Workshop Report:
Toward Comprehensive Monitoring of Narragansett Bay

Held October 19, 2017
Coastal Institute Auditorium
University of Rhode Island’s Narragansett Bay Campus

CONTENTS

LIST OF ABBREVIATIONS

BART – Bay Assessment & Response Team

BCG – Biological Conditions Gradient

CI – Coastal Institute

CWA – Clean Water Act

EPSCoR – Established Program to Stimulate Competitive Research

HAB – Harmful Algal Bloom

LTER – Long Term Ecological Research

MERL – Marine Ecosystems Research Laboratory

NBC – Narragansett Bay Commission

NBEP - Narragansett Bay Estuary Program

NBFSM – Narragansett Bay Fixed Site Monitoring Network

NBNERR – Narragansett Bay National Estuarine Research Reserve

NOAA – National Oceanic and Atmospheric Administration

NSF – National Science Foundation

RI C-AIM – RI Consortium for Coastal Ecology Assessment, Innovation, and Modeling

RIDEM – Rhode Island Department of Environmental Management

RIDOH – Rhode Island Department of Health

RIEMC – Rhode Island Environmental Monitoring Collaborative

RWU – Roger Williams University

SNEP – Southeast New England Program

EPA – United States Environmental Protection Agency

EPA AED – EPA Atlantic Ecology Division

URI – University of Rhode Island

URI GSO – URI Graduate School of Oceanography

URI CELS – URI College of the Environment and Life Sciences

INTRODUCTION

The *Toward Comprehensive Monitoring of Narragansett Bay* workshop was held on October 19, 2017, at the CI Auditorium on URI's Narragansett Bay Campus. This workshop brought together approximately 50 representatives from federal government, state government, non-profit groups, and academic institutions to discuss the current status and future direction of environmental monitoring in Narragansett Bay.

The goals of the workshop were to summarize and discuss current monitoring efforts, identify gaps where additional monitoring is needed, and prioritize monitoring needs to fill identified data gaps. These goals did not include determining the cost of filling these data gaps or expanding current monitoring efforts; however, the relative costs of monitoring efforts were described. For example, replacing buoys for the NBFSMN is a relatively high cost activity while conducting an update of the benthic habitat surveys is a relatively low cost activity. This allowed the focus to remain on identification and prioritization of monitoring efforts and programs. A follow-up effort is needed to collect and synthesize in-depth information related to cost.

This one-day agenda alternated between series of five-minute "ignite" talks and group discussion, both as a full group and in smaller breakout groups of 10-15 people. Participants were provided with background materials prior to the workshop covering current monitoring programs and their statuses as identified by the RIEMC, known monitoring gaps as identified by NBEP in its *2017 State of Narragansett Bay and its Watershed* report, and an EPA report on the Biological Condition Gradient approach to management (Appendices E, F and G, respectively). All graphics were obtained from speaker slides (Appendix C) except where otherwise noted.

The workshop was funded as part of an EPA Southeast New England Program (SNEP) grant awarded to RIDEM, with a sub-award to the CI at URI.[1] The overall grant was a collaboration of key partners to strengthen capacity for data analysis and dissemination in order to support a framework of common environmental indicators applicable to Narragansett Bay. It consisted of three primary tasks:

1. Conduct data synthesis in support of understanding impacts of changing climate.
2. Coordinate a workshop to review indicators and assess linkages to monitoring strategies.
3. Enhance dissemination of information on environmental monitoring efforts and indicators to a broad audience through a new website.

This workshop was in support of the second task. The planning committee consisted of:

Nicole Rohr, CI & RIEMC
Sue Kiernan, RIDEM & RIEMC
Judith Swift, CI
Tom Borden, NBEP
Tara Franey, URI Department of Natural Resources Science

[1] EPA funding through the Health Communities Grant Program in association with the Southeast New England Program under assistance agreement 00A00185 to RIDEM.

The planning committee included three organizations active in RI environmental monitoring:

RIDEM is the primary state agency responsible for management of natural resources. In this role, RIDEM is responsible for water quality under the Clean Water Act (CWA) and reports to EPA on the implementation of the state's CWA program, including status of impaired waters.

RIEMC is chaired by the **CI** with RIDEM and NBC serving as vice chairs (RIGL §46-31-9). Other members represent federal and state agencies, academia, non-profit organizations, and private consulting groups. RIEMC is charged with developing and coordinating an environmental monitoring strategy that addresses critical state resource management needs. This in turn serves to provide the public and elected leaders with a deeper understanding of the status of Rhode Island's environment and natural resources.

NBEP is part of EPA's National Estuary Program to protect and restore the water quality and ecological integrity of Narragansett Bay and its watershed. In 2017, NBEP released its *State of Narragansett Bay and its Watershed* report, which tracked 24 indicators to "evaluate key stressors to Narragansett Bay and its watershed; assess the chemical, physical, and biological conditions; describe past and recent trends; look ahead to potential future changes; and identify data and research essential to advancing our understanding of these changes."

WORKSHOP AGENDA

8:30AM Welcome and Workshop Goals—Judith Swift and Nicole Rohr, CI
8:40AM Brief Overview of Rhode Island Monitoring—Sue Kiernan, RIDEM
8:50AM Biological Conditions Gradient—Giancarlo Cicchetti, EPA AED
9:00AM Current Monitoring: Moderator—Autumn Oczkowski, EPA AED
- Benthic Communities—Emily Shumchenia, Environmental Consultant
- Primary Productivity/Nutrients—Candace Oviatt, URI GSO
- Phytoplankton—Tatiana Rynearson, URI GSO
- Clarity/Chlorophyll—Eliza Moore, NBC
- Macroalgae—Carol Thornber, URI CELS
- HABs/Shellfish—David Borkman, RIDEM
- Fish—Joe Zottoli, URI GSO

9:45 AM Group Discussion: Moderator—Sue Kiernan, RIDEM
- Did we get the monitoring and gaps right? What would participants add?

10:30AM Break-out Groups: Prioritize gaps to best inform environmental health
12:30PM Opportunities to fill data gaps: Moderator—Nicole Rohr, CI
- New Data Synthesis/Tools—Q Kellogg, CI
- New Data Collection/Technology —Colleen Mouw, URI GSO
- Comprehensive Efforts—Bethany Jenkins, URI CELS

12:45PM Group Discussion: Report out and agree on prioritization
2:15PM Group Discussion: Opportunities to fill data gaps
3:30PM Concluding remarks and adjourn

WORKSHOP OPENING SESSION

RIEMC vice chair and RIDEM deputy chief of the Office of Water Resources Sue Kiernan opened the workshop with a review of environmental monitoring in RI. Kiernan noted the framework of 20 monitoring priorities that are regularly reported on by the RIEMC. Of these 20, 12 are related to Narragansett Bay and 11 of those have been implemented. Kiernan highlighted the significant amount of water quality monitoring conducted throughout the bay, which is especially concentrated in the upper part of the bay, which experiences the greatest concentration of human impacts; however, RIDEM noted that RIEMC-reported monitoring does not always align with Rhode Islanders' priorities. For example, while ongoing monitoring of submerged aquatic vegetation (eelgrass), salt marshes, and marine aquatic invasive species resonates well with the public, it is more difficult to communicate the importance of continuous dissolved oxygen monitoring. Kiernan also noted vulnerabilities within existing monitoring programs, which are principally due to uncertain funding. For example, since the early 2000s, there has been comprehensive water quality monitoring in the bay due to the NBFSMN, but the infrastructure and equipment is aging and will need to be replaced over the coming years.

Recently, some monitoring efforts have expanded into new areas. For example, a bistate effort between RI and MA purchased new buoys for Mt. Hope Bay to further elucidate water quality trends in Narragansett Bay, and a fisheries habitat assessment in the Seekonk River will link recent water quality improvements to biological response. Many geographic areas, however, remain "gaps" in monitoring such as coastal ponds and embayments (the only one of the 12 coastal monitoring priorities mentioned above that has not been implemented), the Sakonnet River, and the mouth of Narragansett Bay where it meets the Atlantic Ocean.

An issue discussed by the monitoring community prior to the workshop is the need for a framework to contextualize the individual monitoring programs and help set priorities. One possible framework is a Biological Conditions Gradient (BCG), which helps tie the condition of the ecosystem to stressors and can help connect monitoring results with management goals and decision-making (Fig. 1). Giancarlo Cicchetti from EPA AED provided an overview of BCG including examples of how other areas have used this tool to manage resources and achieve restoration goals. Ciccheti noted that BCG is not about any single indicator, but rather focuses on pulling all indicators together, noting three major elements: science, stakeholder engagement, and management.

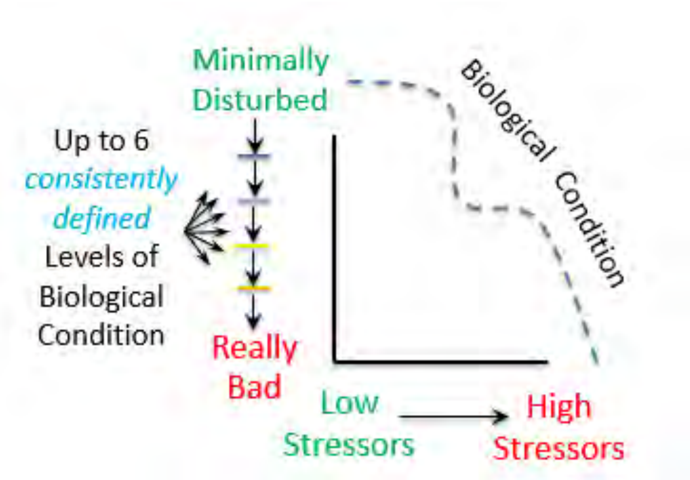

Figure 1: In a Biological Conditions Gradient, level of stress (x-axis) on the ecosystem is linked to a corresponding biological condition (y-axis).

Ciccheti outlined the steps to developing a BCG approach: (1) identify stakeholders, environmental issues, and biological indicators that matter to the stakeholders, and employ this information to set the scope for the rest of the process; (2) create the actual BCG, which is a stress-response model that correlates the level of stress on an ecosystem to its biological condition. A simplified example includes the condition of the ecosystem on the y-axis (response) and the amount of stress on the ecosystem on the x-axis (Fig. 1). This stress axis can be developed on a low to high scale, based on specific years or on parameters such as nutrients.

This model is then used to communicate with stakeholders, translating stakeholder vision of a desired future into targets and management actions needed to reach that vision. Monitoring and adaptation is needed to complete this process.

Ciccheti highlighted Tampa Bay, Florida, as an example of employing a biotope mosaic approach to develop a BCG in 1995. To create the BCG, habitat states—for example, acres of seagrass from 1900 to 1995—were graphed as the response on the y-axis using time as the stressor on the x-axis. At a 1995 stakeholder workshop, participants agreed on a target of restoring seagrass to the acreage that was present in 1950. Management actions were implemented and, after a lag in response time, that target was met in 2015.

There is extensive experience and documentation for applying this approach to freshwater streams, but BCG for an estuary is comparatively new and less well tested, the Tampa Bay example notwithstanding; however, there is significant guidance available. A joint NBEP and EPA workshop in 2009 was aimed at developing a BCG for Narragansett Bay. Recently, EPA released a document on "Implementing the Biological Condition Gradient Framework for Management of Estuaries and Coasts," and an EPA-funded study was published that focused on a BCG model for Greenwich Bay, which feeds into Narragansett Bay.

While the work originally envisioned at the 2009 workshop was not completed, NBEP's extensive *2017 State of Narragansett Bay and Its Watershed* reported on indicators framed within a BCG approach. During this workshop's group discussions, participants agreed it was worth working further toward a BCG framework, emphasizing the need for such a framework to properly identify gaps and priorities. Participants also discussed the challenges of using stakeholder vision to set management actions, as the stakeholder vision could indicate that the public does not fully understand or appreciate the importance of the condition of the bay, and public attitudes can change with the amount of time spent living near the bay, the current condition of a specific indicator, and the level of access individuals have to the bay for economic and recreational opportunities.

