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RESTORATION OF THE SOUTHERN BUG RIVER ECOSYSTEM BY REMOVING THE BIOMASS OF HIGHER WATER PLANTS

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Abstract

The purpose of the study is to analyze the parameters of higher aquatic plants of the Southern Bug River using multispectral methods and a quadcopter, as well as to develop environmental protection measures to improve the ecological state of the river. The location of the Southern Bug River (Ukraine) in the zone of intensive economic activity, the illegal development of a natural backwater strip near the river causes an increased anthropogenic pressure on aquatic ecosystems, which leads to their aggravated eutrophication, one of the features of which is a growing concentration of nutrients. The bioindication of surface water quality using higher aquatic plants, a comprehensive assessment of the impact of all hydromorphological, chemical and physicochemical indicators on their development was carried out. The assessment of the ecological state of water bodies using bioindication with the multispectral method and a quadcopter was carried out. After correcting the measurement results, the parameters of higher water plants in the water body were obtained. By segmenting the water body according to selected indicators, it is possible to determine the integral effect of pollutants in a specific section of the water body.

***Keywords**: Ecosystem, Quadcopter, Biomass, Higher aquatic plants, Eutrophication, Water protection, Surface water quality*

Introduction

In recent decades, the problem of clean water in many countries of the world is one of the most relevant ones, since the human activity contributes to a significant deterioration in the quality of water of surface water bodies. Today, when planning water management measures, it is necessary to take into account the general nature, trends and the extent of human intervention in natural processes, to assess and predict the environmental, economic and social consequences. One of the most acute environmental problems of our time is ensuring the rational and sustainable use of water bodies and their protection. In terms of water resources, Ukraine is one of the last places among European countries. The scarcity of water resources and

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their extensive use lead to the fact that the ability of water bodies to restore their ecosystems and water quality often approaches a critical level, and along with this, the biological diversity decreases. When water bodies are polluted, a change in the functioning of aquatic ecosystems occurs, this affects the change in productivity and number of biological populations, etc. As a result, this leads to a change in the properties of the water body and the danger to living resources of the ecosystem and human health. The known methods for the restoration of river and riverine ecosystems, providing for drainage of flooded areas after reaching the maximum phytomass of higher aquatic vegetation, followed by the removal of all biomass using an environmentally friendly technology [1, 2]. The main biological indicators that are recommended to be used to assess the ecological status of water bodies using bioindication methods in the Water Framework Directive 2000/60/EC are the composition, quantity and presence of sensitive taxa for benthic invertebrates, macrophytes, benthic algae, fish and phytoplankton [3].These are the features of using higher water plants to assess the ecological status of water bodies. Higher water plants are regarded as an “important element of quality for classifying the ecological status” of natural and “ecological potential” of highly modified and artificial water bodies. Macrophytes are used to assess the eutrophication of water bodies. In particular, when studying macrophytes, such indicators as morphology, river flow, depth and transparency of water bodies are additionally taken into account. They are characterized by high seasonal fluctuations in the structure and number of groups. A typical frequency of research is once or twice a year. The study is recommended from mid to late summer.

In 2018, Ukraine introduced a new “Procedure for the implementation of state water monitoring” [4]. State water monitoring is carried out in order to ensure the collection, processing, storage, generalization and analysis of information on the state of water bodies, forecasting its changes and developing scientifically sound recommendations for making decisions in the field of water use, protection and recreation of water resources [4].

In the paper [5], a combination of multispectral satellite (Worldview-2) and hyperspectral (FieldSpec 3 ASD) studies was performed to study aquatic macrophytes in the Vembanad estuary (India).In order to identify the species of aquatic macrophytes, the near infrared range (NIR) was selected, which is associated with multiple scattering in the structure of the leaves. In this case, the optimal spectral bands in the range of 700-900nm were determined, which allow distinguishing certain types of macrophytes with high reliability. Due to the limited spatial resolution of satellite images, it was possible to identify the species composition only for large macrophyte groups.

