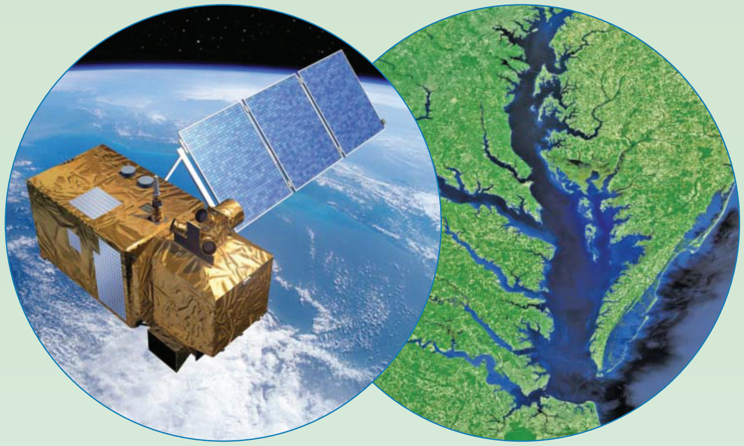

Remote Sensing Harmful Algal Bloom Workshop

CHESAPEAKE AND COASTAL BAYS REGION

Workshop Report

Edited by

Michael Allen, Jeffrey Brainard, Jenna Clark, and Fredrika Moser

A Maryland Sea Grant Publication

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Publication number
UM-SG-TS-2014-02

This report summarizes presentations, discussions, and recommendations from the Remote Sensing Harmful Algal Bloom Workshop — Chesapeake and Coastal Bays Region, held May 1, 2014 in Annapolis, Maryland. The workshop, sponsored by Maryland Sea Grant and the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NCCOS), was convened to discuss mechanisms for developing federal-state-academic-nonprofit partnerships that can improve our capabilities for detecting and reporting harmful algal blooms in the Chesapeake and coastal bays. The workshop agenda, list of attendees, and select handouts are included in the appendices.

This publication was made possible by a grant to Maryland Sea Grant from the National Oceanic and Atmospheric Administration, Department of Commerce, through the National Sea Grant College Program, Grant number NA10OAR4170072.

A limited number of paper copies of this publication are available from Maryland Sea Grant; send requests to: communications@mdsg.umd.edu. A pdf of the report can be downloaded from the web at: http://www.mdsg.umd.edu/workshop-remote-sensing-harmful-algal-blooms

Maryland Sea Grant College
University System of Maryland
4321 Hartwick Road, Suite 300
College Park, MD 20740
T 301. 405.7500 / F 301.314.5780
www.mdsg.umd.edu

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Executive Summary

The Chesapeake and coastal bays of Maryland, Virginia, and Delaware are valuable natural resources that support a variety of coastal community industries, including fisheries and tourism. Harmful algal blooms (HABs) are one environmental stressor that can negatively affect ecological, economic, and human health. HABs occur when phytoplankton grow rapidly and are often fueled by excess nutrients in the water and warm temperatures.

Historically, algal blooms have caused significant negative economic and ecological consequences in the Chesapeake Bay region. Multiple state agencies (in Maryland and Virginia) collaborate to manage bay surveillance networks as well as coordinate management responses. However, detecting, identifying, and responding to bloom reports is time and labor intensive. Additionally, the in situ surveillance networks provide very low resolution spatial coverage. Remote sensors on satellites that detect the presence of phytoplankton and other algae species are another tool that has been successfully employed in other parts of the United States to identify and track blooms over much broader spatial scales and at higher resolutions.

To address these concerns and opportunities, Maryland Sea Grant, along with the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NCCOS), held a workshop on May 1, 2014, to discuss mechanisms for developing federal-state-academic-nonprofit partnerships that can improve our capabilities for detecting and reporting harmful algal blooms in the Chesapeake and coastal bays. The workshop featured talks introducing HABs of the Chesapeake and coastal bays and current remote sensing technologies as well as operational examples of their use; hands-on breakout groups familiarizing participants with remote sensing data and products; and group discussion about species of concern, research gaps, and stakeholder needs. A key component of the workshop was to provide guidance to NCCOS on regional needs for remote sensing tools and products as well as next steps for addressing group needs and concerns.

NCCOS has developed models (for other regions of the United States) to create a "cyanobacterial index" from the remote sensing data, which describes the abundance of chlorophyll biomass and can be used to identify algal blooms and hotspots. These models can incorporate data from a number of different satellites, but there are tradeoffs in spatial, temporal, and spectral resolutions among the satellites. For the Chesapeake and coastal bays, only the soon-to-be-launched Ocean Land Colour Imager (OLCI) will provide sufficient spatial, temporal, and spectral resolution to effectively image tributaries and coastal lagoons.

With the OLCI instrument, NOAA will have the capability to provide current imagery of HAB conditions at a 300 by 300 meter pixel resolution. An existing tool, the HAB Viewer, will provide public access to this imagery. NOAA also has experience developing and disseminating HAB bulletins to interested stakeholders to provide context and discussion about current blooms in the images. The consensus of participants was that each product could be useful to the Chesapeake and coastal bays management community.

However, because of the large spatial scale and inherent diversity of habitats and algal species in the Bay, its tributaries, and the coastal bays, participants suggested that specific algal bloom alert systems be developed to address local impairments rather than investing in a new HAB bulletin for the region (at least initially). To effectively share alerts and other HAB information, a formalized communication network including specific points of contact and an information dissemination tree is needed. Many stakeholders who could make use of the information will need training.

Participants identified a number of scientific and technical challenges that should be addressed to improve the interpretation and utility of the remote sensing imagery. First, descriptive terms (e.g., "bloom," "harmful," "nuisance") and species-specific thresholds for what constitutes a bloom event need to be better defined. Second, current techniques only distinguish between cyanobacteria and non-cyanobacteria blooms and provide relative abundances. The ability to identify different taxa that occur in the Chesapeake Bay, particularly those that commonly cause problems in more saline waters (e.g., dinoflagellates), and provide cell abundances would add value to image interpretation. Third, models that provide a HAB forecast a few days into the future have been developed for other regions of the United States and would be useful here. However, coupled hydrodynamic-ecological forecast models to predict distributions and transport of HABs in the Chesapeake and coastal bays do not exist. Further, the differences between the mainstem Chesapeake Bay, its tributaries, and coastal lagoons give rise to blooms of different algal taxa. Therefore, smaller-scale localized models or localized alerts or bulletins may be required to predict blooms and educate the public.

Ultimately, participants suggested a new workgroup consisting of the key players from Maryland and Virginia, including members from the government, scientific, and management communities, should be assembled to develop an action plan to address the highest priority products and research challenges and act as a general point of contact for future HAB activities in the region.

Introduction

The Chesapeake Bay and coastal bays of Maryland, Virginia, and Delaware are valuable natural resources that support a variety of coastal community industries, including fisheries and tourism. These industries depend on the health of the bays for their success. Harmful algal blooms (HABs)[1] are one environmental stressor that can negatively affect these industries by degrading water quality, killing fish and shellfish, and potentially jeopardizing human health (Center for Disease Control and Prevention 2013).

Harmful algal blooms occur when phytoplankton and other microbes grow rapidly, especially in summer months, primarily fueled by excess nutrients in the water. Excess algal accumulation also arises because removal of algae (e.g., by grazing) cannot keep pace with their production. Numerous bloom-forming species occur in the Chesapeake Bay region, and a number of them have been studied extensively, including *Microcycstis aeruginosa*, *Prorocentrum minimum*, *Karlodinium venficum, Cochlodinium polykrikoides*, and *Aureococcus anophagefferens* (see Appendix 3). Other bloom species appear to be emerging in some areas of the watershed (e.g., *Alexandrium monolitum*). Such blooms have developed seasonally in the region in recent years, but their occurrence can be difficult to forecast and detect until they have grown large enough to cause serious detrimental effects.

Algal blooms have caused significant negative economic and ecological consequences in the Chesapeake Bay region. HABs have led managers to temporarily close multiple recreational sites in Maryland and Virginia to avoid health risks. HABs also threaten Chesapeake Bay fisheries and have led to millions of dollars in economic losses, either directly through the production of toxins or indirectly through bloom decomposition which can contribute to hypoxic conditions that kill fish (Maryland DNR 2013).

The monitoring and assessment of algal blooms in the Chesapeake and coastal bays is led by state agencies. In Maryland, the Department of the Environment (MDE), the Department of Health and Mental Hygiene, and the Department of Natural Resources (DNR) collaborate to manage a state-wide harmful algal bloom (HAB) surveillance program. Virginia's HAB program includes the Virginia Department of Environmental Quality, the Virginia Department of Health, and other state partners who routinely monitor the main bay and tributaries and respond to and investigate causes of fish kills. 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. DNR, MDE, and the University of Maryland Center for Environmental Science Institute of Marine and Environmental Technology in Maryland, and Old Dominion University and the Virginia Institute for Marine Science in Virginia, provide analytical support for the states' HAB programs (see Appendix 4).

Since the adoption of the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science (NCCOS) has been working to understand and predict HAB dynamics in regions throughout the country. NCCOS has collaborated and conducted research to develop and operationalize remote sensing products for monitoring and forecasting the movements of specific HAB species of concern. For example, NCCOS, as part of its HAB Forecasting program, developed an ecological forecasting system to calculate distributions of the cyanobacterium species *M. aeruginosa* in Lake Erie based in part on the use of satellite imagery from the Medium Resolution Imaging Spectrometer (MERIS) onboard the European Space Agency's (ESA) ENVISAT-1 spacecraft. This system combines a "cyanobacterial index" (CI) generated from the spectral reflectance measured by satellite with data on the physical conditions of Lake Erie (Wynne et al. 2010). By coupling the index with oceanographic models of ecological conditions and currents, NCCOS developed "nowcasts" and forecasts of bloom dynamics in Lake Erie that have been used by local stakeholders. Similar products have been developed for other parts of the country. MERIS imagery was first analyzed for this purpose in 2008 and continued until April 2012 when ENVISAT-1

[1] HABs will include eukaryotic and prokaryotic cyanobacteria in this report.

unexpectedly went offline (Wynne et al. 2013). Subsequent to the loss of MERIS, imagery with lower spatial and spectral resolution has been used (Moderate Resolution Imaging Spectroradiometer [MODIS]). In 2015, the European Space Agency plans to launch the replacement for MERIS, called the Ocean Land Colour Imager (OLCI). OLCI will routinely collect 300 m resolution data (i.e., a pixel size of 300 meters by 300 meters) with MERIS spectral resolution, and by 2018, will be collecting data daily.

Because of its recent success with coupling satellite data with oceanographic models for detection and forecasting of selected HAB events in Lake Erie, the Gulf of Mexico, and other regions in the United States (NOAA 2013), NCCOS has recently been tasked to help improve HAB detection and forecasting in the Chesapeake Bay and Mid-Atlantic coastal bays (Federal Leadership Committee for the Chesapeake Bay 2012). Working with local partners, NCCOS hopes to help develop a system that will provide resource managers and public health officials with information that is more accurate and timely than what is currently available.

To help further local collaborations and efforts, NCCOS reached out to Maryland Sea Grant to develop a process for engaging local stakeholders involved with harmful algal bloom monitoring and decision making. As a result, Maryland Sea Grant held a one-day workshop on May 1, 2014, to discuss mechanisms for developing federal-state-academic partnerships that can improve our capabilities for detecting and reporting harmful algal blooms in the Chesapeake and coastal bays. This workshop sought to provide:

- a forum for members of the research and management communities to discuss HAB tracking and identify needs,
- a venue for NCCOS to introduce workshop participants to their HAB remote sensing technologies,
- an opportunity for participants to discuss their needs for tracking and identifying HABs and to provide feedback to NCCOS about potential products it could develop to help managers and specific user groups to detect HABs, and
- a forum to develop federal-state-academic-NGO partnerships for improving HAB detection in the Chesapeake and coastal bays.

Workshop participants included state and local natural-resource managers, nonprofit organizations, state environmental managers, and scientists. This report highlights the findings from the workshop.

Workshop Process

The workshop was planned by a steering committee led by Maryland Sea Grant with significant input from the stakeholder community. In February 2014, the committee developed a needs assessment survey that was distributed to potential attendees. This survey sought to identify the participants' understanding of HABs and potential impacts of HABs on water quality and human health, their knowledge and use of remote sensing tools and products, and their guidance as to what a workshop could provide. Using this information, the steering committee framed an agenda and developed a number of materials that were distributed to all workshop participants (see appendices).

The workshop featured a series of talks that introduced HABs of the Chesapeake and coastal bays and current remote sensing technologies as well as operational examples of their use; hands-on breakout groups that used weTable[2] technology to facilitate interacting with remote sensing data and products; small group discussion about species of concern, research gaps, and stakeholder needs; and large group discussion to prioritize remote sensing products for the region and next steps.

