The Water Quality Standards Indicator and its Friends

Peter Tango USGS@CBPO

Chesapeake Bay Monitoring Coordinator

STAR Meeting

June 26, 2025

Reminder – The WQSAM Outcome (2014)

- **Continually improve the capacity** **to monitor and assess** the effects of management actions being undertaken to implement the Bay TMDL and improve water quality. Use the monitoring results to **report annually to the public on progress made in attaining established Bay water-quality standards and trends in reducing nutrients and sediment in the watershed**.

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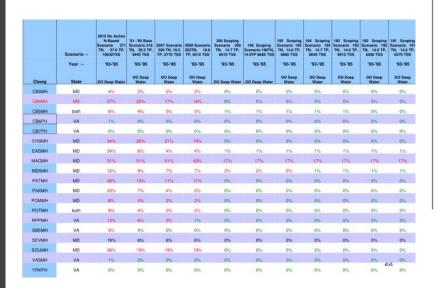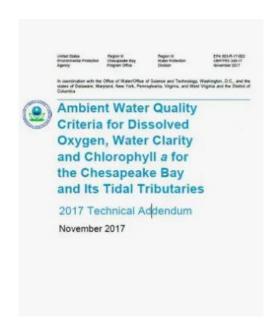

Exciting?

Compelling?

Happy marriage in creating the indicator

- Modeling scenario "stoplight plots" of the TMDL accounting for meeting water quality standards

Conditional Probability assessment for gap filling monitoring results:

- USEPA 2004
- USEPA 2017

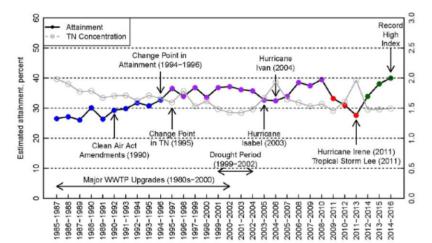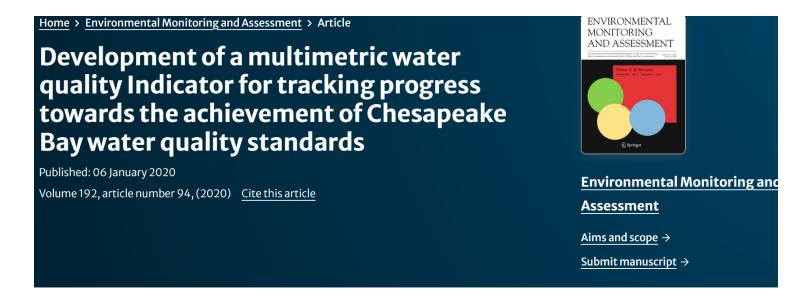# Peer reviewed foundations behind the WQSAM indicator

Short Communication

Chesapeake Bay's water quality condition has been recovering: Insights from a multimetric indicator assessment of thirty years of tidal monitoring data

Qian Zhang [a], Rebecca R. Murphy [a], Richard Tian [a], Melinda K. Forsyth [b], Emily M. Trentacoste [c], Jennifer Keisman [d], Peter J. Tango [e]

Home > Environmental Monitoring and Assessment > Article

Development of a multimetric water quality Indicator for tracking progress towards the achievement of Chesapeake Bay water quality standards

ENVIRONMENTAL MONITORING AND ASSESSMENT

Environmental Monitoring and Assessment

Aims and scope →

Submit manuscript →

Ana L. Hernandez Cordero, Peter J. Tango & Richard A. Batiuk

Mythbuster Metrics:
Beyond the WQSAM Indicator...
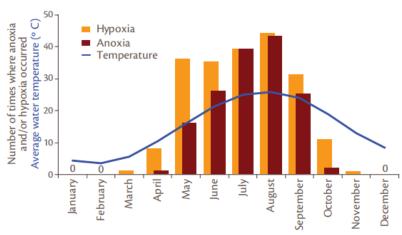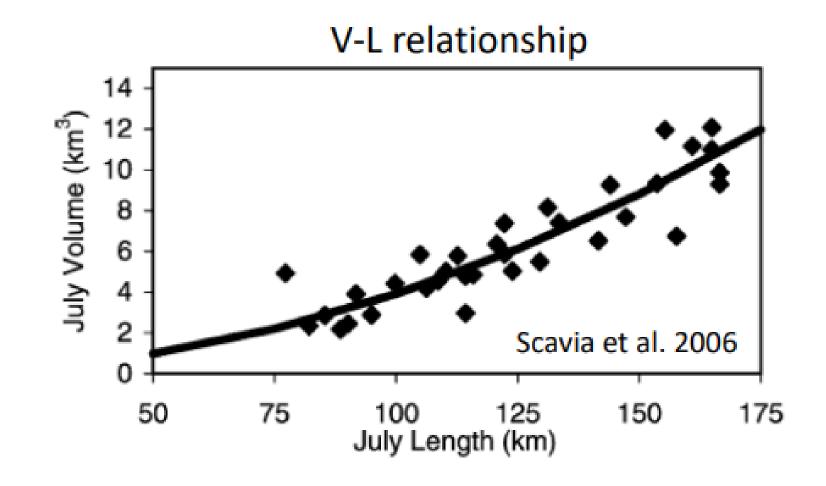
Dissolved oxygen (mg L⁻¹)

Figure 4: Occurrences of hypoxia and anoxia are higher in the summer months than the winter months because oxygen-consuming processes increase with temperature. Data from 1985–2005.

Beyond WQ Stds attainment – diverse, important habitat metrics

- Dead zone length

- Dead zone area

- Dead zone volume

- Start date, end date

- Speed of hypoxia formation

- Duration

- Intensity

- Attainment deficit, attainment buffer

Who cares about length of hypoxia in the bay?

Our scientists do ☺…

Ecological Forecasting and the Science of Hypoxia in Chesapeake Bay

JEREMY M. TESTA, J. BLAKE CLARK, WILLIAM C. DENNISON, E. CAROLINE DONOVAN, ALEXANDER W. FISHER, WENFEI NI, MATTHEW PARKER, DONALD SCAVIA, SUZANNE E. SPITZER, ANTHONY M. WALDROP, VANESSA M.D. VARGAS, AND GREGORY ZIEGLER

...because it is one the foundations to how we forecast summer hypoxia for Chesapeake Bay

University of Michigan Chesapeake Bay hypoxia forecasting model

Driver:

Jan-May average **Susquehanna TN load**

Calibration target:
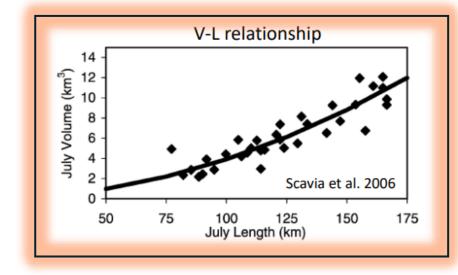
Mean July hypoxic volume (HV) ([DO] < 2 mg/L)

Model output:

Average subpycnocline [DO] as a function of distance from TN source

Hypoxic length = sum of all segments with [DO] < 2 mg/L

V-L relationship

Scavia et al. 2006

Hypoxic length → **hypoxic volume** through empirical V-L relationship

Bertani and Scavia

Length of bay with hypoxia also tells a story of recovery, aligns with our science understanding of bay behavior through time

