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Messaging and Forecasting Hypoxia for Long Island Sound

Workshop Proceedings

Office of Research and Development
Atlantic Coastal Environmental Sciences Division

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Center for Environmental Measurement and Modeling
Office of Research and Development
U.S. Environmental Protection Agency
Atlantic Coastal Environmental Sciences Division
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Notice and Disclaimer

The information generated in these proceedings were developed under CEMM Quality Assurance Project Plan (QAPP) "Forecasting hypoxia in Long Island Sound and selected tidal embayments" J-ACESD-0034088-QP-1-0, effective date 7/12/2023. This report has been reviewed by the ORD/CEMM/EPD Quality Assurance Manager and it has been determined to be consistent with EPA Category B quality assurance requirements. This product does not deviate from the QAPP. There was no data collected in relation to these proceedings, they instead share summaries of discussions held during the workshop.

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions to balance human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's Office of Research and Development (ORD) is solving environmental problems and building the scientific knowledge base necessary to manage ecological resources, understand how pollutants affect human and environmental health, and prevent or reduce environmental risks in the future. The regional offices of EPA are responsible for executing EPA programs within their respective states and territories.

Collaboration brings ORD's strong scientific and technical foundation together with regional expertise in regulations and place-based issues. EPA relies on ORD to help fulfill its statutory obligations and address the most pressing environmental and public health challenges. By working closely with external stakeholders with whom regional offices are connected, ORD ensures a highly coordinated research program that produces useful work for the American public and the EPA's regional and program offices. These resources also help state and local agencies, Tribes, and communities inform actions to protect their environment, safeguard public health, and support a robust economy.

The Center for Environmental Measurement and Modeling (CEMM) within ORD builds necessary methods and models to implement environmental statutes and improves the Agency's ability to measure and model environmental contaminants. Research in CEMM encompasses tracking contaminants in the natural environment, including contaminants of emerging concern, and developing regulatory methods, models, and environmental indicators. Researchers also work to develop tools that inform and evaluate environmental management practices and policies.

This proceeding is one such tool for EPA scientists and management as well as other agencies and organizations for use in developing communication tools about nutrient pollution, especially hypoxia and forecasting. It documents the methods and findings of a workshop of experts convened to identify the recommended design and content for communicating about a hypoxia forecast in Long Island Sound. The goal of this document is to contribute to the literature on good practices for communicating complex science and to identify and share lessons to inform future communication efforts on nutrient pollution, hypoxia, and forecasts.

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Executive Summary

The U.S. Environmental Protection Agency Office of Research and Development and Region 2 held a workshop on May 23, 2023, to understand communication needs for hypoxia in Long Island Sound. The express purpose of the workshop was:

> *Working with people at the interface of science and practice to identify the best engagement approaches to use hypoxia forecasting in improving public awareness about hypoxia in Long Island Sound*

The Messaging and Forecasting Hypoxia in Long Island Sound workshop shared information on the early work on the hypoxia forecasting model for Long Island Sound and elicited perspectives of attendees on key audiences and design for related communication products. Workshop participants were selected based on their expertise at the interface of Long Island Sound environmental challenges and stakeholder engagement. Through structured presentations and small and large group discussions participants shared their knowledge and perspectives on the best approaches for communicating hypoxia and forecasting in Long Island Sound. This workshop proceedings presents the motivation for the workshop, the structure of the event, and the findings from the day's discussions.

The one-day workshop had two sections. Each section began with a presentation on background information that primed a small group discussion, followed by full group discussion of key topics. Small groups were chosen by the organizers to reflect a mixture of expertise across water quality, water monitoring, habitat quality, scientific research, and stakeholder engagement. The small group discussions focused on (1) primary audiences and their interests, (2) messaging for identified audiences, (3) design considerations for a web tool on a hypoxia forecast, and (4) challenges to communicating about a hypoxia forecast. Key findings from the workshop included:

- Targeted messaging is key to convey usefulness of a hypoxia forecast to various audiences and motivate behavior change to reduce nutrient pollution.
- Design of the online tool should be interactive, customizable to different uses of Long Island Sound, accessible for those speaking languages other than English and with disabilities, easy to use, and easy to interpret.
- Key challenges to communicating a hypoxia forecast include (1) creating interest in and urgency about hypoxia, (2) explaining the science of hypoxia in waterbodies, (3) identifying appropriate trusted messengers for each audience we should be communicating with, and (4) reaching audiences who live far away from Long Island Sound.

Overall, the Messaging and Forecasting Hypoxia for Long Island Sound workshop was an important platform for EPA to connect with federal, state, and local stakeholders. Through the workshop, participants identified recommended approaches to communicating about hypoxia and more specifically about the hypoxia forecast EPA is developing for Long Island Sound. Having this workshop before the forecast model is developed and finalized allows researchers to refine the geographical scope and design of communication tools to better reflect the users and uses identified. Outputs of this workshop include a summary email to attendees following the event with high-level findings and this proceedings report. The anticipated long-term outputs include the hypoxia forecast and various communication tools for promoting widespread use. Similar workshops may be of use to EPA in the future to identify what aspects of EPA research are of interest to external audiences and to increase effective messaging and design of communication products that translate scientific findings.

1. Introduction

1.1 Background

Hypoxia, or low dissolved oxygen, is an important nutrient-related water quality issue that impacts aquatic life in lakes and coastal waters globally. Although low oxygen can occur naturally, the extent and severity of hypoxia is increased by anthropogenic nutrient loads resulting from wastewater, stormwater, agricultural runoff, atmospheric deposition, and other sources. Hypoxia is well studied in Long Island Sound, an estuary of national significance, and has been the focus of successful environmental management for decades (O'Donnell and Fake, 2020). Long Island Sound is located between Connecticut and the north shore of Long Island in New York. The Long Island Sound watershed extends northward into Massachusetts, Rhode Island, Vermont, and New Hampshire (Figure 1). The Long Island Sound Study, an EPA Geographic Program and National Estuary Program, has facilitated successful management through environmental monitoring and scientific research, public engagement, and policy development. Nutrient loading reductions prescribed by the 2000 Total Maximum Daily Load (NYSDEC and CT DEEP, 2000) achieved a long-term decrease in the extent of hypoxia, mainly via improved treatment of municipal wastewater. Despite this notable success, hypoxia persists at a variety of spatial and temporal scales, requiring ongoing effort to expand and sustain the restoration, especially in the face of climate changes that can exacerbate the threat of hypoxia (Whitney and Vlahos, 2021).

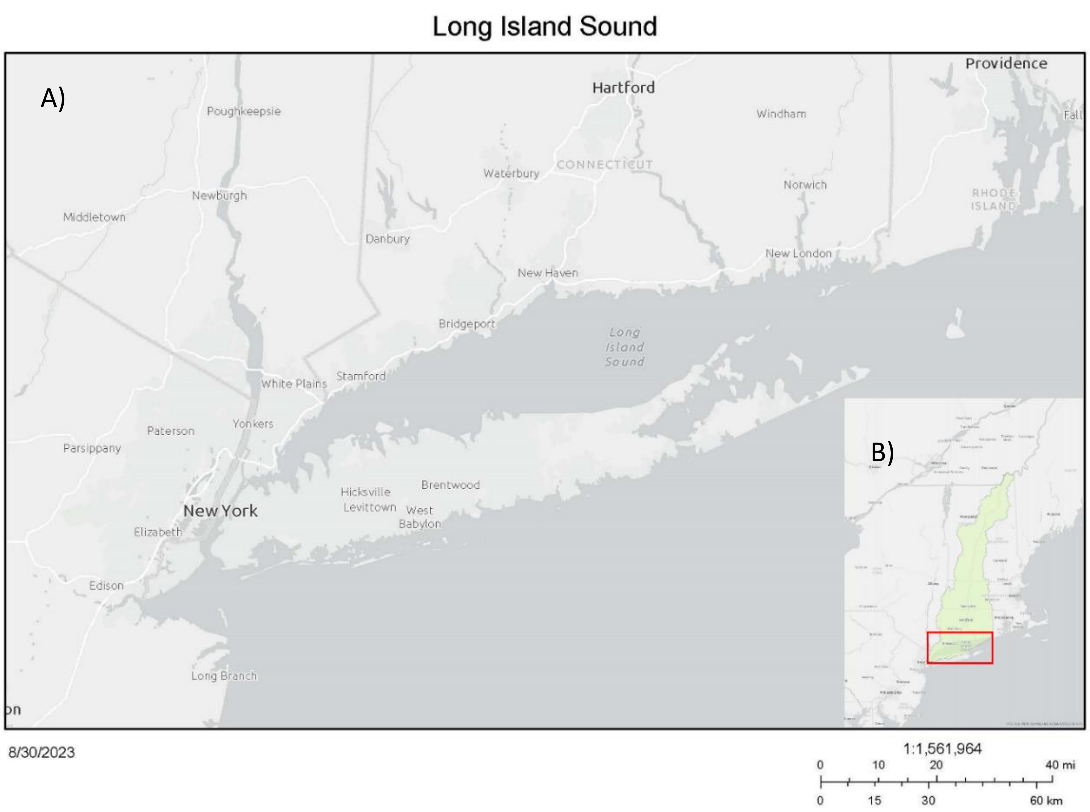


Figure 1. The figure shows a) the Long Island Sound; while b) shows the entire Long Island Sound watershed, extending up to Canada, with the red box indicating where Long Island Sound is located.

Communicating hypoxia across partners and with affected communities remains challenging. Maintaining interest and engagement over time to initiate or sustain restoration of water quality improvements, or "messaging on slow impacts," presents a unique challenge (Canfield et al., 2021). Moreover, hypoxia impacts to aquatic life are difficult to measure and communicate to stakeholders than more tangible nutrient-related impacts like harmful algal blooms (HABs) or seagrass loss. Although practitioners often cite large-scale fish kills as a key hypoxia impact, possibly because photographs of them clearly imply severe impact (e.g., Tomasetti and Gobler, 2020), aquatic life impacts associated with hypoxia avoidance, chronic effects and less obvious mortality are more common and likely more ecologically important.

Ecological forecasting is a useful approach to help explain the hypoxia issue, its causes, and possible solutions (Testa et al., 2017; Scavia et al., 2021). In some cases, hypoxia forecasting also serves as an operational tool to support recreational and commercial users (i.e., fisheries, aquaculture), and a critical communications tool to support public engagement. Communications related to hypoxia forecasts can also increase attention to important developments in scientific research and analysis and environmental management. Hypoxia forecasts have been applied successfully to the northern Gulf of Mexico, Chesapeake Bay, and Lake Erie where predictions have been used as a basis for annual press releases and national news media coverage, creating opportunities to discuss important scientific information even if forecasts are not correct.

However, there are key challenges with communicating complex environmental problems, including relating risk to people's beliefs and priorities (Fischhoff and Scheufele, 2013), and the potential temporal and spatial disconnects between input and environmental impact (Hoijer, 2010). A key challenge in the case of hypoxia becomes conveying the urgency of action and engagement over an extended period rather than just responding to singular, disaster-like events (Hoijer, 2010). Further, while there is expansive research into communicating the science of some environmental challenges, much less research has examined how to communicate about the challenges of nutrient management and its consequences (Canfield et al., 2021). While work specifically on the science of communicating about nutrient pollution and its effects is limited, social science research incorporating structured workshops with collaborative qualitative data collection can lead to improved understanding of communication needs and priorities of environmental challenges (Osmond et al., 2010; Jamshed, 2014; Reddy et al., 2020).

1.2 Purpose of this Report

The U.S. Environmental Protection Agency's Office of Research and Development and Region 2's Long Island Sound Office are developing a Long Island Sound Hypoxia Forecast Tool to predict hypoxic extent and duration in Long Island Sound and its embayments (bays) for each summer and to enhance the communication and awareness of hypoxia and its impacts – from water quality to habitat quality. The tool will include (1) a natural science element that will inventory, synthesize, and review existing models on hypoxia in Long Island Sound based on early-season environmental observations, and develop new models using existing data that emphasize quantifying variability and uncertainty; and (2) a web-based communication platform to share and contextualize the forecast for stakeholders. To guide the development of the forecast tool and identify best engagement approaches to use hypoxia forecasting, an in-person workshop was held to gather input from people at the interface of science and practice in Long Island Sound. This work emphasizes understanding community needs and values to improve targeted communications and motivate community behavioral change to mitigate environmental challenges. Maintaining public focus on Long Island Sound issues to sustain nutrient reductions, specifically from nonpoint sources, is an important challenge that could be addressed by developing a hypoxia forecast system. This system could address the problem that early policy success combined with a failure to maintain public awareness has been associated with less positive long-term outcomes of nutrient management (Gross and Hagy, 2017).

2. Workshop Proceedings

The workshop was held from 9am to 3pm on May 23, 2023, at the EPA Region 2 Office in New York City, New York. It was structured into morning and afternoon sessions. Each session included a presentation to the full group followed by small breakout group discussions and then a full group discussion of key points (See Appendix A for agenda). Participants were invited based on their position at the interface of science and stakeholders in Long Island Sound, with an effort to represent many partnership organizations affiliated with the Long Island Sound Study. There were three breakout groups, each with a facilitator and a notetaker to help navigate through a pre-defined set of questions (See Appendix B) and capture insights from the groups. In the morning small group discussion, topics included defining key audiences, key information to convey, why different people would use a forecast, messengers, and potential challenges to communicating. The afternoon small group discussion covered more of the details of making the tool, including terminology, the most appropriate formats for identified audiences, equity considerations, and messaging recommendations. Two invitees who could not attend in-person were asked the same list of questions during separate virtual meetings. The findings of the workshop discussions are organized thematically in Section 3.