Following the workshop, attendees were invited to complete a post-workshop survey to assess the success of the workshop and suggest future activities.

[2] http://www.mdsg.umd.edu/wetable

Harmful Algal Bloom and Remote Sensing Presentation Highlights

To give attendees a full introduction to algae that are of concern in the Chesapeake and coastal bays, Dr. Kevin Sellner presented a summary of taxa traits and historical distributions. He noted that the growth of HABs is dependent on several environmental factors including temperature, water movement, and nutrient concentrations. Additionally, the frequency and extent of algal blooms in Chesapeake coastal waters may decline in the future if continuing regulatory efforts succeed in reducing excess nutrient inputs to these systems. However, changes in water temperature, sea level, and water inputs from upstream caused by global climate change could affect future occurrence and persistence of algal blooms. Given their life histories and current local conditions, most algae of concern (with the exceptions of *Dinophysis* and *Pseudo-nitzschia*) have the potential to become HABs that are detectable using remote sensing technology. These detectable HABs include species in the genera *Alexandrium, Aureococcus, Cochlodinium, Karlodinium, Microcystis, Prorocentrum*, some harmful macroalgae, and possibly several *Raphidophytes* (*Chattonella, Heterosigma, Fibrocapsa*). The detectable HABs tend to aggregate at the surface during blooms, while *Dinophysis* tends to collect along density layers in the water column, making it difficult to observe by satellite or even by shipboard sampling. Additional details about the characteristics and toxicities of the algae are included in Appendix 3.

Since many of the attendees were not familiar with the remote sensing technologies developed by NCCOS, Dr. Richard Stumpf, HAB forecast manager at NCCOS's Center for Coastal Monitoring and Assessment, presented on current technologies, their limitations, and recent sample imagery from the Chesapeake and coastal bays. Remote sensors on satellites (and airplanes) detect the presence of phytoplankton and algae species primarily by measuring chlorophyll in the water. A number of different satellites can detect chlorophyll reflectance in fresh and salt water (Table 1). But there are tradeoffs in spatial, temporal, and spectral resolutions among the satellites and the availability and cost of imagery. For example, to effectively track the movement of HABs over time, a satellite must frequently pass over the same site. The temporal resolution of 1-2 days provided by MODIS and MERIS is optimal for this analysis.

Table 1. Key spatial, temporal, and spectral characteristics of remote sensors available to detect chlorophyll. Color scale is based on how well each sensor characteristic is suited for HAB remote sensing, where green is good, orange is marginal, yellow is adequate, and red is poor. Spectral bands in red and near-infrared, sometimes called the "red edge," are most effective at finding algal blooms in lakes and estuaries. *Credit: Richard Stumpf*

Satellite or Sensor	Spatial Resolution[1]	Image Frequency	Number of Key Spectral Bands
MERIS	300 m	2 day	10 (5 on the red edge)
MODIS (high res)	250/500 m	1-2 day	4 (1 red, 1 NIR[2])
MODIS (low res)	1 km	1-2 day	7-8 (2 in red edge)
Landsat	30 m	8/16 day	4 (1 red, 1 NIR)
IKONOS[3] (very high res)	1-4 m	Variable[1]	4 (1 red, 1 NIR)

[1] *Width of individual pixels in the image.*
[2] *Near-Infrared.*
[3] *Imagery from the IKONOS or equivalent sensors is commercial and available by request only.*

Spatial scale is another important constraint in satellite imagery. Each image is made up a series of pixels, where the pixel size determines the spatial resolution of the image. For example, a pixel from a MERIS image covers a distance 300 m across on the water. Although this is not a major issue in the open ocean, it becomes problematic within narrow tributaries, because one pixel may capture an area that contains both land and water. The sensor thus detects the chlorophyll from land plants as well as that from the tributary, creating a false positive bloom signal. This can be compensated for by removing the mixed pixels; however, information on many of the tributaries of the Chesapeake and coastal bays will be lost. Thus, higher resolution imagery would be better for detecting chlorophyll in smaller tributaries, lakes, and bays.

Other constraints arise from the number and precision of wavelengths measured by the instrument, which influences the pigments that can be detected and thus the algae that can be identified. NCCOS developed models to create a "cyanobacterial index" from the remote sensing data, which describes the abundance of chlorophyll biomass associated with cyanobacteria in an image. Although algae are widely distributed in coastal waters and the open ocean, the index allows researchers to identify "hot spots" of high biomass production that indicate an algal bloom. This index uses key spectra on the red to near-infrared range. By examining the spectral signatures of individual blooms, it is possible to separate some groups of algae from others (e.g., cyanobacteria from diatoms). The current CI product surveys the shape of the spectral curve around 681 nm (between the 665, 681, and 709 nm bands from MERIS) to determine whether high chlorophyll features are dominated by cyanobacteria (Wynne et al. 2008). Satellites that can detect fewer spectral bands are less sensitive at quantifying chlorophyll and ultimately ineffective at distinguishing types of algae (Table 1). For example, MODIS can quantify cyanobacteria but has less bands in this region, so it cannot reliably distinguish cyanobacteria from other blooms. Therefore, having appropriate spectral resolution for the algae of interest can allow for separation of algal groups with different spectral characteristics.

Dr. Stumpf discussed a number of other opportunities and limitations associated with current remote sensing products. He noted that of the different satellite sensors available, MERIS was the most effective tool, because it could detect more wavelengths than MODIS or Landsat, took imagery of the same locations frequently (every 2 days), and had a moderate spatial resolution (300 m). Since MERIS went offline, researchers have modified imagery from MODIS to continue forecasts for Lake Erie at reduced (~ 1 km) resolution. However, eventually these data will be significantly supplemented by higher resolution images collected by OLCI, a sensor to be carried aboard the planned ESA Sentinel-3 satellite to be launched in 2015. OLCI has specifications to match those of the offline MERIS sensor. Thus, OLCI will be more appropriate for tracking algal blooms in coastal areas such as the sub-estuaries of the Chesapeake and coastal bays.

There are two major limitations for effectively using remote sensing technologies to forecast and identify HABs in Chesapeake Bay. The first limitation is that the model developed by NCCOS to forecast *Microcystis* bloom movement in Lake Erie (a hydrodynamic model coupled to the CI product) cannot be used to predict bloom movement over time in the Chesapeake Bay. Rather, hydrodynamic models specific to simulating circulation within the Chesapeake Bay and its smaller tributaries would need to be coupled with the remotely sensed data to develop forward looking forecasts similar to the HAB forecasts produced for Lake Erie. Another alternative is for NCCOS to import hydrodynamic model output into its existing bloom index models using an existing tool (given the appropriately formatted output data) and use it to track a bloom and produce a forecast. The second limitation is that onsite field data collection is currently needed to identify algal species in the Chesapeake and coastal bays as well as to determine whether such blooms contain toxic algae, thus presenting a hurdle to rapid identification and management of blooms. Currently, NCCOS is looking to create coupled models that would offer some species discrimination by merging satellite data with data on different species characteristics and preferred habitats. For example, some algae are most likely to bloom in certain parts of the Bay, under high or low salinity, and during certain seasons.

In the afternoon session, Dr. Stumpf introduced participants to the communication and data distribution products and capabilities that NCCOS has developed for the HAB community. NCCOS has developed a "HAB Viewer," a prototype public website that displays satellite data about harmful algal blooms in the

Bay.[3] It currently displays data through April 2012, when the MERIS sensor failed. The Bay is one of only four areas in the United States where NCCOS is providing these detailed data; the others are Lake Erie, other parts of Ohio, and Florida.

NCCOS also works with local partners to develop bulletins that are distributed to local stakeholders. The subscriber list often includes members from public health, natural resources, and scientific fields. The bulletins can contain information regarding forecasts, field operations, public health information, buoy data, models, and analyses of ocean color satellite imagery. Distribution of these bulletins differs by region and depends on local management preferences. Bulletins from Lake Erie and Florida lakes were distributed to the participants to review.

Case Studies of Remote Sensing Technology

New Jersey's Use of Remote Sensing for the Detection of Algal Blooms

The New Jersey Department of Environmental Protection (NJ DEP) collects remote sensing data from a regular series of low-level aerial overflights of the New Jersey shoreline from April to October. Data on algal blooms is recorded by a sensor mounted aboard a Forest Fire Service monitoring aircraft that flies at an altitude of about 500 ft six days a week during the summer. The sensor measures chlorophyll *a* levels from 0-50 ug/L. The department has used this tool to detect and track, in real time, algae blooms that may have caused fish kills.

The department has also deployed a Slocum Glider in cooperation with NOAA and Rutgers University. The glider is an underwater autonomous vehicle that can be deployed for up to a month at a time to collect data about the distribution of chlorophyll *a* concentrations throughout the water column, data that can be used to help detect and study algal blooms. The glider sensors also measure dissolved oxygen, temperature, and salinity. These tools allow the NJ DEP to quickly respond to algal blooms to assess their toxicity, track them, and alert public-health officials to take precautions.

— Robert Schuster, New Jersey Department of Environment Protection

Remote Sensing for HAB Detection, Response, and Protection: Public Health Applications in Florida

The Florida Department of Health (FL DOH) uses the NCCOS satellite data to produce a weekly bulletin that provides forecasts and locations of HABs. The department produces an Inland HAB Health Bulletin sent to about 100 individuals at 20 organizations concerned with managing HABs in Florida lakes. In partnership with NCCOS, FL DOH has been successful in creating a product that can disseminate necessary remote sensing information in addition to other relevant material related to HABs and management (Appendix 6). In addition to the bulletin, the FL DOH maintains a password-protected database and notification system, Caspio, which collects information on HABs and facilitates coordination on blooms between departments.

— Andrew Reich, Florida Department of Health

[3] http://www2.nccos.noaa.gov/coast/

Understanding Remote Sensing Products and Community Needs

Building on the pre-workshop assessment, workshop breakout sessions were included to introduce participants to remote sensing technologies and HAB products as well as to discuss needs, questions, and opportunities concerning expanded use of remote sensing to detect and respond to HABs. Participants considered and commented on regional HAB issues that might be addressed by using versions of existing NCCOS products (e.g., bulletins, HAB viewer). They also identified a series of technical issues that would need to be addressed to make the NCCOS products more useful for the community.

Two morning breakout stations familiarized workshop participants with the satellite imagery technology through hands-on interaction and discussion. The imagery was presented via the weTable system at the first two stations, which used interactive projection technologies to display Google Earth imagery of past HABs in the Chesapeake and coastal bays. The technology allowed participants to pan and zoom maps, turn on and off layers, and mark up remote sensing imagery for the region. Participants identified and discussed specific areas in the Chesapeake and coastal bays where HABs were potential threats to public health and aquaculture and fisheries. In post-workshop surveys, participants noted that this was an innovative way to introduce the remotely sensed data to the small groups and to help them understand its potential strengths and weaknesses.

At the third station, participants discussed current gaps in HAB monitoring and research. They were hopeful that remote sensing information could be used to better direct overall monitoring and research efforts. However, the group noted that there were significant knowledge gaps about the many different species of bloom-forming algae in the region, including their environmental triggers, toxicity, and potential risks to humans. There was also concern that limited staff and funding hampered research and quick responses to alerts.

This discussion continued during an afternoon breakout where the application of remote sensing technologies to monitoring and research gaps was addressed. The group suggested:

- Considering the utility of existing algorithms for chlorophyll in the Chesapeake Bay (L. Harding)
- Starting small by targeting specific tributaries for case studies, where detailed ecological and hydrodynamic models may be coupled with remote sensing data (e.g., James River)
- Pursuing focused work on accessory pigments (other light absorbing compounds in algae that work in conjunction with chlorophyll *a*) and remote sensing algorithms to better distinguish among algal species
- Pursuing hindcasts of HAB "hot spots" to enhance our understanding of bloom development

Participants also emphasized the importance of information flow among all parties and proposed that points of contact and an information dissemination tree or network was needed to distribute data, bulletins, alerts, and other types of information efficiently (Figure 1).

Two other afternoon breakout sessions examined existing HAB bulletins (Appendices 6 and 7) and the HAB Viewer using weTables. Participants liked and saw the utility of the HAB bulletins but raised a number of issues that would need to be addressed prior to implementation. Importantly, they liked the context and explanation that was provided by the example bulletins (e.g., product description/interpretation; definitions; three-day forecasts; ancillary information such as water temperature, wind patterns, drought context). However, further clarification would be needed on forecast uncertainty, terminology (what determines a bloom, a nuisance bloom, a harmful bloom), and scale (whole Bay bulletin vs. tributary-specific bulletin, or some hybrid). Participants also emphasized that bulletins should be directed toward managers trained to understand them and have limited distribution. There was concern that such information, without appropriate context, may create unwarranted public alarm. If a bulletin(s) is pursued, further discussions will be necessary about distribution lists, frequency, contents, and a number of the research gaps outlined below.

