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INCORPORATING GEOGRAPHIC INFORMATION TECHNOLOGIES INTO A FRAMEWORK FOR BIOLOGICAL DIVERSITY CONSERVATION AND PREVENTING BIOLOGICAL THREATS TO LANDSCAPES

As the long-term sustainability of both natural and artificial phytocenoses is under serious threat from biological invaders, the global community is working hard to prevent invasions and rapidly eradicate or halt the spread of invasive species. By tracking the actual spread of "invaders" or predicting areas at risk of invasion, geographic information systems (GIS) and remote sensing of the Earth (RSE) can significantly assist the process of ensuring biosecurity at the state level. Research has shown the potential of remote sensing and GIS applications for invasive species mapping and modeling, even though it is currently restricted to a small number of taxa. This article gives examples of how GIS and RSE can be used to track invasive species like Utricularia australis R. br. and Lemna aequinoctialis Welw. To describe the distribution of species, current Internet databases of species distribution and the author's own research were used. It also talks about promising ways to find and track the spread of invasive species, like using NDVI indices, chlorophyll and xanthophyll content to find changes in regional biodiversity, some problems with finding changes in biodiversity in agricultural landscapes, and mapping invasion risk. The study also demonstrates how GIS technology may be used to identify agricultural landscape biodiversity using radiometric space data from Sentinel 1, followed by a verification of the findings. The prospects of spatial, spectral, and temporal analysis of images are determined, as they make it possible to outline the boundaries of ecosystems, biometric characteristics of species, characteristics of their current and potential areas of distribution, etc.

Keywords: *invasive species, vegetation indices, distribution, bioinvasion, pest infestation.*

INTRODUCTION

Due to their rapid expansion, the threat to biodiversity, and damage to ecosystems, invasive species are now of concern to ecologists, agronomists, and conservationists. As a result of invasions, grasslands may experience changes to their hydrologic regime, nutrient accumulation and cycling, and carbon sequestration [17]. It is widely acknowledged that the fast proliferation and worldwide dispersal of invasive species are major contributors to the degradation of biodiversity around the world [9, 16]. According to [2], bioinvasion is an important aspect of global change and one of the key reasons why species become extinct.

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In recent years, remote sensing technology has attracted considerable interest in the issue of ensuring the biological security of landscapes. It is a tool that offers well-documented advantages, including a synoptic overview, multispectral data, multitemporal coverage, and cost-effectiveness [5, 6]. It is now widely used for data collection and processing. This has proven to be an effective and practical approach to the study of complex geographic terrain types and a variety of hard-to-reach ecosystems. This method provides a wide variety of sensor systems, including field spectrometers, satellite electro-optical cameras, and airborne multispectral scanners.

Using remote sensing technologies, local species can be found, mapped, and monitored [7, 12]. The study of seasonal and long-term trends in biological invasion is complicated by spatial heterogeneity [7, 15]. However, remote sensing could provide pertinent information due to its broad perspective [15]. Satellite imagery has been available for most of the world since 1972.

Satellite images are reusable and allow observing the dynamic nature of landscape features, and therefore provide the means to detect major changes in land cover and quantify rates of change [18, 25].

For Ukraine's native flora and fauna of plant and animal species, the past several decades have seen a widespread invasion of foreigners. This process is heavily influenced by human economic activities. Moreover, global warming facilitates the speed and intensification of trade and other contacts among many countries. The invasion is increasingly seen as a major environmental issue.

Alien species are those that have made their home outside of the historical region because of direct or indirect human activity. They fall into two categories: invasive species are introduced via other means; introducers, whose emergence on the territory is brought about by intentional human activity (wild cultural or plant species introduced for the goal of naturalization; and animals); (water, land, and air transport; movement of goods; introduced organisms; active dispersal facilitated by economic activity, etc.). Humans generally have power over the first group of species' quantity and distribution but not over the second group. Aggressive species that drive out local populations can be divided between two categories of alien creatures. The presence of communities and neutral ones in a specific region is linked to their occupation of unoccupied ecological niches without causing any harm to the surrounding flora and wildlife.

In Ukraine nowadays, the number of species that are considered "invasive" is growing along with the spread of plant and animal species outside of their natural habitats. Ecosystems are being degraded by pollution, climate change, and fragmentation in many parts of the world. Additionally, there is difficult to foresee and control the growing pressure on natural ecosystems due to the expansion of invasive alien species.

The Global strategy on invasive alien species and the European strategy on invasive alien species have opened new perspectives and outlined fundamentally new approaches to solving these problems. Since this Strategy, in 2019, Ukraine adopted the National Strategy for the Treatment of Inhabitant Species and Invasive Alien Species of Flora and Fauna in Ukraine for the period until 2030, and on July 7, 2022, by Order No. 573 of the Cabinet of Ministers of Ukraine, the Action Plan was approved for the implementation of the Biosafety and Biological Protection Strategy for 2022—2025.

