US EPA BENTHIC HABS DISCUSSION GROUP WEBINAR

June 1, 2022, 12:30pm – 2:00pm Pacific Daylight Time

Webinar registration:

https://zoom.us/webinar/register/WN_Ii7rSc49T_utCeQLPzPqVA

GUEST SPEAKERS:

DR. HAMISH BIGGS, NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH (NIWA), NEW ZEALAND

DR. CARL LEGLEITER, OBSERVING SYSTEMS DIVISION OF THE UNITED STATES GEOLOGICAL SURVEY (USGS)

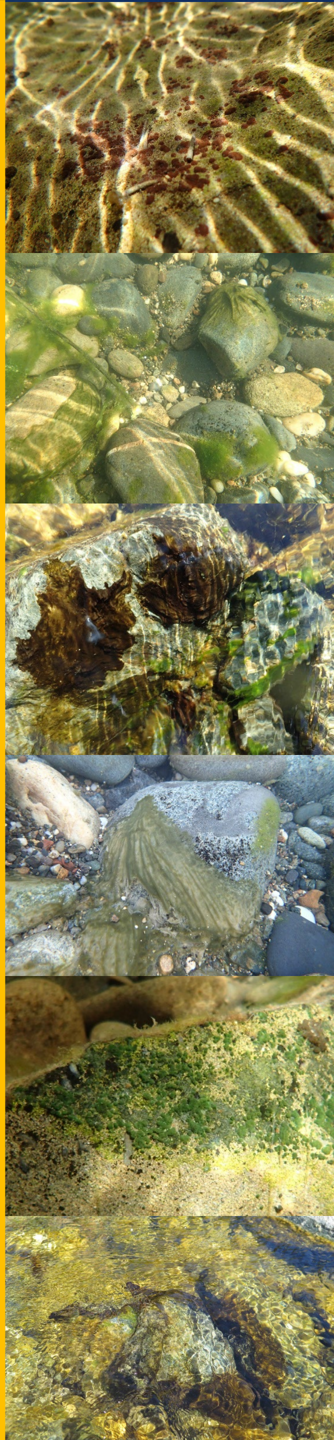
I. AGENDA

I **Welcome, Agenda Overview, Introductions, and Announcements**
Keith Bouma-Gregson, Margaret Spoo-Chupka, and Eric Zimdars

II **Presentation: Drones in freshwater sciences: Remote sensing toxic benthic cyanobacteria**
Guest Speaker – Dr. Hamish Biggs

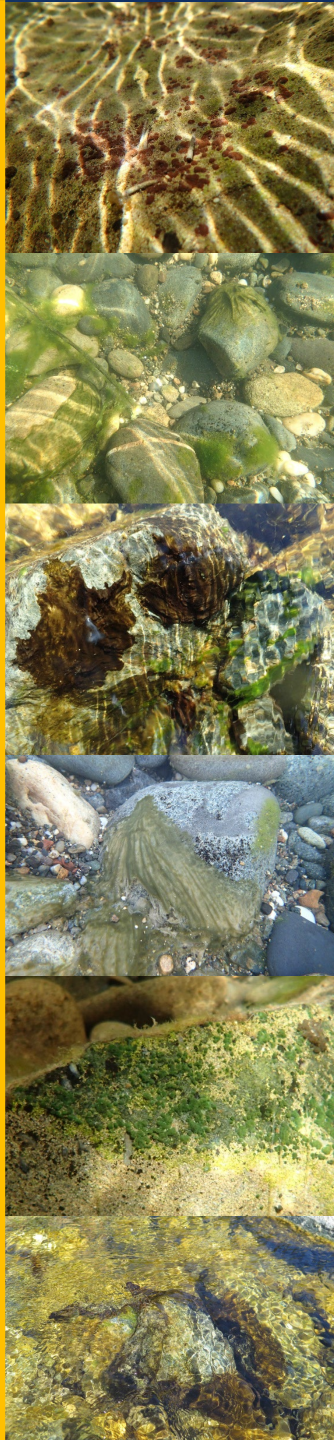
III **Presentation: Remote sensing approaches to characterizing harmful algal blooms in inland waters**
Guest Speaker – Dr. Carl Legleiter

IV **2022 Schedule, Wrap Up & Next Steps**
Facilitators & Benthic HAB members



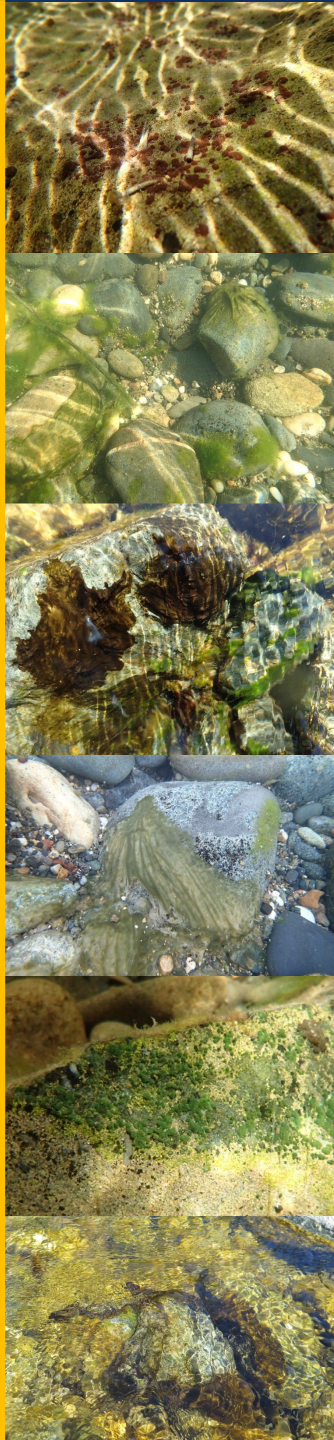
I. INTRODUCTIONS

Name	Affiliation	Contact Information
Margaret Spoo-Chupka	Metropolitan Water District of Southern CA	Phone: 909-392-5127 Email: MSpoo-Chupka@mwdh20.com
Keith Bouma-Gregson	U.S. Geological Survey	Phone: 510-230-3691 Email: kbouma-gregson@usgs.gov
Eric Zimdars	U.S. Army Corps of Engineers	Phone: 206-764-3506 Email: Eric.S.Zimdars@usace.army.mil
Janice Alers-Garcia	U.S. EPA, Washington, DC	Phone: 202-566-0756 Email: Alers-Garcia.Janice@epa.gov



I. ANNOUNCEMENTS

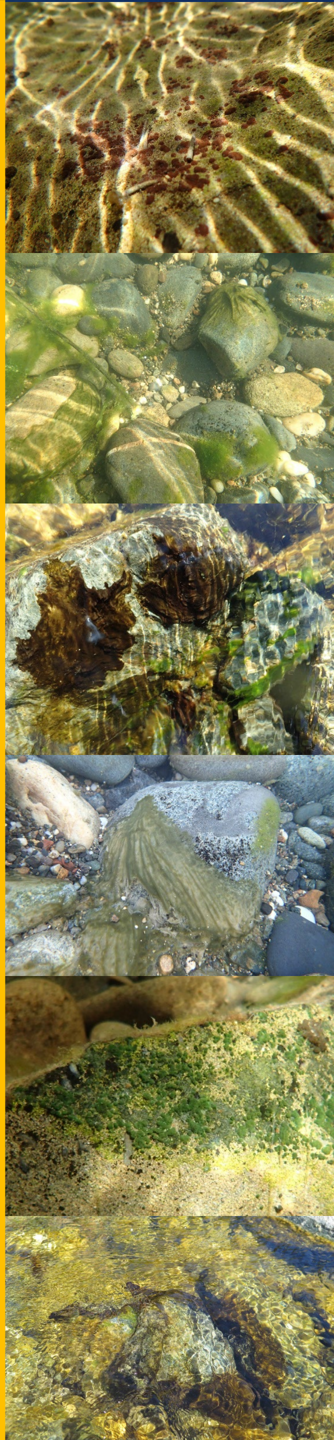
- Upcoming Meetings
  - U.S. Symposium on Harmful Algae: October 23-28, 2022, Albany, New York Abstract
- Recent Papers
  - Legleiter and Hodges, 2022, *Mapping Benthic Algae and Cyanobacteria in River Channels from Aerial Photographs and Satellite Images: A Proof-of-Concept Investigation on the Buffalo National River, AR, USA*
  - Aziz et al., 2022, *Microseira wollei and Phormidium algae more than doubles DBP concentrations and calculated toxicity in drinking water.*
  - Barrientos et al., 2022, *Abundance of Benthic Algae in Forestry Watersheds and the Associated Forest Cover Factors*.