The water quality in the Küçükçekmece Lake (Turkey) was studied using multispectral satellite monitoring from the Landsat-5 [6]. Multiple regression analysis was performed according to the results of remote multispectral measurement of satellite water quality parameters and such parameters obtained in situ: chlorophyll a concentration, total phosphorus, total nitrogen, transparency, biological oxygen consumption, chemical oxygen consumption. The spatial separation ability of the satellite images ranged from 10 to 30m. The satellite images were converted to digital topographic maps corrected by 50 ground control points with an accuracy of 0.5 pixels. The multispectral images of the water body were processed and each of the pixels was classified using the Bayesian classifier, which made it possible to identify and visualize the zones of the water body into which agricultural wastewater, surface runoff from forest areas, mixed municipal and industrial wastewater from urban areas are discharged. As a result of multispectral image processing, maps of the spatial distribution of water quality parameters in a water body were created, which provide valuable information for understanding the local and global changes in the water quality parameters to control their pollution.

In paper [7], the water quality of the River Sava (Croatia) was monitored using hyperspectral data to obtain the chlorophyll a concentrations, transparency, and the sum of suspended substances in water. The environmental monitoring system of water quality has been created, which has sufficient spatial resolution to localize pollution sources and has sufficient speed and separation ability in time to record the fact of discharge of pollutants. The measurements were carried out using FieldSpec 3 ASD and PRR-800 spectrometers in the range from 350 to 1050 nm. In order to calibrate the spectral characteristics at the level of the water surface, the Lambert standard Spectralon 99% was used. Along with hyperspectral measurements, traditional physicochemical measurements of water quality parameters were carried out. The strongest correlation with the concentration of chlorophyll a ($r = 0.85$) was obtained for the ratio of reflection coefficients at wavelengths of 745 and 418 nm, for the substances suspended in water ($r = 0.88$) for reflection coefficients at wavelengths of 373 and 396 nm, and for transparency ($r = 0.85$) for reflection coefficients at wavelengths of 396 and 390 nm.

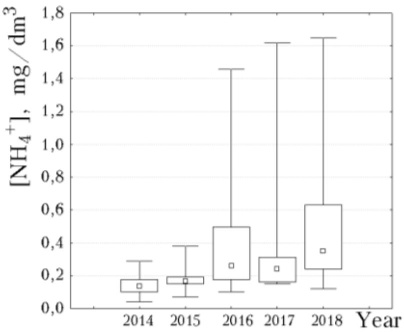
In many studies [8-17], mathematical models of aqueous media with phytoplankton particles of various shapes and sizes were proposed, as well as the methods and tools for multispectral environmental monitoring of water bodies by the phytoplankton parameters. Subsequently, multispectral methods and tools were adapted to study the parameters of higher water plants in water bodies [18, 19].

Higher algae with the ability to remove pollutants from water: nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, manganese, sulfur), heavy metals (cadmium, copper, lead, zinc), phenols, sulfates, petroleum products, synthetic surface substances and improve the indicators of organic pollution, such as biochemical oxygen consumption and chemical oxygen consumption [20]. The root system of cattail (Typhalatifolia) has a high storage capacity for heavy metals. The concentration of metals in the root system of cattail, which grew on the banks of sludge collectors of power plants, reached (mg/kg): iron –199.1; manganese –159.5; copper –3.4; zinc –16.6 [21]. Similar approaches are used to determine the ecological state of various types of water bodies based on the analysis of phytoplankton parameters such as the total content of chlorophyll a in the aquatic environment or the ratio between different pigments [22-26].

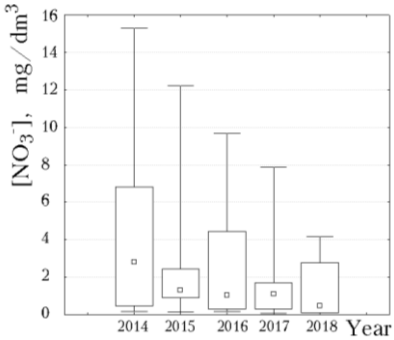
Methods and tools for assessing the ecological state of surface water according to the characteristics of higher aquatic plants

The location of the Southern Bug River (Ukraine) in the zone of intensive economic activity as well as the illegal development of the nature conservation zone near the river, lead to an increased anthropogenic pressure on aquatic ecosystems, characterized by increased eutrophication, one of the features of which is a growing concentration of nutrients. In this regard, the feasibility of environmental assessment of the state of the hydroecosystem according to the criteria that are included in the block of hydrochemical indicators is obvious. When using bioindication of the surface water quality with macrophytes, a comprehensive assessment of the impact of all hydromorphological, chemical and physico-chemical indicators on their development is carried out. With a significant variation of these impact indicators during the year, the biological indicators of macrophytes, namely, the area of the projective cover of the water mirror, the species composition of macrophyte groups and the relative share of the projective cover of each of the species will depend on the average values of the impact indicators during the growing season. Aim of the work is to analyze the parameters of higher aquatic plants of the Southern Bug River using multispectral methods and a quadcopter, as well as to develop environmental protection measures to improve the ecological state of the river.

