])

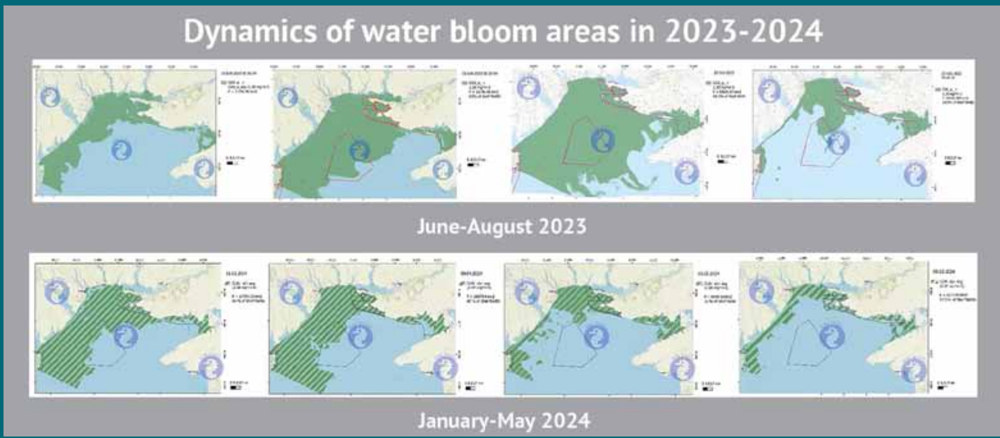
Peak development of the phytoplankton bloom was recorded on 25 July 2023, when it covered 32,450 km^2 of the Ukrainian sector of the Black Sea[162, 212] – an area 16 times larger than the former Kakhovka Reservoir.

Intense phytoplankton blooms reduce light penetration into deeper water layers, suppressing the development of benthic organisms. The seasonal die-off and subsequent decomposition of phytoplankton increase biochemical oxygen demand (BOD$_5$), leading to oxygen depletion, similar to the processes observed in the Dnipro reservoirs during cyanobacterial blooms. This results in the mortality of sessile and planktonic organisms[216] and forces fish to migrate.

Water Blooms within Protected Areas

The phytoplankton bloom affected several Emerald Network sites, as well as the marine waters of the Black Sea Biosphere Reserve, Biloberezhzhia Sviatoslava National Nature Park, Dzharylhach National Nature Park, and the entire marine area of the Danube Biosphere Reserve in Odesa Region. The bloom also completely covered Ukraine's three largest marine wildlife reserves: Zernov's Phyllophora Field (402,500 ha), Small Phyllophora Field (38,500 ha), and Karkinitskyi (27,646 ha). Off the coast of the Crimean Peninsula, the Lebedyni Islands Branch of the Crimean Nature Reserve also fell within the affected area.

ENVIRONMENTAL CONSEQUENCES



Changes in the Extent of Water Bloom in the Black Sea from 10 June to 24 August 2023. Based on data presented at the seminar The Impact of Military Activities on Ukraine's Marine Ecosystems[121]

Long-term Consequences

In the second half of June 2024, a phytoplankton bloom was recorded in the Black Sea in the area where organic matter had accumulated following the Kakhovka terrorist attack[130]. This indicates that the consequences of pollution in the Black Sea are likely to be long-lasting, particularly due to contaminants deposited over extensive areas of the seabed. During summer, as seawater temperatures rise – especially in deeper water layers that warm more slowly – the decomposition of organic matter intensifies, increasing oxygen consumption. This may result in oxygen depletion and the mass mortality of marine organisms in the near-bottom waters of the north-western Black Sea.

In addition, storms may remobilize contaminated bottom sediments, causing secondary pollution of the water column[212]. Pollutants deposited in June 2023 are harmful to aquatic organisms[[125] and may adversely affect their growth and reproduction. Heavy metals accumulated in the marine environment may also be transferred through the food web and become increasingly concentrated at higher trophic levels, including in marine mammals and humans.

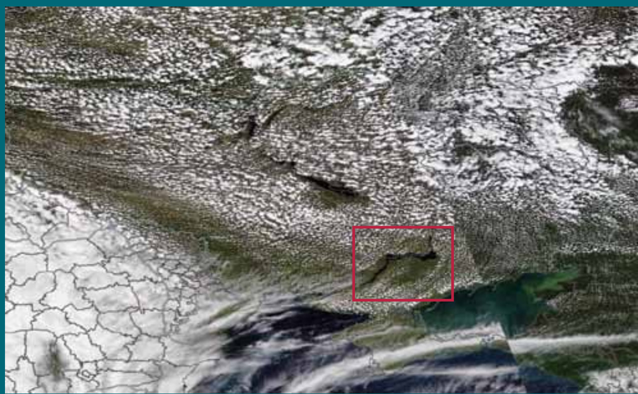
The amount of anthropogenic debris that entered the Black Sea remains unknown. Future research should focus on its distribution, particularly that of microplastics[121].

MICROCLIMATE

The Kakhovka Reservoir influenced the microclimatic conditions of the surrounding area. During the last three decades of its existence, however, a clear trend towards increasing average monthly water temperatures was observed. This reflected not only the effects of global climate change but also increasing water losses from the reservoir through evaporation[190]. One might therefore expect increased precipitation in the surrounding region, yet this did not occur.

The reservoir had its greatest influence during the warm season, primarily through the formation of local breezes driven by temperature differences between the water surface and the surrounding land. During the day, convective air currents developed over the heated land, while cooler air from above the reservoir flowed into the lower layers of the atmosphere. At night, as the land surface cooled, this circulation was reversed. The disappearance of the reservoir disrupted these microclimatic processes, resulting in an increase in land surface temperature (Land Surface Temperature – LST) of 1.0°C or more in adjacent areas[81].

However, the increase in temperature should not be considered in isolation from the broader set of microclimatic processes. Contrary to the widespread assumption that water evaporated from the reservoir returned as precipitation over the surrounding area, this was not entirely the case. Moisture evaporating from the reservoir was dispersed by atmospheric circulation and fell as precipitation hundreds or even thousands of kilometers away, including beyond Ukraine. The surrounding region remained within a "rain shadow" during the spring and summer months, as confirmed by satellite imagery[31].

