Inter-agency Coordination Group on Environmental Assessments for Ukraine

Policy and technical brief on the use of Earth observations to assess ecosystems damage in Ukraine

May 2024

Policy observations

This brief summarizes information shared in a webinar on Earth observations of ecosystems damage in Ukraine, organized within the framework of the informal inter-agency coordination group on environmental assessments for Ukraine. It has been prepared at the request of participants in the webinar, particularly those representing the Recovery and Reform Support Team at the Ministry of Environmental Protection and Natural Resources of Ukraine.

The seminar was largely technical in nature, but led to some observations of policy relevance:

1. Numerous initiatives, domestic and international, are underway and engaged in data collection and analysis to support Ukraine in identifying the damage done by war to ecosystems in the country. Communication, cooperation and collaboration need to be strengthened, to remove duplication, promote synergies and foster innovation. This seminar represented one such effort.
2. There is no national centre that brings together all of the resultant information to nurture a systematic and broad understanding of the damage done, though the Ministry of Environmental Protection and Natural Resource of Ukraine and the UNDP Coordination Centre for Environmental Damage Assessment could both play a role in this.
3. Such a centre would need to provide access to diverse sources of data, including remotely sensed imagery, incident reports (such as those in Ecodozor), studies and reports, and historical time-series and spatial data from across the country. It should also be a centre of expertise in combining these diverse sources to provide policy-relevant information.
4. Various sensors and platforms can be used to detect physical damage to ecosystems,[1] but the accuracy and reliability of remote measurements depend on measurements on the ground ("ground-truthing").[2] Use of historical measurements on the ground, social media posts and use of multiple sensors (such as high cost very-high-resolution imagery), can overcome this limitation to a degree, but it must always be borne in mind.
5. It was suggested that the legal recognition of environmental damage in Ukraine is inadequate, though this was not the focus of the webinar. One path forward is perhaps the transposition of the EU Environmental Liability Direction, within the country's process of accession to the EU. Anyway, Earth observations may be only a part of the evidence in a legal setting given the indirect nature of the measurements. They may need to be backed up by measurements on the ground, or at least include use of high-resolution sensors.

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[1] According to the EU Environmental Liability Directive 2004/35/CE: "damage means a measurable adverse change in a natural resource or measurable impairment of a natural resource service which may occur directly or indirectly". It may be necessary to distinguish "disturbance", as a departure from the typical or normal ecosystem condition.

[2] This information is distinct from measurements of economic damage, the determination of criminal damage, and questions of liability and compensation.

6. Assessment methods need to be standardized, transparent and reproducible.
7. There have been enormous technical advances in terms of the sensors that can be used and the processing possibilities. However, some sources of information, such as high-resolution imagery, can be too costly for use over wide areas. In addition, though processing has been popularized by the availability of tools such as Google Earth Engine (GEE),[3] many processing tools require highly specialized skills. Significant data storage and computational resources are also required.

Introduction

The organization of the seminar was led by the Secretariat of the Ramsar Convention on Wetlands (Flore Lafaye de Micheaux), the United Nations Economic Commission for Europe (UNECE) (Nicholas Bonvoisin) and the Organization for Security and Cooperation in Europe (OSCE) (Saule Ospanova). Presentations were made by:

- Nickolai Denisov, Zoï Environmental Network, Switzerland
- Ekrem Yazici, Food and Agriculture Organization of the United Nations (FAO)
- Iryna Dronova, University of California Berkeley
- Andrzej Talarczyk, Forest and Natural Resources Research Centre / Taxus IT, Poland
- Eoghan Darbyshire, the Conflict and Environment Observatory (CEOBS), United Kingdom
- Yves Barthelemy, OBSCOM, France

The webinar had a particular focus on wetlands and forest ecosystems. It began with presentations by Dr. Denisov, Zoï Environmental Network, on Ukraine's nature before and through the war and by Mr. Yacizi, FAO, on an overview of forest ecosystems in Ukraine. These comprehensive presentations are not summarized here. The webinar concluded with a panel discussion involving all presenters, with a focus on barriers, challenges and opportunities. The main issues raised in the seminar are set out below.

Objectives of Earth observation

Earth observations (EO) are about using various remote sensing technologies to monitor our environment – the land, water, vegetation, air and much more. Earth observations offer the possibility to cover large areas, possibly at lower cost, and to monitor continuously.

In the context of the ongoing war in Ukraine, and the occupation by parts of the country by the Russian Federation, the use of Earth observations to assess environmental damage is driven by the lack of access to many areas, whether in the conflict zone, under the control of the Russian Federation, in a restricted-access buffer zone along the northern border of Ukraine, mined, or with unexploded ordnance being present. Further, there are resource limitations to carrying out ground surveys because there are few qualified staff and little equipment.

