Applying novel techniques to assess and forecast harmful algal blooms in

CHESAPEAKE BAY

to protect fisheries, aquaculture and human health

2023 WORKSHOP REPORT

Sea Grant National Florida Maryland

FOR MORE INFORMATION

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CHESAPEAKE BAY WORKSHOP REPORT

ACRONYMS USED

CBEFS - Chesapeake Bay Environmental Forecast System
CBP – Chesapeake Bay Program
CDOM – Colored dissolved organic matter
Chl-a – Chlorophyll-a
DNR – Maryland's Department of Naturl Resources
ELISA – Enzyme-linked immunosorbent assay
GCOOS – Gulf of Mexico Coastal Ocean Observing System
HAB – Harmful algal bloom
HAB-FB – Harmful Algal Bloom - Forecasting Branch
IFCB – Imaging Flow Cytobot
IOOS – Integrated Ocean Observing System
MARACOOS – Mid-Atlantic Regional Association Coastal Ocean Observing System
MCI – Maximum Chlorophyll Index
MDE – Maryland Department of Environment
MDH – Maryland Department of Health and Mental Hygiene
MSI – MultiSpectral Instrument
NCCOS – National Centers for Coastal Ocean Science
NHABON – National HAB Observing Network
NIR – Near infrared
NOAA – National Oceanic and Atmospheric Administration
PMN – Phytoplankton Monitoring Network
OLCI – Ocean and Land Colour Instrument
RE10 – Red Edge 2010
RGB – Red, Green, Blue
RS – Remote sensing
SCCOOS – Southern California Coastal Ocean Observing System
SOP – Standard operating procedures
UMCES - University of Maryland Center for Environmental Science
USGS – United States Geological Survey
VDH – Virginia Department of Health
VIMS – Virginia Institute of Marine Science
VMRC – Virginia Marine Resources Commission

INTRODUCTION

This report highlights the findings of the *Applying novel techniques to assess and forecast HABs in Chesapeake Bay to protect fisheries, aquaculture and human health* workshop held over two half-days, on January 18 and 19, 2023 at Virginia Institute of Marine Science (VIMS), in Gloucester Point, Virginia. The workshop, organized by Sea Grant, with steering committee support, sought to assess Harmful Algal Blooms (HABs) and Cyanobacterial Harmful Algal Bloom (CyanoHABs) forecasting opportunities & limitations at scales needed for resource management & industry business practices, and brought together agency, industry, and academic experts to discuss this topic. The workshop was supported by the National Oceanic and Atmospheric Administration's (NOAA) National Sea Grant College Program and National Centers for Coastal Ocean Science, along with Maryland Sea Grant and Florida Sea Grant.

Forty-one participants from state agencies, nonprofit organizations, academic institutions, extension, aquaculture, charter boat operations, and the recreational fishing community attended the workshop, allowing for a diverse and comprehensive assessment of forecasting needs and opportunities. The objectives of the workshop were as follows:

- To understand how HABs affect the operations of aquaculture, recreational fishing & other water dependent users.
- To understand the HAB spatial information & forecasting needs of resource managers (and areas of synergy w/ researchers).
- To learn about potential forecast data products & how output could be used (capabilities & limitations).
- To compile information on potential uses of (satellite imagery & forecasting) tools and products.
- To assess current monitoring and observing efforts that could lead to the development of a forecast and identify gaps.

The Chesapeake Bay estuary is an economically and ecologically important natural resource. The largest estuary in the United States and one of the largest estuaries in the world, the Chesapeake Bay receives approximately half of its freshwater from the Susquehanna River, at the head of the bay, and the rest from numerous smaller tributaries that flow into the bay. (Levinson et al., 1998).

The majority of Chesapeake Bay lies within Maryland and Virginia – although tidal waters include the District of Columbia and Delaware – and its 166,000 km2 watershed extends into three additional states (West Virginia, Pennsylvania, and New York).

Economic benefits derived from the Bay's natural resources have been valued at more than $100 billion annually (CBF, 2014). The Bay supports economically important fisheries and a vital tourism industry (Klemick et al., 2018). However, it has experienced significant symptoms of eutrophication in the last century (Kemp et al., 2005).

Over 1400 phytoplankton and cyanobacteria species have been identified for Chesapeake Bay; numerous potentially harmful algal and cyanobacteria bloom forming species occur (Marshall 1996, Marshall et al. 2005, Tango and Butler 2008). HABs and CyanoHABs are often associated with the rapid and substantial increase in biomass in aquatic systems that result in harm. HABs in Chesapeake Bay are fueled primarily by excess nutrients (Brush, 2009).

Exposure to toxins associated with HABs and CyanoHABs may be hazardous for humans, pets, and wildlife, leading to economic losses in recreation and tourism (e.g., Rattner et al. 2022). HABs can also affect the health of recreational and commercial fisheries in addition to seafood grown in aquaculture operations.

Within NOAA's National Centers for Coastal Ocean Science (NCCOS), the Harmful Algal Bloom - Forecasting Branch (HAB-FB) is a research group whose mission is to develop HAB monitoring and forecasting tools and to deliver near real-time forecasting products to project the location, intensity, severity, and duration of HABs and CyanoHABs around the United States. Recognizing that every region is different – the species, the oceanography, the dynamics, etc. – each forecast is tailored to individual regions, and the specific needs of the region.

In the interest of improving HAB monitoring with satellite data products and forecasting tools in the Chesapeake Bay, and to assist NCCOS in obtaining broad stakeholder input regarding needs and potential applications, the workshop summarized here was developed (See agenda with links to presentations in Appendix A).

WORKSHOP PROCESS

The workshop was planned by a steering committee led by NOAA Sea Grant. The steering committee met monthly to formulate the workshop process, content, speakers, and participants. To facilitate development of the workshop content and process, two needs assessments – one targeting industry and a second targeting the broader scientific community were implemented. The surveys sought to determine respondents understanding of HABs, how HABs affect professional roles and business practices, knowledge about and needs for satellite and forecasting tools and products, and current and preferred communication modes and formats.

Both survey instruments were reviewed by the University of Florida's Institutional Review Board (IRB202201559) and distributed via email to targeted individuals in the Chesapeake Bay region.

Results of the survey (see Appendix B) helped guide the development of an agenda that included a mix of presentations, panel discussions, open forum discussions, and demonstrations. Workshop participants were invited based on their role or interest in HABs. And, although attendees were encouraged to attend in-person, virtual accommodations were made for those invitees who would otherwise have not been able to attend.

OVERVIEW OF HAB ASSESSMENT & FORECASTING TOOLS & PRODUCTS

SATELLITE BACKGROUND

To give attendees an introduction to remote sensing technologies currently being used by NOAA, Dr. Richard Stumpf, NCCOS HAB-FB presented on current satellite detection technologies, advances in algorithm development supporting image interpretation over the last several years, and spatial, spectral, and temporal limitations associated with satellite detection of HABs.

Existing ocean color satellites retrieve water-leaving radiances at several wavelengths in the visible range of the color spectrum. Several different satellites can detect HABs in fresh and salt water but there are tradeoffs in spatial, temporal, and spectral resolutions among the satellites (see table 1).

TABLE 1. Satellite comparisons for bloom applications. *Spatial scale refers to individual pixel size. Temporal resolution denotes image frequency. Key spectral bands indicate the number of suitable bands for bloom applications. Color scale is green=good, yellow=okay, orange=marginal and red=poor. Source Richard Stumpf*

Good Okay Marginal Poor *Near Infrared

Satellite	Spatial Scale	Temporal Resolution	Key Spectral Bands
Sentinel-3 OLCI	300 m2	5-6 per week (2 satellites)	10 (5 on red edge)
MODIS high res	250/500 m2	1 every 1-2 days	4 (1 red, 1 NIR1*)
MODIS low res	1 km2	1 every 1-2 days	7-8 (2 in red edge)
Landsat	30 m2	1 each 8- or 16-days	4 (1 red, 1 NIR1*)
Sentinel-2a & 2b MSI	20 m2	1 every 5 days per 2 satellites	5 (1 red; 2 NIR1*, 1 in red edge)

Current efforts to monitor and detect HABs with ocean color sensors include use of sensors such as the Ocean and Land Colour Instrument (OLCI) aboard Sentinel-3 that has a 300 m-pixel resolution. Sentinel-2 MultiSpectral Instrument (MSI) is also being explored for shorelines and narrow tributaries. Sentinel-2 has a lower temporal and spectral resolution but a significantly higher spatial resolution of 20-meters.