Nowadays, the Educational and Scientific Center of Ecology and Environmental Protection of the Polissia National University, together with the Chornobyl Radiation Ecological Biosphere Reserve, initiated the creation of regional databases on the spread of invasive alien plant species (quarantine species: *Ambrosia artemisiifolia L., Cuscuta campestris Yunk* and transformer species: *Quercus rubra L., Robinia pseudoacacia L., Acer negundo L., Echinocystis lobata (Michx.) Torr. et Gray, Amelanchier spicata (Lam.) K.Koch, Impatiens parviflora DC., Heracleum mantegazzianum Sommier & Levier* and *Heracleum sosnowskii Manden, Solidago canadensis L.*) as a potential part of the state flora.

An example of the successful use of databases and GIS technologies in nature conservation activities is the monitoring of the spread and assessment of the current state of invasive alien species that pose a threat to the natural ecosystems and biodiversity of Ukraine. Their diversity, territorial differentiation, and regional saturation with the use of GIS technologies 00,for further integration into open databases and the creation of maps of their distribution. According to the Decree of the Cabinet of Ministers of Ukraine dated July 7, 2022, No. 573-r "On Approval of the Plan of Measures for the Implementation of the Biosafety and Biological Protection Strategy for 2022—2025" [21], these issues have acquired national importance.

Open databases on the distribution of species can serve to solve several important problems: monitoring and forecasting the distribution of existing and the appearance of new, uncharacteristic for a specific region, species. Remote sensing (RS) and geographic information systems (GIS) can contribute to this, for example, by mapping the actual distribution of infestations or predicting their distribution for areas at risk of invasion. GIS could also be used to put together information about how to deal with invasive species [1, 8].

Data gathering and processing have made it possible to examine a variety of hard-to-reach ecosystems and complex geographic topographical types, which has considerably aided research on the spread of invasive species. The use of remote sensing technologies for invasive species detection, mapping, and monitoring has numerous beneficial aspects. It is well known that spatial variability makes it difficult to analyze seasonal and long-term trends in a biological invasion.

Mapping the distribution of various species, ecosystems, landscapes, and bioclimatic conditions of plant and animal existence can also help identify factors of invasiveness. Accurate assessment and modeling of species distribution are necessary for mapping the nature and extent of bioinvasions, the consequences of unchecked spread, or the potential threats of invasions. So, the goal of this article is to show how to improve the accounting and distribution of invasive species using GIS technologies.

MATERIALS AND METHODS

The assessment of the features of the distribution of invasive species was carried out using satellite survey data. At the same time, the GIS tool ArcGis from ESRI was used.

To assess the spread of quarantine species, we used multi-time data sets collected in many observations and stored in herbariums, collections, and databases of the Ukrainian Biodiversity Information Network, UkrBin, and our own research results.

Materials from the set of Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments installed on the Landsat 8 satellite were used to solve the problems of applying GIS technologies for landscape security using remote sensing data of the Earth's surface. Processing products from satellite data used in this study are available on the Unated State Geological Survey Geoportal (USGS) [19]. Such a method has already been used by the authors of the article in several previous publications, where exactly this method of data processing was used during biodiversity monitoring and assessment of the consequences of fires in the Chornobyl Radiation-Ecological Biosphere Reserve [4, 21].

Indicators obtained from the spectral channels of sensors mounted on Landsat 8 or Sentinel 2 satellites (ratio of spectral bands) and Landsat 1 radiometric survey data were used to monitor the security of landscapes [6]. Sentinel 2's spectral channels generally have higher resolution than Landsat 8's. The Sentinel 2 spacecraft has been in orbit since June 23, 2015, nevertheless, it should be mentioned. Consequently, information from the Landsat 8 satellite can be used to gain retroactive information about ecosystems (or earlier Landsat series satellites). Information from the Sentinel 2 satellite is preferred for current monitoring. Additionally, by merging data from both sources, it is possible to create scenes with a low level of cloudiness or data with a better temporal resolution.

The state of biodiversity and coverage by dominant invasive species were assessed using satellite data and checked on field observations in natural ecosystems. By comparing the NDVI vegetation indices, the concentration of chlorophyll and xanthophyll, changes in the state of the vegetation cover were revealed. After analyzing the received satellite images, trips were made to the damaged territories in order to validate the decryption data. The specified methods made it possible to estimate the approximate area and location of invasive species with significant coverage areas.

To display the NDVI index, a standardized continuous gradient or discrete scale is used, showing values

