A rapid risk assessment of the environmental impact of the Kakhovka Dam breach during the Ukraine conflict

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Assessing habitat and biodiversity loss in active conflict zones is a major challenge[1]. Independent scientific evidence on wartime impacts is essential to inform the environmental priorities of reconstruction and recovery plans. Such plans are typically developed during the conflict resolution period[2], but the relevant evidence has historically emerged many years after conflict resolution. Here, we describe the early scientific assessment of the potential environmental impact caused by the Kakhovka Dam breach during the conflict in Ukraine, and highlight the need to build on this initial evidence to inform biodiversity recovery plans in the region.

The Kakhovka Dam is located on the lower Dnipro River in the Kherson region of Ukraine, an internationally recognised biodiversity hotspot that currently lies at the ‘front line’ of the ongoing conflict. On 6 June 2023, the dam, which provides water for the Kakhovka hydroelectric plant, suffered a catastrophic breach. The cause of the breach is disputed. In the immediate aftermath, the international community understandably focused on addressing humanitarian impacts of displaced communities and disruption and contamination of drinking water supplies. In the days following the breach, limited evidence was publicly available through which to assess the scale of the impact on downstream habitats.

On 9 June 2023, the UK Foreign and Commonwealth Development Office (FCDO) commissioned a rapid assessment of the immediate environmental impacts of the destruction of the Kakhovka Dam. The purpose of this assessment, initially, was to inform discussions on the dam breach impacts during the Ukraine Recovery Conference, 21-23

June, 2023, London. URC 2023 was co-chaired by the UK and Ukrainian Governments and raised over $60 billion towards Ukraine's recovery and reconstruction.

Between 12th and 26th June 2023, a multidisciplinary team of UK scientists developed and applied a risk-assessment approach combining hydrological and hydraulic modelling with GIS analyses incorporating 23 geospatial datasets that allowed identification of hazards, habitats and species within the impact zone. Hazard risk assessment was conducted using the UN Disaster Risk Reduction (UNDRR) Programme Hazards Framework[3].

On 4th July 2023, evidence from the UK-led study was reported to the FCDO and its domestic and international stakeholders, including the UK Embassy in Ukraine and the United Nations Environment Programme (UNEP). UNEP were responding to a request for support in assessing impacts of the breach by the Ministry of Environment Protection and Natural Resources (MEPNR) of Ukraine, utilising evidence from the UK study in their report released October 25th 2023[4]. Evidence from the UK study was also requested by the US Centre for Disease Prevention and Control and used to inform the United Nations Children's Fund (UNICEF) coordinated WASH (water, sanitation and hygiene) Cluster in Ukraine.

Here, we summarise the UK report for the FCDO (which can be read in full in ref 5), in the hope that it may prompt further assessments both in this region and in other events. The main findings of the report include:

- Hydraulic modelling indicated a maximum flood extent of around 83,000 hectares, including areas of permanent water; this occurred between 6 and 9 June 2023, depending on the distance downstream of the dam. The temporary flood extent was around 53,000 hectares, consisting of 62% herbaceous wetland, 31% mixed terrestrial non-croplands, 5% built-up land, and less than 2% cropland. Floodwater depth in urban areas reached 2 m and maximum flow speeds on the floodplain reached 1 m/s, with flow speeds exceeding 3 m/s in the river channels up to 15 km downstream of the dam, likely leading to significant short- to medium-term alteration of downstream benthic habitats within the river system.
- 1,087 potential pollution sources were identified within the flood impact zone representing 15 hazard types as classified under the UNDRR Hazard Classification Framework[3] and a total area of 'hazardous land' of ~4,300 ha (**Fig 1**). Potential pollution sources inundated included wastewater treatment works, petrol stations, landfills and industrial infrastructure. Historical pollutants contained within reservoir bed sediments – potentially including mine waste and radioactive substances – along with sediment containing pollutants from the aforementioned sources, may have been mobilised. Chemicals released from these sources include inorganic and organic pollutants known to be highly hazardous and/or to bioaccumulate in trophic networks.
- Over half a million hectares of habitat of conservation importance (including Ramsar and Emerald Network designation) was affected by the dam breach, (**Fig 1**). This includes 138,000 ha downstream of the dam, extending to the Black Sea Biosphere Reserve, 186,000 ha in coastal areas and 205,000 ha upstream of the dam affected by the water draw-off from the reservoir.
- 21 specific habitats with conservation designation were assessed as 'at risk' from more than one hazard type resulting from the dam breach, with eight habitats simultaneously affected by 10 or more hazards.
- The Kakhovka Reservoir was home to about 43 fish species, of which 20 species have commercial value (annual catches amounted to about 2,600 tonnes). Unconfirmed reports citing estimates from the Ukraine State Fisheries Agency

suggested that 28,000 crucian carp (a traditional food species) were lost following the dam failure. Estimates for potential total mature fish losses reach 95,000 tonnes with a commercial value of USD 108 million.