Participants thought the HAB Viewer was a very useful data distribution hub but suggested it may need to be renamed, because not every algal bloom detected by remote sensing in the Chesapeake Bay and coastal bays is harmful. In addition, the group encouraged NCCOS to further raise awareness in the science and management community about the availability of the HAB Viewer as many of the workshop participants were unaware of its availability.

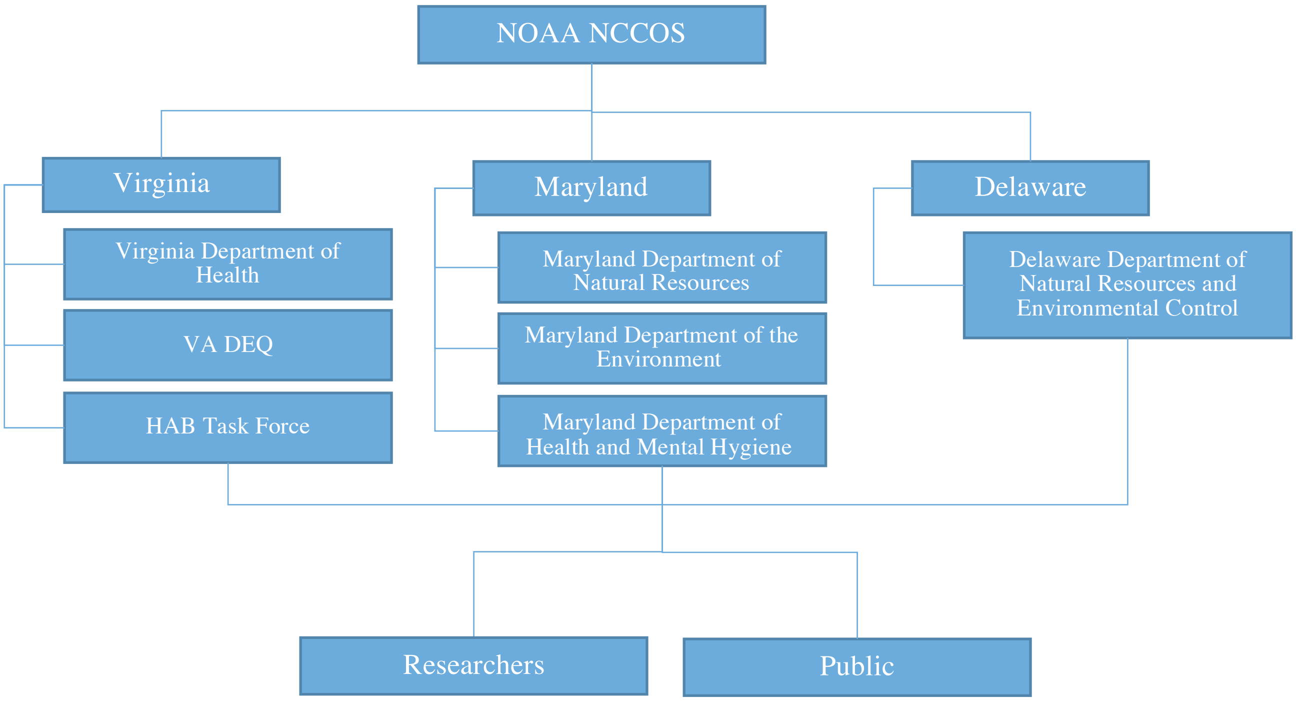

Figure 1. A preliminary dissemination tree for distributing harmful algal bloom information from NCCOS to stakeholders in Delaware, Maryland, and Virginia.

Important Opportunities and Limitations for HAB Remote Sensing

The breakout sessions and dialog effectively primed participants to discuss the opportunities and limitations of employing remote sensing technology to inform HAB detection in the Chesapeake and coastal bays. The afternoon discussion sought to summarize these observations, prioritize them, and determine conclusions and actions for moving forward. These findings and recommendations can be grouped into 1) current NCCOS products and capabilities, 2) research gaps and technical challenges for applying these capabilities in the Chesapeake and coastal bays, and 3) potential capabilities and products that the Chesapeake and coastal bay management and research community could pursue.

In order to prioritize the needs of the community, participants were asked to indicate their level of support for a research direction or product/capability in a tangible way. One option was whether they would be willing to contribute their resources of some kind – e.g., money, time, constructive feedback, and/or existing data – to support it. Another option was whether they might use the product or practice (i.e., it would be “nice to have”) but were not willing or able to commit resources to create it. Each list below is ordered from highest to lowest priority.

Current Products and Capabilities That Could Be Deployed

1. **Nowcast of HAB conditions** in the bays at 300 m resolution is possible once the OLCI sensor is online.
2. **HAB Viewer** currently distributes remotely sensed imagery publicly.
3. **HAB bulletins** that notify managers and other users about recent data indicating the incidence and locations of HABs are straightforward to produce and disseminated in multiple jurisdictions.

Research Gaps and Technical Challenges

1. **Identification and imagery of HABs should be species-specific.** This would allow users to distinguish among the multiple species of algae that occur in the Chesapeake and coastal bay blooms, only some of which produce toxins. This would expand NCCOS' existing capability that distinguishes only between cyanobacteria and other kinds of algae.
2. **Descriptive terms and thresholds for blooms need to be better defined**. Managers and the public could benefit from clarification of the language used in the HAB remote sensing products. In some cases, quantitative definitions or scales may be needed. For example, what is a bloom? Should there be a trigger/threshold for a HAB "hot spot" based on an index or cell count value? How should "harmful blooms" versus "nuisance blooms" be defined?
3. **Chlorophyll and cyanobacterial indices should be translatable to cell counts.** Currently the indices are only relative and cannot be converted into cell counts per milliliter of water. These calibrations may need to be species-specific and employ standard methods for determining cell abundances.
4. **HAB models should account for variation in chlorophyll abundance within a species.** Chlorophyll produced can vary by season and by the level of available nutrients, affecting the models' abilities to accurately forecast distributions.
5. **Localized, tributary-specific HAB information may need to be developed.** Because of the region's size and physical complexity, it might be challenging to use a single HAB model for all parts of the region. Separate tributary products may be necessary (e.g., the James River).
6. **Coupled HAB forecast models should be developed for the bays and tributaries.** Such models may include hydrodynamic and ecological components to predict HAB distributions and transport into the future.
7. **A suspended solids product could be derived from remote sensing data.** Such a product could inform the Chesapeake Bay Program's TMDL monitoring and modeling efforts, would provide another indicator for Bay water quality (e.g., for existing Report Cards), and may not be difficult for NCCOS to develop.

Potential Products and Capabilities to Pursue

1. **An alert system for sharing new bloom information with managers should be considered.** While many participants were interested in receiving a regularly produced written bulletin, such a product may not be the best use of resources given the sporadic occurrence of HABs in the region. A viable alternative could be a process that sends e-mail alerts as needed from NCCOS to a discrete set of interested managers.
2. **Chesapeake and coastal bays networks for algal species identification are limited and should be augmented.** A solid network of regional experts is necessary to verify and validate HAB alerts and information that will be shared on the HAB Viewer.
3. **Resource managers must be trained on the use of HAB information and products.** Decision makers must be able to understand and interpret information coming from NCCOS or other sources in order to translate it to appropriate advisories and decisions (e.g., beach closures, hatchery alerts). Coordinated training sessions by NCCOS or the Maryland and Virginia HAB task forces may help. Training in the future for those receiving local alerts (e.g., hatchery owners, local municipalities) should be coordinated by state officials.
4. **HAB Viewer imagery and existing regional data resources should be integrated.** Portals such as Maryland DNR's *Eyes on the Bay* and the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) website have numerous resources that could be overlain with HAB imagery and data.

5. **An annual report or seasonal synthesis summarizing HAB conditions could be developed.** Such information could inform "report cards" that track progress in improving water quality.
6. **A higher spatial resolution remote sensing product could be pursued.** This would likely involve investigating other sensors with higher spatial resolution, with the caveat that temporal resolution may be sacrificed. This would help capture HAB patchiness in the Bay as well as significantly extend the capabilities for remote sensing of blooms in tributaries.

Summary

The consensus of workshop participants was that all three current NCCOS products could be useful to the community. In particular, the HAB Viewer online tool is an especially helpful and desirable product for NCCOS to maintain. Imagery from this product could be combined with other regional data resources to improve its utility. Although an algal bloom bulletin for the Chesapeake and coastal bays would be interesting and potentially useful, a targeted alert system might be more appropriate for focusing sampling and management efforts in the region. For example, an alert could be distributed if a bloom were to exceed a predetermined threshold. Participants emphasized the alert system was the highest priority, but agreed that whatever products were developed, training would be needed for the user community.

Conclusions and Future Steps

Participants strongly supported that the most important step forward would be the creation of a small workgroup to develop an action plan to address the highest priority products and research challenges that emerged from the workshop discourse. This workgroup would consist of the key players from Maryland and Virginia, including members from the government, scientific, and management communities (most likely a subset of the existing Maryland and Virginia HAB task forces).

This workgroup's near-term priorities would include:

- Refining and augmenting the dissemination pathways and mechanisms for HAB information so that all interested parties would receive the information in a timely manner
- Working with NCCOS and partners to define a set of descriptive terms and thresholds for identifying blooms locally as well as to help improve species identification from imagery
- Providing guidance to NCCOS on implementing a HAB remote sensing alert system
- Providing connections, data, and/or samples to help NCCOS validate the remote sensing models and algorithms
- Serving as a general point of contact for NCCOS for the regional HAB community

The workgroup would interface with the Maryland and Virginia HAB task forces to assure that the directions for and products of remote sensing for the Chesapeake and coastal bays continue to meet the needs of the entire community.

Acknowledgements

The organization and development of the workshop and workshop materials was guided by a steering committee composed of the following individuals:

Margaret Mulholland, Old Dominion University, Norfolk, VA
Kevin Sellner, Chesapeake Research Consortium, Edgewater, MD
Richard Stumpf, NOAA NCCOS, Silver Spring, MD
Michelle Tomlinson, NOAA NCCOS, Silver Spring, MD
Mark Trice, Maryland Department of Natural Resources, Annapolis, MD
Cathy Wazniak, Maryland Department of Natural Resources, Annapolis, MD
Jeremy Werdell, NASA, Greenbelt, MD

Maryland Sea Grant and NOAA NCCOS are grateful to them for their time and dedication to the workshop.

Thanks also to our invited speakers from New Jersey, Robert Schuster, and Florida, Andrew Reich for their perspective and unique experiences with remote sensing imagery. The workshop was supported by the NASA Applied Science Program (Human Health and Air Quality) announcement NNH08ZDA001N under contract NNH09AL53I to NOAA and NOAA Award NA10OAR4170072 to Maryland Sea Grant.

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APPENDIX 1

REMOTE SENSING HARMFUL ALGAL BLOOM WORKSHOP

CHESAPEAKE AND COASTAL BAYS REGION

MAY 1ST, 2014 · THE O'CALLAGHAN ANNAPOLIS HOTEL, 174 WEST STREET, ANNAPOLIS, MD

WORKSHOP GOALS

The main goal of this workshop is to help develop federal-state partnerships for improving harmful algal bloom detection in the Chesapeake and coastal bays and provide guidance to NOAA NCCOS for developing remote sensing models and delivering appropriate products for specific user groups in the region.