CURRENT MONITORING

Moderator: Autumn Oczkowski, EPA AED

Seven invited speakers each gave five-minute presentations about ongoing biological monitoring in Narragansett Bay. Speakers were asked to focus their remarks on what they currently are monitoring, methods used, monitoring results including data storage and availability, and any advantages, challenges, and/or future opportunities to expand or improve monitoring. A brief question and answer session followed each presentation, with a longer discussion at the conclusion of all presentations. Speakers' slides are available in Appendix C.

- Benthic Communities—Emily Shumchenia, environmental consultant
- Primary Productivity/Nutrients—Candace Oviatt, URI GSO
- Phytoplankton—Tatiana Rynearson, URI GSO
- Clarity/Chlorophyll—Eliza Moore, NBC
- Macroalgae—Carol Thornber, URI CELS
- HABs/Shellfish—David Borkman, RIDEM
- RIDEM Fish—Joe Zottoli, URI GSO

Benthic Communities

Presenter: Emily Shumchenia, environmental consultant

Emily Shumchenia presented on image analyses of benthic habitats in Narragansett Bay, which have been organized through URI, EPA, and NBC. Shumchenia outlined the importance of benthic communities—an essential part of the bay's food chain. Studying these communities provides information about biogeochemical processes at the sediment-water interface of Narragansett Bay. There have only been a few recent or recurring surveys of benthic habitat that comprehensively sampled the entire bay, one in 1988 and another in 2008.

Methods

One type of benthic monitoring is sediment profile imagery where a camera is mounted on a frame within a wedge-shaped prism that enters the sediment, allowing the camera to capture images of the sediment-water interface once it is lowered from the boat at each site (Fig. 2). Both the 1988 and 2008 studies used this method at the same sites, allowing a direct comparison in benthic habitat change over that period of time. This comparison showed a bay-wide increase in small, tube-building crustaceans in the genus *Ampelisca*. Beds of these pollution-sensitive organisms are considered an indicator of improving water quality. An increase in area covered by this *Ampelisca* biotope was also observed in Boston Harbor following the relocation of that city's wastewater treatment facility outflow offshore, reflecting reductions in nutrient loading.[2]

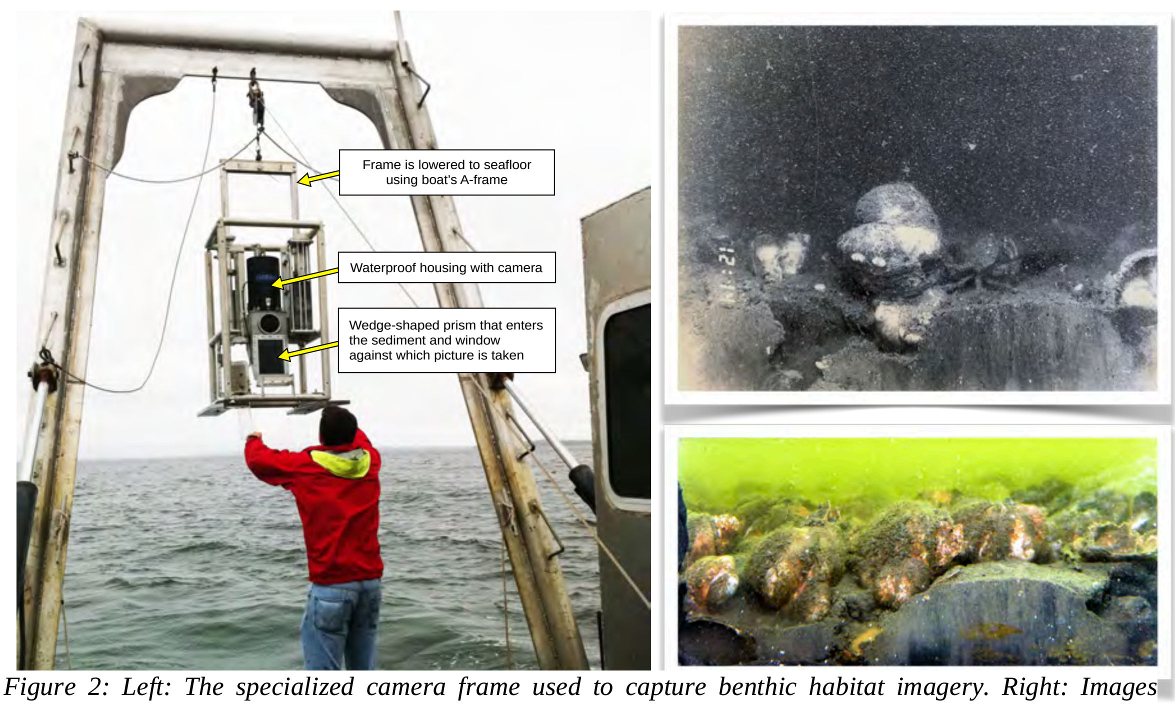

Figure 2: Left: The specialized camera frame used to capture benthic habitat imagery. Right: Images contrasting benthic habitat in Narragansett Bay in 1988 and 2008.

[2] Tucker, J., Giblin, A. E., Hopkinson, C. S., Kelsey, S. W., & Howes, B. L. (2014). Response of benthic metabolism and nutrient cycling to reductions in wastewater loading to Boston Harbor, USA. Estuarine, Coastal and Shelf Science, 151, 54-68.

Results

Monitoring showed five times more area dominated by *Ampelisca* in 2008 than in 1988. This trend was amplified in the Providence River Reach, which showed no *Ampelisca* in 1988, and 78% coverage in 2008 (Fig. 3). This bolsters confidence that nutrient reduction efforts over the last several decades are having their desired effect on benthic communities.

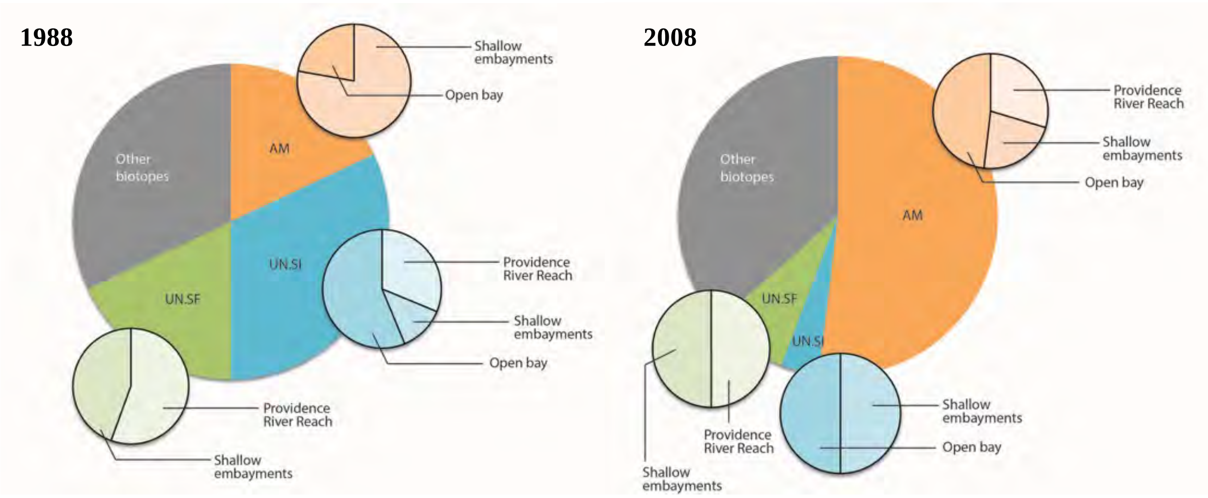

Figure 3: Benthic biotope types in Narragansett Bay by percent area in 1988 and 2008, with insets contrasting Providence River Reach, shallow embayments and open bay. 2008 data shows a notable increase in Ampelisca biotopes, which are shown in orange. AM – Ampelisca, UN.SF – Very Soft Mud , UN.SI – Silty.

Data use/availability

This work is ongoing with URI and EPA, and results are used for estuarine bioassessment. There is frequent coordination between EPA, NBC, and RIDEM on imagery, classification, methods, and sampling locations. Conducting another bay-wide sediment profile imagery survey is a goal for 2018, as it marks 10 years from the previous survey, and would provide new information regarding potential impacts of the most recent pollution reduction efforts on this biological community. Funding is currently being sought by URI GSO for this 2018 survey.

Advantages, challenges, and future opportunities

Overall, this monitoring approach is effective, as the sediment profile camera captures both the benthic community and habitat. The images can also serve as an outreach tool. The sediment profile imagery collection and analysis process is inexpensive when compared with collecting and analyzing a similar number of traditional benthic grab samples. There are also opportunities to support other monitoring efforts with this technique such as dissolved oxygen monitoring, because the images capture real-time benthic biological and geochemical response to water quality changes. Additional tools could be attached to the camera frame, including dissolved oxygen and water clarity sensors. Performing a sediment profile imagery survey every 3-5 years would be valuable, considering the temporal variability of this ecosystem and the efforts over the last five years to improve Narragansett Bay habitat quality through improvements to wastewater treatment facilities.

Primary Productivity

Presenter: Candace Oviatt, URI GSO

Primary productivity refers to the rate of photosynthetic activity in the ecosystem by plants, primarily phytoplankton. Photosynthesis represents the starting point for energy to enter the food chain, and primary productivity is the upper limit of what an ecosystem can support. In Narragansett Bay, primary production is routinely monitored through measuring daily changes in oxygen and carbon levels. Nutrients and chlorophyll *a* changes are also monitored and indirectly indicate changes in primary production. This monitoring helps us track the impact of managed nutrient reduction efforts over the last 12 years.

Methods

This monitoring program relies on the NBFSMN, a joint effort coordinated by RIDEM Office of Water Resources with the cooperation of URI GSO, NBC, and NBNERR. This network consists of buoys and dock sites that are fitted with instruments that record water quality data every 15 minutes. Currently, there are 14 stations that operate during the summer months, with four of those operating year-round. These stations collect data on temperature, salinity, oxygen, chlorophyll, and pH (Fig. 4).

Nutrient monitoring is conducted by Oviatt's Marine Ecosystems Research Laboratory (MERL) at URI GSO. This program was supported by NOAA's Coastal Hypoxia Research Program from 2006 to 2016 and is currently supported by RIDEM. Water samples are taken at 13 stations monthly and analyzed for ammonia, nitrite, nitrate, total nitrogen, phosphate, and total phosphorous. These survey data have been compared with survey data gathered before the managed nutrient reduction.