Chesapeake Bay is optically complex due to the diversity of phytoplankton assemblages along with the influences of river run-off which often contain terrestrial suspended particulates or colored dissolved organic matter (CDOM). Satellite measurements of chlorophyll-a (Chl-a), phycocyanin and fluorescence are helpful for determining the presence of blooms. Wavelengths and algorithms that are most sensitive to the targeted pigments, and least sensitive to sediments, CDOM, and the bottom are used. These include:

- **a)** Cyanobacteria Index: the relative abundance of cyanobacteria biomass as determined by the cyanobacteria index algorithm developed by Wynne et al. (2008). The cyanobacteria index is helpful for bloom detection in the upper areas of Chesapeake Bay.
- **b)** Chlorophyll-a (RE10): Chl-a concentration determined by a near-Infrared to red ratio as described by Gilerson et al. (2010). This is the most used algorithm in Chesapeake Bay.
- **c)** Low fluorescing Algae: the relative abundance of phytoplankton which are low or non-fluorescing and do not contain phycocyanin (non-cyanobacteria) tends to highlight dinoflagellate blooms of several harmful species.
- **d)** Maximum Chlorophyll Index (MCI): The Maximum Chlorophyll Index (MCI) detects high biomass blooms and shows relative density patches of Chl-a, as developed by Gower et al. (1999, 2005). MCI applied to higher resolution Sentinel 2 imagery, may to help resolve harmful cyanobacteria blooms in smaller systems.
- **e)** True Color: A Red, Green, Blue (RGB) composite image. Relative Fluorescence: the relative chlorophyll fluorescence representative of chlorophyll concentration for high biomass blooms, determined by the Red-Band Difference developed by Amin et al. (2009). In Chesapeake Bay, this algorithm is useful in delineating high biomass blooms such as many potentially toxic dinoflagellates.
- **f)** Relative Fluorescence: the relative chlorophyll fluorescence representative of chlorophyll concentration for high biomass blooms, determined by the Red-Band Difference developed by Amin et al. (2009). In Chesapeake Bay, this algorithm is useful in delineating high biomass blooms characteristic of many potentially toxic dinoflagellates.

See HAB-FB Ocean Color Satellite Imagery Processing Guidelines for additional information.

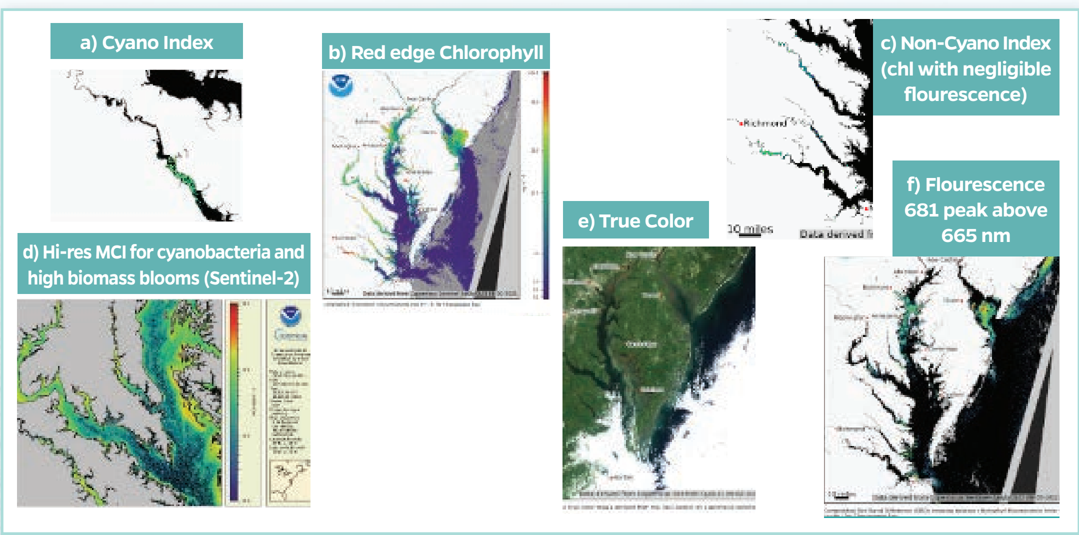


FIGURE 1. *Several algorithms (a-f) are applied for Chlorophyll a, using a ratio of NIR to Red bands, which is less influenced by sediment and CDOM in coastal areas. Image letters (a-f) correspond to the wavelengths and algorithms described above. Image credit NCCOS. Imagery derived from Copernicus Sentinel data from EUMETSAT. See: https://coastwatch.noaa.gov/cw_html/NCCOS.html*

Bloom definitions for algae often cover a range of 10-100 micrograms per liter (μg/L) where >100 μg/L may be considered exceptional blooms. Bloom thresholds frequently above 10 μg/L have been proposed for numerical criteria in support of water quality standards attainment assessments in Chesapeake Bay (Harding et al. 2015). Therefore, bloom detection for management purposes should frequently be useful when effectively characterizing concentrations of >10 μg/L, however, lower-level detections should enhance bloom detection across all salinity zones and for diverse ecosystem protections highlighted in Harding et al. (2015). Satellite methods currently used can detect blooms >10 μg/L, but new algorithms may allow for detection down to 2 or 3 μg/L. NCCOS HAB-FB is currently conducting research in this area.

There are several limitations that must be considered when using satellites for ocean color applications. Land, via satellite imagery, is very bright compared to water. Mixed pixels, where the shoreline goes through a pixel, will overwhelm what is coming off the water. As a result, these pixels must be omitted. Additionally, satellites cannot see through clouds, so on cloudy days, a significant amount of data may be lost. Satellites can detect variations in chlorophyll to about one Secchi depth, which is about 1.5m dependent upon season and bay location (Harding et al. 2019). Consequently, satellite imagery is not useful for tracking sub-surface blooms or low concentrations at the surface.

The limited spectral resolution of existing ocean color measurements also cannot be used to discriminate algal species. Current algorithms and a trained eye can discern between cyanobacteria, dinoflagellate, and diatom taxa. Species may often be inferred by ecological relationships such as specific environmental or seasonal conditions that favor the growth of certain algal and cyanobacterial species of concern (e.g., *Alexandrium monilatum, Karlodinium venificum, Margalefidinium* (formerly *Cochlodinium) polykrikoides, Microcystis aeruginosa, Prorocentrum minimum*), but validation via field sampling and taxonomic identification is required.

CURRENT SATELLITE USE IN CHESAPEAKE BAY

To get participants thinking about how satellite imagery could be used for decision-making, Dr. Peter Tango, Chesapeake Bay Monitoring Coordinator with the United States Geological Survey (USGS), offered a glimpse into the satellite imagery applications of the Chesapeake Bay Program (CBP). The CBP is a partnership across the Bay's political boundaries which establishes goals and outcomes for the restoration of the Bay, its tributaries and the lands that surround them (Chesapeake Bay Watershed Agreement 2014).

By linking different technologies such as fixed wing aircraft and drones with satellite imagery and *in situ* samples, the CBP can assess management actions and episodic events, and through a collaboration among industry and agencies, the Chesapeake Bay watershed now has the highest resolution land change assessment in the nation at a 1-meter scale. At this scale managers can see small changes on the landscape, such as changes in impervious surfaces, and link that to impacts in adjacent water quality, brook trout, or even bugs on the water. As such, when thinking about the types of products and overall utility of satellite imagery, scale, and location are important, regardless of whether one is looking at the land or water.

Different scales of information, both in space and time, are critical when thinking about research to application. For instance, submerged aquatic vegetation is one of the quintessential indicators of water quality in the bay. VIMS organized the first aerial assessment of SAV in the 1970s and an assessment has been conducted consistently since the CBP began in 1984. There are tradeoffs when using aerial imagery due to the amount of time it takes to piece together and evaluate the imagery. As such, multiple surveys, even at select locations, throughout the year is not possible without sacrificing the ability to conduct a single survey of the entire bay. Satellite imagery may do a better job of looking over large scales, providing data not only during the season of greatest interest, but throughout the year to observe changes in species and changes in coverage across seasons, neither of which are well understood.

One impact that affects the CBP work, and its understanding of bay processes is temperature change. Researchers at University of Maryland Center for Environmental Science (UMCES) and some of the NOAA products are tracking temperature changes through time with Satellite Imagery. The use of satellite allows the Bay Program to look at the scales that *in situ* monitoring cannot provide.

Another area of interest for the CBP is in evaluating if satellite can be used for bay-wide water quality assessments, and how to get the resolutions in the timeframe that are important for managers. The CBP recognizes the potential for integrating the multiple uses of high-resolution imagery into its programs – assessing SAV coverage, shoreline structures, the state water quality criteria assessments, and aquaculture site evaluations and permitting mentioned during the panel discussion, to name a few.

A final tool example used by the Bay Program is the NOAA Sea Nettle forecast system that is built on sea surface temperatures and salinity. Sea nettles have a very narrow salinity and temperature range. By mapping the entire bay region, it is possible to see where sea nettles would likely congregate. Knowing where and when to expect sea nettles can help swimmers and waders avoid a stinging encounter. A sea nettle forecast may also provide an early warning to water treatment operators who are impacted by this biotic nuisance when they aggregate at water intakes.

FORECASTING HABS AT NOAA

Michelle Tomlinson, NCCOS HAB-FB introduced HAB forecasting, and using case studies from around the United States, showcased a suite of regionally specific forecasting products.

There are generally three components to forecasts. If remote sensing is suitable, it is used to initiate models or show where algal cells are located. A hydrodynamic model is then used to move the cells via currents and winds. The final component is validation, which relies on monitoring data collected by state agencies and other groups. Across the country there are several bloom forecasting methods employed with each method tailored to decision-making needs and species of interest.

