NEW YORK STATE
WATER RESOURCES INSTITUTE
Department of Biological and Environmental Engineering

230 Riley-Robb Hall, Cornell University
Ithaca, NY 14853-5701
http://wri.cals.cornell.edu

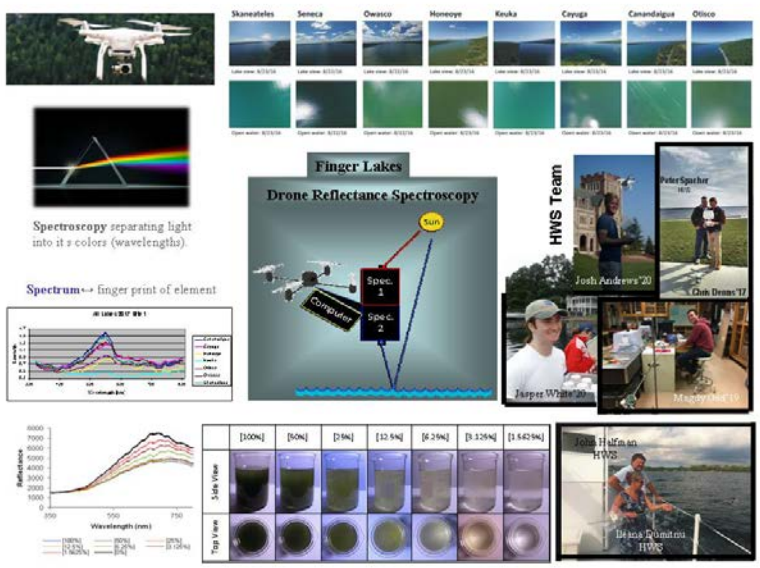
Tel: (607) 254-7163
Fax: (607) 255-4449
Email: nyswri@cornell.edu

Remote Sensing of Harmful Algal Blooms by Unmanned Aerial Systems (Drones)

I. Dumitriu,[a] J. Halfman,[a] and P. Spacher,[a,b]

dumitriu@hws.edu halfman@hws.edu spacher@hws.edu

a) Hobart and William Smith Colleges, Geneva NY b) Rochester Institute of Technology, Rochester NY



Abstract: With the recent rise in harmful algae blooms (HABs) events in the Finger Lakes region, it is imperative to develop efficient means to identify, track, and predict blooms. Aerial imaging has proven increasingly applicable as an environmental research tool as camera, spectrometers and drone technologies advance. Challenges for monitoring HABs: (1) Blooms are transient phenomena (2) Thousands of algal bloom species co-exist with other constituents in the water body (sediments, and dissolved organic matter) (3) Presence of other constituents obscures signature of algal blooms. (4) Calibration and quantifying output sensor data. This project focuses on investigation of HABs using spectrometers, optical and multispectral camera mounted on unmanned aerial systems (UAS). From these imagery and in-situ data we hope to generate a correlation between aerial images and HABs concentration.

Three Summary Points of Interest

- Unmanned Aerial Systems (UAS)/drones are ideal platforms for monitoring HABs in Finger Lakes.
- Unique spectral signature of algae makes reflectance spectroscopy a viable tool to detect and map HABs.
- The Chlorophyll-*a* reflectance peak at ~720 nm linearly correlates to its concentration in the lake water.

Keywords: Remote Sensing, Harmful Algal Blooms, Spectroscopy, Unmanned Aerial Systems

Introduction

Cyanobacteria, or blue-green algae, are the most ancient phytoplankton on the planet. The 3.5+ billion year evolutionary history of cyanobacteria has provided them with numerous physiological adaptations and mechanisms (intracellular storage capabilities for nitrogen and phosphorus; ability to converting "inert" atmospheric nitrogen into ammonia; self-regulated buoyancy; capability of producing toxins) enabling them to take advantage of environmental changes and extremes. [1].