- Habitats in the flooded areas downstream are composed mostly of herbaceous wetlands (around 35,000 ha, 51% of the affected downstream area) in the Dnipro River Delta. These wetlands are a mosaic of rivers, streams, pools, floodplain forests, swamps, reedbeds and sandbars.
- Affected habitats are part of the distributions of 567 species that have a listing the IUCN Red List[6]; 58 of these species have a threat status of vulnerable or worse. Endangered species span all habitat types, including terrestrial (e.g. Great Bustard), freshwater (e.g. Donets ruffe), semi-aquatic (e.g. European mink) and marine (e.g. Harbour porpoise).

The approach developed by the UK study may be applied to provide consistent and comparable risk-assessments for other conflict zones as well as following disasters related to extreme weather events. Our response demonstrates that it is now possible to conduct evidence-based assessments of disaster impacts, even when access to the affected area is severely limited. This early provision of evidence is essential in priming disaster responses and offers a baseline for further scientific assessments of recovery of biodiversity and habitats.

We encourage the international scientific community to build on this initial assessment to further quantify the ecological impacts of the dam breach and the broader conflict in the Lower Dnipro River Basin[7]. To support this process, we call for international coordination to consolidate multiple evidence streams, foster collaborative and transparent monitoring and surveillance programmes, and to ensure open access of relevant data to the wider scientific community. These steps are needed to strengthen evidence provision for post-disaster habitat and biodiversity restoration planning.

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Competing interests

The authors declare no financial/non-financial competing interests.

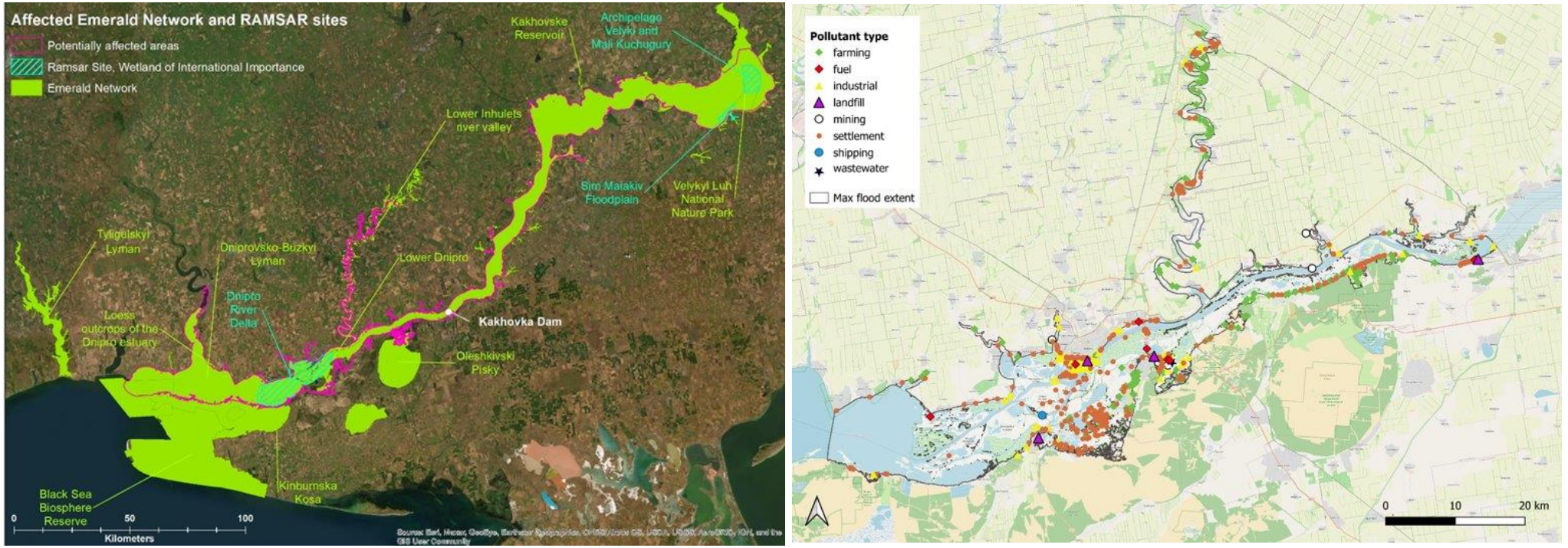

Figure 1. The potential ecological impacts of the Kakhovka Dam breach. a, Areas directly impacted by the Kakhovka Dam breach, either by downstream flooding or drainage of the Kahkovka Reservoir. Estimated peak extent of downstream floodwaters, derived from UNOSAT pre-flood / flooded water extents, upstream pre-flood reservoir boundary from the OpenStreetMap (OSM) water layer; Emerald Network and Ramsar site boundaries derived from the World Database on Protected Areas. b, Location of pollution sources within the maximum hydraulic flood zone identified by the FCDO report using a screen of 23 geospatial datasets, originally sourced from OSM, HydroWaste and the Ukrainian Government. Web links for data sources cited: https://www.unosat.org/products/3618; https://download.geofabrik.de/europe/ukraine.html; https://www.hydrosheds.org/products/hydrowaste; https://help.khoda.gov.ua/index.html