California Case Study – In California, blooms of *Pseudo-nitzschia* sp. can be very toxic at low concentrations making satellite inappropriate for bloom detection. *Pseudo-nitzschia* sp. produces domoic acid which can sicken or kill marine mammals and seabirds. Toxins can also affect humans, causing amnesiac shellfish poisoning if shellfish contaminated with toxins are consumed. A model developed by the Southern California Coastal Ocean Observing System (SCCOOS) in collaboration with the NCCOS HAB-FB and others within NOAA tries to predict domoic acid concentrations/levels along the coast. The bloom is forecasted using a series of satellite-derived products (reflectances, chl-a, salinity, and temperature), relationships established through logistic regression approaches, combined with a hydrodynamic model. The online forecast shows the oceanography, cell density, and predicted toxin levels.

Pacific Northwest Case Study – Like California, Oregon and Washington State also experience blooms of *Pseudo-nitzschia* sp. *Pseudo-nitzschia* sp. in the Pacific northwest is a concern due to the razor clam fishery, which is important commercially, recreationally, and as a subsistence fishery. Unfortunately, in this region blooms of *Pseudo-nitzschia* sp. are highly toxic at low concentrations, therefore ocean color imagery is not as useful. A hydrodynamic forecast model is combined with beach sampling for toxins and looks at the trends in toxicity at the shellfish beds. This forecast is compiled into an emailed HAB bulletin. The bulletin provides information to managers in both states that aids them in determining when to open and close shellfisheries, thus helping to protect the health of harvesters and consumers in the region (NOAA n.d.).

Gulf of Maine Case Study – *Alexandrium catenella* is another HAB that is extremely toxic at very low levels. *A. catenella* causes paralytic shellfish poisoning and can result in paralysis and death in humans if toxic shellfish are consumed. Due to regulatory measures, shellfish poisonings are not occurring, but the economic consequence of closing the shellfish fishery during HAB events is significant. A 3-4-day forecast shows where the bloom is headed around the coast and a second forecast predicts what the bloom season will look like (see Gulf of Maine predictive models). The seasonal forecast is a coupled biophysical approach. A NOAA cruise collects cysts from the sediments. Research has shown that the cysts from the year before, affect the initiation of the bloom the next year. A biophysical model grows, and transports mapped cysts along the coast. The hydrodynamic model output has helped to reduce miscommunications that led to consumers avoiding shellfish and aids resource managers in budget planning.

Gulf of Mexico Case Study – *Karenia brevis* produces brevetoxins which cause neurologic shellfish poisoning if shellfish are consumed. *K. brevis* can also cause respiratory irritation when cells become aerosolized due to waves and wind action near the shore. Persons exposed to aerosolized toxins may temporarily have a scratchy throat or cough, but for individuals with underlying lung conditions, aerosolized toxins can lead to serious respiratory distress. A respiratory forecast was developed in collaboration with the Gulf of Mexico Coastal Ocean Observing System (GCOOS) which predicts the location along the coast of possible respiratory irritation and forecasts respiratory irritation out every three-hours. The respiratory forecast incorporates cell counts and a wind model which predicts if the blooms will intensify along the coast at specific beach locations.

Lake Erie Case Study – Similar to the Gulf of Maine, a seasonal forecast system was developed for cyanobacteria in Lake Erie. This forecast predicts how bad the bloom is going to be based on the previous year using phosphorus data provided by Heidelberg University. Additionally, once a bloom is detected with satellite, a hydrodynamic model developed by the Great Lakes Environment

W. VOGELBEIN/VIMS.

Research Lab, is used to move the cells around and predict short-term movement. Although freshwater cyanobacteria are not as big a concern in Chesapeake Bay proper, cyanotoxins are showing up in shellfish in some of the tributary areas.

Chesapeake Bay Current Forecast Efforts – In the Chesapeake Bay, NCCOS HAB-FB are working on a project in Virginia, to predict *Margalefidinium polykrikoides* and *Alexandrium monilatum*. These very colorful blooms occur in the York, the Rappahannock, and the James Rivers, and are an issue for larval stages of shellfish. A NCCOS HAB-FB postdoc is currently working on a time dependent model to predict the start of the bloom. This model is looking at the oceanography, solar radiation, and river flushing to try and better predict the timing of these blooms, with a goal of being able to provide enough warning for mitigation measures to be implemented.

A second project seeks to scale up a 3-dimensional biophysical model developed by Xiong et al., 2023, which incorporates satellite data from NCCOS HAB-FB to initiate the model, and a hydrodynamic model moves the blooms around (figure 2). Xiong tested the model retrospectively for *M. polykrikoides* for 2020. NCCOS HAB-FB is working to advance this into a more predictive model.

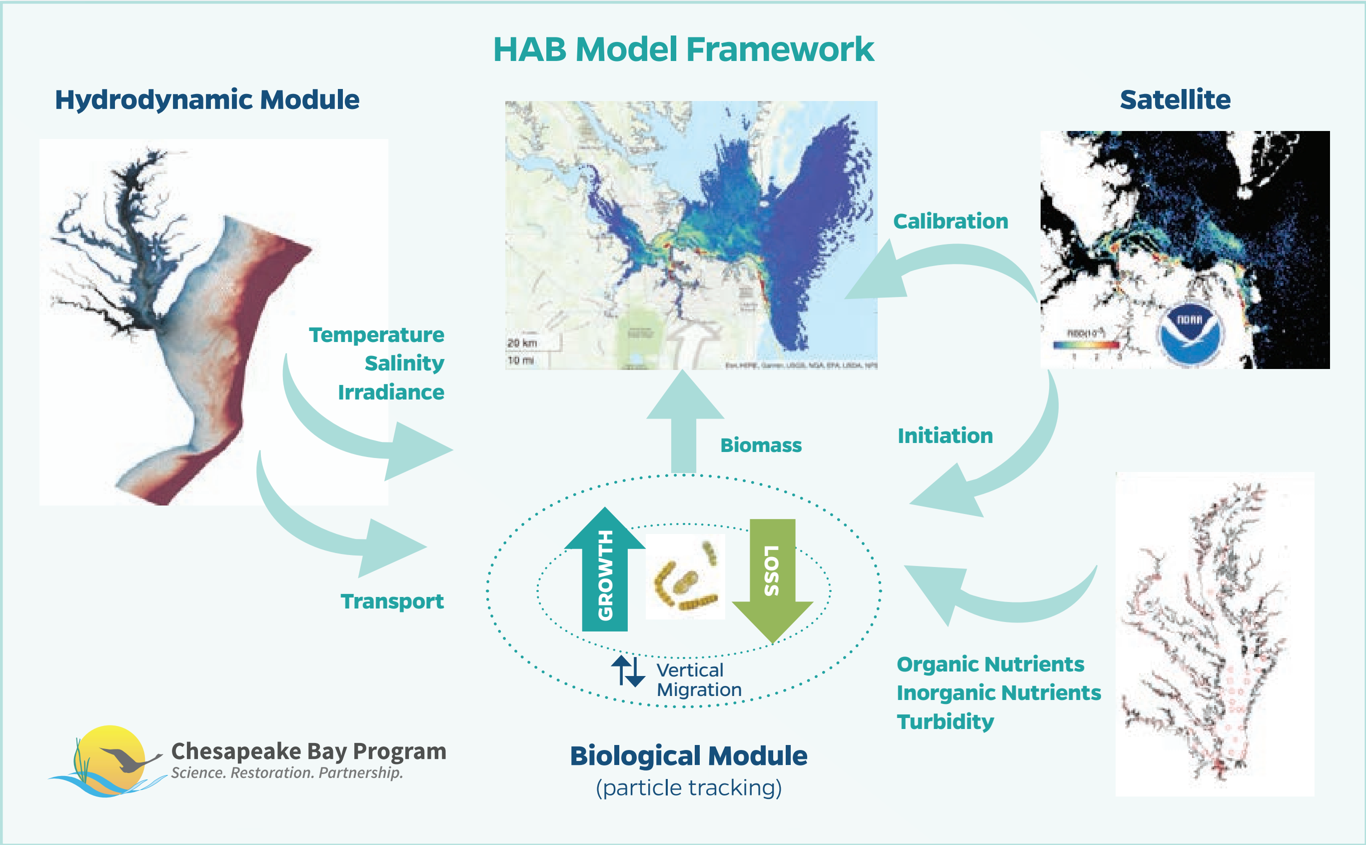


FIGURE 2. *Three-dimensional biophysical model for tracking the progression of harmful algal blooms in Chesapeake Bay: A novel Lagrangian particle tracking model with mixotrophic growth and vertical migration. Source Xiong et al., 2023.*

ADDITIONAL HAB FORECASTING PRODUCTS UNDER DEVELOPMENT

Dr. Marjy Friedrich, VIMS and her research team are also working on a General Additive Model (GAM) for forecasting several HAB species. Currently they have a *Prorocentrum minimum* model that is added to the Chesapeake Bay Environmental Forecast System (CBEFS) modeling environment. Marjy gave a demonstration of this machine-learning based model on day two of the workshop. The model relates water temperature, water pH and salinity, and the total organic nitrogen in the water to the percent probability of encountering *P. minimum.*

Other modeling approaches, including forward looking models that focus on scenario testing regarding climate change and eutrophication (e.g., UMCES), are being explored within the research community in the Chesapeake Bay region, and for additional HAB species.