2.1 Presented Materials

Two presentations were given for the workshop. The first presentation was on the potential hypoxia forecasting tool for Long Island Sound. In this presentation, Jim Hagy from the U.S. Environmental Protection Agency Office of Research and Development gave a presentation on the possibilities of forecasting in Long Island Sound as a primer for the conversation. The second presentation, given by Cayla Sullivan, U.S. Environmental Protection Agency Region 2 Long Island Sound Program, focused on learning from existing hypoxia communication tools.

2.1.1 Topical Presentation: Potential Forecasting Tool for Long Island Sound

Jim Hagy introduced a definition of ecological forecasting, explored the benefits and challenges of forecasting hypoxia in Long Island Sound in the context of similar work in other water bodies, and provided some initial suggestions of what aspects of hypoxia in Long Island Sound could be forecasted. He provided an overview of an initial analysis of dissolved oxygen in Long Island Sound implemented using Generalized Additive Models (GAMs), describing both the strengths of the analysis and the challenges associated with using GAMs to develop a forecast. The presentation concluded by suggesting some directions that could be taken for future work on both data analysis and communications.

A key distinction between a prediction and a forecast is in addition to predicting the future state of an ecosystem (in this case, aspects related to hypoxia), a forecast describes the logic underlying the prediction, which provides context for audiences to understand the prediction and its implications around issues of nutrient pollution, eutrophication, and associated hypoxia. A hypoxia forecast could address the extent, duration, and severity of hypoxia in open waters of Long Island Sound, as well as the frequency of hypoxic conditions in the relatively shallow bays that surround the Sound. GAMs are a flexible data modeling tool that are capable of fitting complex water quality patterns in space and time. While the flexibility of GAMs allows them to describe patterns that have occurred in the past and the relationship of oxygen to key drivers, they may not be as effective for predicting future water quality. Future work will focus on quantifying and improving the ability of models to predict future oxygen conditions and developing effective communication strategies to complete the forecast, shaped by information learned from discussions with stakeholders.

2.1.2 Topical presentation: Building awareness: Other tools that have been effective in communicating about hypoxia

Cayla Sullivan presented on tools that are effective in communicating about hypoxia including existing Long Island Sound-specific tools and existing hypoxia forecasts in other large aquatic watersheds. The Long Island Sound tools include the Long Island Sound Study (LISS) Microsite: Ecosystem Targets and Supporting Environmental Indicators, Connecticut Department of Energy and Environmental Protection (CT DEEP) and Interstate of Environmental Commission's (IEC) Hypoxia Review Report, Long Island Sound Integrated Coastal Observatory System (LISICOS), Save the Sound's SoundHealth Explorer and Report Card, and University of Connecticut's Center for Land Use Education and Research (CLEAR) Mapping Products.

Cayla also presented on existing hypoxia forecast tools in other areas, including the Gulf of Mexico, Chesapeake Bay, and Lake Erie. The Gulf of Mexico's forecast predicts the size of the so-called "dead zone" (the region impacted by hypoxia) using four nitrogen-focused models, each of which consider U.S. Geological Service's (USGS) estimates of springtime nitrogen loading from the Mississippi/Atchafalaya River Basin. National Oceanic and Atmospheric Administration (NOAA) releases the estimate of the size of hypoxic zone for the summer in late spring and then conducts an annual water monitoring cruise in late July. The Gulf of Mexico forecast generates public media by telling a story regarding what happened that year and if the forecast either under- or overestimated the observed size. The Chesapeake Bay Environmental Forecast System uses a three-dimensional, numerical model, driven by weather provided by NOAA and river input provided by USGS's stream gauges, to forecast conditions daily. The system reports three conditions, a nowcast which describes dissolved oxygen on the present day, a two-day forecast which describes dissolved oxygen levels up to two days in advance, and a forecast trend which describes the difference between the nowcast and forecast. The Chesapeake Bay system also reports on the dead zone size, depth to low oxygen, and generates hypoxia line plots. Lake Erie's Experimental Hypoxia Forecast is updated daily and uses a hydrodynamic model and weather forecast data to predict the location and movement of hypoxia up to five days in advance.

2.1.3 Existing Long Island Sound communication tools

Cayla's presentation describes several existing environmental tools, both for hypoxia forecasting and relevant to hypoxia forecasting. These tools were used to prompt small group discussion on designing a web tool for Long Island Sound hypoxia forecasting:

- The LISS Microsite showcases the 20 ecosystem targets and supporting environmental indicators, including extent of hypoxia. This target is to measurably reduce the area of hypoxia in Long Island Sound from pre-2000 Dissolved Oxygen TMDL averages to increase attainment of water quality standards for dissolved oxygen by 2035 (Long Island Sound Study, 2015), as measured by the five-year running average size of the zone (Figure 2). The supporting environmental indicators under this target are duration of hypoxia, severely hypoxic and anoxic areas, and volume of hypoxia. The data to support this indicator are from several different water quality monitoring programs including CT DEEP's Long Island Sound Water Quality Monitoring Program (open waters of the Sound), IEC's Western Basin Water Quality Monitoring Program, University of Connecticut's LISICOS, and Save the Sound's Unified Water Study (bays and harbors).

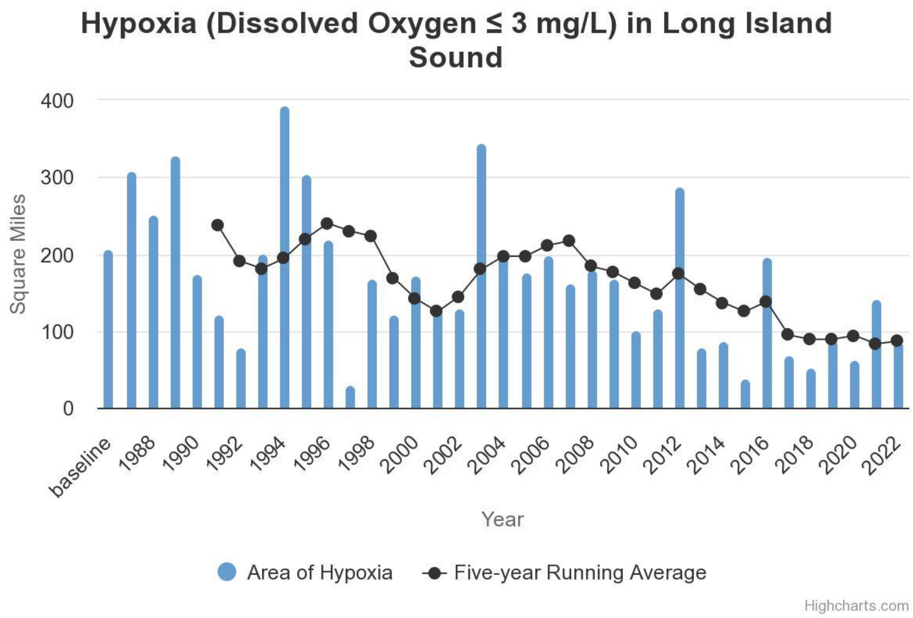


Figure 2. The graph shows the five-year running average of hypoxia extent in Long Island Sound monitored by CT DEEP's Long Island Sound Water Quality Monitoring Program and IEC's Western Long Island Sound Monitoring Program. Data from Long Island Sound Study.

- CT DEEP and IEC's Hypoxia Review Report is an annual report that communicates in-situ data results, hypoxia area, volume and duration, and chlorophyll-a from their water quality monitoring program. This report also includes a frequency of hypoxia in Long Island Sound bottom waters which is then compared to 1994 (the establishment of the monitoring program) (Figure 3).

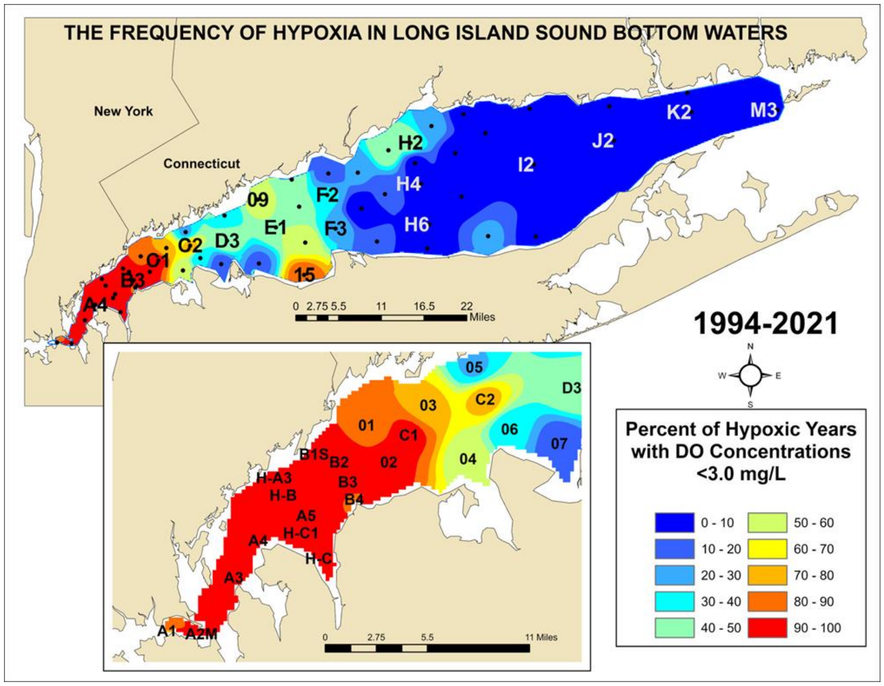


Figure 3. The map, produced by CT DEEP's Long Island Sound Water Quality Monitoring Program, shows the areas of Long Island Sound that are most frequently affected by hypoxia in bottom waters. The colors on the map represent the percentage of years in which hypoxic conditions have occurred in the bottom waters of the Sound since the program was established in the early 1994. The labels show the station name. These maps are developed based on the data collected during the week of each year when the maximum area of hypoxia was reported.

- The LISICOS is a real-time water quality monitoring program showcasing the dissolved oxygen measurement at two buoys in Long Island Sound (Figure 4).

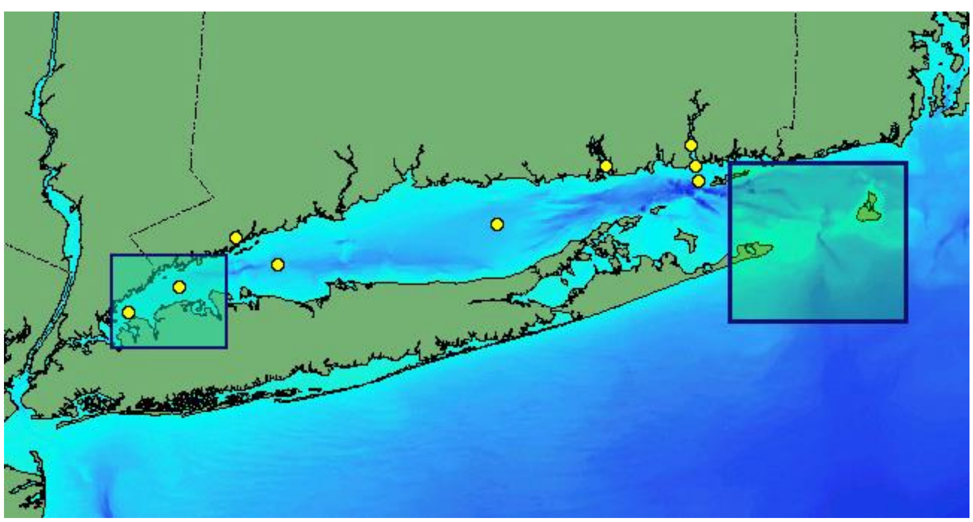


Figure 4. A) The map above shows Long Island Sound Integrated Coastal Observatory System monitoring stations in Long Island Sound. The yellow dots represent the real-time monitoring devices, while the two boxes indicate the coastal ocean dynamics applications radar (CODAR) sensors.

- [Save the Sound's Sound Health Explorer (SHE)](#) is an online interactive dashboard that allows the user to click on basins or embayments to view health indictors (Figure 5). One of the indicators is dissolved oxygen which is given a "grade" depending on its health measurements to indicate poor or good quality. Save the Sound also produces a [biennial report](#) to present the CT DEEP, IEC, and Unified Water Study water quality monitoring results by calculating an associated "grade" with each basin and embayment to communicate the health of the Sound.