Harmful algal blooms (HABs) of the cyanobacteria might lead to taste and odor events, or produce powerful toxins that can cause human or animal illness. But HABs are completely natural phenomena which have occurred throughout recorded history [2] and have been reported in the scientific literature for more than 130 years (Francis, 1878) [3]. The increasing interest in utilizing coastal and inland waters for aquaculture, fishing and recreation is leading to an increased awareness of toxic algal species. As a result, what we are faced with today is that in the past two decades the public health and economic impacts of HABs events appear to have increased in frequency, intensity and geographic distribution.

The transient nature of HABs, in both space and time, results in monitoring challenges, and therefore adds to the difficulty in scientifically understanding the ecological criteria that trigger HABs. To our knowledge, no strong and clear correlations were observed between basic water quality parameters (dissolved oxygen, pH, conductivity, temperature, nitrate and soluble reactive phosphate) and the presence of cyanobacteria and/or toxin levels (levels of toxins did not always coincide with high cell counts). The expensive and time consuming traditional *in situ* monitoring programs lacks sufficient spatial and temporal coverage to decipher the complex phenomena occurring during an HAB episode, and the lab results take days to complete, long after the bloom disappears. Optical remote sensing is increasingly being used for monitoring water quality parameters in the ocean, coastal waters as well as inland lakes [4, 5, 6]. Wynne & Stumpf compiled 13 years of satellite data and extracted the HAB frequency maps for Lake Erie [7]. These maps allow the prediction of algal bloom position and timing, and prove the feasibility of satellite remote sensing of algal blooms in *large* bodies of water, such as the Great Lakes.

Efforts using satellite remote sensing are hampered by infrequent satellite flyovers, limited detection bands and inadequate pixel resolution for inland waterways. More recently, unmanned aerial systems (UAS), aka drones, have emerged as a very popular remote sensing technology, composed of aerial platforms capable of carrying small-sized and lightweight sensors [8]. Their low-cost, ease of use and rapid deployment capability make them ideal for monitoring HABs in various inland waterways ranging from lakes to urban ponds [9, 10].

In this research study we used drones outfitted with spectrometers to remotely detect and map HABs. The unique algal pigments in various algal groups emit unique light absorbance/reflectance spectra, and it was found that the algal biomass can be roughly estimated by measuring lake water chlorophyll-*a* concentration [9]. For seven of the Finger Lakes reflectance spectra were recorded by a two-spectrometer system at the same time and at the same location where the *in situ* data were collected. We found that the height of the chlorophyll-*a* reflectance peak at ~720 nm (extracted from the remote sensing data reflectance spectra) linearly correlates to the chlorophyll-*a* concentration in the lake water (determined in lab from *in situ* data). **The ultimate objective of this work is to develop a rigorous remote sensing method to monitor the harmful algal blooms in freshwater systems.**

Results & Discussion

The spectroscopic system used in this study includes two spectrometers - one pointing up to measure the down-welling solar radiation and the other one pointing down to measure the reflected/backscattered light. During the summer of

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

2017 and 2018, Dumitriu and Spacher recorded low altitude and high-resolution spectral images for seven of the Finger Lakes, see figure 1 below.

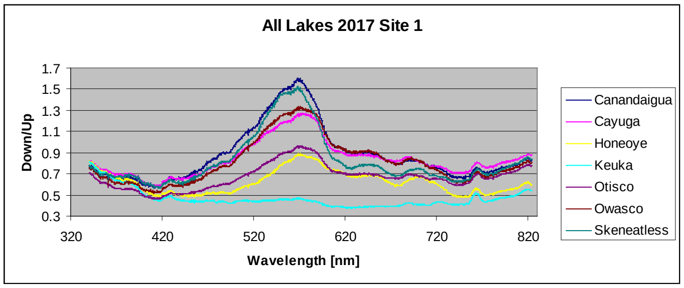


Fig. 1. Reflectance spectra of the Finger Lakes. Down = spectra recorded by the pointing down spectrometer measuring the reflected/backscattered light. Up = spectra recorded by the pointing up spectrometer measuring the down-welling solar radiation

Halfman, HWS Department of Environmental Science and Department of Geoscience, collected *in situ* data ***at the same time and the same location*** as the remote sensing (spectral) measurements providing the means to analyze, correlate and interpret the data.

