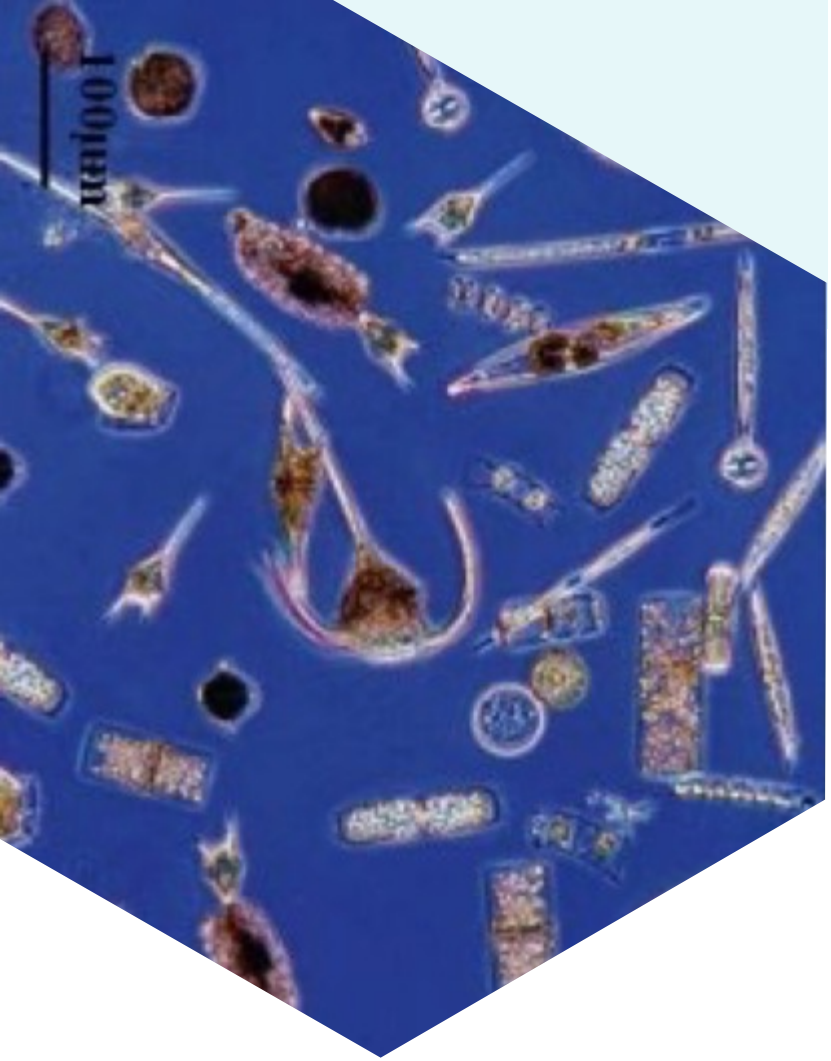
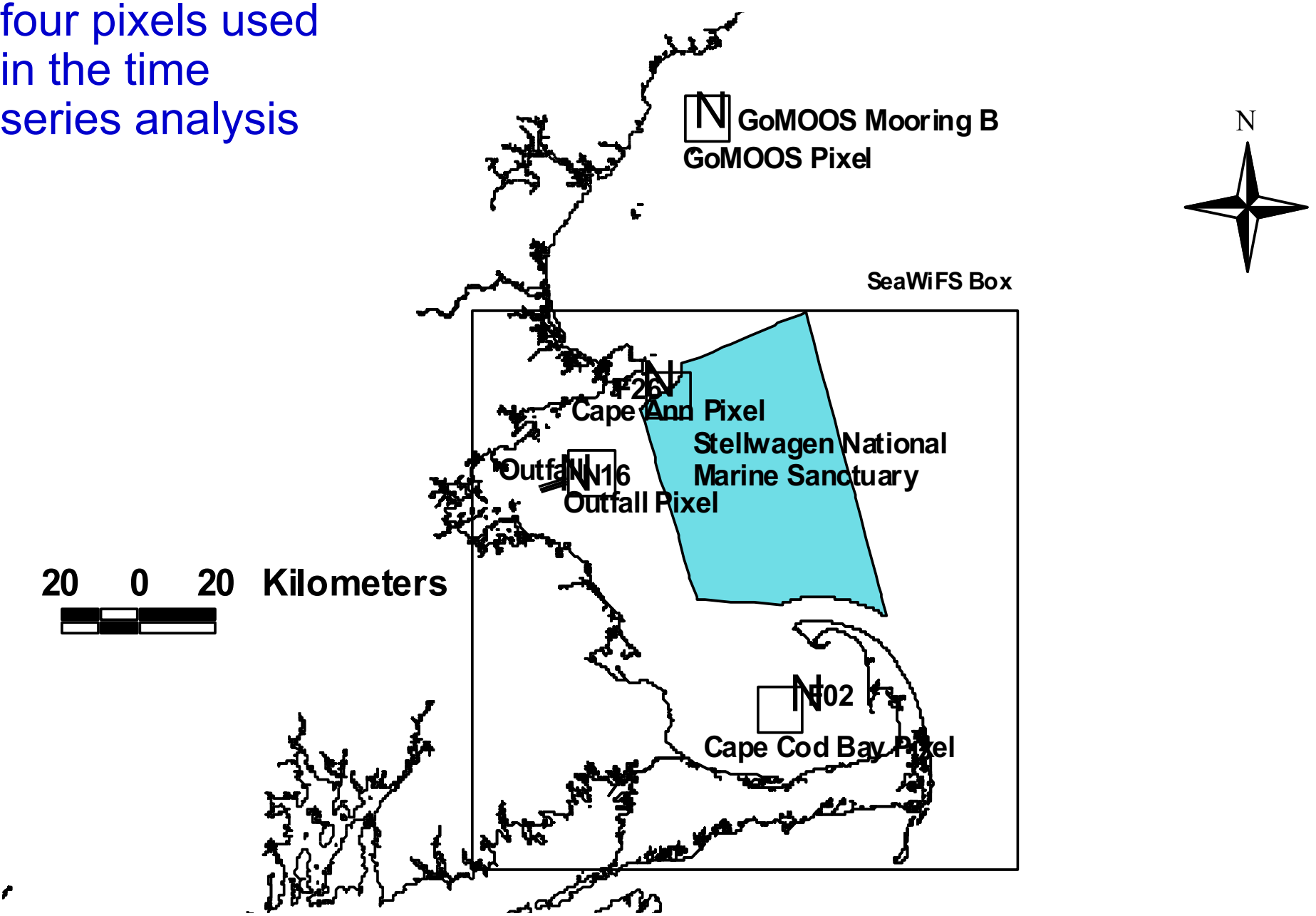


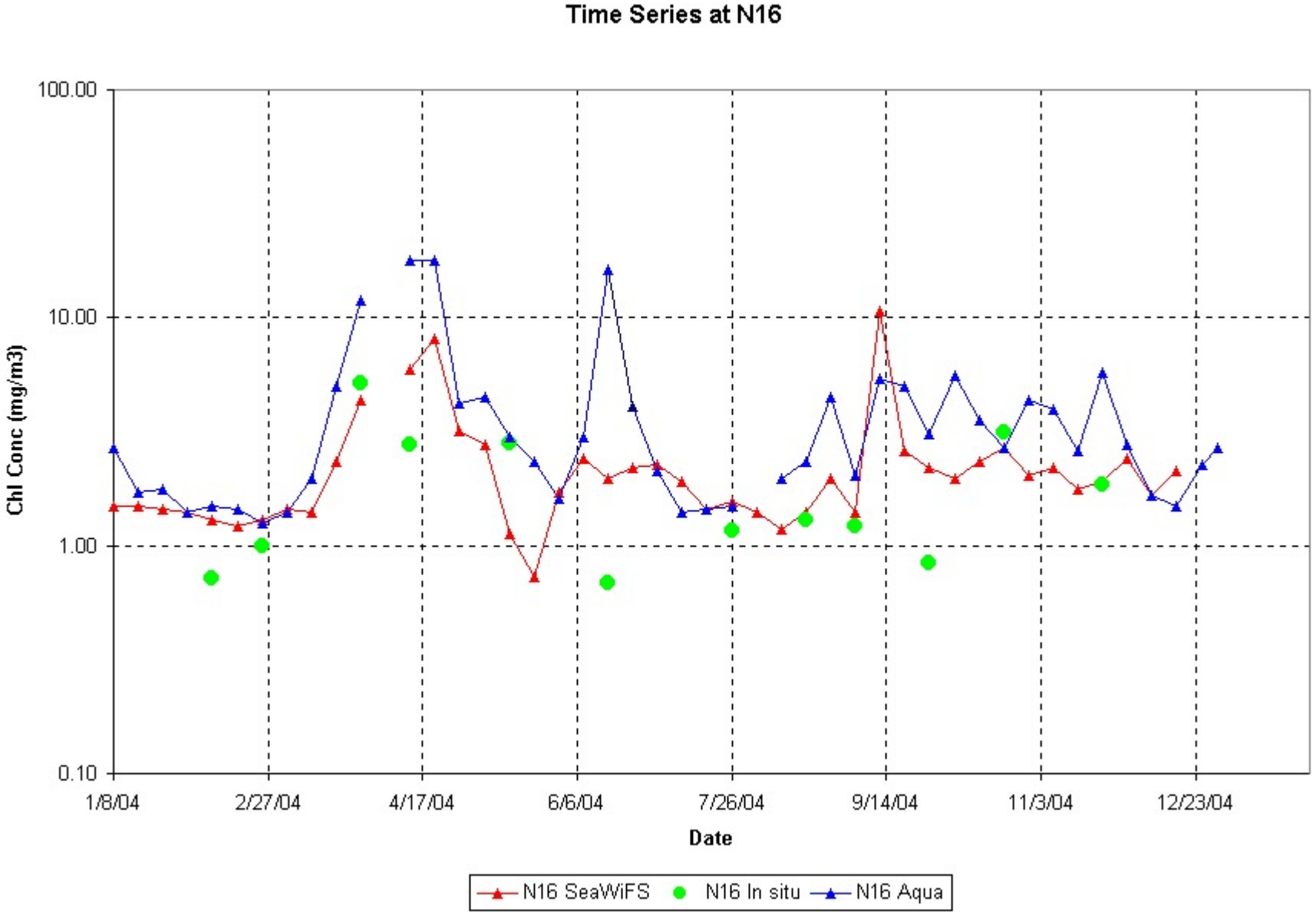
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Monetizing Ocean Color?

