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APPLICATION OF REMOTE SENSING IN ENVIRONMENTAL STUDIES: ADVANTAGES AND CHALLENGES

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Abstract. Growing concern about environmental challenges has led to the development of new observation tools to perform monitoring and assessment in a broad range of environments, application to conservation management and for mapping of natural resources. Although, the emerging methods and technologies of remote sensing are a powerful tool, they meet some difficulties and limitations in their real applications. This paper overview several projects and initiatives in Lithuania and Bulgaria related with application of both unmanned aerial vehicles and satellite imagery in various types of environment assessments. The benefits and limitations that emerged during the investigations have been discussed in the international workshop organised by the EU project of LIFE programme ALGAESERVICE for LIFE.

Key words: remote sensing methods, environmental sampling, field work, algal blooms

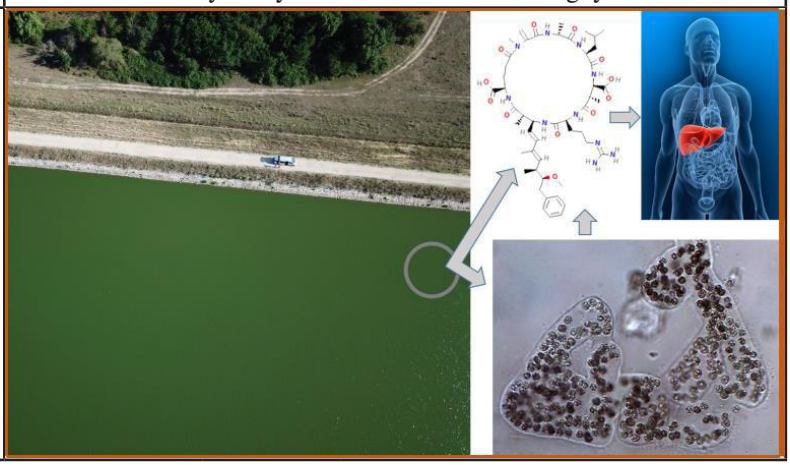
INTRODUCTION

European Union outlines the main needs and potential applications of remote technologies, especially in the areas related to agriculture, forestry, biodiversity, plant health, soil, inland waters and coastal areas, fisheries and aquaculture, etc. (https://knowledge4policy.ec.europa.eu/earth-observation/eu%C2%A0policy-areas_en). Therefore, nowadays remote sensing technologies (unmanned aerial vehicles (UAV), satellites, radars, etc.) have become great tool for observation and analysis of various processes in environment *e.g.*, changes of land cover, spread of invasive plant species, waterbody eutrophication. It was an inevitable process as technologies evolved and commonly used point or ground-based observations which are limited, costly, time-consuming and labor intensive became insufficient. Especially it is important in cases when territories of interest are remote, difficult to reach or cover large areas. Thus, to observe and analyze the processes that are crucial for proper interpretation of results and decision making requires modern remote sensing techniques. To maintain accuracy and avoid errors these new methods as well as other traditional methods require verification and proper processing of obtained data which is gathered using various remote sensing techniques (Noor et al. 2018, Li et al. 2020, Mertikas et al. 2021).

In order to discuss and share knowledge about the use of remote sensing methods in environmental research the scientific-practical workshop "Remote sensing in environmental studies: advantages and challenges" was organized in the Nature Research Center (Vilnius, Lithuania) on 12th of October, 2021 within the EU project of LIFE programme "Algae – economy based ecological service of aquatic ecosystems" (LIFE17 ENV/LT/000407 ALGAESERVICE for LIFE). Eight presentations from representatives of different institutions from Bulgaria and Lithuania were presented during the workshop also the technical possibilities of unmanned aircrafts were presented during the breaks of the workshop. More than 100 participants took place in the workshop from different institutions from Bulgaria, Poland and Lithuania. Main results of the researches of the seminar speakers are presented in the article.