Because of the unique spectral signatures of algal pigments, the compositions of algal populations in aquatic systems are detectable by remote sensing. The toxins produced by algae are not directly detectable by the imagery, but toxin concentration is often correlated with algal biomass density, which in turn, is directly related to the concentration of photopigments. One of the most abundant photopigments produced by all types of algae is chlorophyll-*a*, therefore, can serve as an indicator of the presence of an algal bloom. In the reflectance spectra over visible and near-infrared (NIR) wavelengths, the chlorophyll-a shows absorbance peak at ~670 nm and a reflectance peak at ~720 nm [11].

In our research study the height of the chlorophyll-*a* reflectance peak at ~720 nm extracted from the remote sensing collected spectra was plot versus the chlorophyll-*a* concentration determined in the lab using the *in situ* data, see figure 2 below. A linear correlation between these two parameters can be observed. In order to determine the uncertainties in our measurements and understand how background influences the images we are recording reflectance spectra of the collected water samples in lab using the two spectrometers in a fiber optics set-up. For more details on the experimental set-up see the method section of the report. We are still working on identifying all uncertainties sources and quantifying their influence on recorded imagery.

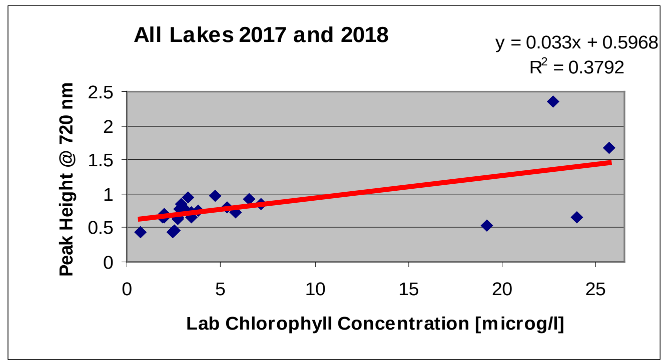


Fig. 2. The height of the chlorophyll-*a* reflectance peak at 720 nm versus the chlorophyll-*a* water lake concentration

The goal of this research is to find relatively simple, spectral signature-based chlorophyll-*reflectance algorithms* that are adaptable to imagery collected in the field by drones. There are challenges to overcome. (1) Algae bloom species co-exist with other constituents in the water body (sediments, and dissolved organic matter) and their presence obscures spectral signature of algal blooms. (2) Calibration is necessary in order to quantify the output sensor data.

Future research plans to use a multispectral camera instead of the two-spectrometer system to record the reflectance spectra. This camera captures images in narrow wavelength bands thus reducing the influence of the other constituents in the water, and allowing more precise extraction of the chlorophyll-a signature from the reflectance spectra. The illumination conditions may vary from one spectrum to another (different time of the day, drone position and cloud coverage during data collection). In order to be able to compare two spectra or extract quantitatively information from spectra they should

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

be first calibrated. We are still experimenting with various calibration panels (RGB, black and white) to understand how imagery is affected by illumination conditions and the altitude of the drone flight. Also sun glare and roughness of the lake surface (waves) affect the spectra. In order to minimize the above influences we collected the data around noon time on calm days (when possible) and optimally positioned the spectrometers above the water surface. We are using collimators and polarizing filters to reduce glare in the imagery.

In summary, by analyzing the collected reflectance spectra collected by a two-spectrometer system we determined that the height of the chlorophyll-*a* reflectance peak at ~720 nm linearly correlates to the chlorophyll-*a* concentration in the lake water. Thus remote sensing by drones outfitted with spectrometers proves to be a successful avenue to monitor HABs and water quality in the Finger Lakes.