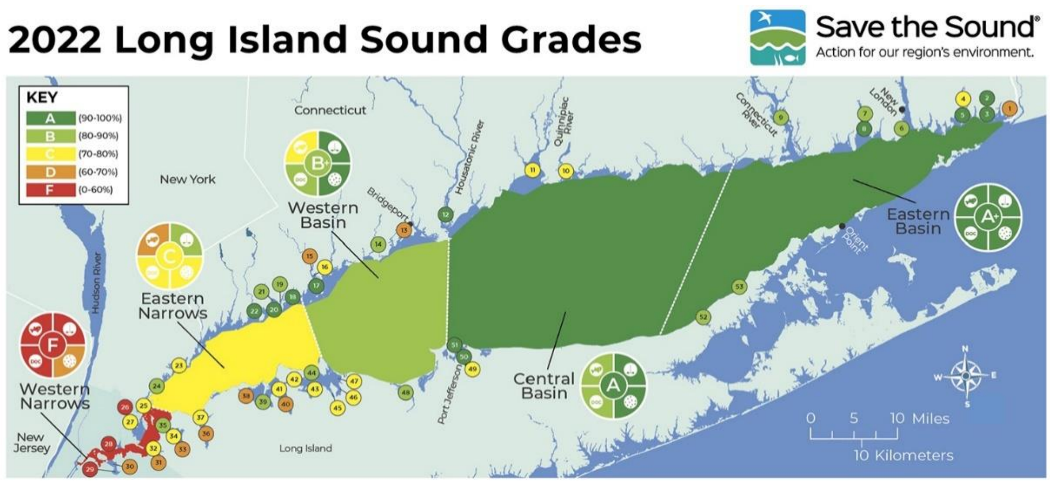
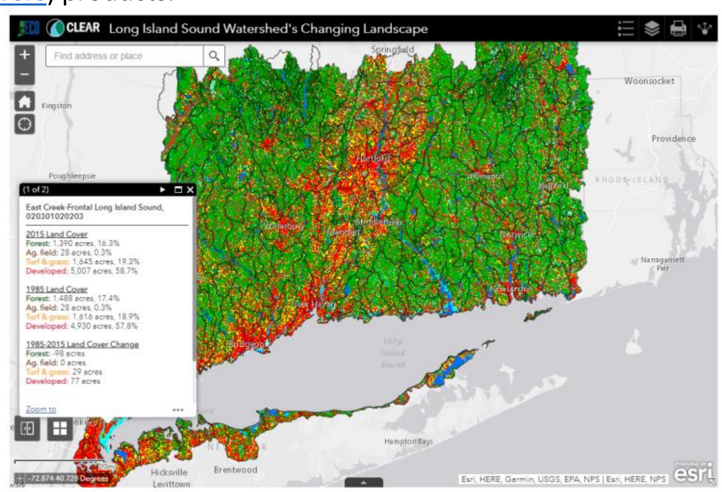


Figure 5. The 2022 Report Card grades by Long Island Sound basin and embayments.

- [University of Connecticut's CLEAR](#) has a multitude of mapping products that can be connected to hypoxia (Figure 6). Specifically, connecting to their land cover (i.e., [Long Island Sound Watershed's Changing Landscape](#)) and aquaculture (i.e., [Aquaculture Mapping Atlas](#), [Shellfish Restoration Map Viewers](#)) products.

A)



B)

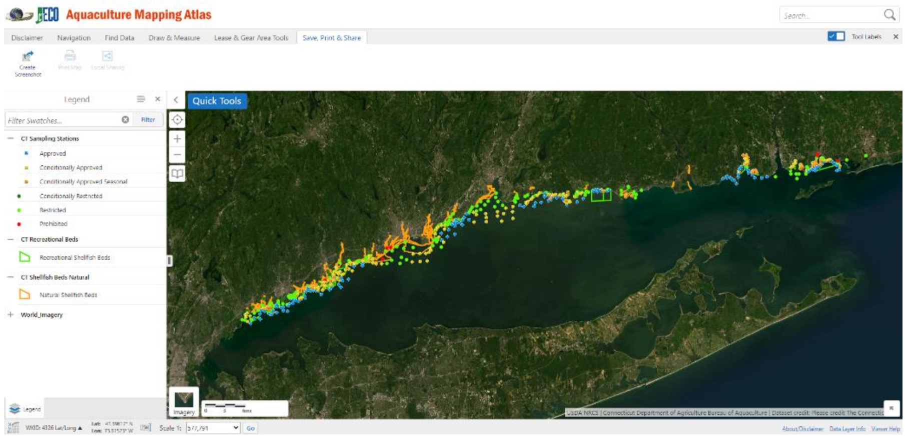


Figure 6. Two different mapping products developed by University of Connecticut's CLEAR that include data that are related to and can be connected to hypoxia forecasting: A) Long Island Sound Watershed's Changing Landscape and B) Aquaculture Mapping Atlas.

3. Workshop Findings

Discussion throughout the workshop defined who might benefit from using a hypoxia forecast for Long Island Sound and effective communication tools, messages, and design to reach those potential users. Key topics of conversation covered why different audiences would use the forecast, effective environmental communication campaigns that this project could learn from, potential equity impacts of hypoxia, and considerations in tool design. There were also numerous recommendations for designing the most useful, accessible, and accurate communication tool for the potential users. A primary topic of interest for holding the workshop was the need for hypoxia forecasting in Long Island Sound. This topic did not elicit extensive comments and perspectives, but we share those that did arise related to forecasting challenges below. What follows are the thematically organized findings of the workshop discussions. The recommendations are consolidated into a table at the end of the findings section (Table 1).

3.1 Defining the Audience and Messages

Designing a useful tool requires defining for whom the tool is being made and how it will be used. Discussion identified numerous distinct audiences that would use a hypoxia forecast, and how their uses of the tool would vary. Participants shared key messages to convey about hypoxia in Long Island Sound along the themes of behavior change, environmental impacts, and economic impacts. Additional topics covered the challenges in reaching the identified audiences as well as what organizations would serve as effective messengers in motivating behavior change to improve hypoxia problems in Long Island Sound.

Related to uses and needs of users was discussion of the usefulness of a hypoxia forecast. In both small and large group discussion participants noted there is not currently significant interest or concern about hypoxia in Long Island Sound outside of those actively working to address and understand low oxygen levels in the Sound. With many environmental, public health, and societal challenges about which to be worried, there was a perception that hypoxia in Long Island Sound is not a priority concern for many. Participants discussed if the forecast will be addressing identified community needs, how to ensure these needs are incorporated in communication design, and how to make sure the tool is available and useful for said communities. Past science and risk communication research has termed the limited capacity people have to simultaneously worry about many issues as a “finite pool of worry” (Linville & Fischer, 1991; Weber, 2006). Keeping this finite pool of worry in mind, participants brainstormed key messages to target audiences, motivate action, and maximize usefulness of the tool.

3.1.1 Potential audiences

Participants identified eight main audiences that could potentially use the hypoxia forecast based on their dependence and use of Long Island Sound (Figure 7). These major user groups who would benefit the most from a forecasting tool for Long Island Sound were identified as (1) regulators and decision-makers (including local, state and federal agencies), (2) wild harvest commercial and recreational fishers and shellfishers and shellfish aquaculturists, (3) media (reporters), (4) wastewater treatment plant operators, (5) environmental conservation and protection nongovernmental organizations (NGOs;

operating at watershed and local scales, as well as funding entities), (6) coastal recreators, (7) scientists (both at formal institutes and community science groups), and (8) the "general public."[1]

Location and demographics will impact forecasting needs and uses. As Long Island Sound borders both Connecticut and New York, the needs of users in different states are expected to reflect their different relationships to the Sound. Additional demographics that participants identified as affecting use and interest included if the communities are more rural or urban, socioeconomically disadvantaged, and in the east or west end of the Sound. Based on these differences, audiences in these communities will have different histories and priorities. These additional considerations were discussed as key in both use of the forecast and in finetuning messages about hypoxia to meet varied needs.

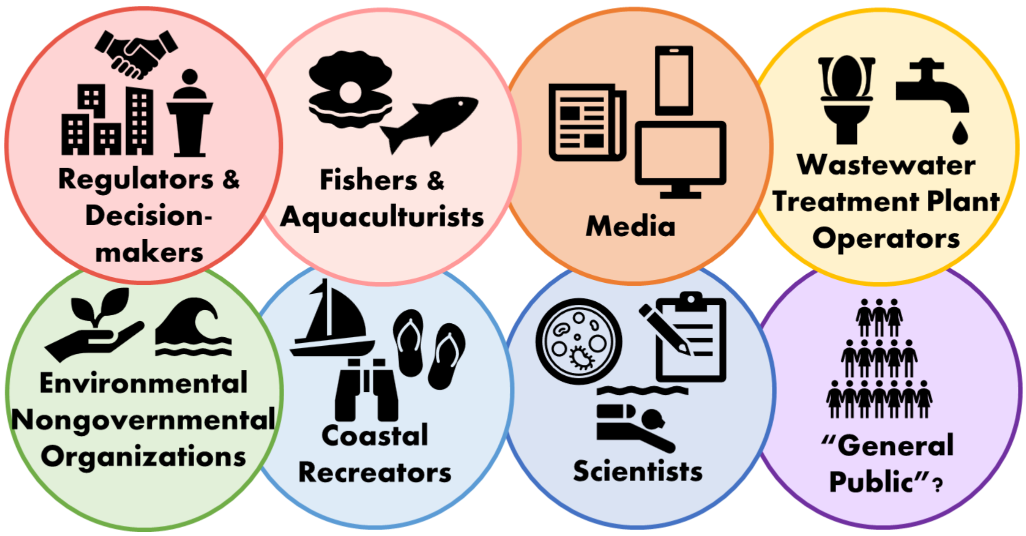


Figure 7. Potential audiences for a hypoxia forecast in Long Island Sound

3.1.2 Audience uses of a hypoxia forecast

Workshop participants discussed how the various user groups may differ in their motives for use (Figure 8). Potential uses broke into three categories: 1) planning, 2) science, and 3) education and curiosity. Planning uses related to informing management decisions, identifying locations for focusing nutrient and water quality monitoring, deciding on timing and location of placing spat for aquaculture, and when to fish. Uses of the forecast for science included understanding hypoxia and identifying data gaps for scientists and potentially environmental NGOs. The final use category of education and curiosity captured uses including students doing research using data from the forecast, and media and public interest in when and where hypoxia is happening. There was also suggestion that fostering curiosity and interest with this tool could be a way to raise awareness of nutrient pollution in Long Island Sound and motivate behavior changes to reduce hypoxia. This final category of use was the primary expected use

[1] While participants recognized that forecasted hypoxia information is primarily of interest to those who are using Long Island Sound for work or leisure, there was still a desire to make the forecast tool accessible for others who have curiosity about hypoxia in Long Island Sound, hence the quotations around the "general public."

of the forecast for coastal recreators, media sources, and the public generally, thus also being of interest to all identified audiences.

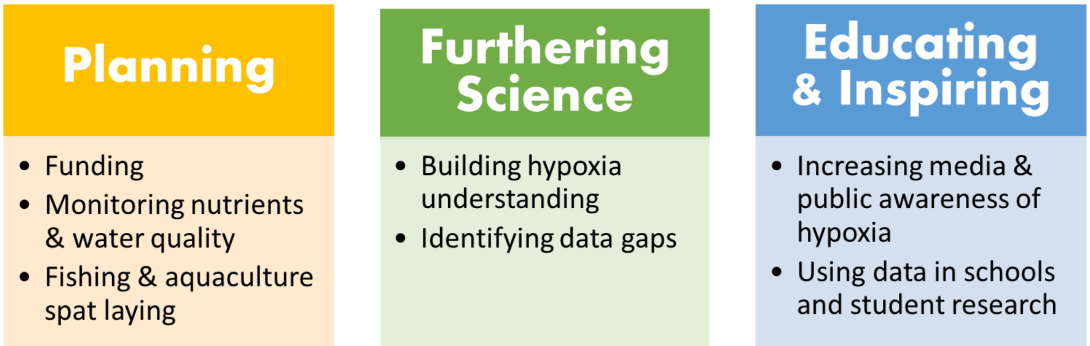


Figure 8. Potential uses of a hypoxia forecast. *The thematic categories for using a hypoxia forecast or general hypoxia interest broke into planning, science, and general education and curiosity.*

3.1.3 Equity concerns

Another prompt for participants sought to identify equity concerns and considerations in both impacts of hypoxia and in communicating about hypoxia in Long Island Sound. Participants raised the need to "decrease knowledge gaps," noting that many people potentially impacted by hypoxia are not familiar with the science of hypoxia. Another knowledge gap participants identified was the role of nitrogen in nutrient pollution and the impacts of this pollution, and they recommended doing more outreach to marginalized communities. Participants' primary point was that hypoxia is an impact of nutrient pollution and can serve as an indicator of decreasing environmental health. Participants noted harmful algal blooms can result from the same nutrient pollution that causes hypoxia, and such blooms create equity issues as disadvantaged communities will have fewer resources to mitigate the problem. Further, blooms may also impact a community's access to swimming water and, in the case of some rivers and lakes, safe drinking water.

While ensuring people have accurate information is key to accurate risk assessment and motivating behavior change, it is also important to approach education efforts knowing there are multiple ways to know about a scientific topic. Assuming audiences know nothing about hypoxia and simply providing information is considered a "deficit approach" to science communication and has been repeatedly proven ineffective (Reincke et al., 2020; Simis et al., 2014). As such, when working to improve awareness, it is important to both share scientific knowledge and work to understand the knowledge and experiences that the audience you are communicating with already has. When designing online communications to be equitable, participants identified considerations of color choice (for color-blindness or cultural sensitivity), language and translation, and Americans with Disabilities Act Section 508 compliance to provide more accessible information for all viewers.

Participants identified equity concerns related to reliance on hypoxia-impacted waters in Long Island Sound. Access was the primary use concern and was tied closely to communication. Inequitable access to the nearshore environment was noted, demonstrating a need for better communication of public access points to the waterfront, regardless of hypoxic status of water. If there is fear of swimming in hypoxic waters based on inaccurate or lack of information, people will be less likely to use Long Island Sound during hypoxic events. This points to the need for on-site signage that explains that hypoxic waters are safe for recreation but may impact what wildlife can live there. Further, participants noted the need for signage to be accessible to users, providing information in the languages used in various areas around the Sound, and colors that can be interpreted for those who are colorblind. Most directly, for fishers and shellfishers, their livelihood could be impacted by reduced catch in hypoxic waters. Fishing concerns would be tied to the nearshore environment more than the depths of Long Island Sound. The main target species for commercial fishers may be in deeper waters rather than nearshore environments, but subsistence fishers are likely to be impacted by hypoxia in bays and nearshore waters. The potential for reduced fish catch and overall reduced wildlife during hypoxic events represents a disamenity, or environmental bad, that participants noted could represent an environmental injustice if marginalized communities are disproportionately proximal to hypoxic waters and rely on fish caught there.