Results

The monitoring data show an overall decrease in nutrients and primary productivity over time (Fig. 5). Averaging results from all monitoring stations, total nitrogen decreased by

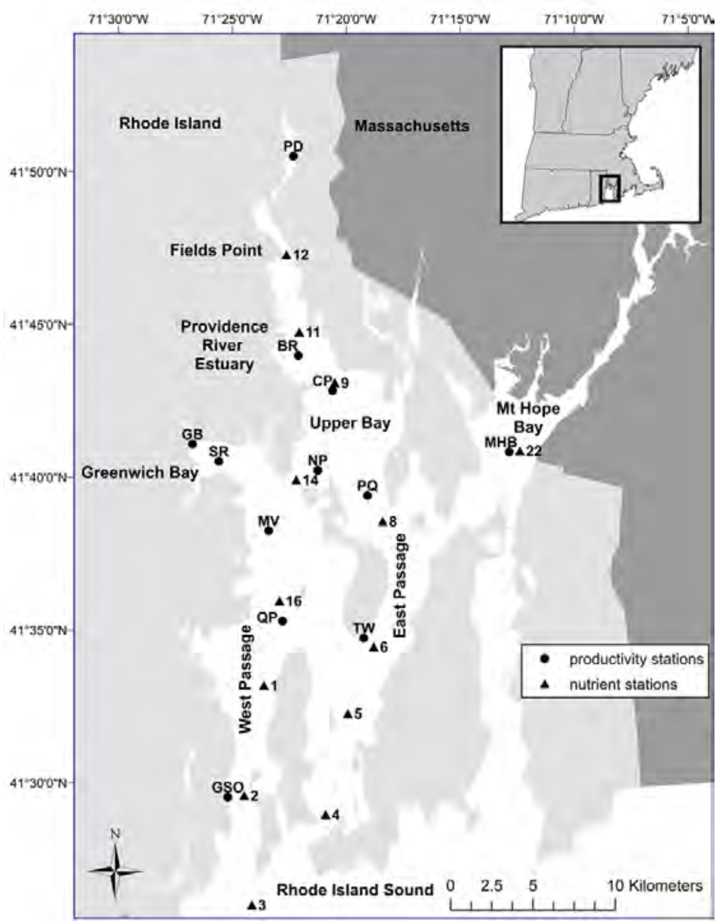

Figure 4: Locations of monitoring stations in Narragansett Bay

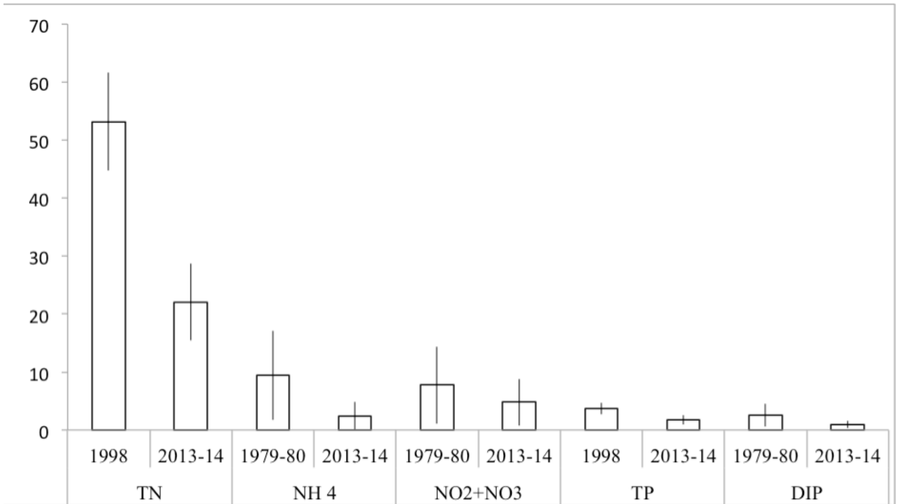

Figure 5: Mean Narragansett Bay nutrient decrease (µM)

60% between 1980 and 2013-2014.[3] Primary production decreased 33% over this time.

There are significant spatial variations of both nutrients and primary productivity with a north-south gradient, showing high nutrients and productivity in the northern bay, and lower levels in the southern bay. The upper-middle section had the greatest reduction in primary productivity, approximately 40-44%, while certain embayments, such as Greenwich Bay, experienced smaller decreases; this is due to additional sources of nutrients in Greenwich Bay, such as groundwater inputs from septic systems.

Data uses/ data availability

NBFSMN data inform many analyses and reports on the overall health of the bay. Data are available from RIDEM's BART website and NBC's Snapshot website. Nutrient data are available from the MERL website.

Advantages, challenges, and future opportunities

The amount of data collected on water quality in the bay, including extensive temporal and spatial coverage, makes water quality a key asset in tracking long-term change in the ecosystem; however, there are challenges to continuing this monitoring effort, including lack of funding for improving equipment and expanding sites, and the uncertainty of future stable funding from different partners in the network. Current plans are in place to enable continuation of the NBFSMN into the future.

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[3] Oviatt, Candace, Leslie Smith, Jason Krumholz, Catherine Coupland, Heather Stoffel, Aimee Keller, M. Conor McManus, and Laura Reed. 2017. Managed Nutrient Reduction Impacts on Nutrient Standing Stock Concentrations, Metabolism and Hypoxia in Narragansett Bay. Estuaries and Coasts. Doi: 10.1016/j.ecss.2017.09.026

Phytoplankton

Presenter: Tatiana Rynearson, URI GSO

Phytoplankton significantly contributes to the foundation of the food chain in Narragansett Bay. The phytoplankton community controls how much sunlight is converted into energy that can be used by other organisms and can also impact the aquatic environment in other ways. Blooms of phytoplankton can block out sunlight, drive down oxygen levels in the water, and some species can produce toxins that impact wildlife and humans. The Narragansett Bay long-term plankton time series has focused on monitoring phytoplankton from the same station in the bay since the 1950s. This monitoring provides researchers with the opportunity to observe annual, inter-annual, and long-term change, and compare it with other estuaries.

Methods

Monitoring is conducted by taking a weekly water sample employing a boat from the West Passage, located approximately between Wickford and the northern tip of Conanicut Island (Fig. 6).

Then, phytoplankton cells are counted and species are identified. Zooplankton are also sampled on a weekly basis; these samples are preserved but analysis has been limited.

Other measurements are taken each week to support the monitoring, including temperature, salinity, turbidity, nutrients, and dissolved oxygen.

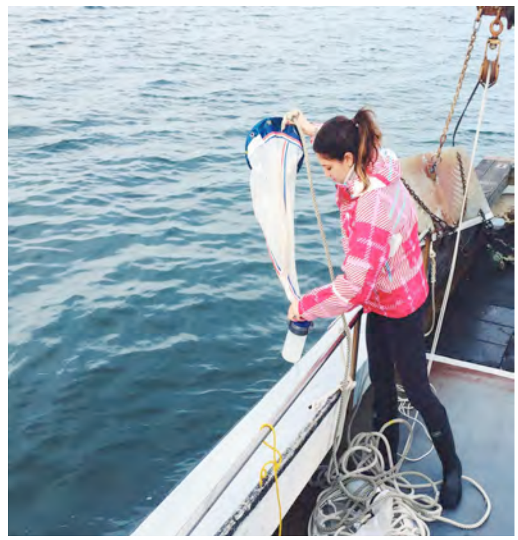

Figure 6: Researcher using a phytoplankton net.

Results

Long-term phytoplankton monitoring has shown temperature dependent dynamics, with the most important types of phytoplankton being key to setting up the annual cycle. For example, the *Skeletonema* genera of phytoplankton make up 49% of total phytoplankton community on average. These are among the most important phytoplankton in the bay and their population can vary significantly throughout the year. In winter, *Skeletonema* can make up over 99% of the phytoplankton community. In addition, spring phytoplankton blooms are usually comprised of *Skeletonema.*

Within this genera of phytoplankton, seven different species of *Skeletonema* have been found that look identical but respond differently to changes in water temperature. One individual species dominates winter blooms, while in summer there is a diversity of species (Fig. 7). This is significant as water temperatures are increasing due to climate change, which has the potential to alter the yearly dynamics of phytoplankton diversity.

DNA fingerprinting and genome transcription has also been used to learn more about genetic diversity within the phytoplankton community of Narragansett Bay. Thus far, these studies have

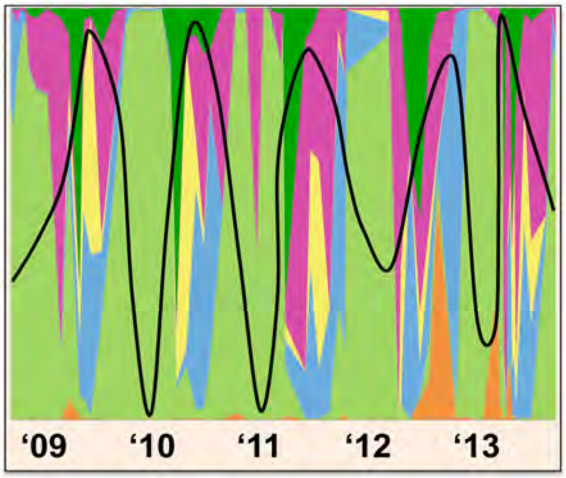

Figure 7: Seasonal phytoplankton cycle in NB, with one Skeletonema species becoming dominant in the winter, and giving way to a greater diversity of phytoplankton in summer months (Canesi and Rynearson 2016).

shown that genetic diversity—and hence adaptive potential to climate change—is high in Narragansett Bay, meaning that the phytoplankton community is fairly flexible to changes in the environment.[4]

Data uses/data availability

Phytoplankton monitoring data are available on the URI website or the Narragansett Bay Time Series website.

Advantages, challenges, and future opportunities

The long record established by this phytoplankton monitoring is a valuable resource, and continuing this monitoring allows tracking of long-term changes in the Narragansett Bay ecosystem. Workshop attendees agreed that keeping this project funded is a major priority (see "Final Priorities Designation" section). Currently, funding is provided through a teaching assistantship at URI; however, internal structure changes at the university have put that at risk and the project may be in danger of losing support in the near future. Researchers may need letters of support from other scientists and managers in the Narragansett Bay community to URI GSO highlighting the importance of the phytoplankton monitoring.

Currently, researchers are studying the magnitude of temperature change needed to create perturbations in observed phytoplankton patterns. There is a goal to observe spatial variation in phytoplankton populations with a new monitoring station being established by NBC in the upper bay. Two additional new projects also offer opportunities to leverage phytoplankton monitoring: a new Long Term Ecological Research (LTER) Network monitoring project on the Northeast U.S. continental shelf (including Rhode Island Sound and the mouth of Narragansett Bay), and an NSF-funded Established Program to Stimulate Competitive Research (EPSCoR) project (see "Filling Gaps" section).

[4] Canesi, Kelly L. and Tatiana A. Rynearson. 2016. Temporal variation of Skeletonema community composition from a long-term time series in Narragansett Bay identified using high-throughput DNA sequencing. MEPS 556: 1-16. Doi: 10.3354/meps/11843.

Clarity/Chlorophyll

Presenter: Eliza Moore, NBC

Monitoring water clarity and chlorophyll levels are part of NBC's extensive Narragansett Bay monitoring program. This program monitors the bay as it is the receiving waters of NBC's waste treatment facility effluent. This monitoring program helps track the effectiveness of water quality upgrades funded by NBC's ratepayers to ensure that efforts taken to reduce nutrients are actually working to protect the bay. Both clarity and chlorophyll can indicate the presence of a phytoplankton bloom, which may be related to high nutrient levels.

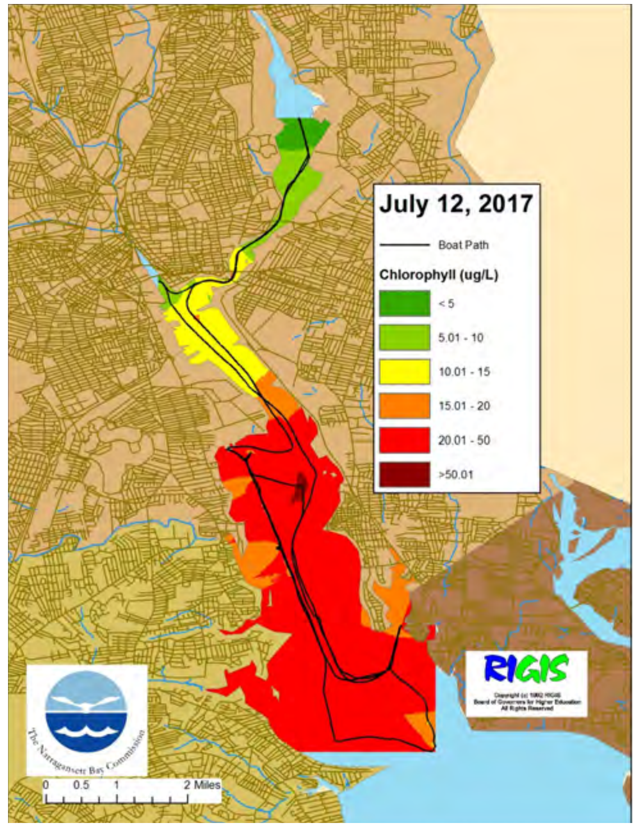

Figure 8: Map of interpolated chlorophyll a concentrations from one sampling date in 2017, showing a gradient of chlorophyll lowers from North to South. Data are highly interpolated for visibility.