Ajit Subramaniam

Location of the four pixels used in the time series analysis

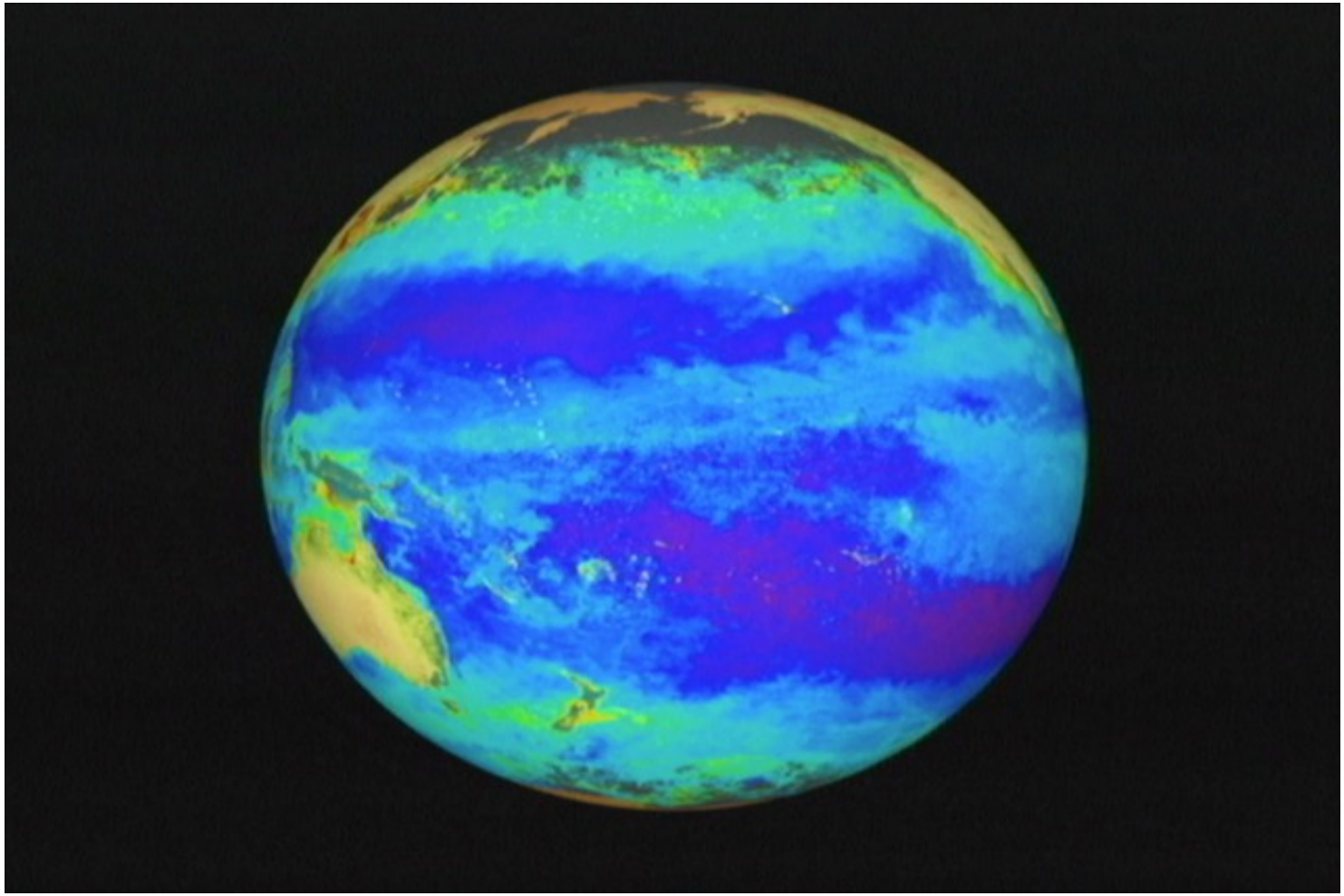



Time Series at N16
100.00
10.00
1.00
0.10
Chl Conc (mg/m3)
1/8/04
2/27/04
4/17/04
6/6/04
7/26/04
9/14/04
11/3/04
12/23/04
Date
N16 SeaWiFS
N16 In situ
N16 Aqua

Mission Application[1]	Impact[1]
HAB identification, characterization, and tracking[1]	75% reduction in HAB impact (US fisheries ~$244B; HAB health cost ~$1B/yr)[1]
Oil Spill Recovery[2]	$132M recovered (2021) $114M recovered (2022)[2]
Cloud-free monitoring for fisheries and resources[1]	Improved catch rate forecast Big Eye Tuna ($100M) Sablefish ($110M)[1]
Whale watch[1]	Reduce whale by-catch and contact[1]

1. NOAA Technical Report: The Value of Geostationary Ocean Color, M. Ford, M. Tomlinson, 2021, https://repository.library.noaa.gov/view/noaa/33278
2. NOAA. Office of Response and Restoration: NOS Fiscal Year 2022 Year in Review, National Ocean Service website, https://oceanservice.noaa.gov/annualreport/2022/orr.html , 01/20/23.

Global Distribution of Phytoplankton Biomass – from Satellite

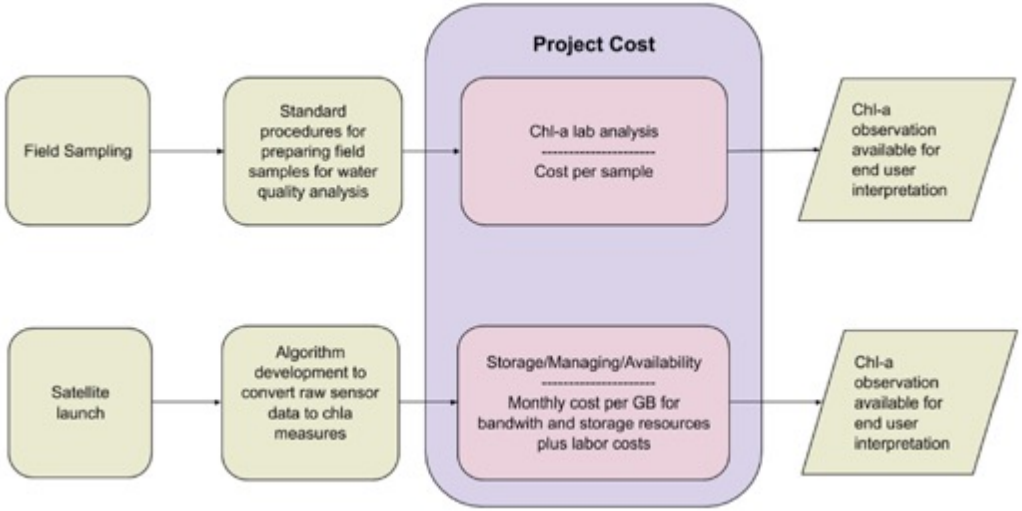


Environ Monit Assess (2020) 192: 808
https://doi.org/10.1007/s10661-020-08631-5

Exploring the potential value of satellite remote sensing to monitor chlorophyll-a for US lakes and reservoirs

Michael Papenfus · Blake Schaeffer · Amina I. Pollard · Keith Loftin

All measurements are subject to error. It is a misnomer to assume in situ measures contain no error, are a "ground-truth," or a better representation of the environment any more than satellite-derived water quality measures are devoid of error. Models, satellite algorithms, and in situ measures are all approximate representations of the environment (Wainwright and Mulligan 2013) where fitness for purpose would need to be evaluated for the selected approach. In situ measures may contain significant error depending on the analysis method, where stan-