AGENDA

8:30 - 9:00 AM	Registration and Breakfast Reception
9:00 - 9:15 AM	Welcome and Workshop Overview, *Fredrika Moser, Maryland Sea Grant*
9:15 - 9:45 AM	Harmful Algal Blooms in the Chesapeake and Coastal Bays, *Kevin Sellner, Chesapeake Research Consortium*
9:45 - 10:15 AM	Introduction to Remote Sensing and Harmful Algal Blooms, *Richard Stumpf, NOAA*
10:15 - 10:30 AM	Mid-morning Break
10:30 – 11:30 AM	Break-out Session
11:30 AM – 12:00 PM	Remote Sensing Example, New Jersey, *Robert Schuster, New Jersey Department of Environmental Protection*
12:00 – 1:00 PM	Lunch with Presentations
12:30 – 1:00 PM	Remote Sensing Example, Florida, *Andrew Reich, Florida Department of Health*
1:00 – 1:30 PM	Remote Sensing Chesapeake and Coastal Bays Examples and Demonstration, *Richard Stumpf, NOAA*
1:30 – 2:30 PM	Break-out Session
2:30 – 2:45 PM	Afternoon Break
2:45 – 3:45 PM	Facilitated Discussion on Potential Remote Sensing Products and Research Gaps
3:45 – 4:00 PM	Workshop Conclusions, *Fredrika Moser, Maryland Sea Grant*

APPENDIX 2a

PRE-WORKSHOP NEEDS ASSESSMENT SURVEY

SUMMARY OF RESULTS

Before conducting the remote sensing harmful algal bloom workshop, a needs assessment survey was distributed to all potential attendees in February 2014. This survey was aimed at identifying the participants' understanding of harmful algal blooms and remote sensing and to obtain guidance as to what the participants hoped to learn from the workshop. The questions were related to harmful algal blooms (HABs) and remote sensing technologies in the Chesapeake and coastal bays. Specifically, these included questions regarding background information on HABs and remote sensing; current tools and products for HAB detection; workshop expectations; and HABs role in water quality and human health risks. We received twenty-five responses and used these results to help plan the workshop. Additionally based on the survey results, we developed a list of harmful algae species of concern and listed them in a "Harmful Algae Species of Concern" handout for workshop participants. Below are the key findings from the survey summarized and organized by topic. Expanded details from the survey are available from Maryland Sea Grant upon request.

HABS TOOLS AND PRODUCTS

This section of questions covered what HAB tools and products are used, what may be needed in the future, and what are our current limitations in HAB understanding and management. In particular, respondents noted the following limitations:

- Timely detection and confirmation of HABs (including analysis time) (9)
- Funding for research, sampling, monitoring stations, and general resources (7)
- Lack of knowledge of the toxicity and human impacts of HABs (5)
- Lack of staff for sampling and trained HAB experts (4)
- Lack of single point of contact with a clear message about HABs (4)
- Limited information on temporal and spatial extent of blooms (2)
- Lack of understanding of environmental triggers (2)

Note: Responders were asked for their top three, thus explaining the large sample size (n=40).

NEW PRODUCTS FOR THE DETECTION AND TRACKING OF HABS

The questions in this section asked about the background knowledge of responders to remote sensing technologies used for HAB detection including use of remote sensing data and familiarity of the NOAA HABViewer website. Most (13/20) answered that they haven't used any remote sensing data for HABs previously. Seven people reported having used either remote sensing reflectance or aerial photography.

When further asked about the reasons for not using remote sensing data, the following barriers were identified from a list of choices provided in the survey:

- Do not know where to find it (6)
- Do not know how to process it (8)
- Do not have appropriate GIS software (3)
- In general, do not know what to do with it (6)

ROLE OF HABS IN WATER QUALITY AND HUMAN HEATH

We asked a couple of questions to understand what were the major concerns regarding HABs. The top four concerns about HABs were public health response (76.2%), environmental response (71.4%), routine monitoring (71.4%), and impacts on fisheries/aquaculture (66.7%). (n=21)

WORKSHOP EXPECTATIONS

The last section of the survey included questions on what attendees would like to gain from the workshop and how they would quantify workshop success. When asked about specific components of the workshop, most said they would like to gain background knowledge of HABs, learn about current HAB research, and participate in discussions of research and development priorities for remote sensing in the Chesapeake and coastal bays. Over half also said that they would like to see demonstrations of existing remote sensing tools for HAB detection.

Finally, when asked what would be the most important outcome(s) of this workshop, the summarized responses mostly clustered around the following: create greater collaboration between members in the community; improve understanding of current research; learn about remote sensing monitoring technology for HABs; and inform future HAB management and research activities.

Harmful Algae in the Chesapeake and Coastal Bays of MD and VA

Alexandrium monilatum

This chain forming, fish killing dinoflagellate blooms during late summer in the lower York River and James River estuaries leading to mass die offs of cultured Rapa whelk populations. It was first seen in 2007 and has been documented nearly every year since. As a cyst former, recurrent blooms are likely into the future, dominating summer productivity and surface organic matter. Dense surface accumulations, rich in chlorophyll are detectable using remote sensing.

Aureococcus anophagefferens

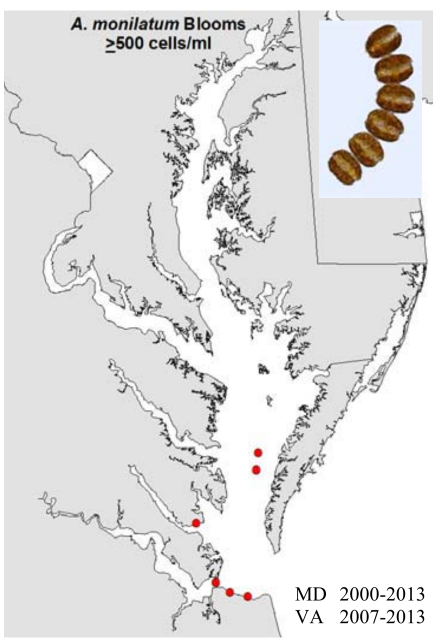
This 2 µm pelagophyte produces dense 'brown tide' blooms that peak in May-mid July. Common along the Atlantic seaboard generally in long residence time high salinity lagoon systems. Populations reach sufficient densities to shade underlying submersed grasses, and remain largely ungrazed within the water column. In embayments on Long Island, NY, this organism caused collapse of the scallop fishery. This algae contains unique pigments and due to its small size and dense accumulations should be detectable remotely.

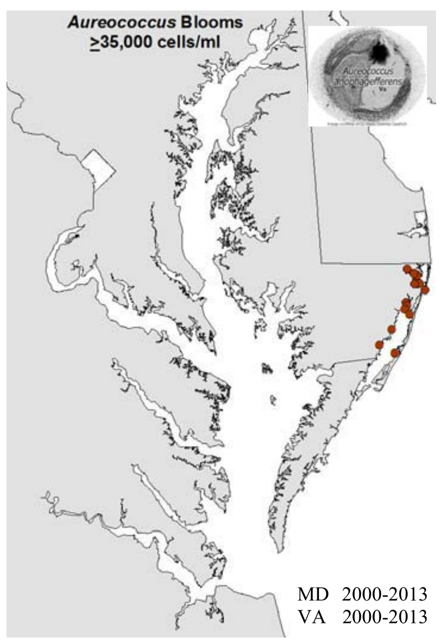
Cochlodinium polykrikoides

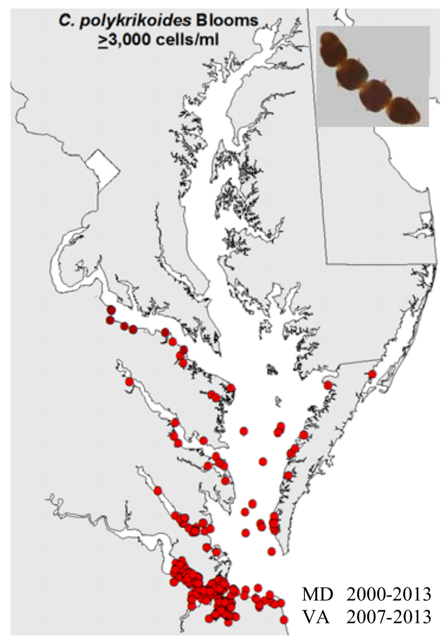
This large (30-40 µm x 20-30 µm) chlorophyll-containing, unarmored dinoflagellate is found globally, forming small to many celled chains. In the Bay, it arises from cyst beds following summer rain events (mid to late July), and expands through division and transport to cover much of the lower James and York Rivers. These 'mahogany-tide' blooms are harmful to early life stages of fish and shellfish but not people and should be detectable with remote sensing.

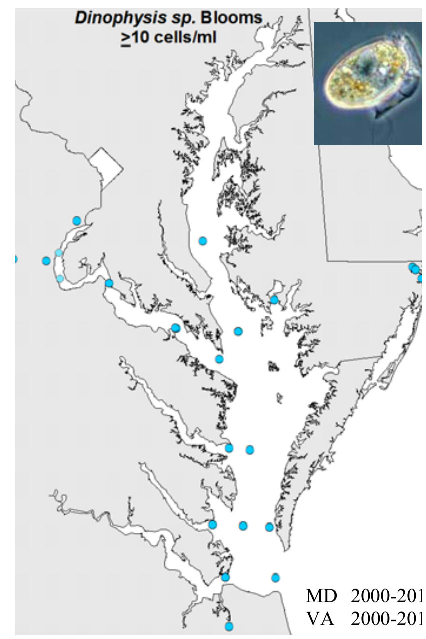
Dinophysis spp.

This is a coastal ocean dinoflagellate that can contain some to no pigments. *Dinophysis* produces okadaic acid as well as other toxins that lead to diarrhetic shellfish poisoning, DSP. Primarily blooms subsurface in thin layers. Only occasionally seen in the Chesapeake, it often blooms in the MD coastal bays (blooms Jan-June). In 2002, the lower Potomac had a temporary closure of oyster harvests. Its delivery up-bay is tied to presence in coastal waters as well as drought conditions. At bloom levels (10 cells/ml), it is still scarce and likely not detected with remote detection.



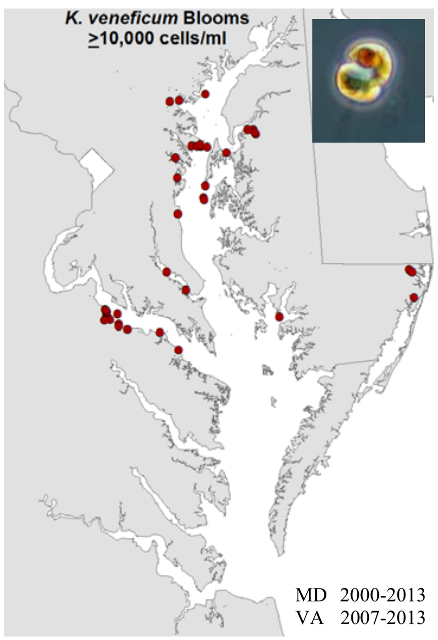






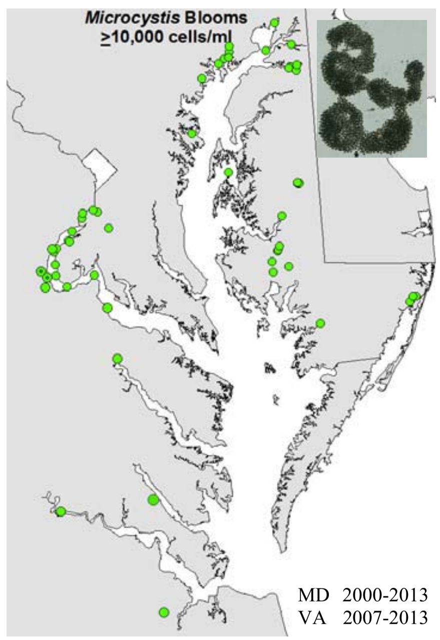
Karlodinium veneficum

This is a small (9-18 µm x 7-14 µm) chlorophyll-containing dinoflagellate common to the Bay and its tributaries producing ichthyotoxins named karlotoxins. Known as the 'fish-killer,' the toxins now number 5 varieties and are toxic or allelopathic to most taxa containing cholesterol, i.e., phytoplankton, protozoa, and metazoans. The taxon is generally a spring-to-fall species. It is autotrophic and mixotrophic with faster growth rates when feeding on prey, often cryptophytes. It is detectable using remote sensing.



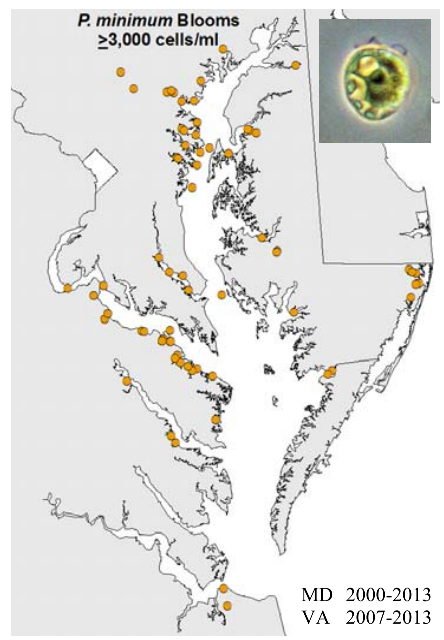
Microcystis aeruginosa

This is a fresh to brackish cyanobacterium (2-3 µm sphere), that is a global problem as high biomass or toxic blooms. Single small cells rich in chlorophyll and phycobilin accessory pigments which form large, visible scums on the surface. This species can produce liver toxins (microcystins) and neurotoxins. Populations exhibit daily vertical movement, rising to the surface in the early day from gas-filled vesicles and descending in late afternoon. Populations are poorly grazed. It is a summer bloomer that can be detected remotely using the Great Lakes cyano-index.