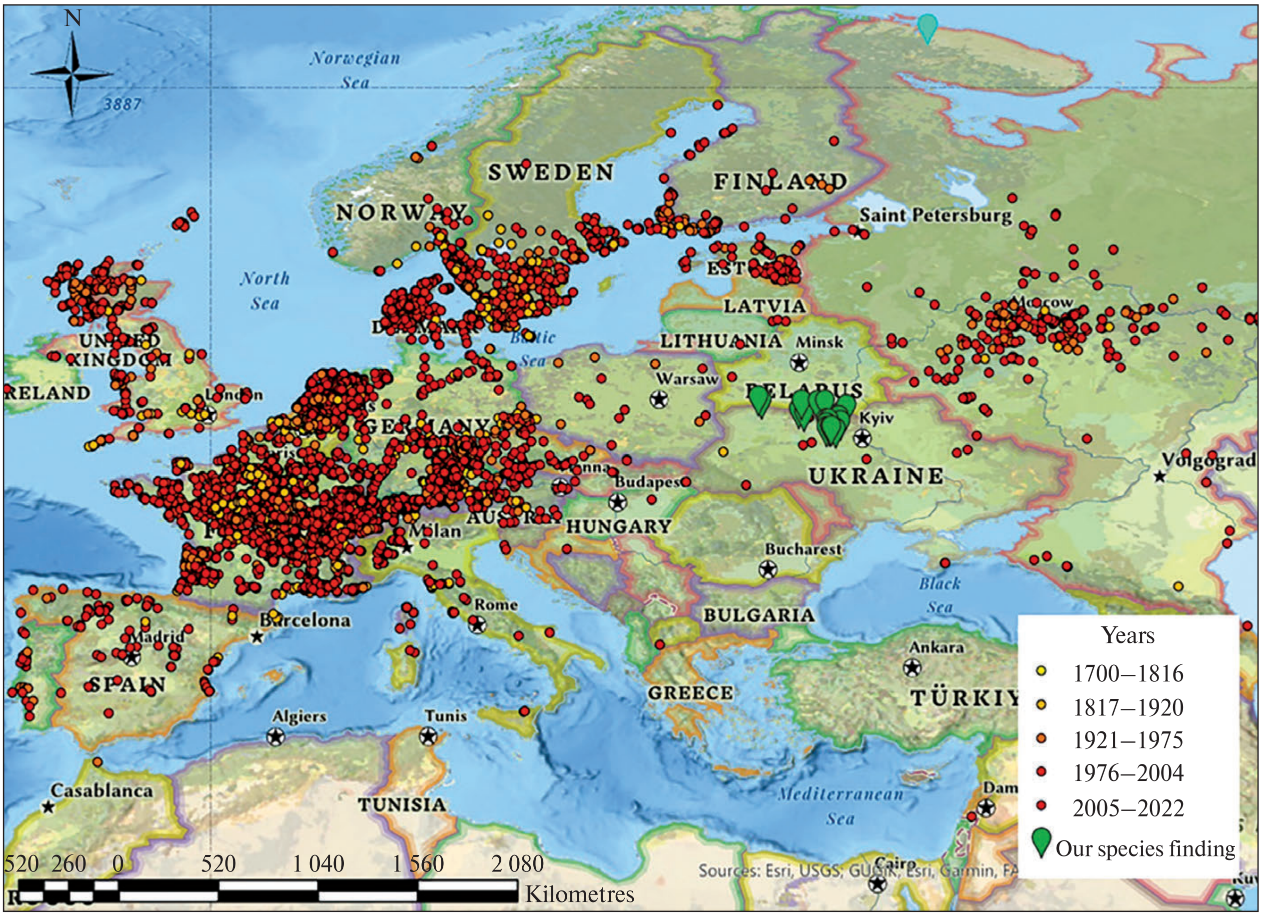

Figure 1. Current distribution of *Utricularia australis* (resource: [24] and own research [14])

in the range from –1 to 1% on a scale in the range from 0 to 255 (used for display in some processing packages, which corresponds to the number of gray gradations), or in the range 0...200 (–100...+100), which is more convenient, because each unit corresponds to a 1 % change in the indicator. Natural objects that are not related to vegetation have a fixed NDVI value due to the peculiarity of reflection in the NIR-RED parts of the spectrum (which allows you to use this parameter for their identification).

RESULTS AND DISCUSSION

Visualization of the actual (potential) distribution of species (individuals) in space. This approach is implemented by creating maps of invasive species at the national or continental level, which are formed through the interpolation of data collected in many observations and stored in herbaria, collections, and databases. Examples of informational Internet resources for collecting such data are the Ukrainian Biodiversity Information Network, UkrBin, iNaturalist, etc.

Since 1972, satellite imagery has been accessible for the majority of the world's regions. Satellite photos are useful for tracking changes in the terrain and determining how quickly significant changes are occurring because they may depict many distinct periods in time.

We have previously identified potentially harmful organisms in earlier investigations. For instance, Utricularia australis, which can be found in Ukraine, is classified as "vulnerable" in the Red Book of Ukraine. Prior to about 20 years ago, only the Transcarpathian region of Ukraine was home to the species, which eventually migrated to western Ukraine.

Figure 2. Current distribution of *Lemna aequinoctialis Welw*. in the world (resource: [10] and own research [4])

New locations were documented with the help of up-to-date species distribution databases (such as the Ukrainian Biodiversity Information Network, UkrBin, and the author's own study) [16]. Previous research has shown that sunny locations with shallow water that is low in inorganic phosphorus (10 gdm^{-3}) but high in nitrogen (800...1600 gdm^{-3}) are ideal for the growth of *U.australis.* This research demonstrated a broader spectrum of responses to the presence of organogenic materials in the water. Migratory patterns of this species in Ukraine over the past 20 years are mapped, providing further evidence of this.

When considering thermoclimatic, cryoclimatic, and continental factors, Ukraine's climate is ideal for the development of phytocenoses, in which *U.australis* plays a significant role in both distribution and creation. This suggests that *U.australis* is a eurytopic species, able to adapt to a wide variety of environmental conditions across a broad range of the key chemical factors that characterize its habitats.