Nitrogen reductions have decreased hypoxia in the Chesapeake Bay: Evidence from empirical and numerical modeling
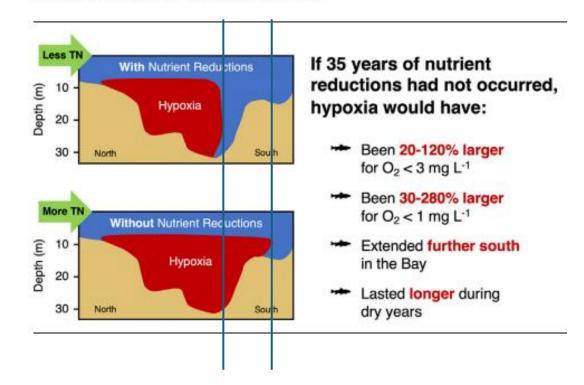
Luke T. Frankel [a,*], Marjorie A.M. Friedrichs [a], Pierre St-Laurent [a], Aaron J. Bever [b], Romuald N. Lipcius [a], Gopal Bhatt [c,d], Gary W. Shenk [c,e]

[a] Virginia Institute of Marine Science, William & Mary, 1370 Greate Road, Gloucester Point, VA, USA
[b] Anchor QEA LLC, 1201 3rd Avenue, Suite 2600, Seattle, WA, USA
[c] Chesapeake Bay Program Office, 1750 Forest Drive, Suite 130, Annapolis, MD, USA
[d] Department of Civil & Environmental Engineering, The Pennsylvania State University, 212 Sackett Building, University Park, PA, USA
[e] U.S. Geological Survey, Virginia and West Virginia Water Science Center, 1730 East Parham Road, Richmond, VA, USA

Frankel et al. 2022

GRAPHICAL ABSTRACT

If 35 years of nutrient reductions had not occurred, hypoxia would have:

� Been **20-120% larger** for $O_2 < 3$ mg L^{-1}

� Been **30-280% larger** for $O_2 < 1$ mg L^{-1}

� Extended **further south** in the Bay

� Lasted **longer** during dry years

Myth: The Summer Dead Zone is June-September

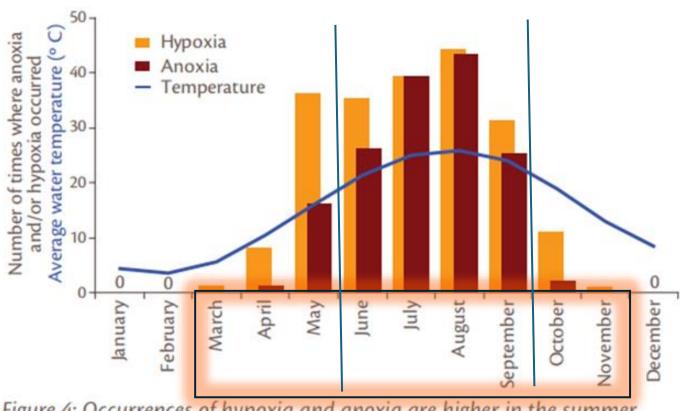The dead zone can start in March and end in November
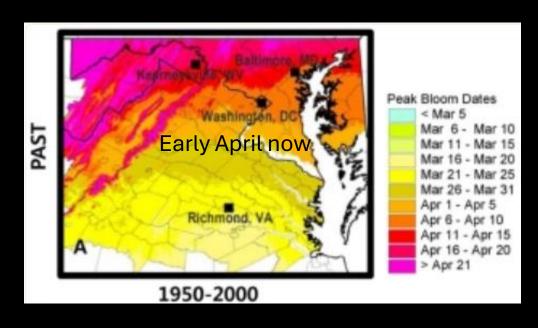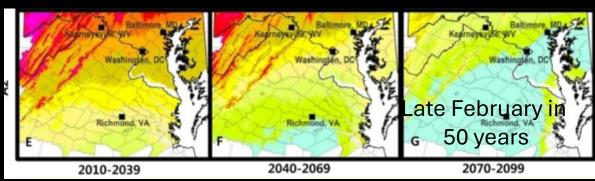
Figure 4: Occurrences of hypoxia and anoxia are higher in the summer months than the winter months because oxygen-consuming processes increase with temperature. Data from 1985–2005.

UMCES-Ecocheck 2007

* Tracking starting dates and ending dates are important phenological metrics for informing and explaining system changes

Seasonal timing (phenology) affects biology

Myth: July is the worst month for the Dead Zone

Myth: July is the worst month
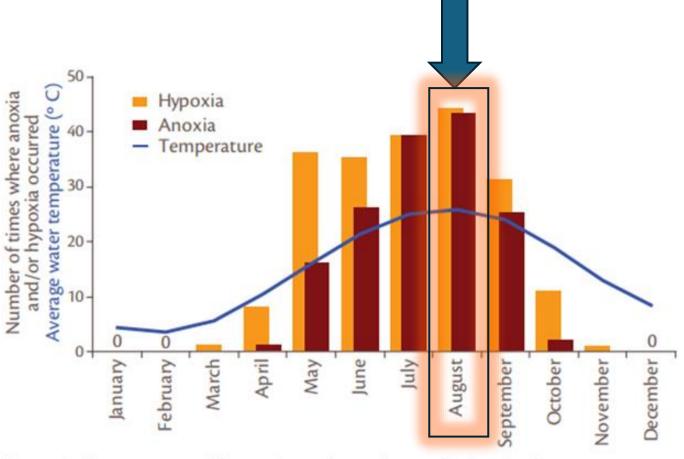
Figure 4: Occurrences of hypoxia and anoxia are higher in the summer months than the winter months because oxygen-consuming processes increase with temperature. Data from 1985–2005.

UMCES-Ecocheck 2007

There are variations on the expression of **peak timing.**
Some such metrics have shown shifts in hypoxia timing

Long-Term Trends in Chesapeake Bay Seasonal Hypoxia, Stratification, and Nutrient Loading

Rebecca R. Murphy, W. Michael Kemp and William P. Ball
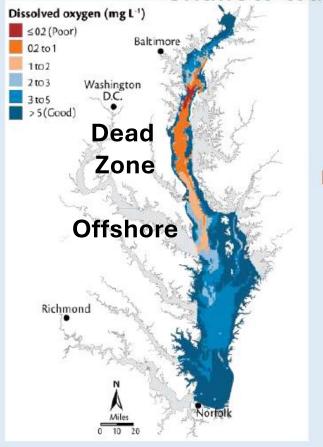
Myth: Fish die in the Dead Zone

Tidal Bay Monitoring. Degraded deep water habitats, however, fish kills and algal blooms are reported annually throughout shallow waters of the estuary.

Dissolved oxygen (mg L⁻¹)
- ≤ 02 (Poor)
- 02 to 1
- 1 to 2
- 2 to 3
- 3 to 5
- > 5 (Good)

Dead Zone

Offshore

Management and monitoring target mismatch?

Dead Fish

Inshore

● Early 2000s Maryland fish kills

Sassafras River *Microcystis* bloom

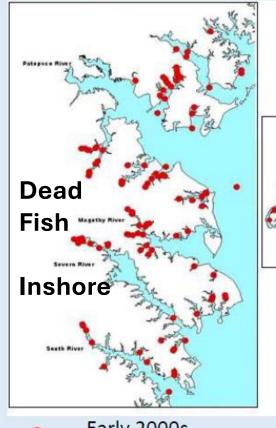Does fixing this... ...fix this?