1. Application of unmanned aerial vehicles in environmental studies

1.1. Drone applications in Bulgarian algological studies

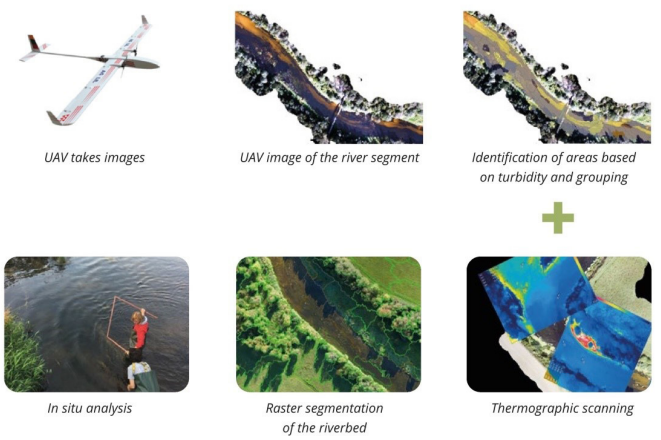
Project	*Cyanoprokaryotes – a new potential risk factor for malignant diseases in Bulgaria?*		
Funded	Scientific Research Fund of the Bulgarian Ministry of Education, grant number DN 13-9/15.12.2017		
Duration	2017 - 2023	**Website**	https://cyanoprokaryota.weebly.com/
Implementers	Sofia University "St. Kliment Ohridski" Leaders: Prof. Maya Stoyneva and Assoc. Prof. Blagoy Uzunov		
Graphical abstract			

The project is aimed at the study of specific blue-green algae (cyanoprokaryotes, cyanobacteria) capable of releasing cyanotoxins related to cancer and other diseases of social importance in the country. An interdisciplinary approach has been applied to successfully solve the added tasks. Sampling was done according to an innovative methodology with selection of sites as a result of aerial drone observations. This was the first in Europe and the fifth in the world realized and published application of a drone in working with hazardous algal blooms in freshwaters and the first in studies of thermophilic habitats. Furthermore, for the first time in Bulgaria a method for determining the abundance of phytoplankton by high performance liquid chromatography (HPLC) has been applied.

As a result, new data were collected on the abundance and biodiversity of cyanoprokaryotes in the country with the finding of 127 species (46 new for Bulgaria) and proving their significant role in the phytoplankton of the shallow waterbodies. New data have been obtained on cyanotoxins in the country, with first records for Bulgaria of cylindrospermopsin from Lake Vaya and Reservoir Mandra, and first finding of microcystins in Reservoir Sinyata Reka. Microcystins were

found also in the Lake Durankulak, where for the first time saxitoxins have been also detected. Polyphasic approach, based on microscopic, chemical and molecular genetic studies, was applied in investigation of toxigenic species and evidence for the genetic ability for microcystins production in *Microcystis wesenbergii*, long considered to be non-toxic, was provided. Data on malignant diseases were collected from the University Hospital "St. Marina" - Varna and their primary treatment was performed.

1.2. Application of unmanned aerial systems to investigate macroalgae agglomerations

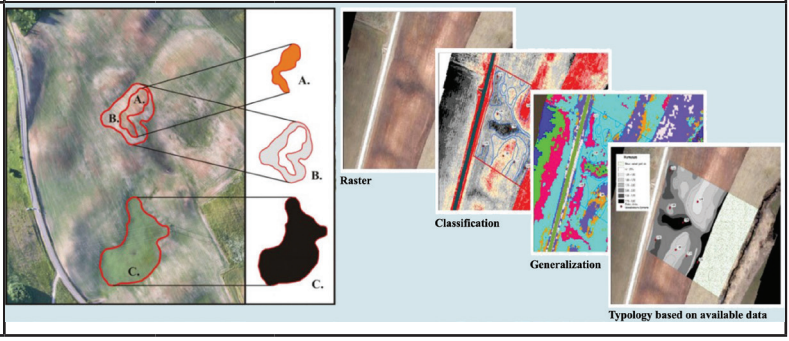
Project	*Algae – economy based ecological service of aquatic ecosystems* (LIFE17 ENV/LT/000407)		
Funded	EU LIFE Programme, the Ministry of Environment of the Republic of Lithuania, the National Fund for Environmental Protection and the Water Management in Poland, and by the project partners		
Duration	2018 - 2023	**Website**	www.algaeservice.gamtostyrimai.lt/
Implementers	Nature Research Centre (coordinator), Nature Heritage Fund, Baltic Environment, Spila, A. Mickiewicz University in Poznan, Institute of Nature Conservation (Polish Academy of Sciences)		
Graphical abstract			