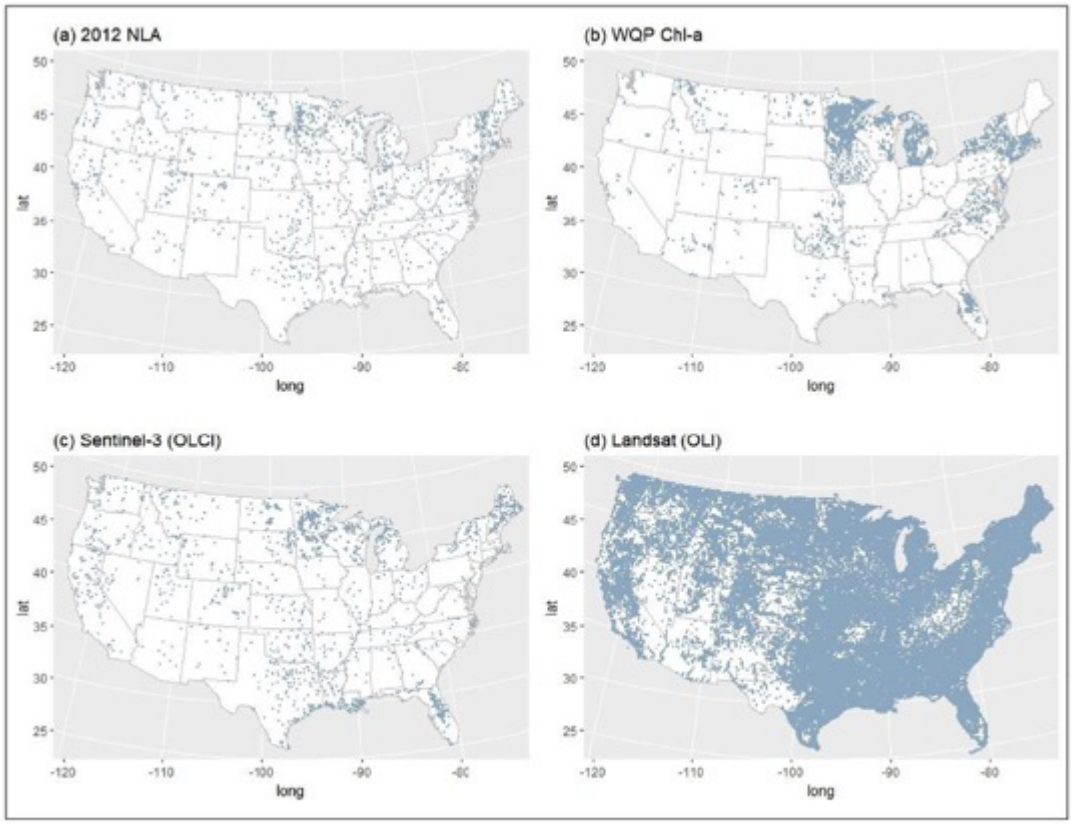


Fig. 3 Comparison of the number of lakes monitored in (**a**) 2012 National Lakes Assessment, (**b**) lakes that have been monitored for chl-a in situ with reporting in the National Water Quality Data Portal, and those resolvable by satellite sensors: (**c**) Sentinel-3 (OLCI) and (**d**) Landsat-8 (OLI)

- Avoided costs associated with satellite based Chl – if satellite based observations were not available, how much would it cost using in-situ methods to produce observations at the same spatial and temporal scales:
- $6-316M depending on satellite platform and timeframe
- Does not take into account remote areas, catching episodic events, challenges in sampling due to COVID
- Mitigates environmental justice issues

Society and Natural Resources, 20:849–859

ISSN: 0894-1920 print/1521-0723 online
DOI: 10.1080/08941920601171683

Routledge
Taylor & Francis Group

Insights and Applications

Harmful Algal Blooms and Coastal Business: Economic Consequences in Florida

SHERRY L. LARKIN AND CHARLES M. ADAMS

Department of Food and Resource Economics, University of Florida, Gainesville, Florida, USA

- HABs reduced restaurant revenues by $2.8M per month and lodging revenues by $3.7M per month
- In comparison, a tropical storm reduced restaurant revenues by $0.5M per month and had no effect on lodging revenues

Harmful Algae. 2006 October 1; 5(5): 526–533. doi:10.1016/j.hal.2005.09.004.

Environmental exposures to Florida red tides: Effects on emergency room respiratory diagnoses admissions

Barbara Kirkpatrick[a,*], **Lora E. Fleming**[b,f], **Lorraine C. Backer**[c], **Judy A. Bean**[d], **Robert Tamer**[d], **Gary Kirkpatrick**[a], **Terrance Kane**[e], **Adam Wanner**[f], **Dana Dalpra**[a], **Andrew Reich**[g], and **Daniel G. Baden**[h]

54% increase in respiratory diagnoses admissions in hospitals during red tide events

Harmful Algae 81 (2019) 59–64

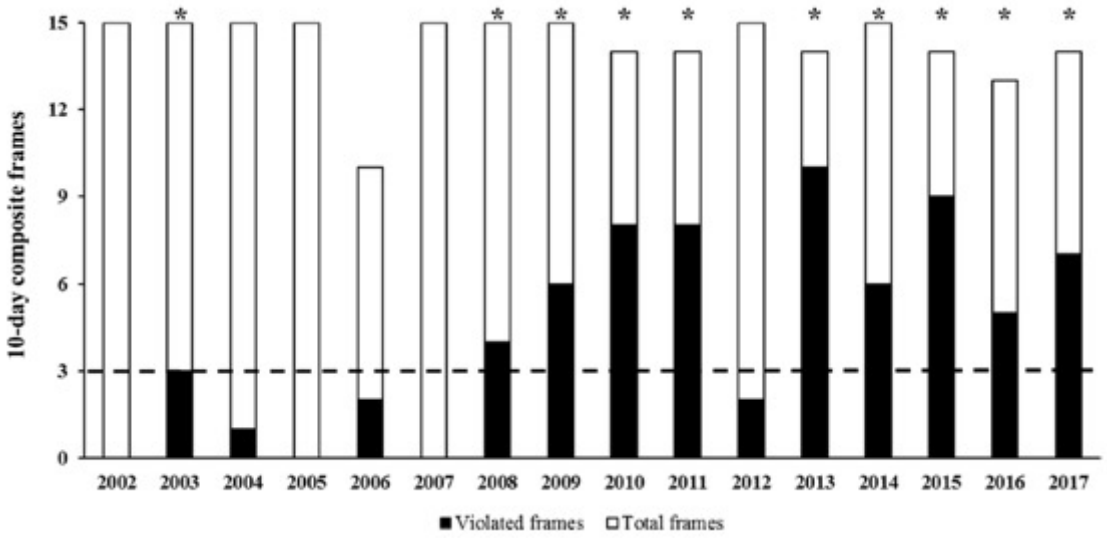
Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Science meets policy: A framework for determining impairment designation criteria for large waterbodies affected by cyanobacterial harmful algal blooms

Timothy W. Davis[a,*], Richard Stumpf[b], George S. Bullerjahn[a], Robert Michael L. McKay[a], Justin D. Chaffin[c,e], Thomas B. Bridgeman[d], Christopher Winslow[c,e]



Satellite remote sensing was used to develop the framework for determination of impairment of Lake Erie Based on this method, it was found that Western Lake Erie was impaired every year except 2012

Gulf of Mexico Harmful Algal Bloom Bulletin

Region: Southwest Florida

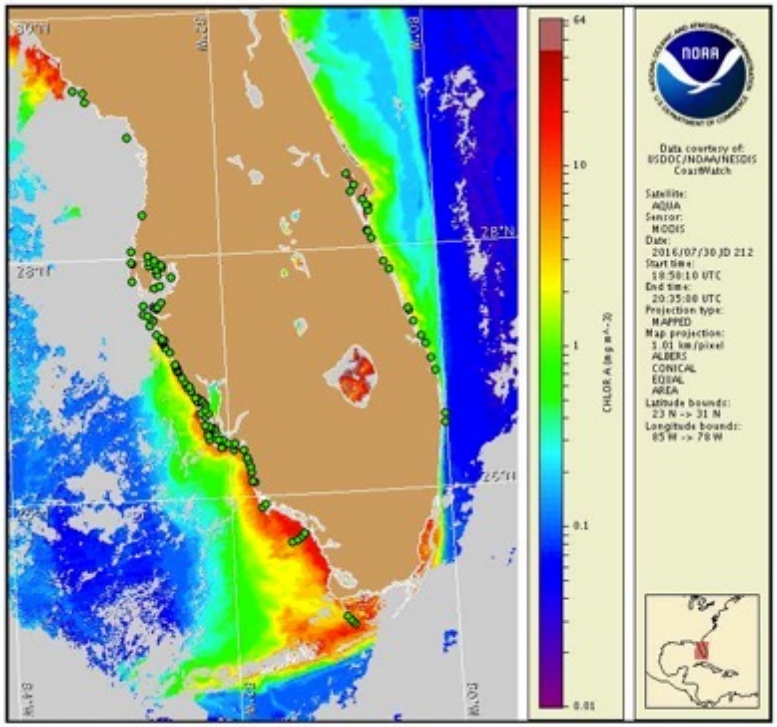
Monday, 01 August 2016

NOAA National Ocean Service

NOAA Satellite and Information Service

NOAA National Weather Service

Last bulletin: Monday, July 25, 2016



Satellite chlorophyll image with possible *K. brevis* HAB areas shown by red polygon(s), when applicable. Points represent cell concentration sampling data from July 22 to 29: red (high), orange (medium), yellow (low b), brown (low a), blue (very low b), purple (very low a), pink (present), and green (not present). Cell count data are provided by Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute. For a list of sample providers and a key to the cell concentration categories, please see the HAB-OFS bulletin guide:

http://tidesandcurrents.noaa.gov/hab/hab_publication/habfs_bulletin_guide.pdf

Detailed sample information can be obtained through FWC Fish and Wildlife Research Institute at:

http://myfwc.com/redtidestatus

To see previous bulletins and forecasts for other Harmful Algal Bloom Bulletin regions, visit at: http://tidesandcurrents.noaa.gov/hab/bulletins.html

Conditions Report

Karenia brevis (commonly known as Florida red tide) ranges from not present to background concentrations along the coast of southwest Florida, and is not present in the Florida Keys. No respiratory irritation is expected alongshore southwest Florida Monday, August 1 through Monday, August 8.

Check http://tidesandcurrents.noaa.gov/hab/beach_conditions.html for recent, local observations.