Tidal Bay Monitoring. Degraded deep water habitats, however, fish kills and algal blooms are reported annually throughout shallow waters of the estuary.

Sassafras River *Microcystis* bloom

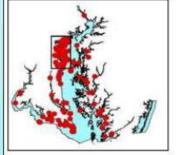**Dead Fish**

Inshore

🔴 Early 2000s Maryland fish kills

...fix this?

CESR

Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response

AN EXAMINATION OF HOW THE CHESAPEAKE BAY ECOSYSTEM HAS RESPONDED TO THE LAST FOUR DECADES OF MANAGEMENT EFFORTS.
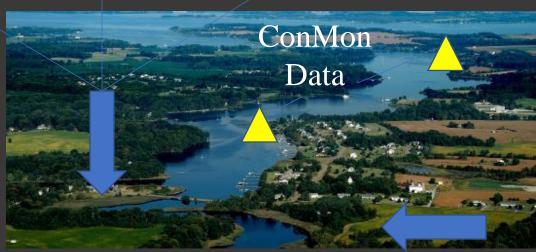
September 26, 2005
Across the water…MD DNR investigates a local fish kill

Maryland

ConMon Data
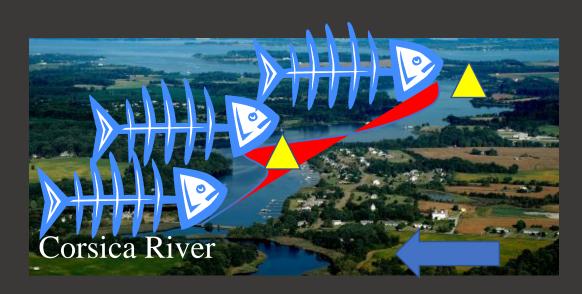
September 28, 2005
Estimated 30,000-50,000 fish dead; 15 species affected

Dissolved Oxygen mg/L

18
16
14
12
10
8
6
4
2
0

Citizen:Evidence of fish in distress

DNR finds hundreds of dead fish

MDE and DNR 3-5 x 10^4 dead fish

Stress
Death

9/22   9/24   9/26   9/28   9/30   10/2   10/4

Time

Sycamore Pt. ——— Cedar Pt.
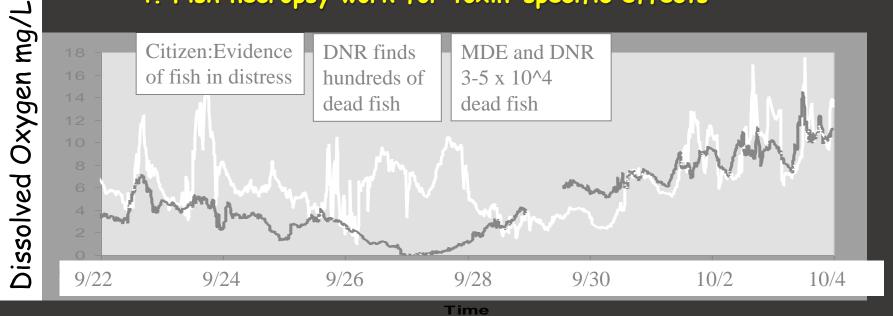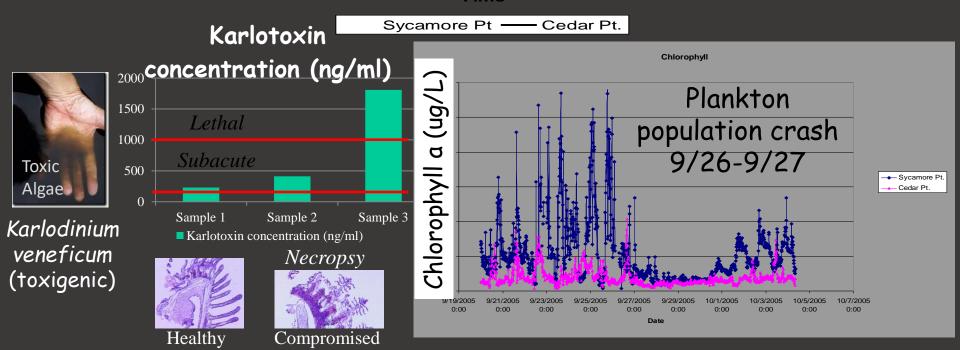
Fish Kill in the Corsica

Corsica River

Building Environmental Intelligence
4. Fish necropsy work for toxin-specific effects

Dissolved Oxygen mg/L

Citizen:Evidence of fish in distress

DNR finds hundreds of dead fish

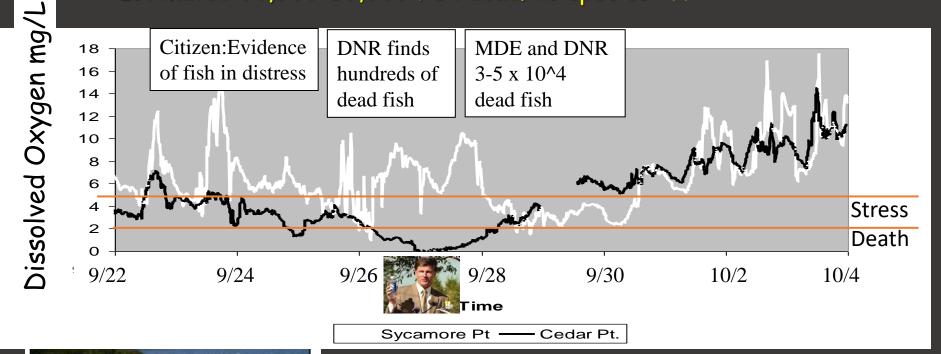MDE and DNR 3-5 x 10^4 dead fish

9/22 9/24 9/26 9/28 9/30 10/2 10/4

Time

Sycamore Pt —— Cedar Pt.

Karlotoxin concentration (ng/ml)

Toxic Algae

Karlodinium veneficum (toxigenic)

2000
1500
1000
500
0

Lethal
Subacute

Sample 1   Sample 2   Sample 3

■ Karlotoxin concentration (ng/ml)

Necropsy

Healthy   Compromised

Chlorophyll

Chlorophyll a (ug/L)

Plankton population crash 9/26-9/27

Sycamore Pt.
Cedar Pt.