Remote studies of rivers in Lithuania were carried out using an unmanned aerial system that consisted of a fixed-wing UAV and built-in visual or infrared spectral cameras. The main purpose was to map the vegetation cover in the riverbeds in order to identify the areas overgrown with filamentous macroalgae, to estimate their quantities and to account for potential resources. Prior to implementation, the best hydrometeorological conditions suitable for the maximum accuracy of the results of remote sensing of algae and the minimum impact of possible disturbances were determined.

The preparation and analysis of the collected material included three steps: 1) Building an orthophotomosaic by combining a set of aerial photographs; 2) Analysis of raster images based on different colour characteristics of the aerial photographs. Heterogeneous areas were identified and grouped in accordance with the turbidity data. On the basis of the classification, as well as expert opinion and direct studies, polygons were automatically assigned to one of the classification types using software; 3) An inventory of macroalgal agglomerations using ArcGIS software according to a number of parameters (*e.g.* the area and volume occupied by algae, hotspots of agglomerations). Raster segmentation and classification of the orthophoto maps of the studied channels allow the effective identification of river sections with different concentrations of algae and the calculation of their amount. Riverbed scanning using an infrared wave (thermal imaging) sensor confirmed the results obtained from the visual spectrum orthophotography analysis and captured the polygons with the highest concentrations of macroalgae.

Transparency, insolation and the degree of shading of the water surface were the main limiting factors for the accuracy of the study. So, if the factors limiting quality of the assessment are taken into account, the application of remote sensing technologies provides qualitatively new high-detail information, significantly reduces time and money, and enables more broad assessment.

1.3. Opportunities and strengths of ecosystem research using remote sensing methods

Project	*Development of Innovative Service "Remote Sensing Studies of Soil and Consultantions"*		
Funded	Rural development 2014-2020 for Operational Groups (in the sense of Art 56 of Reg.1305/2013)		
Duration	2018 - 2021	**Website**	https://ec.europa.eu/eip/agriculture/en/find-connect/projects/inovatyvios-pa-slaugos-dirvo%C5%BEemio-aerodistanciniai
Implementers	Lithuanian Agricultural Advisory Service and Institute of Geosciences, Vilnius University		
Graphical abstract			

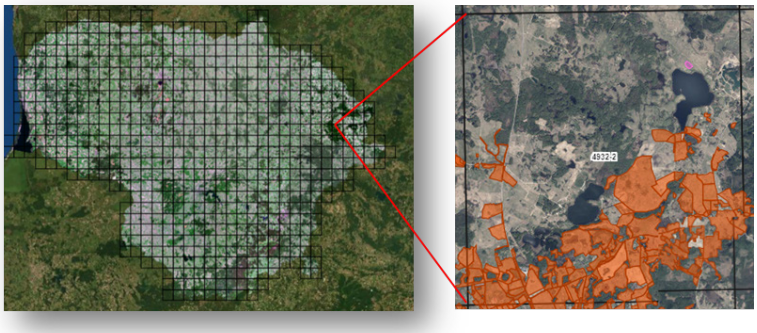
The idea of remote sensing of the soil is based on the aim to perform detailed mapping of the soil cover of the study area using unmanned aerial systems (UAS), at the same time distinguishing soil facies - homogeneous habitats. These areas have identical or very close physical and chemical characteristics (granulometric structure, humus content, moisture content, degree of erosion) within their boundaries, and for which the same agrotechnical measures could be applied individually or to the whole complex of related habitats and achieve the same impact result. The results of this work can become a basis for the concept of precision agriculture.