Methods

Water clarity is measured weekly at six sampling stations in upper Narragansett Bay by taking a Secchi depth and a photosynthetic active radiation depth profile at each. Total Suspended Solids (TSS) are also measured biweekly. Additionally, turbidity sensors are present on NBC's fixed sites at Phillipsdale Landing and Bullock Reach, which automatically send data every 15 minutes as part of the NBFSMN.

Chlorophyll is measured from biweekly surface grab samples. It is also monitored through weekly surface mapping, during which NBC's *R/V Monitor* travels a set transect through the bay, recording the specific location as well as temperature, salinity, dissolved oxygen, and chlorophyll *a* data, allowing NBC to create maps of surface conditions (Fig. 8).

Results

Clarity in the bay generally shows a spatial gradient, with clarity improving moving from the north to south, and a seasonal cycle showing higher clarity in the fall months then continually decreasing through winter, spring, and summer. Thus far, the monitoring data do not show a clear trend over multiple years (Fig. 9, top).

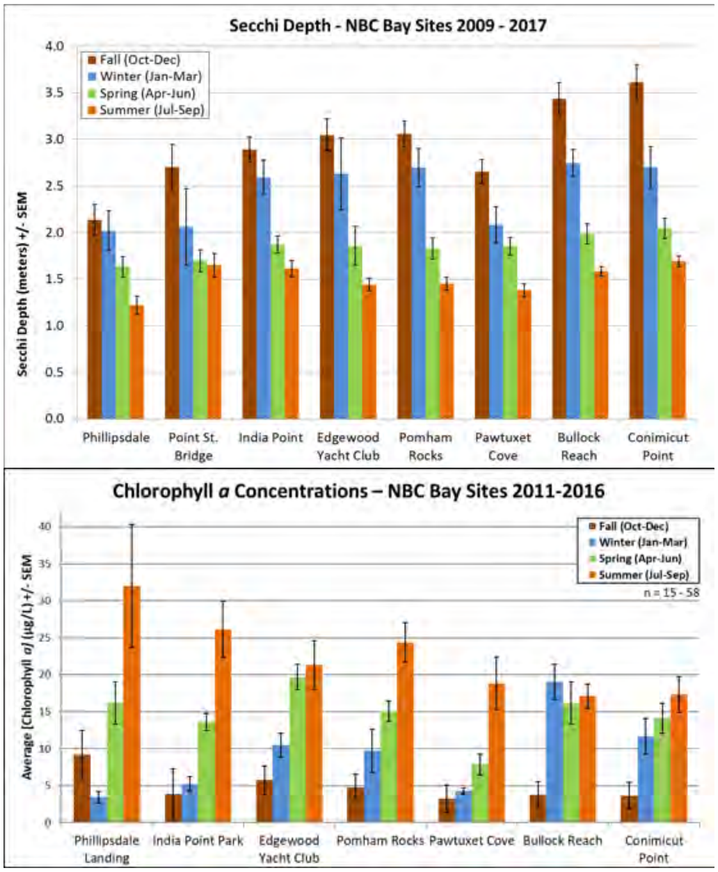

Figure 9: Secchi Depth and Chlorphyll a *Concentrations at NBC monitoring sites.*

Chlorophyll monitoring also shows significant variability among different areas of the bay. The seasonal trends also vary by location (Fig. 9, bottom). For example, higher chlorophyll is observed during the winter months at the more southern sites, such as Bullock Reach and Conimicut Point, while sites in the upper bay are dominated by intense and highly variable phytoplankton blooms, leading to higher and more variable chlorophyll levels (such as at Phillipsdale Landing in the summer).

Data uses/data availability

Data are available on NBC's snapshot website and can be requested through the website. NBC's monitoring goals include making data available to outside organizations to use and synthesize data in novel ways; for instance, these data were used in NBEP's *2017 State of Narragansett Bay and Its Watershed* report.

Advantages, challenges, and future opportunities

Monitoring is currently planned to continue through the foreseeable future, though funding requires approval from NBC's board each year and approval hinges on demonstrated value to ratepayers and relevance to NBC's mission of protection and enhancement of water quality in Narragansett Bay.

There is potential to leverage data from this and other monitoring efforts by intercalibrating data, particularly clarity measurements, e.g., Secchi depth measurements from various monitoring efforts and photosynthetically active radiation (PAR) measurements. Water clarity is well understood by the public, so this monitoring effort may be a strong candidate as the "canary in the coal mine" to help communicate with Rhode Islanders about the importance of monitoring.

Macroalgae

Presenter: Carol Thornber, URI CELS

Macroalgae, or seaweed, is a key part of primary production in Narragansett Bay, along with phytoplankton and submerged aquatic vegetation (eelgrass). When macroalgal blooms wash up on shore, they are very visible to the public, creating a nuisance. In addition, decomposition results in an unpleasant smell and can contribute to low oxygen in adjacent waters. The Thornber lab monitors macroalgae in order to investigate the spatial and temporal variability of macroalgal blooms and how blooms are impacted by nutrient reduction from infrastructure upgrades at wastewater treatment facilities on Narragansett Bay.

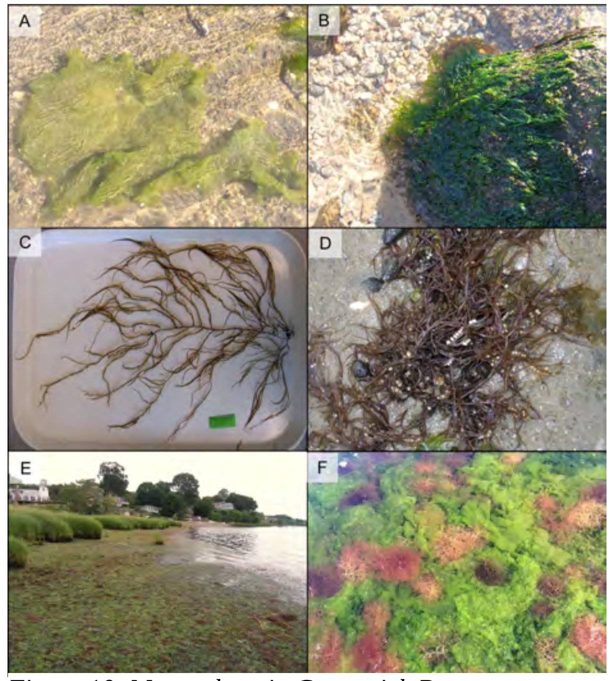

Figure 10: Macroalgae in Greenwich Bay.

Methods

Aerial surveys were performed from 2007-2012 on the upper western side of Narragansett Bay to track macroalgae. Current monitoring is focused on ground surveys at several locations in Greenwich Bay, which have been conducted since 2005. This area was selected because of high public interest in using the beaches for recreational purposes and the frequent occurrence of macroalgal blooms.

Ground surveys are conducted at locations accessible by land in both the intertidal and high subtidal (less than one meter deep) zones. In the intertidal zone, quadrats are set up along transects and percent coverage of macroalgae is recorded. Macroalgae from inside these quadrats are collected, then sorted and analyzed in the lab to obtain total biomass and individual species biomass. In the subtidal zone, a fixed volume of macroalgae are collected for each site and analyzed in the lab for individual species biomass.

Results

Macroalgal monitoring has shown a diversity of species in Greenwich Bay: blade forming *Ulva spp.* in large sheets (sea lettuce), tubular *Ulva spp.* (green algae), and *Gracilaria* spp. (red algae), including both native and introduced species (Fig. 10). There is usually a mix of species, with approximately 5-20 species in a given area.

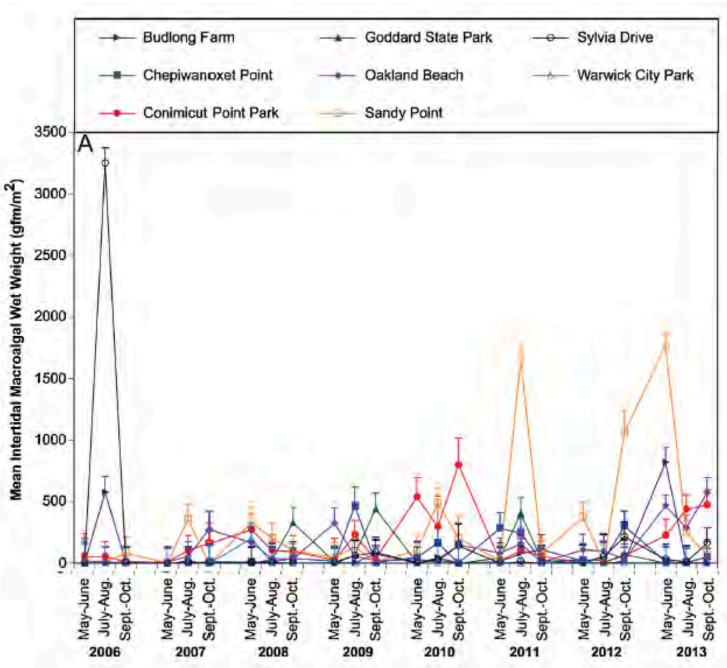

Figure 11: Spatial and temporal variation in total macroalgae biomass in the intertidal zone monitoring.

In the intertidal zone, large spatial and temporal variability have been observed, and no consistent long-term trends are seen. Similar variation and lack of trends apply to the subtidal zone data, with low correlation between intertidal and subtidal data (Fig. 11).

Data uses/data availability

A paper written in collaboration by URI researchers and RIDEM was recently published in the journal *Harmful Algae*,[5] and prior publications by the Thornber lab also document algal bloom density and ecology [e.g., 6,7,8,9]. Additional maps showing monitoring results related to the paper are available on the NBEP website.

Advantages, challenges, and future opportunities

One of the major challenges to this monitoring effort is funding. The program runs on relatively low costs: all sites are accessible from land, reducing infrastructure cost, i.e., no boat is needed, and a major part of the work is time in the lab for analysis, but available funds are similarly low. Other issues are limited data for the rest of Narragansett Bay, lack of funding to expand monitoring into new areas, difficulty of collection, and difficulty establishing spatial variability.

Future monitoring is planned to help track the impact of climate change and nutrient reductions on macroalgae in Narragansett Bay.

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[5] Thornber, Carol S., et al. 2017. Spatial and temporal variability in macroalgal blooms in a eutrophied coastal estuary. Harmful algae 68: 82-96.

[6] Guidone, M., Thornber, C., Wysor, B., O'Kelly, C. 2013. Molecular and morphological diversity of Narragansett Bay (RI, USA) Ulva (Ulvales: Chlorophyta) populations. Journal of Phycology. 49: 979-995. doi: 10.1111/jpy.12108.

[7] Guidone, M., Thornber, C., Van Alstyne, K. 2015. Invertebrate herbivore impacts on two co-occurring bloom-forming Ulva species. Hydrobiologia. doi: 10.1007/s10750-015-2204-6.