OBSERVATIONS

NATIONAL OBSERVING NETWORK

There is a clear link between HAB observing and HAB forecasting – HAB forecasts require observations. This is the premise of the National HAB Observing Network (NHABON). Dr. Quay Dortch, NCCOS introduced NHABON including its rationale and how it operates.

NHABON is a cost-effective approach for rapid, early warning of HABs tailored to the needs of each region while taking advantage of leveraging, economies of scale, and coordination. At the core of NHABON is HAB observations, which includes new automated HAB observing methods and standard measurements that have been routinely conducted, including cell counts, chlorophyll measurements, satellite measurements, and anything that measures HABs and their toxins, including environmental measurements and atmospheric measurements.

NHABON is needed to integrate local, state, regional, and federal HAB observing capabilities and deliver products operationally. Integration of observation data allows for modeling and prediction, development of synthesized products for decision-making, and to support early warning and forecasts that are key to keeping communities safe. Regardless of application, two-way conversation is imperative to ensure products are meeting societal needs.

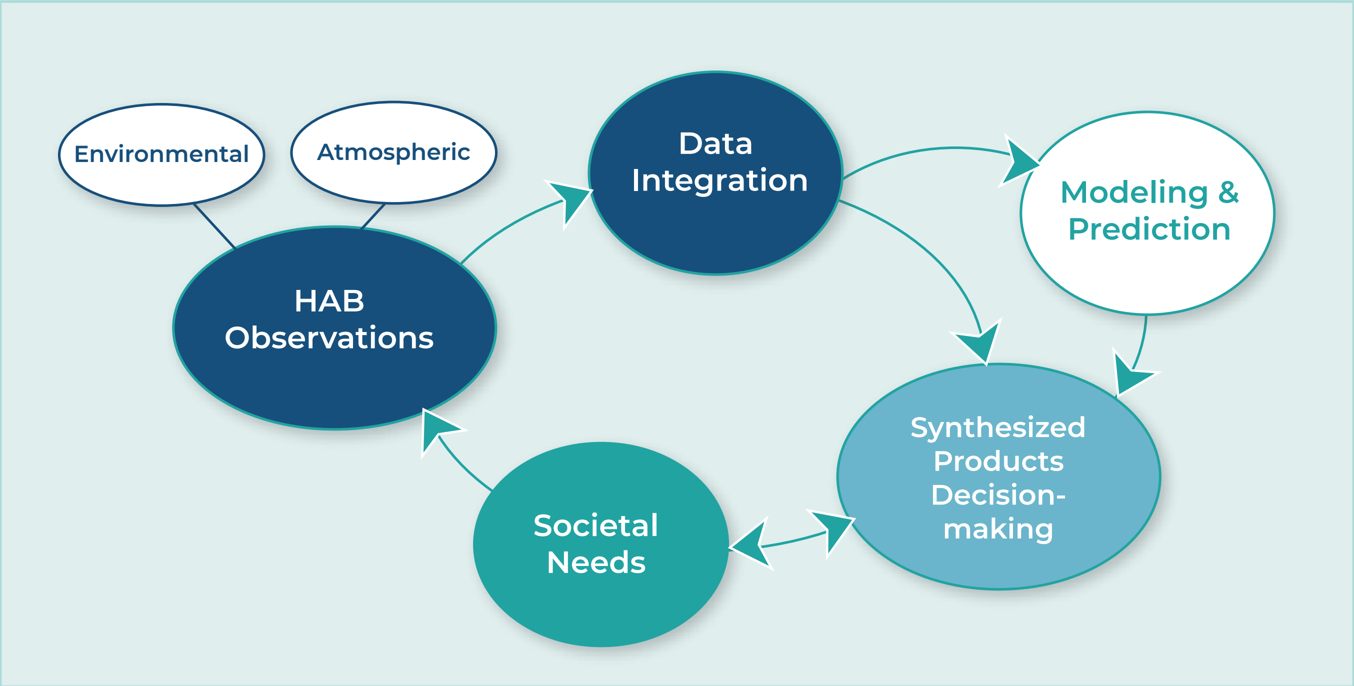


FIGURE 3. *HAB Observing Entity—IOOS Regional Association, state Observing System, other. HAB observations support early warnings and forecasts that are key to keeping communities safe. Source Quay Dortch*

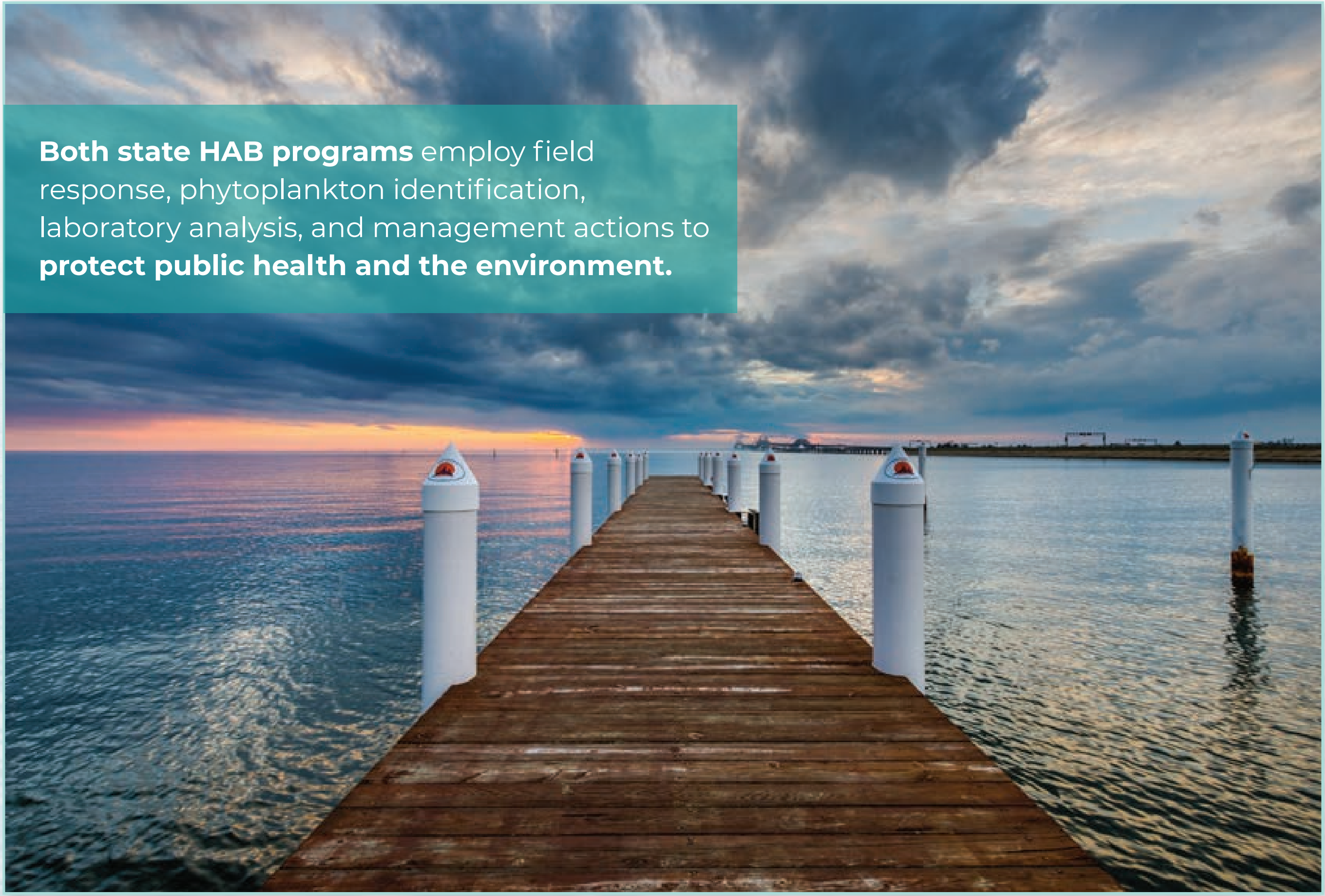
NHABON comprises regional observing networks and multiple HAB observing entities. The Framework for the National HAB Observing Network includes extensive details on HABs, the status of regional systems, the array of tools and technology available to provide observations, and the roles and responsibilities for the various players involved. It includes the following criteria – 1) it needs to be sustained, 2) it can be used for HAB detection, early warning, and forecasting, 3) it needs to support state, tribal, and national missions, to predict, mitigate, and manage HABs, 4) it must be able to detect both the known species and the emerging species, and 5) it needs to be flexible, scalable, and tailored to regional needs. There is no one size fits all.

Following the establishment of NHABON, the Integrated Ocean Observing System (IOOS) Association developed a 5-year implementation strategy which lays out in detail the resource requirements for implementation and what it might cost. NCCOS and IOOS have been working together very closely on this strategy and it builds on several previous efforts, including NCCOS investments in research technology and forecasting.