Methods

Dumitriu and Spacher, HWS Department of Physics, have developed a spectroscopy system that is lightweight and efficient for use on a drone, see figure 3. The spectrometer system includes two spectrometers and controlling hardware/software installed on a light drone. One spectrometer points up to measure the down-welling solar radiation. The other spectrometer points down to measure the reflected and backscattered spectra from the lake. The proposed spectrometers are very light, just 68 grams, and are controlled by a Raspberry Pi. Similar paired spectrometers were successfully used already to identify aquatic and shoreline plants in controlling invasive species [12]. In order to determine the uncertainties in the measurements and understand how background influences the images we are using the laboratory experimental setup shown in left panel of the Figure 3. The components for the experimental setup include white light source, reflectance probe and holder, 3D printed containment cylinder (different colors for the cylinder allows for exploring background influence on the imagery), beaker/water sample, and spectrometer. The source light travels to the sample via a fiber optic cable and illuminates the interior of the containment cylinder. Within the cylinder, the sample is placed in a beaker. The light reflects off the surface of the water sample and is directed to the spectrometer via a second fiber optic cable. Data (spectra) is collected by the spectrometer.

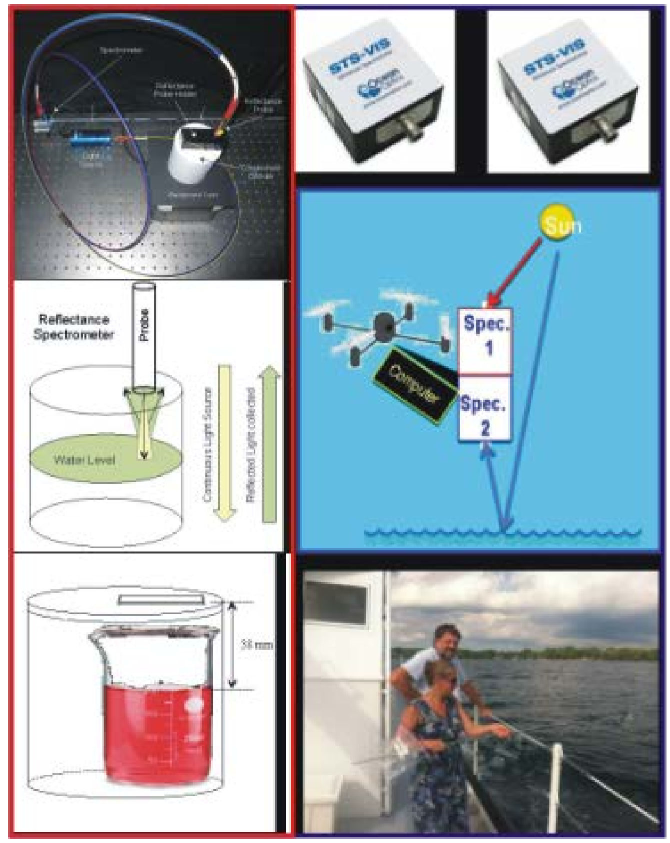


Fig. 3. *(left panel)* (top) Laboratory experimental set-up (middle) In-lab reflectance spectroscopy conceptual model (bottom) The containment cylinder. *(right panel)* (top) STS-VIS spectrometers. (middle) In-field reflectance spectroscopy conceptual model (bottom) On board on HWS Scandling research vessel, Ileana Dumitriu and John Halfman testing in the field the two-spectrometer system by recording reflectance spectra of Seneca Lake in September 2017.

Student Training

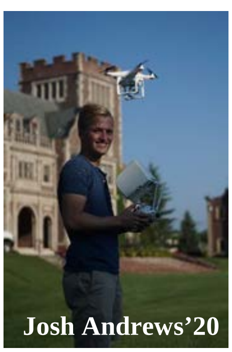
A total of nine undergraduate students participated in this project. Four students worked on collecting and analyzing the remote sensing data. Five students worked on collecting water sample in the Finger Lakes and analyzing them in the lab in order to generate the *in situ* data for this project.