[8] Potter, E.E., Thornber, C.S., Swanson, J.D., McFarland, M. 2016. Ploidy distribution of the harmful bloom forming macroalgae Ulva spp. in Narragansett Bay, Rhode Island, USA, using flow cytometry methods. PLOS ONE. 11(2): e0149182. doi:10.1371/journal.pone.0149182.

[9] Rinehart, S., Guidone, M., Ziegler, A., Schollmeier, T., Thornber, C. 2014. Overwintering strategies of bloom-forming *Ulva* species in Narragansett Bay, RI. *Botanica Marina*. doi: 10.1515/bot-2013-0122.

HABs/Shellfish

Presenter: David Borkman, RIDEM

RIDEM and RIDOH are required to monitor certain types of harmful algal blooms (HABs) that are potentially tied to shellfish poisoning. This program ensures regulatory compliance with the U.S. Food and Drug Administration's National Shellfish Sanitation Program and protects public health as well as the greater than $12 million value of Rhode Island's shellfish industry.[10]

HAB monitoring focuses on three genera of algae: *Alexandrium*, *Dinophysis*, and *Pseudo-nitzschia*. Each of these genera contain species that can produce a biotoxin that causes shellfish poisoning when it accumulates in the animals' tissues, such as quahogs, oysters, and clams. Human consumption of these tainted shellfish can cause symptoms ranging from gastrointestinal distress to neurological impacts such as temporary amnesia, and, in rare cases, death. By monitoring for the presence of these algae in Narragansett Bay, Rhode Island can strategically close areas to shellfishing activity, preventing contaminated shellfish from entering the market and thereby protecting human health and the reputation of the state's shellfish industry.

Methods

Figure 12: Blue mussels at a sentinel site, to be used to determine if algal toxin is present in shellfish after the algae is detected in water

The HAB monitoring effort has multiple steps. First, phytoplankton abundance is measured throughout the year, approximately twice a month from May to October and once a month from November to April. During each sampling date, water samples are taken at 56 stations in 17 shellfish growing areas throughout the bay and coastal salt ponds. The samples are filtered through a 20 μm mesh and then analyzed using light microscopy to obtain a cell count. When this count exceeds a certain threshold, shellfish biotoxin analysis is performed using seven sentinel sites around Narragansett Bay. These sites contain blue mussels in aquaculture cages suspended in water off of docks (Fig. 12). Shellfish from these sites are harvested and tissue is analyzed for the presence of the algal biotoxin. If the biotoxin is present, then action is taken to halt shellfish harvesting in the area until monitoring shows that the biotoxin is no longer present.

Results

HAB monitoring recently detected blooms of *Pseudo-nitzschia* in Narragansett Bay, including some instances where domoic acid, a biotoxin produced by some species, was detected and shellfish harvesting was closed. The first such closure occurred in October of 2016, resulting in

[10] Value of combined wild harvest and aquaculture in 2016. Rhode Island Sea Grant and Coastal Resources Center. Rhode Island Shellfish by the Numbers. Available at: http://www.shellfishri.com/wp-content/uploads/2017/05/RI-Shellfish-By-the-Numbers_FINAL_printout.jpg.

an initial closure for the entire bay for 8 days, and subsequent closures for specific locations, including the lower bay and Lower Sakonnet River for 16-17 days in total. In 2017, cell counts of *Pseudo-nitzschia* again exceeded the threshold of 20,000 cells per liter 23 times. In only one of these instances, March 2017, was a toxin detected and a shellfish closure instituted (Fig. 13).

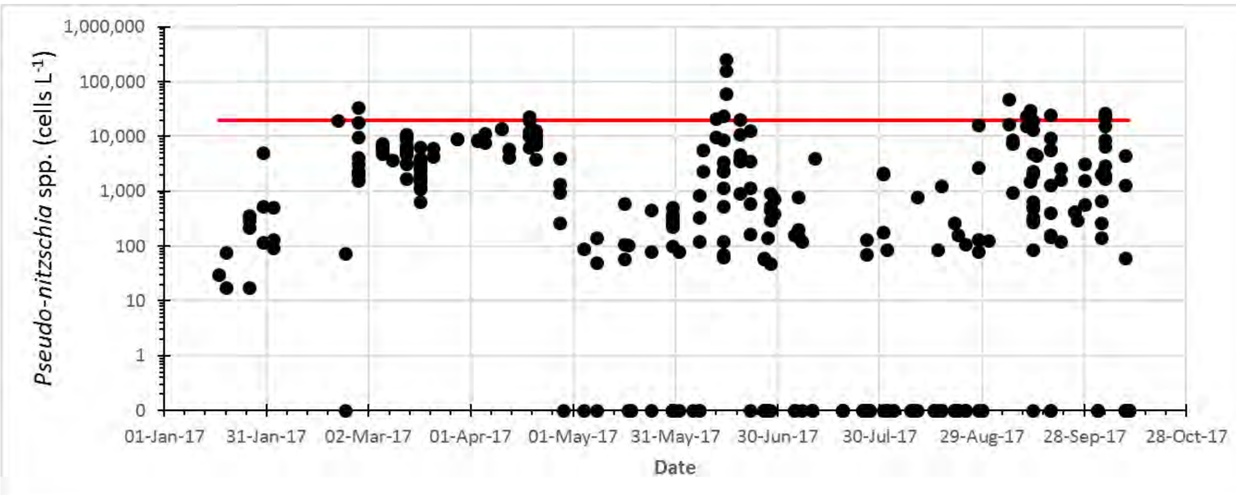

Figure 13: Monitoring results for Pseudo-nitzschia algae in Narragansett Bay in 2017, showing several instances where cell counts exceeded the 20,000 cells/L (red line) threshhold limit.

Data uses/data availability

The HAB monitoring data are shared with RIDOH, RI phytoplankton researchers, and neighboring states, and is included in BART reports and RIDEM reports. The data are also posted on the RIDEM website.

Advantages, challenges, and future opportunities

Funding is a challenge for this program, as there is no dedicated funding for this mandatory monitoring so all funding must come from other sources. The current monitoring program has been in place for two years but was just recently codified into the Harmful Algal Bloom and Shellfish Biotoxin Monitoring and Contingency Plan in August 2017.

Fish

Presenter: Joe Zottoli, URI GSO

In addition to their ecological role in Narragansett Bay, fish are economically and culturally important for Rhode Islanders. The URI GSO Fish Trawl Survey has been tracking fish species populations in the bay since 1959, making it the longest record of its kind in North America and the second longest in the world. The unique length of this record makes it a key resource for tracking the long-term impacts of climate change, human activity, and management actions.

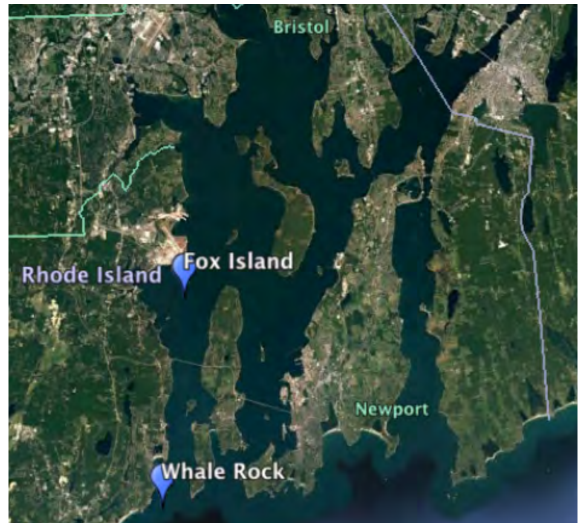

Figure 14: Two locations of the weekly fish trawl survey.

Methods

The Fish Trawl Survey is performed weekly at two stations, Fox Island and Whale Rock (Fig. 14). The standardized survey is always performed at the same speed (2 kts), time of day (morning), duration (30 minutes), and net dimension.

The data collected from the trawl have expanded over time and currently include:

1. Abundance and biomass of each species.
2. Lengths of individual fish.
3. Sex of each winter flounder.
4. Temperature, dissolved oxygen, and salinity at each site at the surface and the bottom, measured with a YSI Sonde.

Results

Results from the Fish Trawl Survey showed notable shifts in the 1980s and 1990s in the Narragansett Bay fish community. Looking at average catch for each tow, the data show that some fish species have been “winners” that are increasing in abundance, including butterfish, scup, cancer crab, long-finned squid, and little skate, while others have been “losers” such as winter flounder, silver hake, and red hake (Fig. 15). There has also been an increasing dominance of invertebrates, and a shift from demersal species, which live close to the ocean floor, to pelagic, or open water dwelling species (Fig. 16). This trend has reversed in recent years with the

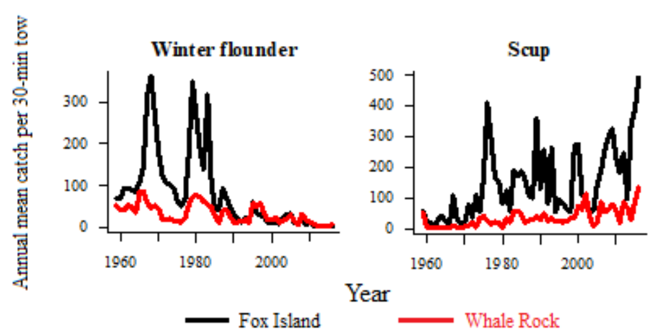

Figure 15: Examples of trends in average mean catch per tow for a "loser" species (Winter flounder) and a "winner" species (scup)

resurgence in demersal species.

Overall, the winners tend to be mostly warmer water species, while the losers are mostly cooler water species. Suggested causes for these changes include changes in pollution, fishing pressure, and water temperature. Analysis of the trawl data shows that the weighted average preferred temperature of species in the fish community has increased over time by about 2 degrees Celsius—similar to the increase in water temperature in Narragansett Bay.

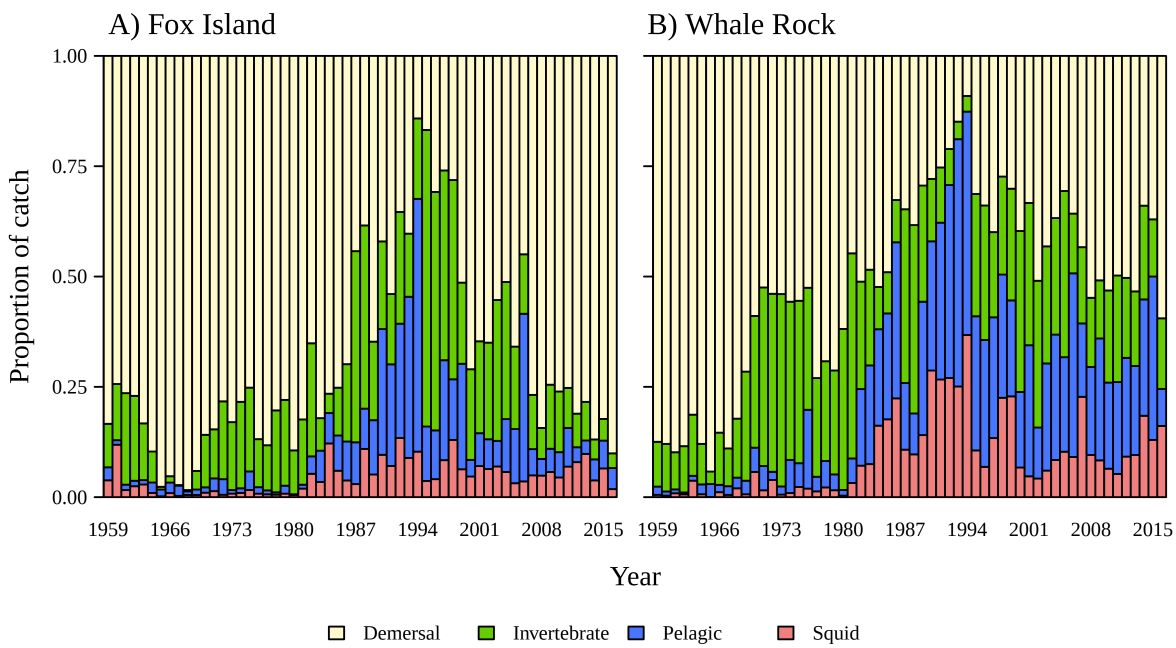

Figure 16: Proportion of catch from Fish Trawl Survey at each location

Data uses/ data availability

Data can be found on the URI GSO Fish Trawl Survey website. Weekly data on individual species as well as hydrographic data are available on the website or by request through the Fish Trawl Survey website.