Currently there are several regional NHABON pilot projects. Some of them are more highly developed, and others are just beginning. The Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) recently received pilot funding from NHABON and will be hiring a part-time person specifically dedicated to working on HABs. The aim is to inventory current projects and related technology, identify gaps, and work with technology partners to create options for a harmful algal bloom tool targeted toward Mid-Atlantic stakeholders. The funding will also be applied to integrating and maintaining HABs-focused data sources such as monitoring data and forecasts into the MARACOOS data portal, OceansMap.Virginia and Maryland each have well-developed/robust state HAB observing systems. Their involvement could be at many different levels.

CHESAPEAKE BAY MONITORING AND OBSERVING

As previously stated HAB forecasts require observations. State agencies lead the monitoring and assessment of algal blooms in the Chesapeake and coastal bays. In Maryland, the Department of the Environment (MDE), the Department of Health (MDH), and the Department of Natural Resources (DNR) collaborate to manage a state-wide HAB surveillance program (MDE n.d.). In Virginia, the Department of Environmental Quality (DEQ) and the Virginia Department of Health (VDH), work together to regularly monitor the water and shellfish growing areas for the presence of HABs (VDH n.d.). Both state HAB programs employ field response, phytoplankton identification, laboratory analysis, and management actions to protect public health and the environment. State agencies coordinate with local health departments and researchers at regional universities. The University of Maryland Center for Environmental Science Institute of Marine and Environmental Technology, Old Dominion University, and the Virginia Institute for Marine Science, provide analytical support for the states' HAB programs (Allen et al., 2014). These efforts could support the development of a regional forecast.



Both state HAB programs employ field response, phytoplankton identification, laboratory analysis, and management actions to **protect public health and the environment.**

UNDERSTANDING USER NEEDS

AGENCY & INDUSTRY PANELS

Building on the pre-workshop needs assessment (Appendix B), two panel discussions, one with agency personnel and the second with industry representatives sought to better understand how HABs affect agency and business operations, if and how satellite imagery is currently being used, and what specific needs could potentially be met via satellite and forecasting information.

HAB spatial information & forecasting needs of agency resource managers

Agency panelists were Cathy Wazniak, Maryland Department of Natural Resources, Todd Egerton, Virginia Department of Health, Charlie Poukish, Maryland Department of Environment, Tom Parham, Maryland Department of Natural Resources, and Andrew Button, Virginia Marine Resource Commission.

The goal is to get the [Maryland Fishing] report in the hands of industry to **help them understand where blooms are** so they can alter their gear locations or fishing trips as needed.

There are several state agencies involved in HAB monitoring, ecosystem health and restoration, public health, shellfish regulatory oversight, etc. As such, internal and external communication and partnerships are vital. Both Maryland and Virginia conduct routine monitoring as well as response monitoring; however, they are constrained by staff limitations. As a result, in situ monitoring frequency is not always robust enough.

Maryland Department of Natural Resources (DNR), Division of Tidewater Ecosystem Assessment, has 35 routine monitoring sites for phytoplankton, a subset of which is also monitored for picoplankton. Their mission is to assess the phytoplankton community, relate changes to variations in nutrient load, and evaluate impacts to the ecosystem. DNR's dataset is used to provide annual updates, long-term distribution maps of trends, and assess seasonal changes. A challenge for DNR is temporal frequency because algae change on the order of 1-2 weeks, and they only monitor once a month. They also need better information on the movement of blooms and their toxins. DNR have been using satellite data since about 2010 to help them keep up with monitoring.

Additional DNR monitoring is used to track progress towards bay restoration. DNR is interested in how changes in bay conditions affect fisheries. Timely information is important so they can respond. DNR currently pulls data from multiple sources. They use NOAA satellite data to determine bloom location and combine that with wind conditions. The results are sent out via a Maryland Fishing Report, that reaches ~70,000 people weekly. The goal is to get the report in the hands of industry to help them understand where blooms are so they can alter their gear locations or fishing trips as needed.

Maryland's Department of Environment (MDE) has been monitoring HABs since the 1980s. MDE has an Enzyme-linked immunosorbent assay (ELISA) lab for quick toxins monitoring (e.g., microcystin) and implements closings for public health based on those results. A challenge for MDE is that several impoundments are experiencing hypereutrophication. Another challenge for MDE is timely information for decision making.

Virginia Department of Health (VDH), Division of Shellfish is concerned with human health, specifically toxins that can make their way into shellfish. They have a biotoxin control plan in place and to date, there have been no poisonings due to HAB toxins. VDH conducts in situ monitoring monthly at 70 sites. They are currently working with NOAA to understand where blooms might be, to assess if their monitoring stations are really capturing blooms, and to determine if additional sampling is needed. Because they only sample once a month, VDH would like to use satellite for routine monitoring to fill in data gaps. VDH is also interested in evaluating if satellite data can be used to inform shellfish closures and reopenings. However, this would require as small a spatial scale as possible to avoid broad general closures.

The Virginia Marine Resources Commission (VMRC) manages the shellfish resources and shellfish harvest that occur in Virginia's tidal waters. VMRC works closely with VDH Division of Shellfish on regulatory oversight. VMRC is interested in what impacts HABs are going to have on the longevity of the shellfish industry and what procedural processes need to occur. VMRC also conducts fisheries and restoration efforts, so they are concerned about changing impacts from HABs.

HAB effects on the operations of aquaculture & other water dependent users

Industry panelists were Natalie Ruark, Seed to Shuck, Maryland, Capt. Chris Guvernator, Holly Cove Charters, Virginia, Karen Hudson, Virginia Sea Grant/VIMS Aquaculture Extension Marine Advisory Program, Virginia, and Capt. Walt, Light Tackle Charters, Maryland.

There are several ways in which HABs affect water-dependent industry operations. In the case of charter boat captains who focus on ecotourism, HABs affect their ability to find marine life. These operators typically use dip nets to capture

FIGURE 4.
An industry stakeholder panel helped to identify forecasting needs and interests.

various marine organisms and when an area is experiencing a HAB, it is predictably devoid of marine life. Additionally, these captains must avoid wading through the water to access remote islands when signs of HABs are present. Similarly, fishing charter captains are impacted by HABs due to poor quality fishing. Fishermen report that when a HAB is present fish leave and do not return for several days after the bloom has passed (other hypotheses are that fish may be present but not feeding under the bloom effects). As such for these charter boat captains, it is important for them to know where a bloom is and where the bloom is likely to be headed.

Although many charter boat captains and recreational anglers just use their own observations, local knowledge, and industry connections to determine the presence of HABs, some are also using the Chesapeake Bay Environmental Forecast System (CBEFS) developed by VIMS to help them plan trips. For these captains, hypoxia is the most important CBEFS parameter. In one instance, a fishing charter captain described using CBEFS in conjunction with NOAA weather forecast, NOAA tides, and Windy.com to determine where a HAB has been and predict where it is headed.

In the case of aquaculture, HABs impact hatchery, nursery and field grow out operations. They worry about human health impacts as well as impacts to the shellfish. Growers want to know if they should harvest. Owners and managers want to know if their workers are safe, and they want to ensure the product doesn't harm others. A standard hatchery practice is to fill tanks with ambient water to use the next day. Hatchery managers want to ensure they are not introducing HABs to the hatchery that could have deleterious effects on larvae and small product. Some facilities currently use meters to monitor water quality. However, because they are only capturing Chl-a as a proxy for HABs, they generate a lot of false positives. They want to know how to implement a sampling program that would prevent them from using water that could be harmful.

Like charter boat captains and recreational anglers, most aquaculturists use their observations to determine the presence of HABs. Additionally, VIMS produces a HABogram that combines NOAA satellite and other resources and provides a text description of what's present and what that means for industry. Industry also uses the Virginia Algal Bloom Surveillance Map and Maryland Eyes on the Bay map-based websites which contain cell count information. A few are also looking at the CBEFS website. Important water quality parameters for aquaculture are acidification, followed by temperature and salinity.

EXPLORING TOOLS & PRODUCTS

Day two of the workshop focused on exploring NOAA satellite tools and imagery as well as CBEFS developed by VIMS.

RS TOOLS

Michelle Tomlinson, NCCOS HAB-FB gave a brief overview of RS Tools, an ArcGIS tool that NOAA developed to work with satellite imagery. RS Tools was developed as part of the CyAN project – a multiagency cyanobacteria assessment project for freshwater cyanobacteria blooms across the country. RS Tools loads up as a toolbox within ArcGIS Pro and allows calculation of all composites and extraction of time series data for points and polygons using ArcGIS.

BREAKOUT SESSIONS

Participants rotated through three breakout demonstration sessions which were set up to allow engagement with imagery and tools in small group settings. Two stations featured NOAA imagery with a focus on freshwater or marine HABs. The third station provided an in-depth look at the CBEFS. These small group and informal sessions allowed participants to view relevant imagery and tools, ask questions and provide input relative to needs identified and discussed during the first day of the workshop.