A final equity concern noted was in who is held responsible for hypoxia in Long Island Sound. While the western narrows of Long Island Sound have the worst water quality grades (Save the Sound, 2022), it is not the sole fault of those in the western portion of the Sound for the levels of hypoxia and nutrient pollution in their waters. The discussion emphasized that New York City is not wholly responsible for hypoxia in Long Island Sound, and it is important to change behavior and regulations across the region. This is an equity concern in that those in the western sound have the worst water quality, but pollution is coming from a larger area in the northeastern United States that comprises the Sound's watershed.

3.1.4 Who is communicating?

Identifying the right people to communicate about hypoxia was another conversation focus in successfully building awareness. As previously discussed, one challenge participants discussed was determining the correct communicator, noting that not all researchers are trained to fill the communication role. Further, there may be distrust in government among communities, with government being seen as representing polluters. Science communication is a skill that requires relationship building. Participants noted some potential audiences for this tool will likely ask, "who are you to tell me what to do?" if the communicator is not trusted by the audience. People and organizations that are well respected in communities will be more trusted messengers of scientific information.

Understanding the unique demographics and interests of the various audiences is key to selecting a trusted communicator that can motivate behavior change related to nutrient loading in the Long Island Sound watershed for each audience. Participants emphasized the need for local communicators from local organizations, including nongovernmental organizations, newspapers, boat captains, and formal stakeholder liaisons (like the Citizen Advisory Group). These highly local entities will help initiate understanding and trust in hypoxia information as accurate, reliable, and of concern to these audiences. While federal government agencies may not play a role in directly sharing information with communities, when it comes to communicating regulatory information on nutrients, the U.S. EPA does have a role to play in creating, implementing, and potentially revising regulatory documents such as the Total Maximum Daily Load (TMDL). Funders, specifically New York State Department of Environmental Conservation's Water Quality Improvement Projects, Clean Water State Revolving Funds, Long Island Sound Study, and National Fish and Wildlife Foundation's Long Island Sound Futures Fund, were identified as key to addressing nutrient loading for local organizations as they can provide money to implement new approaches.

3.1.5 Important messages in communicating hypoxia

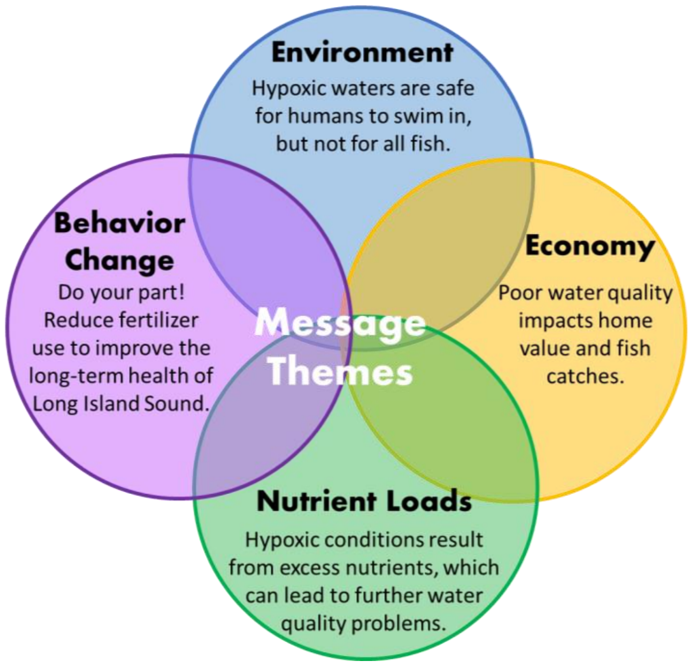


***Figure 9. Themes of messages recommended for explaining hypoxia effectively**. All themes are connected to each other.*

To best communicate about hypoxia, workshop participants identified recommended messages focused upon economic impacts, needed behavior changes, environmental impacts, and nutrient loads (Figure 9). Within these message themes, there will need to be nuanced messaging to best reach audiences of varied uses and demographics (e.g., effective messages for people living on the shoreline of the Sound would differ from those to motivate nutrient management in the upper watershed of the Sound). Recommended messaging on economic impacts focused on the cost of poor water quality. The examples provided included how poor water quality can impact home values and reduce catches for commercial fishing.

Behavior-change messages focused on projecting urgency and promoting action, answering questions like “What do I have to do with hypoxia?” and “What can I do to help?” One simple message towards planning fishing behavior was using the tool to specify if it is a “good summer” or “bad summer” for hypoxia levels, such that recreational fishers could modify their behavior and reduce fishing if it was a bad summer for hypoxia. Participants recommended explaining how hypoxia is an example of the consequences of excess nutrients, and promoting actions related to nutrient management more generally, while emphasizing that actions will not have immediate impacts. Addressing that behavior changes will not immediately affect nutrient loading challenges in Long Island Sound is key to accurately communicating science and setting expectations.

Environmentally focused messages about hypoxia will require precision in addressing the different risks of hypoxia for humans and other species. Participants recommended messages such as “hypoxic waters are not dangerous for humans to recreate in, but they do affect what fish can survive here.” Participants recommended emphasizing that hypoxia worsens water quality and leveraging concern for protecting environmental quality to motivate a desire to reduce hypoxia extent.

Related to environmental impacts and behavior change, the final angle suggested was messaging about nutrient loading. These messages connected hypoxia to nutrient loads, especially nitrogen, that are primarily the result of fertilizer use. Participants also sought to use the connection between nutrients and hypoxia as a warning and indicator of possible further water quality impairments, such as harmful algal blooms, due to nutrient loads. Using multiple angles to communicate about hypoxia in Long Island Sound will help to reach the varied audiences with their different uses of the Sound.

3.1.6 The importance of terminology

Based on expertise in impacts of nutrient pollution, and past efforts to communicate about such impacts, participants identified scientific jargon that requires intentional use and definition. There was not agreement about whether these terms should be avoided entirely or simply used thoughtfully, so we include all identified terms that warrant careful consideration and usage:

- Dissolved oxygen (usually abbreviated as DO): amount of oxygen in water that is available to aquatic organisms. This is a key term to understanding hypoxia, as hypoxic systems by definition have low levels of DO (USGS, 2018). Some participants recommended simply referring to this as "oxygen," since the general public better understands the necessity of oxygen for life. The primary challenge anticipated with this term was in differentiating between oxygen levels in the body and oxygen levels in water.
- Eutrophication: an increase in the rate of supply of organic matter to a water body (Nixon 1995), sometimes caused by excess nutrient loading that can result in overgrowth of plants, which can cause low oxygen levels (Cloern et al., 2020). Participants primarily noted that this was a common term used in describing nutrient pollution, but is also jargon that requires definition.
- Harmful algal bloom (HAB): rapid growth of algae or cyanobacteria that disrupt human and aquatic life uses of a water body, sometimes by producing toxins that are harmful to animals, humans, or flora. Occurrence of HABs is sometimes connected to excess nutrients in a waterbody. Participants emphasized the need to clearly communicate the nuances of risk of HABs exposure, as well as the relationship between HABs and nutrient pollution, the same root cause as hypoxia (NOAA, 2023a).
- Nitrogen: a naturally occurring element that humans made more bioavailable to support food production. Nitrogen pollution can be in the form of nitrate, ammonium, and sometimes organic nitrogen. Participants disagreed on how much specificity was needed in understanding nutrient pollution for people not involved in scientific research or management. The conclusion was that more information and understanding of the root cause of hypoxia (nutrient pollution) would be helpful for residents in motivating and sustaining behavior change (EPA, 2023).
- Dead zone: referring to a water area with extremely low dissolved oxygen. This term was first used in the Gulf of Mexico in reference to the large area of bottom water hypoxia that occurs there. Because it has been very effective as a communications tool and has helped focus public attention, policy action, and scientific research on Gulf Hypoxia, it has been adopted elsewhere. This term can sometimes mislead because non-bottom waters in the same area often have abundant life. Participants found this term effective for motivating concern about water quality. Simultaneously, participants were concerned that it does not accurately portray the livability of hypoxic areas for some flora and fauna (NOAA, 2023c).
- Forecast: a prediction or estimate of future events accompanied by an estimate of the uncertainty around the prediction and an explanation of the rationale or logic for the prediction. Concerns about careful definition here related to explaining the probability involved in forecasting rather than it being a prescriptive foretelling of what is to come (Scavia et al., 2021).

3.1.7 Challenges in communicating hypoxia

Workshop participants discussed the many challenges they had experienced or anticipated in communicating about hypoxia. One challenge that cut across many other identified concerns was the lack of visibility of hypoxia, both for those regularly engaging with Long Island Sound and those located farther away. Not being able to visually demonstrate the consequences of hypoxia accurately makes it difficult to portray as a major, urgent concern. For example, there was considerable discussion about the complexities of using "fish kills" in discussing hypoxia. Fish kills are often cited as a consequence of coastal hypoxia with accompanying photos that, in the region, nearly always depict dead menhaden (*Brevoortia tyrannus* or *B. patronus*; also known as pogy or bunker). However, these fish reside in surface waters, filter-feeding on algae, making them unlikely to be impacted by bottom water hypoxia. They succumb to hypoxia that occurs under specialized circumstances, and sometimes their high abundance itself contributes to the low oxygen. Thus, while fish kills can result from hypoxia, these events poorly represent the more typical aquatic life impacts of coastal hypoxia, especially persistent low oxygen in bottom waters, which is very unlikely to cause mass mortality of menhaden. More broadly, relatively low awareness and worry about impacts of hypoxia on human health compared to other environmental concerns was another challenge identified. This relatively low worry also existed among participants in the room, as they struggled to identify scientifically accurate ways to portray hypoxia in Long Island Sound and thereby motivate action to address it.

Explaining the science story of hypoxia in Long Island Sound was another challenge. Many who seek information about hypoxia are likely to find information about hypoxia in the human body rather than hypoxia in the water. Other challenges involve the offset in time, space, and causal mechanisms between nutrients introduced into a system on land and their later effect of contributing to hypoxia in the water. This complexity, paired with the lack of simple imagery to depict hypoxia impedes effective communication about hypoxia.

A common strategy to convey interest and urgency around hypoxia has been to cite long-term increases in the number of waterbodies with hypoxia, its increasing severity and impact, and the potential for irreversible ecological harm (i.e., tipping points). However, the story of Long Island Sound should be told also by celebrating the successes in reducing nutrient loading and the extent of hypoxia in the Sound and articulating the actions that led to improvements. Thus, an additional nuance is communicating the ongoing challenge of addressing hypoxia that remains in Long Island Sound while celebrating progress made in reducing nutrient loads. This success story may improve messaging effectiveness, as research shows positive message frames can help motivate behavior change (Gifford and Corneau, 2011).

Another challenge was motivating concern in audiences who are located further from Long Island Sound. Participants discussed how nutrients from as far as New Hampshire can impact hypoxia levels in Long Island Sound, making it important to motivate behavior change about nutrient loading in a community that has no immediate proximal relationship with Long Island Sound. This distance from Long Island Sound makes the previously stated challenge of lack of strong imagery for hypoxia stand out.

A final challenge discussed was finding the right entity or individual to communicate about hypoxia. Scientists who know the technical complexities of hypoxia in Long Island Sound are often not the most effective communicators, as they may struggle to explain the science in a way that is accessible for people whose experience with the Sound is more focused on recreation, fishing, or regulations than it is on research. The numerous challenges identified above made clear to workshop participants that it is essential to have a talented, trusted communicator share about the importance of addressing and understanding hypoxia.

3.1.8 Challenges specific to communicating hypoxia through a forecasting tool

Perspectives on forecasting focused on the challenges of making a forecasting tool that had useful information for decision-making. Keeping data sources current was a concern, as without the most up-to-date information, the forecast will be less accurate. Relatedly, workshop participants had concerns about what data and models should be used in the forecast to predict hypoxia most accurately while also providing forecasting information about areas of Long Island Sound that are heavily used. The bays and nearshore areas of the Sound are most accessible for users, leading to the recommendation of including hypoxia levels for those areas to improve forecast useability. Explaining that forecasts are not guaranteed outcomes but are based on models and inherently include some uncertainty was a key communication challenge anticipated in creating a useful forecasting tool.

3.2 Existing Environmental Communication Efforts

3.2.1 Effective communication campaigns (for hypoxia or otherwise)

Building on examples from the presentation, participants discussed traits and examples of environmental communication campaigns they had found to be effective. The general sentiment was the need for creative campaign design, such that it stands out while also educating. Inclusive approaches to science, such as has been promoted by Openscapes, and the Project WET water education organization were seen as good examples of creative approaches to education. Other traits to emulate included websites being interactive and user-friendly, with the Sound Health Explorer and interactive maps of power outages shared by power companies being cited as examples of informative, effective ways to communicate online. Additional effective campaign structures were educational calls-to-action that explained environmental conditions and provided a clear, simple ask of the viewer, with the intended impact of viewers feeling they were doing their part to protect the environment. One example was a Trout Unlimited campaign that broadcasted when water conditions were stressful to fish and asked people to avoid fishing. Other examples of action-oriented messaging were New York City public service announcements about combined sewage overflows and a related water conservation campaign asking residents to resist washing clothes during rainstorms. Motivating environmental stewardship was seen as another effective approach, as demonstrated in campaigns on the danger of microbeads for wildlife, as this led people to demand action to protect wildlife. Consistent signage explaining the environmental challenge was also seen as effective, with the example of the U.S. Geological Survey's annual signage about eutrophication at sites prone to this problem.