The data from the survey are used for environmental monitoring, stock assessments, and academic publications. Additionally, an annual summary report is submitted to RIDEM each winter.

Advantages, challenges, and future opportunities

The Fish Trawl Survey is currently funded through a partnership between URI and RIDEM and is expected to continue into the foreseeable future. One challenge is monitoring fish that are not included in the trawl data. As the trawl is designed to capture demersal fish, it may not be adequately capturing the status of pelagic fish. Since the monitoring has shown significant shifts in the proportion of demersal versus pelagic fish over time, this is a key area to focus on in the future.

As noted before, the length of this fish trawl record makes it a uniquely important resource for documenting changes in a range of fish communities over time, especially in relation to long-term changes, such as climate change and warming water.

PRIORITY-SETTING BREAK-OUT GROUPS AND DISCUSSION

Workshop attendees were randomly divided into four breakout discussion groups. Each group was given the same task: to identify monitoring gaps and assign priorities, considering level of effort, funding, leverage, and collaborations required for each. Each breakout group reported back to the full group.

Group 1 focused mainly on the gaps in current monitoring efforts that are most important to continue. Zooplankton samples collected in concert with phytoplankton monitoring that have not been analyzed were emphasized as a gap. Other identified gaps included emerging contaminants, coastal ponds and embayments, and wadeable rivers and streams. Additional monitoring areas that the group noted as important included tributary nutrient loading, non-point source pollution, and shelf exchange from Rhode Island Sound, as well as continuing phytoplankton and fish trawl monitoring. Group 1 also emphasized the importance of data synthesis going forward.

Group 2 discussed many of the same areas identified by Group 1, but additionally pointed to specific geographical areas as gaps, such as the Seekonk and Palmer Rivers. Another area emphasized was Wickford Harbor, which warrants particular concern as nearby towns switch from septic systems to wastewater treatment in the coming years. Observing how the ecosystem responds to this change was identified as a key opportunity. A fishing community organizer noted that fouling organisms are a potential monitoring area that would be of interest to fishermen, and discussed the extent to which current Aquatic Invasive Species monitoring meets that need as well as other methods and resources that might be available.

Group 3 engaged in a more theoretical discussion of environmental monitoring, considering the drivers behind motivation to monitor and how those drivers impact the gaps that need to be filled. as well as many of the challenges behind establishing monitoring programs that meet priorities. In addition, this group also strongly considered the idea of creating a BCG model for Narragansett Bay, what considerations would need to go into the process, and how adopting the model could help to set priorities. Organization and collaboration of modeling efforts were emphasized, along with the need to analyze previously collected stores of zooplankton samples.

Group 4 felt that maintaining many of the current monitoring programs is a very high priority, including water quality (through NBFSMN), phytoplankton, fish, and salt marsh monitoring. Maintaining these current programs was discussed as an important way to track the impacts of climate change on water, organisms, and ecosystems in Narragansett Bay. This group also discussed the potential of new technology to support monitoring efforts, such as remote sensing, the inclusion of traditional aerial imagery, drone imagery, and satellite monitoring.

Further discussion led to agreement on 16 main priority areas for monitoring, dividing them into high, medium, and low priorities. Within the high priorities (the largest group), attendees further categorized each priority based on the amount of funding needed to continue monitoring or fill the gap (Table 1). These priorities reflect a measure of the *immediacy* of the funding need as well as the *importance* of the monitoring, i.e., a “low priority” area is not necessarily lower value monitoring but may have stable and reliable funding.

FINAL PRIORITIES DESIGNATION

Table 1: Monitoring priorities with relative funding requirements as collectively designated by workshop attendees

High Priorities		
High Funding Requirements	**Medium Funding Requirements**	**Low Funding Requirements**
• Fixed Site Monitoring Network	• Benthic Imaging • Chlorophyll, nutrient and productivity monitoring • Eelgrass • Zooplankton	• Fish trawls • Phytoplankton • Salt marsh monitoring • Water clarity • Gelatinous Zooplankton • Toxics/Microplastics/Micro-fabrics
Medium Priorities		
• Macroalgae • Coves and embayments • Improving quality areas		
Low Priorities		
• Open ocean inputs • Sediment flux • Phytoplankton new site • Hydrodynamics • Emerging contaminants		

High Priorities

High Funding Requirements

Fixed Site Monitoring Network

Infrastructure upgrades and replacements necessary to continue operating the NBFSMN were rated as one of the highest priorities. The water quality data across temporal and spatial scales are highly valuable for analysis and to monitor the overall condition of Narragansett Bay. While significant funding is needed for this, there is currently a four-year funding plan in place, which is viewed as sustainable over that time span.

Attendees also discussed the possibility of expanding the areas and time frames covered by the network, including adding additional sites and monitoring in more months, as some of the sites do not monitor in winter months. Along with the funding requirements, communication of the data that are produced by this monitoring was seen as key, as well as developing tools to synthesize and make the most use of the data.

Medium Funding Requirements

Benthic Imaging

This priority refers to benthic video sled imaging discussed by Emily Shumchenia ("Current Monitoring" section). The opportunity to perform another round of monitoring in 2018 and observe changes in the benthic community over time was considered to be invaluable. This method of monitoring was also highly rated because of its efficient use of resources: equipment and personnel can be leveraged for other efforts and has a moderate funding requirement.

Chlorophyll, nutrient and productivity monitoring

This monitoring includes the activities presented by Candace Oviatt and Eliza Moore ("Current Monitoring" section). These activities were highly prioritized because the data are used by many people and for many purposes. This partially overlaps with the NBFSMN upgrades above, but also includes other monitoring efforts that track chlorophyll, nutrients, and productivity. It also includes the year-to-year operational costs of the NBFSMN.

Eelgrass

Eelgrass and other submerged aquatic vegetation provide critical habitat for fish and invertebrates. Current eelgrass monitoring operates on three tiers: a landscape scale, Geographic Information System or GIS-based assessment using aerial photography; field-based, rapid assessment monitoring; and intensive and detailed monitoring at particular sites. Eelgrass can be an indicator for other water quality parameters in the bay, such as clarity and nutrients, and the ability to compare future data sets with data already collected is highly valued to observe change over time. The funding for this monitoring is moderate, but vulnerable to budget changes.

Zooplankton (non-gelatinous)

Unanalyzed zooplankton samples collected during the phytoplankton monitoring efforts as discussed by Tatiana Rynearson ("Current Monitoring" section) were emphasized as an underutilized resource with strong potential to provide valuable information. The discussion noted that zooplankton is an important part of the food chain and can have significant impacts on phytoplankton, planktivorous fish, and larval fish. For example, sudden increases in phytoplankton populations creating algal blooms may be tied to changes in zooplankton grazing pressure. This link in the food chain is important to modeling efforts in Narragansett Bay.

Low Funding

Gelatinous Zooplankton

Gelatinous zooplankton, e.g., jellies, were also noted as a low monitoring priority, as large numbers of these organisms can enter the bay and presumably have a significant impact based on the smaller zooplankton they eat. It was also noted that a change in the abundance in these organisms might be important to track as a possible aspect of climate change. There is not currently a monitoring effort that could monitor gelatinous zooplankton but suggestions include a trawl survey designed for these specific organisms coupled with video monitoring. This monitoring is of particular interest as part of a new GSO research effort (“Filling Gaps” section).

Fish trawls

The long historical record of the fish trawl monitoring makes this program exceptionally valuable and has proven useful for monitoring long-term change. The Rhode Island public also has an interest in fish in the bay. The funding outlook for this program is strong, and the current monitoring is already funded through RIDEM Marine Fisheries Section and URI GSO.

Phytoplankton

Like with the fish trawl monitoring, the Narragansett Bay phytoplankton time series conducted at URI GSO has created a historical record that provides a valuable opportunity to monitor long-term change in the ecosystem through its continuation going forward. As noted by URI GSO, structural changes at URI may make funding for this program vulnerable in the future.

Salt marsh monitoring

Salt marsh monitoring is high priority due to the current risk of losing marshes from sea level rise. Marshes are “drowning in place” as sea level rise continues to accelerate and there are not unobstructed pathways for marshes to move inland. Similar to eelgrass monitoring, salt marsh monitoring is currently conducted on three tiers: a landscape scale, GIS-based assessment using aerial imagery; field-based rapid assessment monitoring; and intensive, research-based assessment at separate sites.

Thus far, funding for this monitoring is in place, but in many cases, the monitoring has been funded on an opportunistic basis, with no stable funding source, making the monitoring of salt marsh vulnerable going forward.

Water clarity

In addition to the established water clarity efforts with the NBFSMN, attendees felt that there was strong potential to increase the temporal and spatial scope of water clarity monitoring. Measuring water clarity using a Secchi disk is a relatively quick and simple method that could be recorded at the same time as other ongoing monitoring efforts and combining these data could yield useful information. A standardized collection and reporting protocol would be helpful in implementing this.

Toxics/Microplastics/Micro-fabrics

Monitoring toxic substances is highly relevant to fisheries and oyster management in upper Narragansett Bay. Currently, there is limited research on mercury in estuarine fish, with slightly more monitoring effort for Rhode Island’s freshwater lakes and ponds. The highest priority would be to monitor toxic substances in targeted places, where, for instance, water quality improvements and toxic site cleanups have raised the question of whether fishing could now be allowed in certain areas, but monitoring of toxins is essential to support that decision.

Medium Priorities

Macroalgae

Macroalgae monitoring, as presented by Carol Thornber (Current Monitoring Section) was viewed as a medium priority. Monitoring efforts to date have taught researchers a good deal, and macroalgae is an important issue to the public (primarily related to nuisance seaweed). The monitoring method is also relatively cost effective. One suggestion was to include a spatial analysis of macroalgae, with the suggestion of aerial imagery as a possibility to expand spatial coverage of the monitoring.

Coves and embayments

Water quality in coves and embayments is important to monitor specifically, as it is not necessarily represented by the results of monitoring in other locations. The principle area discussed in this section was Wickford Harbor. As noted in the Group 2 discussion, this is a current opportunity to observe the response of the water quality and the ecosystem to changes in management, in this case, the shift from septic to sewer waste disposal. Efforts to expand biological monitoring efforts in this area over the time of the shift were also discussed. There is currently some volunteer monitoring planned for this area, but it would not necessarily provide the same management value as, for example, continuous dissolved oxygen data.

Discussants also noted potential methods for monitoring coves and embayments. Buoys, as used in the NBFSMN, have previously not worked in shallow water due to circulation issues. HOBO Water Quality Loggers were also suggested as a less expensive option. RIDEM noted that they have some YSI sensing equipment that is used for monitoring different locations on a priority basis and could be directed to these areas.

Improving water quality monitoring

Much effort and funding has been expended to improve water quality in Narragansett Bay, which is being reflected in quality improvements in areas in the upper bay and the Providence and Seekonk Rivers. Monitoring the improvements in water quality, and how that is reflected in biological responses is a priority and is viewed as a means to get the word out to the public. Efforts could specifically target public support by focusing on methods like monitoring fish using video.