Their adaptability allows them to thrive in a variety of environments, both artificial and natural, and in a wide range of hydrochemical indicators, even in highly polluted reservoirs, leading us to anticipate the continued spread of this species in Ukraine and an increase in the number of its localities (Fig. 1). According to the Ukraine's Red List, the species is currently classified as "threatened". The GIS study concluded that the species' status should be reevaluated. Additionally, comparable findings came from a series of investigations (conducted in 2019) on the species identification of members of the family Lemnaceae's genus Lemna (Fig. 2). Duckweed samples were obtained in Ukraine's northern areas, and morphological and molecular markers were used to identify the species (barcoding) [14].

As a result, *Lemna aequinoctialis Welw*, a new species of watercress that is not native to Ukraine, was found. For this reason, we have currently completed the most thorough description of *Lemna aequinoctialis*' range in Europe, which also includes the most recent information on the distribution of watercress species in Ukraine. Thus, it was determined that there are 14 species in the genus Lemna L. based on educational Internet resources. *Lemna gibba L., L. minor L., L. trisulca L., and L. minuta Kunth* are the four species of the genus *Lemna* that are listed on the List of Vascular Plants of Ukraine. The DNA-diagnostic method was used in our work to identify another adventive duckweed species that had been found in the village of Levkiv, in the Zhytomyr area, in northern Ukraine. This species, known as little duckweed, is new to Ukraine (*Lemna aequinoctialis Welw*.). So, there are six types of *Lemna* in Ukraine right now. Three of them are native, and the other three got there by accident.

We have been able to track and find the most likely places where this invasive species got into Ukraine by using GIS analysis.

Remote sensing methods. Remote sensing offers the possibility of a comprehensive evaluation of the Earth's surface. The vegetation and distinctive qualities of some plant species, such as canopy architecture, vegetative density, leaf pubescence, phenological stage, etc., can be evaluated via aerial photography. Recent advancements have made photography and videography from spacecraft and drones an affordable, practical, and adaptable substitute for conventional photography, particularly when the data needs to be recorded digitally.

The near-infrared (NIR) and infrared (IR) wavelength ranges are also covered by some systems. In the visible region of the electromagnetic spectrum, multispectral scanners record the reflectivity in a variety of spectral bands. Several spectral bands with a width of 100 nm or greater can be found in broadband scanners. More (from tens to several hundreds) but thinner (from tens to few nm) spectral bands are present in hyperspectral scanners. The distinction between various forms of land cover, such as woods, bare soils, and populated regions, has been accomplished with success using broadband scanners. Hyperspectral scanners' increased spectral resolution enables them to discern more minute distinctions, such as those between different species. This is impacted by atmospheric conditions. Additionally, this ratio is adversely impacted by declining spectral (bandwidth) and spatial (pixel size) resolution. For a spectral resolution of the order of 50...100 nm, modern SPOT HRIV and Landsat TM scanners support an acceptable signal-to-noise ratio with pixel sizes in the range of 10...20 m. The resolution of panchromatic satellite images like IKONOS is 1 m. Hyperspectral scanners like MODIS can capture data with a high level of spectral resolution thanks to their 250-meter-wide pixels.

The data obtained by remote sensing devices will be directly related to the properties of this cover. Currently, it is possible to classify some species based on the ability of the ecosystem cover (either vegetation or fauna) to reflect electromagnetic radiation, which is captured by remote sensing devices. In this way, the dominant species in the forest canopy, in the fields, on the surface, or in the layer of water bodies are easily detected. For example, when several invasive species dominate the canopy of the earth's surface, forming homogeneous single-species plantations that spread over large areas, such manipulations are possible for most forest ecosystems with many tree species, such as *Quercus rubra L., Robinia pseudoacacia L., Acer negundo L.,* etc. The dominance of invasive species among "invaders" is not limited to tree species, it also occurs in grasses (for example, quarantine species: *Ambrosia artemisiifolia L., Cuscuta campestris Yunk,* and transform species: *Echinocystis lobata (Michx.) Torr. et Gray, Amelanchier spicata (Lam .) K. Koch, Impatiens parviflora DC., Heracleum mantegazzianum Sommier & Levier and Heracleum sosnowskii Manden, Solidago canadensis L., etc.*), floating (*Eichhornia crassipes, Trapa natans, Acorus calamus L, Azolla caroliniana Willd.)* and submerged aquatic vegetation (transformer species — *Elodea canadensis Michx.,* etc.).

The aquatic ecosystems' layers are dominated by a few of the registered invasive species. The limitations of the remote sensing methods previously discussed for these habitats are due to how little light is reflected by submerged creatures. However, this is also doable with a portable fixed-band radiometer set up to gather data in Landsat TM. It is possible to connect the locations of some macrophytes to environmental elements that influence the growth of aquatic plants using herbicide application maps and GIS information on nutrients, dissolved oxygen, biological oxygen demand, and turbidity.

By performing spatial correlation, GIS tools often identify invasive species because of their impact on dominant plant species. The possibility of using remote sensing for research on invasive understory species has a certain basis. Examples of this category include plant species such as *Chromolaena odorata, Ulex europaeus, Clidemia hirta, Lantana camara, Mimosa pigra, Psidium cattleianum, Rubus ellipticus, Schinus terebinthifolius,* and most invasive animal species. Most invasive animals, as well as representatives of lower flora, grasses, shrubs, and fauna, are "inhabitants" of the understory, which makes their study using direct remote sensing methods almost impossible. Nevertheless, the combination of remote sensing techniques, GIS, and expert knowledge still offers the potential to detect understory infestations through the development of risk models and maps. This can help predict how likely it is that invasive species will spread in real and possible sites and areas where ecological conditions are good for it.