Participants also discussed existing effective campaigns to communicate about hypoxia. The Bay Game for Chesapeake Bay teaches about stakeholder interests, decision-making, agriculture, and nutrient delivery, and how all these factors play into hypoxia challenges for the Bay. Hypoxia in the Gulf of Mexico is covered in national news and media, which has increased interest in the state of the Gulf (NOAA, 2023b). Participants sought to get this level of coverage for Long Island Sound, looking to promote both awareness and especially willingness to change behavior to achieve environmental benefit.

3.2.2 Tools to connect with forecasting hypoxia

Discussing effective campaigns led participants to recommend connecting planned hypoxia communication in Long Island Sound with existing tools and campaigns in the area that are frequently used and well-liked. Connecting to existing tools would allow for building on audiences already interested in the environmental health of Long Island Sound. The potential tools discussed to add hypoxia information to were:

- Biomass Area-Day Depletion (BADD) Index by Connecticut Department of Energy and Environmental Protection that documents hypoxia severity and spread.
  - Could be adapted to Long Island Sound to demonstrate what areas of Long Island Sound are not available to specific fish species due to hypoxia.
- DECinfo Locator by the New York Department of Environmental Conservation, that includes over 80 data layers on environmental quality monitoring and natural resources across New York.
- Long Island Sound report card by Save the Sound that tracks and shares the ecological health of Long Island Sound with an easy to interpret color and letter grade rating.
  - Could add hypoxia and nitrogen loading data and integrate explanation of the concepts into communication efforts around the sound.
- National Risk Index mapper by the Federal Emergency Management Agency that demonstrates which communities are most at risk to natural hazards.
  - Could add hypoxia forecasting data as a layer to this map.
- Reclaim our Water Initiative by Suffolk County focused on updating septic systems to manage nutrients.
  - Connecting hypoxia data with the septic program could improve nutrient management education, resources, and motivation for residents of Suffolk County.

3.3 Web Tool Design and Information

Workshop participants had many ideas on the design of a web tool about hypoxia building on discussion of potential audiences and strengths of existing communication tools. They agreed that the internet should serve as the primary hub for the tool rather than print communications, and use of a press release to announce the tool. Discussions on design addressed naming the tool, ways of communicating and interacting with the tool, the information the tool should include, accessibility and display recommendations, and distribution of the final product. While it may not be feasible to incorporate all provided recommendations into the final tool, this discussion provided a thorough list of considerations and ideas for improving effective communication.

In line with discussion of what made existing tools effective, design recommendations for the hypoxia tool were for an interactive, easy-to-use tool. To ease interpretation of the forecast, participants recommended that scientific thresholds (e.g., percent oxygen saturation) be translated into colors. While there was not a recommended name, there was agreement that the tool should not be named "Long Island Sound Hypoxia Forecast," as hypoxia and forecast are seen as scientific jargon that will likely be immediately be perceived as inaccessible for audiences besides scientific researchers.

Participants also contributed technical design recommendations. Having a server that allows for smooth loading of data will be important. Recommendations for displaying the data included a YouTube video introducing the general context of hypoxia in Long Island Sound, providing pop-up definitions when users hover over scientific jargon, and ensuring phone compatibility. Data visualization suggestions included Microsoft Power BI or ArcGIS StoryMaps.

The agreed upon goal was to create a tool that allows for targeted messaging, such that users can interact with the web tool to show the information most relevant to their uses of the Sound. The primary mode of this suggestion was to create a menu where users can view specific scenarios and add or remove layers of data based on the user. Users could change parameters such as precipitation and temperature, which participants believed would be helpful for researchers and decision-makers. Fishers and shellfishers need to know near future hypoxia information, making a short-term timeline of hypoxia levels week over week useful in deciding when to fish. For general users, the primary information suggested was to demonstrate the impacts of point source pollution. Providing data on the bays of Long Island Sound was also recommended, since this is where people primarily spend their time. As there have been improvements in the spatial distribution of hypoxia in Long Island Sound over time, participants recommended including this positive framing, potentially with an interactive timeline to show change over time, to demonstrate that behavior change does make a difference. Creating different paths for the tool while also creating a generalized version would help ensure anticipated users get the information they need, which could also be consolidated into specialized one-pagers for distribution to specific audiences based on their use.

The final discussion was in distributing the tool and announcing it was available for public use. If pursuing a broad rollout of the tool initially, participants anticipated the need for additional expertise in effective communication and design, such as public relations experts and website designers, to ensure the initial rollout is effective. Participants instead suggested a "soft launch" initially to audiences familiar with hypoxia in Long Island Sound, allowing for feedback from informed users. Following revision based on soft launch feedback, the tool could then be distributed widely. Communication recommendations to promote broad use of the tool included newsletters of organizations focused on Long Island Sound, social media, and targeted publications for the different audiences. To further promote the tool for anticipated audiences, a media kit should be prepared, providing targeted messages for the different anticipated users. This communication and distribution of the tool also could be tied to the five-year communication plan for the Long Island Sound Study and other communications plans associated with organizations to which workshop participants belong.

Table 1. Summary of recommendations for design of an effective Long Island Sound hypoxia forecast communication tool

Recommendation	Description	Section
Define intended audience(s) for communications and understand their relationships to the Sound	Eight potential audiences were identified: regulators and decision-makers, fishers and aquaculturists, media, wastewater treatment plant operators, environmental nongovernmental organizations, coastal recreators, scientists, and the public. Additional demographics and related equity concerns could affect audiences' relationships to the Sound and need to be considered in communication.	3.1.1 3.1.3
Target communications to anticipated audience uses of the tool	Three primary uses of a hypoxia forecast were identified: planning, furthering science, and educating & inspiring. Leveraging these uses could help demonstrate its value. In tool design, this should manifest as different "layers" or "paths" so that users can look at their most relevant information.	3.1.2 3.3
Choose a communicator who is trusted and well-known by the intended audience	Who is communicating impacts how the information is received. Local nongovernmental organizations, newspapers, boat captains, and formal stakeholder liaisons were all recommended as effective communicators to turn to in distributing information about the hypoxia forecast tool.	3.1.4
Frame messages effectively and learn from past effective environmental campaigns	Four effective frames for communicating about the tool were identified: environment, economy, nutrient loads, and behavior change. The implementation of these messages will vary based on the audience, their relationship to the Sound, and communication goal. Use local success stories to demonstrate we can noticeably and measurably improve this environmental challenge.	3.1.5 3.1.7 3.2.1
Use terminology thoughtfully and with clear definition	Several scientific terms were identified as needing explicit definition and thoughtful use in communications with nonscientists, as they can often be poorly or misunderstood. These included dissolved oxygen, eutrophication, harmful algal bloom, forecast, nutrients, and dead zone.	3.1.6
Addressing challenges in communicating about hypoxia	Challenges related to communication include the complexity of hypoxia science, the lack of hypoxia imagery, the lack of general urgency to manage nutrient loads that can lead to hypoxia, and conveying both the progress made and lasting challenges of hypoxia in the Sound.	3.1.4
Integrate with existing user-friendly, environmental tools	Incorporating hypoxia forecast data with existing tools for the Sound will connect users who are already interested in the health of the Sound with new information.	3.2.2
Consider accessibility and ease of use in tool design	The forecast tool needs to be easy for users to learn to use, with information that can be quickly and easily understood. This could include translating dissolved oxygen levels to colors, while being thoughtful about accessibility for colorblind users. Providing different "paths" would allow a generalized view of hypoxia in the Sound and allow varying users to further investigate relevant environmental quality data.	3.3

4. Conclusion and Next Steps

In conclusion, this workshop served to bring together people working in Long Island Sound at the interface of users and environmental protection to document their perspectives on designing a hypoxia forecast tool for the Sound. Through a one-day workshop including presentations, small group discussion, and large group discussion, participants identified potential audiences, messages, and web tool design characteristics, and discussed the challenges of conveying the usefulness of the tool and the urgency of action around hypoxia. There was agreement that a forecasting tool can help motivate awareness and behavior change around the larger issue of nutrient management, and hypoxia can be a vehicle to shift perspectives on water quality protection. In designing the tool, scientific language needs to be chosen and defined thoughtfully, as typical jargon relevant to hypoxia is not consistently understood. Further, the tool needs to be created in a way that specific audiences can view the information that is most relevant to their interests (map layers suggested for this). Discussion and presentations identified numerous existing communication tools in the region that this forecast could be incorporated with to encourage use and further motivate behavior change. While it is likely the final tools will not be able to incorporate all recommendations, the workshop provided a thorough list of considerations in designing both the forecast tool and a communication tool about the forecast.

While we have emphasized the findings of workshop discussions, it is also important to comment on the feasibility of recommendations. Based on the current model for the tool, there are constraints on its utility for nutrient loading policy decisions that were not captured in the workshop discussion but are relevant to how the forecast might be used. The focus of the model is on seasonal hypoxia predictions, which does not accommodate the short-term communication recommendations provided. As the tool is still in development, the forecast could provide shorter term forecasts, but such forecasts would not likely be used in policy decisions. Despite these limitations, the forecast tool and communication tool design will move forward with thoughtful consideration of how to incorporate the communication recommendations with the desired utility of the forecast.

The next steps for this project are to advance technical development of predictions and forecast formulation while also beginning to scope development of communication tools. The goal is to have the models developed by May of 2024 and the possibility of a forecast soft launch at that time. To continue engaging with the people brought together for the May 2023 workshop, researchers anticipate informally discussing progress on the models and building toward more complete implementation of open science principles in project development. Another workshop could also be convened to engage with anticipated users and more of the general public audience to better understand why they might care about or need a hypoxia forecast. We anticipate working closely with the tremendous resources who are the participants from the 2023 workshop if such a follow-up workshop becomes a reality. We look forward to continuing collaborative work to promote a better-informed and environmentally motivated community around Long Island Sound.

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Appendices

Appendix A- Messaging and Forecasting Hypoxia Workshop Agenda

Messaging and Forecasting Hypoxia - Workshop agenda - 9am-3pm
May 23, 2023 - 290 Broadway New York, NY

Purpose: Working with people at the interface of science and practice to identify best engagement for a forecasting website, and other engagement practices, to improve public awareness about hypoxia in Long Island Sound

8:30-9:15 am Check-in and Welcome

9:15-9:45am Presentation
Planned forecasting tool, intended use, and website, *Jim Hagy, EPA Office of Research and Development*

9:45-10:00am Transition to group discussions

10:00-11:00am Small group discussion 1: *Defining the audience and messages*

11:00-11:45am Full group discussion

11:45am-12:30pm Lunch on your own

12:45-1:15pm Presentation
Tools in Long Island Sound and communicating about hypoxia, *Cayla Sullivan, EPA Region 2 Long Island Sound Program*

1:30-2:15pm Small group discussion 2: *Designing tools*

2:15-2:30pm Report out

2:30-3:00pm Wrap up

Appendix B- Discussion Questions

Small group discussion 1: *Defining the audience and messages*

1. Audience definition: Who would most benefit from this hypoxia forecast in Long Island Sound?
2. What do you see as the major reasons for someone to use a hypoxia forecast?
3. What messages are important to communicate about forecasting hypoxia?
4. What is important information to include on a hypoxia forecasting website? Does this differ based on audience?
5. What are the major challenges in explaining hypoxia concerns in Long Island Sound?
6. What are the challenges of explaining the usefulness of forecasting?

Full group discussion

- Two sentence summary from each group
- What are the shared messages that came out across groups?

Small group discussion 2: *Designing tools*

1. Building awareness: What messages/examples are effective in communicating about hypoxia causes? and impacts? What terms need to be used/avoided/defined?
2. Tool development: What formats are most accessible to our audience(s)?
3. Does hypoxia create equity concerns (potential impacts on economic well-being? Health concerns? Disamenities for marginalized communities?)?
4. Are there other forecasting/hypoxia communication tools that you know about that are informative/easy to understand/interesting?
5. Behavior change/ask: What orgs/gov. departments should be the focus of increased public interest in reducing nutrient loading to the Sound?

Report out

- Two sentence summary from each group
- What are the shared messages that came out across groups?

Wrap up of all group findings

- What are the shared messages that came out across sessions?
- What are the lasting concerns for explaining hypoxia forecasting's importance?

Appendix C - PowerPoint presentations

Potential Forecasting Tool for Long Island Sound by Jim Hagy

Forecasting Hypoxia in Long Island Sound

James Hagy, EPA Office of Research and Development
Kaytee Canfield, EPA Office of Research and Development
Kate Mulvaney, EPA Office of Research and Development
Anna lisa Mudahy, Oak Ridge Institute of Science and Education
Cayla Sullivan, EPA Long Island Sound Office
Melissa Duvall, EPA Long Island Sound Office
Ben Lawton, Oak Ridge Institute of Science and Education
Jim Ammerman, NEIWPCC / LISS Science Coordinator

Name of Center, Division or Branch Here   Office of Research and Development

What is Ecological Forecasting?

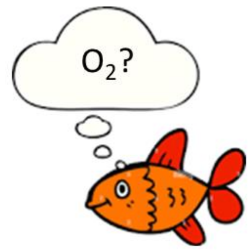
- "the process of predicting the state of ecosystems ... with fully specified uncertainties" (Clark et al. 2001)
- Forecast Logic -- P. Saffo (2007), Six Rules for Effective Forecasting.
  - "Unlike a prediction, a forecast must have a logic to it... The forecaster must be able to articulate and defend that logic."
  - "Moreover, the consumer of the forecast must understand enough of the forecast process and logic to make an independent assessment of its quality"
- Forecast models vs. Scenario Models (Testa et al. 2018)
  - what we expect will happen
  - what we expect would happen if x, y, z occurs.

Average citizens, who are not storm modelers, consume and evaluate forecast logic on their own, to inform their decisions

EPA   Office of Research and Development

Is a hypoxia forecast useful?