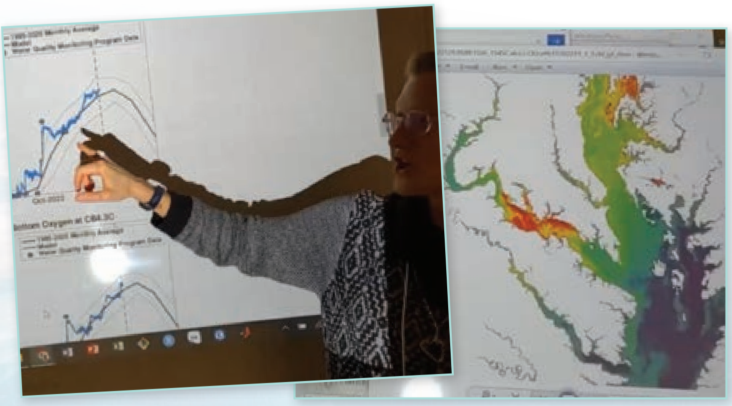


FIGURE 5. *Demonstrations via small group breakouts session.*

POTENTIAL USES OF SATELLITE IMAGERY & FORECASTING TOOLS AND PRODUCTS

Potential uses of satellite imagery and forecasting tools and products were captured throughout the workshop, most notably during the panel discussions, groups discussions after presentations, and during breakout sessions on day two. To the degree possible, potential uses are identified by state and stakeholder.

AGENCY

- There is academic interest in using satellites to improve models.
- Resource managers would like a monitoring system that can track the emergence and growth of harmful algal blooms.
- Virginia is interested in understanding where blooms might be and using satellite to assess if current monitoring stations are capturing blooms and whether additional sampling is needed.
- There is interest from Maryland in increasing their temporal and spatial ability to track blooms.
- There was a discussion on determining how blooms have changed over time – Are we seeing more blooms in the bay?
- During one of the breakouts, there was a question about numeric interpretation (criteria) – can pixels be related to HABs? – Probability of toxin level?
- Also, during the breakouts, there was discussion about using a standard anomaly application to identify how to determine blooms, i.e., on hotter days – e.g., >10µg/L.
- There was considerable interest in Sentinel-2 MSI data. Knowing MSI-MCI can't confirm cyanobacteria, there was interest in monitoring blooms with MSI in Lake Anna. Someone thought it would be nice to have animated images showing bloom progression in the Bay.
- There was a discussion on the suitability model and how to merge satellite data and the suitability model outputs to have a classified map of identified bloom types in the Bay. In addition, many agreed there is a need for a model/tool to separate bloom types (*P. minimum, M. polykrikoides,* etc.).
- There was interest from Virginia in using satellite data to inform shellfish closures and reopening. However, the spatial scale would need to be very tight to avoid impacting areas unnecessarily.
- Currently CBEFS provides an experimental HAB forecast on *P. minimum*. There was interest in a *Microcystis* model, using phycocyanin signal from remote sensing – applicable Bay-wide. Also including an alert system.
- Interest in focus on shallow water monitoring in lower Potomac. DNR is installing vertical diel profilers which will provide data to improve models.


PHOTO BY WILL PARSON/CHESAPEAKE BAY PROGRAM

INDUSTRY

- During the breakout, there was interest in knowing the direction of a bloom over the last 48 hours and pace, to forecast pace of movement with direction and magnitude.
- Recreational anglers would be interested in an app for where HABs are at certain tides and times.
- A charter boat captain was interested in assessing patches of HABs versus Tannins.
- Aquaculture would be interested in an as close to real-time HAB map with annotation about what it means for a stakeholder.
- Additionally, aquaculture would like quick, timely information for harvesters to understand if it's safe to harvest that product. Just because it's a bloom doesn't mean it's harmful.
- There was considerable interest in having an early warning for hatcheries. If they knew there was a HAB in area, they could potentially modify practices to avoid water coming into Hatchery. It would be costly, and they are not set up to do so now.
- There was also interest in turbidity and water clarity for siting aquaculture.
- One breakout discussed what a product should include, and it was decided a star or banner to flag a bloom and provide interpretation on what's in the water and how to avoid – maybe broken down by Bay segments.
- There is interest in learning how to read the images. There was considerable discussion on image interpretation using local knowledge and familiarity, such as a deep channel in Tangier Sound, right of Smith Island, potentially upwelling, bringing up nutrients, and starting blooms.
- There was discussion at the CBEFS station about whether species mattered. For instance, if it was important to know what *Alexandrium* was doing if we know *Margalefidinium* is present. Since there is a transition period between the two, it would be helpful for aquaculturists to capture in the forecasts.
- There was interest in linking the CBEFS hypoxia and HAB forecast to help anglers/charter boat operators, watermen, and managers know when to move equipment (crab pots). Similarly, a tool to follow trend would be helpful for aquaculturists (HAB to DO) to identify when to move pots/adjust systems.
- Finally, charter boat captains would like to have a laminated species identification factsheet that they could use as a communications tool when out on the water with customers when they run across a bloom.

MONITORING / OBSERVING OPPORTUNITIES AND LIMITATIONS

Numerous monitoring and observing opportunities were identified along with a few limitations. For instance, recreational anglers and charter boat captains would be interested in a HABs reporting app. One mentioned the Dolphin Watch App, developed by the UMCES, which is easy to use while out on the water. BloomWatch was also discussed as a possible reporting tool for industry. BloomWatch relies on uploaded photos linked to a location. A potential pitfall is that BloomWatch does not relay information to resource managers for follow up but perhaps there could be a way to do so.

Several participants from the recreational fishing and ecotourism industry offered to collect samples while out on the water. Workshop participants briefly discussed how to streamline logistics of collecting samples, taxonomic ID, etc. It was noted that preserved samples are easier because of less time sensitivity, and sampling can be coordinated through volunteer organizations with standard operating procedures (SOPs) available online. A data management plan would also be necessary for consistency in collection.

It was suggested that the CBP reassess their **phytoplankton monitoring program** to address … gaps, and thus better meet HAB decision-making needs.

Aquaculture nursery and hatchery operations are also interested in collecting data or water samples at their facilities for agencies and/or university partners. Instruments called Imaging Flow Cytobots (IFCB), and flow cams, would be cost-prohibitive for individuals to buy, but it's likely that they could be deployed in sentinel regions, or by a group of aquaculturists, or at a hatchery. They can provide phytoplankton cell counts 24 hours a day every 20 to 30 minutes but must be trained for the species in the area. Other instruments include flow cams and HABscope. The latter are being developed by NCCOS and others. HABscope is lower tech and cannot identify as many species, but hopefully soon it can be trained for more species. Old Dominion University has been building low-cost planktoscopes that are high throughput imaging systems. With funding, they hope to distribute them broadly in the lower bay network for early detection of blooms. A possible avenue for getting the HABscope, the planktoscopes, or other instruments out to industries would be to decentralize the labs.

Charter captains also expressed interest in having a species key with photos that could be used to provide information to customers when they encounter a bloom. VIMS (Dr. Kimberly Reece) have an older version that needs to be updated for Bay wide species (add Maryland). Cathy Wazniak, DNR and Dr. Todd Egerton, VDH offered to help Dr. Reece update this.

Several participants asked if agencies should be collecting more information, e.g., at top, middle and bottom of bloom to train the algorithms. However, the goal of creating better satellite and forecasting products and tools is to assist agencies, not to add work to their existing workload. NOAA also felt enough data was already being collected. More important was ensuring samples collected are being taken within the bloom to aid in identification of bloom species for ecological models.

Finally, there was discussion on the monthly phytoplankton monitoring of the CBP, which was not designed to collect HAB data and thus not focused on the needs of the HAB community. The Bay Program takes monthly discrete samples, but this low frequency sampling misses a lot of the blooms when they occur. Consequently, it is not conducive to satellite validation. There is also a lot of HAB data collected by agencies and universities that does not go to the CBP. As a result, the data available is incomplete. It was suggested that the CBP reassess their phytoplankton monitoring program to address these gaps, and thus better meet HAB decision-making needs.

CONCLUSIONS

Several overarching themes emerged during the workshop. In the case of industry, there is a need for better communications products that are tailored to their specific activities and a desire to inform products with local knowledge. There is also a strong willingness to participate in the data collection process. In the case of agencies, there is a desire to use satellite to supplement ongoing data collection and to inform aquaculture siting and closure/reopenings, in addition to bay restoration efforts. Moreover, the CBP would like to explore the use of satellite for assessments and members of the research community are interested in using satellite to inform models. Participants across the board are excited about the potential for higher spatial resolution Sentinel-2 imagery and the development of models for additional HAB species. Participants also desire continuing to communicate, share resources and collaborate on HAB detection and forecasting efforts.

NEXT STEPS FOR NCCOS HAB-FB

The following next steps have been identified by the NCCOS HAB-FB due to the workshop. Those steps in which work has already begun are noted with an asterisk (*) and further explanation.

- Explore citizen science monitoring opportunities.
  - *NCCOS have been in contact with NOAA Phytoplankton Monitoring Network (PMN) to discuss adding some community science (formally known as citizen science) monitoring within Maryland waters.
- Reach out to industry partners who were interested in collecting samples.
- Visit some of the aquaculture farms to get a better sense of their needs and see how they might participate in monitoring/PMN.
- Initiate discussions regarding adding models for other HAB species.
- Further develop Sentinel-2 for narrow coastal regions.
  - *A federal Interagency working group is developing a proposal for Sentinel-2 for inland lakes as well as narrow coastal regions.
- Follow up with MARACOOS regarding coordination on forecast output.