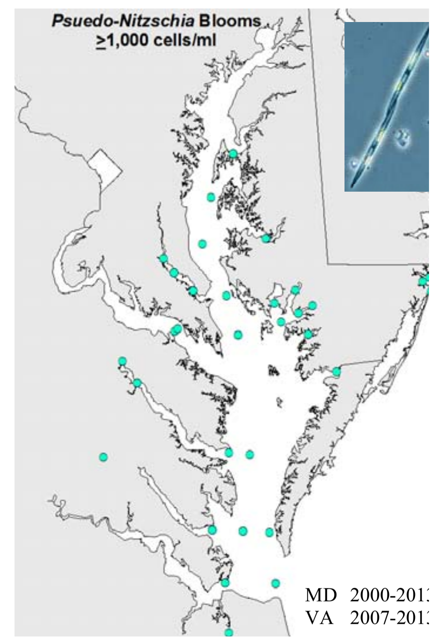
Prorocentrum minimum

Blooms of this chlorophyll-rich dinoflagellate (14-22 µm x 10-15 µm) are called 'mahogany tides' and are a normal constituent of the late spring, post-diatom bloom community. They are transported throughout the bay at or near the pycnocline during the winter-early spring, followed by mixing into surface waters in May. Some non-U.S. strains are toxic to shellfish, but most often *P. minimum* is regarded as benign in bay. However, it does contribute to low oxygen and the dead zone. Should be easily detected as an increase in chlorophyll.



Pseudo-nitzschia spp.

This genus contains chlorophyll-bearing pennate (long & narrow) diatoms that can produce domoic acid a neurotoxin that causes amnesic shellfis poisoning, ASP, in Canada, CA, LA, and the Northwest, and then most othe continents. Several *Pseudo-nitzschia* species have been identified in CB in cooler months, but densities are very low and domoic acid production is low to undetectable. Hence, the genus doe not pose a threat to human health or other fauna at this time. The very low densities would prevent detection usin remote sensing.



Compiled by: Todd Egerton (Old Dominion University), Margaret Mulholland (Old Dominion University), Kevin Sellner (Chesapeake Research Consortium), and Catherine Wazniak (Maryland Department of Natural Resources)

Harmful Algae in the Chesapeake and Coastal Bays of MD and VA (cont.)

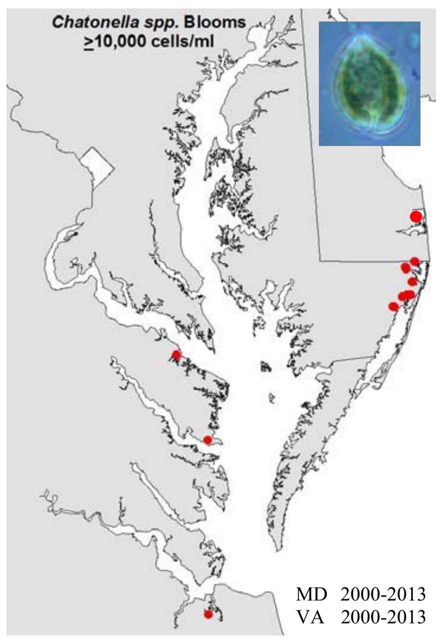
Raphidophytes (*Chattonella, Fibrocapsa, Heterosigma*)

Delaware's coastal bays and a portion of Maryland's are frequented by several raphidophyte species (~10 µm bi-flagellated cells) that can yield fish mortalities or low dissolved oxygen events. These are usually observed in upper tributaries or the small nutrient-rich, long-residence time canals of the coastal bays, often summarized by Delaware's Citizen Monitoring Program (http://citizen-monitoring.udel.edu/).

Raphidophytes are pigment rich making remote sensing possible. However, the small size of the canals may result in insufficient pixel resolution in the satellite images, at least until the cells are transported into the larger, open bays.

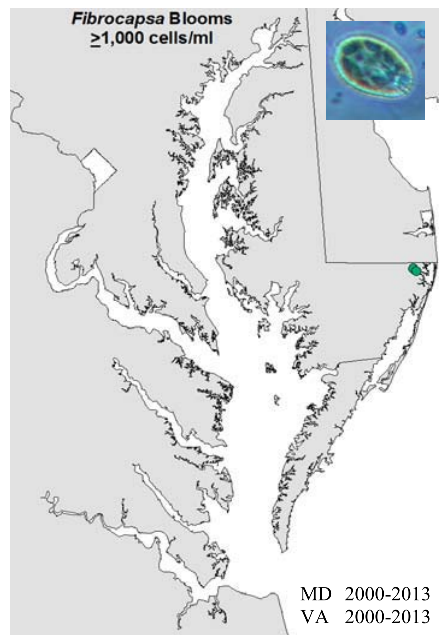
Chattonella

Chattonella cf. *verruculosa* (aka *Chloromorum toxicum)* and *Chattonella subsalsa* are two species that can produce brevetoxins (causes Neurotoxic Shellfish Poisoning). Brevetoxin is also produced by *Karenia brevis*, a species associated with FL red tides, fish kills/sea mammal deaths. Exposure to brevetoxins can cause itchy skin, runny nose, watery eyes, and respiratory irritation akin to an asthma attack. *C.* cf *verruculosa* has been associated with large fish kills in other areas, and was implicated in a fish kill event in DE during 2000. No evidence of toxic activity in MD.



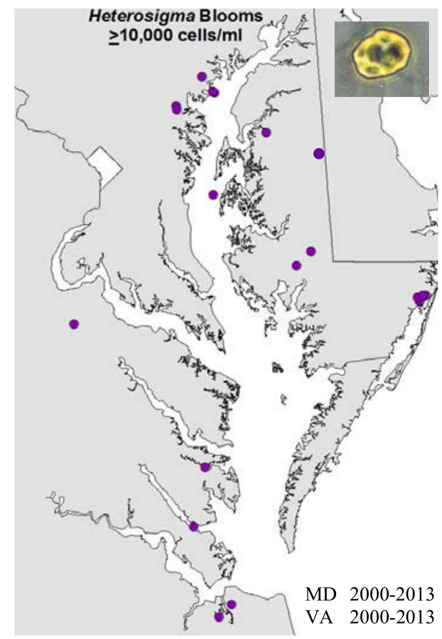
Fibrocapsa

Fibrocapsa has had devastating impacts on mariculture operations in Japan. Strains of *F. japonica* from the North Sea in Europe have been capable of producing a toxin that killed fish in laboratory studies. Two seals that died in the Wadden Sea in Germany were found to have high levels of the toxin fibrocapsin. North Sea strains of *F. japonica* grow well at 11-25°C, 20-30 salinity. While found in the Chesapeake Bay region, it has never bloomed there. Blooms have been found in the Maryland coastal bays.



Heterosigma akashiwo

Heterosigma is more wide spread. *H. akashiwo* is found on both coasts of the US and is considered the causative organism in offshore fish farm kills in Washington state and Japan. Blooms prefer warmer temperatures (>15 °C) and moderate salinity (~15). Blooms can persist as long as stable water strati fication persists in the warmer months. An unidentified ichthyotoxin (fish killing toxin) and reactive oxygen species (ROS) have been suggested as the caus ative agent in mariculture fish kills. No documented effects to humans**.**



Macroalgae in the Coastal Bays and *Lyngbya*

Macroalgal Blooms

Dense accumulations of macroalgae (seaweed) have been observed in the DE and MD coastal bays as well as some areas in the Chesapeake Bay. They can lead to <u>substantial shading of underwater grasses and low dissolved oxygen</u> events through nocturnal respiration and/or decomposition. Largely ungrazed, these blooms can also impede recreational boating. Brown algae (pheophytes) are not a dominant type but red and green are abundant. Large and chlorophyll-rich, these algae should be detectable with remote sensing, if they remain in the euphotic zone.

Rhodophytes, Red Algae

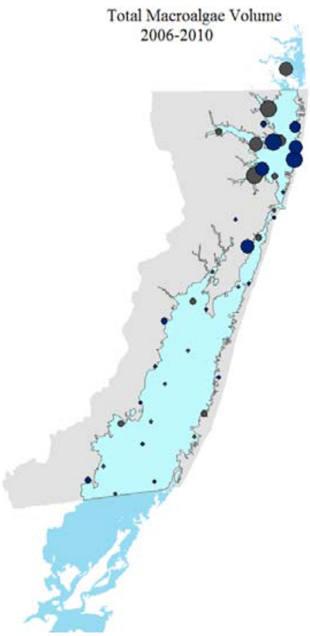
The Agarh's Red Weed (*Agardhiella tenera*) is the dominant species in the MD coastal bays with Graceful Red Weed (*Garcilaria sp.*) second. These two genera are the most characteristic plants in warm bays and sounds south of Cape Cod. Red algae are commercially raised and harvested for their agar and carrageenans which are used in the food, cosmetic, and medical industry. *Gracilaria tikvahiae* is often found in areas undergoing eutrophication.

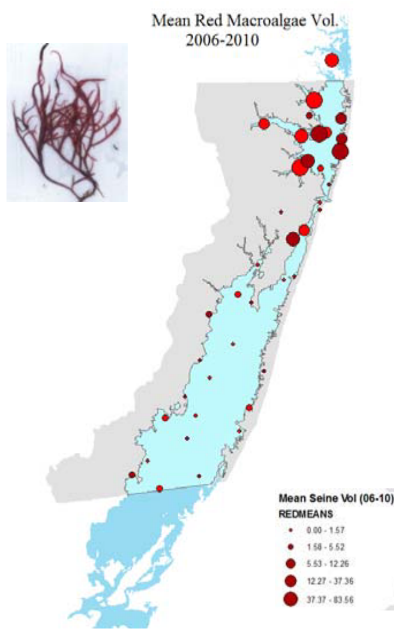
Chlorophytes, Green algae

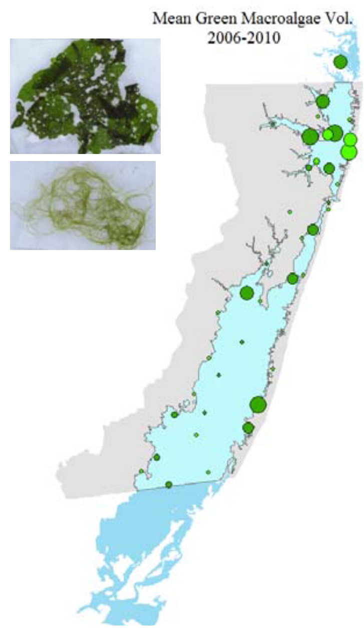
Green Hair Algae (*Chaetomorpha sp.*) and Sea Lettuce (*Ulva*) were the most abundant green macroalgae. *Ulva* was widespread throughout the coastal bays and present during all seasons. *Ulva* spp. have been associated with eutrophication. The state of Delaware found *Ulva* to be so abundant that they initiated a harvesting program to reduce the threat to habitat, through depleted dissolved oxygen. *Ulva* is initially attached, but in later stages of life is free drifting.

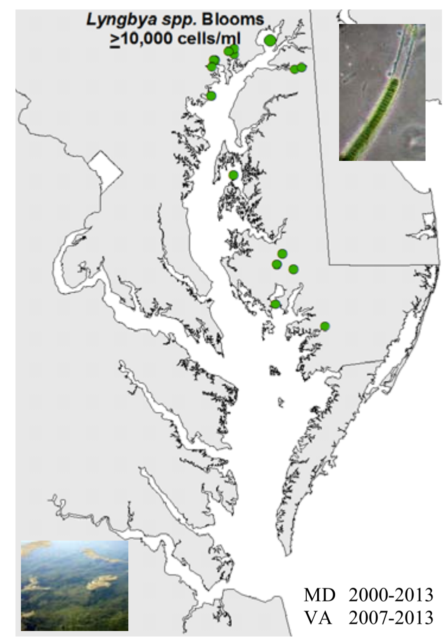
Lyngbya spp.

Lyngbya is a benthic, filamentous cyanobacteria. The wool-like strands often clump together and rise to the surface forming large floating mats. Found in lakes, rivers, springs, and water supply reservoirs throughout southeastern US, it is capable of forming thick nuisance blooms during the summer months under optimal growing conditions (24°C and favourable light). It is a problem in Florida where toxins cause <u>skin and gastrointestinal inflammation</u>. In the northern bay it has fouled crab pots an fishing gear, and covered seagrass beds.