- We (obviously) think a forecast would be useful.
- Operational needs for short-term forecasts (several days)
  - *Fisheries and Aquaculture*
  - *Drinking water treatment (Lake Erie)*
- Operational need for longer-term forecasts (2-3 months) may be less.
  - Informing monitoring design?
- We seek your input!



Cognitive benefits of ecological forecasting

- Cognition = how we think
- Because we understand ecological processes affecting hypoxia, we may fail to examine or explain our understanding effectively
- Forecasting challenges us
  - to test our knowledge and analytical skills
  - to improve our explanations
- Forecasting can engage scientists and other stakeholders in a collective learning process.
  - Forecasting competitions
  - Feedback involving forecasters and forecast users
  - Forecasting in popular media ("Five Thirty Eight" political forecast, national coverage of Gulf hypoxia forecasts)
  - Completing the narrative of the LIS partnership ... storytelling opportunity

Is it possible to forecast LIS hypoxia?

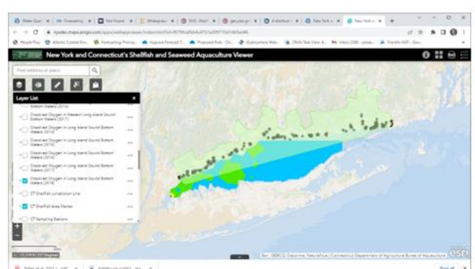
- Forecasting starts with quantitative description
  - Outside View / Inside View – Daniel Kahneman .. "Noise"
- "the primary goal of forecasting is to identify the full range of possibilities, not a limited set of illusory certainties."

What about hypoxia could we forecast?

- Hypoxia in open water
  - Hypoxic area
  - Duration of hypoxia
  - Integrative measures of hypoxia extent and duration
  - Maps of DO concentration

- Hypoxia in shallow water
  - Where does low oxygen occur
  - Diel-cycling
  - # of days with hypoxia

- Aquatic life - specific forecasts
  - Link DO forecast to habitat quality or condition for target species.
  - Link DO forecast to specific users or operations



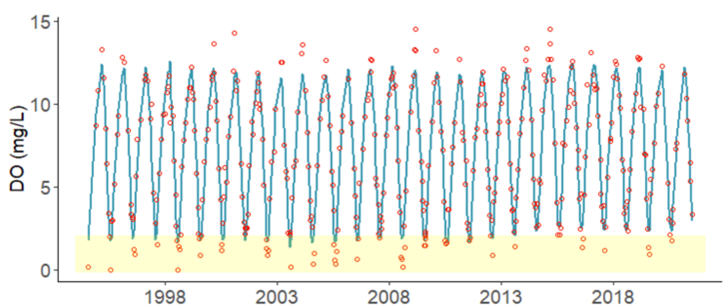
Generalized Additive Models (GAMs) are useful for modeling DO in LIS

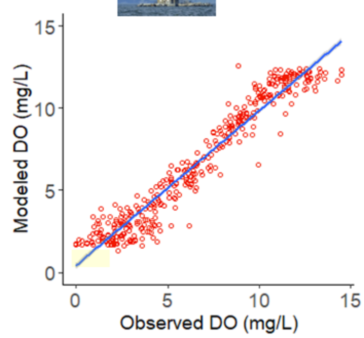
- Modeled near-bottom CTDEEP data
  - 50 stations from 1991-2021
- GAM approach adapted from work on Chesapeake Bay.
- Use smooth functions
  - Latitude, Longitude, Depth
  - Year, day of year (cyclical), hour (cyclical)
- Include interactions
  - year * day of year
  - year * longitude
  - day of year * longitude
- Model explains 92% of deviance

We used the data collected by CTDEEP from 1991-2022

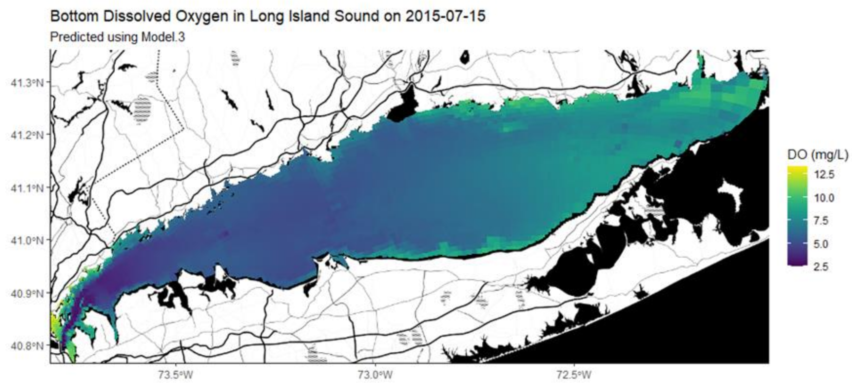
The GAM predicts observed DO at Execution Rocks, but some residuals are potentially critical.

Measured and Modeled Bottom Water DO at Execution Rocks, 1994-2021

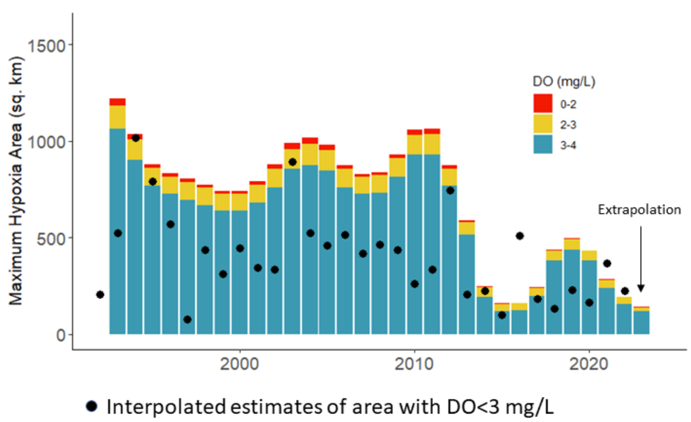




We can use the GAM to predict a map of bottom water DO on any day

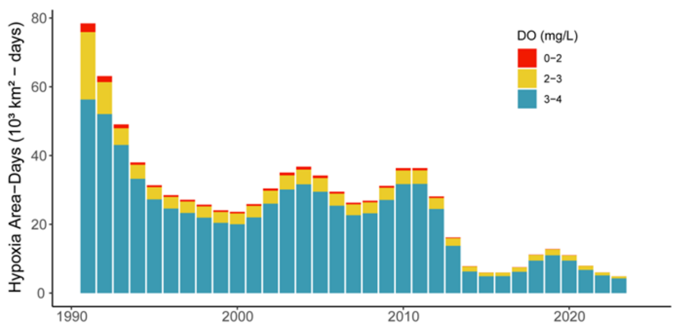


The GAM can predict hypoxic area every day, and show the annual maximum

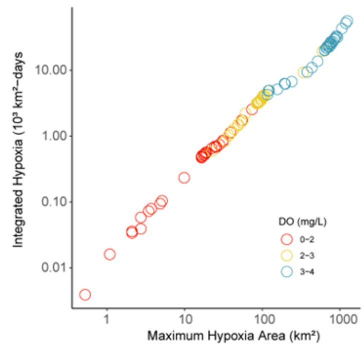


- However, the estimated area <3 mg/L (yellow+red) is much less than the interpolated area.
- Correct explanation remains unresolved
- This remains a work in progress!

Integrated hypoxic area is closely related to maximum areal extent



- Closely related to maximum extent



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A lot of work remains to be done

- Evaluate model performance in greater detail (e.g., using cross-validation)
- Evaluate performance for projections of 2-3 months.
- Include other data
- Change the model to better suit goal of predicting the future, rather than explaining the past.
- Replace factors like “year” with variables like TN loading, or “day of year” with water temperature
- Consider tides, temperature anomaly, winds, etc.
- Consider approaches for modeling DO in shallow waters.

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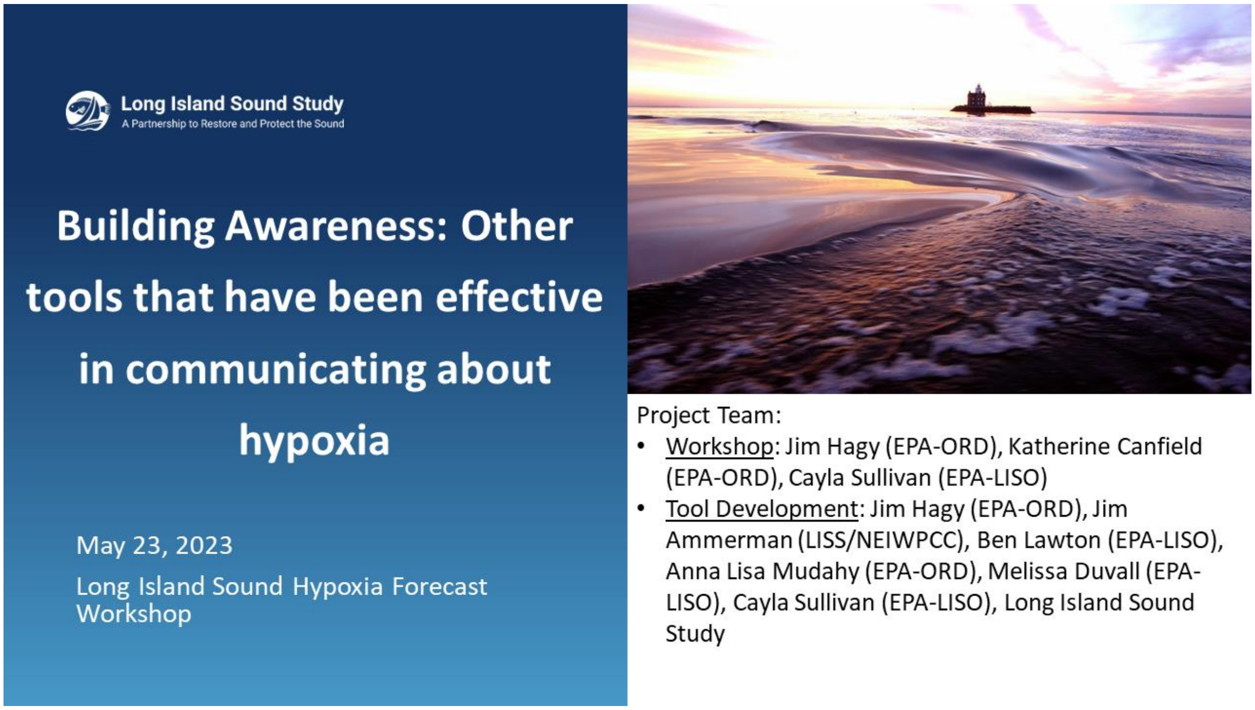
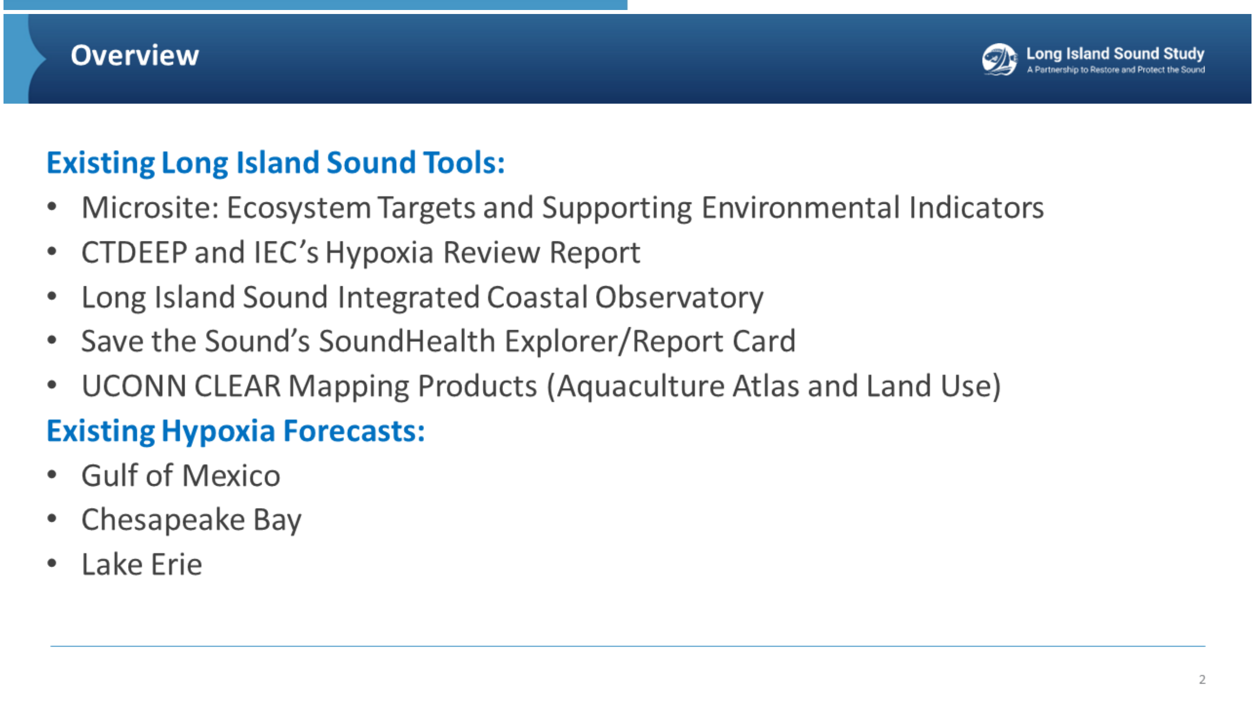
Develop the forecast to support communication around LIS story with different target audiences

- Scientists interested in understanding, monitoring, and modeling hypoxia and its impacts
- Policy makers concerned with developing and implementing actions that may affect environmental quality of Long Island Sound
- Interest groups who advocate around issues related to the environmental status of LIS and interactions with communities surrounding LIS.
- Concerns around environmental justice, resiliency to climate change, and long-term sustainability.