The most appropriate (technical and natural) test conditions were identified and clearly defined, limiting the parameters that significantly reduce the quality of the final results. It should be noted that due to the negative shading effect, which has a significant negative effect on the test results, it is necessary to perform the tests at a cloud cover of less than 3 points, or at full cloud cover, when only scattered sunlight reaches the ground. For both arable land the height of the sun above the horizon, which should be at least 25 degrees, remains an important factor in ensuring the accuracy of the primary data. Adherence to these conditions eliminates most of the external noise affecting the image quality of the surface under study.

With regard to the properties of the test object, it is necessary to emphasize that the uniformity of the test surface is incomparably more important than the nature of the surface coating, which was considered a significant and even limiting factor at the beginning of the tests. Studies have shown that if the surface of the land is even (nature of cultivation, type of grazing), regardless of whether it is ploughed or covered with grassy vegetation, it is easy to see and record the differences in soil properties caused by natural processes. In the case of cultivated soil, these signs are directly visible, and in the case of grassy cover, they are reflected through differences in the nature of the vegetation. The latter observation is particularly important and significant, as it allows to obtain reliable research results not only in the presence of open surfaces, but also in the study of surfaces with grass cover, crops in the initial germination phase, or even the surfaces affected by no-till technology.

1.4. Can drones make botanical field work easier?

Project	*Development of Innovative Service "Remote Sensing Studies of Soil and Consultantions"*
Funded	Project (Contract No. 05.5.1-APVA-V-018-01-0012) co-financed by the European Union Structural Funds according to the 5th Priority of the European Union Funds Investment Operational Program for 2014–2020 "Environment, Sustainable Use of Natural Resources and Adaptation to Climate Change" under the measure “Biodiversity protection” (05.5.1-APVA-V-018)

Duration	2019 - 2022	**Website**	www.gamtostyrimai.lt/
Implementers	Nature Research Centre		
Graphical abstract			

During the planning of the investigation of the status of invasive and alien plant species in Lithuania, one of the main goals was to map 64 plant species. Most of the species are being mapped using a grid, approximately 5 x 5 kilometers. However, Invasive Alien Species of Union concern must be mapped as precisely as possible. Of these species, three of them occur in Lithuania: *Asclepias syriaca*, *Heracleum sosnowskyi* and *Impatiens glandulifera*. To achieve precise mapping, three unmanned aircraft vehicles are being used: i) two quadcopters (dji mavic pro and dji mavic 2 zoom); ii) one fixed wing drone (UAV Birdie) with a parrot sequoia camera.

Impatiens glandulifera mostly occurs in wet natural habitats such as alluvial forests, hygrophyte belts close to rivers or lakes, *etc.*; therefore, it is almost unrecognizable via drone. *Asclepias syriaca* does not cover vast areas in Lithuania and can be easily found during investigations of other species.