When characterizing the spread of invasive species over wide areas, the green NDVI index GreenNDVI might be instructive. It's a typical relative speed index that shows how much biomass is actively photosynthesizing (usually called the vegetation index). Plant cover assessment is one of the most popular indices used to address issues with quantitative indicators. It is used for regional mapping, analysis of various landscape types, and evaluation of resources and biosystem areas on the size of continents and nations. However, most of the time, NDVI is determined from a collection of images taken at various times (during various seasons) using predetermined temporal indications. This paints a dynamic picture of how the boundaries and properties of various vegetation kinds alter throughout time (monthly, seasonal, and annual changes).

Although NDVI, a man-made dimensionless indicator, is designed to evaluate vegetation's biological and climatic features, it can also demonstrate a strong relationship with some metrics that fall into a completely different category, such as productivity (temporal fluctuations), biomass, etc.

It is frequently necessary to consider the temporal difference between the parameter and the corresponding response of NDVI because the dependence between these parameters and NDVI is typically not direct and is related to the peculiarities of the studied territory, its climatic and ecological characteristics. NDVI maps are frequently employed as one of the additional intermediate layers for more complicated sorts of analysis because of all these qualities. Maps of various landscape types, vegetation kinds, natu-

Figure 3. An example of the calculation of NDVI indices for the territory of the Chornobyl Radiation-Ecological Biosphere Reserve of the Uzh district with continuous overgrowth of the water mirror species Trapa natans

ral habitats, soil types, phytohydrological maps, and other ecological and climatic maps can be produced as a result (Fig. 3). Additionally, on its foundation, a wealth of data can be gathered for use in assessments and forecasts of the spread of invasive species, biological variety, the intensity of disturbance and damage from different natural and anthropogenic disasters, accidents, etc. These statistics are frequently employed in the calculation of other, globally and territorially bound indexes (LSI leaf surface index, FPAR index of photosynthetically active radiation absorbed by plants).

Additionally, the expansion of higher aquatic plants and phytoplankton can be used to estimate the degree of eutrophication in a body of water. The index of chlorophyll-a concentration is used for this. Chlorophyll-a concentration is a useful indication of water productivity and trophicity, and it is connected to phytoplankton's primary production. According to the European Union's Framework Directive 2008/56/EU, the amount of chlorophyll in the water column is a collection of indicators for determining the degree of eutrophication and a clear indication of what happens when specific compounds are added to water.

Furthermore, xanthophyll activity indexes assess pigments found in stressed plants. In inhibited vegetation, xanthophyll production is seen to be intense. Chlorophyll is not considered by the indices because "greenness" indices are used to measure it.

The detection of plant cover areas that are under stress is one of the areas in which the Leaf Pigments Index is applied. In many cases, indices can detect vegetation stress before it is obvious to the naked eye.

To calculate them, data from specific visible spectral bands are used.

This indication can be helpful in identifying places with drying forest plantations, areas with a higher degree of dehydration, and, thus, areas with a higher risk of fire during dry spells, among other things. Additionally, this indication can be used to recognize the development centers of plants whose colors range from red to yellow and orange, which can be crucial in recognizing the growth centers of species like Quercus rubra L. and others whose colors occasionally diverge from those of usual vegetation.

Monitoring and forecasting the hazards of the spread of invasive species. Ecologists have long sought to forecast the likelihood of biological invasions and likely invasions. The creation of models for predicting the likely or present threat of the appearance and spread of infestation is the key problem facing GIS technologies in this field. The degree to which introduced species become invasive varies by location. A species' ecological behavior in a novel setting may be nearly impossible to predict. The effects of a particular disturbance vary according to the characteristics of the ecosystem or community. It is important to assess changes from the perspective of ecological effects rather than from the perspective of species features. Compared to plants, it is far more challenging to estimate the number of animal species, population size, and associated characteristics. The properties of environmental contamination and the dynamics of species variety, and consequently the effective spread and resettlement of alien species, are typically found to be closely related.

The Invasive Species Vegetation Database is an integrated multimedia method to depict geographic features and related data regarding the interactions between flora, fauna, and human activities. We may be able to more accurately predict invasion spread patterns by utilizing these promising quantitative methodologies in an integrated GIS context. Satellite technologies and the simultaneous use of data can be used for a variety of purposes to monitor and control insect pests such as the screwworm (a nuisance of cattle), desert locust (a pest of agriculture depending on rainfall), and cyanobacteria (preventing water "blooms").

For the goal of regional early detection and prevention of crop losses or pest infestation or for the phenological mapping of natural vegetation, agricultural crops can be periodically monitored, and their economic efficiency projected (Fig. 4).