There is also interest in improving water quality monitoring as it relates to carbon and nutrient fluxes in the mudflats, with the potential for modeling.

Low Priorities

Attendees also noted a number of lower priorities. Many of these, such as inputs to Narragansett Bay from the open ocean, hydrodynamics, sediment flux, and emerging contaminants are already the focus of ongoing or forthcoming research projects. A new phytoplankton monitoring site in

Upper Narragansett Bay being established by NBC is also listed as a priority, as it provides an opportunity for spatial analysis of phytoplankton dynamics and is already underway.

Other monitoring areas and priorities that were discussed throughout the day, but not explicitly named as an item in this list include: fresh and saltwater beaches, non-point source pollution, weather data, sediment (amount), climate change, stream gauges, fouling organisms, wadeable rivers and streams (nutrient loading), genomics, modeling, and aquatic invasive species.

FILLING GAPS

In the afternoon, the workshop's focus pivoted towards filling the identified monitoring gaps and new opportunities to do so, beginning with three five-minute ignite talks, each focused on a new approach or program for monitoring. Each presenter was asked to describe the approach, methodology, results, and how the approach is useful and/or innovative.

New Data Synthesis/Tools

Presenter: Q Kellogg, Coastal Institute

Historical data can be reanalyzed in new ways to learn more about Narragansett Bay and help make the most of monitoring efforts. Q Kellogg of the Coastal Institute presented work on data synthesis of long-term records from stream gages in the four major basins in the Narragansett Bay watershed, with some stretching back as far as 90 years. The objective of this analysis was to determine how river flow into the bay has changed in the last 50 years, and in particular, if the frequency or magnitude of high flow events (defined here as three consecutive high flow days) has changed. The analysis also ties in water quality data from the NBFSMN to determine if hypoxia events in Narragansett Bay are correlated with conditions preceding the event, such as water temperature, chlorophyll *a*, and river flow into the bay.[11]

Methods

This method used existing data collected for other purposes, such as USGS streamflow data and water quality data from the NBFSMN. Analyses were performed with R, a powerful open source statistical software. Using R comes with several advantages, including an active user community that can provide support and recommendations, both locally and worldwide through the 'rhodyRstats' group, a Rhode Island group of R users that hosts skill sharing and co-working events and is supported by the Coastal Institute. Another advantage is the availability of different packages, groups of functions relevant to specific disciplines and analyses that are easy to install and use, such as packages specific to retrieving and organizing USGS stream flow data.

Results

Evaluating annual hydrologic flow measures over this long record shows that generally, minima are getting lower and maxima are getting higher over the last fifty years. In essence, extremes are becoming more extreme (Fig. 17). Currently, Kellogg is comparing flow measures prior to 1970 and following 1970, working with Gavino Puggioni, URI professor in statistics, to determine the best method to see if these two time frames are significantly different. This division is being used because a shift in precipitation patterns has been observed, starting around 1970. That year is also relevant to the North American Oscillation, which impacts weather patterns.

[11] This work was made possible through funding awarded by EPA through the Health Communities Grant Program in association with the Southeast New England Program under assistance agreement 00A00185 to RIDEM.

USGS Gage Name	USGS Gage ID	Start Year	1-day Min	7-day Min	30-day Min	Median	Mean	30-day Max	7-day Max	1-day Max
ANNUAL – START YEAR to 2016										
TAUNTON RIVER NEAR BRIDGEWATER, MA	01108000	1931	74	58	29	18	20	20	5.4	-1.1
WADING RIVER NEAR NORTON, MA	01109000	1927	-29	-50	-43	2.1	4.7	20	17	14
THREEMILE RIVER AT NORTH DIGHTON, MA	01109060	1968	-59	-58	-49	-17	-13	-12	-20	-17
SEGREGANSET RIVER NEAR DIGHTON, MA	01109070	1968	-61	-73	-79	-23	-10	-12	-23	-30
QUINSIGAMOND RIVER AT NORTH GRAFTON, MA	01110000	1941	-80	-69	-17	16	11	33	39	78
BRANCH RIVER AT FORESTDALE, RI	01111500	1941	-29	-52	-48	-0.043	4.5	29	32	44
BLACKSTONE RIVER AT WOONSOCKET, RI	01112500	1930	98	-25	-18	28	17	20	8.8	11
WOONASQUATUCKET RIVER AT CENTERDALE, RI	01114500	1943	1.7	-58	-58	15	16	54	57	84
SO. BRANCH PAWTUXET RIVER AT WASHINGTON, RI	01116000	1942	173	-17	-20	13	12	22	30	32
PAWTUXET RIVER AT CRANSTON, RI	01116500	1941	102	-39	-26	0.17	8.8	30	62	57

Figure 17: Percent change in annual hydrologic measures for the period of record. Shaded values are $p < 0.1$.

Innovation/Utility

This work builds on previous work done in 2009, with the first five years of available data from the Fixed Site Monitoring Network,[12] but adds 10 additional years of subsequent data and combines it with long-term USGS stream gage trends. These trends analyses can improve understanding of how climate change may influence the frequency and severity of hypoxia events in Narragansett Bay. Hypoxia events are also expected to be influenced by recent nutrient reductions from wastewater treatment plant upgrades.

Kellogg is planning to publish two reports online using R markdown, which is an R language that can create reports that are seamlessly enmeshed with code for data analysis and graphs, allowing for research that can be shared and reproduced. This work will also be available on the RIEMC website and will be submitted to RIDEM as technical reports.

[12] Codiga, D.L., H.E. Stoffel, C.F. Deacutis, S. Kiernan, and C.A. Oviatt, 2009. Narragansett Bay hypoxic event characteristics based on fixed-site monitoring network time series: Intermittency, geographic distribution, spatial synchronicity, and interannual variability. Estuaries and Coasts, 32:621-641.

New Data Collection/Technology

Presenter: Colleen Mouw, GSO

Soon after this workshop, URI GSO completed set up for a new monitoring station at the GSO dock, which is now fully operational. This station will use advanced technology to conduct continuous monitoring for particles, phytoplankton, and other important water quality parameters and is funded by multiple sources including NSF, NASA, The Moore Foundation, and others.

Methods

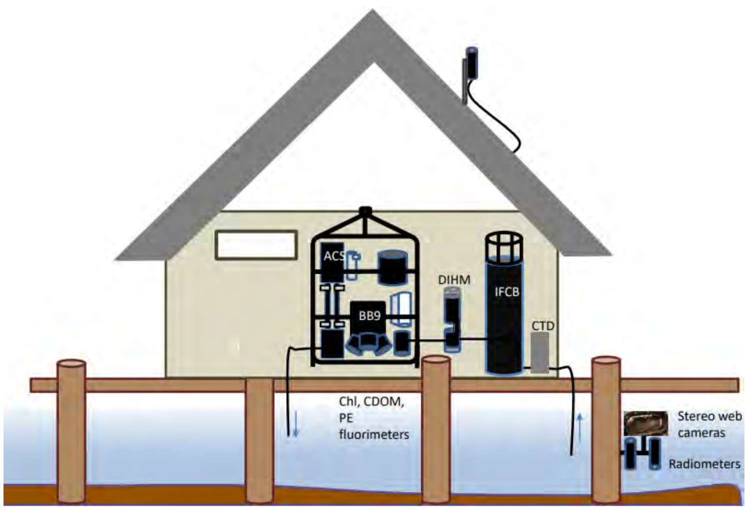

Figure 18: Diagram of the Imaging Flow Cytobot (IFCB) and other monitoring equipment housed in the new monitoring station on the GSO dock.

This station will automatically sample water from Narragansett Bay and monitor particles using an Imaging Flow Cytobot and a Digital In-line Holographic Microscope, which will produce high-resolution images (Fig. 18). These two instruments cover a large range of particle sizes and will allow researchers to see phytoplankton in the water on a continuous basis.

This station will also continuously measure temperature, salinity, absorption, scattering, chlorophyll, CDOM (Colored Dissolved Organic Matter), PE fluorescence (Phycoerythrin, a fluorescence-based indicator for the presence of cyanobacteria) and is equipped with radiometers and stereo web cameras.

Results

The phytoplankton images are automatically uploaded and available on a dedicated section of the GSO website (Fig. 19). The rest of the dataset will be made available on a website in the near future.

Two years of operation have been funded through Rhode Island Sea Grant to work with Brown University to build a web portal (linked above) to publish data, counts, sizes, and other quantitative information produced by the monitoring station.

Innovation/Utility

The fully automated nature of this station adds remote sensing potential to this type of monitoring, allowing for the future development of algorithms to predict phytoplankton community composition based on physical factors.

The data produced by this monitoring have potential for helping to understanding many aspects of the Narragansett Bay environment, including harmful algal bloom identification and monitoring, understanding phytoplankton population dynamics, non-algal particle quantification (turbidity), CDOM variability, light availability/attenuation, and real-time view of conditions.

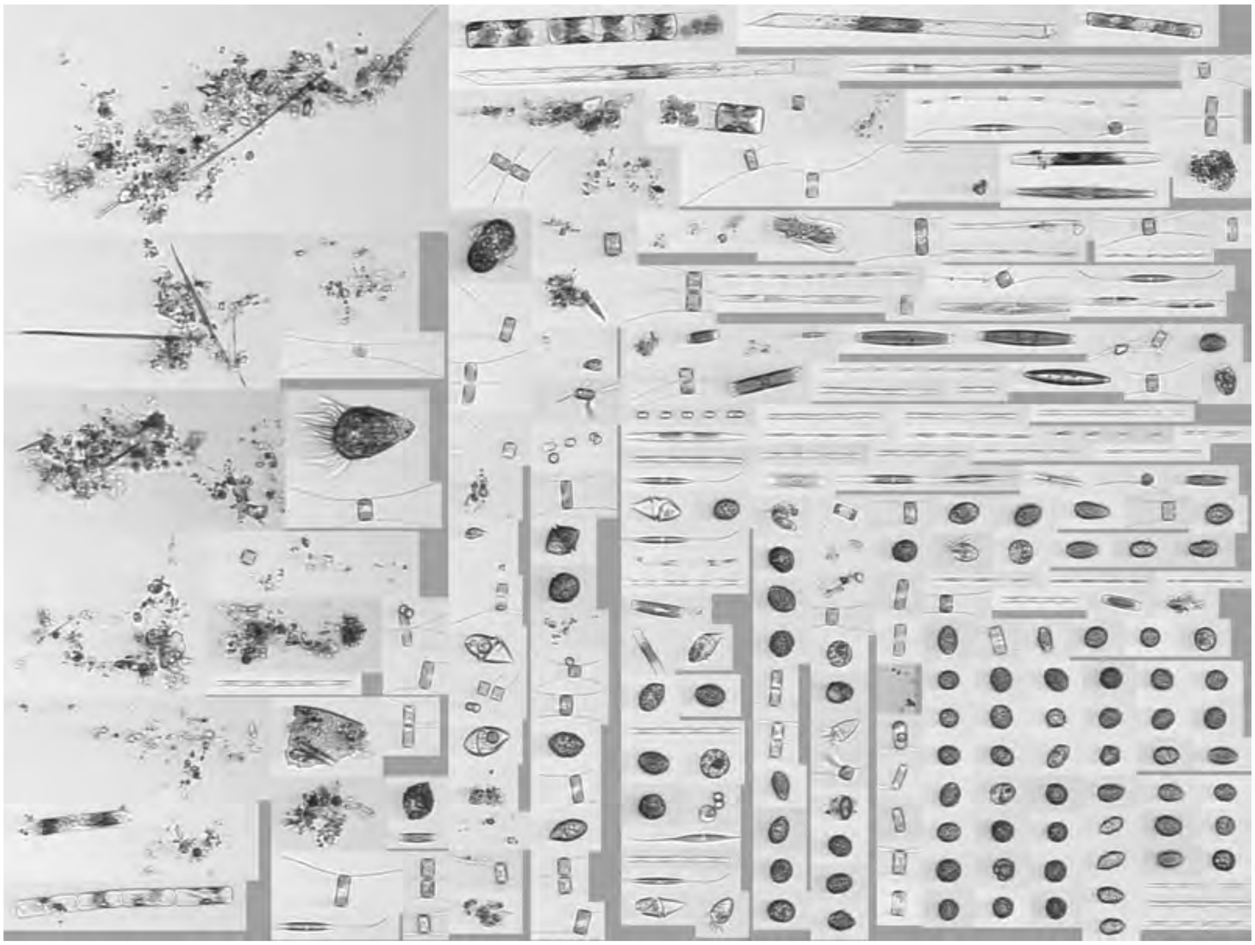

Figure 19: Particle images captured by the Imaging Flow Cytobot on March 14, 2018.