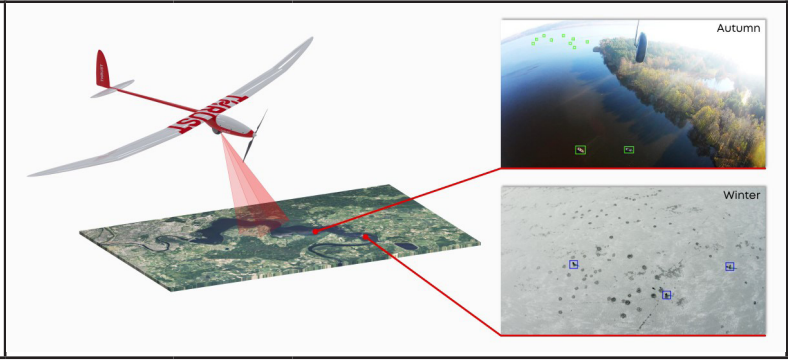
Heracleum sosnowskyi, as previous knowledge shows, in total, covers more than 10K ha across the country. In some regions, it grows only in small patches or individually. The mapping of *H. sosnowskyi* was carried out using drones at sites where intensive invasion is historically known and at sites which were reported by field workers as invaded. Currently, an area of more than 15K ha is mapped as invaded by *H. sosnowskyi*. The drones flew more than 280 km over approximately 16 hours of flight time. A huge number of images were captured and after used to map this invasive species.

During the field work complications arose, these could be classified into two types. The first is related with species biology and ecology. There is a relatively short period (approximately two weeks of blooming) when *H. sosnowskyi* can be effortlessly recognized. In some places, this species is controlled and as a result it is difficult to observe vegetative individuals. Sometimes it invades forest edges and is not visible via drone. The second group of complications is more technical. Fixed wing drones are generally only effective in large invaded areas. Also, one

must have a suitable place for drone landing, which is not always possible at certain sites. Furthermore, the success of the investigation and quality of images depend on weather conditions. Additionally, drones have several issues, for example, relatively short flight time and sometimes drones (or pilots) fail – drones fall down or fly away.

Despite the challenges, drones have made the investigation of invasive plant species more precise, simpler, and have saved time and human resources.

1.5. Assessing recreational fishing effort using remote methods

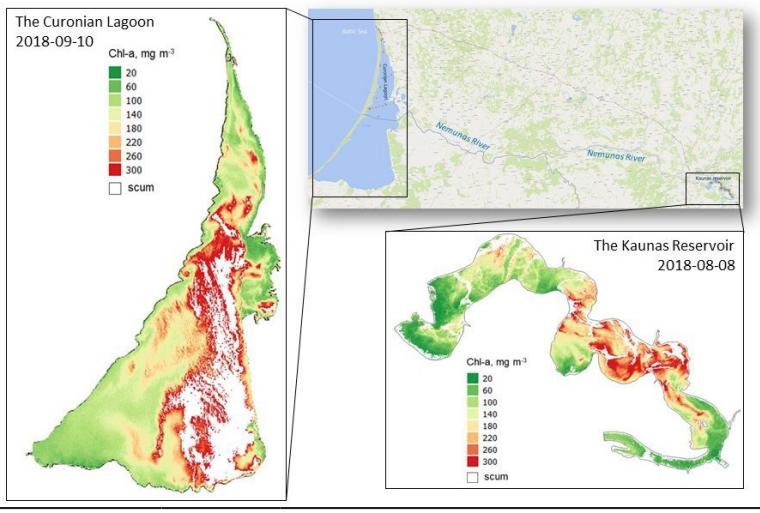
Project	*Sustainable inland fisheries*		
Funded	European Regional Development Fund (project No 01.2.2-LMT-K-718-02-0006) under grant agreement with the Research Council of Lithuania (LMTLT)		
Duration	2019 - 2022	**Website**	www.sif.lt
Implementers	Nature Research Centre, UAB Aerodiagnostika		
Graphical abstract			

Recreational fishing has become a major force on inland and coastal aquatic ecosystems, with nearly 15% of Europeans at least occasionally engaging in recreational fishing activities. Assessing spatial and temporal distribution of anglers, and total fishing effort has been a major challenge for inland and coastal ecosystem management. This assessment is also important from a socio-economic perspective, because recreational fishing contributes to local economies and is important for human wellbeing. In most countries, recreational fishing effort estimates are highly uncertain, or simply non-existent. In this study, we applied two novel approaches to assess recreational fishing effort in Lithuania – aerial inspection using autonomous fixed wing drones and anonymous data from a popular GPS-enabled angler fish finder device. We show that drone-based angler counts are highly accurate and efficient, and the method can be used to survey large areas in short time with minimum CO_2 emissions, disturbance to anglers and wildlife. By employing both standard and infrared cameras, as well as machine