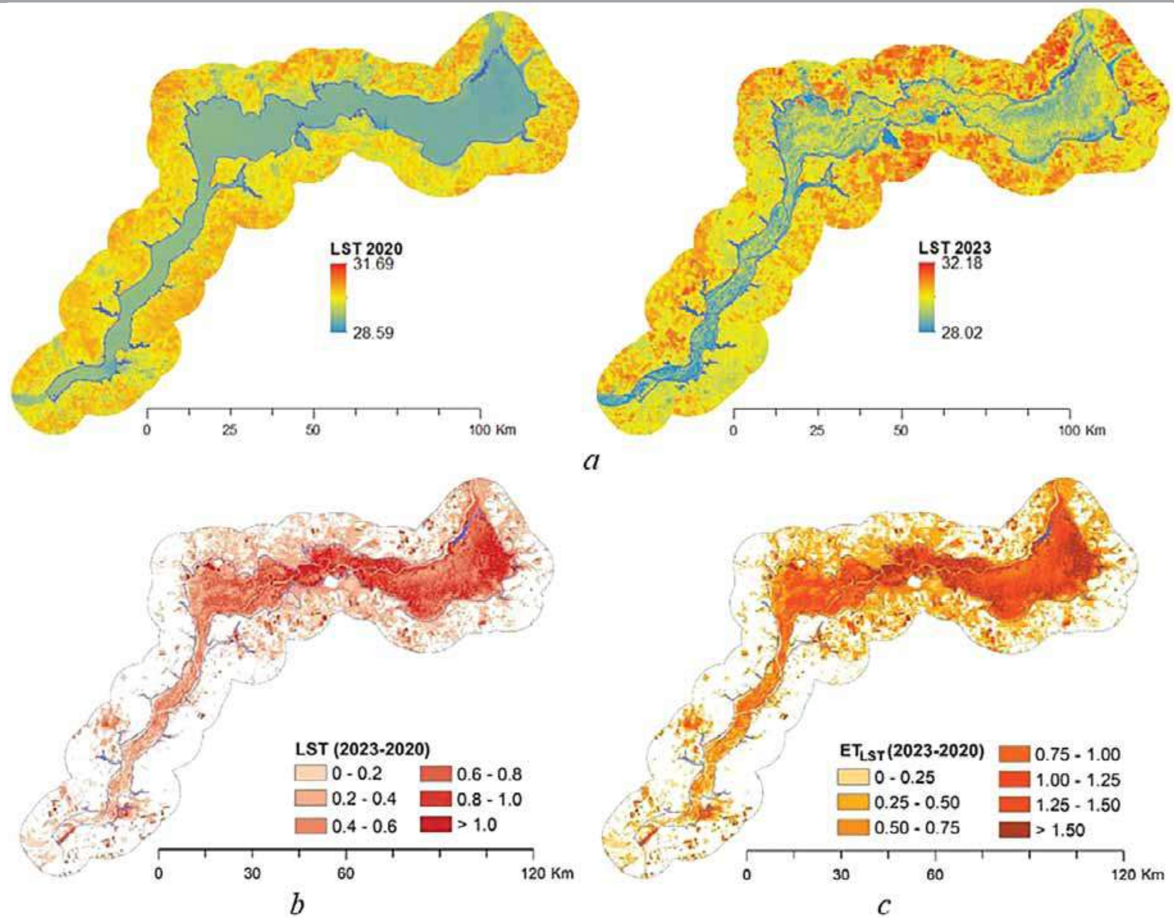


"Rain Shadow" over the Dnipro Cascade of Reservoirs Shown in Satellite Imagery[31]

The temperature regime of the Dnipro River has changed following the loss of the reservoir. Previously, the reservoir warmed considerably during summer and slowed the downstream release of spring floodwaters. Under present conditions, water temperatures in the Lower Dnipro are expected to be higher in spring and lower in autumn than they were while the reservoir existed[118]. These changes may also influence the thermal regime of adjacent terrestrial areas. Although this hydrological regime is essentially natural, it differs markedly from the conditions that prevailed between 1955 and 2023. Consequently, many aquatic organisms are now exposed to a different temperature regime, which may alter the timing of their life cycles.

Thus, the destruction of the dam and the drainage of the reservoir have had contrasting effects. On the one hand, they resulted in a rapid increase in local land surface temperatures. On the other hand, they may contribute to increased precipitation during the spring and summer months, when rainfall is most beneficial for agriculture. In the coming years, the floodplain willow forests already developing across the bed of the former reservoir are expected to moderate summer heat and increase atmospheric humidity during periods of high temperatures[165]] (see the section **Beginning of the Recovery of the Natural Ecosystems of Velykyi Luh**).

Spatiotemporal Patterns of Land Surface Temperature (°C) and Evapotranspiration (ET/LST, mm/day) in the Area of the Drained Kakhovka Reservoir and Adjacent Territories (September 2020 and 2023)[81]



ECOSYSTEM SERVICES

The concept of ecosystem services has not yet been incorporated into Ukrainian legislation. Nevertheless, an internationally recognized classification of ecosystem services[30] plays an important role in environmental management worldwide. Experts from the Ukrainian Nature Conservation Group adapted this classification to conditions in Ukraine. This made it possible to compare the ecosystem services previously provided by the Kakhovka Reservoir with those now provided by the habitats that have developed on its former bed and to carry out a comparative rapid assessment.

Some ecosystem services were lost with the disappearance of the reservoir. For example, the reservoir acted as a 100% effective barrier to the spread of wildfires across both natural and managed landscapes. In most cases, however, the emergence of natural habitats over large areas has increased the benefits provided by ecosystems. For instance, the rapid establishment of woody vegetation has greatly enhanced the role of phytoremediation by removing hazardous substances from the contaminated sediments accumulated on the former reservoir bed. At the same time, shoreline erosion has ceased, while carbon sequestration in woody biomass and soil formation processes have begun.

The table below presents the results of a rapid assessment comparing the ecosystem services provided by the artificial ecosystem of the Kakhovka Reservoir with those provided by the recovering natural floodplain ecosystem of the Dnipro River. The assessment considers only the natural characteristics of the ecosystems and does not account for the engineering functions of the Kakhovka HPP dam or the irrigation canal network. For example, the delivery of water through an irrigation canal is a technological service rather than an ecosystem service.

Although Ukrainian experts cannot yet accurately quantify the losses or changes in ecosystem services, it is already clear that both the range of services and the mechanisms by which they are provided have changed. For example, across much of the former reservoir bed, organic matter that previously accumulated in mollusc shells is now being incorporated into woody biomass or contributing to the future formation of peat deposits and soils. Conditions for commercial fisheries have deteriorated, whereas opportunities for recreational fishing have increased. Consequently, different groups of people may perceive these changes as either positive or negative, depending on their livelihoods and interests.

30 Common International Classification of Ecosystem Services (CICES) https://cices.eu/

Kakhovka Reservoir		Dnipro River Floodplain, Velykyi Luh
Surface water for drinking (chemical composition and water quality)	<<	Surface water for drinking (chemical composition and water quality)
Surface water used as a material resource (non-potable purposes)	>>	Surface water used as a material resource (non-potable purposes)
Surface water used as an energy source	>>	Surface water used as an energy source
Bioremediation	<<	Bioremediation
Filtration, absorption, storage, and sequestration by ecosystems	<<	Filtration, absorption, storage and sequestration by ecosystems
Reduction of fire spread across natural and managed landscapes	>>	Reduction of fire spread across natural and managed landscapes
Reduction of odor, dust and noise pollution	<<	Reduction of odor, dust and noise pollution
Regulation of zoonotic diseases	<<	Regulation of zoonotic diseases
Landscape aesthetics	<<	Landscape aesthetics
Pollination	<<	Pollination
0	<<	Protection against bank erosion
Seed dispersal	<<	Seed dispersal
Habitat maintenance	<<	Habitat maintenance
Regulation of pathogens	<<	Regulation of pathogens
Regulation of land surface and air temperature (warmer autumn)	?	Regulation of land surface and air temperature (cooler summer)
0	<<	Soil protection, soil formation and groundwater regulation
Carbon sequestration and storage	<<	Carbon sequestration and storage
Production and accumulation of organic biomass	<<	Production and accumulation of organic biomass
Fish and other aquatic biological resources	>>	Fish and other aquatic biological resources
Research on biodiversity and natural processes; environmental education	<<	Research on biodiversity and natural processes; environmental education
Nature-based upbringing of children	<<	Nature-based upbringing of children
Artistic inspiration	<<	Artistic inspiration
Formation of the identity of ethnic and social groups	<<	Formation of the identity of ethnic and social groups
Hunting, fishing, and related activities	<<	Hunting, fishing, and related activities
Recreation and tourism	=	Recreation and tourism

BEGINNING OF THE RECOVERY OF THE NATURAL ECOSYSTEMS OF VELYKYI LUH

During the first weeks following the destruction of the Kakhovka HPP, numerous pessimistic scenarios were put forward regarding the future of the exposed reservoir bed. Few natural ecosystems remained around the former reservoir that could serve as sources of biodiversity for its recovery. Consequently, it was difficult to predict how the ecosystem would regenerate.

With this in mind, researchers initiated long-term monitoring of habitat recovery across the former reservoir bed[31]. Field studies were conducted on the right bank of the Dnipro, in bays closest to the destroyed dam[54], as well as near the village of Malokaterynivka and on Khortytsia Island in Zaporizhzhia Region. Survey sites were selected with safety considerations in mind, ensuring that they were not visible from the opposite bank occupied by Russian forces. The research expeditions were accompanied by representa tives of the Ukrainian Armed Forces.

During the first field surveys, conducted on 30 June 2023 (three weeks after the dam's destruction) and again on 19 October 2023 (three and a half months later), researchers observed rapid vegetation recovery. **Four habitat types had already begun to develop[21]: willow thickets, wetland habitats, sparsely vegetated areas, and areas covered with dead mollusc shells**. In June 2023, only 10 species of vascular plants were recorded within the surveyed areas of the former reservoir, whereas by October this number had increased to 68. Of the recorded species, only 16 were non-native, and none had become dominant[71].

