https://doi.org/10.15407/scine20.05.003

URUSKYI, O. S.[1] (https://orcid.org/0000-0001-8118-9869),
STANKEVICH, S. A.[2] (https://orcid.org/0000-0002-0889-5764),
DUDAR, T. V.[3] (https://orcid.org/0000-0003-3114-9732),
MOSOV, S. P.[4] (https://orcid.org/0000-0003-0833-3187),
and PRYSIAZHNYI, V. I.[5] (https://orcid.org/0000-0001-7825-9037)
[1] Progresstech Ukraine,
3, Sholudenka St., Kyiv, 04116, Ukraine,
+380 44 594 5660, ukr@progresstech.ua
[2] Scientific Centre for Aerospace Research of the Earth, National Academy of Sciences of Ukraine,
55-B, Oles Gonchar St., Kyiv, 01054, Ukraine,
+380 44 290 2600, st@casre.kiev.ua
[3] National Aviation University,
1, Liubomyra Huzara Ave., Kyiv, 03058, Ukraine,
+380 44 406 7792, dudar@nau.edu.ua
[4] Institute of Public Administration and Research in Civil Protection,
21, Vyshhorodska St., Kyiv, 02000, Ukraine,
+380 44 430 8217, idundcz@dsns.gov.ua
[5] National Space Facilities Control and Test Center,
8, Kniaziv Ostrozskykh St., Kyiv, 01010, Ukraine,
+380 44 281 6900, ncuvkz@spacecenter.gov.ua

INTEGRATED ASSESSMENT OF DISTURBED ECOSYSTEMS USING REMOTE SENSING TECHNIQUE

Introduction. *Today, there is a need for a shared vision of restoration of disturbed ecosystems, which is defined as "the process of stopping and reversing degradation, leading to improved ecosystem services and restoration of biodiversity."*

Problem Statement. *The assessment and restoration of disturbed ecosystems has become especially relevant for the Ukrainian society now, as warfare has caused large-scale changes in environment and both short-term and long-term consequences for ecosystems in Ukraine.*

Purpose. *Assessment of ecosystems disturbed as a result of warfare impact by remote sensing.*

Materials and Methods. *Multispectral satellite imagery, ground truth data and ecosystems characteristics of study area have been used. Remotely sensed data processing, geospatial modelling, and mathematical statistics have been applied.*

Results. *A warfare impact on the ecosystems of Ukraine has been overviewed. Possibility of using remote sensing methods have been considered; their advantages and disadvantages have been generalized.*

A demo example of the described technique for assessing the ecosystem conditions along the E40 highway on the west of Kyiv has been shown with the use of multi-time satellite imagery of very high resolution (0.5 m on the

Citation: Uruskyi, O. S., Stankevich, S. A., Dudar, T. V., Mosov, S. P., and Prysiazhnyi, V. I. (2024). Integrated Assessment of Disturbed Ecosystems Using Remote Sensing Technique. *Sci. innov.*, 20(5), 3—15. https://doi.org/10.15407/scine20.05.003

ground) between May 2020 and March 2022. The analysis of the obtained maps allows us to assess short-term changes in land cover: a decrease in the area of water bodies, coniferous and leafy plants, an increase in the open soil area. The ecosystem conditions map of the studied area enables identifying plots of high risk.

Conclusions. *Integrated remote assessment of the condition of disturbed ecosystems and geospatial analysis of corresponding risks are useful tools for the territory management. Remote sensing techniques are particularly important in the context of large-scale warfare. In many cases, only remote sensing techniques can provide information on the condition of ecosystems that are inaccessible or dangerous for ground-based research. Currently, the proposed approach has been elaborated and tested over other territories, different ecosystems and other data sources. Completed and tested integral geo-information technology will be relevant for the post-war recovery of the territory of Ukraine. Further research should be focused on building a pool of quantitative models for probabilistic assessment of the risk of disruption of various ecosystems under different conditions, as well as on obtaining an array of statistical data to increase the reliability of the resulting maps.*

Keywords: remote sensing, disturbed ecosystems, warfare, and geoinformation technology.

The critical need to halt, prevent, and reverse ecosystem degradation and to effectively restore degraded terrestrial, freshwater, and marine ecosystems across Europe and globally necessitates a shared vision of ecosystem restoration. This vision is defined as "the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity." Ecosystem restoration encompasses a wide continuum of practices that vary depending on local conditions and societal choices [1].

The principles and methodology behind the project are mainly based on the Ecosystem Approach and the Short-Term Action Plan for Ecosystem Restoration, both adopted by the Parties to the Convention on Biological Diversity, as well as the International Union for Conservation of Nature's Principles for Nature-Based Solutions, Principles for Ecosystem Based Approaches, Principles for a Landscape Approach, Principles for Forest and Landscape Restoration, the Society for Ecological Restoration (SER)'s International Principles and Standards for the Practice of Ecological Restoration.

Each of ten principles that underpin Ecosystem Restoration and presented in the UN Decade have to be considered and implemented in environmental programs for ecosystem restoration. Successful ecosystem restoration aims to contribute to the achievement of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals. The above determines the extreme relevance of the mentioned topic, especially in the near future.

In the view of ongoing degradation of different ecosystems, restoration is an inevitable component of nature protection and conservation management. The UN Decade on Ecosystem Restoration runs from 2021 through 2030. Restoring ecosystems and enhancing biodiversity is a cornerstone of the European Green Deal.