learning algorithms, video post-processing time can be greatly shortened and angler count accuracy improved further, especially under visually challenging conditions. Using nearly 40 missions distributed over one year in a popular fishing destination Kaunas Reservoir we developed a statistical model to predict angler numbers across seasons and weekdays. Further, we calibrate observed angler numbers with daily anonymous fish finder device usage, to produce daily angler number estimate in Kaunas Reservoir, and, potentially, anywhere in Lithuania. We are currently developing improved machine learning algorithms for drone video analytics and expanding angler number calibration to other locations in Lithuania.

2. Application of satelite images in environmental studies

2.1. Remote sensing solutions in water quality monitoring and management

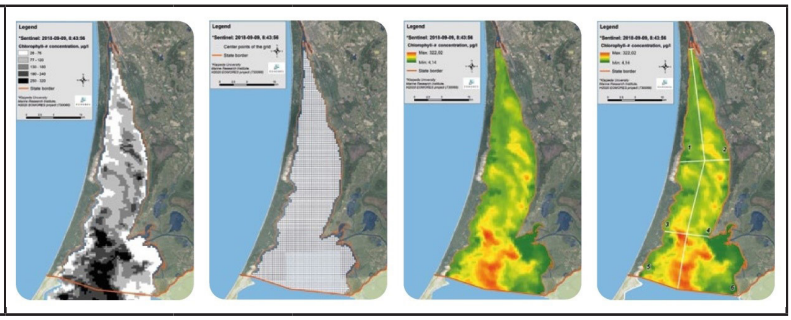
Project	• *"Phosphorus as driver of cyanobacterial hyperblooms in the Curonian Lagoon (Patchy)" [S-MIP-17-11]* • *Horizon 2020 EOMORES project [730066]* • *contract TODAY [4000122960/18/NL/SC]*		
Funded	• Research Council of Lithuania (LMT) grant • European Union • European Space Agency PECS		
Duration	2017 - 2020	**Website**	https://eomores-h2020.eu/, http://apc.ku.lt/
Implementers	Klaipeda University (all projects), EOMORES consortium: Water Insight, the Netherlands (coordinator); Deltares, the Netherlands; CNR-IREA, Italy; SYKE, Finland; Tartu Observatory, Estonia; Klaipeda University, Lithuania; The University of Stirling, United Kingdom; PML, United Kingdom; Evenflow, Belgium		
Graphical abstract			

The projects are related to remote sensing solutions in water quality monitoring and management with a focus on cyanobacteria hyperblooms mapping in two Lithuanian water bodies: the Curonian Lagoon and the Kaunas Reservoir. The long-term analysis (1985–2018) in the Curonian Lagoon was based on a significant amount (over 500) of synoptic satellite images: Landsat series, MERIS on-board Envisat, MSI on-board Sentinel-2A/B, and OLCI on-board Sentinel-3A. Despite the pronounced seasonal variations in the growth of cyanobacteria during the time series, the duration of the period, when cyanobacteria hyperblooms are present, has been consistently getting longer since 2008 (Vaičiūtė et al. 2021). Dense cyanobacteria blooms, so-called hotspots, were more frequently observed in the southern and central parts of the lagoon, i.e., the mostly stagnant south-southwestern part of the lagoon (Ferrarin et al. 2008). The spatial distribution patterns were related to the presence of muddy sediments that are rich in phosphorus, water renewal time and internal hydrodynamics features. Similarly, the ongoing eutrophication significantly alters cyanobacteria hyperblooms during summer period in the Kaunas Reservoir (a dammed part of the River Nemunas). Chlorophyll-*a* concentration estimated from MSI Sentinel-2 A/B images can range from 4.6 to more than 5000 mg m^{-3} exceeding the threshold of high-risk for public health proposed by the World Health Organization (WHO 2021). We hypothesize that characteristic hydrological patterns and meteorological conditions alter the main, longstanding, well-established spatial patterns of cyanobacteria hyperblooms in the Kaunas Reservoir. This hypothesis will be tested by adapting the methodology used in the case of the Curonian Lagoon. The investigations confirmed that remote sensing methods are providing a significant data and information about the status quo of ongoing eutrophication, the spatial variability of cyanobacteria hyperblooms, a risk for public health, and can support the planning of eutrophication mitigation actions in both waterbodies and the River Nemunas basin as a whole.