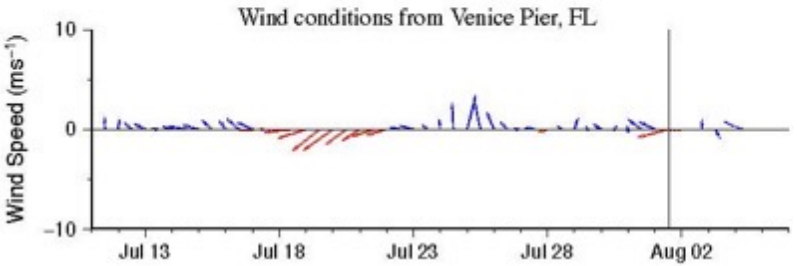
Analysis

Recent samples received from along- and offshore southwest Florida from Pinellas to Monroe counties, including the Florida Keys, all indicate that *Karenia brevis* is not present, with the exception of two background concentrations collected at Englewood Beach and Gasparilla Pass in Charlotte County (FWRI, MML, SCHD, CCENRD; 7/21-7/28). Detailed sample information and a summary of impacts can be obtained through FWC Fish and Wildlife Research Institute at: http://myfwc.com/redtidestatus.

Recent ensemble imagery (MODIS Aqua, 7/30) is partially obscured by clouds alongshore southwest Florida from Pinellas to Sarasota counties, limiting analysis. Patches of elevated to very high chlorophyll (2 to > 20μg/L) with the optical characteristics of *K. brevis* are present from Venice Beach in southern Sarasota County to Marco Island in central Collier County and extend up to 9 miles offshore.

Forecasted winds over the next week may decrease the potential for *K. brevis* bloom formation at the coast.

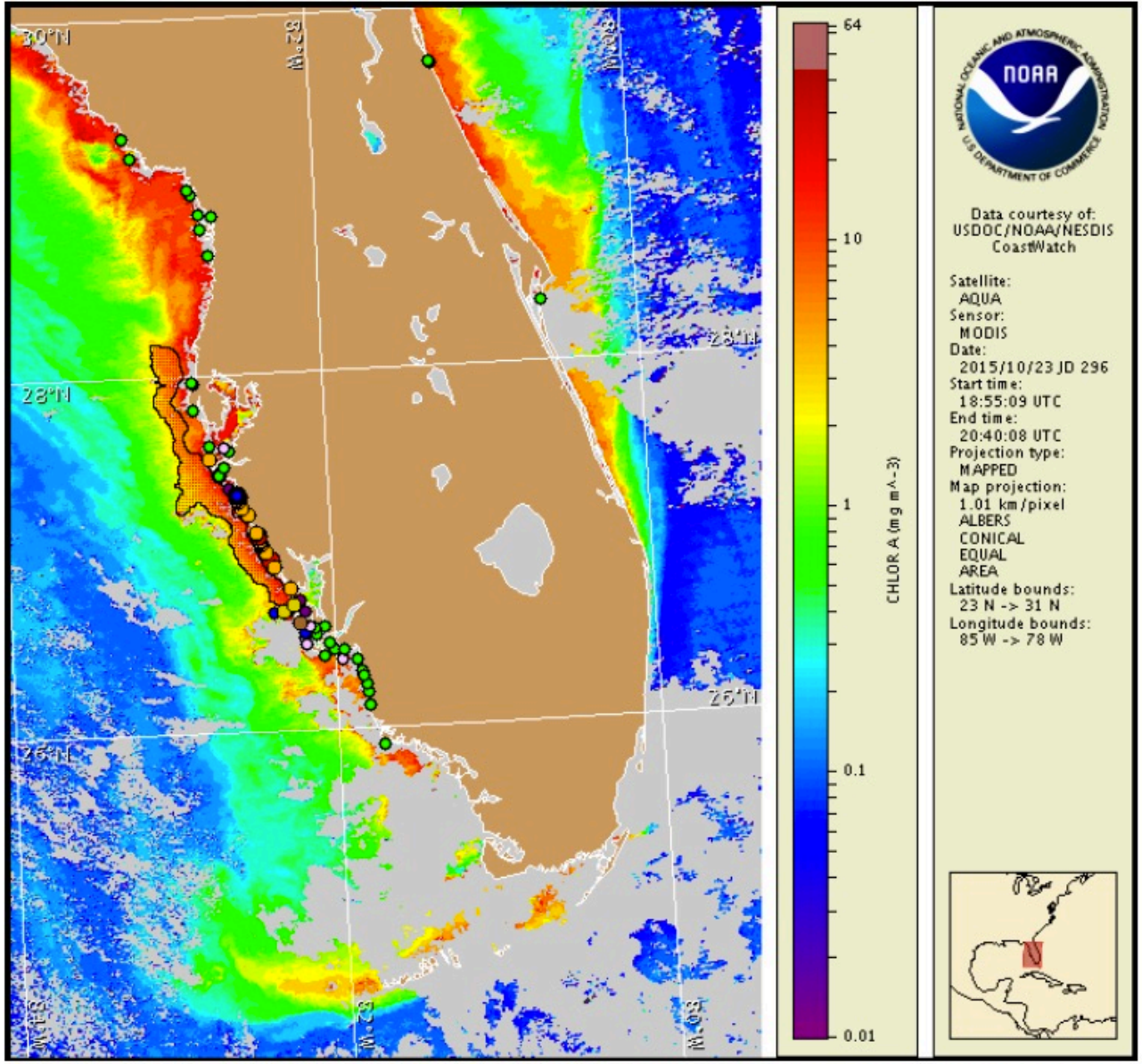
Davis, Yang



Wind speed and direction are averaged over 12 hours from buoy measurements. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts. Wind observation and forecast data provided by NOAA's National Weather Service (NWS).

Wind Analysis

Englewood to Tarpon Springs (Venice): Variable winds (10kn, 5m/s) today. East winds (10kn) Tuesday becoming south to southeast winds (5-10kn, 3-5m/s) Tuesday afternoon through Thursday. South to southwest winds (5kn, 3m/s) Friday.



Satellite chlorophyll image with possible *K. brevis* HAB areas shown by red polygon(s), when applicable. Points represent cell concentration sampling data from October 16 to 23: red (high), orange (medium), yellow (low b), brown (low a), blue (very low b), purple (very low a), pink (present), and green (not present). Cell count data are provided by Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute. For a list of sample providers and a key to the cell concentration categories, please see the HAB-OFS bulletin guide:

Experimental Lake Erie Harmful Algal Bloom Bulletin

National Centers for Coastal Ocean Science and Great Lakes Environmental Research Laboratory

19 September 2014, Bulletin 24

The area of highest concentration remains in the western basin. There is a potential for scum, especially in the area around West Sister Island in the Western Basin.

Strong southwest winds over the weekend will promote mixing as the bloom continues a slight north east transport into Monday.

The imagery shows the persistent bloom in Sandusky Bay is present.
There are no reported harmful algal blooms or suspicious features in the Eastern Basin at this time.

-Dupuy, Stumpf

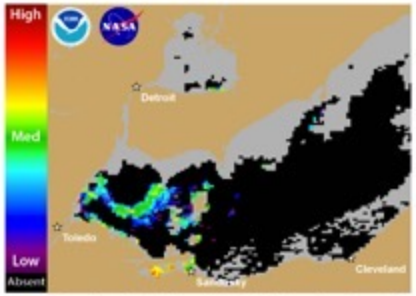


Figure 1. Cyanobacterial Index from NASA's MODIS-Aqua data collected 18 September 2014 at 1:25 pm. Grey indicates clouds or missing data. Black represents no cyanobacteria detected. Colored pixels indicate the presence of cyanobacteria. Cooler colors (blue and purple) indicate low concentrations and warmer colors (red, orange, and yellow) indicate high concentrations. The estimated threshold for cyanobacteria detection is 35,000 cells/mL.

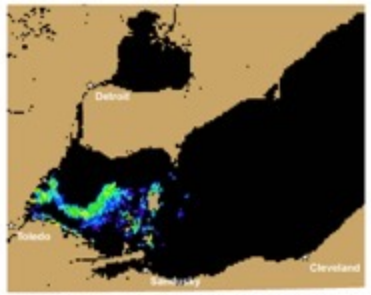


Figure 2. Nowcast position of bloom for 19 September 2014 using GLCFS modeled currents to move the bloom from the 18 September 2014 image.

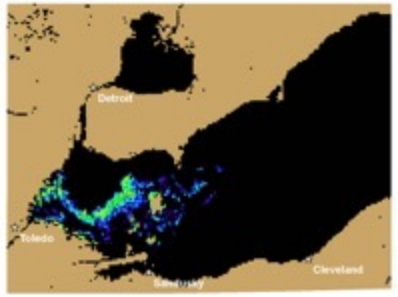
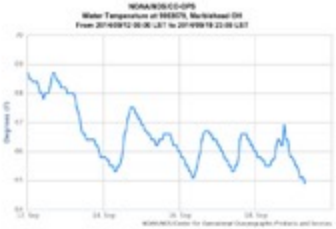


Figure 3. Forecast position of bloom for 22 September 2014 using GLCFS modeled currents to move the bloom from the 18 September 2014 image.

Wind Speed, Gusts and Direction from Marblehead, OH. From: NOAA/Center for Operational Oceanographic Products and Services (CO-OPS). Note: 1 knot = 0.51444 m/s. Blooms mix through the water column at wind speeds greater than 7.7 m/sec (~ 15 knots).