ITEM II

GUEST PRESENTATION: DRONES IN FRESHWATER SCIENCES: REMOTE SENSING TOXIC BENTHIC CYANOBACTERIA

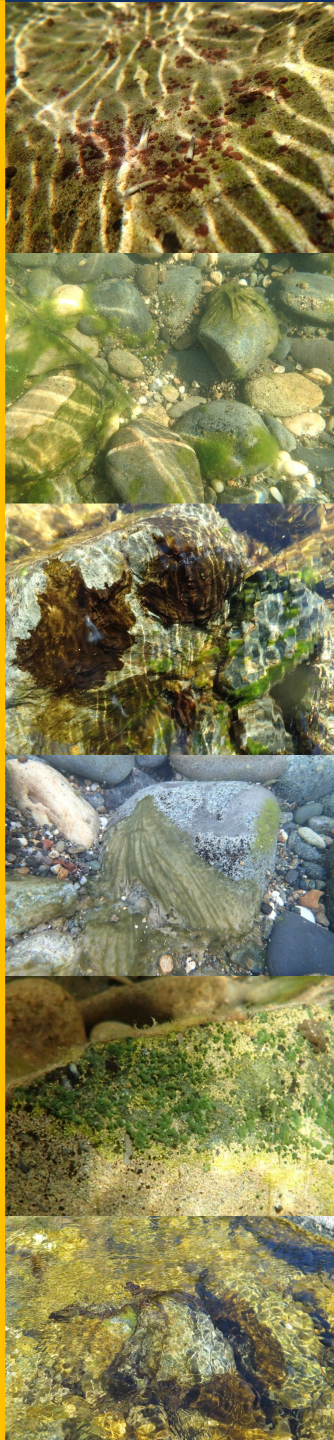
DR. HAMISH BIGGS, THE NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH (NIWA), NEW ZEALAND



ITEM III

Remote sensing approaches to characterizing harmful algal blooms in inland waters

Dr. Carl Legleiter, Observing Systems Division, U.S. Geological Survey (USGS)



Remote sensing approaches to characterizing harmful algal blooms in inland waters

Carl Legleiter - USGS Observing Systems Division
Tyler King – USGS Idaho Water Science Center

Benthic HABs Discussion Group Webinar - Use of Remote Sensing Technologies to Monitor for Benthic Algae

June 1, 2022

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Overview

Context

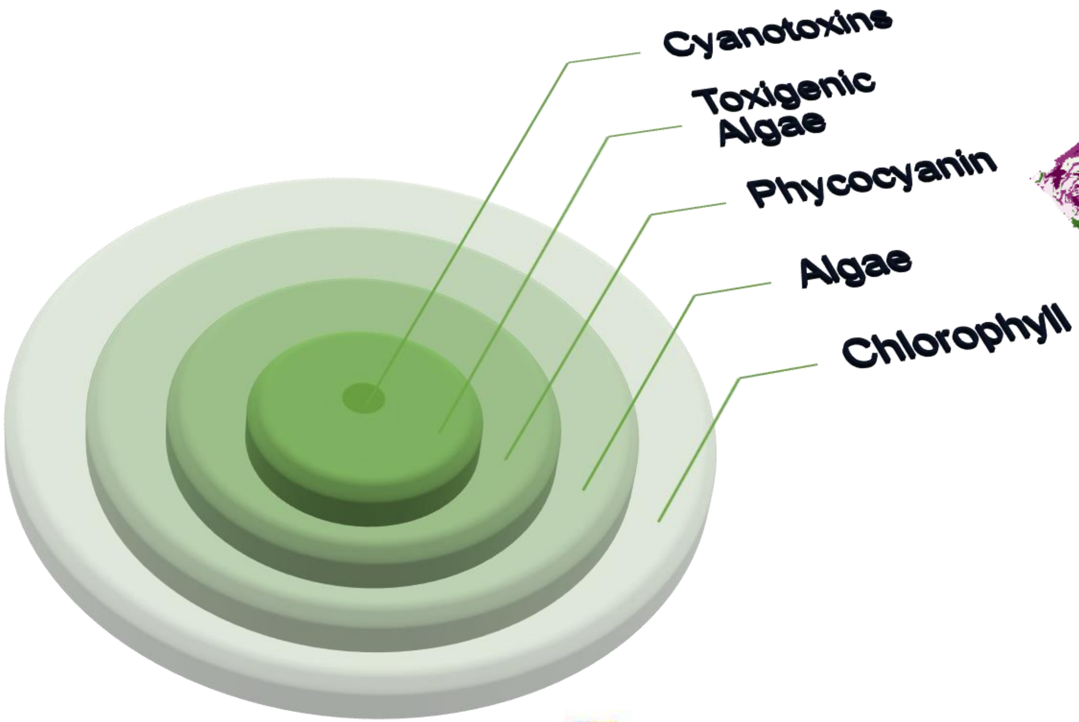
- Challenges in remote sensing of algal blooms

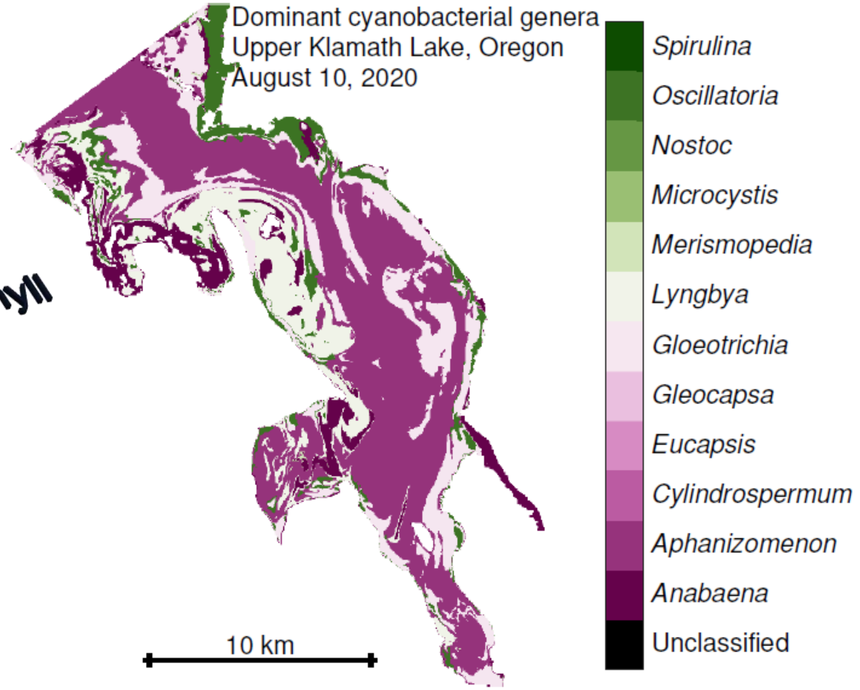
From reservoirs to rivers

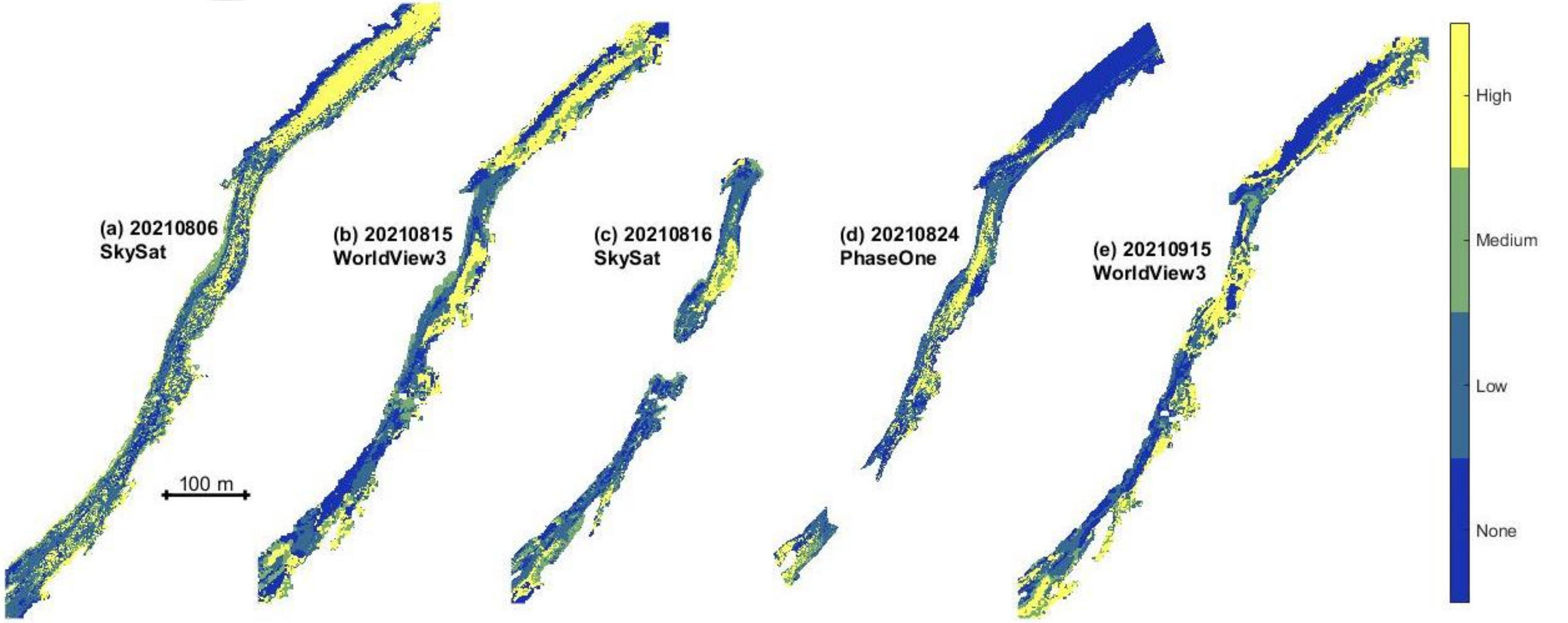
- Remote sensing of benthic algae
- Buffalo River pilot study

Seeking specificity

- Hyperspectral imaging in the lab and from space: Spectral Mixture Analysis for Surveillance of HABs (SMASH)