2.2. Sentinel satellite images for observation of hotspots of cyanobacteria blooms

Project	*Algae – economy based ecological service of aquatic ecosystems (LIFE17 ENV/LT/000407)*		
Funded	EU LIFE Programme, the Ministry of Environment of the Republic of Lithuania, the National Fund for ENVIRONMENTAL PROTECTION and the Water Management in Poland, and by the project partners		
Duration	2018 - 2023	**Website**	www.algaeservice.gamtostyrimai.lt/
Implementers	Nature Research Centre (coordinator), Nature Heritage Fund, Baltic Environment, Spila, A. Mickiewicz University in Poznan, Institute of Nature Conservation (Polish Academy of Sciences)		

Graphical abstract



The Horizon 2020 project EOMORES (in cooperation with Klaipėda University) has a series of services for monitoring the quality of inland and coastal water bodies based on a combination of the most up-to-date satellite data, innovative *in situ* instruments. This tool to measure chlorophyll-*a* concentrations was applied to identify hot-spots of cyanobacteria blooms in the Curonian Lagoon. GIS analysis tools were used to model data for the period of 2018–2019.

The first step included raw raster data conversion to actual points of chlorophyll-*a* concentrations. Further vector data was modelled using IDW tool via ArcMap 10.8.1 software to better distinguish hot spots of potential blooming zones. Such approach allowed not only getting maps of spatial distribution of chlorophyll-*a* concentrations throughout different months and days but also precise calculations. In this way it is possible to distinguish hot spots of cyanobacteria blooms where harvesting would be the most effective.

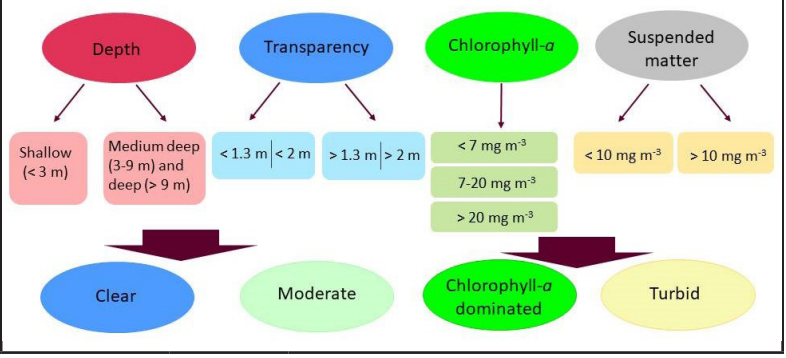
Analysis of the concentrations of chlorophyll-*a* shows that in year 2018 the highest mean and maximum values of concentrations were distributed in zones 5 and 6 of Lithuanian part of Curonian Lagoon. The highest mean and maximum concentrations of chlorophyll-*a* were observed at September (max of mean = 169.5 mg m^{-3} and max = 322.0 mg m^{-3}). The trend of concentrations between zones remained quite stable till the end of September, while during October these values distributed unevenly. Probably due to the change of meteorological conditions which leads to form different distribution of currents in the Curonian Lagoon. Nevertheless, the analysis of minimum concentrations of chlorophyll-*a* proved the highest possibility of distribution of potential cyanobacteria blooms in 5 and 6 zones of the Curonian Lagoon as lowest concentrations of chlorophyll-*a* distributed in the rest of the zones with minimal exceptions.