Averaged forecasted currents from Great Lakes Coastal Forecasting System over the next 72 hours.



Water Temperature from Marblehead, OH. From: NOAA/Center for Operational Oceanographic Products and Services (CO-OPS).

Supported by the NASA Applied Sciences Health and Air Quality Program.
Wind forecasts derived from NOAA/National Weather Service in Cleveland.

For more information and to subscribe to this bulletin, go to:
http://www.glerl.noaa.gov/res/waterQuality/?targetTab=habs

Resources

Satellites Help Keep Communities Safe from Toxic Algal Blooms

MOLLIE BLOUDOFF-INDELICATO

That's where satellite technology can make a difference. "I'd love to send my monitoring team to all these lakes, but we have limited resources," says Kate Fickas, an environmental scientist and program coordinator at the Utah Department of Environmental Quality. "Satellites help tell this significant story about how things are changing."

GeoHealth

RESEARCH ARTICLE
10.1029/2020GH000254

Quantifying the Human Health Benefits of Using Satellite Information to Detect Cyanobacterial Harmful Algal Blooms and Manage Recreational Advisories in U.S. Lakes

Signe Stroming[1], Molly Robertson[2], Bethany Mabee[2], Yusuke Kuwayama[2], and Blake Schaeffer[3]

[1]School of Foreign Service, Georgetown University, Washington, DC, USA, [2]Resources for the Future, Washington, DC, USA, [3]Office of Research and Development, United States Environmental Protection Agency, Research Triangle Park NC, USA

Key Points:

- Cyanobacterial harmful algal blooms (cyanoHABs) are a human health risk that is typically mitigated by recreational advisories and warnings
- We present a framework to quantify the socioeconomic benefits of using remote sensing technology to test for the presence of cyanoHABs
- Satellite technology yielded between $55,000 and $1,057,000 in socioeconomic benefits associated with improved human health outcomes

Abstract Significant recent advances in satellite remote sensing allow environmental managers to detect

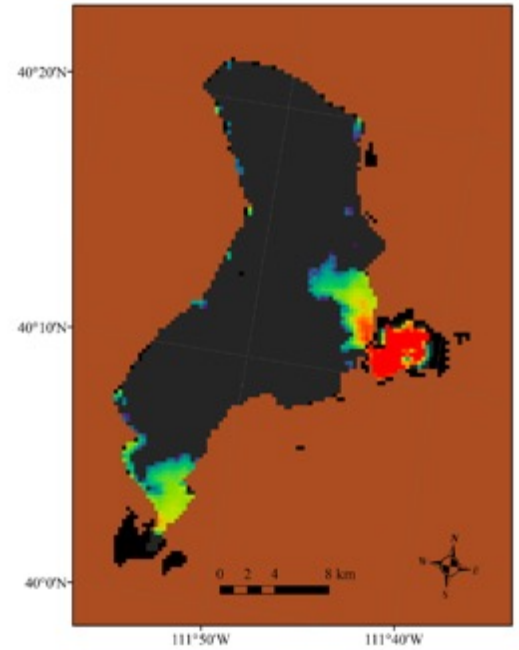


Figure 1. Copernicus Sentinel-3 daily satellite image on 21 June 2017 of Utah Lake, Utah from the CyAN project. Note: Brown pixels are land, gray pixels in the lake indicate no detection of cyanobacteria, black pixels are quality controlled for clouds, straylight, or glint. Cool blue and purple colors are low concentrations of cyanobacterial biomass and warm colors of yellow, orange, and red are elevated concentrations of cyanobacteria.

	Reference Case	Counterfactual Case
INFORMATION	**Satellite data on HABs** In-situ testing by environmental managers User reports of algal blooms	In-situ testing by environmental managers User reports of algal blooms
DECISIONMAKER ACTIONS	Warnings and public advisories Water access closures Actions considered **weekly** or as reported	Warnings and public advisories Water access closures Actions considered **monthly** or as reported
OUTCOMES FOR PEOPLE AND THE ENVIRONMENT	Algal blooms can be detected earlier in some cases, leading to **decreased exposure** and fewer negative health outcomes	Algal blooms that develop in between monthly tests are likely to result in cases of human illness

Table 2
Cost of Illness and Its Determinants in the Reference and Counterfactual Cases

Key figure	Reference case (satellite data)	Counterfactual case (no satellite data)
Time until advisory posting	0 days	7 days
Number of people exposed to cyanoHAB	0 people	8,000 people

INFORMATION

Satellite data from CyAN
In-situ testing by Utah DEQ
User reports of algal blooms

In-situ testing by Utah DEQ
User reports of algal blooms

DECISIONMAKER ACTIONS

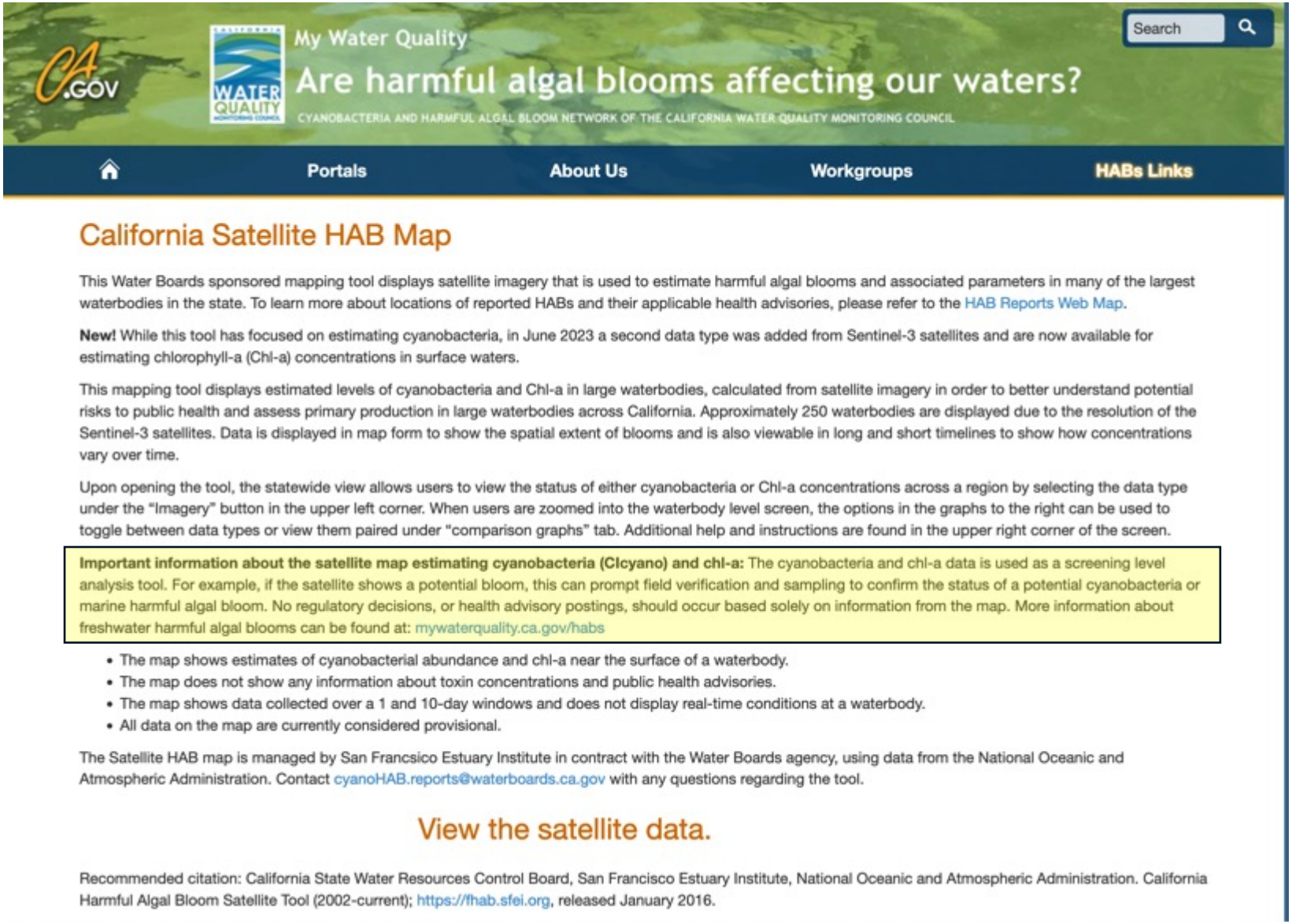
Warnings posted June 29, 2017 informing visitors that lake was unsafe for swimming, boating, or fishing.