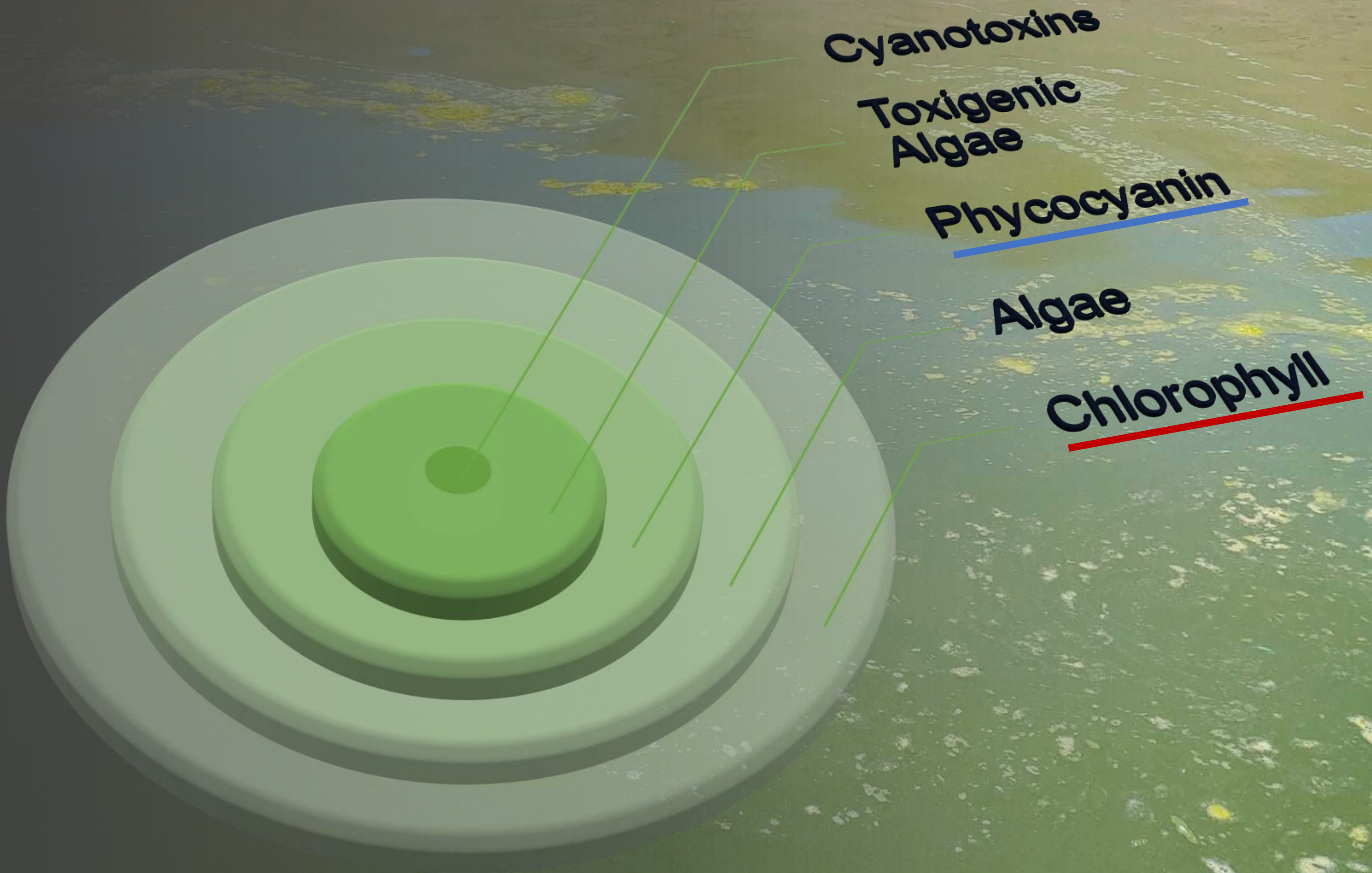






Remote Sensing of Algal Blooms: The Bloom Target

- Toxins cannot be detected directly via remote sensing
- Chlorophyll-a → photosynthetic material
- Phycocyanin → cyanobacteria



Brownlee Reservoir, 2020-07-06
Photo Credit: Idaho Power Company

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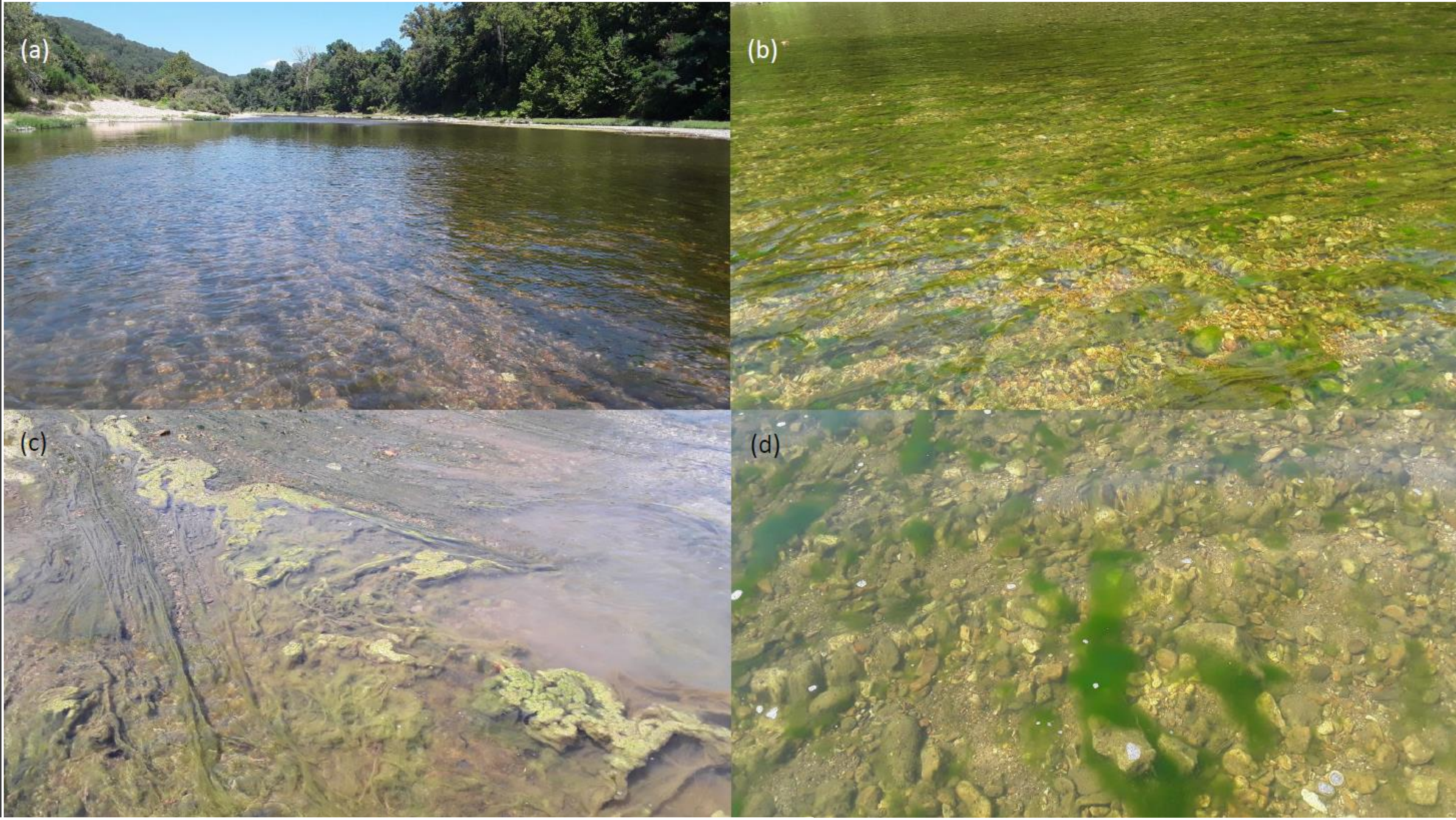
From reservoirs to rivers

Bottom-attached (benthic) algae are a burgeoning nuisance in rivers worldwide

- Adverse effects on aquatic ecosystems
- Potential public health threat (e.g., dog deaths)
- Degraded recreational opportunities

Pilot study on Buffalo National River, Arkansas

- Funded by USGS/NPS WQ Partnership
- Assess utility of remote sensing for mapping benthic algae in rivers



Benthic algae along the Gilbert reach of the Buffalo River illustrating the diverse algal forms present within the reach. Photos from Derek Filipek of the NPS.

remote sensing MDPI

Article

Mapping Benthic Algae and Cyanobacteria in River Channels from Aerial Photographs and Satellite Images: A Proof-of-Concept Investigation on the Buffalo National River, AR, USA

Carl J. Legleiter [1,*] and Shawn W. Hodges [2]