The Sentinel data obtained and analyzed for 2019 complemented and proved the same period as well as zones with the potentially highest concentrations of chlorophyll-*a*. Data of 2019 also showed that the 5 and 6 zones of the Curonian Lagoon experienced the highest risk of cyanobacteria blooms (concentrations of chlorophyll-*a*: max of mean = 59.3 mg m^{-3} and max = 200.5 mg m^{-3}).

According to the analysis of Sentinel data the most relevant period for cyanobacteria harvesting in the Curonian Lagoon could be from the end of July till the first part

of November as the Sentinel data showed that even at the end of October of 2018 the concentrations of chlorophyll-*a* can reach maximum of 263.7 mg m^{-3} (90.2 mg m^{-3} in average).

2.3. Water quality parameters assessment in Lithuanian lakes using remote sensing and machine learning

Project	*PhD studies*		
Funded	Vilnius University PhD study programme		
Duration	2018 - 2022	**Website**	www.hkk.gf.vu.lt/en/
Implementers	Dalia Grendaitė, supervisor Edvinas Stonevičius		
Graphical abstract			

Remote sensing data help to observe water bodies in large areas frequently. However, remote sensing data come with uncertainties. The largest ones are from atmospheric influence and accuracy of biophysical or geophysical parameter retrieval algorithms. To be able to use remote sensing data reliably and effectively we need well performing atmospheric correction (AC) and accurate parameter retrieval algorithms. The analysis of various AC algorithms (Acolite, Acolite Rayleigh, iCOR, Sen2Cor, C2RCC, C2X, and POLYMER) for chlorophyll-*a* concentration retrieval showed high uncertainty of reflectance values related to AC product selection (Grendaitė & Stonevičius 2021). Nevertheless, some chlorophyll-*a* algorithms (band difference algorithms) were less dependent on the AC product selection and provided closest to *in situ* chlorophyll-*a* concentrations regardless of the AC product selected. In addition, since most algorithms and AC products show relatively higher bias for low chlorophyll-*a* concentrations (<10 mg m^{-3}), deriving algorithms for groups of lakes may improve the chlorophyll-*a* concentration retrieval from Sentinel-2 MSI data. We classify lakes to water types based on often routinely measured in monitoring programmes water quality parameters, such as, chlorophyll-*a* concentration, water transparency, and suspended matter. We aim to create a data-driven model that use lake spectra from satellite and machine learning methods and assign a lake a class that is defined by water quality parameters. This method could be used in areas where *in situ* spectral data is scarce. We test machine

learning algorithms (logistic regression, support vector machine, random forest, adaboost, xgboost) to separate lakes into four classes: clear, moderate, turbid based on chlorophyll-*a* concentration, and turbid due to other reasons. Machine learning model inputs are derived from lake spectra (reflectance amplitude, band ratios, the derived water colour parameter). The separated classes are used for construction of water parameter retrieval algorithms from satellite data. The developed class of lakes and parameter algorithms can be tested and adapted to other regions.

3. Demonstrations of unmanned aircrafts

Antanas Gedvilas, the President of the Unmanned Aircraft Association	
Graphical abstract	

During the workshop fixed wing original aircrafts were introduced, their characteristics, advantages over drones and the examples of their application in the various types of assessment were discussed.

CONCLUSIONS

The discussion of results obtained after application of remote sensing vehicles during the Workshop revealed their important role in time-saving and better orientation for observation and selection of sampling sites despite the different technical challenges that yet have to be faced in each specific study.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication

of this article.

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The workshop was organised in the frame of the Algae Service for LIFE project (LIFE17 ENV/LT/000407) financed by EU LIFE Programme, and co-financed by the Ministry of Environment, of the Republic of Lithuania, the National Fund for Environmental Protection and the Water Management in Poland, and by the project partners.

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