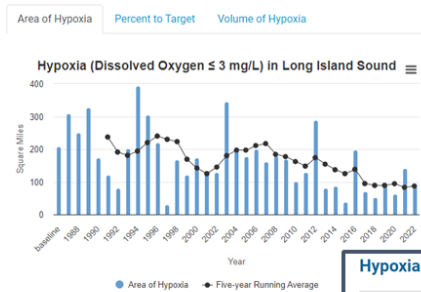
Building awareness: Other tools that have been effective in communicating about hypoxia by Cayla Sullivan





Microsite

- **Ecosystem Target: Extent of Hypoxia**
- Measurably reduce the area of hypoxia in Long Island Sound from pre-2000 Dissolved Oxygen TMDL averages to increase attainment of water quality standards for dissolved oxygen by 2035, as measured by the five-year running average size of the zone.
- **Supporting Indicator: Duration of Hypoxia**
- **Supporting Indicator: Severely Hypoxic and Anoxic Areas**



Hypoxia Data

Here are links to find data on dissolved oxygen levels and the extent of hypoxia in Long Island Sound:

- CT DEEP Long Island Sound Water Quality Monitoring Program (open waters of the Sound)
- Interstate Environmental Commission (Western Narrows)
- Long Island Sound Integrated Coastal Observing System (real-time monitoring)
- LIS water quality monitoring program survey data on the LISICOS website
- Save the Sound Unified Water Study (bays and harbors)

CTDEEP and IEC's Hypoxia Review Report

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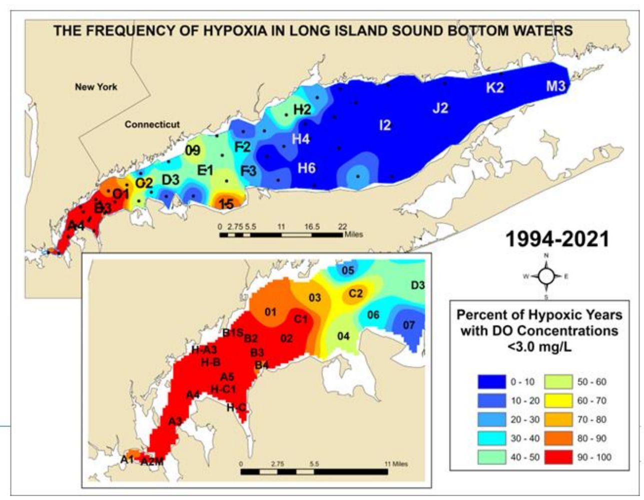
2021 Long Island Sound Hypoxia Season Review

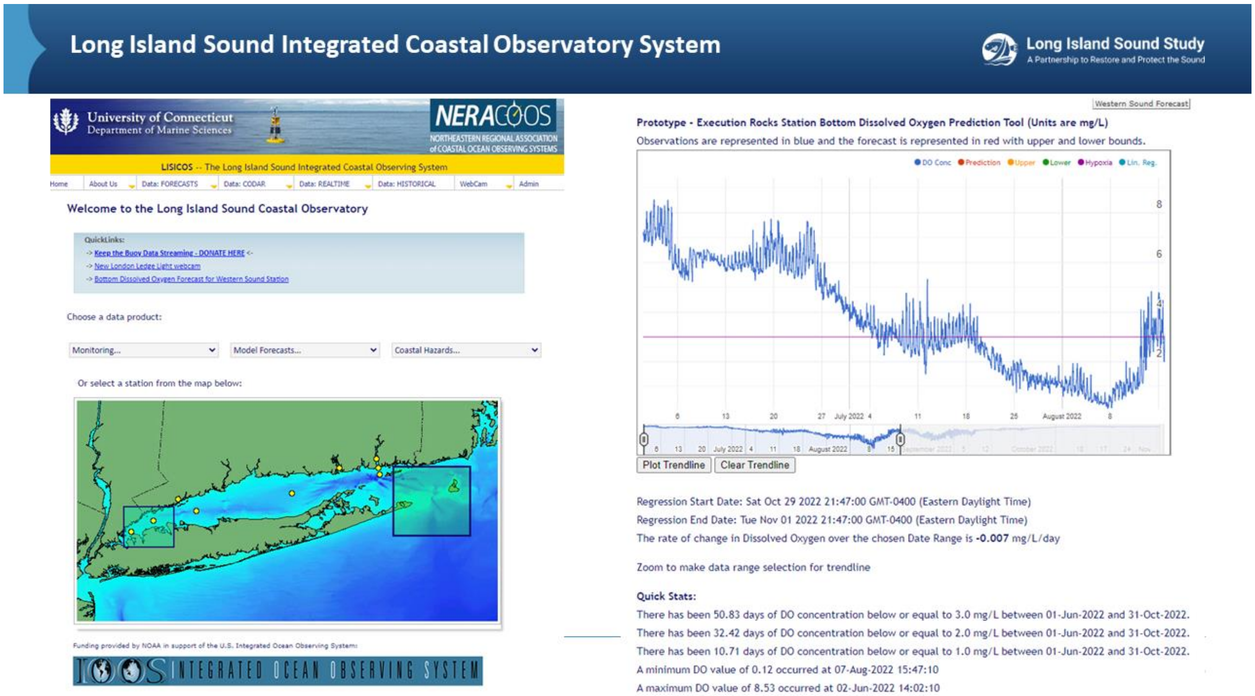
Connecticut Department of Energy and Environmental Protection
79 Elm Street, Hartford, CT 06106
Katherine S. Dykes, Commissioner

Interstate Environmental Commission
2800 Victory Blvd., Building 6S, Room 106
Staten Island, NY 10314
Evelyn Powers, Executive Director

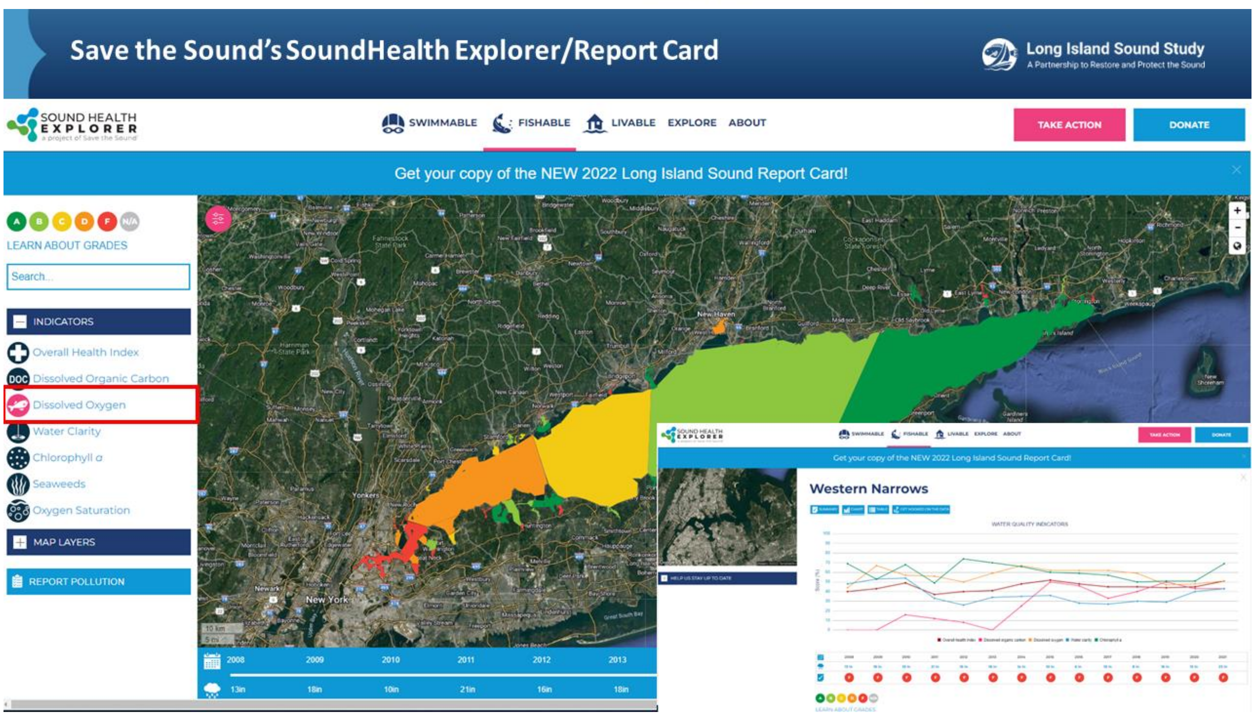
US Environmental Protection Agency, Long Island Sound Office
Stamford Government Center, 888 Washington Blvd., Suite 9-11,
Stamford, CT 06904-2125
Mark Tedesco, Director

- Annual report communicates in situ data results, hypoxic area, volume and duration, and chlorophyll





Long Island Sound Integrated Coastal Observatory System
Long Island Sound Study
A Partnership to Restore and Protect the Sound
University of Connecticut
Department of Marine Sciences
NERACOOS
NORTHEASTERN REGIONAL ASSOCIATION of COASTAL OCEAN OBSERVING SYSTEMS
LISICOS -- The Long Island Sound Integrated Coastal Observing System
Home About Us Data: FORECASTS Data: CODAR Data: REALTIME Data: HISTORICAL WebCam Admin
Welcome to the Long Island Sound Coastal Observatory
QuickLinks:
-> Keep the Buoy Data Streaming - DONATE HERE <-
-> New London Ledge Light webcam
-> Bottom Dissolved Oxygen Forecast for Western Sound Station
Choose a data product:
Monitoring... Model Forecasts... Coastal Hazards...
Or select a station from the map below:
Funding provided by NOAA in support of the U.S. Integrated Ocean Observing System:
IOOS INTEGRATED OCEAN OBSERVING SYSTEM
Western Sound Forecast
Prototype - Execution Rocks Station Bottom Dissolved Oxygen Prediction Tool (Units are mg/L)
Observations are represented in blue and the forecast is represented in red with upper and lower bounds.
DO Conc Prediction Upper Lower Hypoxia Lin. Reg.
July 2022 August 2022
Plot Trendline Clear Trendline
Regression Start Date: Sat Oct 29 2022 21:47:00 GMT-0400 (Eastern Daylight Time)
Regression End Date: Tue Nov 01 2022 21:47:00 GMT-0400 (Eastern Daylight Time)
The rate of change in Dissolved Oxygen over the chosen Date Range is -0.007 mg/L/day
Zoom to make data range selection for trendline
Quick Stats:
There has been 50.83 days of DO concentration below or equal to 3.0 mg/L between 01-Jun-2022 and 31-Oct-2022.
There has been 32.42 days of DO concentration below or equal to 2.0 mg/L between 01-Jun-2022 and 31-Oct-2022.
There has been 10.71 days of DO concentration below or equal to 1.0 mg/L between 01-Jun-2022 and 31-Oct-2022.
A minimum DO value of 0.12 occurred at 07-Aug-2022 15:47:10
A maximum DO value of 8.53 occurred at 02-Jun-2022 14:02:10



Save the Sound's SoundHealth Explorer/Report Card
Long Island Sound Study
A Partnership to Restore and Protect the Sound
SOUND HEALTH EXPLORER
a project of Save the Sound
SWIMMABLE FISHABLE LIVABLE EXPLORE ABOUT
TAKE ACTION
DONATE
Get your copy of the NEW 2022 Long Island Sound Report Card!
A B C D F N/A
LEARN ABOUT GRADES
Search...
INDICATORS
Overall Health Index
Dissolved Organic Carbon
Dissolved Oxygen
Water Clarity
Chlorophyll a
Seaweeds
Oxygen Saturation
MAP LAYERS
REPORT POLLUTION
New Haven
Yonkers
New York
2008 2009 2010 2011 2012 2013
13in 18in 10in 21in 16in 18in
Western Narrows

University of Connecticut's CLEAR Mapping Products

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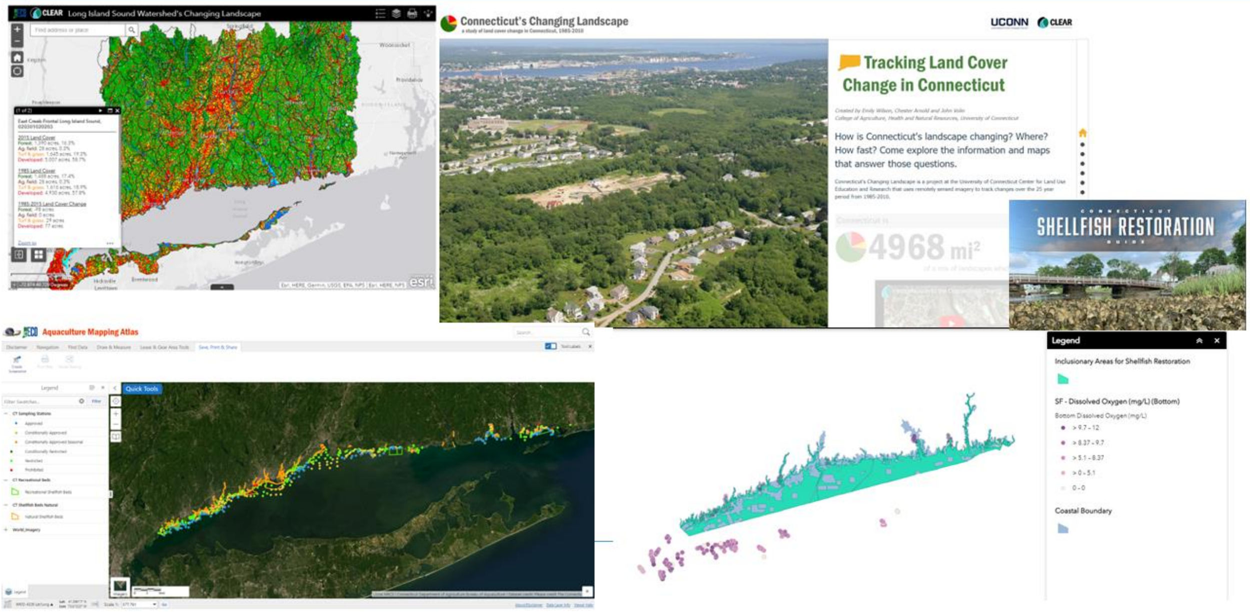