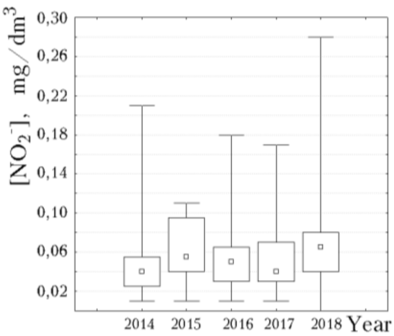
The results of statistical processing of measurements of selected hydrochemical parameters of surface water quality in the Southern Bug River (observation point: Southern Bug River –582km., Vinnitsa, Sabarovsky Reservoir, drinking water intake of the city) are shown in figure 1. Since the data do not correspond to the normal distribution law by the Shapiro-Wilk criterion, the values of the median and interquartile range are indicated on the diagrams.



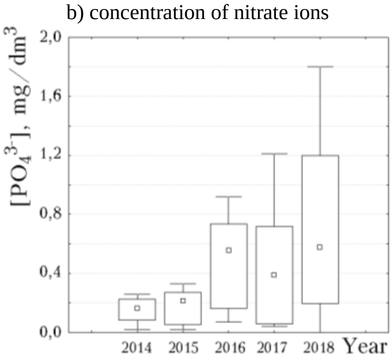
a) concentration of ammonium ions



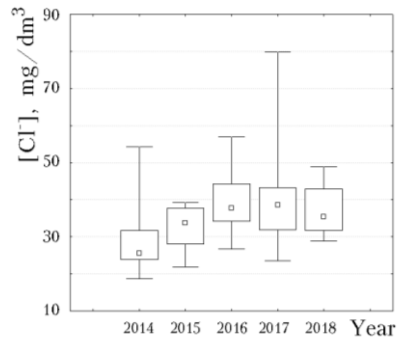
b) concentration of nitrate ions



c) concentration of nitrite ions



d) concentration of phosphate ions



e) concentration of chloride ions

Fig. 1. Hydrochemical parameters of water quality (observation point: Southern Bug River - 582km, Vinnitsa, Sabarovsky Reservoir, drinking water intake of the city)

The structural scheme for assessing the ecological state of water bodies using bioindication, multispectral method and quadcopter is shown in figure 2. First, with the help of a multispectral camera and a quadrocopter, an array of multispectral images of the surface of a water body was formed. At the same time, the GPS coordinates were fixed for each position of the quadcopter, its height and orientation in space. Then, using the developed regression equations, the biomass and the ratio between the pigments in the surface layer of the aquatic environment were calculated. The calculation results were adjusted relative to the reference information, which allows compensating for the change in the spectral composition of the incident solar radiation using an exemplary tool (Lambert standard) with known spectral characteristics. They were also compensated for the effect of localized absorption, the effect of atmospheric aerosol and reflection from the surface of the aquatic environment.

