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Research paper

A novel cross-satellite based assessment of the spatio-temporal development of a cyanobacterial harmful algal bloom

Benjamin P. Page*, Abhishek Kumar, Deepak R. Mishra

Center for Geospatial Research, Department of Geography, University of Georgia, Athens, GA 30602, USA

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A B S T R A C T

As the frequency of cyanobacterial harmful algal blooms (CyanoHABs) become more common in recreational lakes and water supply reservoirs, demand for rapid detection and temporal monitoring will be imminent for effective management. The goal of this study was to demonstrate a novel and potentially operational cross-satellite based protocol for synoptic monitoring of rapidly evolving and increasingly common CyanoHABs in inland waters. The analysis involved a novel way to cross-calibrate a chlorophyll-*a* (Chl-*a*) detection model for the Landsat-8 OLI sensor from the relationship between the normalized difference chlorophyll index and the floating algal index derived from Sentinel-2A on a coinciding overpass date during the summer CyanoHAB bloom in Utah Lake. This aided in the construction of a time-series phenology of the Utah Lake CyanoHAB event. Spatio-temporal cyanobacterial density maps from both Sentinel-2A and Landsat-8 sensors revealed that the bloom started in the first week of July 2016 (July 3rd, mean cell count: 9163 cells/mL), reached peak in mid-July (July 15th, mean cell count: 108176 cells/mL), and reduced in August (August 24th, mean cell count: 9145 cells/mL). Analysis of physical and meteorological factors suggested a complex interaction between landscape processes (high surface runoff), climatic conditions (high temperature, high rainfall followed by negligible rainfall, stable wind), and water quality (low water level, high Chl-*a*) which created a supportive environment for triggering these blooms in Utah Lake. This cross satellite–based monitoring methods can be a great tool for regular monitoring and will reduce the budget cost for monitoring and predicting CyanoHABs in large lakes.

1. Introduction

Cyanobacterial harmful algal blooms (CyanoHABs) have been a major cause for concern in aquatic ecosystems around the globe. Massive annual CyanoHABs in the Baltic Sea and in Lake Erie, Ohio are some of the most dynamic examples (Hansson and Hakansson, 2007; Steffen et al., 2014). CyanoHABs are becoming increasingly common in lakes and rivers from varying climatic regions and making local, national, and global headlines as the resulting effect of these blooms can be both economically and environmentally devastating. One such example was the 2014 Toledo, Ohio drinking water crisis due to CyanoHABs in Lake Erie. In 2016 alone, there have been numerous reports regarding massive CyanoHABs in large water bodies throughout the United States and around the world. For example, the Indian River Lagoon (IRL) in Florida experienced a historic brown bloom and CyanoHAB in February–March (2016) causing the death of thousands of fish, leaving a foul odor throughout surrounding towns and hindering recreational activities. Not so long after, in June 2016, a state of emergency was declared in Florida coinciding with the massive CyanoHAB in Lake Okeechobee flowing into the St. Lucie River. Furthermore, CyanoTRACKER (cyanotracker.uga.edu), a citizen science project to raise awareness and community participation to report CyanoHABs, has reported over 100 large domestic and international blooms in 2016 alone.

Factors that ultimately lead to the formation of different types of algal blooms in inland waters have been investigated for years. Studies have shown the effects of anthropbogenic eutrophication can be intensified in inland waters as a result of increased summer temperatures associated with frequent drought events that are followed by heavy rainfall (Ahn et al., 2002; Tyler et al., 2008). This hyper-eutrophic condition promotes a lake with a certain susceptibility to experience planktonic (freely floating) algal blooms when combined with excessive Phosphorus (P) and Nitrogen (N) input from the surrounding watershed, to manifest these toxic, food-web disrupting CyanoHABs (Paerl et al., 2014). These blooms often contain harmful cyanobacteria, a type of photosynthetic bacteria which produce hazardous compounds including neurotoxins and hepatotoxins capable of inducing severe gastroenteritis, liver failure, and even death (Greenfield et al., 2014).

* Corresponding author at: Department of Geography, University of Georgia, 210 Field Street, Room 313, Athens, GA 30602, USA.
E-mail address: bpage@uga.edu (B.P. Page).