Currently, the European Commission adopted proposals to restore damaged ecosystems and bring nature back across Europe, from agricultural lands to forests and urban environments. The proposal for a Nature Restoration Law is a key step in avoiding ecosystem collapse and preventing the worst impacts of climate change and biodiversity loss. As far as the mentioned proposal concerns almost every country, the topic of ecosystems restoration includes active outreach and educational work spreading knowledge about EU subjects to wider society and bringing the EU closer to the public.

For the last decades the topic of restoring damaged ecosystems has also been of high priority for the Ukrainian society. But since the start of the war, it became much more important as the war has caused widespread and severe damage to the environment and inflicted both immediate and longer-term consequences on the ecosystems and the Ukrainian economy and beyond. Nowadays Ukraine has been tracking the environmental damage done by the warfare activities and in the nearest future restoration of damaged ecosystems will require common efforts and dialogue between the academic world and society, civil servants, civil society actors, representatives of the different levels of education and of the media.

Essential elements of the restoration approach are:

(1) introduction to environmental problems that restoration can address;

(2) rationale for restoration;

(3) training in a stepwise process for restoration; and

(4) group problem-solving and design of ecological restoration projects to address various problems.

In this paper we are supposed to stop on the first two aspects. We are considering the impact on ecosystem within the territories of active war fare and within the territories under occupation. Then we are going to emphasize on remote sensing methods available to use in case of hard to reach objects and integrated assessment of damaged ecosystems. Training in stepwise process for restoration and group problem-solving are definitely followed after the first two are considered.

WARFARE IMPACT ON ECOSYSTEMS OF UKRAINE (overview)

An ecosystem is a system consisting of biotic and abiotic components that function together as a unit. The biotic components include all the living things whereas the abiotic components are the nonliving things. Thus, an ecosystem science definition entails an ecological community consisting of different populations of organisms that live together in a particular habitat [2].

In other words, the concept of an ecosystem refers to a structural and functional unit of the biosphere. This unit encompasses both organisms and the abiotic environment, which interact and influence each other's properties. These interactions are essential for sustaining life [3]. A system that arises in nature and develops due to the constant interaction between biotic and abiotic factors of the environment is defined as natural ecosystem (forests, mountains, oceans, deserts, etc.). A system created by man and consisted of plants, animals, people and technology for its own benefit is defined as artificial ecosystem (cities, villages, power plants, pipelines, etc.). Mr. Arthur G. Tansley coined the term ecosystem in 1935.

For the entire time of the full-scale invasion (since 24.02.2022), the military actions have already caused losses to Ukraine's ecosystems worth USD 40 billion. This is pollution of atmospheric air, soil, damage to forest resources, pollution of the Black sea and the Sea of Azov. Because of the war, almost 700 fauna species and over 800 plants species are endangered. Some of them are listed to the Red Book [4].

Among all the natural ecosystems of Ukraine, forest ecosystems suffer severely from intensive hostilities. The full recovery of these ecosystems requires a long time of 20—30 years, on average. The massive use of artillery, missiles and strike aircraft against military and infrastructure facilities in and near forests causes forest fires that in dry conditions may destroy thousands ha forest. So, for example, this happened during the spring of 2022 in the Chornobyl exclusion zone and its surroundings, where more than 10,000 ha forest burned.

In total, 3 million ha forest that is almost a third of the forest stock have already been affected in Ukraine. Some of them are lost forever. Loud explosions cause severe stress to forest animals, and tens of thousands of vertebrates die in the fires caused by shelling, not to mention countless invertebrates and plants.

At the same time, soils and underground waters are polluted with large quantities of toxic metals and other chemical compounds — products of the ammunition detonation, the impact of which on forest ecosystems, although not as strong as from the shock waves of explosions, but will continue tens of years.

The construction of trenches and fortifications destroys vegetation cover and increases soil erosion. Garbage and military waste pollute the soil and groundwater. A lot of unexploded ammunition remains in the forests of Chernihiv, Sumy, Luhansk, Donetsk and Kherson regions. The presence of significant areas of mined forest territories, the complete demining of which will be extremely expensive and time-consuming, means that certain areas of the forest will be removed from any economic use for decades [5–7].

Damaged industrial facilities and settlements become sources of chemical pollution of coastal and marine environment. Fuel spills from stricken vessels endanger protected wetlands, and the widespread use of sea mines increases the risk to vessels and the subsequent risks of releases to the environment in the event of mine detonation. The activity of surface ships and submarines in the Black Sea during the war has already led to the death of hundreds of marine mammals, most of which are bottlenose dolphins [8].

Ecosystems of freshwater bodies, from which the population uses drinking water, are being polluted. The destruction of water pipes and other water infrastructure during shelling, water treatment facilities and the impossibility of quickly repairing them affects the quality and quantity of water available to the Ukrainian population. It also leads to the pollution of freshwater reservoirs as a result of untreated sewage entering them. As a result of such actions, return water already enters the Dnipro and the Siverskyi Donets rivers without any treatment [9, 10]. A large number of fish die due to the ingress of chemicals into reservoirs.