The quality, quantity and scope of data coming from remote sensing and the means of processing that data have expanded in recent years. In addition, AI and machine learning technologies often outperform human image interpretation, pattern detection and causal agent identification, and enable novel approaches, as well as being vastly more rapid.

Table 1 illustrates, for example, uses of remote sensing to monitor wetlands. Dr. Dronova listed several key areas of progress: (i) detection and prediction of wetlands as landscape units; (ii) local,

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[3] Mention of a commercial company or product does not represent endorsement by the United Nations or its Member States.

regional and global-scale wetland delineation and surface classification (including in areas where difficult to detect, such as in forests); (iii) inference of flooding and inundation patterns; and (iv) integration of remote sensing data with modelling tools.

Table 1. Major uses of remote sensing in wetlands monitoring (after Dr. Dronova)

Detection, mapping and change analysis	Proxies of ecosystem properties
• Classification of spatial extents of wetland vegetation and habitat types from the images • Detection and delineation of wetlands as land cover units in landscape patterns • Measuring their properties and change over time including anomalies and short-term effects – how they are changing and responding to management, for example	• Using spectral properties of image products to model vegetation biomass, productivity, flooding, carbon sequestration, etc. • Such proxies can be inputs to more complex spatial and hydrological models • Can also use directly as indicators

Dr. Talarczyk spoke of how forest disturbance and damage can be assessed to: (i) identify sources of damage and define extent, and identify departures from expected conditions whether natural or external; (ii) identify management responses; (iii) identify conditions that favour disturbance or damage, and potential risk areas; and (iv) enhance understanding of forest dynamics after disturbance.

Use of Earth observations is not a panacea, however. Some of the limitations in data and processing are discussed in the chapters below. In addition, the natural world is complex and made more complex by interactions with economic and military activities:

- Ecosystems are dynamic with changes occurring across seasons but also over much longer timespans (temporal variability). Those changes are themselves important – a mudflat is a feeding ground for migratory bird species but at other times may be fully flooded and home to other species, for example. Gaps occur naturally in the tree canopy and a falling tree creates new habitats. A flood will lead to changes to vegetation and biomass, but with a time lag;
- Ecosystems were already under stress over a period of decades and degrading and evolving as a result. This trajectory needs to be considered when assessing damage caused by conflict;
- Even the highest resolution remote sensors are unable to detect fully the spatial heterogeneity of numerous species in an area of diverse flora and fauna, with small or scattered plants, for example;
- Different conditions on the ground – an oil spill and non-photosynthetic vegetation – are spectrally similar, making it difficult to distinguish between them.

The remote sensing may have different objectives, and these may be difficult to reconcile, or require different approaches to the selection of data sources and analysis techniques. The intent may be to:

- Understand physical damage and what (and who) caused that damage. Remote sensing yields a spectral response or returned signal – not direct information on the disturbance or damage, and limited information on the possible cause of the disturbance. Combining the remotely sensed data with ground-based monitoring is necessary. There may also be a need to reconcile the technical approach (data selection and processing, especially if using AI) with legal definitions of environmental damage;

- Indirectly detect (or understand) the baseline conditions (before the damage happened), at least in the most general aspects, that could nevertheless require comparison and verification with ground-based data;
- Understand the damage with the aim of prioritising and devising a management response – remediation, reconstruction or restoration, for example;
- In addition, cover a large area to provide a complete picture and systematic analysis and, again, support prioritization of follow-up activities.

A clear understanding of the objectives is a vital first step in any assessment and must guide the subsequent steps.

Practical issues such as the needed expertise and skills and appropriate methodology (as well as basic issues such as workflows) need to be addressed up front too.

Finally, the sorts of impacts that might be observed include:

- Fire, flooding, water pollution, soil compaction, loss or change of vegetation, changes to geomorphology and other damage;
- Direct (inside the site) and indirect (outside) impacts:
    - Direct impacts include bombing, fire, construction and military equipment;
    - Indirect impacts are transmitted to the site by water, air, etc.

Data sources

Limitations

The reliability of Earth observations is limited by the need for so-called ground-truthing – verifying what conditions on the ground result in a particular combination of signals gathered through remote sensors. Two very different conditions on the ground can result in the same signal being picked up by a satellite even at only 500 km above the Earth.

In addition, some up-to-date satellite imagery is censored or restricted because of its military sensitivity. Other practical limitations include:

- The high cost of higher-resolution imagery;
- Cloud cover obscuring some wavelengths;
- The tree canopy obscuring what is happening on a forest floor, or wetland;
- The surface of the planet obscuring what is happening below the surface, notably in terms of groundwater;
- Remote sensors can detect few pollutants, and cannot detect pollutants such as propellants, heavy metals and other chemicals in soil, diseases and noise (e.g., SONAR), except by seeing subsequent damage or disturbance.