Warnings posted when bloom was reported by visitor or after next in-situ test, **7 days** after June 29, 2017

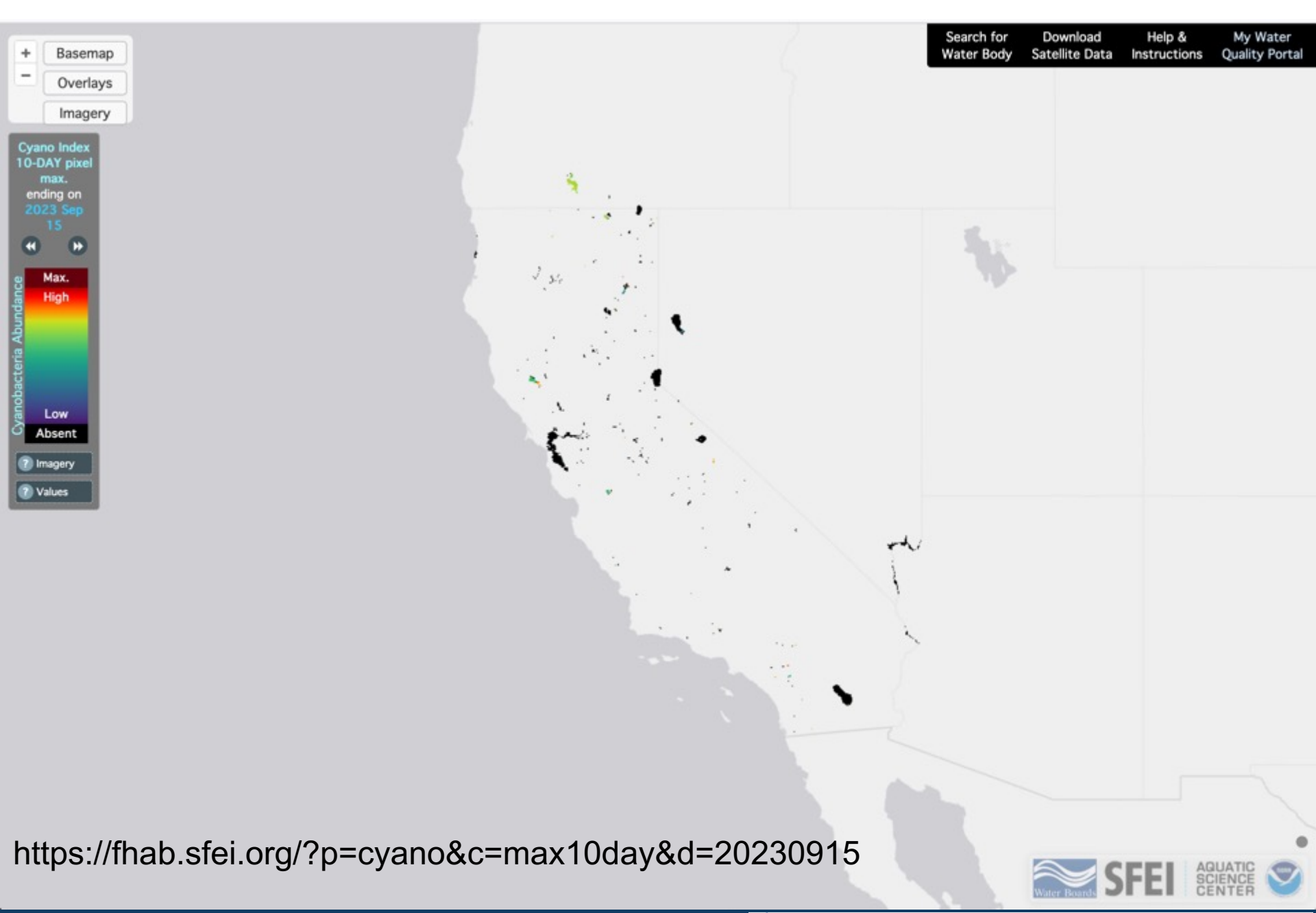
OUTCOMES FOR PEOPLE AND THE ENVIRONMENT

Bloom was detected prior to negative health effects, preventing public exposure to toxins and **avoiding ≈ $370,000 in social costs**

Bloom would be detected after people had been exposed, leading to adverse health effects **≈$370,000 in social costs**



https://www.mywaterquality.ca.gov/habs/where/satellite_map.html



COLUMBIA CLIMATE SCHOOL
LAMONT-DOHERTY EARTH OBSERVATORY

VALUABLES

AN RFF/NASA CONSORTIUM

Valuing Satellite Data for Harmful Algal Bloom Early Warning Systems

Stephen C. Newbold, Sarah Lindley, Shannon Albeke, Joshua Viers, George Parsons, and Robert Johnston

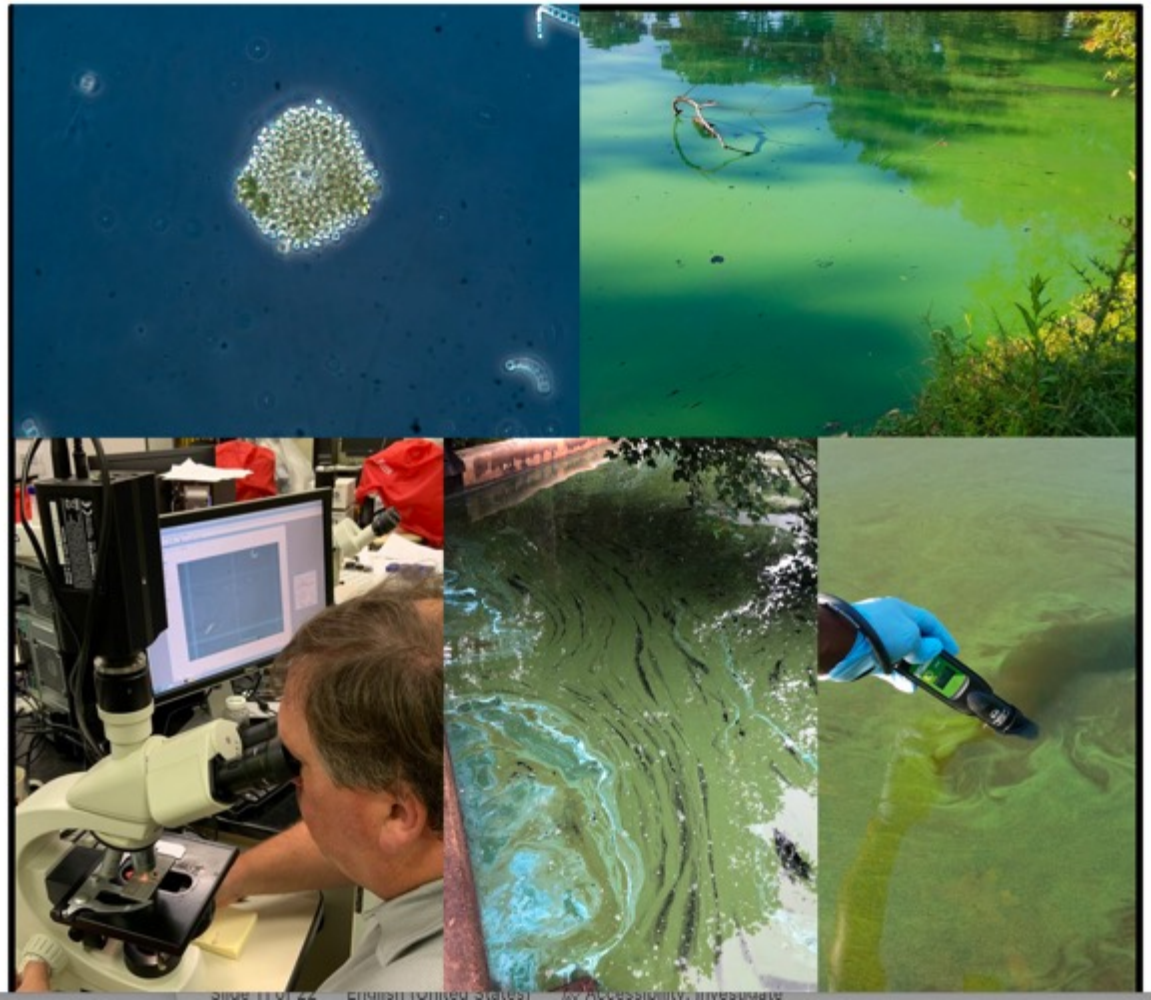
https://media.rff.org/documents/WP_22-23.pdf

	(Reference scenario)	*(Counterfactual scenario)*
INFORMATION	No early warning system in place, recreators' expectations of future HAB occurrences based on average long-run frequencies of previously observed HABs.	Early warning system (e.g., MyWaterQuality Portal) provides near real-time predictions of HABs in major recreational use surface water bodies in California.
DECISIONMAKER ACTIONS	On each outing, recreators choose a water body to visit for boating, fishing, or swimming given knowledge of average long-run frequencies of HABs.	On each outing, recreators choose a water body to visit for boating, fishing, or swimming activities given predictions of HABs by the early warning system.
OUTCOMES FOR PEOPLE AND THE ENVIRONMENT	Relatively low HAB avoidance rate by recreators, relatively high rate of disruption of recreational activities and relatively high rate of exposure to cyanotoxins.	Relatively high HAB avoidance rate by recreators, relatively low rate of disruption of recreational activities and relatively low rate of exposure to cyanotoxins.

- Study looking at visitors to 100 large lakes in California between April – Sept 2019
- Value of complete mitigation: $7.4M
- Value of satellite based early warning system: $2.5M

NJ Department of Environmental Protection
Division of Water Monitoring and Standards
Bureau of Freshwater & Biological Monitoring

2020 Cyanobacterial Harmful Algal Bloom (HAB) Freshwater Recreational Response Strategy



iii. Remote Sensing – Satellite Imagery, Aircraft Flight Reconnaissance and Unmanned Aerial Vehicles (UAVs)

While discrete laboratory analyses (cell identification and enumeration, and toxin analyses) serve as the definitive determination of whether results exceed NJ Health Advisory Guidance levels, remote

sensing data provides useful screening information on the spatial extent and relative cell density a bloom. Remote sensing is also a valuable tool to assess HAB trends (i.e., whether the HAB is increasing or dissipating).