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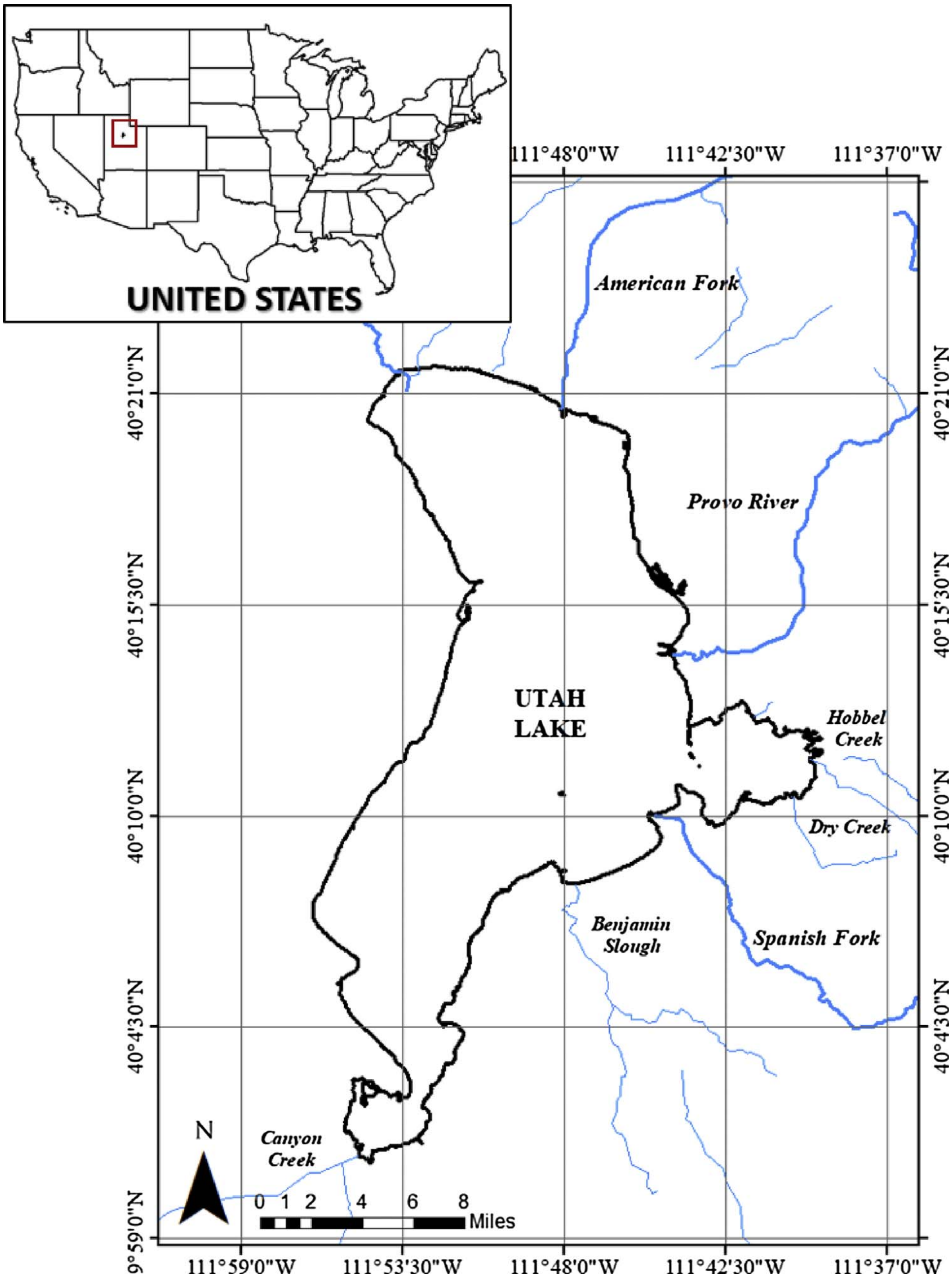

Fig. 1. Study location of Utah Lake, USA along with its major connecting rivers and creeks.

However, there exist uncertain gaps where the interactions between different physical parameters are not studied with large scale spatio-temporal data. A recent study also suggested for more research to assess which combinations of weather, climate, land-use and management practices put water quality most at risk (Michalak, 2016).

Utah Lake, the focus of this paper, observed a historical algal bloom in the summer of 2016 which forced authorities to close the lake for the first time in the lake's history, after lab results for samples collected by the Utah Department of Environmental Quality (UDEQ) showed the concentration of various cyanobacteria cells to be of three times over the threshold for closing a body of water. Positioned in north-central Utah at an altitude of 1368 m above sea level, surrounded by the Traverse Mountains and located between 40°14′42″N and 111°47′51″W, Utah Lake is a shallow (mean depth: 3 m) freshwater lake with a complex ecosystem which covers about half of Utah Valley's floor with a surface area of roughly 390 km2 (Meritt, 2014) (Fig. 1). Utah Lake is highly eutrophic in nature and historically known for summer algae blooms, often consisting of toxic cyanobacteria species such as *Aphanizomenon flos-aquae*, *Dolichospermum crissum*, *Geitlerinema spp*. (*I–III*), *Microcystis aeruginosa*, *Oscillatoria princeps*, and *Pseudanabaena species* (UDEQ, 2016) (Strong, 1974). UDEQ reported that all of the aforementioned species were found in the lake during the 2016 CyanoHAB. Authorities of UDEQ stated in multiple news reports that the lake is rich in phosphorous and that the low level of water coupled with warm temperature triggered the bloom. Other reasons provided by the lake management for the cause of the algal bloom pointed to the waste water discharge from surrounding treatment plants, which is responsible for 80% of the lake's phosphorous input. However, local organizations are not sure that removal of phosphorous can control the bloom in the future, and for this purpose a long-term study will be underway to determine how much phosphorous the lake can handle without showing any adverse effect (Utah Lake Water Quality Study (2015–2019), UDEQ). Recently, a $1 million grant has been requested by UDEQ for this study and according to their proposal investment on