Among the plants recorded within the surveyed areas, perennial native species predominated. Their abundance continues to increase, suggesting that annual species are likely to disappear over the coming seasons. This will allow perennial plant communities to determine the future composition of the vegetation,

31 Between 2023 and 2024, seven field expeditions were carried out with the participation of specialists from the Ukrainian Nature Conservation Group, Environment-People-Law (EPL), the M.G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine, Kherson State University, Kamianska Sich National Nature Park, Falz-Fein Askania-Nova Biosphere Reserve, the Institute of Marine Biology of the National Academy of Sciences of Ukraine, Zaporizhzhia National University, Ivan Franko National University of Lviv, and the Khortytsia National Reserve. Specialists from the Department of Soil Science, Institute of Geoecology, Technical University of Braunschweig also participated in the analysis of samples collected during the expeditions.

enabling researchers to predict the composition of habitats with considerable confidence for many years ahead.

Vegetation is developing rapidly owing to the high moisture content of the substrate and the presence of nearby plant communities that disperse their seeds by wind or water. The rapid recovery of vegetation is stabilizing the soil structure, thereby reducing the risk of wind erosion and the dispersal of heavy metal contaminants.

The destruction of the dam in early June coincided with the seed maturation period of willows and poplars. This greatly increased the competitive advantage of native species during vegetation recovery. By November 2023, willow-poplar stands accounted for 70% of the vegetation cover across the former Kakhovka Reservoir. Importantly, most other widespread plant species were not producing seeds at that time and had no viable seed bank in the reservoir bed. As a result, the anticipated spread of non-native species did not occur. By contrast, willow seeds remain viable for only a few weeks. Had the reservoir been drained at another time of year, the developing vegetation would most likely have followed a very different trajectory, potentially including the dominance of non-native plant species. This is supported by observations from the Mylivska Balka area of the former Kakhovka Reservoir, upstream of the road embankment, where the land emerged from the water only several months after the disaster. Willows are absent there, while invasive Tatarian lettuce (*Lactuca tatarica*) and Canadian horseweed (*Erigeron canadensis*) are the dominant species.

Willow Forests

The most widespread habitat type to develop across the former reservoir bed was willow forest dominated by hybrids between the native white willow (*Salix alba*) and the long-naturalized alien crack willow (*Salix fragilis*) (EUNIS habitat type G1.11[27]).

By the end of June 2023, the surveyed areas of the former reservoir bed were already densely covered with willow seedlings, with an average density of 90 individuals per square meter. Three months later, extensive willow thickets covered large areas of the former reservoir bed[32]. During this period, the average height of willows increased from 50 cm to 190 cm, corresponding to a mean daily growth rate of 1.7 cm. The tallest individuals reached 309 cm, indicating highly favorable conditions for the development of gallery willow forests. This prediction was confirmed in October 2024, when the average height of willows at the study sites reached 4.66 m, with the tallest measured individual reaching 5.46 m[154]. The structure of the willow stands also became substantially more complex. During their first year, they consisted of a single vegetation layer, whereas by the second year they had developed distinct tree regeneration, shrub, herbaceous, and moss layers.

32 For comparison, at the Oskil Reservoir, which was destroyed by Russian forces in April 2022, this combination of favorable conditions did not occur. As a result, ecosystem recovery followed a different trajectory, characterized by the predominance of wetland habitats and a different balance between native and invasive plant species [17].

From a legal perspective, all young forests naturally regenerating within Velykyi Luh are classified as naturally regenerated forests and may be designated as forest land. Given the limited success of attempts to increase forest cover in the steppe zone through artificial afforestation – which is now prohibited under Ukrainian legislation – the legal recognition of these naturally regenerated forests could contribute to achieving national forestry objectives. It could also support the implementation of the presidential program Green Country, which aims to plant one billion trees.

Natural Functions of Floodplain Willow Forests

The dominant habitat type developing on the former reservoir bed is listed in Resolution No. 4 of the Bern Convention[71] as G1.11 Riverine *Salix* woodland and in Annex I of the EU Habitats Directive as habitat types 91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) and 92A0 *Salix alba* and *Populus alba* galleries. These habitat types are protected at the European level and are considered priorities for the designation of internationally important protected areas across Europe.

At present, the young willow-poplar forest developing on the bed of the former Kakhovka Reservoir is the largest floodplain forest in Europe. The ecological importance of floodplain willow forests lies in their capacity to stabilize soils and improve water quality by filtering nitrogen and phosphorus compounds, petroleum hydrocarbons, and by absorbing toxic heavy metals[58]. This habitat type is also considered the most climate-resilient forest type within Ukraine's steppe zone[71]. In addition, willow floodplain forests support a higher diversity of bird species than any other forest type in the region.

Wetland Habitats

Wetland habitats occupied considerably smaller areas, accounting for approximately 13% of the former reservoir bed by November 2023. During the first survey in June, only isolated reed shoots were observed. By October, however, this habitat type had become well established, developing primarily along permanent watercourses. This habitat type is also protected under the Bern Convention (Resolution No. 4, habitat C3.2 *Water-fringing reedbeds and tall helophytes other than canes*[28]). It is also included in the European Red List of Habitats as C5.1a *Tall-helophyte bed*[71].

Habitats Developing on Muddy Sediments

The third and fourth groups of newly formed habitats comprised muddy sediments with sparse vegetation, as well as communities developing on shell deposits and sandy substrates. These habitats were concentrated mainly in the central part of the former reservoir and on the highest elevations of the former reservoir bed. It was in these areas that the largest colonies of zebra mussels were concentrated, as their proximity to the water surface provided access to oxygen-rich water. These sites now present the most challenging conditions for plant growth and therefore are revegetating the most slowly, currently (by the end of 2024) supporting only sparse vegetation.

By November 2023, 50% of the former reservoir bed was covered by vegetation[56]. Willow thickets occupied 655.2 km², wetland vegetation covered 274.6 km², while dried muddy or takyr-like[33] sediments accounted for 226.9 km². At that time, the largest area (728.7 km²) consisted of shell and sandy deposits with sparse vegetation. The remaining 239.6 km² of the former reservoir were occupied by water, including the re-established channel of the Dnipro River, its side channels, and newly formed isolated water bodies[71].

General View of the Bed of the Former Kakhovka Reservoir in theDdrained Respublikhanets Bay, Kamianka Ravine, on 30 June and 19 October 2023 (photo by O. Khodosovtsev)

Field expeditions conducted in 2024 confirmed that the young forest habitats had successfully survived the winter and continued to grow. As the biomass and density of the vegetation cover increased, the area occupied by vegetation in the central part of the former reservoir also continued to expand. Satellite imagery from June 2024[79] clearly shows that the proportion of open areas had decreased substantially, while the proportion covered by vegetation had increased. At the same time, the bed of the former Kakhovka Reservoir still contains areas with muddy, takyr-like substrates, as well as areas covered by shell deposits formed from the shells of dead molluscs. These areas are revegetating slowly but are gradually being shaded by trees, which are expanding their crowns over them. As a result, the area covered by vegetation continues to increase, while the shade

33 Takyr is a type of desert landscape characterized by clay-rich surfaces that temporarily fill with water after rainfall, forming shallow water bodies.

Mosaic of Forest and Wetland Habitats on the Bed of the Kakhovka Reservoir near Chervonohryhorivka, June 2024 (photo: State Border Guard Service of Ukraine)

created beneath the trees increases the likelihood that other plant species will become established.

The number of vascular plant species recorded on the former reservoir bed has also continued to increase steadily. Researchers recorded only 11 vascular plant species in June 2023, 69 species in October, and by May 2024 the total had reached 146 vascular plant species and two bryophyte species. Near Khortytsia Island in Zaporizhzhia Region, a locality of rye sedge (*Carex secalina*), a species listed in the Red Data Book of Ukraine, was recorded on the former reservoir bed. This indicates that the vegetation developing on the former reservoir bed is acquiring conservation significance.

On the slopes of the former reservoir occupied by limestone outcrops, petrophytic steppes have begun to recover. These areas remained almost unvegetated during the first year after they emerged from the water. Their slow rate of revegetation is due to the fact that they are separated from the source of petrophytic steppe diaspores by belts of reed beds and willow-poplar stands that extend almost continuously along the shoreline of the former Kakhovka Reservoir. These belts act as a barrier, preventing plant species from the petrophytic steppes located above them from reaching the limestone outcrops exposed after the reservoir was drained. However, during field surveys carried out on 11 April 2024 (the fifth anniversary of the establishment of the park), a site was discovered where steppe communities extend almost to the former shoreline of the reservoir. At this site, a number of steppe plant species were recorded on the exposed limestone outcrops, including purple crownvetch (*Securigera varia*), Ural cephalaria (*Cephalaria uralensis*), Pannonian yarrow (*Achillea pannonica*), red-seeded dandelion (*Taraxacum erythrospermum*), and broomleaf toadflax (*Linaria genistifolia*).