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

William (Jasper) White'20, *Network of Remote Sensors to Monitor the Finger Lakes*, **Undergraduate Student Research Fall 2018**

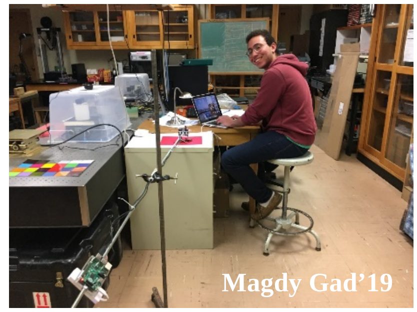
Abstract: Harmful Algal Blooms (HABs) have become a growing concern both locally in the Finger Lakes Region and globally. HABs occur when particular algae species excessively propagate water environments and release harmful toxins. Locally, the prevalence of HABs is clearly worrying since the ecosystem is stressed and the human population is reliant on the surrounding lakes both as freshwater sources and as major tourism attraction for business. Monitoring HABs is vital to understanding why they are becoming more common and being able to predict their movement. Thus, we plan to use a widespread network of remote sensors to effectively monitor water conditions and provide an accurate account of HAB characteristics.

Joshua Andrews'20, *Drone Imaging over the Finger Lakes*, **Undergraduate Student Research Summer 2017, 2018**



Abstract: With the recent commercialization of Drones in the United States, many affordable research applications are capable of being explored. One application I was tasked with was the monitoring of invasive species in the Finger Lakes region as through the use of Drones. Another application I explored was imaging of specific lakes and using the spectral information stored within the images to determine the algae concentration within the lake which would be helpful when monitoring Harmful Algae Blooms (HABs).

Magdy Gad'19, *Developing Detection of Blue Green Algae Using Drones Outfitted with Spectrometers*, **Honors Thesis 2018**



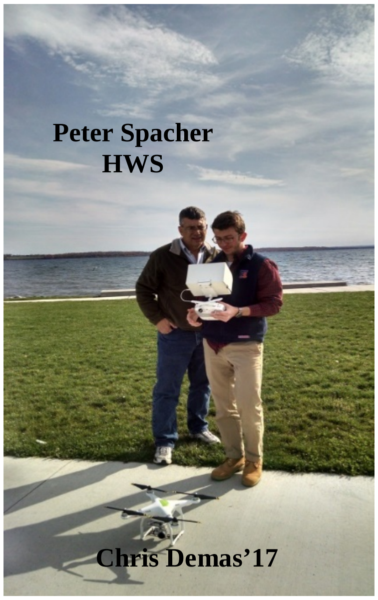
Abstract: Harmful algal blooms (HABs) are a growing epidemic in the world and have led to the destruction of many aquatic ecosystems. Blue-green algae, also known as Cyanobacteria, are a prime cause of HABs and their migratory nature is a mystery which makes them elusive to combat. Current methods of detecting the spread of blue-green algal blooms are costly and inefficient. As such, alternate methods of detection are required to allow for swift reaction against the spread of HABs. This project investigates reflectance and absorbance spectroscopy as an alternate method of detecting blue-green algae, and application of this method for remote sensing using drones. Reflectance and absorbance spectra of water samples collected from Owasco and Seneca Lake were analyzed in the lab. The results from the reflectance spectra of the water samples recorded in the lab have shown a peak at 680 nm which correlates with the concentration of the algae. Reflectance spectra were also recorded in the field at Owasco, Seneca, Cayuga, Otisco, Skaneateles, Honeoye, Canandaigua, and Keuka lakes. The field data spectra have also shown strong signatures in the 600 nm – 700 nm range that correlate with the presence of blue-green algae in the water. These results provide proof of the viability of reflectance spectroscopy as a potential method for detection of HABs, and ultimately its application to drones for remote sensing.