Let us consider agricultural ecosystems. They are also highly subjected to chemical pollution. The detonation of rockets, artillery shells and mines form a number of chemical compounds — carbon monoxide and carbon dioxide, water vapor, nitrogen oxide, nitrogen and other toxic organic matter. Also, many toxic elements evaporate. Among them, there are sulfur and nitrogen oxides that during oxidation may cause acid rains. This can cause burns to plants, mucous tissues of human respiratory organs, birds, etc. Chemicals can enter the soil with precipitation. Fragments of ammunition pose a danger — poisonous substances enter the soil, then into groundwater, and later — into the food chains of animals and people [10, 11].

Ukrainian chernozem, the formation of which takes at least 10,000 years, is being destroyed. The military activities take place precisely on the territory where this unique and very fertile soil layer is spread. Sulfur that settles in the soil after the explosion, reacts with dew or fog and turns into sulfuric acid that causes burns to vegetation, bacteria, and worms — everything that forms the soil [10].

The movement of heavy weapons and military equipment on agricultural lands leads to critical negative impacts and changes of landscape. As a result of their movement, the soil is polluted with fuel and lubricants and other petroleum products. This leads to a decrease in water permeability of the soil, displacement of oxygen, disruption of plant root nutrition, and, as a result, inhibition of their growth and development.

The numerous fires that broke out in agricultural fields in 2022 due to hostilities led not only to the destruction of crops and the infliction of significant damage to the food supply of Ukraine, but also to the infliction of great damage to the organic part of the soil [11].

Artificial ecosystems are also subjected to active missile attacks by Russian troops during the war. Populated areas (cities, villages, etc.), where facilities of the defense industr, state and military administration are located: warehouses with ammunition; weapons and military equipment; concentration of troops; logistical military facilities; storages of oil products, oil refining enterprises; chemical enterprises; thermal power plants; transport infrastructure, etc. In the zone of direct hostilities, such ecosystems practically cease to function as a result of their partial or complete destruction.

Attacks on oil products storage, oil refineries, chemical enterprises, industrial warehouses lead to the fact that spilled oil and chemicals penetrate into the soil, then to underground water, and kill all living things in the earth. Fires that are the result of attacks lead to air pollution and worsening conditions for the population's breathing. Large amounts of military waste, including destroyed military equipment, will in the future create difficulties during disposal and cleaning of the area [12].

Numerous attacks during hostilities on the residential and administrative infrastructure of cities lead to the destruction of buildings, numerous fires in buildings caused by explosions of various munitions, which may cause long-term health threats, such as the risk of cancer and respiratory diseases. Damage to the infrastructure of water supply, sewerage, treatment facilities, and industrial facilities in cities causes the leakage of toxic substances into the environment, and can also be the cause of the emergence of various diseases due to the contamination of sources of drinking water supply. Due to damage to the water supply infrastructure, approximately 1.4 million Ukrainians currently do not have access to safe water, and another 4.6 million have limited access. The destruction of large livestock farms, where the aggressor has destroyed the entire livestock population, poses an additional risk to public health due to unused animal carcasses [12, 13].

We are currently able to preliminarily assess the damage caused to ecosystems from the direct action of military aggression within the territories that have been liberated. As for the temporarily occupied territories and territories where military actions continue to this day, this can be done only with the help of satellite images [14].

ECOSYSTEM CONDITIONS ASSESSMENT BY REMOTE SENSING

The ecosystem conditions assessment itself is a crosscutting complicated contradictory problem that is usually solved by decomposing scores for separate indicators and then combining ones into a final score [15, 16]. This problem's complicatedness is further strengthened if remote sensing mainly is engaged for it. It is clear that the remote sensing techniques will be differ for various ecosystems and distinct types of assessments, but it is possible to draw out a certain sequence of operations common to all cases, which forms the core of any assessment technique. In this study, the authors propose just such a core.

The main entities that form the core of technique for remote assessment of the ecosystem conditions are:

- (bio)physical foundation of the involved indicators and data products;
- use of several (many) separate channels for obtaining information simultaneously;
- formation of a time series of observations, the length of which (seasonal, perennial) is determined by the nature of the phenomenon under study;
- multilevel (spatial, temporal, heterogeneous) statistical processing of observation results;
- multifold data fusion for obtaining a final map of the studied ecosystem conditions assessment.

The geoinformation core of the general technique for the ecosystem conditions assessment by remote sensing is shown in Fig. 1.

The assessment begins with the identification of *n* drivers that determine the ecosystem conditions. In many circumstances, the drivers themselves cannot be measured remotely, so this process shall be mediated by the acquisition of certain signals that can be registered remotely and associated with drivers — i.e. indicators [17]. Often the relationship between drivers and indicators is indirect, "one-to-many" or "many-to-one", and therefore the number of indicators *m*, as a rule, does not equal the number of drivers. Henceforth, only remotely acquired indicator maps are being handled. Within the framework of the proposed paradigm, indicators are not optical signals of remote sensors or their direct derivatives, such as, for example, spectral indices. Indicators should have a (bio)physical essence inherent in the land surface, for example, vegetation cover fraction (VCF) or leaf area index (LAI), land surface temperature (LST), surface soil moisture (SSM), terrain slope, composition of rocks and minerals, etc. The transformation of the sensor's "raw" optical signals into the (bio) physical parameters of the land surface requires intricate thematic processing and sophisticated geospatial modelling [18].