Restoration of the Hydrological Regime of Velykyi Luh

The spring flood of 2024[90] contributed to the recovery of natural habitats on the bed of the former reservoir. During the spring flood, approximately 60% of the former reservoir bed was flooded. Compared with November 2023, the area covered by water increased fivefold. The configuration and extent of the flooded area resemble the wetland habitats and wet meadows that existed here before the reservoir was created. Along with the river flooding, the land surface temperature noticeably decreases as vegetation biomass increases[166].

Currently, the hydrological regime of Velykyi Luh is not yet entirely natural, as it still depends on the operation of the Dnipro Hydroelectric Power Plant upstream and on water releases throughout the Dnipro cascade. However, water releases from the cascade reservoirs are still linked to the natural flood cycle. In the past, excess floodwaters replenished the reservoirs, making it possible to store sufficient water for use throughout the year[61]. Following the destruction of the Kakhovka HPP dam, the annual spring surplus of water in the cascade will pass through Velykyi Luh, partially restoring the conditions of the natural flood regime. The formation of extensive shallow, vegetated areas that are periodically flooded will, in the future, contribute to an increase in the area of fish spawning grounds.

Conservation Value of the Habitats of Velykyi Luh

The destruction of the Kakhovka HPP dam and the emptying of the reservoir restored the free-flowing course of the Dnipro River along a 250-km stretch.

The territory of the Kakhovka Reservoir was included in the Emerald Network of Europe[26]. At the Kakhovka Reservoir (UA0000106) Emerald site, the area of protected habitats was 27.5 km², whereas by the end of 2024 it has increased[34] to at least 930 km²—an increase of 34 times. Accordingly, changes in habitat areas following the destruction of the Kakhovka HPP dam have resulted in an expansion of those habitat types listed in Resolution No. 4 of the Bern Convention and Annex I of the EU Habitats Directive. Thus, in terms of the conservation of rare habitat types, the value of this Emerald Network site has increased substantially, both qualitatively and quantitatively, following the loss of the reservoir.

While protected natural habitats of European importance are actively developing on the bed of the former reservoir, the natural habitats that existed downstream of the former Kakhovka HPP dam, within the temporarily flooded area, suffered substantial losses (see the section **Environmental Consequences of the Destruction of the Kakhovka HPP. Biodiversity**).

34 Information as of October 2023.

CONCLUSIONS

The terrorist attack on the Kakhovka HPP on 6 June 2023 was the most destructive short-term environmental impact in the history of Ukraine. It resulted in substantial economic losses and the destruction of ecosystems of critical importance for biodiversity. The destruction of the dam is regarded as an act of ecocide.

Over the past 68 years, economic activities in southern Ukraine have largely depended on water supplied from the Kakhovka Reservoir. Within a year after the reservoir disappeared, the region had largely adapted to the new conditions by relying on alternative water supply sources and power generation. Three new water pipelines were constructed to supply water for domestic and industrial needs, while enterprises in Dnipropetrovsk Region and the Zaporizhzhia Nuclear Power Plant now obtain water from groundwater sources.

The irrigation infrastructure of the Kakhovka hydropower complex has been destroyed, while most irrigated land is now mined or contaminated with toxic substances, including heavy metals, making its use impossible even after de-occupation. The decline in agricultural production in southern Ukraine is primarily the result of the military occupation rather than the destruction of the Kakhovka HPP dam. Therefore, the existence of the reservoir itself is not the deciding factor in restoring irrigation in the region.

The destruction of the Kakhovka HPP caused a large-scale environmental disaster that fundamentally transformed the ecosystems that had developed in the region during the existence of the reservoir. These changes affected three key zones: the former reservoir bed, flooded areas, and the northwestern Black Sea.

On the exposed reservoir bed, benthic organisms disappeared, while isolated water bodies formed and became traps for fish. The mass mortality of aquatic organisms caused secondary water pollution. Within the zone of catastrophic flooding, mass mortality of numerous species, including rare species protected under international conventions, was recorded. As a result, protected areas and Emerald Network sites were severely affected. More than 80% of the flooded area is protected at both the national and international level.

The northwestern Black Sea was affected by eutrophication, cyanobacterial blooms, and changes in salinity.

Despite its severe negative impacts, the disaster also created conditions for the spontaneous recovery of natural ecosystems, including the restoration of the free-flowing course of the Dnipro River along a 250-km stretch. Migratory fish populations are recovering within the river channel, and new spawning grounds are developing. Native plant species, including willows and poplars, have begun to regenerate across the drained areas, while floodplain habitats and their characteristic biodiversity are also being restored.

The floodplain forests of Velykyi Luh are climate-resilient, reflecting the natural condition of the Dnipro River floodplain. The experience of nature recovery on the site of the former Kakhovka Reservoir may provide an important case study for understanding the consequences of anthropogenic disasters and planning the restoration of natural ecosystems in Ukraine and beyond.

The assessment of the environmental consequences of the terrorist attack remains limited due to the inaccessibility of the affected areas and the lack of accurate quantitative data verified in the field. Comprehensive studies have been delayed by the need for mine clearance, which may result in the loss of part of the evidence as ecosystems continue to recover naturally. In the future, researchers will primarily be able to document the extent of ecosystem recovery rather than the scale of ecosystem destruction that occurred in 2023. Changes in the IUCN Red List status of threatened species resulting from the disaster also create new opportunities for estimating environmental damage. Further analyses of soil samples and refinement of impact assessments are expected to substantially increase quantitative estimates of environmental losses and support their monetary valuation.

Decisions regarding the future of the former Kakhovka Reservoir should also consider the consequences of blowing up the dam. Contamination by toxic substances makes the area unsuitable for agriculture, while the natural regeneration of forest vegetation calls into question the feasibility of constructing a new reservoir, as this would require the destruction of the largest contiguous forest ecosystem in Ukraine's steppe zone.

Ukraine faces the challenge of developing a modern scenario for the post-war recovery of its southern region, including decisions on whether to construct a new reservoir or pursue alternative solutions. The traditional understanding of recovery focuses on rebuilding infrastructure and the economy. However, the quality of life in the region depends directly on the condition of natural ecosystems, including water resources, air quality, soil fertility, climate, and opportunities for recreation. Therefore, the restoration of nature provides the foundation for the region's sustainable development and may ultimately prove more effective than the Soviet model established in the 1950s.

From the first weeks since the destruction of the Kakhovka HPP, the authors of this review, together with scientific institutions and partner organizations, have been studying the processes of natural recovery. The knowledge gained will contribute to Ukraine's progress towards European environmental objectives and will provide the basis for future decisions relating to the area. The authors' vision for its future use are presented in a separate publication "Velykyi Luh or the Kakhovka Reservoir: A Modern Vision".

GLOSSARY

This report uses specialized terminology from the fields of biology, geography, geochemistry, and hydraulic engineering, as well as terms that may be unfamiliar outside Ukraine and therefore require explanation, or that are used in this report in a specific sense.

Velykyi Luh. In Ukrainian, the word *luh* means a floodplain forest, that is, a forest flooded during seasonal floods. A similar-looking and similarly pronounced word in Russian has a completely different meaning of moist grassland. Its Ukrainian equivalents are *luka* or *obolon*, and it refers to a grassland ecosystem within a river floodplain. The name *Velykyi Luh* is a well-known toponym used to denote the floodplain forest that once occupied the Dnipro River valley between Khortytsia Island and the present-day city of Nova Kakhovka, which was subsequently flooded and transformed into the Kakhovka Reservoir. Thus, *Velykyi Luh* is the forest on the site where the Kakhovka Reservoir was created.

Creation of the reservoir. Some government authorities and other stakeholders refer to the future of the Kakhovka Reservoir as its "restoration." The authors of this report do not agree with this terminology and consider the term "creation" of a new reservoir to be more appropriate. If a decision is made to build a new hydropower plant on the site of the former one, large areas where natural ecosystems have already recovered would have to be flooded again to create a new reservoir.