Compiled by: Todd Egerton (Old Dominion University), Margaret Mulholland (Old Dominion University), Kevin Sellner (Chesapeake Research Consortium), and Catherine Wazniak (Maryland Department of Natural Resources)

APPENDIX 4a

HARMFUL ALGAE BLOOM MANAGEMENT

IN THE CHESAPEAKE AND COASTAL BAYS

The assessment of algal blooms in the Chesapeake and coastal bays is led by state agencies. In Maryland, the Department of Environment (MDE), the Department of Health and Mental Hygiene (DHMH), and the Department of Natural Resources (DNR) collaborate to manage a state-wide harmful algae bloom (HAB) surveillance program. Virginia's HAB program includes the Virginia Department of Environmental Quality, the Virginia Department of Health (VDH), and other state partners who routinely monitor the main bay and tributaries and respond to and investigate causes of fishkills. **The Chesapeake and coastal bays HAB surveillance programs focus on protecting public health and the environment by protecting beaches and recreational waters as well as growing areas for shellfish from effects associated with toxins produced by harmful algae.**

Table 1: FDA's action levels for toxins associated with marine biotoxins that can accumulate in shellfish**.** *Since test methods for marine biotoxins in shellfish meats are expensive and our region has not seen action levels or reported illnesses, cell counts are used instead of toxin assays to monitor potentially harmful blooms***.** The last column shows the bloom levels that raise the level of concern in MD and VA.

Algal species	**Main Toxin**	**Shellfish Related Illness**	**Action Level**	**Food Commodity**	**Bloom Level of Concern**
Alexandrium. tamarense species complex	Saxitoxin	Paralytic Shellfish Poisoning	80 µg/100g	All Fish	≥ 500 cells/ml
Karenia brevis, Chattonella	Brevetoxins	Neurotoxic Shellfish Poisoning	20 MU/100g	Clams, mussels, oysters, fresh frozen or canned	*Chatt sp* >10,000 cells/ml
Dinophysis	Okadaic acid, dinophysis toxins, yessotoxins, pectenotoxins	Diarrhetic Shellfish Poisoning	0.16 mg/kg	Clams, mussels, oysters, fresh frozen or canned	≥10 cells/ml
genus *Pseudo-nitzschia*	Domoic Acid	Amnesic Shellfish Poisoning	20 mg/kg	All Fish (except viscera of Dungeness crab)	≥1,000 cells/ml

Both state HAB programs employ field response, phytoplankton identification, laboratory analysis, and management actions as appropriate to protect public health and the environment. State agencies coordinate with local health departments and researchers at regional universities. Analytical support is provided by DNR, MDE, and the University of Maryland Center for Environmental Science Institute of Marine and Environmental Technology in Maryland and Old Dominion University and the Virginia Institute for Marine Science in Virginia. Both states also work closely with the U.S. Food and Drug Administration (FDA) and the Centers for Disease Control and Prevention. FDA has provided guidance for states to use through the Fish and Fishery Products Hazards and Controls Guide and the National Shellfish Sanitation Program (NSSP) (Table 1). Through this program, FDA has established action levels, tolerances, and guidance levels for poisonous or deleterious substances in seafood, including marine biotoxins in fish and shellfish. For Maryland and Virginia, marine biotoxins pose the greatest concern for molluscan shellfish, and both states have biotoxin contingency plans that outline surveillance and management procedures. FDA's action levels for diarrhetic shellfish poisoning, paralytic shellfish poisoning, neurotoxic shellfish poisoning, and amnesic shellfish poisoning are presented in the NSSP Model Ordinance included in the Guide for Control of Molluscan Shellfish.

No federal regulatory guidelines for cyanobacteria or their toxins currently exist in the United States. Maryland has issued advisories against water contact in certain lakes and streams due to microcystin produced by blue green algae. Maryland uses a microcystin threshold of 10 µg/l to issue "no contact" advisories while Virginia uses 6 µg/l. Virginia also uses > 100,000 *Microcystis aeruginosa* cells /mL, or agency confirmed blue-green algal "scum" or "mats" on water surfaces to issue no contact advisories. Drinking water guidelines are based on the World Health Organization provisional value of 1.0 µg/L microcystin-LR.

Other regional HABs are known to starve shellfish (*Aureococcus anophagefferens*), kill fish without apparent harm to people (*Karlodinium veneficum*), produce toxins whose effects have not yet been described (*Cochlodinium polykrikoides*), or disrupt ecosystem function (*Prorocentrum minimum* and dense macroalgae blooms). These blooms continue to be monitored by Maryland, Virginia, and their University partners to document their extent and impacts (Table 2).

When significant HAB events occur in Maryland, DHMH, MDE, and DNR coordinate with local health departments to inform the public through media advisories, posted signs, and postings on multiple websites including DNR's Eyes on the Bay[1], MDE's Healthy Beaches webpage[2], and DHMH's HAB webpage[3]. In Virginia, advisories are also coordinated with local health departments and are issued through media releases, posted signs, and VDH's website[4]. Generally, advisories do not impact fishing, because HAB-related toxins tend to accumulate in internal organs rather than fish parts that are consumed.

Table 2: Algae species, toxins, and bloom levels of concern for ecosystem impacts.

Algal species	Main Toxin	Impacts	Action Level	Bloom level of Concern
Aureococcus anophagefferens	None	Starve shellfish Shade seagrasses	N/A	35,000 cells/ml
Cochlodinium polykrikoides		Lethal to early life stages of fish and shellfish	N/A	500 cells/ml
Karlodinium veneficum	Karlotoxins	Lethal to fish	N/A	10,000 cells/ml
Microcystis aeruginosa	Microcystin	Liver toxin Can bioaccumulate	VA: 6 µg/l MD: 10µg/l in recreational waters	40,000 cells/ml
Prorocentrum minimum	none	Contributor to dead zones	N/A	10,000 cells/ml

[1] http://mddnr.chesapeakebay.net/eyesonthebay/habs.cfm
[2] http://www.marylandhealthybeaches.com/
[3] http://phpa.dhmh.maryland.gov/OEHFP/EH/SitePages/harmful-algae-blooms.aspx
[4] www.vdh.virginia.gov/epidemiology/DEE/HABS/HABmap.htm

APPENDIX 5a

REMOTE SENSING HARMFUL ALGAL BLOOMS POTENTIAL PRODUCTS

NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE (NCCOS)
SCIENCE SERVING COASTAL COMMUNITIES

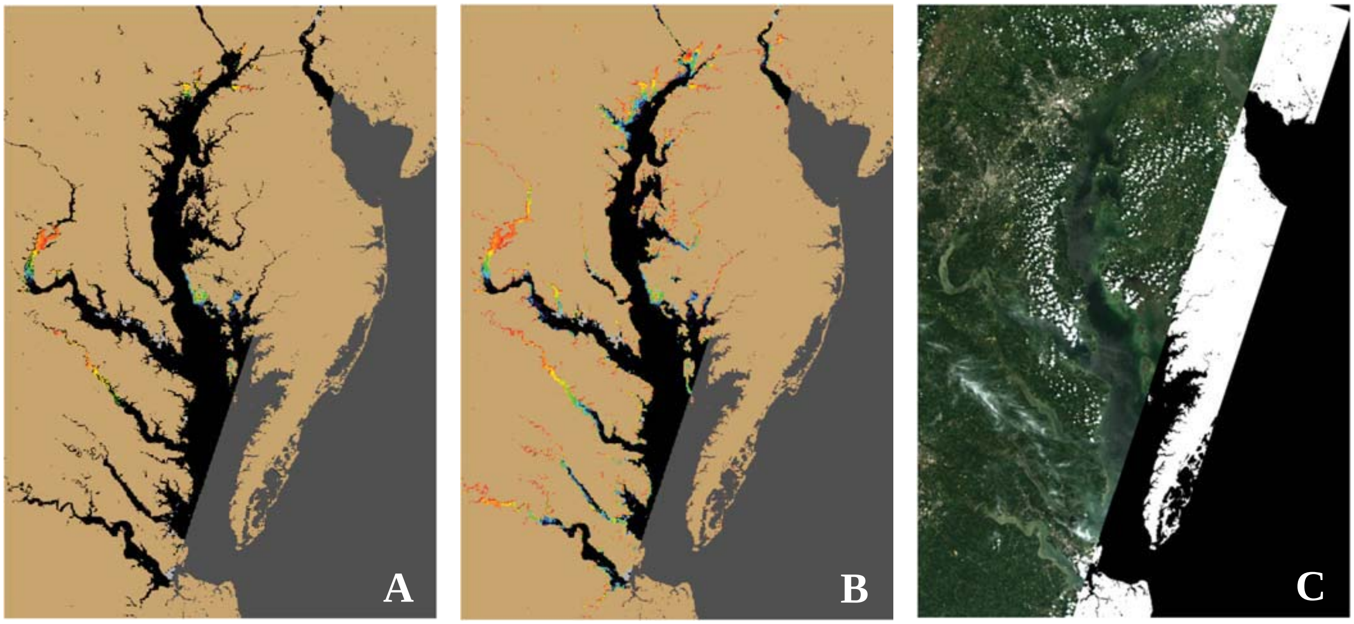
Satellite imagery can help in monitoring for harmful algal blooms (HABs), especially cyanobacteria species and high concentration events for other bloom taxa. Satellite imagery data collected from the European Space Agency's MERIS instrument has been particularly effective with its 300 m resolution, 2-day repeat orbit, and sufficient spectral bands to estimate biomass and detect cyanobacteria blooms in estuaries and lakes. While MERIS data ceased in 2012, the Ocean Land Colour Imagery (OLCI) instrument will replace this capability when its host satellite is launched next year. MERIS-calibrated products should be directly transferable to OLCI. In addition, the Moderate Resolution Imaging Spectrometer (MODIS) sensor is available and provides a chlorophyll product. However, due to the limitations in spatial (1,000 m resolution) and spectral resolution, MERIS is more suitable for use in the Chesapeake and coastal bays.

Example remote sensing products for the Chesapeake and coastal bays could include materials such as the GIS format images, as seen below. Additionally, bulletins, similar to those disseminated for Lake Erie and Florida, could be developed to disseminate remote sensing products and information. Example bulletins are included in the workshop materials for both Florida and Lake Erie. The bulletins are distributed via email to subscribers once-to-twice a week during active HAB periods. The subscriber list often includes members from public health, natural resources, and scientific fields. The bulletins can contain information regarding forecasts, field operations, public health information, buoy data, models, and analyses of ocean color satellite imagery. More information regarding these bulletins can be found on NOAA’s tides and currents website, www.tidesandcurrents.noaa.gov/hab/bulletins.html. *Note: The lower resolution MODIS sensor has provided adequate data to continue the Lake Erie bulletin in summers of 2012 and 2013.*

by Richard Stumpf and Michelle Tomlinson, NOAA NCCOS

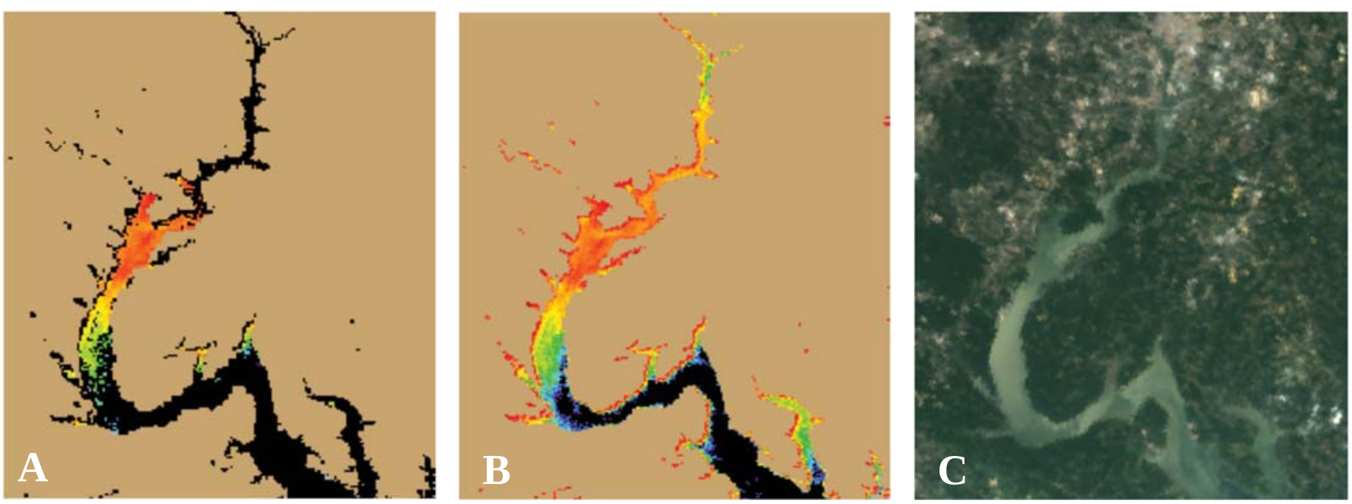
APPENDIX 5b

AUGUST 23, 2011 EXAMPLE CHESAPEAKE BAY IMAGERY



MERIS high resolution (300m) images for Chesapeake Bay on August 23, 2011. (A) Cyanobacterial Index (CImulti) image showing location of cyanobacterial blooms throughout the Chesapeake Bay. A large confirmed *Microcystis aeruginosa* bloom is visible in the Potomac River. (B) A more general Bloom Index (CI) product showing all blooms detected in the CB for the day. In both (A) and (B) warmer colors indicate higher biomass. (C) True color image. *Note: True color imagery is not conducive to monitoring blooms.*