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APPENDIX A

WORKSHOP AGENDA

Applying novel techniques to assess and forecast harmful algal blooms in Chesapeake Bay to protect fisheries, aquaculture and human health

JAN 18-19, 2023
VIMS Watermen's Hall, 1375 Greate Rd, Gloucester Point, VA 23062

AGENDA (DAY 1) – 12PM – 5PM

12:00 Arrive and enjoy lunch on us
12:30 Welcome & Introductions – Overview of workshop goals
Pre-workshop needs assessment survey results – Kirstin Wakefield, MARACOOS
1:00 Agency Panel – Explore Needs & Opportunities – Mike Allen, Maryland Sea Grant
- Cathy Wazniak, Maryland Department of Natural Resources
- Todd Egerton, Virginia Department of Health
- Charlie Poukish, Maryland Department of Environment
- Tom Parham, Maryland Department of Natural Resources
- Andrew Button, Virginia Marine Resource Commission

Summary of key topics identified
2:00 Tools & Products
- Highlight recent research advances that can be integrated into operational approaches – Rick Stumpf, NOAA & Shelly Tomlinson, NOAA
- Showcase success stories – Who's used imagery and how in Maryland & Virginia, and what has been useful – Peter Tango, Chesapeake Bay Program
- Q & A Discussion

3:00 BREAK
3:15 Tools & Products continued
- HAB forecasting – Brief look at what's been done around the country – Rick Stumpf, NOAA & Shelly Tomlinson, NOAA
- National Harmful Algal Bloom Observing Network (NHABON) – Quay Dortch
- Discussion – How can we integrate monitoring/observing into HAB forecasting effort?

3:55 Industry Panel – Explore Needs & Interests – Susanna Musick, VIMS
- Natalie Ruark, Seed to Shuck, Maryland
- Capt. Chris Guvernator, Holly Cove Charters, Virginia
- Karen Hudson, Virginia Sea Grant/VIMS Aquaculture Extension, Virginia
- Capt. Walt, Light Tackle Charters, Maryland

Summary of key topics identified
4:55 Recap of Day 1 and brief look at Day 2
5:00 Workshop Day 1 conclusion

AGENDA (DAY 2) – 8:30AM – 1:30PM

8:30 Welcome, Brief look back of Day 1 and Looking ahead Day 2
8:40 Introduction to RS tools – Shelly Tomlinson, NOAA
Breakout Groups – Rick Stumpf, Shelly Tomlinson, Alex Hounshell, Sachi Mishra (NOAA), Marjy Friedrichs (VIMS)
- Explore NOAA imagery products
- Explore VIMS *Prorocentrum* forecast - CBEFS

10:40 BREAK
11:00 Discussion
- Recap and Discussion regarding Panels in context of Breakouts
- Where do we go from here?

12:00 Wrap up & Evaluation
Lunch before departure

APPENDIX B

PRE-WORKSHOP NEEDS ASSESSMENT SURVEY

Before conducting the workshop, two needs assessment surveys were distributed. The first survey targeted a scientific audience (hereby called the agency survey) and the second survey targeted those engaged in aquaculture, recreational and commercial fishing, charter boat captains and ecotourism (hereby called the industry survey). Surveys were emailed in August 2022 with a follow-up reminder in September 2022. 49 surveys were completed (22 agency and 27 industry). Below are the key findings from the survey summarized and organized by topic. Survey results were presented at the beginning of the workshop (see appendix B). Expanded details from the survey are available from Florida Sea Grant upon request.

HAB RISKS

This first section included questions to understand major risks associated with HABs.

For this question, respondents were asked to indicate the greatest (ecological, human health and business operations risk for their agency/business based on nine (9) attributes: Type of Bloom, Bloom Location, Spatial Extent of Bloom, Duration of Bloom, Magnitude of Bloom, Trajectory of Bloom, Timing during the year, Toxicity to Fish and Shellfish, Human Health Impacts.

AGENCY	INDUSTRY
Ecological Risks • Toxicity to Fish and Shellfish • Hypoxia	* Industry was only asked about business operations risk
Human Health Risks • Shellfish Exposure • Swimming Exposure • Toxicity to Fish and Shellfish	
Business Operations Risk • Toxicity to Fish and Shellfish • Human Health Concerns	Business Operations Risk • Hypoxia • Toxicity to Fish and Shellfish –Shellfish Exposure (Aquaculture) –Swimming Exposure (Rec. Fishery)

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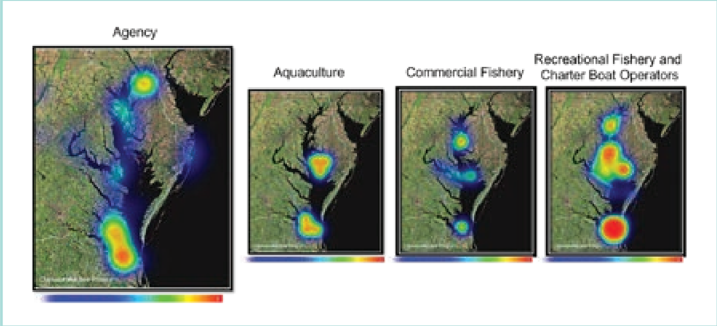
APPENDIX B

Where are HABs of greatest concern?

For this next question, *respondents were asked to select up to three areas on a map where HABs were of greatest concern to their role, business, or activity. A heat map was generated. Hotter colors indicate an area was selected by a higher number of respondents, whereas areas of cooler colors were selected by fewer respondents or a single respondent.*



INVESTMENTS AND LIMITATIONS

This section of questions covered what investments have been made in recent years for detecting and responding to HAB, what may be useful in the future, and what the current limitations in response are. Respondents noted the following:

Investments made for HABs detection/response

AGENCY	INDUSTRY
Collaborative partnerships • HAB Taskforce • Federal Agencies	No investments reported
Hiring more staff and lab upgrades	
Communications	
Technology • IFCB • Satellites and Drones to improve remote sensing algorithms	

Limitations for responding to HABs

AGENCY	INDUSTRY
Funding for research, sampling, and monitoring stations	Limited information on bloom location, spatial extent, duration, magnitude, and timing during the year
Timely detection and confirmation of HABs	Timely detection and confirmation of HABs
Lack of staff for sampling and lack of trained HABs experts	

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APPENDIX B

Tools that would be helpful

AGENCY	INDUSTRY
Monitoring • Dockside Tests, Rapid Collection and Testing for Toxicity, Drones, Staff	No awareness of tools
Mapping • Real-time map of blooms for shellfish growers to determine threat levels	
Remote Sensing • Spatial/temporal scales are limited • Suborbital/UAV/aircraft to reduce cloud cover in satellite images	
Resources • ISSC approved lab methods, VA HAB Lab • HAB Taxonomists • A network for sampling/reporting	

Sources of Satellite Data Currently Being Used

Agency

- ESA Sentinel 2 and 3
- Landsat
- EPA HAB Products
  –https://qed.epa.gov/cyanweb
- NOAA HAB Products
  –https://coastwatch.noaa.gov/cw_html/NCCOS.html
  –https://eastcoast.coastwatch.noaa.gov/data/olci/chlora/daily/cy/

Main Limitations to using satellite

- Where to find the imagery?
- What to do, how to process?
- Spatial Constraints

Other Tools that could be useful for forecasting/assessing HABs

- Long term environmental data models used for HAB prediction
- Easy access to GIS data for smaller regional scale analysis
- Multimedia sensors to add weather, tides, and water quality data
- AUV's paired with flow cytobots and onboard toxin sensors
- Animated imagery for time series and bloom lifespan dynamics
- Wireless microscopes with AI technology for species ID and cell counts

SATELLITE NEEDS

This next section of the survey included questions about what HAB attributes are most important to incorporate into satellite forecasts as they relate to work or business operations.

Of the 9 attributes we asked about, three rose to the top in terms of most useful across all stakeholder groups in the agency category. Notice that industry is not really concerned about the type of bloom, but rather the toxicity and how long it will last. Charter boat operators placed a higher priority on human health impacts than toxicity to fish/shellfish.

APPENDIX B

List of 9 attributes:

AGENCY	INDUSTRY
1) Bloom Location	1) Bloom Location
2) Type of Bloom	2) Toxicity to Fish and Shellfish
3) Toxicity to Fish and Shellfish	3) Bloom Duration and Human Health Impacts

Stakeholders were also asked to rank the forecast products that would be most useful to their work or business operations. Of the 6 items we asked about, real-time satellite bloom information, followed by short-term 1–3-day forecast was ranked 1 and 2 by both agency and industry. Additionally, agency respondents would also like to have different levels of information for different stakeholder groups whereas industry would like a long term 1-2 week forecast.

List of 6 products:

AGENCY	INDUSTRY
1) Real-time satellite bloom information	1) Real-time satellite bloom information
2) Short-term 1–3-day forecast	2) Short-term 1–3-day forecast
3) Different levels of information for different stakeholder groups	3) Long term 1-2 week forecast

HAB DETECTION AND COMMUNICATION MODES

This final section explored how respondents currently receive information and preferred delivery formats.