DOI link

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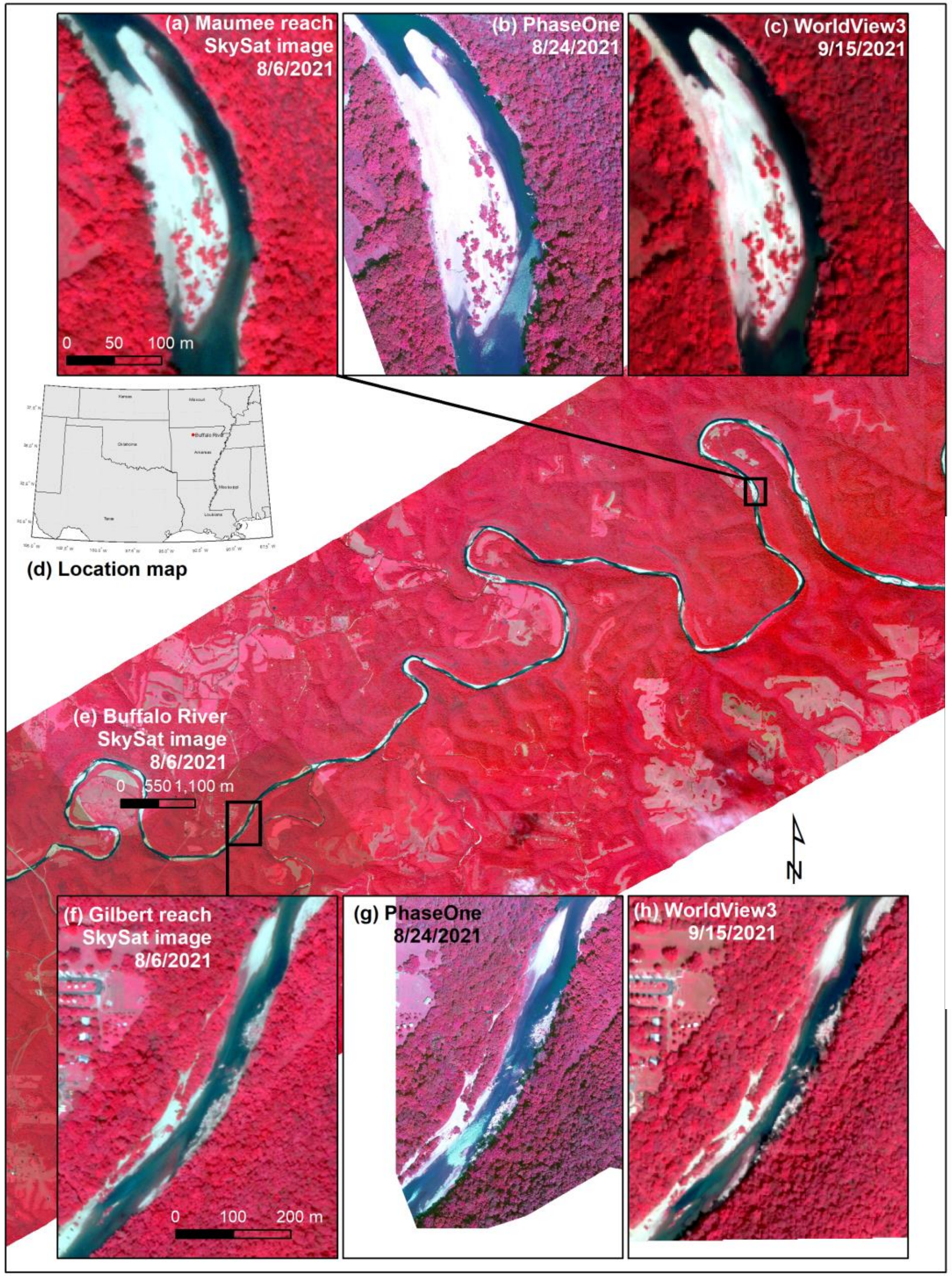
Buffalo River study area and remotely sensed data sets

Benthic algae pose a threat to the 83 fish species found within the park, including eight species of concern; two mussel species are federally listed as endangered

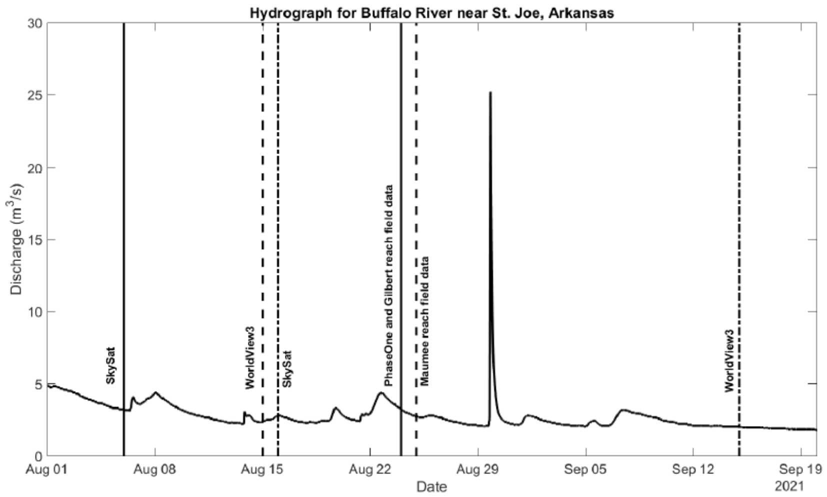
Increasing bloom severity and extent in recent years

- Visitor experiences severely compromised
- Cyanotoxins detected for the first time

Efficient monitoring needed



Sensor	SkySat	WorldView3	PhaseOne
Operator	Planet Labs	DigitalGlobe	USFWS
Platform	Satellite	Satellite	Aircraft
Pixel size (m)	0.5	1.81, 2	0.088
Spectral bands	4: B, G, R, NIR	8: Coastal blue, B, G, Yellow, R, Red edge, NIR1, NIR2	4: B, G, R, NIR



Extensive imagery but focused on two primary study reaches with field data

Gap between field measurements and image acquisition of up to 21 days

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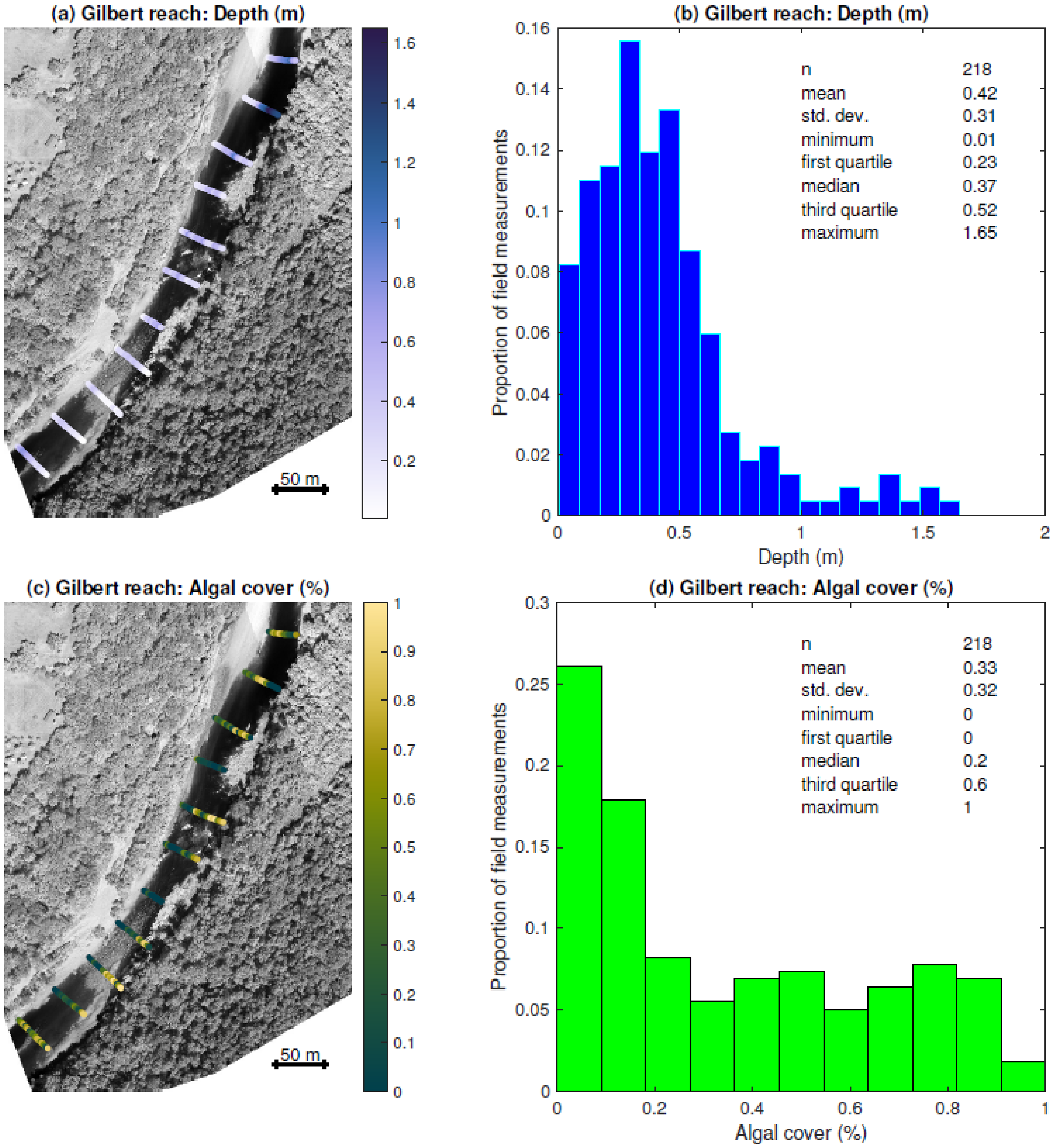
Field observations from Gilbert and Maumee reaches

Regularly spaced transects spaced 50 m apart, with measurements at 18-20 points along each X-section

- Water depth
- Percent cover of benthic algae within 0.3 X 0.3 m area of the streambed
- Spatial positioning from GNSS receiver

Two-person team spent one day at each site

- Impractical for more frequent, larger-scale data collection



Complex, bedrock-controlled channel morphology with dynamic gravel bars leads to a broad range of depths

Percent algal cover data collected in the field at 10% increments based on visual inspection, later aggregated to four ordinal levels of algal cover for classification and mapping:

1. No algae present: 0
2. Low density: 0.1 – 0.3
3. Medium: 0.4 – 0.7
4. High: 0.7 - 1

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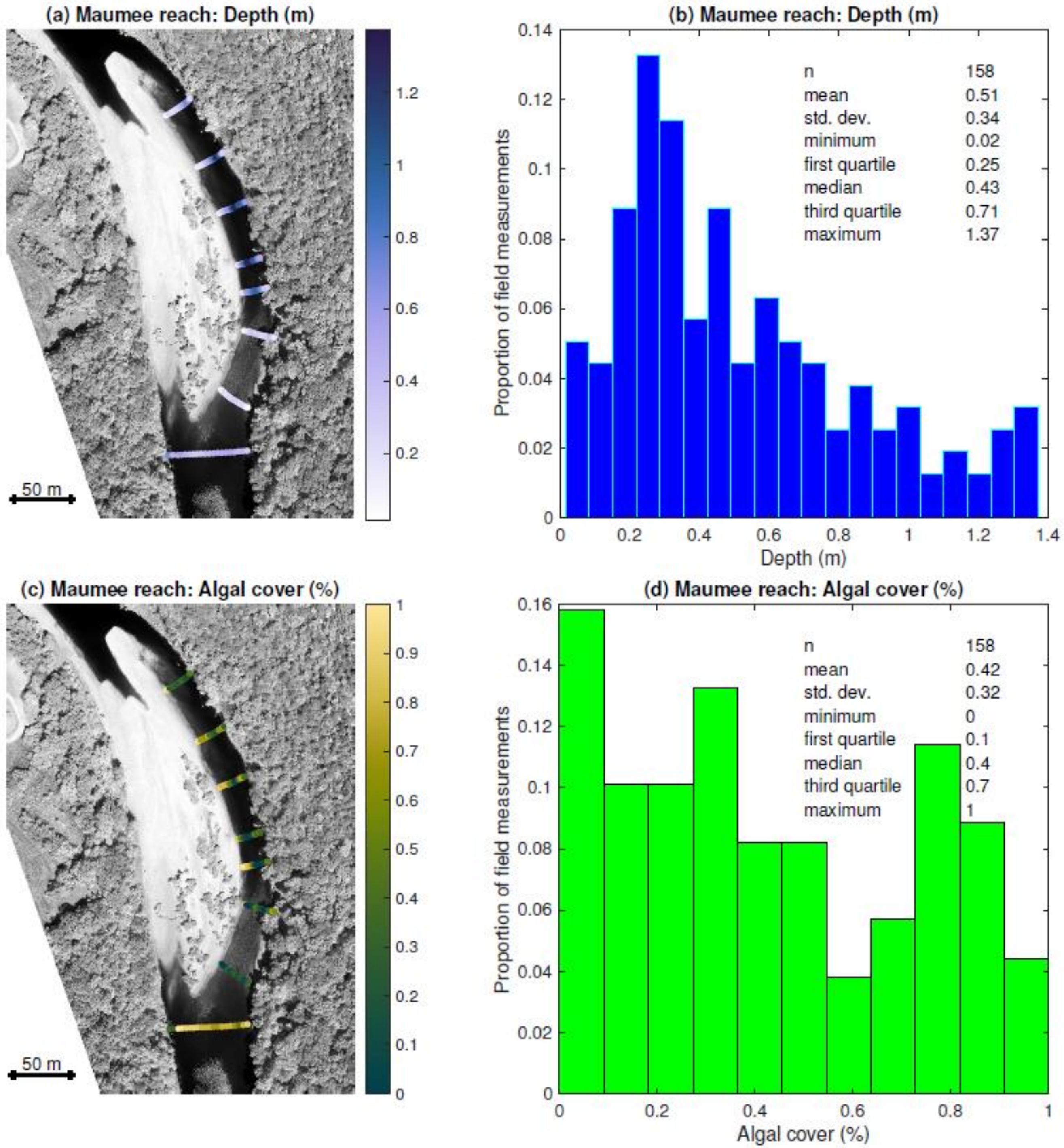

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Spectrally based depth retrieval

Hypothesized that water depth influences algal cover

Inferred depth from images using Optimal Band Ratio Analysis (OBRA)

- Image-derived quantity X calculated for all possible band combinations:
  $X = \ln[R(\lambda_1)/R(\lambda_2)]$
- Regress X against depth for each band ratio
- That which yields highest regression R^2 is optimal
- Yields calibrated relation for mapping depth

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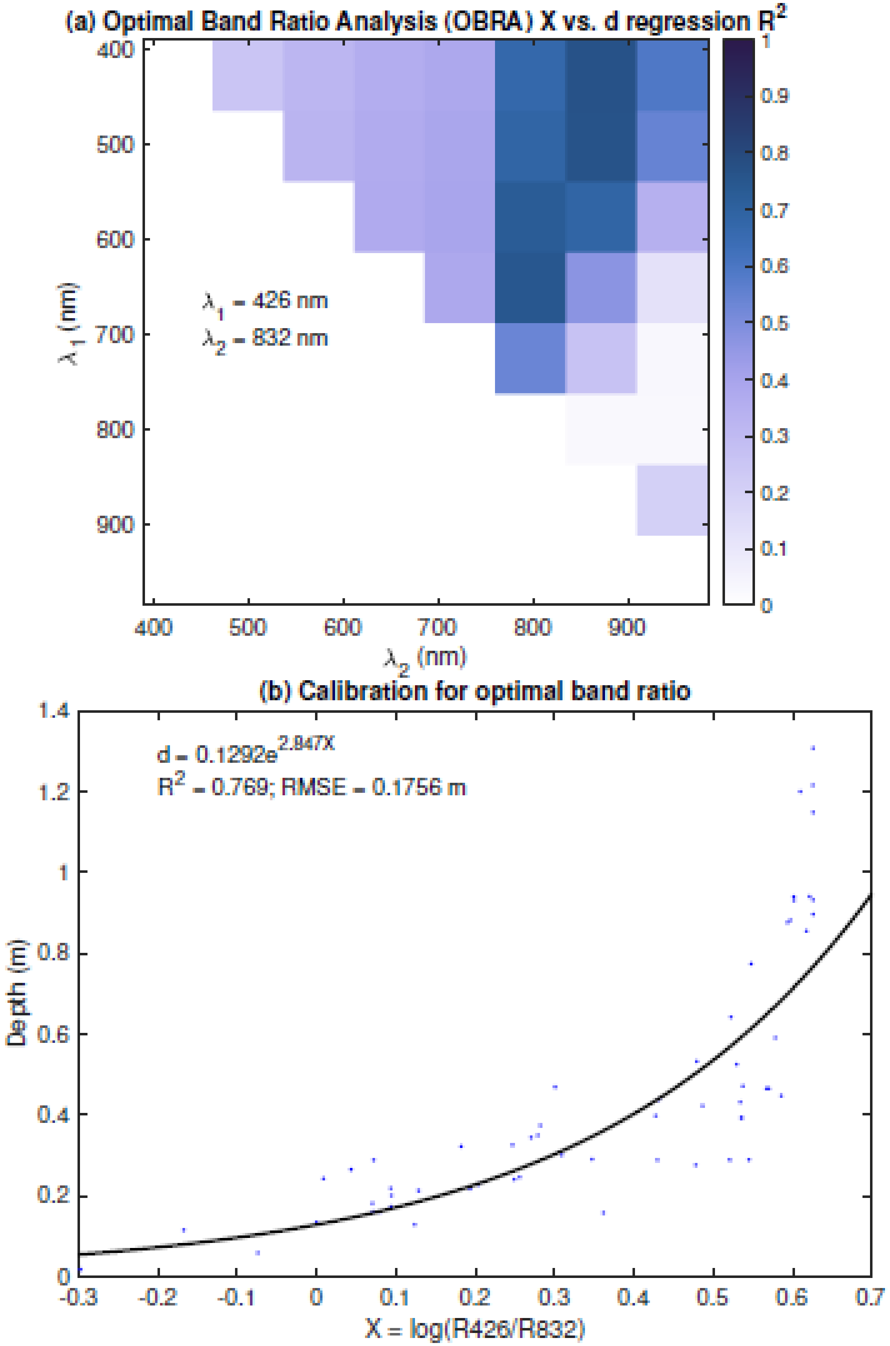
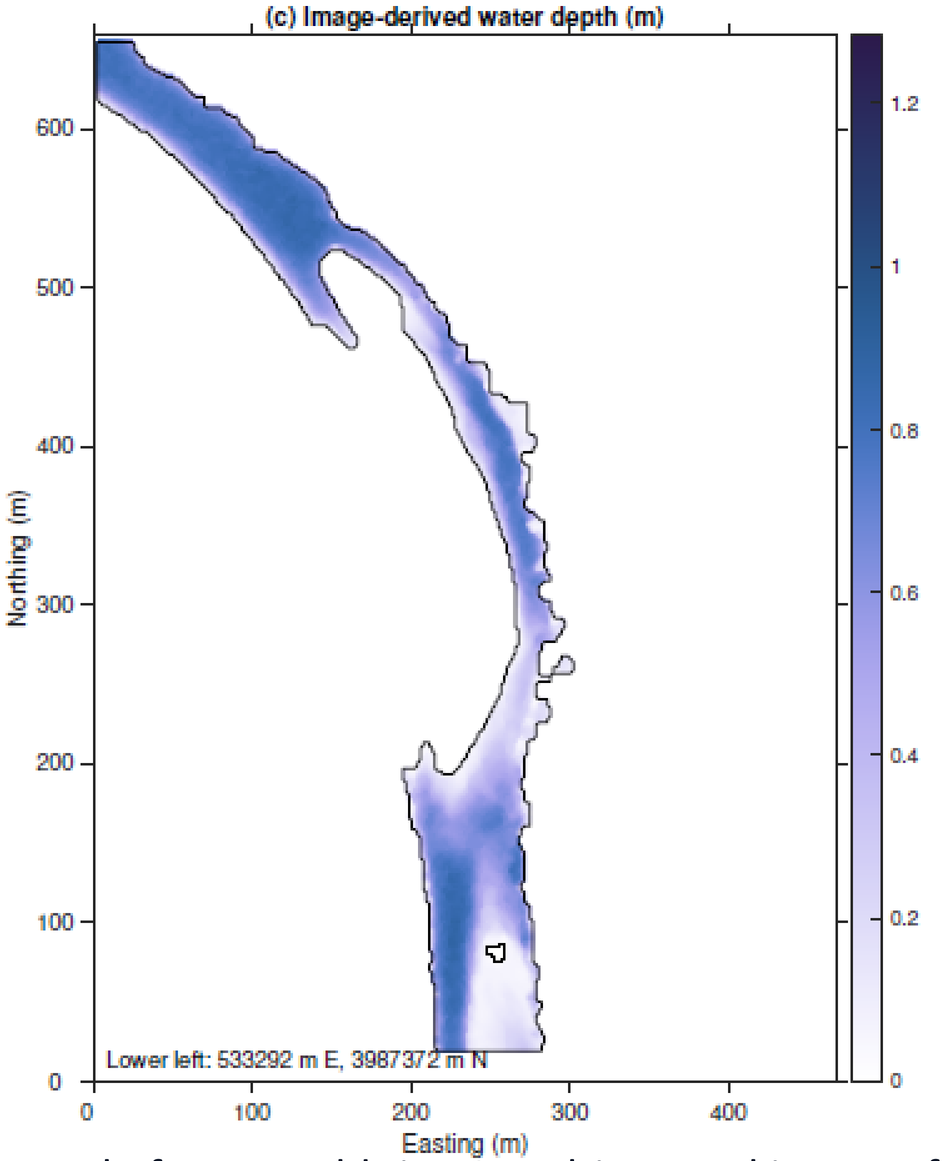