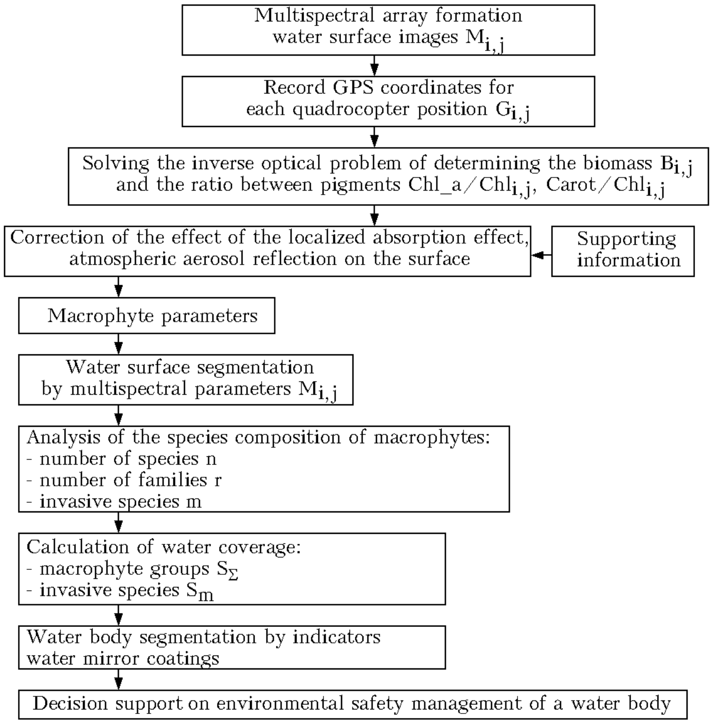


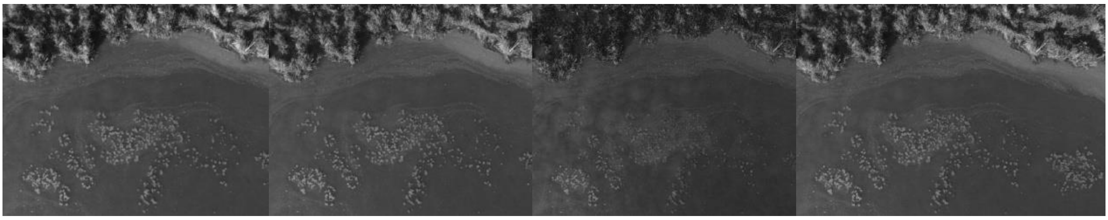
Fig. 2. The structural scheme for assessing the ecological state of water bodies using bioindication, multispectral method and quadcopter

The results of hydrobiological, hydrochemical and hydromorphological measurements of the parameters of the aquatic environment were used. After correcting the measurement results, the parameters of higher water plants in the water body were obtained. This makes it possible to find out the pathways of pollutants entering the water body to support decision-making on managing the environmental safety of the water body. In order to obtain the necessary parameters of higher aquatic plants, one must first segment the surface of the aquatic environment according to multispectral parameters and identify the species composition of macrophytes. As a result of the analysis of the species composition, the number of species and the number of families of higher aquatic plants, as well as the presence of invasive species, were established. Next, the water mirror coverings were calculated for each of the macrophyte groups and invasive species. In this case, the assessment of the ecological state was carried out according to the obtained indicators of water mirror coverage. By segmenting the water body according to these indicators, it was possible to determine the integral effect of pollutants in a specific section of the water body and compare the ecological state of the water body in its different sections.

Analysis of the ecological state of surface water

Figure 3 shows the multispectral images of a coastal plant complex of higher aquatic plants. In the process of studying the development of groups of higher aquatic plants, their species composition was analyzed, and the impoverished qualitative composition of floristic groups was determined, which formed two plant complexes –coastal and aquatorial. The coastal plant complex in the form of a strip along the coastline was represented by common reeds (*Phragmites communis*) – the relative area of the projective cover is 48%, broad-leaved cattail

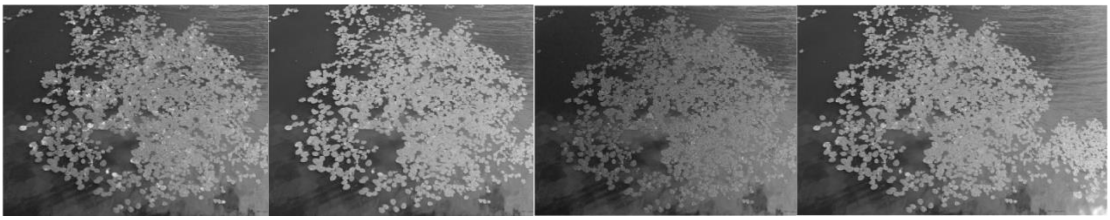
(*Typha latifolia*) – 8% and narrow-leaved cattail (*Typha angustifolia*) – 6%, acute sedge (*Carex acuta*) – 12%, coastal sedge (C. *raparia*) – 4% and ordinary sedge (*C. gracilis*) – 6%.



a) 620 nm b) 530 nm c) 470 nm d) 730 nm

Fig. 3. Multispectral images of a coastal plant complex of higher aquatic plants

Aquatorial "spots" consisted of submerged and floating higher aquatic plants. If there was a high concentration of phytoplankton in the water for a multispectral means of environmental monitoring of water bodies using a quadcopter, it was possible to study only the floating higher aquatic plants. As an object of study, macrophyte groups of yellow water lilies (*Nuphar lutea*) with a leaf diameter of 20–25cm were used. Figure 4 shows the multispectral images of a group of macrophytes of yellow water lilies from a quadcopter at a height of 20m.