9/19/2005 9/21/2005 9/23/2005 9/25/2005 9/27/2005 9/29/2005 10/1/2005 10/3/2005 10/5/2005 10/7/2005
0:00   0:00   0:00   0:00   0:00   0:00   0:00   0:00   0:00   0:00

Date

Myth: There is one Dead Zone in the bay

Patuxent River has one

The Pattern and Influence of Low Dissolved Oxygen in the Patuxent River, a Seasonally Hypoxic Estuary

DENISE L. BREITBURG[1],*, AARON ADAMACK[2], KENNETH A. ROSE[2], SARAH E. KOLESAR[1], MARY BETH DECKER[1,3,†], JENNIFER E. PURCELL[3,‡], JULIE E. KEISTER[4], and JAMES H. COWAN, JR.[2]

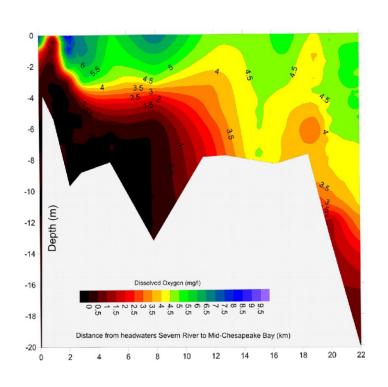[1] The Academy of Natural Sciences, Estuarine Research Center, 10545 Mackall Road, St. Leonard, Maryland 20678

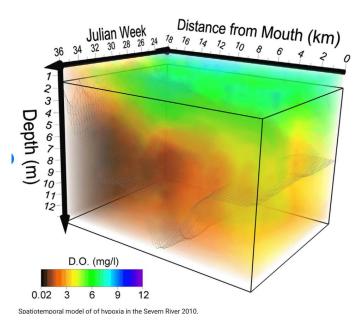[2] Coastal Fisheries Institute and Department of Oceanography and Coastal Sciences, Wetland Resources Building, Louisiana State University, Baton Rouge, Louisiana 70803

[3] Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, Maryland 2113-0775

[4] Hatfield Marine Science Center, Oregon State University, 2030 South Marine Science Drive, Newport, Oregon 97365

Severn River dead zone

Spatiotemporal model of of hypoxia in the Severn River 2010.

Article   PDF Available

Resolving spatiotemporal characteristics of the seasonal hypoxia cycle in shallow estuarine environments of the Severn River and South River, MD, Chesapeake Bay, USA

September 2016 · Heliyon 2(9):e00157

DOI:10.1016/j.heliyon.2016.e00157

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Authors:

Andrew Muller
United States Naval Academy
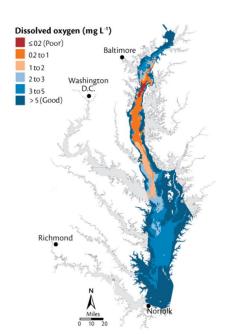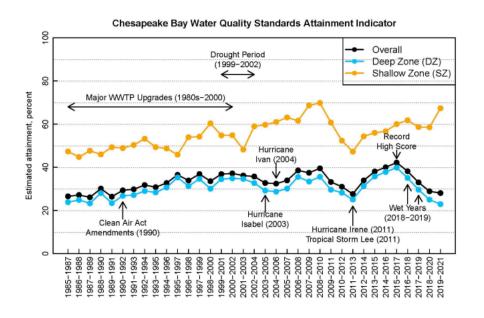
Diana L Muller   **Arianna Muller**

Geographic distribution of hypoxia could be improved in our graphics and communications with such indicators: touch the local scale

Geography, Trajectories, and Controls of Coastal Water Quality: More Rapid Improvement in the Shallow Zone of the Chesapeake Bay
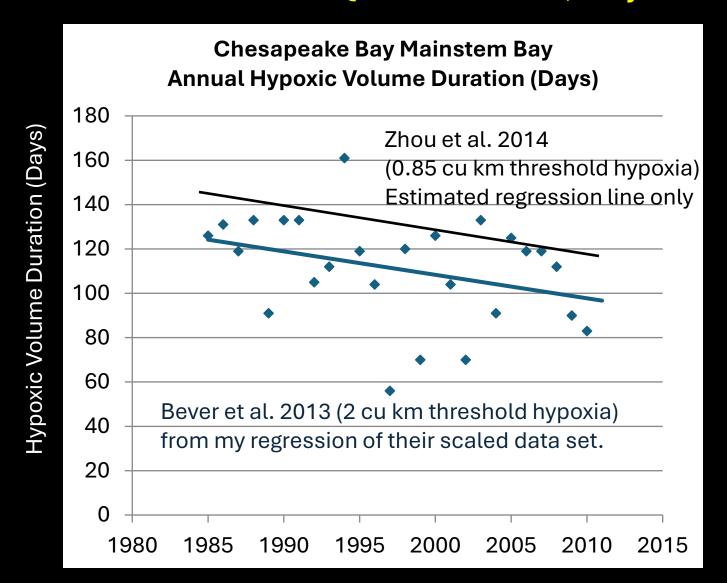
Qian Zhang [1], Rebecca R Murphy [1], Richard Tian [1], Peter J Tango [2]

Affiliations + expand

Myth: Water Quality Standards is the best way to track change in the bay

Hypoxic Volume Days is a more management responsive metric with our data set than WQS attainment, July maximum hypoxia

Chesapeake Bay Mainstem Bay Annual Hypoxic Volume Duration (Days)

Zhou et al. 2014
(0.85 cu km threshold hypoxia)
Estimated regression line only

Bever et al. 2013 (2 cu km threshold hypoxia) from my regression of their scaled data set.

Hypoxic Volume Duration (Days) (y-axis)

The pace of recovery over 30 years was measurable in hypoxia duration;

The pace was about 0.8 days hypoxia improvement per year.

We also have detailed evaluations of bay conditions from Attainment deficits and Attainment buffers from our WQSAM analysis

ORIGINAL RESEARCH article

Front. Mar. Sci., 20 November 2018
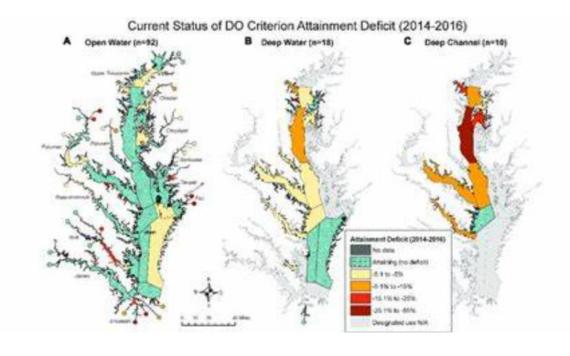Sec. Marine Ecosystem Ecology
Volume 5 - 2018 |
https://doi.org/10.3389/fmars.2018.00422

This article is part of the Research Topic
Research and Management of
Eutrophication in Coastal Ecosystems

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Chesapeake Bay Dissolved Oxygen Criterion Attainment Deficit: Three Decades of Temporal and Spatial Patterns

Qian Zhang[1]*   Peter J. Tango[2]   Rebecca R. Murphy[1]

Melinda K. Forsyth[3]   Richard Tian[1]   Jennifer Keisman[4]

Current Status of DO Criterion Attainment Deficit (2014-2016)

A Open Water (n=92)   B Deep Water (n=18)   C Deep Channel (n=18)