Habitat / biotope. In this publication, the terms *habitat* and *biotope* are used exclusively in the sense defined by Resolution No. 4 of the Bern Convention and Annex I to the EU Habitats Directive, referring to a terrestrial or aquatic area, whether natural or semi-natural, distinguished by its geographical, abiotic, and biotic characteristics.

Bern Convention. The Convention on the Conservation of European Wildlife and Natural Habitats, adopted in Bern, Switzerland, on 19 September 1979 and ratified by Ukraine on 29 October 1996.

Ecosystem services. The direct and indirect benefits that people obtain from the functioning of natural ecosystems, including provisioning services (such as food and water), regulating services (such as climate regulation and the purification of air and water), supporting services (such as soil formation and photosynthesis), and cultural services (such as recreation).

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APPENDICES

1.1. Protected Areas Affected Downstream of the Kakhovka HPP Dam

Biosphere Reserve

1. Black Sea Biosphere Reserve (109,254.8 ha)

National Nature Parks

2. Biloberezhzhia Sviatoslava (35,223.15 ha)
3. Lower Dnipro (80,177.80 ha)
4. Tuzly Lagoons (27,865 ha)
5. Oleshky Sands (11,671.06 ha)

Regional Landscape Park

6. Kinburn Spit (17,800 ha)

Reserves

7. Soliane Lake Hydrological (120 ha)
8. Bakaiskyi Forest (420 ha)
9. Berezovi Kolky Forest (1,312 ha)
10. Stanislavskyi Landscape (659 ha)
11. Oleksandrivskyi Landscape (996 ha)
12. Inhulets Estuary Botanical (50 ha)
13. Khrestova Saga Botanical (30 ha)
14. Petrovo-Solonyskyi Landscape (300 ha)
15. Shaby Botanical (20 ha)
16. Yelyzavetivka Botanical (10 ha)
17. Ivano-Kepine Botanical (25 ha)
18. Bakaiskyi Zholob General Zoological (1,680 ha)
19. Korsunskyi General Zoological (3,357 ha)
20. Shyroka Balka Botanical (116 ha)
21. Sofiivskyi Botanical (194 ha)
22. Yahorlyk Ornithological (30,300 ha)
23. Sahy Landscape (500 ha)
24. Bobrove Lake Landscape (50 ha)
25. Kolo Hleia Landscape (45 ha)
26. Zmiinyi Island General Zoological (232 ha)
27. Zernov's Phyllophora Field Botanical (402,500 ha)

Protected Tracts

28. Tsiurupynsk Pine Forest (290 ha)
29. Starozburivka Acacia Forest (14 ha)
30. Hola Prystan Acacia Forest (42 ha)

Natural Monuments

31. Krynky Beaver Settlement, Zoological (5 ha)
32. Shylova Balka Spring, Hydrological
33. Kozatske Spring, Hydrological
34. Bilozerski Springs, Hydrological (1,983 ha)
35. Mykilske Snake Settlement, Zoological (4 ha)
36. Poniativka Snake Settlement, Zoological (5 ha)
37. Part of Hopry Lake, Hydrological (5 ha)
38. Pedunculate Oak (7 sites)
39. Grove of Oaks, Botanical
40. Poplars, Botanical
41. Grove of Veteran Oaks, Botanical
42. Black Locust Stand, Botanical
43. Veteran Oaks, Botanical
44. Memorial Oaks, Botanical
45. Veteran Plane Trees, Botanical
46. Veteran Pines, Botanical

Parks – Monuments of Landscape Art

47. Hopry Sanatorium Park (18 ha)
48. Lower Dnipro Experimental Station Arboretum (3 ha)

1.2. Protected Areas Affected Upstream of the Kakhovka HPP Dam

National Nature Parks

1. Kamianska Sich (12,261.14 ha)
2. Velykyi Luh (16,756 ha), including:
   - Panai Regional Landscape Park;
   - Lisovyi Masyv na Lysii Hori Landscape Reserve of Local Importance;
   - Krutoskhyly Kakhovskoho Reservoira Landscape Reserve of National Importance;
   - Velyki i Mali Kuchuhury Ornithological Reserve of National Importance.

Reserves

3. Dnipro Rapids General Zoological (1,383 ha)
4. Kairska Balka Landscape (664.9 ha)
5. Soloviinyi Hai Botanical (6.5 ha)
6. Urochyshche Mai Hora Landscape (68 ha)
7. Kamianskyi Forest Landscape (239 ha)
8. Ivanivskyi Pine Forest Landscape (797.3 ha)
9. Vodianski Kuchuhury Landscape (1,237.5 ha)

Protected Tracts

10. Stoiany Protected Tract (15 ha)
11. Malokakhovskyi Pine Forest Protected Tract (177 ha)

Natural Monument

12. Group of Veteran Oaks, Botanical (2 ha)

Park–Monument of Landscape Art

13. Kakhovka Forestry Enterprise Arboretum (15 ha)

2. Proposed Protected Areas Affected by the Destruction of the Kakhovka HPP Dam in Kherson Region[1]

National Nature Park

1. Dolyna Kurhaniv (8,000 ha)

Reserves

2. Burhunska Balka Landscape (745 ha)
3. Viazemskyi Landscape (637 ha)
4. Donchykha Landscape (2,400 ha)
5. Zabaryne Landscape (971 ha)
6. Korovodynskyi Landscape (744 ha)
7. Tiahynska Balka Landscape (967 ha)
8. Kardashynske Boloto Botanical (1,750 ha)
9. Lesovyi Canyon Landscape (35 ha)
10. Vilkhovi Sahy Botanical (142.3 ha)
11. Orlovskyi Botanical (368.1 ha)

1 After: Moisiienko, I. I., Khodosovtsev, O. Ye., Pylypenko, I. O., Boiko, M. F., Malchykova, D. S., Klymenko, V. M., Ponomarova, A. A., Zakharova, M. Ya., & Darmostuk, V. V. (2020). *Prospective Protected Areas of Kherson Region*. Kherson: Helvetyka Publishing House. DOI: 10.32782/978-966-992-0492/1-166.

Natural Monuments

12. Baidy-Bombandery, Complex (7 ha)
13. Miocene Outcrops near the Village of Lvove, Geological (41.7 ha)
14. Ivanivskyi Oak, Botanical
15. Mariika's Oak, Botanical
16. Poplars of Mstyslav and Oleksii Nestruiev, Botanical
17. Poplar of Oleksii Nestruiev (Senior), Botanical
18. Poplar of Sofiia Falz-Fein, Botanical
19. Starozburivka Poplar, Botanical
20. Olha's Ash, Botanical
21. Burial Mound near Bratske, Complex
22. Burial Mound near Ochakivske, Complex

3.1. Emerald Network Sites Affected Upstream of the Kakhovka HPP Dam

1. UA0000106 Kakhovske Reservoir (218,119 ha)
2. UA0000037 Velykyi Luh National Nature Park (16,755 ha)

3.2. Emerald Network Sites Affected Downstream of the Kakhovka HPP Dam

3. UA0000192 Lower Dnipro (52,386 ha)
4. UA0000107 Oleshkivski Pisky (46,259 ha)
5. UA0000321 Lower Inhulets River Valley (13,570.98 ha)
6. UA0000215 Kinburnska Kosa (46,588 ha)
7. UA0000017 Black Sea Biosphere Reserve (115,873 ha)
8. UA0000097 Biloberezhzhia Sviatoslava National Nature Park (35,242 ha)
9. UA0000109 Dniprovsko-Buzkyi Lyman (71,276 ha)
10. UA0000336 Loess Outcrops of the Dnipro Estuary (589.20 ha)
11. UA0000572 Olviiska Khora (1,319.56 ha)
12. UA0000018 Danube Biosphere Reserve (only the marine area was affected, representing a small part of the site)
13. UA0000139 Zernov Phyllophora Field Zakaznyk (403,997 ha)

4. Types of Natural Habitats under Resolution No. 4 of the Bern Convention Affected by the Destruction of the Kakhovka HPP Dam