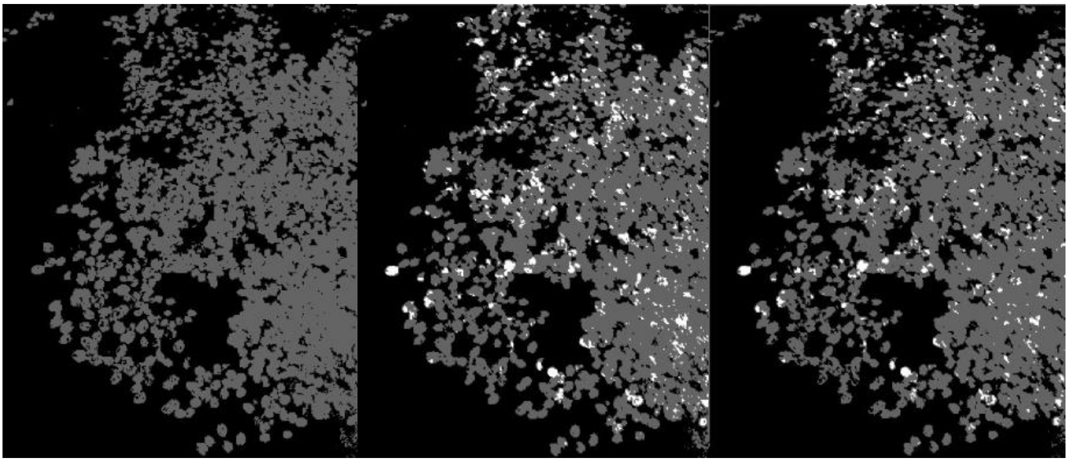


a) 620 nm b) 530 nm c) 470 nm d) 730 nm

Fig. 4. Multispectral images of a group of macrophytes of yellow water lilies (*Nuphar lutea*) from a quadcopter (h = 20 m)

The quadcopter multispectral images should completely cover one grouping of higher aquatic plants. At the same time, to determine the segments of the surface area of the water body, the spatial resolution of the image should allow investigating the state of each plant. Since the spatial resolution of multispectral cameras in each of the channels (426 × 339) is lesser than in the general panchromatic image (1280 × 1024), this limits the size of macrophyte groups, which can be studied by 150-300 plants. Fig. 5 shows an example of segmentation of multispectral images of a group of yellow water lilies (*Nuphar lutea*) according to the biomass parameters, the ratio between chlorophyll a and total chlorophyll; ratios between carotenoids and total chlorophyll. At the same time, it is possible to isolate macrophytes against the general background and calculate the water coverage area, as well as evaluate the relative part of plants with morphological changes as a result of the action of pollutants.

The spatial resolution of the multispectral camera used does not allow assessing the state of plants and determining the relative number of affected plants as a result of exposure to pollutants. Therefore, to assess the ecological state of water bodies, it is necessary to combine the information obtained from a large number of multispectral images, taking into account the GPS coordinates of the quadcopter position for each image. Sometimes, when studying groups of higher aquatic plants in the coastal strip, for their identification and assessment of the morphological state, it is necessary to reduce the flight height of the quadcopter to 1-5m. Figure 6 shows multispectral images of the macrophyte group *Hydrocharis morsus ranae* from a quadcopter at a height of 1.0m.



a) b) c)

Fig. 5. An example showingthe segmentation of multispectral images presentinga group of yellow water lilies (*Nuphar lutea)* by parameters:
a) biomass; b) the ratio between chlorophyll a and total chlorophyll;
c) ratio between carotenoids and total chlorophyll