Example from WorldView3 multispectral image of Maumee reach

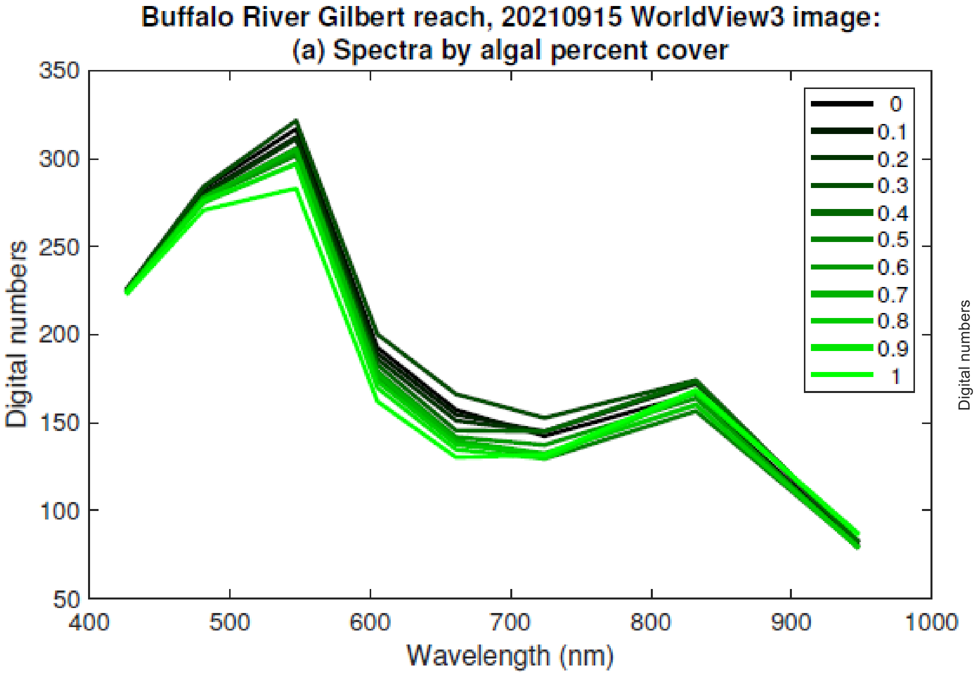
For more on OBRA, see Legleiter & Harrison, 2019

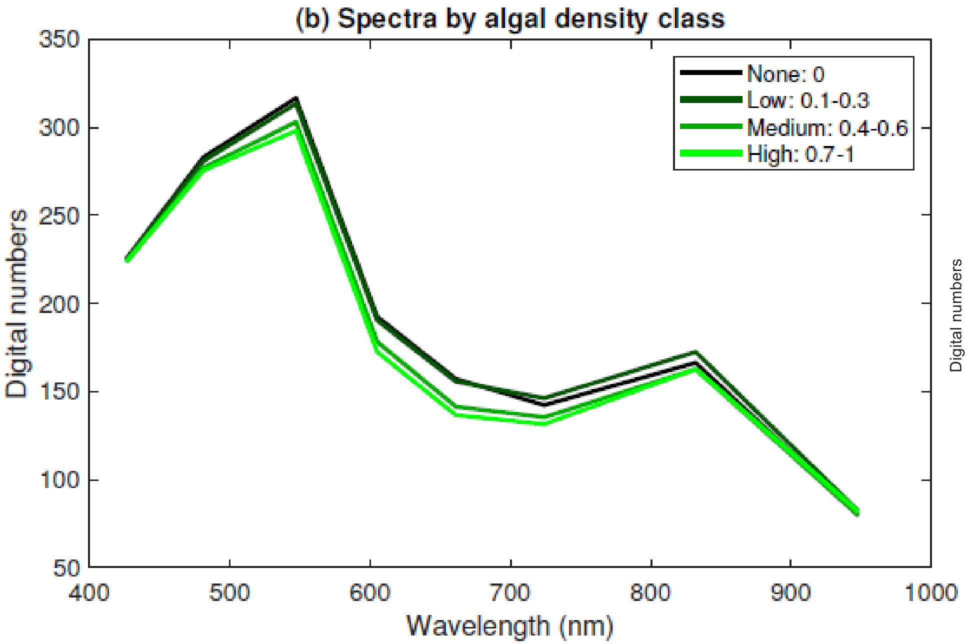
Spectral characteristics of benthic algae

Differences between 11 levels of benthic algae percent cover were subtle and inconsistent and thus were not useful for training classification algorithms

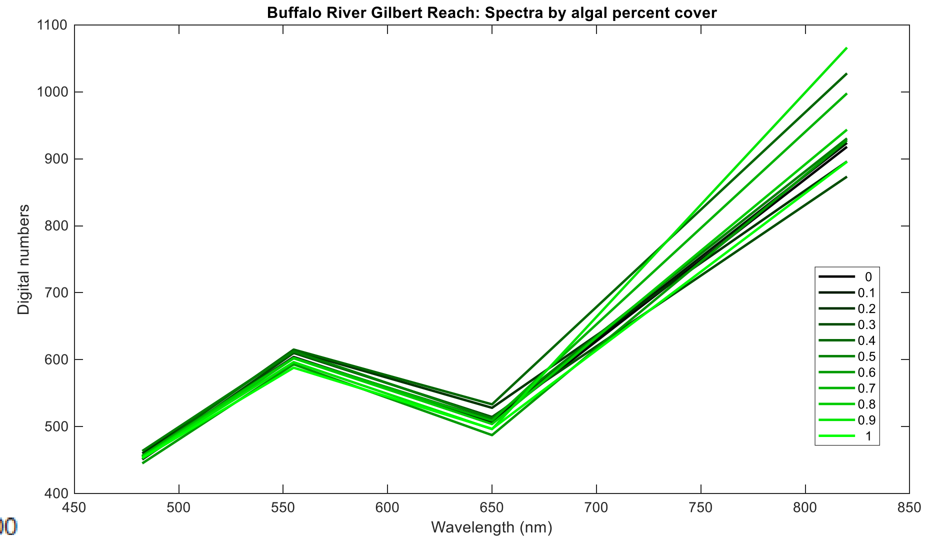
Aggregation to four ordinal levels of cover only slightly improved separability

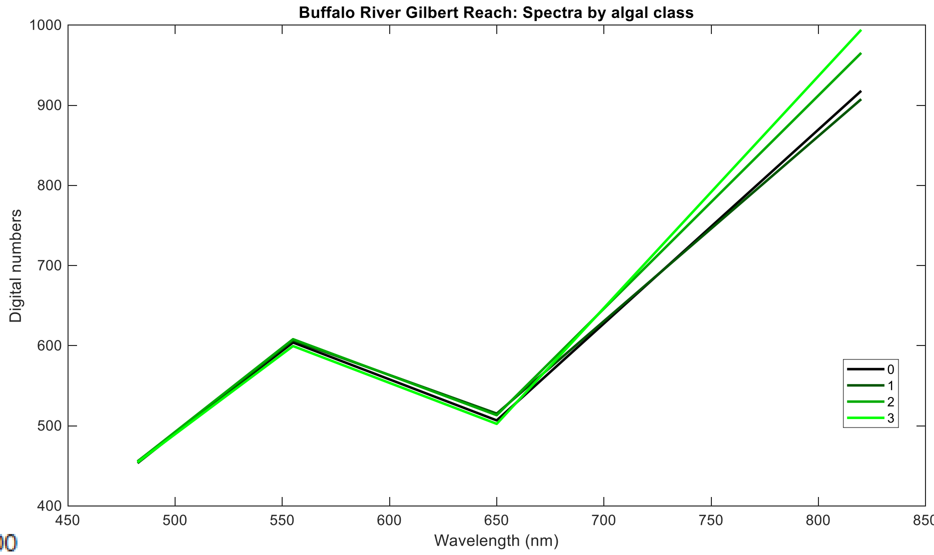
Spectra were even less distinct for four-band data from Planet and PhaseOne