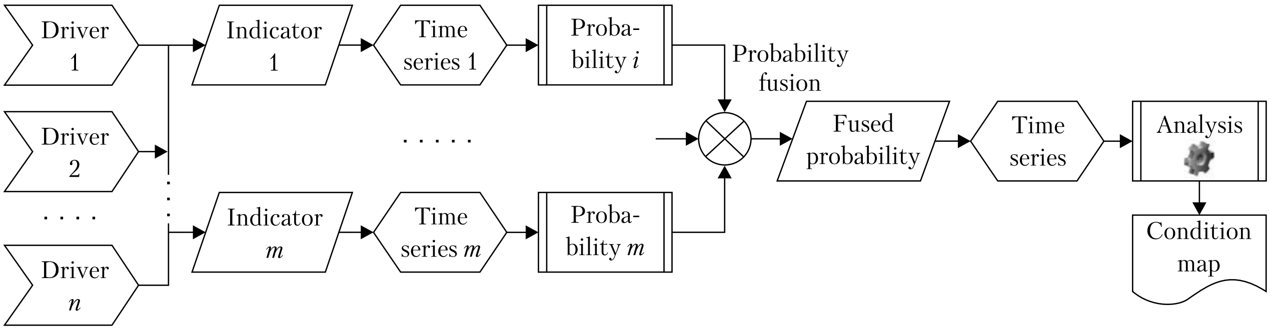


Fig. 1. Flowchart for ecosystem conditions assessment by remote sensing

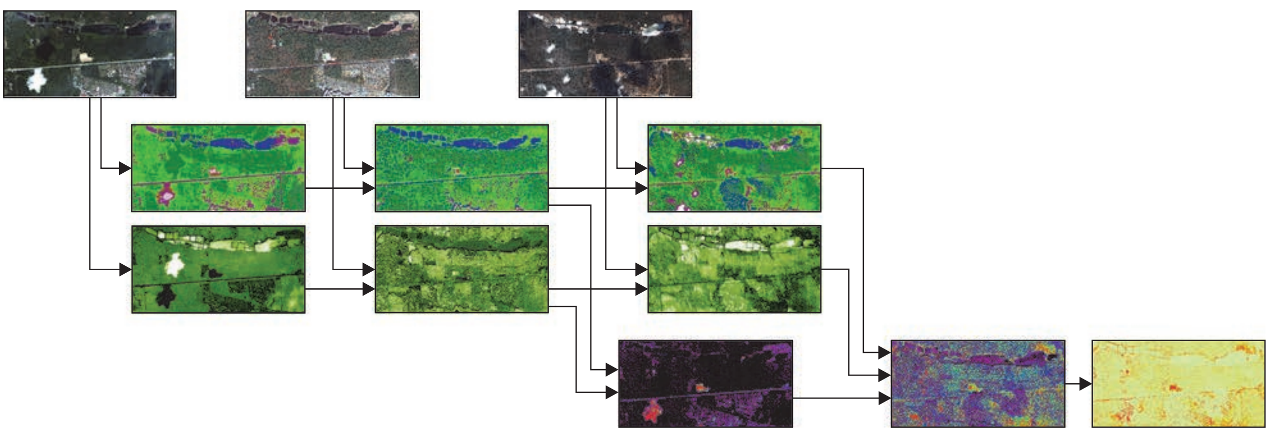


Fig. 2. Demonstration of assessing the state of ecosystems by remote methods

The other problem is related to the impossibility of a direct combination of measurements of different physical nature. Indeed, how to interpret the different indicators influence on the resulting assessment, if their relationship is not exactly known, and besides, contradicts each other? We propose additional thematic or statistical modelling that converts the value of each indicator into a corresponding partial conditional probability of a particular final state of the ecosystem under this value. Then, it becomes possible to combine (fuse) partial probabilities into a single joint probability of the studied ecosystem conditions by one of the well-known methods of probability theory, evidence theory, and so on [19].

At the end, the analysis of the obtained time series of fused probabilities will provide the assessment not only the current conditions of ecosystem, but also to predict its subsequent change [20].

Below, there is a demo example of the described technique applying for ecosystem conditions assessment along the E40 highway at west of Kyiv with the use of multi-time satellite imagery of very high resolution (0.5 m on the ground) between May 2020 and March 2022. Changes in the land cover and vegetation cover classes, which are characterized by the visible atmospherically resistant index (VARI), have been chosen as indicators of the ecosystem conditions.

The specific implementation of general technique shown in Fig. 1 is illustrated in Fig. 2.

Two data products are created for each observation period over the study area, namely — the land cover classification and the VARI distribution.

Then these products are converted into partial probability maps of ecosystem conditions, which are further fused into a single combined probability map at each time frame. Based on the results of the obtained time series analysis, a final map of the ecosystem conditions assessment is formed.

More detailed satellite images used, intermediate data products and the final map of the ecosystem conditions over the study area are in the Annex.

CONCLUSIONS

Integrated remote assessment of the condition of disturbed ecosystems and geospatial analysis of corresponding risks is an important, flexible, convenient and useful tool for managing and planning the development of territories. Remote sensing techniques gain in essential importance in the context of large-scale warfare that are currently taking place in Ukraine. In many cases, only remote sensing techniques can provide information on the ecosystems condition that are inaccessible or dangerous for ground-based research.