Current methods for detecting and responding to HABs

AGENCY	INDUSTRY
In Situ HAB Monitoring Programs	Aquaculture • Public Reporting Systems, Email, Websites
Email/Mailing Lists	Recreational Fishery/Charter Boats • Social Media, Traditional News, Word of Mouth
Integrated Data Portals Remote Sensing, Public Reporting Systems, Websites	Commercial Fishery • Traditional news • Word of Mouth

Preferred tools for communication:

AGENCY	INDUSTRY
Website	Phone App
Collaborative Platform	Email Bulletin
Email Bulletin	Website
Phone App	Social Media (Recreational Fishing)

APPENDIX C

RESOURCES DISCUSSED DURING THE WORKSHOP

Throughout the workshop several resources were shared or discussed in presentations, breakouts, etc. Participants requested that all these resources be shared. Additionally, participants requested access to the full presentations. These items may be found below.

- To access *workshop presentation slides,* see links in Appendix A.
- *Maryland Eyes on the Bay*: A map-based portal of Maryland tidal water quality data and information. Click on a station to see current and long-term data results. https://eyesonthebay.dnr.maryland.gov/
- *Virginia Algal Bloom Surveillance Map*: A map-based portal for HABs in Virginia which is active from May thru October. Citizens may also report HABs via a link at this site. https://www.vdh.virginia.gov/waterborne-hazards-control/algal-bloom-surveillance-map/
- *MARACOOS OceansMap*: A dynamic data visualization tool integrating near real-time observational assets and model forecasts that contribute to ocean monitoring in the Mid-Atlantic region. https://oceansmap.maracoos.org/
- *BloomWatch*: A smartphone-based app for reporting cyanobacteria HABs. Use the BloomWatch app to take good photos and submit potential blooms. https://cyanos.org/bloomwatch/
- *National Phytoplankton Monitoring Network (PMN)*: A community-based network of volunteers monitoring marine phytoplankton and HABs. https://coastalscience.noaa.gov/science-areas/stressor-impacts-mitigation/pmn/
- *Windy*: Wind and Weather Forecast: https://www.windy.com/
- *Email to NCCOS HAB section*: HAB@NOAA.gov
- *NCCOS satellite derived algal bloom beta/experimental products* for Chesapeake Bay. https://coastwatch.noaa.gov/cw_html/NCCOS.html
- *CyAN*: A map based an early warning indicator system to detect algal blooms in U.S. freshwater systems. https://www.epa.gov/water-research/cyanobacteria-assessment-network-cyan
- *Chesapeake Bay Environmental Forecast System (CBEFS)*: Tools developed by VIMS and partners, to accurately predict the current status of important environmental variables and how they are likely to change in the short-term. https://www.vims.edu/research/products/cbefs/index.php
- *Excel conversion for DN concentrations*: Convert from 8-bit (1-250) to Chlorophyll etc. (Chl-a in µg/L). See Appendix E.
- *EO Browser*: Makes it possible to browse and compare enhanced Sentinal-2 images. Click on the left triangle next to the calendar to see usable images from previous days. Chesapeake Bay enhancement Sentinel-2.
- *RS Tools*: RS Tools loads up as a toolbox within ArcGIS Pro and allows calculation of all composites and extraction of time series data for points and polygons using ArcGIS. https://oceancolor.gsfc.nasa.gov/projects/cyan/
- *NOAA CoastWatch*: Helps people access and use global and regional satellite data for ocean and coastal applications. https://coastwatch.noaa.gov/cwn/index.html

APPENDIX D

POST-WORKSHOP EVALUATION

At the conclusion of the workshop, participants were asked to complete a post-workshop evaluation. The evaluation was distributed to all in-person attendees at the workshop and a follow-up email was sent for those who participated virtually and anyone who attended but did not complete onsite. The evaluation was short and divided into three sections.

The first section asked participants to rate the quality of the workshop at facilitating knowledge gain, maintaining interest, and discussion. We used a Likert-scale of 1=Very Well; 2=Fairly Well; 3=Somewhat; 4=Not at all. Respondents rated facilitation of knowledge gain (1.57 mean), maintaining interest (1.33) and discussion (1.38).

Specific comments provided by participants related to this section included 1) some information was too technical for industry, 2) thank you for the patient approach to non-scientific questions, and 3) very interesting forecasting/RS over last decade, good use of time. I learned a lot. One respondent also commented on the workshop format and how the two half-days made it easy for travel.

The second section asked participants to assess how well each of the five workshop objectives were met. For this section a Likert scale of 1=Strongly Agree; 2=Agree; 3=Neutral; 4=Disagree; 5=Strongly Disagree was used. Results are as follows:

- To understand how HABs affect the operations of aquaculture and other water dependent users (1.90)
- To understand the HAB spatial information and forecasting needs of resource managers (1.61)
- To learn about potential forecast data products & how output could be used (1.66)
- To compile information on potential uses of satellite imagery & forecasting tools/products (1.71)
- To assess current monitoring and observing efforts that could lead to the development of a forecast and identify gaps (1.57)

Specific comments related to this section included 1) Loved the participation from industry – really added to the purpose of developing the products, and 2) It would be interesting to have seen the survey broken out into academic/agency/fisheries/etc. (pre-workshop survey results).

The last section asked participants what follow-up they would like to see. This was an open-ended question. Responses follow:

- Follow-up on my part to explore GIS/tools use. May have questions later
- Coordination of sample collecting between states, volunteers, and NOAA satellite folks
- Please continue your awesome collaboration between agencies
- Monitoring instruments for hatcheries/aquaculture
- What next recommended steps are there for NOAA, researchers, industry involvement? Looking forward to exec summary
- Several respondents were interested in a list of resources shown during workshop, including tools and communications products highlighted
- Updates as new imagery products are released
- Distributing meeting notes/summary to attendees

APPENDIX E

CONVERSIONS

This resource was shared in a NOAA imagery breakout and requested by some participants.

CI_v2 – CIcyano
CI_chla – CI Index in chlorophyll units.
Chl_gil_v2 – RE10 coastal/eutrophic chlorophyll, good for chl-a >2 mg/L.
chlOC4 – The global ocean chlorophyll algorithm, ok in lower Chesapeake Bay, it works in water with low levels of sediment and tannins.
chlOC4 global – The OC4 but enhanced to show the low concentrations.
RBD – Relative florescence – chl-a fluorescence
SDB – Satellite derived bathymetry, typically obtained by looking at the sunlight that reflected off the bottom.
Rrs709 – Reflectance of water at 709 nm, (just barely infrared light), this shows sediment or otherwise strong scattering. The band is not sensitive to pigments.

8-bit (DN 1-250) to chlorophyll, etc., chl-a in µg/L

DN	CI_v2	CI_chla	chl_gil_v2	chlOC4	chlOC4 global	RBD	SDB	rrs709
1	6.4863E-05	0.4	0.05	0.049	0.05	0.000102	0.033333	0.0000
10	8.3176E-05	0.5	0.51	0.51	0.07	0.000117	0.333333	0.0002
20	1.0965E-04	0.7	1.06	1.1	0.09	0.000136	0.666667	0.0005
30	1.4454E-04	0.9	1.65	1.6	0.11	0.000158	1	0.0008
40	1.9055E-04	1.1	2.29	2.3	0.15	0.000185	1.333333	0.0011
50	2.5119E-04	1.5	2.99	3	0.20	0.000215	1.666667	0.0014
60	3.3113E-04	2.0	3.76	3.8	0.26	0.000251	2	0.0017
70	4.3652E-04	2.6	4.6	4.6	0.35	0.000293	2.333333	0.0021
80	5.7544E-04	3.5	5.5	5.5	0.46	0.000341	2.666667	0.0026
90	0.0008	4.6	6.5	6.5	0.60	0.000398	3	0.0030
100	0.0010	6.0	7.7	7.7	0.79	0.000464	3.333333	0.0036
110	0.0013	7.9	9	9	1.05	0.000541	3.666667	0.0042
120	0.0017	10.4	10.4	10	1.38	0.000631	4	0.0049
130	0.0023	13.7	12.1	12	1.82	0.000736	4.333333	0.0057
140	0.0030	18.1	14	14	2.40	0.000858	4.666667	0.0066
150	0.0040	23.9	16.2	16	3.16	0.001	5	0.0076
160	0.0052	31.5	18.7	19	4.17	0.001166	5.333333	0.0089
170	0.0069	41.5	21.8	22	5.50	0.001359	5.666667	0.0104
180	0.0091	54.7	25.5	26	7.24	0.001585	6	0.0122
190	0.0120	72.1	30.1	30	9.55	0.001848	6.333333	0.0145
200	0.0158	95.1	35.9	36	12.59	0.002154	6.666667	0.0174
210	0.0209	125.4	43.5	43	16.60	0.002512	7	0.0213
220	0.0275	165.3	53.8	54	21.88	0.002929	7.333333	0.0268
230	0.0363	217.8	68.8	69	28.84	0.003415	7.666667	0.0351
234	0.0406	243.3	76.8	77	32.21	0.003631	7.8	0.0396
240	0.0479	287.2	92.3	92	38.02	0.003981	8	0.0488
245	0.0550	329.7	109.9	110	43.65	0.004299	8.166667	0.0597
250	0.0631	378.6	134.6	135	50.12	0.004642	8.333333	0.0762

APPENDIX F

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