Communication Questions?	Microsite	Hypoxia Review Report	LISICOS	SoundHealth Explorer/Report Card	Uconn CLEAR Mapping Product
Format	Website	Annual Report	Website	Biennial Report with online grades updated in between releases	Various (StoryMap, dashboards, etc.)
Target Audience	Public	Resource Managers, Academics, educated public/stakeholders (including CAC)	Resource Managers, Academics	Public, Elected Officials, Resource Managers, Academics	Everyone
Communication Message	Monitoring Data as a Health Indicator (related to Hypoxia Review Report)	Annual Monitoring Review	Real-time Monitoring	Monitoring Data as Environmental and Public Health Indicator. Communicated in an approach that laypeople can relate	Various (geographic information, statistics/trends, planning tools)
Challenges	Updating data	State IT department, lab delays, lack of expertise with new communication technology (i.e., R Shiny)	Updating data; connecting to server	Applying grades to water quality data with very valuable, but not always in alignment, feedback from stakeholders in the process	Keeping mapping products up to date. Technical hardware, software, and people power limitations to design, develop and maintain the viewers

Gulf of Mexico

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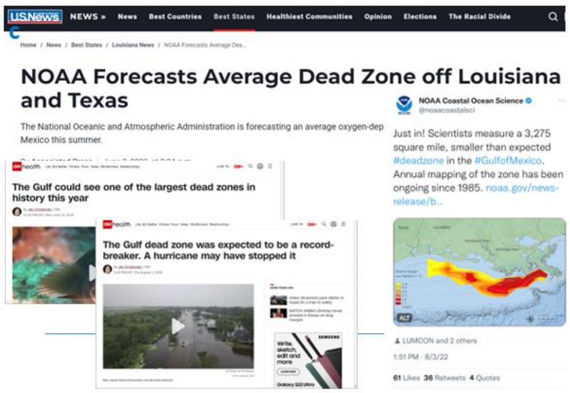
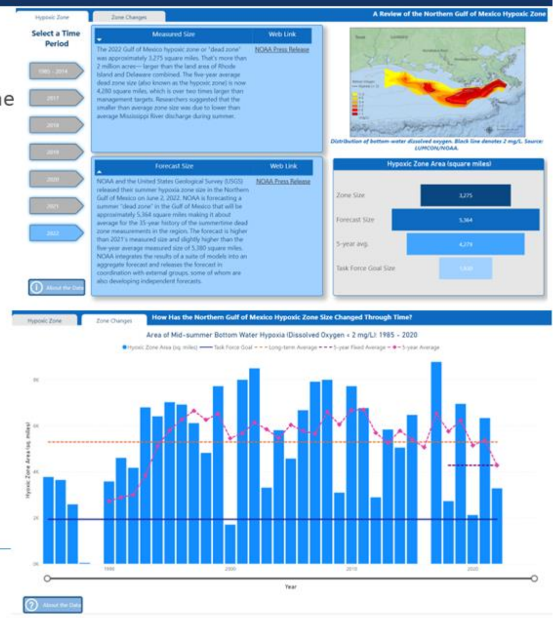
- Predicts the size of the zone using a four nitrogen-focused models including USGS springtime nitrogen loadings
- Late spring, NOAA releases an estimate of the size of the hypoxic zone for the summer
- Late July, NOAA conducts an annual cruise to measure the extent of the zone





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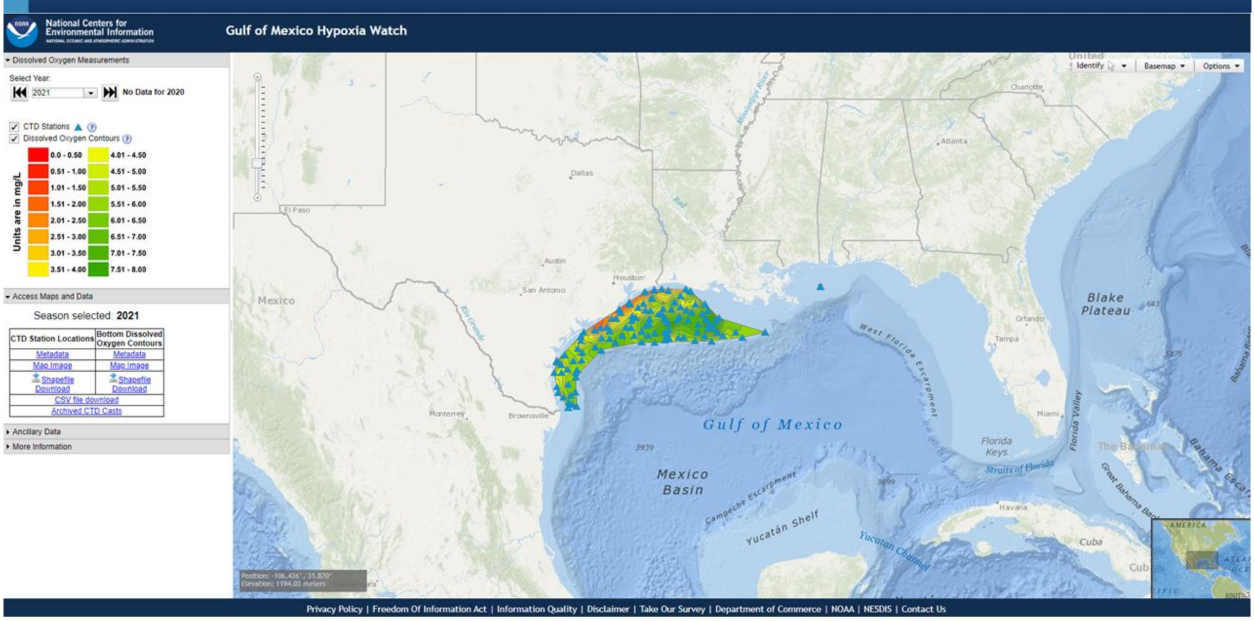
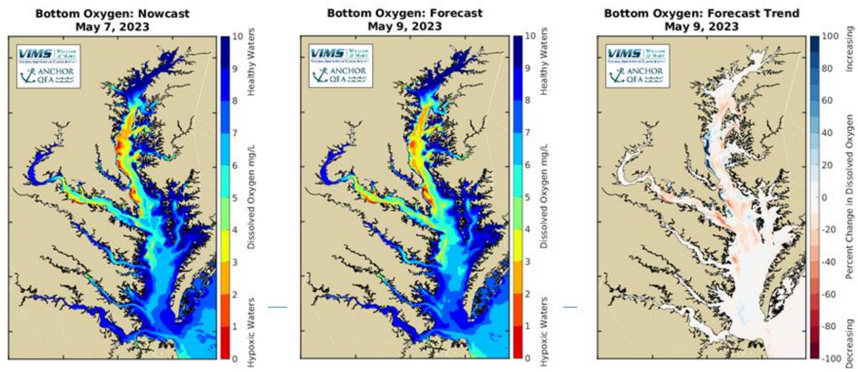


CHESAPEAKE BAY ENVIRONMENTAL FORECAST SYSTEM
Background
Hypoxia (Oxygen)
Dead Zone Size
Depth to Low Oxygen
Hypoxia Line Plots
Bay-wide Salinity
Bay-wide Temperature
Focused Salinity and Temperature Forecasts
Acidification Forecasts
Harmful Algal Blooms
Pathogens (Vibrio)
Bay Nettles
Contact Information

- Uses a 3-D numerical model to forecast the conditions daily; forced by weather provided by NOAA and river input provided by stream gauges operated by USGS
- Simulates 3 conditions:
  - Nowcast: present-day levels of dissolved oxygen
  - 2-Day Forecast: levels of dissolved oxygen in 2 days from nowcast
  - Forecast Trend: difference between nowcast and forecast (% change over 2 days)



Chesapeake Bay

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Real-time Estimates of Hypoxic Water Volume

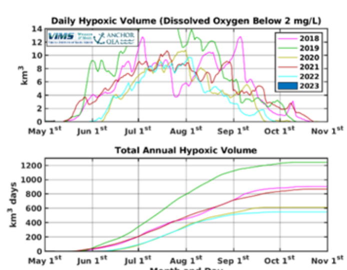
Chesapeake Bay

Quick Summary

2023 Dead Zone Size

The amount of hypoxia in the Bay is expected to increase from spring into summer and then decrease as summer progresses into fall, with hypoxia starting sometime in May. Check back to see how the size of the dead zone increases seasonally and how daily weather changes the amount of hypoxia. Notable weather that may impact the amount of hypoxia are very windy days or periods of very calm wind. The image below will be continually updated throughout 2023 based on the daily forecast model.

Although hypoxia has not started yet in 2023, check back later in the spring and summer for the tracking of hypoxia through the summer of 2023.



- In the spring, the size of the summer dead zone is forecasted based on the amount of nutrient loads
- Monthly sampling to collect observations and estimate the hypoxic volume. However, both methods provide very infrequent estimates of hypoxic volume.
- Daily hypoxic volume forecasts are used to calculate the total annual hypoxic volume throughout the year

Chesapeake Bay

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CHESAPEAKE BAY ENVIRONMENTAL FORECAST SYSTEM

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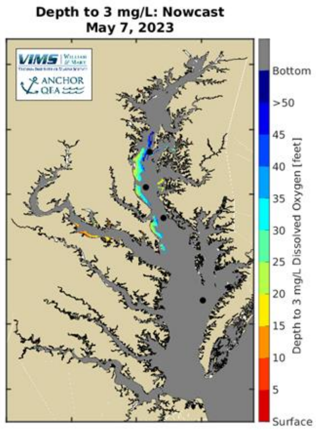
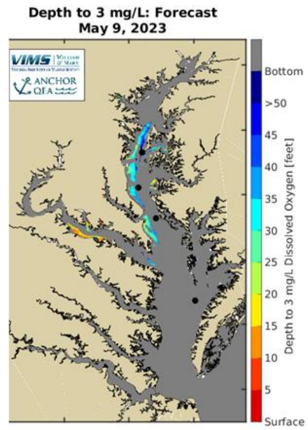
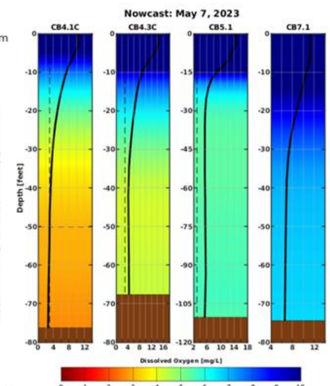
- Estimates the depth below the water surface to a dissolved oxygen concentration of 3 mg/L of nowcast and forecast
- Vertical profiles of dissolved oxygen at the locations shown with dots on the maps







Chesapeake Bay

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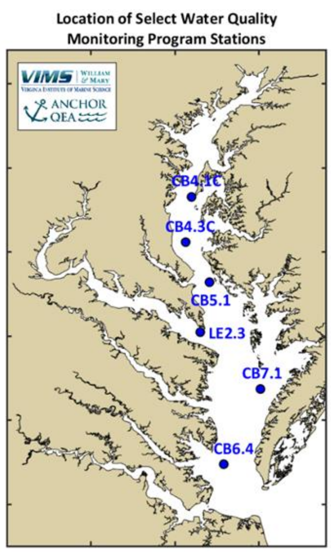

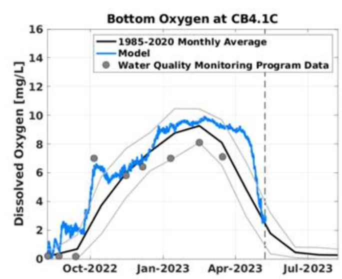

- Overlays the modeled dissolved oxygen on top of long-term averages from observed data
- Compares how the forecasted dissolved oxygen compares to the historical average

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Lake Erie

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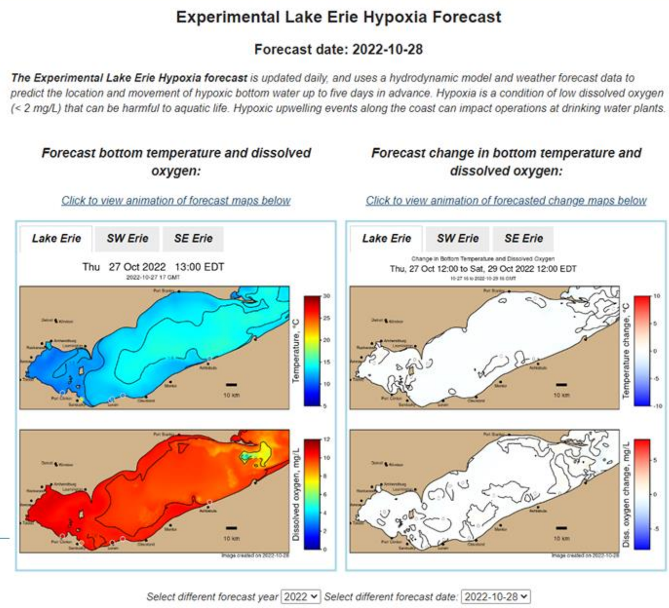

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Discussion: Designing tools

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