Sources

Table 2 illustrates the range of remote-sensing tools now available, in terms of temporal frequency and spatial scope. Relevant satellites circulate above the Earth from every 12 hours to every 16 days (Landsat), or more, and offer resolutions on the ground from below 5m (often commercial satellites) to 30m (Landsat) or more. More modern satellites typically offer higher resolutions and temporal frequency. Sensors, on satellites but also aircraft, can pick up visible light (red-green-blue), other wavelengths (ultraviolet, infrared, etc.), or be multispectral (3-5 bands; perhaps useful for water pollution detection) or hyperspectral (100s of bands; many more uses). Besides satellites and planes, unmanned aerial vehicles (UAVs) – or drones – can be used as sensor platforms.

Table 2. Advances in environmental remote-sensing to support landscape-scale monitoring (after Dr. Dronova)

		Spatial scope	
		Region-wide	Local to site-level
Temporal frequency	High (multiple times per season and over multiple years)	Satellite imagery	Unmanned aerial vehicles (UAVs), field cameras
	Low (on occasion, project-driven, once every few years)	Aerial imagery and specialized datasets	Terrestrial and aerial lidar (an active, pulsed laser technology)

Sensors can be passive – waiting for electromagnetic radiation emitted from the ground to reach the sensor – or active – using lasers, for example, to send a signal and then wait for the reflected signal to return. Lidar – (laser) Light Detection and Ranging – data tend to be collected in a local area, typically by aircraft though there is also the Global Ecosystem Dynamics Investigation (GEDI) Lidar instrument on the International Space Station.

According to Dr. Talarczyk, passive optical sensors are characterised by spectrum, spatial resolution, revisit time, availability of cloud-free imagery, correction (radiometric, atmospheric, topographic), baseline and inability to look under forest canopy. Active sensors include airborne laser scanning (ALS) that can penetrate the tree crowns and synthetic aperture radar (SAR) that operates despite cloud cover; they provide the basis for integrative solutions (“fusion”) and multisensory approaches.

Active sensors can pick up geomorphological changes and oil spills, for example.

Rather than electromagnetic waves, the GRACE satellite senses gravitational waves and allows the detection of changes in water storage and thus groundwater. However, it has a coarse resolution (50x50km) and other limitations that likely make it unsuitable for assessing environmental damage in Ukraine, except perhaps in the context of the Kakhovka Dam breach. Newer satellites of this type retain many of the limitations.

The information – or imagery – gathered by these different remote sensors can be combined to provide new information, as discussed in the next section.

Remotely sensed information can also be combined with older remotely sensed images to produce a series of images over time. Using images from different seasons can improve recognition of wetland (and other) cover types. A long time-series of images (as from Landsat) might also be used to reveal whether an event recorded during the conflict (e.g., a fire) is unusual in a location and therefore whether it is likely natural or the result of military operations. The use of multi-temporal data is made easier by cloud-based processing platforms such as GEE.

> GEE is free of charge with a catalogue of open-access, multitemporal satellite data and derived products; cloud-based data processing (so no need for expensive processing power on your computer and large storage) and multi-source integration; easy collaboration (user community, code sharing, etc.) – Dr. Dronova.

More sources

Remotely sensed information can also be combined with data from other sources, besides very high-resolution (VHR) commercial imagery for local validation, including:

- Historical environmental data, studies and reports, for example, habitat surveys and water quality measurements, as well as older (film-based) aerial photography;
- Ground-based inventories, notably forest inventories, though these are sometime very old. Forests evolve slowly in general, and historical data can still be useful;
- Social media posts, in multiple languages;
- Platforms gathering up to tens of thousands of incident reports, such as Ecodozor (itself based on traditional- and social-media reporting) and ACLED (Armed Conflict Location and Event Data Project);
- Photos and samples taken by demining and humanitarian organizations working closer to the frontline;
- Citizen science – measurements, recordings and other evidence gathered by members of the public. A major limitation of traditional- and social-media and citizen science is that they rely on the presence of people. If an area is sparsely inhabited, data too will be sparse;
- People, including displaced people – whether locals, scientists who have studied a site or managers who have looked after it;
- Information on activities. For example, automatic identification system (AIS) transponders on ships and boats (and it is possible to find “dark ships” too using machine learning);
- Ground measurements from other, accessible sites with similar characteristics;
- International information systems, such as the Ramsar Information System.