1. *C1.222 Floating Hydrocharis morsus-ranae rafts*
2. *C1.32 Free-floating vegetation of eutrophic waterbodies*
3. *C1.33 Rooted submerged vegetation of eutrophic waterbodies*
4. *C1.3411 Ranunculus communities in shallow water*
5. *C2.27 Mesotrophic vegetation of fast flowing streams*
6. *C2.28 Eutrophic vegetation of fast flowing streams*
7. *C2.33 Mesotrophic vegetation of slow-flowing streams*
8. *C2.34 Eutrophic vegetation of slow-flowing streams*
9. *C3.2 Water-fringing reedbeds and tall helophytes other than canes*
10. *C3.4 Species-poor beds of low growing water-fringing of amphibious communities*
11. *C3.51 EuroSiberian dwarf annual amphibious swards (but excluding C3.5131 Toad-rush swards)*
12. *D5.2 Beds of large sedges normally without free-standing water*
13. *E1.9 Open non-Mediterranean dry acid and neutral grassland, including inland dune grassland*
14. *E3.4 Moist or wet eutrophic and mesotrophic grassland*
15. *E5.4 Moist or wet tall-herb and fern fringes and meadows*
16. *F9.1 Riverine scrub*
17. *G1.11 Riverine Salix woodland*
18. *G1.21 Riverine Fraxinus-Alnus woodland, wet at high but not at low water*
19. *G1.22 Mixed oak–elm–ash woodland of great rivers*
20. *X35 Inland Sand Dunes*
21. *H3.1 Acid siliceous inland cliffs*

5. Plant, Fungal and Lichen Species Included in the Red Data Book of Ukraine and Previously Recorded within the Zone of Catastrophic Flooding

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
1	*Chara braunii* C.C.Gmel	VU		
2	*Chara canescens* Desv. & Loisel in Loisel	R		
3	*Scytinium schraderi* (Ach.) Otalora, P.M.Jorg. & Wedin	VU		
4	*Squamarina cartilaginea* (With.) P. James	NE		
5	*Xanthoparmelia convoluta* (Kremp.) Hale	VU		
6	*Pisolithus arhizus* (Scop.) Rauschert	R		
7	*Aldrovanda vesiculosa* L.	R	EN	
8	*Alyssum savranicum* Andrz.	EN		
9	*Anacamptis coriophora* (L.) R.M. Bateman, Pridgeon & M.W. Chase	VU		
10	*Anacamptis morio* (L.) R.M. Bateman, Pridgeon & M.W. Chase	VU		
11	*Anacamptis palustris* (Jacq.) R.M. Bateman, Pridgeon & M.W. Chase	VU		
12	*Anacamptis picta* (Loisel.) R.M. Bateman	VU		
13	*Betula borysthenica* Klokov	R		
14	*Dactylorhiza incarnata* (L.) Soy	VU		
15	*Goniolimon graminifolium* (Aiton) Boiss	VU		
16	*Leucojum aestivum* L.	VU		
17	*Centaurea breviceps* Iljin	VU		
18	*Epipactis palustris* (L.) Crantz	VU		
19	*Nymphoides peltata* (S.G.Gmel.) O.Kuntze	VU		
20	*Pulsatilla pratensis* (L.) Mill.	NE		HDIV, HDII
21	*Stipa borysthenica* Klokov ex Prokudin	VU		

Red Data Book of Ukraine categories:
VU – Vulnerable
EN – Endangered
DD – Data Deficient
NE – Not Evaluated
R – Rare

IUCN Red List categories:
NT – Near Threatened
CR – Critically Endangered
EN – Endangered

6. Plant Communities Included in the Green Book of Ukraine and Previously Recorded within the Zone of Catastrophic Flooding

№	Plant community	Conservation status
1	Communities of the *Aldrovandeta vesiculosae*	Endangered
2	Communities of the *Trapeta natantis*	Typical
3	Communities of the *Batrachieta rionii*	Typical
4	Communities of the *Betuleta borysthenicae*	Not Evaluated
5	Communities of the *Nuphareta luteae*	Typical
6	Communities of the *Stipeta borysthenicae*	Endangered
7	Communities of the *Schoenoplecteta littoralis*	Rare
8	Communities of the *Ceratophylleta tanaitici*	Typical
9	Communities of the *Ceratophylleta submersi*	Typical
10	Communities of the *Nymphaeeta candidae*	Not Evaluated
11	Communities of the *Glycerieta arundinaceae*	Typical
12	Communities of the *Nymphoideta peltatae*	Vulnerable
13	Communities of the *Potamogetoneta sarmatici*	Rare
14	Communities of the *Salvinieta natantis*	Typical

International Agreements and Conventions

AC – Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS);
CMS – Convention on the Conservation of Migratory Species of Wild Animals (CMS);
HDII – Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive), Annex II;
HDIV – Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive), Annex IV;
HDV – Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive), Annex V;
BC2 – Convention on the Conservation of European Wildlife and Natural Habitats, Annex 2;
BC3 – Convention on the Conservation of European Wildlife and Natural Habitats, Annex 3;
BR6 – Convention on the Conservation of European Wildlife and Natural Habitats, Resolution 6:
EB – Agreement on the Conservation of Populations of European Bats (EUROBATS).

7. Plant, Fungal and Lichen Species Included in the Red Data Book of Ukraine and Previously Recorded within the Zone of Catastrophic Flooding

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
Mammals (Mammalia)				
1	*Tursiops truncatus* Montagu, 1821	VU		BC2, CMS, BR6, HDIV, HDII, AC
2	*Crocidura leucodon* Hermann, 1780	DD		
3	*Castor fiber* Linnaeus, 1758			BC3, BR6, HDIV, HDII
4	*Nyctalus leisleri* Kuhl, 1817	VU		BC2, CMS, HDIV, EB
5	*Nyctalus noctula* Schreber, 1774	VU		BC2, CMS, HDIV, EB
6	*Lutra lutra* Linnaeus, 1758	VU		BC2, BR6, HDIV, HDII
7	*Plecotus austriacus* Fischer, 1829	VU		BC2, CMS, HDIV, EB
8	*Mustela erminea* Linnaeus, 1758	VU		BC3
9	*Delphinus delphis* Linnaeus, 1758	VU		Bonn, HDIV, AC
10	*Stylodipus telum* Lichtenstein, 1823	VU	EN	
11	*Alces alces* Linnaeus, 1758	VU		BC3
12	*Eptesicus serotinus* Schreber, 1774	VU		EB, BC2
13	*Neomys anomalus* Cabrera, 1907	VU		BC3
14	*Sicista loriger* (Nathusius, 1840)	EN	CR	BC2, BR6, HDII, HDIV
15	*Phocoena phocoena* Linnaeus, 1758	EN		BC2, CMS, BR6, HIV, HDII, AC
16	*Pipistrellus kuhlii* Kuhl, 1817	VU		BC2, CMS, HDIV, EB
17	*Pipistrellus nathusii* Keyserling & Blasius, 1839	VU		BC2, CMS, HDIV, EB
18	*Pipistrellus pygmaeus* Leach, 1825	VU		BC2, CMS, HDIV, EB
19	*Myotis daubentonii* Kuhl, 1817	VU		BC2, CMS, HDIV, EB
20	*Ellobius talpinus* Pallas, 1770	EN		
21	*Spalax arenarius* Reshetnik, 1939	VU	EN	
22	*Spalax zemni* Erxleben, 1777	VU	EN	
23	*Allactaga major* Kerr, 1792	EN	NT	
24	*Mustela putorius* Linnaeus, 1758	VU		BC3, HDV,
25	*Spermophilus suslicus* Guldenstaedt, 1770	EN		BC2, BR6, HDIV, HDII
26	*Spermophilus odessanus* Nordmann, 1840	EN		
27	*Nothocricetulus migratorius* Pallas, 1773	VU	NT	
28	*Desmana moschata* Linnaeus, 1758	EN		BR6, B2,