Closing thoughts: Top 10 qualities for good indicators:

| Important Indicator Qualities |
| --- |
| 1. Simple and easy to understand |
| 2. Be scientifically well-founded |
| 3. Have a reference or threshold value of significance |
| 4. Be responsive to changes in the environment |
| 5. Show trends over time |
| 6. Feasible to measure and report (reasonable cost/benefit ratio) |
| 7. Updated regularly with reliable procedures (timely with support of a monitoring program) |
| 8. Adequately documented, known quality |
| 9. Be useable by the community |
| 10. Policy relevant |
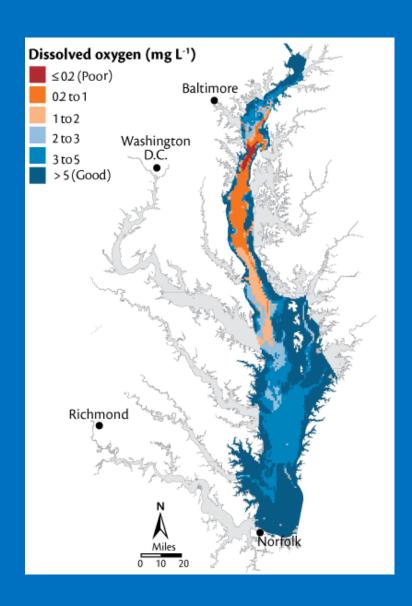
Additional indicator qualities to potentially keep in mind

- **Clear in value:** no uncertainty about which direction is good and which is bad.
- **Clear in content:** easily understandable, with units that make sense.
- **Compelling:** interesting, exciting, suggestive of effective action.
- **Policy relevant:** for all stakeholders in the system.
- **Feasible:** measurable at reasonable cost.
- **Sufficient:** not too much or too little information.
- **Timely:** compliable without long delays.
- **Appropriate in scale:** neither over- nor under-aggregated.
- **Democratically** chosen and accessible.
- **Supplementary:** include what people cannot measure for themselves.
- **Participatory:** make use of what people can measure for themselves and compile it to provide geographic or time overviews.
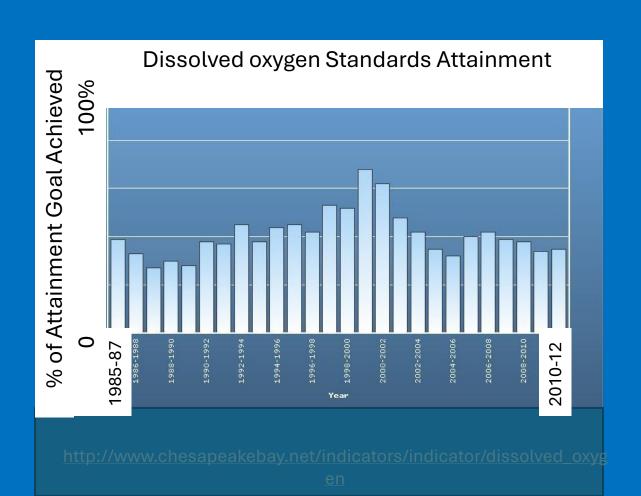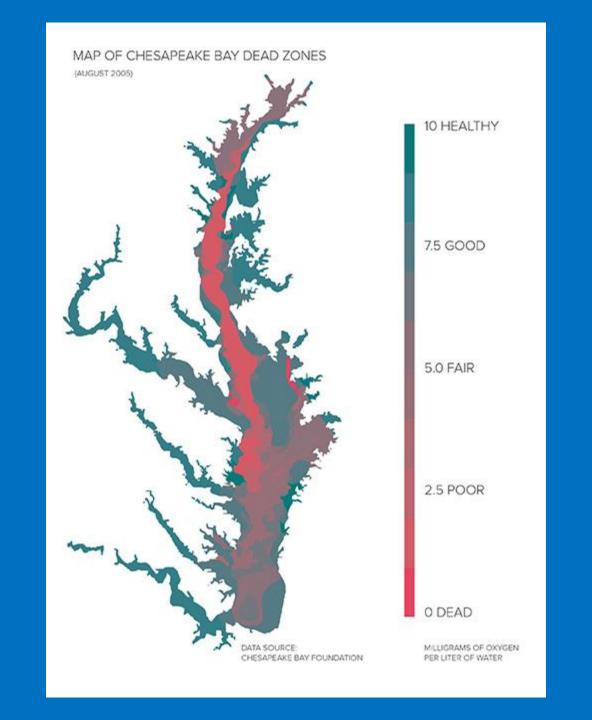
Selected from a report to the Balaton Group by the Sustainability Institute: "Indicators and information systems of sustainable development"

Issue

- The public frequently looks to the Chesapeake Bay Program Office of Communications for updates about The Dead Zone.

- There is no outcome in the Watershed Agreement specifically calling out The Dead Zone event, and no single group tasked with specifically tracking and reporting on the Dead Zone phenomenon.

  - Therefore, collaborative discussions happen but ad hoc annual reporting occurs.

- Requesting input, guidance, discussion on
  - A need to organize a communications strategy within the CBP regarding this annual Bay event
  - Directing any new analyses and resources to produce independent CBP products for reporting, or
  - We are fine, continue pulling together stories sometime after the Dead Zone goes away each year

Dissolved oxygen (mg L⁻¹)
- ≤ 02 (Poor)
- 02 to 1
- 1 to 2
- 2 to 3
- 3 to 5
- > 5 (Good)

Baltimore
Washington D.C.
Richmond
Norfolk

N
Miles
0 10 20
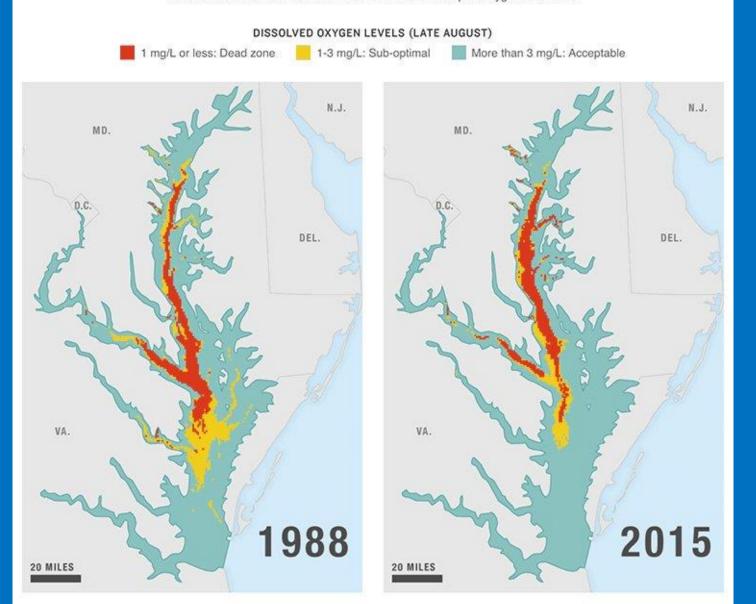
Bay Health Status: Dissolved Oxygen Time Series Water Quality Standards Criteria Attainment for All Tidal Waters 1985-2012

Dissolved oxygen Standards Attainment

MAP OF CHESAPEAKE BAY DEAD ZONES
(AUGUST 2005)

10 HEALTHY

7.5 GOOD

5.0 FAIR

2.5 POOR

0 DEAD

DATA SOURCE:
CHESAPEAKE BAY FOUNDATION

MILLIGRAMS OF OXYGEN
PER LITER OF WATER

The Chesapeake Bay's Shrinking 'Dead Zones'

As nutrient pollution into the bay decreases, fewer algae blooms mean there is more dissolved oxygen available in the water available for fish and other marine animals that require oxygen to survive.