Satellite imagery. Satellite imagery, such as the USEPA's Cyanobacteria Assessment Network Application (CyAN app) https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NERL&dirEntryId=346902. The CyAN app provides weekly satellite data to identify the concentration, location, and time series of cyanobacterial blooms in fresh and coastal waters of the United States. Monitoring this application may be used to inform decisions on staff deployment for other response actions such as field screening and sampling. Due to resolution limitations, satellite imagery is limited to the approximately seven largest lakes in the State (Wanaque Reservoir, Union Lake, Greenwood Lake, Boonton Reservoir, Lake Hopatcong, Lake Tappan, Round Valley Reservoir).

Aircraft Flight Reconnaissance.

The DEP has developed aircraft remote sensing capabilities for general cyanobacteria detection and tracking. A hyper-spectral sensor is used to detect wavelengths of light specific to the cyanobacteria pigment phycocyanin in a waterbody. This advanced monitoring method provides immediate feedback on the presence and relative cyanobacteria cell counts and can serve as a screening method to target waters for sample collection.

Unmanned Aerial Vehicles (UAVs)

DEP is also working on the development and use of UAVs for HAB screening through photography and remote sensing for phycocyanin. UAV surveillance can be used for smaller lakes than the satellite remote sensing.

Harmful Cyanobacterial Bloom (HCB) Action Plan

for Publicly Accessible Waterbodies in Wyoming

Prepared By:
Wyoming Department of Environmental Quality
in cooperation with:
Wyoming Department of Health
Wyoming Livestock Board

Resource constraints may limit the number of lakes and reservoirs that can be inspected by resource management agencies on a routine basis and the public may not consistently report suspected blooms. As such, WDEQ will use Cyanobacteria Assessment Network (CyAN) satellite imagery that detects HCBs due to the unique spectral signature of cyanobacteria. For lakes and reservoirs to be considered resolvable by CyAN, they must meet a minimum size requirement (>900 meters). This results in 40 lakes and reservoirs that can be monitored remotely by WDEQ. WDEQ will analyze imagery for these water bodies using screening metrics that determine the areal extent of blooms, cyanobacteria cell density and bloom persistence over time. WDEQ may also use CyAN imagery and other remote sensing platforms to determine if smaller lakes and reservoirs should be investigated.

Harmful Cyanobacterial Bloom Action Plan – 2021
Wyoming Department of Environmental Quality
Page 7

State of Oregon
DEQ Department of Environmental Quality

Satellite Estimates of Cyanobacteria in Oregon Lakes and Reservoirs

Reporting Period: Nov. 6, 2023 - Nov. 12, 2023

Introduction

This report provides an update to estimates of cyanobacteria abundance derived from satellite imagery for 49 large Oregon waterbodies. Updates are scheduled to occur weekly from March to October each year. Estimates derive from the Cyanobacteria Assessment Network (CyAN) project. Three levels illustrate cyanobacteria abundance (cells/mL): Low: <20,000, Moderate: 20,000-100,000, and High: >100,000. The levels correspond to the World Health Organization (WHO) exposure guideline values (WHO, 2003). For more information on Harmful Algal Blooms in Oregon, please visit websites from the Oregon DEQ and the Oregon Health Authority.

All data presented in this report are provisional and subject to change. Estimates of cyanobacteria from satellite imagery do not imply the presence of cyanotoxins or other water quality impairments and do not have regulatory implications. **Visit the Oregon Health Authority to learn about recreational use and drinking water advisories related to cyanobacteria blooms.** Additional assessments with imagery from the Sentinel 2 Satellites, local visual assessment, and/or water quality sampling are needed to provide additional information on potential human health and environmental effects of cyanobacteria. Please note that estimates of cyanobacteria abundance presented in this report may be skewed by cloud cover, ice cover, sun glint, water surface roughness, dry lake beds, algal mats, and shoreline effects.

Highlighted Waterbodies

Waterbodies with high cyanobacteria abundance (>100,000 cells/mL) based on the average of daily maximum estimates during the 7-day reporting period (7DADM).

Reporting Period: Nov. 6, 2023 - Nov. 12, 2023

Search:

Waterbody_GNISID*	Basin	7DADM (cells/mL)	Days of Data

https://rstudioconnect.deq.state.or.us/Oregon-cyanobacteria-satellite-report/

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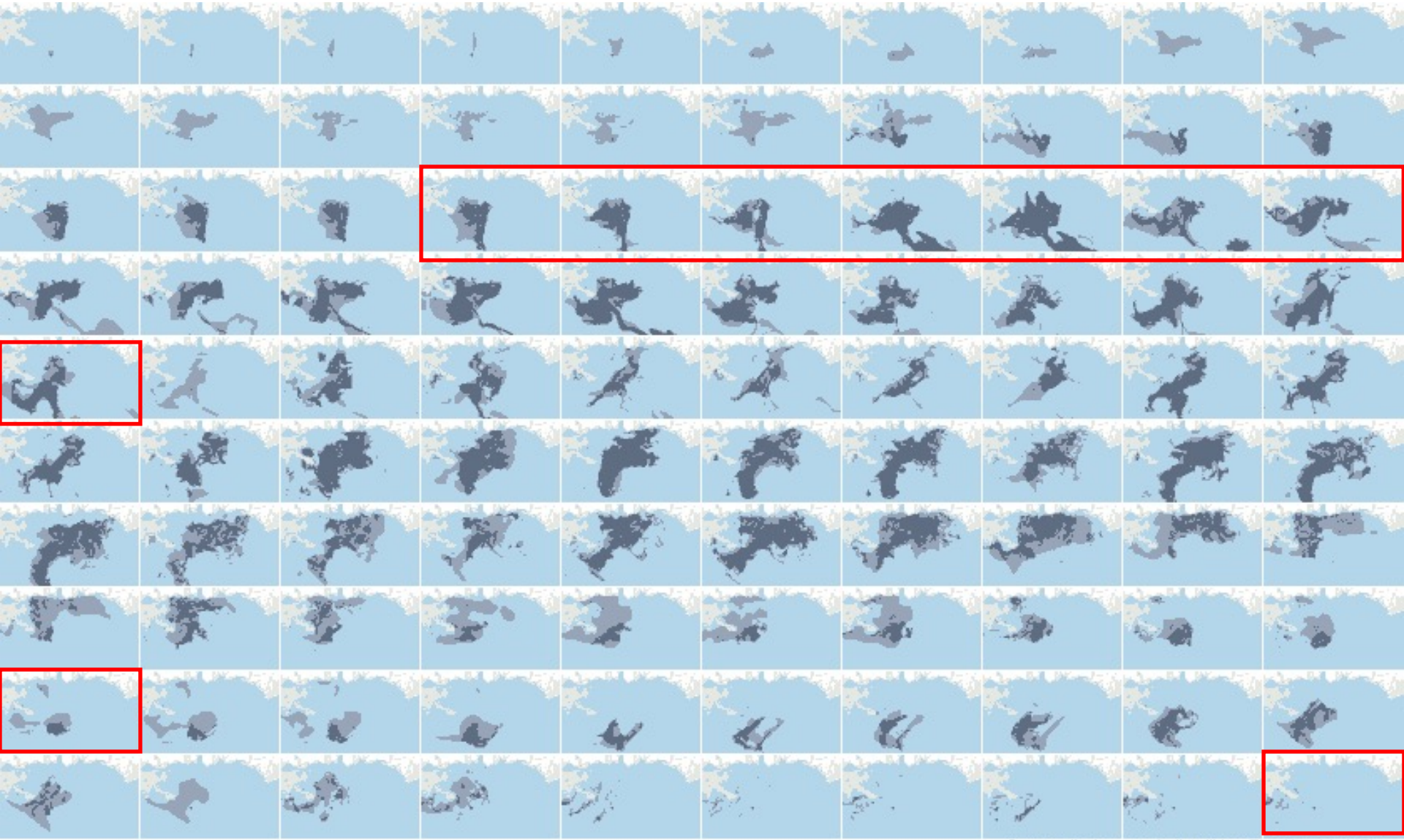
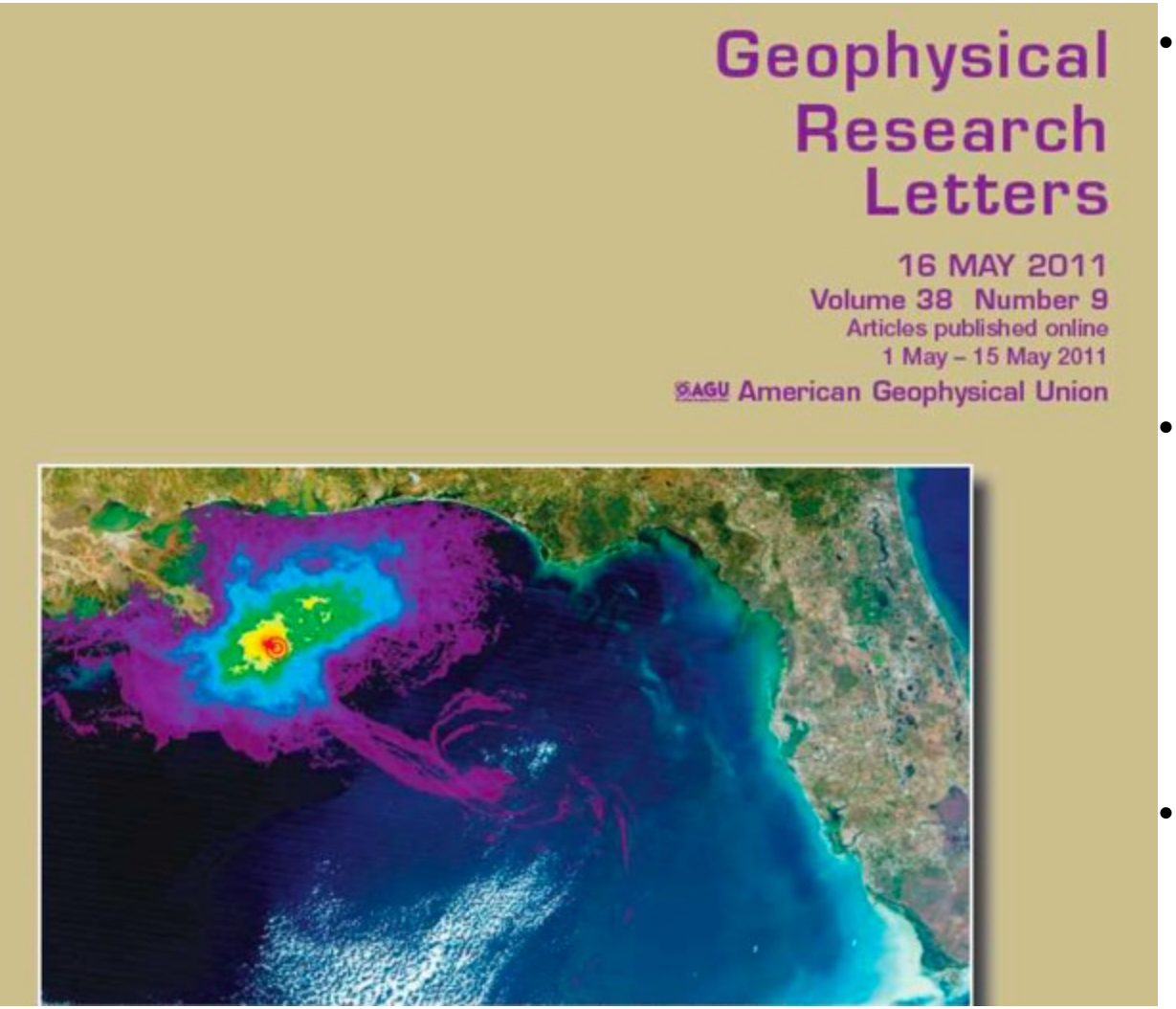