Similar data from 8/6/2021 Planet image





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Machine learning-based classification of algal cover

Random forest or bagged trees: a democratic approach to decision-making

- Bootstrap aggregation → bag: Every tree is grown using an independent sample of training data
- Observations not included in a given sample used to assess “out-of-bag” accuracy
- Allows for different types of variables, non-linear relations, & interactions

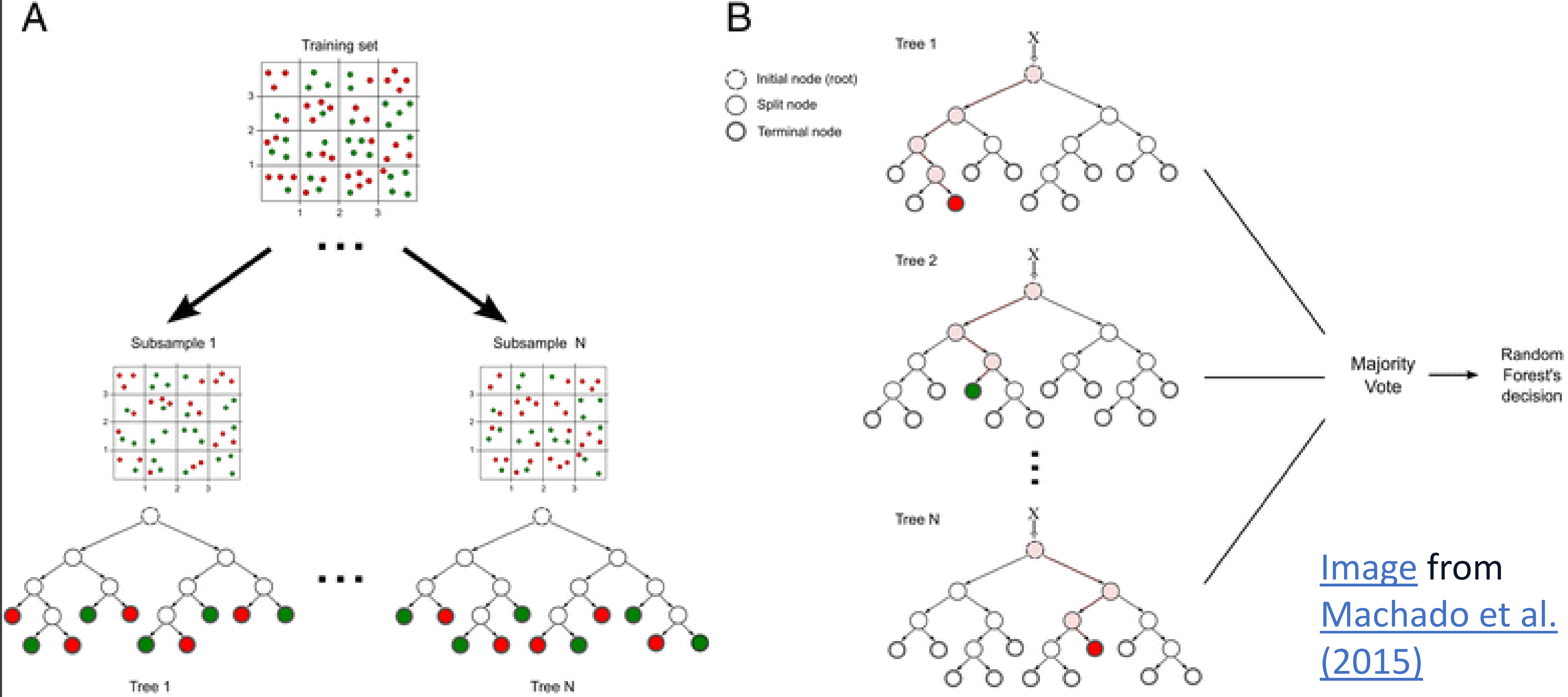

Image from Machado et al. (2015)

Illustration of random forest training and classification. (A) Each decision tree in the ensemble is built upon a random bootstrap sample of the original data that contains examples of each class. (B) Class prediction for new observations is based on a majority voting procedure among all individual trees. The procedure carried out for each tree is as follows: for each new data point, the algorithm starts at the root node of a decision tree and traverses down the tree (highlighted branches) by allowing the value of a specific variable at a given split node (pink) to direct which branch to follow next. This process is repeated until a terminal (leaf) node is reached, which assigns a class (red or green) to this observation. At the end of the process, each tree casts a vote for the preferred class label and the mode of the outputs is chosen as the final prediction.

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Workflow for remote sensing of benthic algae in rivers

Field surveys and processed images used to estimate water depths via OBRA

- Additional predictor for use in random forest

Spectral information extracted from the images, along with the depth maps, served as predictor variables for classifying the response variable: level of algal cover

K-fold cross-validation used for accuracy assessment

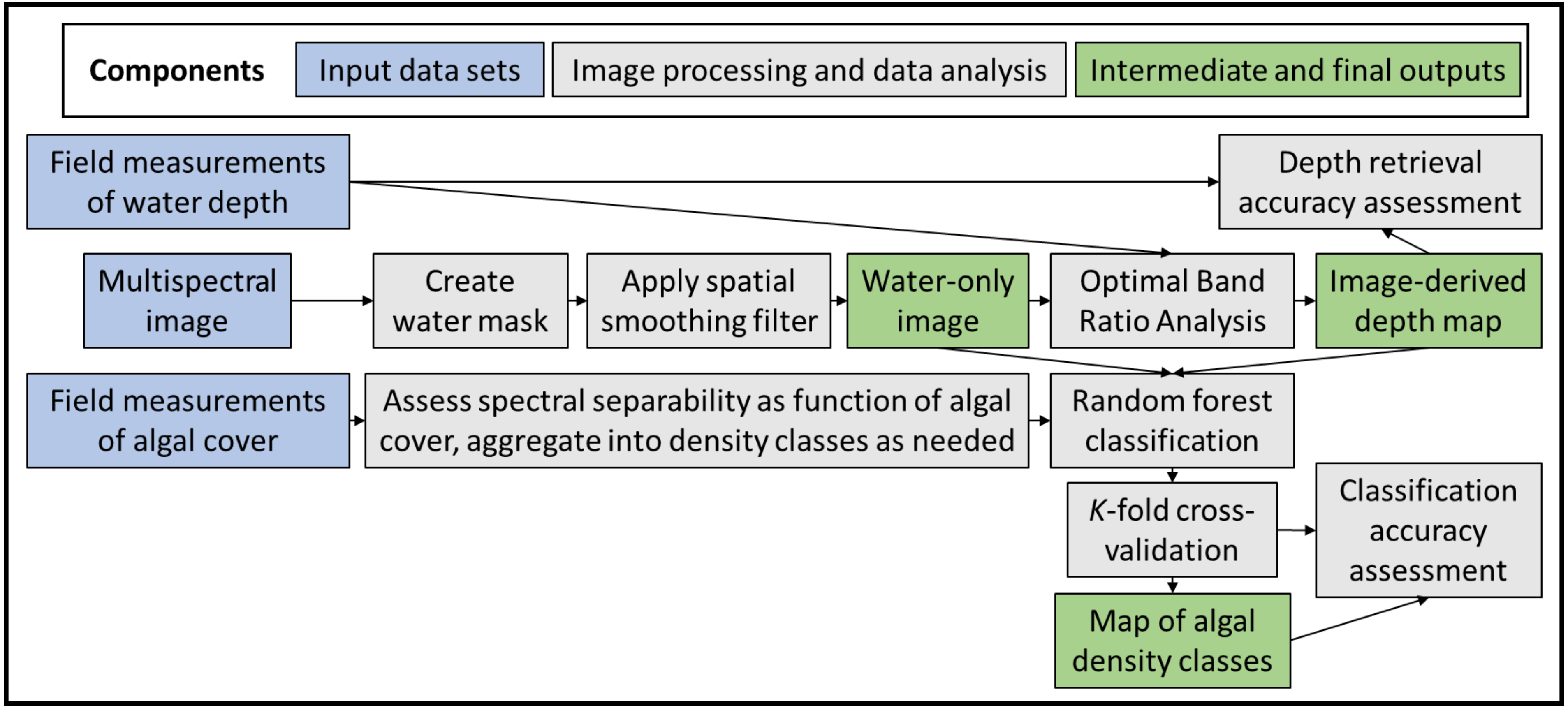

Image processing and random forest classification implemented within MATLAB

- Isolate wetted channel by identifying threshold value of near-infrared band, except where sun glint or shadows caused problems and water mask had to be manually digitized
- Spatial smoothing filter to reduce noise and improve image texture
- Used the ‘fitcensemble’ function in MATLAB with the ‘Bag’ method for classification

K-fold validation: random forest models (i.e., classifiers) trained on in-fold observations used to predict the responses for out-of-fold observations. We used five folds for cross-validation, with each observation randomly assigned into one of five equally sized groups. Algorithm estimates a response for every observation using a model that was trained *without* that observation.