However, remote sensing techniques have a number of shortcomings, such as limited detaility, dependence on seasonal and weather conditions, difficulty for direct interpretation, etc. To overcome these shortcomings, this study proposes an approach for the ecosystem disturbance risk mapping, which is based on extracting a set of remote indicators of the ecosystems condition, probabilistic convolving of ones and a long-term observations time series analysis.

At moment the proposed approach is being elaborated and tested over different territories, different types of ecosystems and different data sources. In particular, a demonstration example is presented in this paper too. Upon completion of the development and debugging of a core geoinformation technology, its implementation will be quite useful for the postwar reconstruction of the territory of Ukraine.

Future works should be focused on developing a pool of quantitative models for probabilistic assessment of the risk of various ecosystems disturbance under various conditions, as well as on collecting big statistical data to improve the reliability of the maps obtained.

ACKNOWLEDGEMENT

This research was carried out within the framework of cooperation between the Scientific Center for Aerospace Research of the Earth, the National Space Facilities Control and Test Center, the Institute of Public Administration and Scientific Research on Civil Protection and the National Aviation University according to Agreements on Scientific and Technical Cooperation No 6/10/2021 of October 11, 2021, 44-nt-22 of February 15, 2022 and 48-nt-22 of October 26, 2022.

REFERENCES

1. UN Environment Programme (UNEP) 2021 Annual Report. Nairobi: UNEP Office, 2022, 21 p. URL: https://www.unep.org/resources/annual-report-2021 (Last accessed: 19.06.2023).
2. *Glossary of basic military terms for use in the educational process and scientific-technical activity of the National Defense Academy of Ukraine*. (2006). (Ed. Mosov S. P.). Kyiv [in Ukrainian].
3. Gandziura, V. P. (2020). *System analysis of environmental quality*. Kyiv [in Ukrainian].
4. Yankovskyi, O. (2023). Scorched land. How does the war affect the ecology of southern Ukraine? URL: https://www.radiosvoboda.org/a/novyny-pryazovya-viyna-pivden-ekolohiya-spalena-zemlya/32191731.html (Last accessed: 19.06.2023).
5. The impact of the war on Ukraine's forests. (2022). URL: http://epl.org.ua/about-us-posts/vplyv-vijny-na-lisy-ukrayiny/ (Last accessed: 19.06.2023).
6. Sobenko, N. (2022). 20% of protected areas of Ukraine suffered from the war. Russia caused losses of UAH 1.35 trillion. URL: https://suspilne.media/310936-vid-vijni-postrazdali-20-prirodoohoronnih-teritorij-ukraini-rf-zavdala-zbitkiv-na-135-trln-grn (Last accessed: 19.06.2023).

7. Yatseno, O. (2022). The war in Ukraine has led to irreparable consequences for the environment — experts. URL: https://ecopolitic.com.ua/ua/news/ekologi-zasteregli-pro-rujnivnij-vpliv-vijni-na-prirodu-ukraini (Last accessed: 19.06.2023).
8. Rusev, I. (2023). Hundreds of dolphins died in the Black Sea: the cause named. URL: https://flot2017.com/v-chernom-more-pogibli-sotni-delfinov-nazvana-prichina (Last accessed: 19.06.2023).
9. Diachuk, M. (2022). Water as a source of life or the germ of war: how the theft of water by the occupiers affects the water supply of Ukraine and Crimea. URL: https://ecoaction.org.ua/voda-iak-dzherelo-zhyttia.html (Last accessed: 19.06.2023).
10. Mygal, M. (2023). War and ecology: why does nature fall victim to armed conflict? URL: https://iaa.org.ua/articles/vijna-ta-ekologiya-chomu-pryroda-staye-zhertvoyu-zbrojnogo-konfliktu (Last accessed: 19.06.2023).
11. Ovsianyi, K. (2023). Before and after. The consequences of a full-scale war for the envirinment of Ukraine. Satellite view. URL: https://www.radiosvoboda.org/a/skhemy-ekolohiya-viyna/32284610.html (Last accessed: 19.06.2023).
12. Kepova, D. (2022). Environmentalists are sounding the alarm; the war is becoming toxic for Ukraine — UN. URL: https://zn.ua/ukr/WORLD/ekolohi-bjut-na-spolokh-vijna-bukvalno-staje-toksichnoju-dlja-ukrajini-oon.html (Last accessed: 19.06.2023).
13. Riener, K. (2023). Environmental consequences of the war in Ukraine and prospects for green reconstruction. URL: https://www.dniprotoday.com/novyny/ekologicni-naslidki-vijni-v-ukraini-ta-perspektivi-zelenoi-rekonstruk-cii-2606 (Last accessed: 19.06.2023).
14. Shevchuk, S. A., Vyshnevskyi, V. I., Bilous, O. P. (2022). The use of remote sensing data for investigation of environmental consequences of Russia-Ukraine war. *Journal of Landscape Ecology*, 15(3), 36—53. https://doi.org/10.2478/jlecol-2022-0017.
15. Vasenko, O. G., Rybalova, O. V., Artemiev, S. R., Gorban, N. S., Korobkova, G. V., Polozentsieva, V. O., Kozlovskaia, O. V., Matsak, A. O., Savichiev, A. A. (2015). *Integral and comprehensive environmental assessment*. Kharkiv [in Ukrainian].
16. Dudar, T., Piestova, I., Lubskyi, M., Zhuravel, O., Tymchyshyn, M. (2021). Remote mapping of environmental hazard indicators within the mining area. *Collection Papers of the III International Scientific-Practical Conference "Modern Trends in Information Systems and Telecommunication Technologies Development" (25—26 January, 2021)*. Kyiv. P. 17—18.
17. Stankevich, S. A., Kharytonov, N. N., Dudar, T. V., Kozlova, A. A. (2016). Remote risk assessment of land degradation using satellite imagery and geospatial modeling in Ukraine. In: Land Degradation and Desertification — a Global Crisis (Ed. Kaswamila A.). Rijeka. P. 53—77. https://doi.org/10.5772/62403.
18. Svideniuk, M. O. (2021). Methodology for determining the physical parameters of ground plane by the results of the optical and radar data fusion. *Ukrainian Journal of Remote Sensing*, 8(3), 4—26 [in Ukrainian]. https://doi.org/10.36023/ujrs.2021.8.3.197.
19. Zaitseva, E., Stankevich, S., Kozlova, A., Piestova, I., Levashenko, V., Rusnak, P. (2021). Assessment of the risk of disturbance impact on primeval and managed forests based on Earth observation data using the example of Slovak Eastern Carpathians. *IEEE Access*, 9, 162847—162856. https://doi.org/10.1109/ACCESS.2021.3134375.
20. Sokolovska, A. V., Tomchenko, O. V. (2013). The study of anthropogenic changes in ecosystems on a basis of tools of GIS/RS technologies using methods of system analysis. *Problems of Continuous Geographic Education and Cartography*, 17, 57—60 [in Ukrainian].