Composite image of oil spill by The New York Times



- Despite challenged due to cloud cover, Ocean color was more useful for daily mapping of the slick extent than SAR for mapping the oil slick because of revisit and swath width issues
- Maps were used for putting out fishing alerts/determining ”no fish zones” and for determining thickness of the oil for prioritizing clean up operations
- Dollar/avoidance costs not known

FORBES >

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Seascape: the state of our oceans

The creeping threat of the Great Atlantic Sargassum Belt

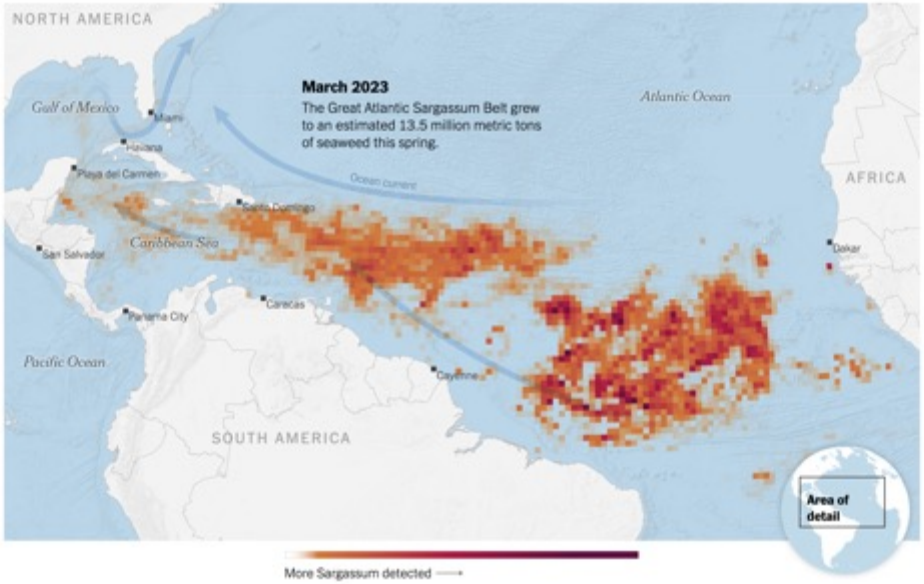
OL
SERVATORY

The New York Times

Those Seaweed Blobs Headed for Florida? See How Big They Are.

By Elena Shao April 19, 2023

Scientists say they spotted more than 13 million tons of Sargassum, a yellowish-brown seaweed, drifting in the Atlantic Ocean last month — a record for the month of March.



Here's what the so-called belt of Sargassum, which can stretch thousands of miles from the western coast of Africa to the Gulf of Mexico, usually looks like in March:

Residents of coastal towns face a daunting task to try to clear the mounds of *Sargassum* by hand.

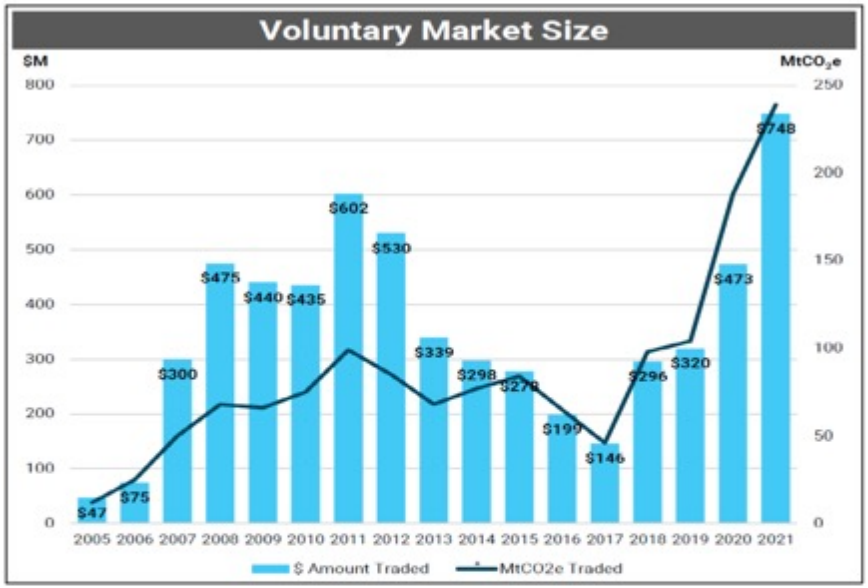
(Credit: Getty Images).

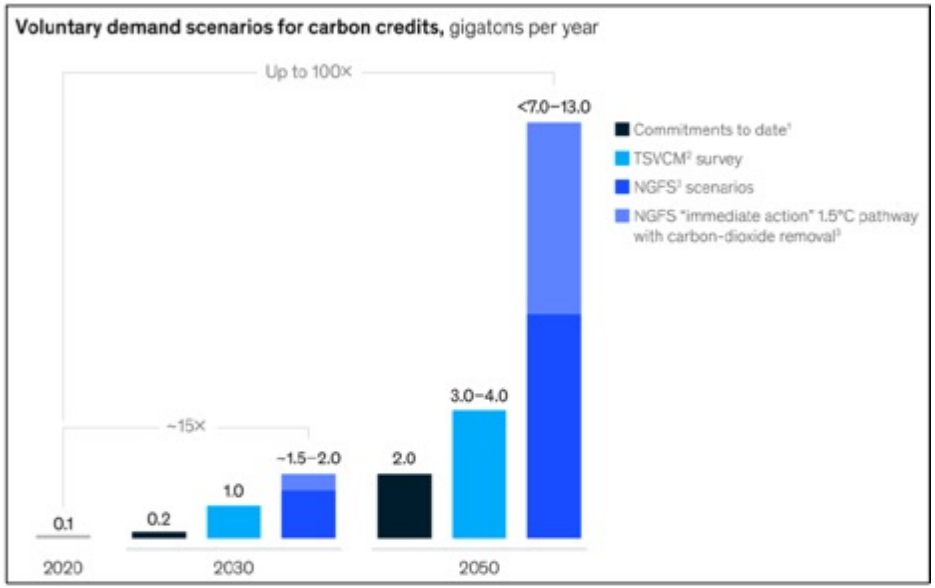
A tractor plows seaweed that washed ashore into the beach sand on March 16, 2023, in Fort Lauderdale, Florida. (Joe Raedle)

It costs $500/day to rent a truck for hauling away Sargassum
So $300-600K per year just for renting trucks

How is the IOCCG community going to play in the mCDR space?

Voluntary Carbon Market (VCM) Forecasts





VCM trade value reached **$1.4B** in **May 2022** after exceeding **$1B** in **September 2021**.**

VCM may be worth **$30-$50B by 2030** (high-end estimate by McKinsey).*

McKinsey & Company

arpa·e CHANGING WHAT'S POSSIBLE

Graphic 1: "Carbon Pricing for ARPA-E Programming." Grant Opperman, August 2022.
*Graphic 2: https://www.mckinsey.com/business-functions/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge
**https://cleanenergynews.ihsmarkit.com/research-analysis/recordhigh-price-forecasts-across-global-carbon-markets-and-st.html

28

COLUMBIA CLIMATE SCHOOL
LAMONT-DOHERTY EARTH OBSERVATORY

What is the cost of asking Ajit to give a talk?

- While it is understandable that space agencies are tied to missions, is the IOCCG community neglecting methods other than large missions?
- Are we thinking of products at the human scale that is useful to a local water district?

Thank you Blake, Rick, and especially Chuanmin

Global Distribution of Phytoplankton Biomass – from Satellite