The evaluation of the possible scope of an invasion's expansion is one of the major problems associated with its occurrence. The spatial scale, the size of the area being researched, and the resolution of the remote sensor all influence the results of all observations. There is no "proper" scale; it all depends on what the study is trying to achieve. However, the landscape scale is typically employed as the proper size for modeling. Under these circumstances, unless the distribution of invasive species is quite widespread, LANDSAT TM and SPOT data with terrestrial resolutions of 30 and 20 meters, respectively, are not adequate for species-level mapping [13, 22]. In other words, this technique can only be used to model and map the landscape pollution brought on by the most widespread plant species. The accuracy and productivity of vegetation mapping could be increased by recent improvements in sensor technology. Some invasive species can be mapped with an accuracy of 75...95 % using remote sensing data with a high spatial resolution (less than or equal to 1 m) but low spectral resolution. Therefore, to overcome these issues, it is crucial to recognize the major significance of image quality and spectral features, and in these circumstances, aerial photographs should be selected. Additionally, it amply demonstrates the necessity of taking the phenological stage into account when taking aerial photos or producing images to map invasive species accurately. Even though dominant plant species can be accurately classified thanks to high spectral and spatial resolution, this is still a challenging task. Few such investigations on the spectral characteristics of invasive species have been made, with the majority using field spectrographs or low-altitude aerial photography. However, there won't be much information that reaches the remote observer. Physiological characteristics of plants, such as, for example, age-related changes in leaf orientation, variation of the leaf area index, and different slopes of places where individuals are found, can also make it difficult to identify a species. These additional factors include atmospheric noise, humidity, shadows, features of the ground cover, and atmospheric noise. Because there are so many invasive species in a

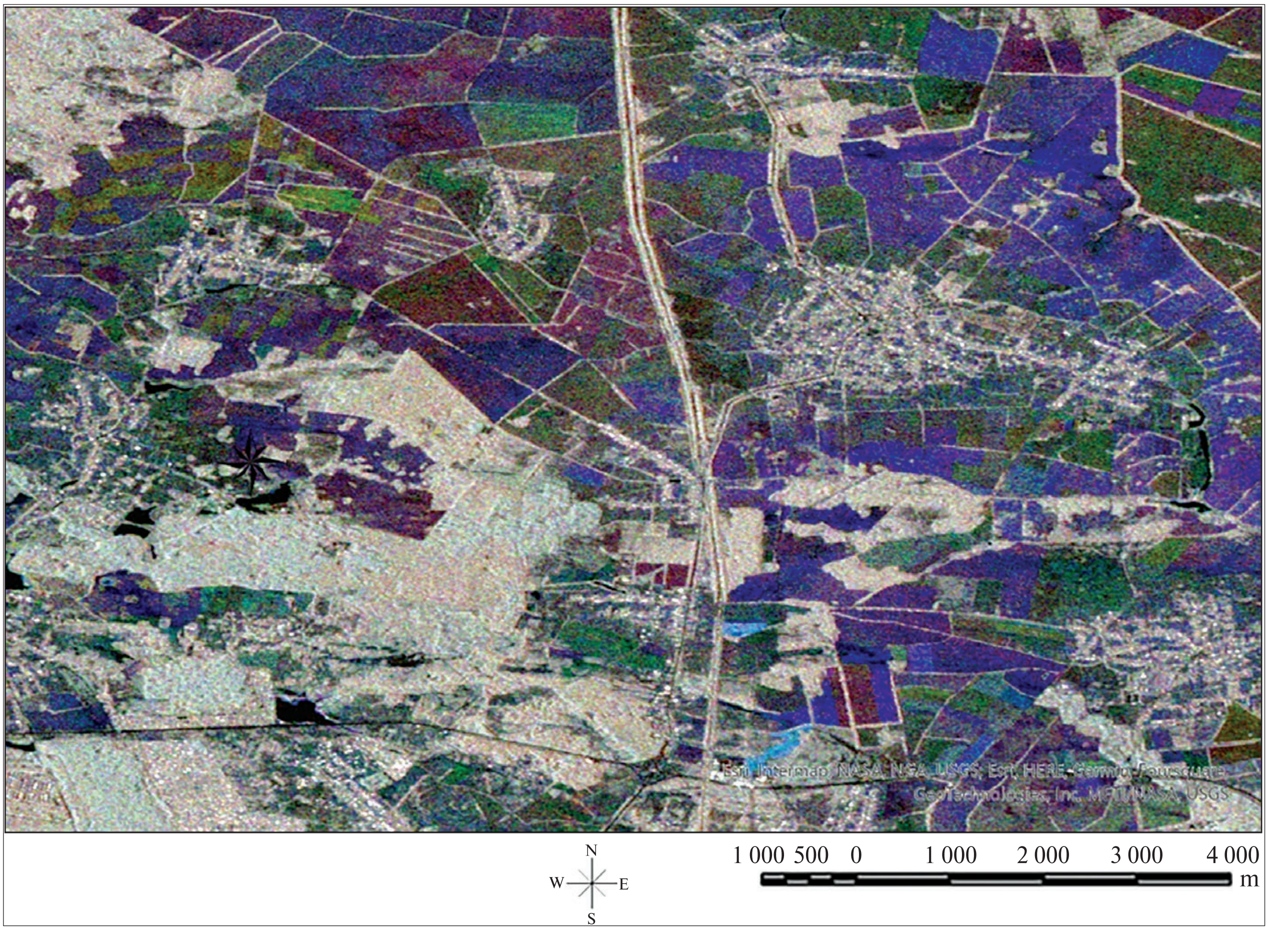

Figure 4. An example of identifying the biodiversity of agricultural landscapes of the Zhytomyr region based on the processing of images of the Sentinel-1 radar spacecraft with subsequent verification of the results

grouping, it is impossible to find the best wavelengths for discrimination. Additionally, it becomes more challenging to distinguish the different elements that make up the mixed spectrum as the number of invasive species per pixel rises. If species variability in spectral characteristics is considerable, these issues will worsen. Therefore, for some invasive species, there is a low likelihood of direct remote monitoring with the ability to accurately identify every individual utilizing direct mapping.