DISSOLVED OXYGEN LEVELS (LATE AUGUST)

- 1 mg/L or less: Dead zone
- 1-3 mg/L: Sub-optimal
- More than 3 mg/L: Acceptable

Source: NPR analysis of Chesapeake Bay Program and USGS data; Rebecca Murphy/Chesapeake Bay Program

Credit: Leanne Abraham/NPR

n p r

LARGE 'DEAD ZONE' FORECAST FOR CHESAPEAKE BAY AFTER WET WINTER AND SPRING

[Facebook] [Messenger] [Twitter] [Share]

June 12, 2019

Chesapeake Biological Laboratory

Ecologists from the **University of Maryland Center for Environmental Science** and the **University of Michigan** are forecasting a large Chesapeake Bay "dead zone" in 2019 due to well-above-average river flows associated with increased rainfall in the watershed since last fall.

11:11 AM

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MARYLAND Department of Natural Resources

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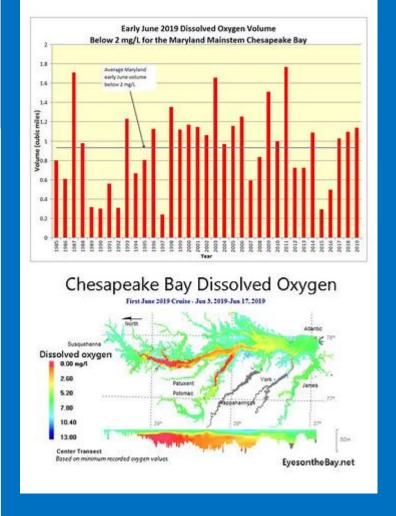> Online Store

July 2019 Hypoxia Report

August 2, 2019

Maryland Department of Natural Resources monitoring data show that dissolved oxygen conditions in the Maryland portion of the Chesapeake Bay mainstem were larger than average in July, as the result of many factors. The hypoxic water volume (areas with less than 2 mg/l oxygen) was 1.92 cubic miles in early July and 2.01 cubic miles in late July. The early July 1985-2018 average hypoxic volume is 1.36 cubic miles, and late July is 1.34 cubic miles. The most recent hypoxic volumes were respectively the fourth-largest for early July and second-largest for late July since 1985.

Larger than average hypoxia was predicted for this summer in part due to massive rainfall causing high flows into the Chesapeake Bay the past year, which delivered higher nutrient loads. Those nutrients fuel algal blooms, which die and are consumed by bacteria, which then deplete oxygen in bottom waters. Also, average winds were generally low in July, which prevented oxygen from mixing into deeper waters.

Type here to search

11:47 AM
11/6/2019

Early June 2019 Dissolved Oxygen Volume Below 2 mg/L for the Maryland Mainstem Chesapeake Bay

Chesapeake Bay Dissolved Oxygen
First June 2019 Cruise - Jun 3, 2019-Jun 17, 2019

The Dead Zone

When nutrient-fueled algae blooms die and decompose, the resulting low-oxygen conditions—known as "dead zones"—can suffocate underwater life and shrink available habitat.

2.7 CUBIC MILES
LARGEST DEAD ZONE RECORDED (2011)

1.7 CUBIC MILES
AVERAGE SIZE OF THE DEAD ZONE SINCE 1985

1.8 CUBIC MILES
SIZE OF THE DEAD ZONE (2017)

The Dead Zone

First reported in the 1930s, the "dead zone" is an area of little to no oxygen that forms when nutrient-fueled algae blooms die and decompose. Because the decomposition process removes oxygen from the water faster than it can be replaced, the decomposition of an algae bloom creates hypoxic or anoxic conditions that can suffocate marine life and shrink the habitat available to fish, crabs and other critters.