Received 21.06.2023
Revised 26.02.2024
Accepted 02.03.2024

О.С. Уруський[1] (https://orcid.org/0000-0001-8118-9869),
С.А. Станкевич[2] (https://orcid.org/0000-0002-0889-5764),
Т.В. Дудар[3] (https://orcid.org/0000-0003-3114-9732),
С.П. Мосов[4] (https://orcid.org/0000-0003-0833-3187),
В.І. Присяжний[5] (https://orcid.org/0000-0001-7825-9037)

[1] Прогрестех-Україна,
вул. Шолуденка, 3, Київ, 04116, Україна,
+380 44 594 56 60, ukr@progresstech.ua
[2] Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України,
вул. Олеся Гончара, 55-Б, Київ, 01054, Україна,
+380 44 290 2600, st@casre.kiev.ua
[3] Національний авіаційний університет,
просп. Любомира Гузара, 1, Київ, 03058, Україна,
+380 44 406 7792, dudar@nau.edu.ua
[4] Інститут державного управління та наукових досліджень з цивільного захисту,
вул. Вишгородська, 21, Київ, 02000, Україна,
+380 44 430 8217, idundcz@dsns.gov.ua
[5] Національний центр управління та випробувань космічних засобів,
вул. Князів Острозьких, 8, Київ, 01010, Україна,
+380 44 281 6900, ncuvkz@spacecenter.gov.ua

КОМПЛЕКСНА ОЦІНКА ПОРУШЕНИХ ЕКОСИСТЕМ ЗА ДОПОМОГОЮ МЕТОДУ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ

Вступ. На сьогодні існує потреба у спільному баченні відновлення порушених екосистеми, яке визначається як «процес припинення та звернення назад до деградації, що призведе до покращення екосистемних послуг і відновлення біорізноманіття».

Проблематика. Оцінювання та відновлення порушених екосистем останнім часом є актуальним, оскільки воєнні дії спричинили широкомасштабні зміни довкілля та обумовили коротко- й довгострокові наслідки для екосистем України.

Мета. Дослідження причин та наслідків впливу воєнних дій на екосистеми за допомогою дистанційного зондування.

Матеріали й методи. Використано багатоспектральні космічні знімки, наземні завіркові дані та екосистемні характеристики території дослідження. Застосовано аналіз дистанційних даних, геопросторове моделювання, математичну статистику.

Результати. Подано огляд впливу воєнних дій на екосистеми України. Розглянуто можливості дослідження дистанційними методами, визначено їхні переваги й недоліки. Наведено результати дослідження екосистем території автомагістралі Е40 західніше Києва за матеріалами багаторазового супутникового знімання надвисокої розрізненості у період з травня 2020 до березня 2022 року. Аналіз отриманих карт дозволяє оцінити зміни земних покривів за короткий час: зменшення площі водних об'єктів, хвойних і листяних насаджень, збільшення площ відкритого ґрунту. Карта порушення екосистем території дозволяє визначити ділянки високого ризику.

Висновки. Комплексне дистанційне оцінювання стану порушених екосистем та геопросторовий аналіз відповідних ризиків є корисним інструментом управління територіями. Дистанційні методи набувають особливого значення під час воєнних дій. Наразі запропонований підхід перевіряється на інших територіях, різних типах екосистем та джерелах даних. Завершена та апробована цілісна геоінформаційна технологія буде актуальною для післявоєнного відновлення території України. Подальші дослідження варто зосередити на побудові пулу кількісних моделей для імовірнісної оцінки ризику порушень різноманітних екосистем за різних умов, а також на отриманні масиву статистичних даних для підвищення достовірності одержуваних карт.