Comprehensive Efforts

Presenter: Bethany Jenkins, URI CELS

The Rhode Island Consortium for Coastal Ecology Assessment, Innovation, and Modeling (RI C-AIM) is a new statewide research consortium funded by a $19 million NSF EPSCoR grant to study the effects of climate variability on coastal ecosystems. This consortium includes investigators from URI (project lead), Brown University, Rhode Island School of Design, Rhode Island College, Bryant University, Providence College, Roger Williams University, and Salve Regina University. The three research cores for RI C-AIM are biological and ecosystem impacts, predicting ecosystem response (modeling), and enabling technologies (e.g., to help to develop less expensive nutrient sensors).

<u>*Methods*</u>

RI C-AIM involves several areas of new monitoring capacity and resources. The Bay Observatory is a proposed augmentation of current monitoring efforts, helping to leverage the existing long-term monitoring datasets for the bay and adding new capacity. This will include a new, technologically advanced monitoring station at the long-term phytoplankton monitoring site (as identified in Tatiana Rynearson's presentation (Current Monitoring Section), another station in Greenwich Bay to observe hypoxia, and a potential pump station near the mouth of the bay to monitor inputs from the Atlantic Ocean. LOBO (Land/Ocean Biogeochemical Observatory) systems will wirelessly transmit parameters at these locations in real-time.

Another part of this initiative will measure nutrient flux from the sediments on the bottom of Narragansett Bay using a benthic lander (Fig. 20). The lander can be moved around to different sites in the bay, and the data are useful in modeling nutrient cycles.

RI C-AIM will also focus on biodiversity monitoring, using an imaging flow cytobot similar to the one on the URI GSO dock monitoring station to obtain real time images of plankton. Unlike the new URI GSO monitoring station, this benthic lander could be moved to different sites in the bay.

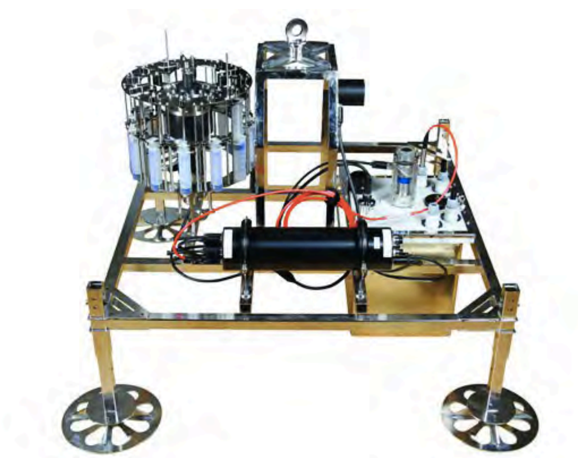

Figure 20: A benthic lander will be mounted with multiple microsensors (oxygen, H2, N2O, pH, H2S) to measure fluxes out of sediment at the bottom of the Bay

A long-term goal for this initiative is event-triggered sampling, where a phytoplankton sampler could be remotely triggered based on results from biogeochemical monitoring or images from the flow cytobot to filter a sample of water and preserve it for downstream DNA analysis.

Results

Data are not yet currently available, but will be hosted at the RI Data Discovery Center, which is a major emphasis for RI C-AIM and its NSF grant. The center will be built and maintained by Brown University. RI C-AIM plans to aggregate other Narragansett Bay data into this portal, including historical and new data, with the vision of creating a “one-stop data shop,” which will improve coordination of monitoring activities and improve the identification of data gaps.

Innovation/Utility

The monitoring conducted through this initiative will be a valuable resource for geneticists/ecologists who will then be able to analyze found DNA to determine which organisms and metabolic pathways were present, and what phytoplankton/pathways are enriched at different times of the year. This will provide insight to inter- and intra-annual phytoplankton dynamics. The additional monitoring capacity in the bay will help researchers to better integrate different monitoring throughout the food chain, linking physical/chemical conditions such as nutrient influx and climate change with rates of primary products, and then to impacts on higher trophic organism.

OTHER MONITORING STRATEGIES AND OPPORTUNITIES

Additional strategies and opportunities to fill data gaps and help support monitoring in Narragansett Bay were discussed after the three ignite talks and throughout the day.

Databases and Data Portals

There have been previous attempts to create a database for Narragansett Bay monitoring data, which have not been sustained. As discussed above, the NSF-funded RI C-AIM initiative has funding to create a new RI Data Discovery Center to host monitoring data for Narragansett Bay. The current plan for the Data Discovery Center is for the back end to have Narragansett Bay data and models so that researchers can obtain the data, with the front end focused on visualization so users can perform queries specific to locations, time periods, and monitoring sector. This resource is currently in development, and technical meetings began in early 2018.

Workshop discussion also focused on what characteristics would make a consolidated database valuable to different users. The NOAA Distributed Oceanographic Data Systems was cited as an example, which, according to one individual, was originally intended to be a more comprehensive data resource but is now only used by physical oceanographers. This example highlights the need for a database to be easy to use. It was emphasized that the database should not be overwhelming to use at first, with an easy way to see what data are available, and with training or instruction on how to use the database. Another important aspect was the uniformity of data and metrics to be included. Many researchers use different metrics, formats, and units for their environmental monitoring and regulatory required reporting, which need to be standardized to create a more useable database. However, placing this burden on the researchers will make it less likely that people will provide data for the database.

Another data sharing option mentioned was a portal, or website, that provides links to other data available online. Several examples were provided, such as the forthcoming RIEMC website, the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) website, and the Long Island Sound Resource Center website. Data portals such as these could be made more useful with some simple, standardized keywords that could be searched.

Remote Sensing

Remote sensing is already used in several monitoring programs, such as submerged aquatic vegetation (eelgrass) and salt marshes. These programs currently use aerial imaging, which can also be used to obtain topographic and bathymetric data with additional potential use for monitoring invasive species. Drone remote sensing was also mentioned, especially for use at specific sites. This method is not optimal for statewide coverage monitoring.

Satellite remote sensing is another potential area, with many satellites currently in orbit collecting an array of data all over the planet. With future pixel resolution improvement, remote sensing could provide a picture of the whole bay, including chlorophyll, surface temperature, and other parameters.

Consolidating data collection

Another theme that was raised many times throughout the workshop was the potential of consolidating different methods of monitoring on the same trips and infrastructure, such as different underwater monitoring tools that could be pooled together to create a multipronged approach, performed at a subset of sites in the bay each year. Another example is combining boat trips for submerged aquatic vegetation and salt marsh monitoring by taking additional measurements during each trip.

Consolidated clarity measurement

Within the theme of consolidated data collection, the most notable potential option was to add clarity measurements to different monitoring efforts. Secchi depth is a quick and simple method to measure water clarity that could be performed along with several other activities, including volunteer monitoring, RIDEM's shellfish program (readings at all shellfish/phytoplankton sites), benthic imaging trips, and others. To make this initiative useful, standardization and instruction for collecting the Secchi depth reading would be needed. Currently, URI Watershed Watch has standardized instructions for reading Secchi Depth that could be adopted. Entering the data in a consolidated location is another issue that would need to be addressed; potential options include a shared spreadsheet that is accessible to all users, or a phone or tablet app that allows for infield data entry and upload (such as Fulcrum).

Setting standards for very simple collection metrics (such as Secchi depth, temperature) could be a project for RIEMC. This would not be enforceable, as researchers/regulators are reporting to different agencies and for different purposes, but it could serve as a reference guide.

Communications/Stakeholders

The overarching issue of communicating about monitoring with stakeholders was the subject of extensive discussion. Many monitoring activities are funded through government funds, so communication with the taxpayers is an important responsibility. Additionally, setting management priorities, as with using a Biological Condition Gradient approach, depends explicitly on stakeholder priorities.

One focus of discussion was being able speak to stakeholders' interests. In many cases, this was viewed as a matter of converting existing data into metrics that people care about, such as herring runs, fish counts, and breeding sites for wading birds. Change in number of winter flounder may be more accessible to people than trends in physical and chemical water quality parameters. One challenge in this kind of reporting is that many resources are very impacted by multiple factors; for example, fish stocks are impacted by water quality in the bay, but also by fishing pressure. It was also noted that communication efforts need to respond to the needs of all Rhode Islanders.

CONCLUSION

The *Toward Comprehensive Monitoring of Narragansett Bay* workshop brought together experts in environmental monitoring of Narragansett Bay, including physical, chemical, and biological aspects. This workshop showcased the wide spectrum of monitoring work that is ongoing and being initiated in Rhode Island. It provided a critical opportunity to make sure researchers and managers are aware of the most up-to-date monitoring efforts and challenges as they continue to collaborate to protect Narragansett Bay while promoting its sustainable use.

In addition to summarizing the current state of environmental monitoring in Narragansett Bay, the workshop participants identified and prioritized monitoring gaps (Table 2; see discussion beginning on page 20) and discussed ways to move forward including filling gaps by using new methods, initiatives, and strategies (see discussion beginning on page 32).

Table 2: Monitoring priorities with relative funding requirements as collectively designated by workshop attendees

High Priorities		
High Funding Requirements	**Medium Funding Requirements**	**Low Funding Requirements**
• Fixed Site Monitoring Network	• Benthic Imaging • Chlorophyll, nutrient and productivity monitoring • Eelgrass • Zooplankton	• Fish trawls • Phytoplankton • Salt marsh monitoring • Water clarity • Gelatinous Zooplankton • Toxics/Microplastics/Micro-fabrics
Medium Priorities		
• Macroalgae • Coves and embayments • Improving quality areas		
Low Priorities		
• Open ocean inputs • Sediment flux • Phytoplankton new site • Hydrodynamics • Emerging contaminants		

Key themes of the workshop included:

- The desire to work further towards a BCG framework to link monitoring to management goals and strategies;
- The importance of maintaining key long-term monitoring programs, specifically the fish and plankton trawls;
- Opportunities to leverage existing resources, such as through analyzing already collected samples, particularly analyzing zooplankton samples, or combining monitoring trips, with NBC identifying opportunities to add Secchi depth monitoring to their already scheduled water quality sampling;
- Sharing data with databases and data portals and developing procedural/reporting standards to facilitate sharing, especially as C-AIM develops a comprehensive website over the next several years; and
- Communication and framing of results to stakeholders to improve public understanding of how Narragansett Bay functions, how it is changing, and how these changes could impact visitors and residents.

This workshop was the first step toward improving monitoring efforts and working toward a comprehensive monitoring plan that will allow researchers and regulators to better understand the complex environmental interactions that make Narragansett Bay productive and unique, including assessment of whether management decisions, such as wastewater treatment facility upgrades, are having the anticipated impacts.

It is an important time to conduct environmental monitoring of Narragansett Bay by tracking the impacts of important changes both on local (e.g., reductions in nutrient loads) and global (e.g., climate change) scales. These themes can help us meet the monitoring needs in Narragansett Bay during this crucial time period.