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
Birds (Aves)				
29	*Phalacrocorax pygmaeus* Pallas, 1773	EN		BC2, CMS, AEWA, BR6, BDI
30	*Falco cherrug* Gray, 1834	VU		BC2, CMS, BR6, BDI
31	*Aquila chrysaetos* Linnaeus, 1758	VU		BC2, CMS, BR6, BDI
32	*Falco naumanni* Fleischer, 1818	EN		BC2, CMS, BR6, BDI
33	*Emberiza melanocephala* Scopoli, 1769	R		BC2
34	*Bucephala clangula* Linnaeus, 1758	R		BC2, CMS, AEWA, BDII
35	*Columba oenas* Linnaeus, 1758	VU		BC3, BDII
36	*Limosa limosa* Linnaeus, 1758	VU		BC3, CMS, AEWA, BDII
37	Г *Anser erythropus* Linnaeus, 1758	VU		BC2, CMS, AEWA, BR6 BDI
38	*Glareola pratincola* Linnaeus, 1766	R		BC2, CMS, AEWA, BR6, BDI
39	*Otis tarda* Linnaeus, 1758	EN		BC2, CMS, BR6, BDI
40	*Grus grus* Linnaeus, 1758	R		BC2, CMS, AEWA, BR6, BDI
41	*Anthropoides virgo* Linnaeus, 1758	EN		BC2, CMS, AEWA,
42	*Circaetus gallicus* Gmelin, 1788	R		BC2, CMS, BR6, BDI
43	*Rufibrenta ruficollis* Pallas, 1769	VU		BC2, CMS, AEWA, BR6, BDI
44	*Buteo rufinus* Cretzschmar, 1827	R		BC2, CMS, BR6, BDI
45	*Nycticorax nycticorax* Linnaeus, 1758			BC2, BR6, BDI
46	*Tringa stagnatilis* Bechstein, 1803	EN		BC2, CMS, AEWA
47	*Plegadis falcinellus* Linnaeus, 1766	VU		BC2, CMS, AEWA, BR6, BDI
48	*Platalea leucorodia* Linnaeus, 1758	VU		BC2, CMS, AEWA, BR6, BDI
49	*Mergus serrator* Linnaeus, 1758	VU		BC3, CMS, AEWA, BDII
50	*Sterna albifrons* Pallas, 1764	R		BC2, CMS, AEWA, BR6, BDI
51	*Numenius arquata* Linnaeus, 1758	EN		BC3, CMS, AEWA, BDII
52	*Himantopus himantopus* Linnaeus, 1758	VU		BC2, CMS, AEWA, BR6, BDI
53	*Numenius phaeopus* Linnaeus, 1758	EN		BC3, CMS, AEWA, BDII
54	*Haematopus ostralegus* Linnaeus, 1758	VU		BC3, BDII
55	*Cygnus bewickii* Yarrell, 1830	R		BC2, CMS, AEWA, BR6, BDI
56	*Burhinus oedicnemus* Linnaeus, 1758	NE		BC2, CMS, BR6, BDI

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№	Species	Red Data Book of Ukraine	IUCN	International conservation status
57	*Ciconia nigra* Linnaeus, 1758	R		BC2, CMS, AEWA, BR6, BDI
58	*Circus pygargus* Linnaeus, 1758	VU		BC2, CMS, BR6, BDI
59	*Circus cyaneus* Linnaeus, 1766	R		BC2, CMS, BR6, BDI
60	*Circus macrourus* Gmelin, 1771	EN		BC2, CMS, BR6, BDI
61	*Larus ichthyaetus* Pallas, 1773	EN		BC3, CMS, AEWA
62	*Aquila pomarina* Brehm, 1831	R		BC2, CMS, BR6, BDI
63	*Anas strepera* Linnaeus, 1758	R		BC2, CMS, AEWA, BDII
64	*Tadorna ferruginea* Pallas, 1764	VU		BC2, CMS, AEWA, BR6, BDI
65	*Hieraaetus pennatus* Gmelin, 1788	R		BC2, CMS, BR6, BDI
66	*Pelecanus crispus* Bruch, 1832	EN		BC2, CMS, AEWA, BR6, BDI
67	*Podiceps grisegena* Boddaert, 1783	VU		BC2, CMS, AEWA
68	*Charadrius hiaticula* Linnaeus, 1758	R		BC2, CMS, AEWA
69	*Charadrius alexandrinus* Linnaeus, 1758	VU		BC2, CMS, AEWA,BR6, BDI
70	*Bubo bubo* Linnaeus, 1758	R		BC2, BR6, BDI
71	*Somateria mollissima* Linnaeus, 1758	VU		BC3, CMS, AEWA, BDII
72	*Oxyura leucocephala* Scopoli, 1769	EN		BC2, CMS, AEWA, BR6
73	*Falco peregrinus* Tunstall, 1771	R		BC2, CMS, BR6, BDI
74	*Coracias garrulus* Linnaeus, 1758	EN		BC2, CMS, BR6, BDI
75	*Pandion haliaetus* Linnaeus, 1758	EN		BC2, CMS, BR6, BDI
76	*Asio flammeus* Pontoppidan, 1763	R		BC2, BR6, BDI
77	*Otus scops* Linnaeus, 1758	R		
78	*Lanius excubitor* Linnaeus, 1758	R		BC2
79	*Lanius senator* Linnaeus, 1758	R		BC2
80	*Ardeola ralloides* Scopoli, 1769	R		BC2, BR6, BDI
81	*Ardea purpurea* Linnaeus, 1766			BC2, Bonn, AEWA, BR6, BDI
82	*Ardea cinerea* Linnaeus, 1758			BC3
83	*Recurvirostra avosetta* Linnaeus, 1758	VU		BC2, CMS, AEWA, BR6, BDI
84	*Casmerodius albus* (Linnaeus, 1758)			BC2, Bonn, AEWA, BR6, BDI
85	*Egretta garzetta* (Linnaeus, 1766)			BC2, BR6, BDI
86	*Aythya nyroca* Guldenstadt, 1770	VU		BC3, CMS, AEWA, BR6, BDI
87	*Netta rufina* Pallas, 1773	R		BC3, CMS, AEWA, BDII
88	*Sturnus roseus* Linnaeus, 1758	R		BC2
89	*Milvus migrans* Boddaert, 1783	VU		BC2, CMS, BR6, BDI

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
	Amphibians (Amphibia)			
90	*Pelophylax esculentus* (Linnaeus, 1758)			BC3, HDV
91	*Pelophylax ridibundus* (Pallas, 1771)			BC3, HDV
92	*Bombina bombina* (Linnaeus, 1761)			BR6, HDIV, HDII
93	*Hyla orientalis* Bedriaga, 1890			BC3, HDV
94	*Triturus dobrogicus* Kiritzescu, 1903	VU		BC2, BR6, HDII,
95	*Emys orbicularis* (Linnaeus, 1758)			BC2, BR6, HDIV, HDII
	Reptiles (Reptilia)			
96	*Natrix tessellata* (Laurenti, 1768)			BC2, HDIV
97	*Natrix natrix* (Linnaeus, 1758)			BC3
98	*Vipera renardi* Christoph, 1861	VU		BC2, BR6, HDIV, HDII
99	*Coronella austriaca* Laurenti, 1768	VU		BC2, HDIV
100	*Dolichophis caspius* Gmelin, 1789	VU		BC2, HDIV
101	*Elaphe sauromates* Pallas, 1811	VU		BC2, BR6, HDIV, HDII
102	*Lacerta viridis* Laurenti, 1768	VU		BC2, HDIV
	Ray-finned fishes (Actinopterygii)			
103	*Benthophiloides brauneri* Beling & Iljin, 1927	R		
104	*Benthophilus stellatus* Sauvage, 1874	R		
105	*Huso huso* Linnaeus, 1758	EN		BC3, CMS
106	*Anguilla anguilla* Linnaeus, 1758	EN		
107	*Umbrina cirrosa* Linnaeus, 1758	R		BC3
108	*Sciaena umbra* Linnaeus, 1758	R		
109	*Gymnocephalus acerinus* Guldenstadt, 1774	EN		
110	*Serranus scriba* Linnaeus, 1758	R		
111	*Salmo labrax* Pallas, 1814	EN		
112	*Lota lota* Linnaeus, 1758	VU		
113	*Syngnathus variegatus* Pallas, 1814	VU		
114	*Syngnathus tenuirostris* Rathke, 1837	VU		
115	*Hippocampus guttulatus* Cuvier, 1829	VU		
116	*Chelidonichthys lucerna* Linnaeus, 1758	R		
117	*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833	EN		CMS, HDV,
118	*Percarina demidoffii* Nordmann, 1840	R		
119	*Callionymus risso* Lesueur, 1814	R		
120	*Acipenser stellatus* Pallas, 1771	EN		BC3, CMS, HDV,
121	*Acipenser ruthenus* Linnaeus, 1758	VU		BC3, CMS, HDV,
122	*Sander marinus* Cuvier, 1828	EN		