Annually, the CBP Communications Team receives and responds to many requests for information about the Dead Zone.
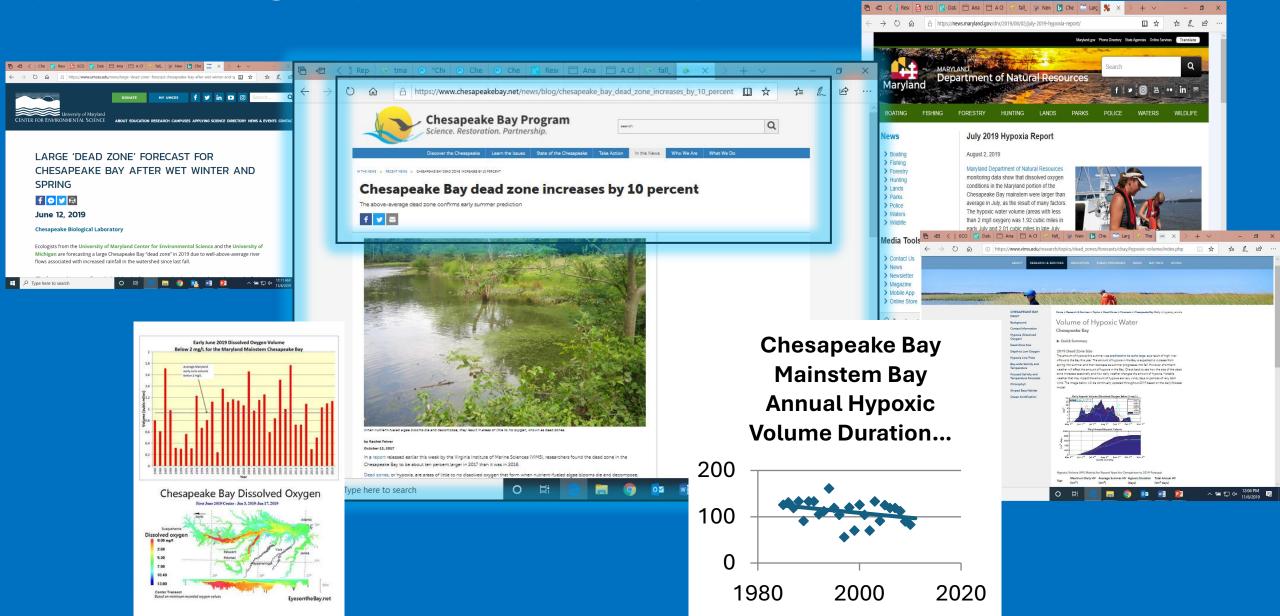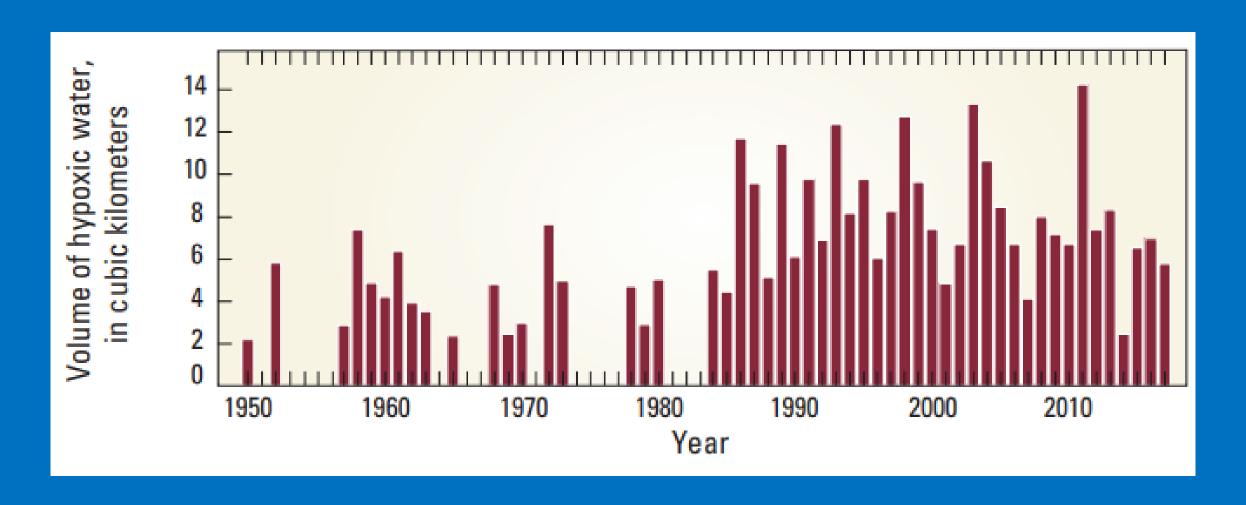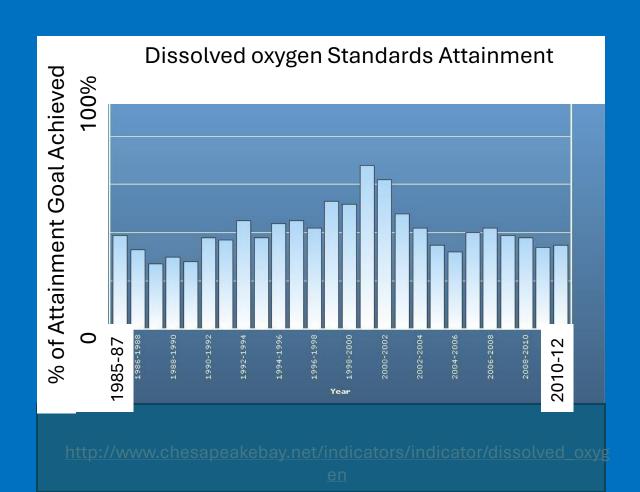
Chesapeake Bay Program Dead Zone reporting is commonly a synthesis of agency and institution reports and research...
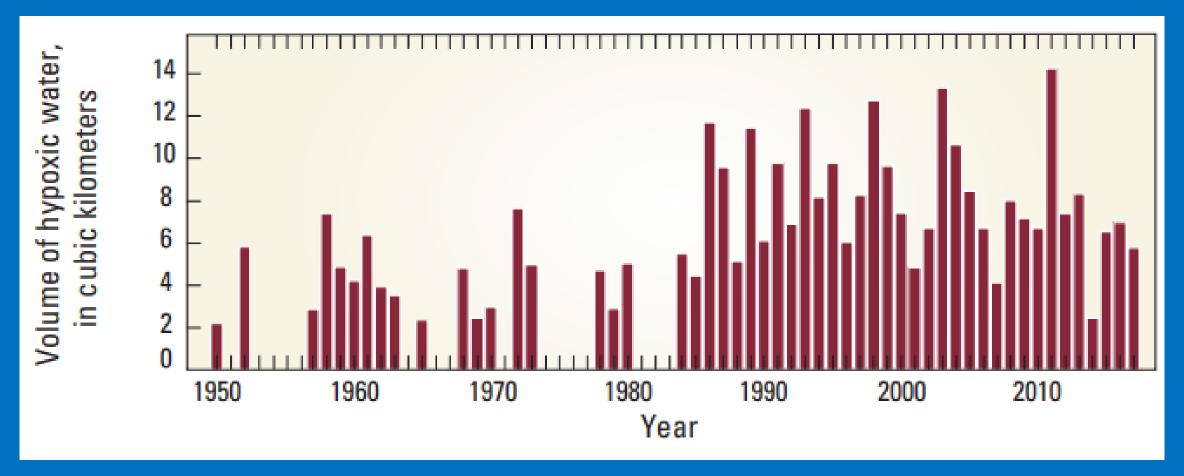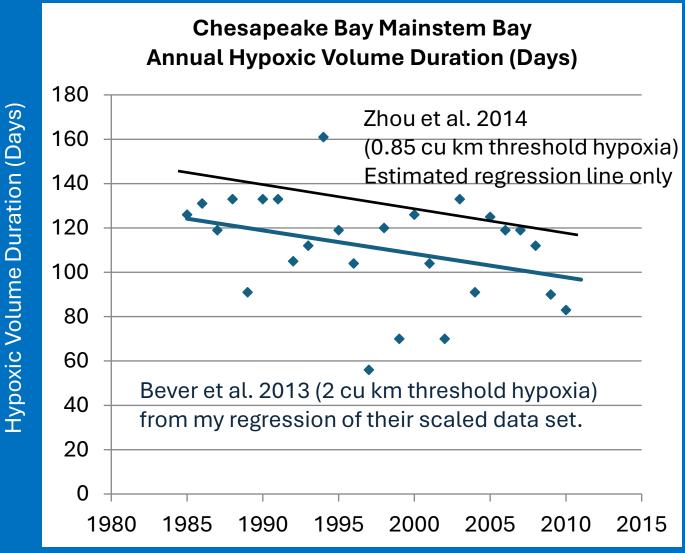
"Hypoxic Volume" – what does that mean?

Clune et al. 2024

Bay Health Status: Dissolved Oxygen Time Series Water Quality Standards Criteria Attainment for All Tidal Waters 1985-2012

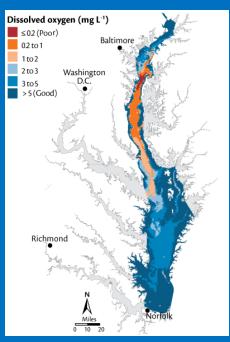Dissolved oxygen Standards Attainment

"Hypoxic Volume" – what does that mean?
In this case it means **July average volume of water <2mg/L for the mainstem Bay**

Clune et al. 2024
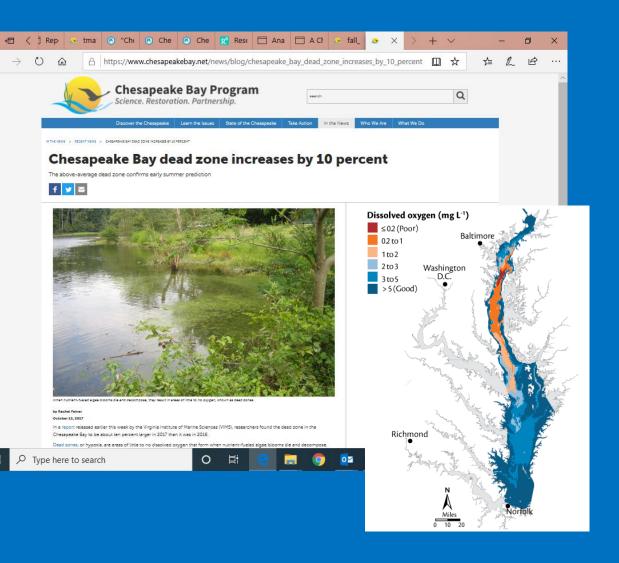
Indicators: What the Public Sees of Our Water Quality Monitoring Program

Chesapeake Bay Mainstem Bay Annual Hypoxic Volume Duration (Days)

Zhou et al. 2014
(0.85 cu km threshold hypoxia)
Estimated regression line only

Bever et al. 2013 (2 cu km threshold hypoxia) from my regression of their scaled data set.