CONCLUSION

The ability of remote sensing techniques and GIS technologies to track changes in various ecosystems can be crucial if the extent of spread or the effects of changing ecosystem structure are to be assessed, even though the use of GIS methods to map invasive species and invasive ecosystems is expanding quickly. Various mapping techniques have been developed because of the development of remote sensing and GIS mapping in the field of bioinvasion distribution features, however the technology still requires development in terms of practical applications for mapping invasive species. Additionally, because biological processes are so complicated, mapping, modeling, and predicting biological invasions will always be a difficult task for ecologists. Because of this complexity, it is challenging to identify or pinpoint invasions that take place in many ecosystems. Research has shown the potential of remote sensing and GIS applications for invasive species mapping and modeling, even though it is currently restricted to a small number of taxa. When it comes to many animal species and the worst plant species in the world, remote sensing applications are severely constrained. However, progress will be accelerated if ecologists and remote sensing specialists use integrated approaches to their research on "invasions" of alien species, including RSE and GIS techniques, modeling, a meta-analysis of previous concept studies, and full utilization of available pre- and post-invasion models to test new hypotheses. Currently, the spatial, spectral, and temporal analysis of images holds great promise because it enables the delineation of ecosystem boundaries, species biometrics, characteristics of their current and potential distribution areas, etc.

REFERENCES

1. Bolch E. A., Santos M. J., Ade C., Khanna S., Basinger N. T., Reader M. O., Hestir E. L. (2020). *Remote detection of invasive alien species*. Remote sensing of plant biodiversity. Springer, Cham, 267—307.
2. Clavero M., Brotons L., Pons P., Sol D. (2009). Prominent role of invasive species in avian biodiversity loss. *Biological Conservation,* **142**(10), 2043—2049.
3. Fedoniuk T., Bog M., Orlov O., Appenroth K. J. (2022). Lemna aequinoctialis migrates further into temperate continental Europe — A new alien aquatic plant for Ukraine. Feddes Repertorium. doi:10.1002/fedr.202200001
4. Fedoniuk T., Borsuk O., Melnychuk T., Zymaroieva A., Pazych V. (2021). Assessment of the consequences of forest fires in 2020 on the territory of the chornobyl radiation and ecological biosphere reserve. *Scientific Horizons*, **24**(8), 26—36. doi:10.48077/scihor.24(8).2021.26-36
5. Fedoniuk T. P., Fedoniuk R. H., Romanchuk L. D., Petruk A. A., Pazych V. M. (2019). The influence of landscape structure on the quality index of surface waters. *J. Water and Land Development*, **43**(1), 56—63. doi:10.2478/jwld-2019-0063
6. Fedonyuk T. P., Galushchenko O. M., Melnichuk T. V., Zhukov O. V., Vishnevskiy D. O., Zymaroieva A. A., Hurelia V. V. (2020). Prospects and main aspects of the GIS-technologies application for monitoring of biodiversity (on the example of the Chornobyl Radiation-Ecological Biosphere Reserve). *Space Science and Technology*, **26**(6), 75—93.
7. Joshi C., De Leeuw J., van Duren I. C. (2004, July). Remote sensing and GIS applications for mapping and spatial modelling of invasive species. *Proc. ISPRS*, **35**, B7.
8. Klein I., Oppelt N., Kuenzer C. (2021). Application of remote sensing data for locust research and management — a review. *Insects,* **12**(3), 233.
9. Lean C. H. (2021). Invasive species increase biodiversity and, therefore, services: An argument of equivocations. *Conservation Sci. and Practice*, **3**(12), e553.
10. Lemna aequinoctialis Welw. GBIF.org (9 November 2022). GBIF Occurrence Download. https://doi.org/10.15468/dl.3mg6yb URL: https://www.gbif.org/species/2867616 (Last accessed: 15.12.2022).
11. Miller H. M., Richardson L., Koontz S. R., Loomis J., Koontz L. (2013). Users, uses, and value of Landsat satellite imagery—Results from the 2012 survey of users. *US Geological Survey Open-File Report*, 1269, 51.
12. Niphadkar M., Nagendra H. (2016). Remote sensing of invasive plants: incorporating functional traits into the picture. *Int. J. Remote Sensing*, **37**(13), 3074—3085.
13. Nykolyuk O., Skydan O., Pyvovar P. (2021). Assessment of the Relationship Between Farm Size and Flexibility: The Case of Ukraine. *Management Theory and Studies for Rural Business and Infrastructure Development*, **43**, 21—37. doi:10.15544/mts.2021.03.
14. Orlov O. O., Fedoniuk T. P., Iakushenko D. M., Danylyk I. M., Kish R. Y., Zymaroieva A. A., Khant G. A. (2021). Distribution and ecological growth conditions of Utricularia australis R. br. in Ukraine. *J. Water and Land Development*, **48**(1—3), 32—47. doi:10.24425/jwld.2021.136144
15. Pettorelli N., Owen H. J. F., Duncan C. (2016). How do we want Satellite Remote Sensing to support biodiversity conservation globally? *Methods in Ecology and Evolution*, **7**(6), 656—665.
16. Pyšek P., Hulme P. E., Simberloff D., Bacher S., Blackburn T. M., Carlton J. T., ..., Richardson D. M. (2020). Scientists' warning on invasive alien species. *Biological Reviews*, **95**(6), 1511—1534.
17. Qiu J. (2015). A global synthesis of the effects of biological invasions on greenhouse gas emissions. *Global Ecology and Biogeography*, **24**(11), 1351—1362.
18. Rocchini D., Andreo V., Förster M., Garzon-Lopez C. X., Gutierrez A. P., Gillespie T. W., ... Neteler M. (2015). Potential of remote sensing to predict species invasions: A modelling perspective. *Progress in Phys. Geography*, **39**(3), 283—309.
19. *Sentinel Hub Public Collections*. URL: https://collections.sentinel-hub.com/ (Last accessed: 15.12.2022).