Chris Demas'17, *Modeling Algae Concentrations via Reflectance Spectroscopy for Remote Sensing*, **Honors Thesis 2017**

Abstract: Harmful algal blooms (HABs) have become a growing concern both locally in the Finger Lakes Region and globally. HABs occur when certain types of algae overpopulate a freshwater source and release harmful toxins. Extensive monitoring of HABs will be key to understanding the root cause for such blooms. Unfortunately, the current in situ colorimetric methods employed to measure HABs are highly inefficient and

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

expensive. Therefore, we are interested an alternative approach to remotely monitor algae blooms through the use of reflectance spectroscopy via drones.



This project serves as a first step in modeling algae reflectance spectra the lab. Our results suggest that reflectance spectra intensity at 665 nm (the chlorophyll a absorption maximum) for algal solutions is correlated with its concentration. Therefore, this research serves as a proof of concept that reflectance spectroscopy is a viable alternative for determining algae concentration in bodies of water.

Notable Awards & Achievements

Pending Cayuga County Legislation, $26,865 for one year. *2019 FLI Owasco Watershed Monitoring Program.* PI **John Halfman**. Co-PIs **Ileana Dumitriu**, **Peter Spacher**, Lisa Cleckner.

2018 Cayuga County Legislation, $22,531 for one year. *2018 Owasco Lake, Stream and Drone Monitoring Proposal*. PI **John Halfman**. Co-PI **Ileana Dumitriu**.

2018 Owasco Watershed Lake Association, $12,986 for one HABs season. *An Assessment of the 2018 HABs Mitigation Monitoring Effort*. PI **John Halfman**. Co-PI Lisa Cleckner.

2017 Emerson Foundation, $90,000 for three years. *Blue-Green Algae Monitoring and Assessment in Owasco Lake*. PI **John Halfman**. Co-PIs **Ileana Dumitriu**, Stina Bridgeman & Lisa Cleckner.

Cayuga County Legislation, $22,669 for one year. *2017 Owasco Lake & Stream Monitoring Proposal*. PI **John Halfman**. Co-PI **Ileana Dumitriu.**

William (Jasper) White'20 - *Remote Water Quality Assessment for Harmful Algal Blooms Prevalence*, **Rochester Academy of Science Undergraduate Research Grant** ($400) fall 2018.

Publications/Presentations

Halfman, J.D., B. Kharrazi*, S. Johnson*, J. Francois*, K. E. Valicenti*, E. Wilber*, J. Andrews*, **P. Spacher, I. Dumitriu** & L.B. Cleckner, 2019. The 2018 Water Quality Monitoring Report, Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 47 pg.

Halfman, J.D., **I. Dumitriu**, & L.B. Cleckner, 2019. Final Report on the Owasco Lake HAB Inhibiting Technologies Assessment. Submitted to Owasco Watershed Lake Association. 57 pg.

Halfman, J.D., B. Kharrazi*, S. Johnson*, J. Francois*, K. E. Valicenti*, E. Wilber*, J. Andrews*, **P. Spacher**, **I. Dumitriu**, K. Amejecor*, T. Massey & L.B. Cleckner, 2019. Blue-Green Algae in Owasco Lake: The 2018 Update. The 2018 Annual Report to the Fred L. Emerson Foundation, Finger Lakes Institute, Hobart and William Smith Colleges. 37 pg.

Dumitriu I., P. Spacher, J.D. Halfman, L. Cleckner. *Study of Harmful Algae Blooms Using UAS Imagery* . Internat. Assoc. Great Lakes Research, Brockport, NY. June 2019.

I. Dumitriu, **P. Spacher**, **J. Halfman**, Lisa Cleckner, *Study of Harmful Algae Blooms Using UAS Imagery*. STRATUS (System and Technologies for Remote Sensing Applications through Unmanned Aerial Systems), Rochester, NY. February 2019.