AUGUST 12, 2011 EXAMPLE POTOMAC RIVER IMAGERY



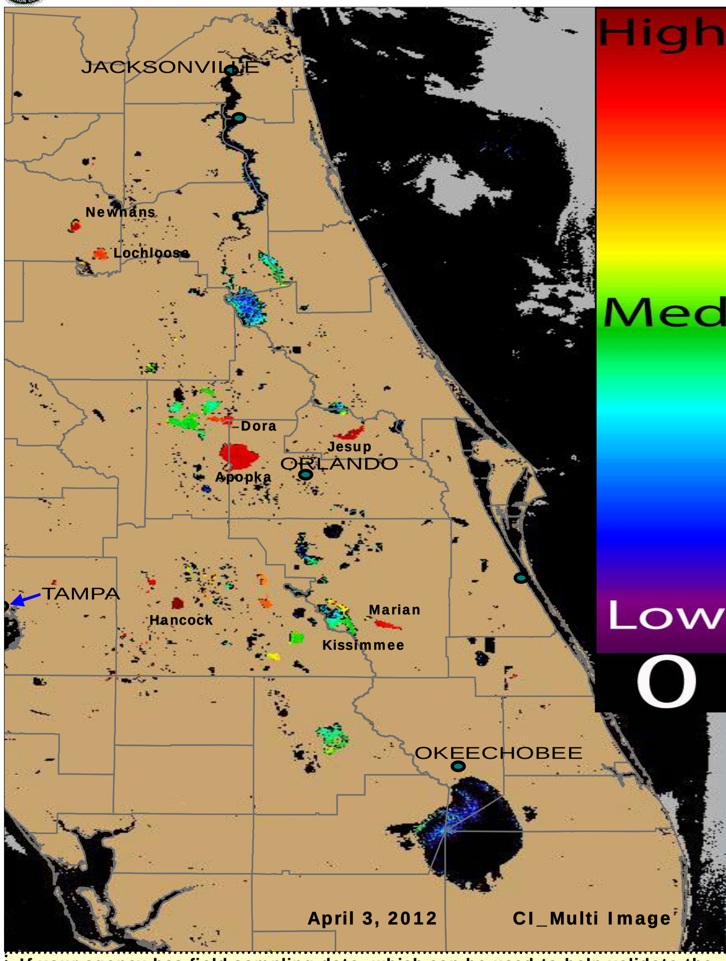
MERIS high resolution (300 m) images for the Potomac River on August 12, 2011. (A) Cyanobacterial Index image showing location of *M. aeruginosa* bloom. (B) Bloom Index product showing all blooms. (C) True color image.

For more information, please contact: Rick Stumpf (richard.stumpf@noaa.gov) or Shelly Tomlinson (michelle.tomlinson@noaa.gov).

Experimental Cyanobacteria Health Bulletin: April 3, 2012

To report an illness related to a marine toxin or algal bloom please contact the Florida Poison Information Center-Miami Aquatic Toxins Hotline at 1-888-232-8635.

For questions about the report: contact Becky Lazensky, FL-DOH, at 352-955-1900. Images/data were obtained from Florida Water Management Districts, The National Oceanic and Atmospheric Administration (NOAA), NOAA National Climatic Data Centers and National Weather Centers. Support to produce this report was received through a NOAA/NASA Agreement (Number: NNH08ZDA001N)



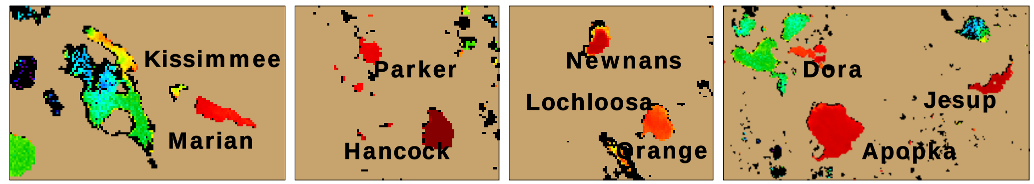
If your agency has field sampling data, which can be used to help validate the MERIS imagery, Contact Becky Lazensky at: 352-955-1900

MERIS Satellite Images display a cyanobacteria index generated with a Medium Resolution Imaging Spectrometer satellite provided by the European Space Agency & NOAA.

Very low likelihood of a bloom
May indicate clouds or missing data
Low estimated cyanobacteria concentrations
Medium estimated cyanobacteria concentrations
Probable bloom or higher est. cyano. concentrations

Cyanobacteria HABs Conditions Report: April 3

- Lakes Kissimmee and Marian (Osceola County) displayed medium and high estimated cyanobacteria concentrations
- Lakes Parker and Hancock (Polk County) displayed high estimated cyanobacteria concentrations
- Newnans, Lochloosa, & Orange Lakes (Alachua & Marion Counties) and Jesup, Dora, and Apopka Lakes (Seminole, Lake, and Orange Counties) displayed high estimated cyanobacteria concentrations



ENVISAT SATELLITE IS DOWN-Impacts on MERIS Images

Envisat (Photo courtesy of European Space Agency)

On April 8th, communications between the European Space Agency (ESA) and the Envisat satellite were lost. The Envisat satellite platform carries the MERIS sensor which captures the images featured in this bulletin. This will impede the production of MERIS satellite imagery until repairs are made or a new satellite is launched. The last MERIS image we have is the April 3rd image. NOAA may provide alternative MODIS imagery until communications are re-established. We will keep everyone updated on the progress. For more information visit: http://www.nature.com/news/workhorse-climate-satellite-goes-silent-

Algal Bloom on the Caloosahatchee River-Update: April 13th

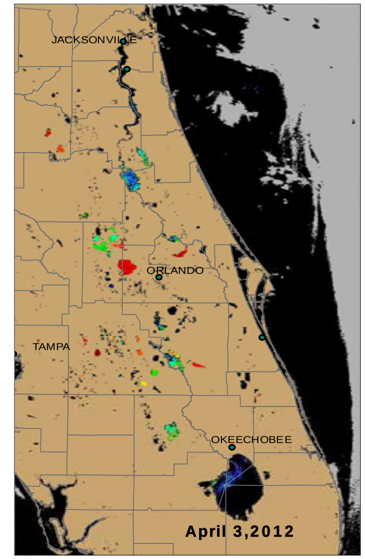
Olga, FL: An ongoing cyanobacteria bloom was reported in the Caloosahatchee River. Samples collected on April 2nd were positive for Planktothrix and Anabaena/Aphanizomenon dominant species. (Green Water Laboratories). These species of algae are potential toxin producers. Toxin testing is being conducted by Green Water Laboratories. The South Florida Water Management District plans to send down pulses of freshwater from Lake Okeechobee to 'flush' out the river and increase flows to the Caloosahatchee. The Lee County Health Department has issued a health advisory for the river.

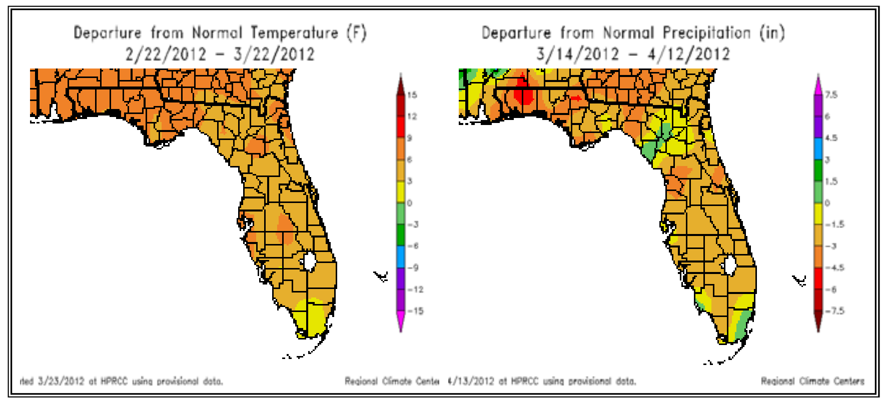
Interpreting Medium Resolution Imaging Spectrometer Satellite Imagery

- The medium resolution imaging spectrometer (MERIS) is located on the Envisat satellite deployed by the European Space Agency.
- The cyanobacterial index algorithm is designed to identify high biomass algal blooms caused by cyanobacteria. However, the current algorithm tends to have false positives, so other blooms may be "flagged". NOAA is currently testing new algorithms that are more specific to cyanobacteria.
- Data can be used to estimate near surface cyanobacteria concentrations which are an indication that algal blooms may be present.
- The algorithms used to generate the satellite images can vary, resulting in some models having a higher likelihood of detecting surface blooms. The satellite identifies the biomass near the surface (in the upper few feet of water). As a result, it may underestimate the total biomass for blooms that are mixed or dispersed through the water column. Turbidity does not otherwise influence the algorithms.
- The satellite imagery does not display the species of algae present.
- While patches of red or warm colors may indicate a bloom, these data have not been verified in most cases using ground-truth methods. Data collected by the satellite is considered experimental.
- Only part of FL is in the satellite's coverage area.
- Several environmental factors may affect how results can be interpreted. For example, areas with abundant aquatic vegetation may present with a high cyanobacteria index on the color spectrum, resulting in a false positive bloom reading.

Weather Conditions: March 14- April 12 Temperature and Precipitation

- Weather conditions can impact the duration and location of blooms and the satellite imagery shown in this report may no longer be relevant. Images represent the last image taken with a realization that blooms may have moved, dissipated or intensified.
- Cloud coverage can obscure imagery and create patches or gray areas on map and obscure bloom detection.





To review HABs satellite reports in the Gulf of Mexico and marine waters visit the NOAA Harmful Algal Bloom Operational Forecast System bulletin archive at: http://tidesandcurrents.noaa.gov/hab/bulletins.html

For Individual Weather Station Data Visit:
http://www.sercc.com/climateinfo/historical historical_fl.html

Questions about the report or suggestions: You can contact
Becky Lazensky, MPH
352-955-1900
Becky_Lazensky@doh.state.fl.us

APPENDIX 7

Experimental Lake Erie Harmful Algal Bloom Bulletin

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

26 September 2013; Bulletin 21

The bloom's intensity is concentrated along the western shore, in Brest Bay and around Sterling State Park. Microcystis concentrations have continued to decline. No scum formation was seen in the imagery, even with the relatively low winds. Water temperature is still above 15 C (59 F), the threshold below which the bloom declines rapidly, so change will be slow over the next week.

The model forecasts for a slight northeastern movement over the next few days.

- Dupuy, Stumpf

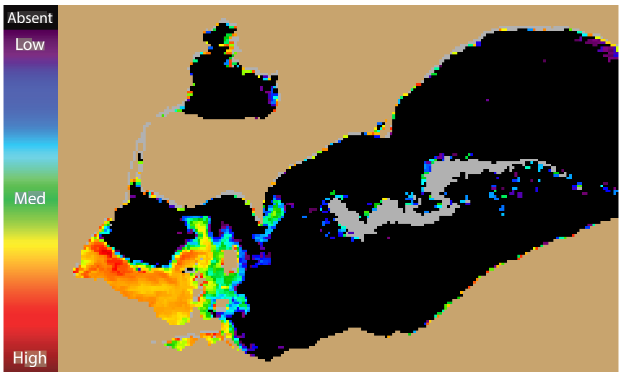


Figure 1. MODIS Cyanobacterial Index from 24 September 2013. Grey indicates clouds or missing data. Black represents no cyanobacteria detected. Colored pixels indicate the presence of cyanobacteria. Cooler colors (blue and purple) indicate low concentrations and warmer colors (red, orange, and yellow) indicate high concentrations. The estimated threshold for cyanobacteria detection is 35,000 cells/mL.

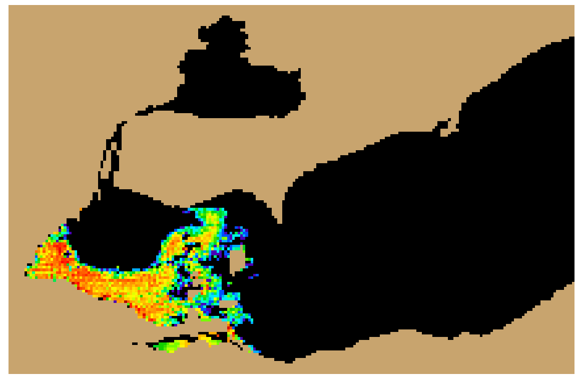


Figure 2. Nowcast position of bloom for 29 September 2013 using GLCFS modeled currents to move the bloom from the 24 September 2013 image.