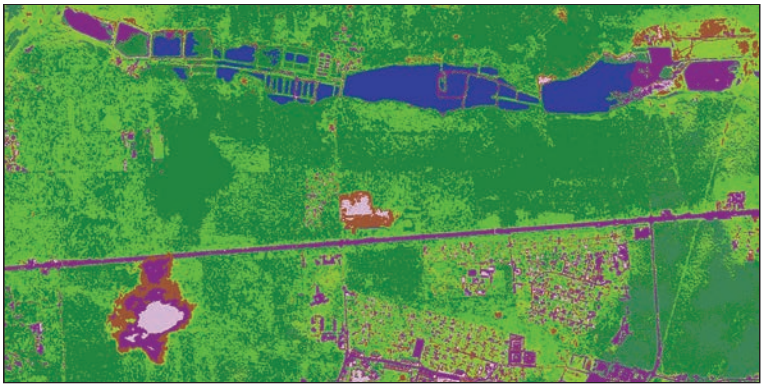
Ключові слова: дистанційне зондування, порушені екосистеми, воєнні дії, геоінформаційна технологія.

ANNEX. Geospatial data used for the ecosystem conditions assessment within the study area

Fig. A1. Multispectral image of study area, acquired on May 15, 2020 by SuperView-1 satellite, 0.5 m spatial resolution (pansharpening)

Fig. A2. Multispectral image of study area, acquired on October 26, 2021 by WorldWiev-2 satellite, 0.5 m spatial resolution (pansharpening)

Fig. A3. Multispectral image of study area, acquired on March 10, 2022 by WorldView-2 satellite, 0.5 m spatial resolution (pansharpening)



Legend: ■ — Artificial pavement; ■ — Grassland; ■ — Coniferous forest; ■ — Deciduous forest; ■ — Open soil; ■ — Barren ground; ■ — Shrubland; ■ — Water surface; ■ — Unclassified

Fig. A4. Land cover classification of study area on May 15, 2020

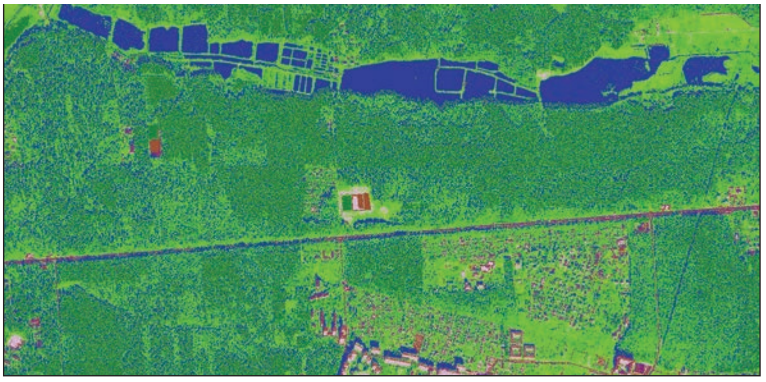


Fig. A5. Land cover classification of study area on October 26, 2021 (legend is the same)

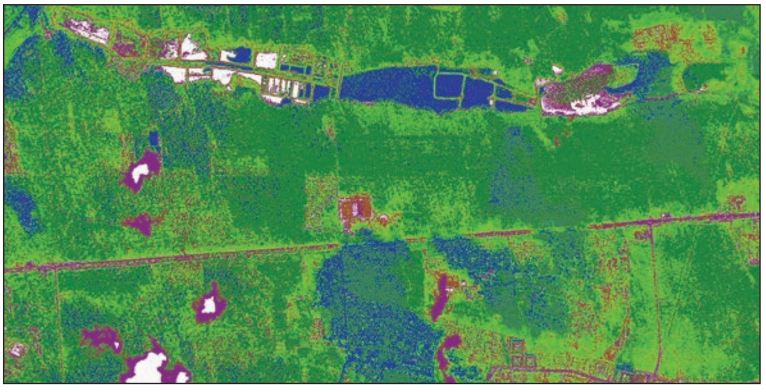
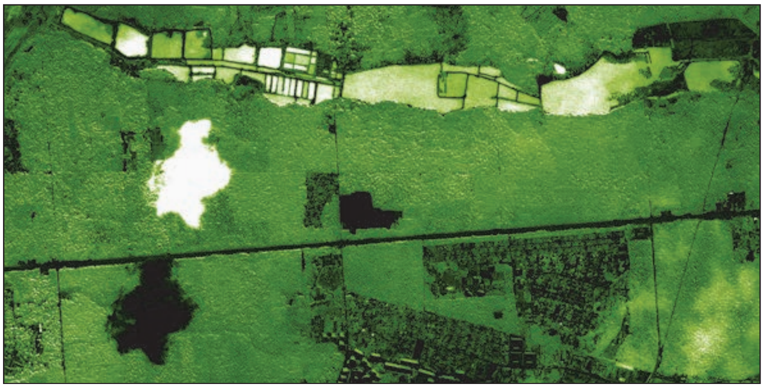


Fig. A6. Land cover classification of study area on March 10, 2022 (legend is the same)