The uses of different sources and different sensors increases the reliability and credibility of the results.

The length of the data record, whether from monitoring or from satellite imagery, may not be long enough to cover natural processes. Records of the environmental situation prior to war have, in many cases, been destroyed or are within the area under the control of the Russian Federation.

The sheer volume of data to be stored may impose cost constraints, though cloud computing offers solutions.

Social media can yield images and descriptions. Images can be geolocated, which can be hard (requiring the matching of surface features on reference imagery, looking for shapes and lines on buildings and landscapes, and finding the point of view for video), but there are many Internet users willing to do this voluntarily.

Zooming in, free and cheap information sources can also be used to identify particularly important sites or areas requiring further study and for which very high resolution (expensive) imagery can then be bought, or more complex processing carried out. A different approach may be needed for each site, depending on the site’s conditions, the degree of confidence about possible impacts, possibility to carry out remedial measures, data availability and other considerations.

Finally, another method of collecting data, though complex, perhaps costly and likely forbidden in an active war zone, is the use of drones for monitoring, collecting samples or reading sensors that have been installed earlier. Indeed, drones will likely be an important tool post-war (and in regained territories) when it will remain difficult to safely access many areas. Drones used for remote sensing can also be equipped with AI to accelerate processing and reduce data volumes transferred.

Data processing and analysis

These multiple sources need to be analysed either individually or by combining them, perhaps by bringing in other tools, i.e., through hybrid solutions.

A hybrid solution might involve different remotely sensed data, other data sources and data generated by models. The analysis might be mathematical, probabilistic (statistical) or involve artificial intelligence and/or machine learning. One particular focus is the “fusion” of images from passive, multispectral sensors with active, radar ones.

A major challenge is making sure that these analyses are user-friendly, use simple equipment and are transparent and affordable. Typical barriers include the need for specialist skills and capacity development; data storage; expensive equipment, image processing software, or processing time (on cloud computing); and difficult-to-explain results. Image processing and analysis require stable access to specialized software and human resources with the relevant skills to work with the software.

Costly, non-standard, opaque or technically challenging approaches (including a need for programming) need to be avoided in practice for routine analysis, though they may be needed in the search for new approaches.

Fortunately, there are good, simple tools, such as GEE. R, Python, QGIS and WEKA may also prove useful. Other useful tools, typically cloud-based and open-access, include:

- Sentinel Hub for looking at fire spread and damage, and flooding;
- Weather conditions using Fire Weather Risk tool on the Copernicus EMS portal;
- The FAO System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL), for forest and land monitoring;
- Fire Information for Resource Management System (FIRMS);
- Tools online to look at water quality using Sentinel-2, for example, the MAGO Water Quality Monitoring Tool.

Increasing complex methods include:

- Multi-source data integration, combining products such as optical and Synthetic Aperture Radar (SAR);
- Object detection through object-based image analysis (OBIA):
  - Very-high-resolution sensors can create “noise” and excessive complexity that complicate pixel-based mapping. There is a higher risk of misclassification (speckling). One approach is OBIA: image segmentation into objects and then classification of the segments (objects);
- Hierarchical classification and analysis, for example, of wetlands;
- Improvement of classification through machine-learning algorithms (e.g., WEKA), open-source statistical and spatial tools (R, Python, QGIS);
- VHR surveys of wildlife on land or at sea, using machine learning (e.g., as has been done for elephants in parts of Africa);
- Combination with mathematical models, such as hydrological and species distribution ones;
- Looking at cascading impacts:
  - For example, the destruction of the Kakhovka Dam damaged a wastewater treatment plant and led to a sudden outflow of freshwater into the marine

    environment. Bothe these effects likely subsequently impacted the ecology of a nearby Ramsar wetland;

- Trajectory-based approaches:
    - Monitor changes in a pixel over time (not just two points in time, but as a time series) to detect disturbance and damage. Use AI (machine-learning) to analyse because of immense data volumes. Need much data and much ground truth.

An important policy consideration is that policymakers need to understand the principles of how an analysis is performed, and its limitations, to be convinced it can be used for evidence-based decisions. Overly complex, opaque or black-box approaches do not usually gain sufficient trust, so they need to be properly documented and explained.

The result of the analysis might be qualitative rather than quantitative, or probabilistic not deterministic. It will often be impossible to be certain of the damage being detected (without a site visit), but for a management response a likely impact may be enough to trigger action.

Finally, pragmatic solutions may be sufficient, but still require standardization. For example, chromomorphic (coloured) dissolved organic matter (CDOM) is a good indicator of water quality. Ecodozor includes a mapping of the frontline as a proxy for damage, based on information on shelling and the duration of proximity to the frontline.

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