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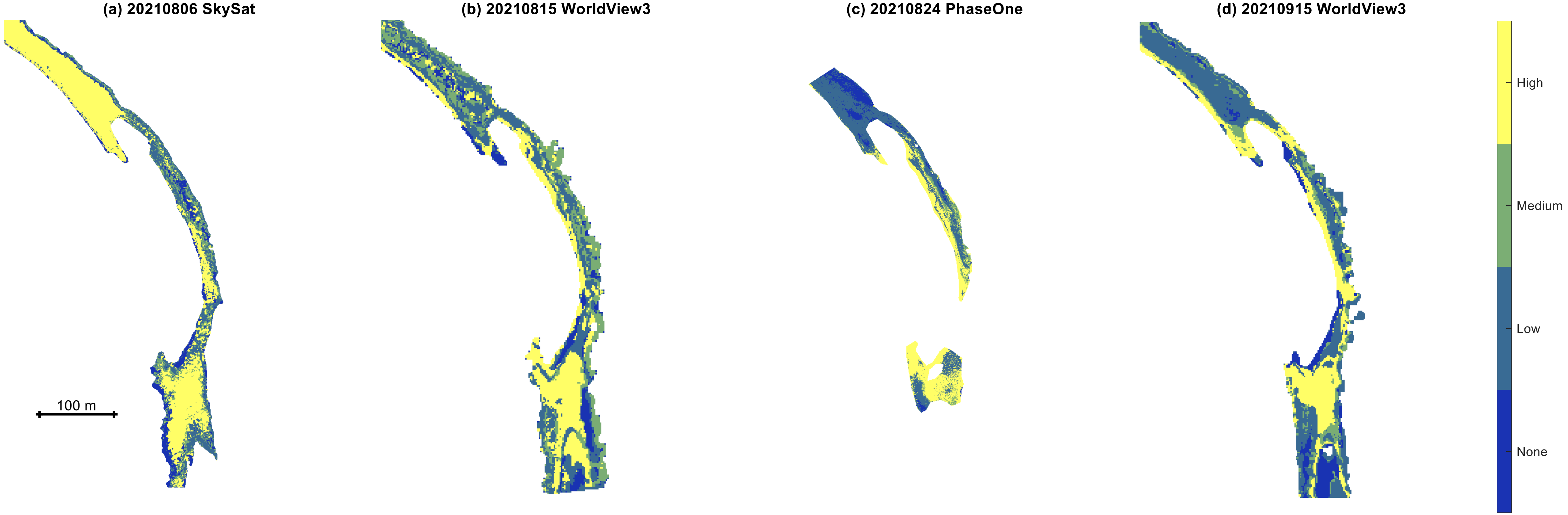
Algal density time series: Maumee

Classified maps were somewhat pixelated in appearance, and the spatial pattern of areas with no algae or a low, medium, or high density of algae on the streambed varied over time, but some consistent patterns also emerged



Zones of high algal density were found spanning the full channel width upstream of the point bar on the left bank and along the bar's shallow margins. The gap in (c) was due to sun glint in the PhaseOne image, evident as bright water, that precluded depth retrieval and classification.

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Assessing the accuracy of algal classifications

Confusion matrices summarize the proportion of pixels mapped as the same class in the field (rows) and predicted from the image (columns), appearing on the main diagonal. Off-diagonal entries provide information on which categories were confused with one another. The smaller table lists the true positive rate in the first column and the false negative rate in the second.

Buffalo River Maumee reach, 20210915 WorldView3 image:
Algal density classification confusion matrix
Classes: 0 = None, 1 = Low, 2 = Medium, 3 = High

True Class \ Predicted Class	0	1	2	3
0	54.5%	31.8%	13.6%	
1	12.0%	66.0%	14.0%	8.0%
2	3.4%	37.9%	37.9%	20.7%
3		7.0%	7.0%	86.0%

True Class		
0	54.5%	45.5%
1	66.0%	34.0%
2	37.9%	62.1%
3	86.0%	14.0%

For highest algal density class (3), 86% of pixels mapped as high density in the field were correctly classified from the image, 7% of these pixels were mistaken as medium density, and another 7% as low density. The true positive rate was thus 86% and the false negative rate was 7% + 7% = 14%. The intermediate class, however, was correctly classified for only 37.9% of the pixels mapped as medium in the field.

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Assessing the accuracy of algal classifications

Overall, classifications were not very accurate, with a large proportion of pixels erroneously assigned to algal density classes other than that as which they were mapped in the field

Overall accuracy was higher when depth was included as a predictor variable

Accuracies were higher for Maumee than Gilbert and tended to increase over time

Buffalo River algal classification summary				
Reach	**Date**	**Sensor**	**Validation accuracy without depth (%)**	**Validation accuracy with depth (%)**
Gilbert	8/6/2021	SkySat	38.5	37.6
Gilbert	8/15/2021	WorldView3	47.1	54.4
Gilbert	8/16/2021	SkySat	39	38.3
Gilbert	8/24/2021	PhaseOne	47.8	49
Gilbert	9/15/2021	WorldView3	50.2	54.3
Maumee	8/6/2021	SkySat	49.2	55.4
Maumee	8/15/2021	WorldView3	59.3	62
Maumee	8/24/2021	PhaseOne	50	63.7
Maumee	9/15/2021	WorldView3	61.1	64.6

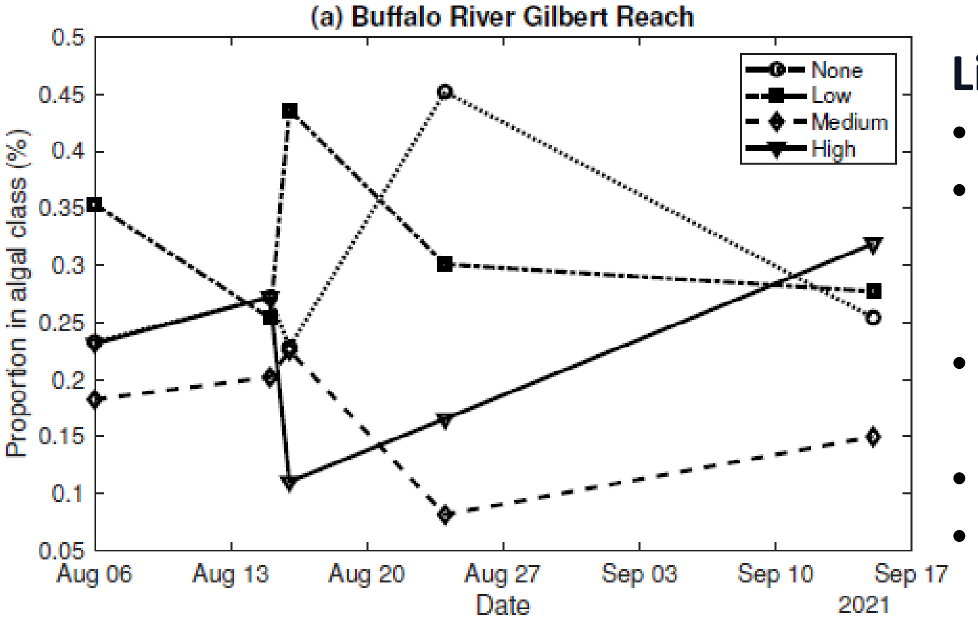
For the conditions observed along the Buffalo River at the time the images were acquired, mapping benthic algae from readily available remotely sensed data using established depth retrieval and image classification methods was more difficult than anticipated

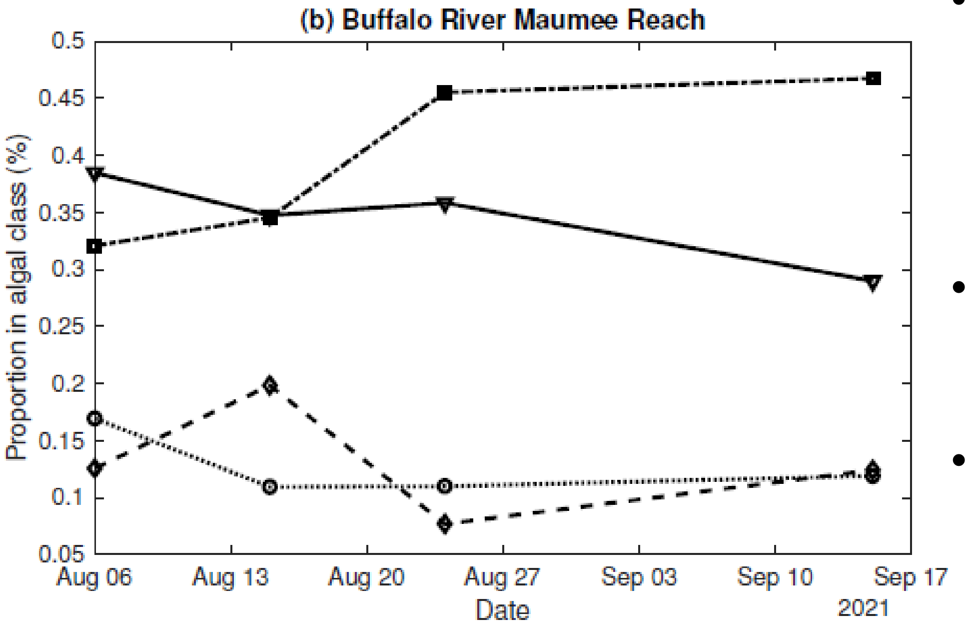
Potential for monitoring benthic algae in rivers via remote sensing

Remote sensing could enable more efficient detection and mapping of algal blooms over larger spatial extents, including inaccessible locations

This approach could help to identify hot spots of excessive algal growth

Longer-term observations could yield insight on causative factors





Limitations of remote sensing approach

- Initial pilot study limited in extent
- Long time gaps between field data collection and image acquisition, during which conditions could have changed
- Some image data sources require a significant financial investment
- Image processing expertise required
- Sensor characteristics play an important role and spectral resolution could be a significant constraint
- Platforms can be problematic: cloud cover can contaminate satellite images, airborne acquisition requires coordinating with contractors, and uncrewed aircraft systems (UAS) are subject to regulations
- Environmental conditions must be appropriate: shallow, clear water, and no riparian vegetation overhanging channel
- Temporal dynamics of blooms pose challenges and place a premium on rapid response and/or frequent data collection

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Thanks for listening!

Questions?

cjl@usgs.gov