a) 620 nm b) 530 nm c) 470 nm d) 730 nm

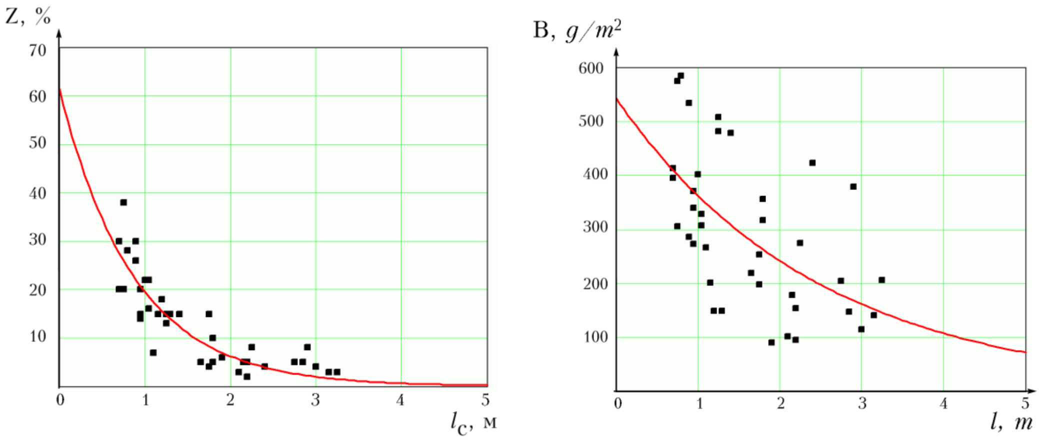
Fig. 6. Multispectral images of the macrophyte group (*Hydrocharis morsus-ranae*) from a quadcopter (h = 1 m)

Analysis of biomass characteristics of higher aquatic plants

The intensity of macrophyte distribution in a water body depends on the hydromorphological parameters. A noticeable trend is the gradual overgrowing of the surface of the water mirror in recent years. As light overgrowth of the surface of the water is characteristic for deeper water areas, with average depths of more than 3m.

On the basis of the obtained data on the state of macrophyte development, a correlation analysis was performed in the MathCAD program to determine the interrelated parameters of water bodies (Fig. 7). The inverse relationship between the average depth of water bodies and the water cover area (r = –0.716) is especially pronounced, the relationship between the average depth and macrophyte biomass is slightly weaker (r = –0.504). These dependences can be explained by the accumulation of nutrients in the shallow sections of the river, as well as the better development of certain types of macrophytes in the sections of the river with a low flow rate.

Due to the vegetation of higher aquatic plants, the intensity of which is characterized by an average biomass in the range of 120.360g/m^2 during the observation period, approximately 3 tons/hectare of primary organic matter is formed in reservoirs annually during the growing season.



a) b)

Fig. 7. Dependence a) coverage area of water areas and b) biomass of higher aquatic plants on the average depth of a river section

Summing up the results of the studies on the macrophyte development indicators, it is necessary to pay attention to the significant volumes of formed primary organic matter. In such a situation, a significant accumulation of great volumes of dead organic matter occurs in water bodies, which leads to their silting. Removing the biomass of higher water plants from water bodies annually using environmentally friendly methods can completely solve the problem of siltation.

Conclusions

An analysis pertaining to the results of statistical processing of surface water quality indicators of the Southern Bug River according to hydrochemical indicators and their comparison with the results of experimental studies and mathematical modeling of the development and production of macrophytes makes it possible to control the integral level of pollution. At the same time, the study showed that the samples that belong to the 3rd class of water quality of the 4th-5th category, corresponding to slightly and moderately polluted waters are dominant. According to the trophic status, they are in the range from eutrophic to eupolitrophic, in saprobity from β''-mesosaprobic to α'-mesosaprobic. At the same time, the hydrochemical studies make it possible to assess the level of pollution at a particular point in time and in a small sample volume. In contrast, the study of macrophyte characteristics allows us to integrally assess the level of pollution of a water body and the complex anthropogenic impact on its ecosystem for a long time on a fairly large area. Due to this, the studied methods have various fields of application. In general, the results of experimental studies on the class and category of surface water quality obtained using such methods coincide with statistical discrepancies. The proposed multispectral methods for studying the ecological state of water bodies using a quadrocopter, based on bioindication by the parameters of higher aquatic plants, can only be used for floating and air-water plants, such as *Nuphar lutea* or *Hydrocharis morsus-ranae*. Other methods should be used to study the parameters of submerged higher aquatic plants.

The location of the Southern Bug River (Ukraine) in the zone of intensive economic activity and other factors determine the increased anthropogenic pressure on aquatic ecosystems, the growing concentration of nutrients and the eutrophication of the water body. Due to the vegetation of higher aquatic plants in the river, up to 3 tons/hectare of primary organic matter is formed annually. As a result of the life of higher water plants, significant volumes of dead organic matter are formed, which causes the siltation of water bodies. In order to restore the river ecosystems, annually, after reaching the maximum biomass of higher aquatic vegetation, it is necessary to remove higher aquatic plants using environmentally friendly technology. Compared with the traditional methods of river cleaning using dredgers for pumping sludge, this method allows to obtain the biomass of higher aquatic plants, which can be used, for example, for the production of biogas.

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