Finger Lakes Research Conference: The Big Three-Contaminants, Invasive Species, and Nutrients. Geneva, NY. January 2019.

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

Halfman, J., Valicenti*, Katherine E., and Johnson, Shelby*, Department of Geoscience, Hobart & William Smith Colleges, Geneva, NY, 14456; Cleckner, Lisa, Massey, Trevor, Finger Lakes Institute, Hobart & William Smith Colleges, Geneva, NY; **Dumitriu, I.**, and **Spacher, P.**, Department of Physics, Hobart & William Smith Colleges, Geneva, NY, 14456;and Hall, Dana, Program Manager, Owasco Lake Watershed Association, PO Box 1, Auburn, NY. *Testing technologies to mitigate blue green algae blooms along the shoreline of Owasco Lake, central New York.* AGU Fall Meeting, Washington, D.C., December 2018

Jasper White*, **I. Dumitriu**, **P. Spacher**, and **J. Halfman**, *Drone Imaging –Identifying Harmful Blue Green Algae Blooms.* Rochester Academy of Science, Geneseo, NY. November 2018.

38th International Symposium of the North American Lake Management Society; Cincinnati, OH. October 2018

Bradt*, S., **J. Halfman**, J. Andrews*, **I. Dumitriu**, and **P. Spacher**, 2018. *Blue green algae and macrophyte surveillance by drones (UAVs) in Owasco Lake, NY.* Geological Society of America Northeast Regional Annual Meeting Abstracts with Programs, v. 50: no. 2; Burlington, VT. March 2018.

Halfman, J., R. Razavi, L. Cleckner, **I. Dumitriu**, & **P. Spacher**. 2017. *Nutrient loading trigger for Blue-Green Algae blooms in the Finger Lakes, NY.* Finger Lakes Research Conference, Geneva, NY. November 2017.

Dumitriu, I. Demas, C.***, Spacher, P. & J. Halfman,** 2017**.** *Study of Harmful Algae Blooms using UAS Imagery*. Division of Atomic, Molecular & Optical Physics (DAMOP), Sacramento, CA. June 2017.

Dumitriu I., P. Spacher, J.D. Halfman. 2017. *Drone quantification of algal distributions and concentrations in lakes*. Internat. Assoc. Great Lakes Research, Detroit, MI. May 2017.

Dumitriu, I., P. Spacher, & **J. Halfman**, 2017. *Quantification of Harmful Algae Blooms using UAS Imagery.* American Association of Physics Teachers (AAPT). Atlanta, GA. February 2017

*undergraduate student co-author

References

[1] Hans W. Paerl *et. al.*, Science of the Total Environment **409**, 1739 (2011).
[2] G.M. Hallengraeff , Phycologia **32** (2), 79 (1993).
[3] J.M. O'Neil *et. al*., Harmful Algae **14**, 313 (2012)
[4] Li Shen *Sensors **12**,* 7778 (2012).
[5] K. Dornhofer *et.al.*, Ecological Indicators **64**, 105 (2016).
[6] B. P. Page Int. J Appl Earth Obs Geoinformation **66**, (2018).
[7] T. T. Wynne *et. al*., Toxins, **7**, 1649 (2015).
[8] T. Adão *et.al***.,** Remote Sens. **9**, 1110 (2017).
[9] Tung-Ching Su *Remote Sens., 7,* 10078 (2015).
[10] de la Cruz A. *et al*., *J Earth Environ Sci* 148 (2017).
[11] R. Beck *et. al.*, Remote Sens. **9**, 538 (2017).
[12] http://www.spectrecology.com/2015/12/777/

Disclaimer

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Geological Survey. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Geological Survey.

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073

Remote Sensing of Harmful Algal Blooms by Unmanned Aerial Systems (Drones)

This material is based upon work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G16AP00073