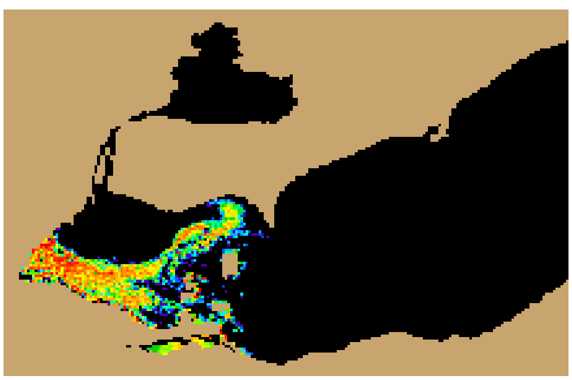
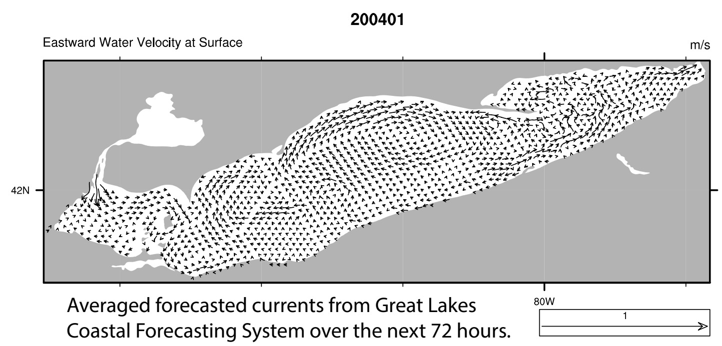
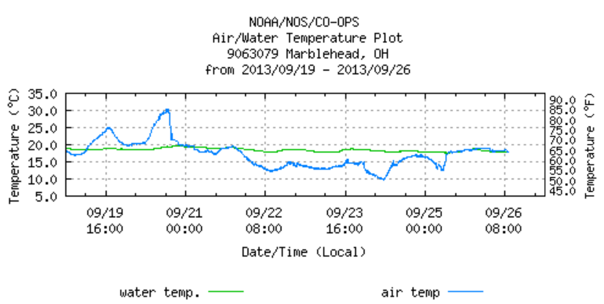


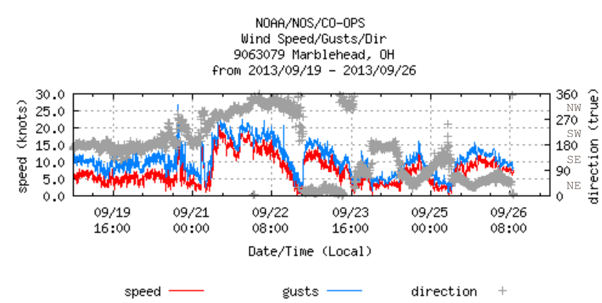
Figure 3. Forecast position of bloom for 29 September 2013 using GLCFS modeled currents to move the bloom from the 24 September 2013 image.



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



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



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).

For more information and to subscribe to this bulletin, go to : http://www.glerl.noaa.gov/res/Centers/HABS/lake_erie_hab/lake_erie_hab.html

APPENDIX 8

POST WORKSHOP ASSESSMENT SURVEY

SUMMARY OF RESULTS

After conducting the remote sensing harmful algal bloom workshop, a post survey was distributed to all attendees in May 2014. This survey sought to capture additional input and opinions of the workshop participants. We asked for feedback on portions of the workshop including the presentations, break-out activities, and discussions. Additionally, the survey included questions that allowed participants to give additional input on discussion topics. We received thirteen responses from mostly academic participants and used these results to help evaluate the effectiveness of the workshop. Expanded details from the survey are available from Maryland Sea Grant upon request.

WORKSHOP EVALUATION

This section of questions evaluated the presentations, activities, and overall organization of the workshop. The survey responders rated the overall organization (average 1.75), presentations (1.71), and the activities (1.95) on a scale of excellent (1), very good (2), good (3), average (4), and poor (5). Additional comments from the responders mentioned that the weTable technology was helpful, especially for visualizing the remote sensing imagery in a small group setting. The workshop materials that were distributed were ranked between excellent and very good (1.71).

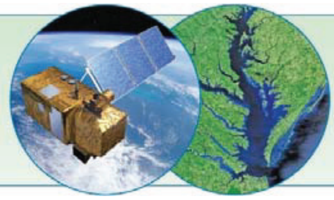
HAB VIEWER

The workshop participants were asked about their interest in and the utility of the HAB Viewer website. 75% of the people who answered said that they would use the HAB Viewer if it had current imagery of the Chesapeake and coastal bays. Only 50% would use the website for historical data and 63% would use the website to download data for their own use (n=8).

IDENTIFIED RESEARCH GAPS

During the workshop, we asked participants to identify and rank research gaps relevant to harmful algal bloom remote sensing. From the discussion and post workshop survey, the highest ranked gaps were: “nowcasting” and forecasting bloom distributions, developing threshold levels for issuing species-specific alerts, and improving detection of specific taxa from remotely sensed data.

APPENDIX 9a



Remote Sensing Harmful Algal Bloom Workshop
CHESAPEAKE AND COASTAL BAYS REGION
Thursday, May 1, 2014
O'Callaghan Hotel, 174 West Street, Annapolis, Maryland

REGISTERED PARTICIPANTS

Michael Allen
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-6372
mallen@mdsg.umd.edu

Jeffrey Brainard
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-6377
brainard@mdsg.umd.edu

Kathy Brohawn
Maryland Department of Environment
Science Services Administration
Montgomery Park
1800 Washington Blvd
Baltimore, MD 21230
410-537-3608
kathy.brohawn@maryland.gov

Christopher Brown
NOAA
5825 University Research Ct., Suite 4001
College Park, MD 20740
301-405-8031
christopher.w.brown@noaa.gov

Arthur Butt
Commonwealth of Virginia
Department of Environmental Quality
629 E Main Street
Richmond, VA 23219
804-698-4314
arthur.butt@deq.virginia.gov

Vicky Carrasco
Department of Agricultural and Resource Economics
2115B Symons Hall
University of Maryland
College Park, MD 20742
301-405-5809
vcarrasc@umd.edu

Jenna Clark
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-6375
clark@mdsg.umd.edu

Sean Corson
NOAA, Chesapeake Bay Office
410 Severn Ave, Suite 207
Annapolis, MD 21403
410-627-0336
sean.corson@noaa.gov

Danielle Dupuy
NOAA NCCOS
1305 East-West Highway
Silver Spring, MD 20910
301-713-4383 ext 147
danielle.dupuy@noaa.gov

Todd Egerton
Old Dominion University, Biological Sciences
Norfolk, VA 23529
757-683-4994
tegerton@odu.edu

Chunlei Fan
Morgan State University
Patuxent River Environmental and Aquatic Research Laboratory
1700 E. Coldspring Lane
Baltimore, MD 21251
443-885-4468
chunlei.fan@morgan.edu

Michael Fincham
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-6382
fincham@mdsg.umd.edu

Adam Griggs
Interstate Commission on the Potomac River Basin
30 West Gude Drive, Suite 450
Rockville, MD 20850
301-274-8103
agriggs@icprb.org

APPENDIX 9b

Adrienne Hieb
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-6371
hieb@mdsg.umd.edu

Roman Jesien
Maryland Coastal Bays Program
9919 Stephen Decatur Highway
Ocean City, MD 21842
410-231-2297
rjesien@mdcoastalbays.org

Clifford Mitchell
Environmental Health Bureau
Maryland Department of Health and Mental Hygiene
201 West Preston Street, Room 327
Baltimore, MD 21201
410-767-7438
Cliff.Mitchell@maryland.gov

Fredrika Moser
Maryland Sea Grant
4321 Hartwick Ave, Suite 300
College Park, MD 20740
301-405-7500
moser@mdsg.umd.edu

Wesley Moses
Naval Research Laboratory
Remote Sensing Division
4555 Overlook Ave SW
Washington, DC 20375
402-560-8428
wesley.moses@nrl.navy.mil

Margaret Mulholland
Old Dominion University
Ocean, Earth and Atmospheric Science
4600 Elkhorn Avenue
Norfolk, VA 23529
757-683-3972
mmulholl@odu.edu

Diana Muller
South River Federation
2830 Solomon's Island Rd, Suite A
Edgewater, MD 21037
443-534-2847
riverkeeperdiana@southriverfederation.net

Aimee Neeley
NASA/GSFC/SSAI
8800 Greenbelt Road
Mail Code 616.1
Greenbelt, MD 20771
301-614-5778
aimee.neeley@nasa.gov

Judith O'Neil
UMCES, Horn Point Laboratory
2020 Horns Point Rd
P.O. Box 775
Cambridge, MD 21613
410-221-8411
joneil@umces.edu

Susan Park
Virginia Sea Grant
P.O. Box 1346
1375 Greate Rd
Gloucester Point, VA 23062
804-684-7436
spark@vims.edu

Kathy Phillips
Assateague Coastkeeper
P.O. Box 731
Berlin, MD 21811
410-629-1538
Coastkeeper@actforbays.org

Allen Place
UMCES, Institute of Marine and Environmental Technology
701 East Pratt Street
Baltimore, MD 21202
410-234-8828
place@umces.edu

Kimberly Reece
Virginia Institute of Marine Science
Environmental and Aquatic Animal Health
P.O. Box 1346
Gloucester Point, VA 23062
804-684-7407
kreece@vims.edu

Kevin Sellner
Chesapeake Research Consortium
645 Contees Wharf Road
Edgewater, MD 21037
410-798-1283
sellnerk@si.edu

Richard Stumpf
NOAA, Coastal Ocean Science
1305 East-West Highway
N/SCI1
Silver Spring, MD 20910
301-713-3028 ext 173
richard.stumpf@noaa.gov

Brian Sturgis
National Park Service
Assateague Island National Seashore
7206 National Seashore Lane
Berlin, MD 21811
410-629-6075
brian_sturgis@nps.gov

APPENDIX 9c

Marc Suddleson
NOAA NCCOS
N\SCI2
1305 East-West Highway
Silver Spring, MD 20904
301-713-3338 ext 162
marc.suddleson@noaa.gov

Richard Tian
Chesapeake Bay Program Office
410 Severn Avenue
Suite 109
Annapolis, MD 21403
410-295-1328
rtian@chesapeakebay.net

Michelle Tomlinson
NOAA NCCOS
1305 East-West Highway
Rm 9116
Silver Spring, MD 20910
301-713-3028 ext 225
Michelle.Tomlinson@noaa.gov

Mark Trice
Maryland Department of Natural Resources
Tawes State Office Bldg D-2
580 Taylor Ave
Annapolis, MD 21401
410-260-8649
mtrice@dnr.state.md.us

Krisztian Varsa
University of Maryland
Sea Grant Extension
1114 Shawan Road
Cockeysville, MD 21030
410-771-1761
kvarsa@umd.edu

Ronald Vogel
NOAA, Center for Weather & Climate Prediction
5830 University Research Court
College Park, MD 20740
301-683-3313
Ronald.Vogel@noaa.gov

Alice Volpitta
Blue Water Baltimore
3545 Belair Road
Baltimore, MD 21213
410-236-9136
avolpitta@bluewaterbaltimore.org

Harry Wang
VIMS, Physical Sciences
1375 Grate Road
Gloucester Point, VA 23062
804-684-7215
hvwang@vims.edu

Catherine Wazniak
MD DNR
580 Taylor Ave
Annapolis, MD 21401
410-260-8638
cwazniak@dnr.state.md.us

Jeremy Werdell
NASA Goddard Space Flight Center
Ocean Biology Processing Group
NASA/GSFC Mail Code 616.2
Greenbelt, MD 21045
301-286-1440
jeremy.werdell@nasa.gov

Edward Whereat
UD Citizen Monitoring Program
UD CEOE
700 Pilottown Road
Rm 123 PEL
Lewes, DE 19958
302-645-4252
whereat@udel.edu

Jennifer Wolny
Maryland Department of Natural Resources
1919 Lincoln Drive
Annapolis, MD 21401
410-990-4532
jwolny@dnr.state.md.us

Meng Xia
University of Maryland Eastern Shore
Department of Natural Sciences
1 Backbone Street
Princess Anne, MD 21601
410-621-3551
mxia@umes.edu

www.mdsg.umd.edu