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№	Species	Red Data Book of Ukraine	IUCN	International conservation status
	Insects (Insecta)			
123	*Euchloe ausonia* Hubner, 1804	VU		
124	*Ammophila sareptana* Kohl, 1884	R		
125	*Andrena chrysopus* Perez, 1903	R		
126	*Anoplius samariensis* Pallas, 1771	R		
127	*Arge beckeri* Tournier, 1889	R		
128	*Libelloides macaronius* Scopoli, 1763	VU		
129	*Sympetrum pedemontanum* O.F.Muller, 1766	VU		
130	*Megachile giraudi* Gerstaecker, 1869	R		
131	*Bolivaria brachyptera* Pallas, 1773	VU		
132	*Marumba quercus* Denis & Schiffermuller, 1775	R		
133	*Acherontia atropos* Linnaeus, 1758	R		
134	*Proserpinus proserpina* Pallas, 1772	R		BC2, HDIV
135	*Hemaris tityus* Linnaeus, 1758	R		
136	*Callimorpha dominula* Linnaeus, 1758	VU		
137	*Rhyparioides metelkana* Lederer, 1861	EN		
138	*Chelis maculosa* Denis & Schiffermuller, 1775	VU		
139	*Acanthaclisis occitanica* Villers, 1789	EN		
140	*Cerambyx cerdo* Linnaeus, 1758	VU		BR6, HDIV, HDII
141	*Dorcadion equestre* Laxmann, 1770	VU		
142	*Aromia moschata* Linnaeus, 1758	VU		
143	*Hoplitis fulva* Eversmann, 1852	R		
144	*Dasypoda spinigera* Kohl, 1905	R		
145	*Bombus armeniacus* Radoszkowski, 1877	EN		
146	*Bombus argillaceus* Scopoli, 1763	VU		
147	*Bombus laesus* Morawitz, 1875	VU		
148	*Bombus muscorum* Linnaeus, 1758	R		
149	*Bombus zonatus* Smith, 1854	R		
150	*Bombus fragrans* Pallas, 1771	EN		
151	*Bombus ruderatus* Fabricius, 1775	R		
152	*Saga pedo* Pallas, 1771	R		BC2, HDIV
153	*Anax imperator* Leach, 1815	VU		
154	*Dolerus ciliatus* Konow, 1891	R		
155	*Eumenes tripunctatus* Christ, 1791	VU		
156	*Empusa pennicornis* Pallas, 1773	VU		

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
157	*Empusa fasciata* Brulle, 1832	VU		
158	*Lucanus cervus* Linnaeus, 1758	R		BC3, BR6, HDII,
159	*Zegris eupheme* Esper, 1805	EN		
160	*Iris polystictica* Fischer-Waldheim, 1846	R		
161	*Campsoscolia klugii* Vander Linden, 1827	EN		
162	*Cucullia argentina* Fabricius, 1787	R		
163	*Cucullia argentea* Hufnagel, 1766	R		
164	*Orgyia dubia* Tauscher, 1806	VU		
165	*Bittacus italicus* Muller, 1786	VU		
166	*Callimenus multituberculatus* Fischer-Waldheim, 1833	EN		
167	*Zygaena laeta* Hubner, 1790	EN		
168	*Calopteryx virgo* Linnaeus, 1758	VU		
169	*Calosoma sycophanta* Linnaeus, 1758	VU		
170	*Xylocopa valga* Gerstaecker, 1872	R		
171	*Xylocopa iris* Christ, 1791	EN		
172	*Xylocopa violacea* Linnaeus, 1758	R		
173	*Satanas gigas* Eversmann, 1855	VU		
174	*Asilus crabroniformis* Linnaeus, 1758	VU		
175	*Leucomigus candidatus* Pallas, 1771	R		
176	*Liometopum microcephalum* Panzer, 1798	R		
177	*Boreus westwoodi* Hagen, 1866	VU		
178	*Hamearis lucina* Linnaeus, 1758	VU		
179	*Larra anathema* Rossi, 1790	NE		
180	*Mantispa styriaca* Poda, 1761	R		
181	*Megarhyssa superba* Schrank, 1781	R		
182	*Melitturga clavicornis* Latreille, 1806	VU		
183	*Parnassius mnemosyne* Linnaeus, 1758	VU		BC2, HDIV
184	*Zerynthia polyxena* Denis & Schiffermuller, 1775	VU		BC2, HDIV
185	*Euphydryas aurinia* Rottemburg, 1775	VU		BC2, BR6, HDII,
186	*Polochrum repandum* Spinola, 1805	VU		
187	*Hipparchia statilinus* Hufnagel, 1766	R		
188	*Saturnia pyri* Denis & Schiffermuller, 1775	VU		
189	*Eudia pavonia* Linnaeus, 1758	R		
190	*Eudia spini* (Denis & Schiffermuller, 1775)	EN		

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№	Species	Red Data Book of Ukraine	IUCN	International conservation status
191	*Pseudophilotes bavius* Eversmann, 1832	VU		BR6, HDIV, HDII
192	*Plebejus pylaon* Fischer de Waldheim, 1832	VU		
193	*Megascolia maculata* Drury, 1773	NE		
194	*Periphanes delphinii* Linnaeus, 1758	VU		
195	*Emus hirtus* Linnaeus, 1758	R		
196	*Tasgius pliginskii* Bernhauer, 1915	VU		
197	*Stizus bipunctatus* Smith, 1856	R		
198	*Cephalota besseri* Dejean, 1826	R		
199	*Erythromma lindenii* Selys, 1840	R		
200	*Catocala sponsa* Linnaeus, 1767	R		
201	*Tapinoma kinburni* Karawajew, 1937	R		
202	*Tomares nogelii* Herrich-Schaffer, 1851	VU		
203	*Triphysa phryne* Pallas, 1771	VU		
204	*Carabus bessarabicus* Fischer von Waldheim, 1823	VU		
205	*Carabus hungaricus* Fabricius, 1792	VU		BR6, HDIV, HDII,
206	*Ceratophyus polyceros* Pallas, 1771	VU		
Arachnids (Arachnida)				
207	*Galeodes araneoides* Pallas, 1772	R		
Maxillopoda				
208	*Colpocyclops dulcis* Monchenko, 1977	DD		
209	*Colpocyclops longispinosus* Monchenko, 1974	DD		
Branchiopods (Branchiopoda)				
210	*Branchinecta orientalis* Sars, 1901	EN		
211	*Branchinectella media* Schmankewitsch, 1873	VU		
212	*Tanymastix stagnalis* Linnaeus, 1758	VU		
Malacostracans (Malacostraca)				
213	*Kuzmelina kusnezowi* Sowinsky, 1894	DD		
214	*Iphigenella acanthopoda* G. O. Sars, 1896	DD		
215	*Eriphia verrucosa* Forskel, 1775	EN		
216	*Katamysis warpachowskyi* G. O. Sars, 1893	DD		
217	*Niphargogammarus intermedius* Cârâuşu, 1943	DD		
218	*Pontastacus pachypus* (Rathke, 1836)	EN		
219	*Lanceogammarus andrussowi* G.O. Sars, 1896	DD		
220	*Shablogammarus shablensis* Cărăușu, 1943	DD		

№	Species	Red Data Book of Ukraine	IUCN	International conservation status
Gastropods (Gastropoda)				
221	*Laevicaspia lincta* Milaschewitsch, 1908	VU		
222	*Clathrocaspia knipowitschii* Makarov, 1938	EN		
Bivalves (Bivalvia)				
223	*Anodonta cygnea* Linnaeus, 1758	VU		
224	*Adacna fragilis* Milaschewitsch, 1908	VU		
225	Б *Hypanis plicata* Eichwald, 1829	VU		
Clitellates(Clitellata)				
226	*Archaeobdella esmonti* Grimm, 1876	EN		
227	*Hirudo verbana* Carena, 1820	VU		
228	*Trocheta danastrica* Stschegolew, 1938	VU		

Scientific Publication

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