Legend: 0 10

Fig. A7. VARI spatial distribution within the study area on May 15, 2020

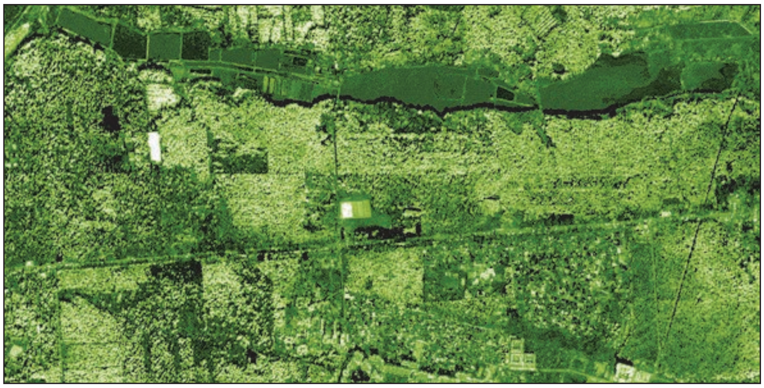


Fig. A8. VARI spatial distribution within the study area on October 26, 2021 (legend is the same)

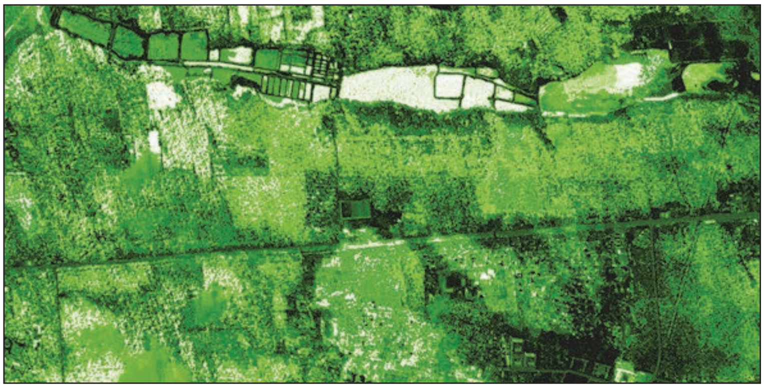
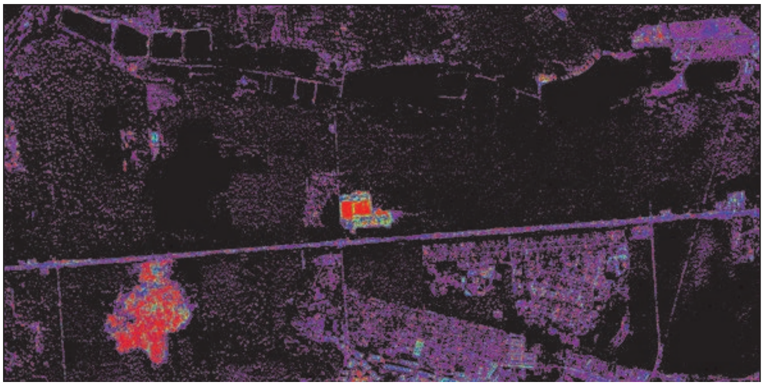


Fig. A9. VARI spatial distribution within the study area on March 10, 2022 (legend is the same)



Legend: 0.0 [colour scale] 1.0

Fig. A10. Combined probability map of study area on October 26, 2021

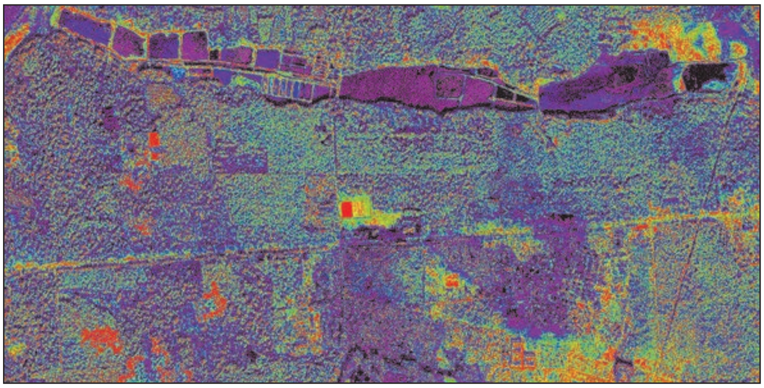
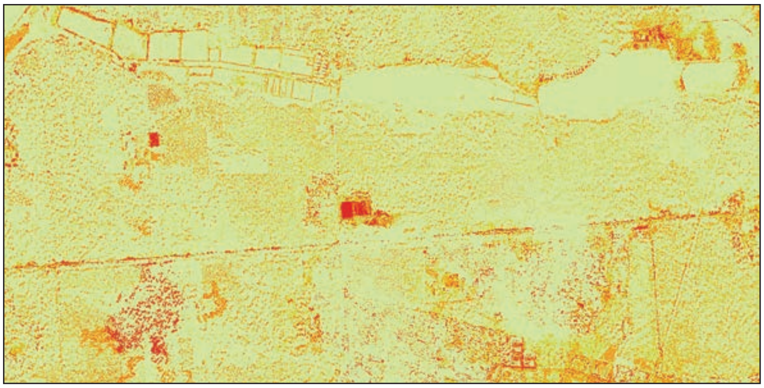


Fig. A11. Combined probability map of study area on March 10, 2022 (legend is the same)



Legend: ■ — No risk; ■ — Low risk; ■ — Moderate risk; ■ — High risk; ■ — Unclassified

Fig. A12. Ecosystem conditions map of study area on March 10, 2022