20. Skydan O. V., Danyk Yu. H., Fedoniuk T. P., et al. (2022). *Space and geoinformation support for decision-making in key areas of national security and defense of Ukraine: monografy.* Ed. red. O. V. Skydan. Zhytomyr: Poliskyi natsionalnyi universytet, 280 p. ISBN 978-617-7684-81-6 [In Ukrainian].
21. Skydan O. V., Fedoniuk T. P., Pyvovar P. V., Dankevych V. Y., Dankevych Y. M. (2021). Landscape fire safety management the experience of Ukraine and the EU. *News Nat. Acad. Sci. Republic of Kazakhstan. Ser. Geology and Techn. Sci.*, **6**(450), 125—132. doi:10.32014/2021.2518-170X.128
22. Skydan O., Pyvovar P., Topolnytskyi P., Prysiazhna T. (2022). Analysis of rural areas of Ukraine on the basis of ESA WorldCover 2020. *Scientific Horizons*, **25**(5), 74—85. doi:10.48077/SCIHOR.25(5).2022.74-85
23. The decision of the National Security and Defense Council of Ukraine dated October 15, 2021 “On the Biosafety and Biological Defense Strategy”. URL: https://zakon.rada.gov.ua/laws/show/668/2021?lang=en#Text (Last accessed 15.12.2022). [In Ukrainian].
24. Utricularia × australis R. Br. GBIF.org (9 November 2022). GBIF Occurrence Download. https://doi.org/10.15468/dl.hspebk. URL: https://www.gbif.org/species/7297904 (Last accessed: 15.12.2022).
25. Wegmann M., Leutner B., Dech S. (eds.). (2016). *Remote sensing and GIS for ecologists: using open source software*. Pelagic Publishing Ltd.

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ЗАЛУЧЕННЯ ГЕОІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ У СТРУКТУРУ ЗБЕРЕЖЕННЯ БІОЛОГІЧНОГО РІЗНОМАНІТТЯ ТА ЗАПОБІГАННЯ БІОЛОГІЧНИМ ЗАГРОЗАМ ЛАНДШАФТІВ

Оскільки довгострокова стійкість як природних, так і штучних фітоценозів знаходиться під серйозною загрозою з боку біологічних загарбників, світова спільнота наполегливо працює, щоб запобігти інвазіям і швидко викорінити або зупинити поширення інвазивних видів. Відстежуючи фактичне поширення «загарбників» або прогнозуючи території, яким загрожує вторгнення, географічні інформаційні системи (ГІС) і дистанційне зондування Землі (ДЗ) можуть суттєво допомогти процесу забезпечення біологічної безпеки на державному рівні. Дослідження показали потенціал дистанційного зондування та ГІС-додатків для картографування та моделювання інвазивних видів, навіть незважаючи на те, що наразі він обмежений невеликою кількістю таксонів. У цій статті описано приклади застосування ГІС-технологій та ДЗЗ для відстеження кількох інвазивних видів (*Utricularia australis R. br.* та *Lemna aequinoctialis Welw.*). Для опису поширень видів було використано актуальні інтернет-бази даних поширення видів та власні дослідження автора. Визначені перспективні шляхи виявлення та моніторингу поширення інвазивних видів, застосування індексів NDVI, вмісту хлорофілу, а також ксантофілу для виявлення змін у біорізноманітті регіонів, деякі питання ідентифікації змін біорізноманіття в агрокультурних ландшафтах, а також картографування ризиків вторгнення для територій, на яких раніше ці види не зустрічалися. У статті також показано можливості застосування ГІС-технологій при ідентифікації біорізноманіття агроландшафтів із застосуванням радіометричної космічної інформації з Sentinel-1 з подальшою верифікацією результатів. Визначені перспективи просторового, спектрального і часового аналізу зображень, оскільки вони дають змогу окреслити межі екосистем, біометричні характеристики видів, характеристики їх поточних і потенційних територій поширення тощо.

Ключові слова: інвазійний вид, вегетаційні показники, поширення, біоінвазія, зараження шкідниками.