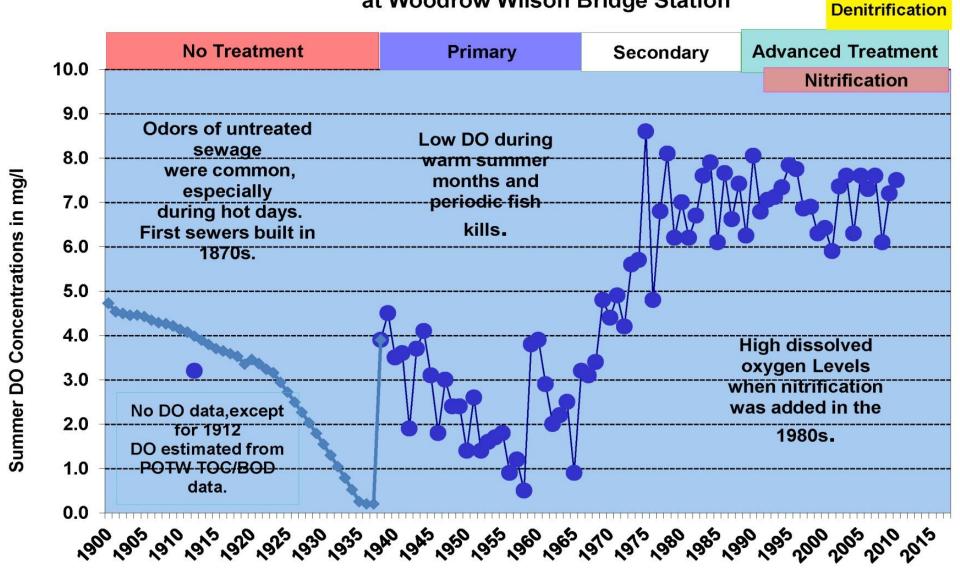Chesapeake Bay Hypoxia Summer 2012

Is it satisfactory to the CBP to continue Dead Zone reporting in an ad hoc messaging fashion?

Is there a need to establish a separate analysis prepared by CBP analysts to identify as "The Chesapeake Bay Program Dead Zone report?"

Is there a need to organize an annual collaborative newsletter at a set time each year integrating forecasts-summer conditions-final findings?

Potomac Estuary Wastewater Treatment and Summer Surface DO Concentrations at Woodrow Wilson Bridge Station

CHESAPEAKE BAY DAILY

Background

Contact Information

Hypoxia (Dissolved Oxygen)

Dead Zone Size

Depth to Low Oxygen

Hypoxia Line Plots

Bay-wide Salinity and Temperature

Focused Salinity and Temperature Forecasts

Chlorophyll

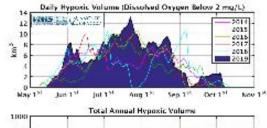Striped Bass Habitat

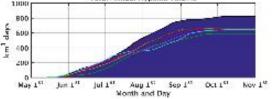Ocean Acidification

Volume of Hypoxic Water

Chesapeake Bay

▶ Quick Summary

2019 Dead Zone Size

The amount of hypoxia this summer was predicted to be quite large, as a result of high river inflows to the Bay this year. The amount of hypoxia in the Bay is expected to increase from spring into summer and then decrease as summer progresses into fall. However, short-term weather will affect the amount of hypoxia in the Bay. 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 2019 based on the daily forecast model.
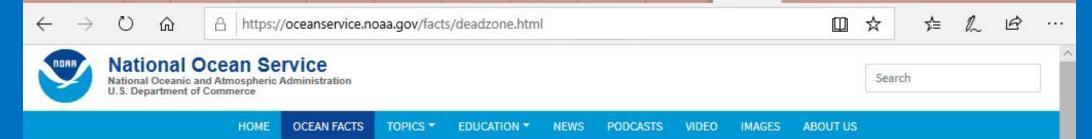

Hypoxic Volume (HV) Metrics for Recent Years for Comparison to 2019 Forecast

Year	Maximum Daily HV [km³]	Average Summer HV [km³]	Hypoxic Duration [days]	Total Annual HV [km³ days]

NOAA

National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Search
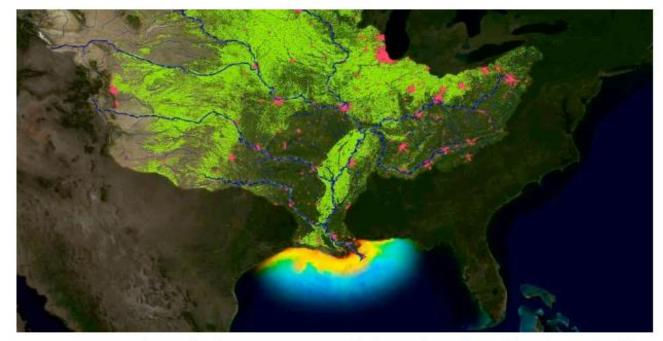
HOME   OCEAN FACTS   TOPICS ▾   EDUCATION ▾   NEWS   PODCASTS   VIDEO   IMAGES   ABOUT US
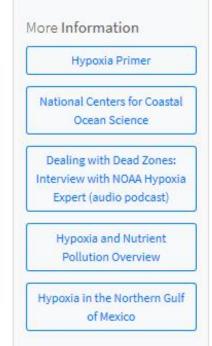
What is a dead zone?

"Dead zone" is a more common term for **hypoxia**, which refers to a **reduced level of oxygen** in the water.
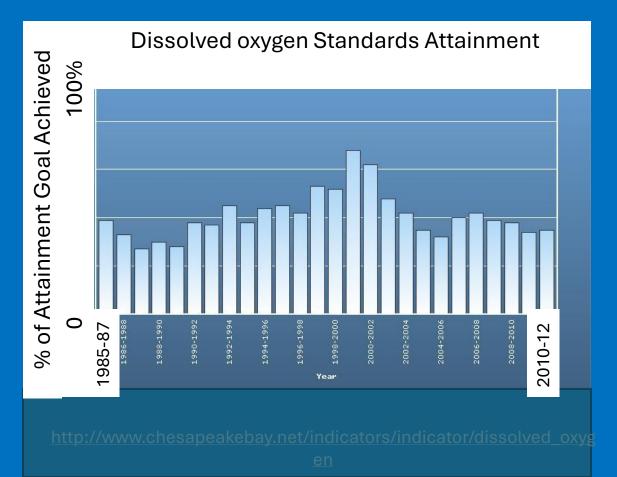

Hypoxic zones are areas in the ocean where the oxygen concentration is so low that animals can suffocate and die, and as a result are often called "dead zones." The largest hypoxic zone in the United States, and the second largest hypoxic zone worldwide, forms in the northern Gulf

More **Information**

- Hypoxia Primer
- National Centers for Coastal Ocean Science
- Dealing with Dead Zones: Interview with NOAA Hypoxia Expert (audio podcast)
- Hypoxia and Nutrient Pollution Overview
- Hypoxia in the Northern Gulf of Mexico

Bay Health Status: Dissolved Oxygen Time Series
Water Quality Standards Criteria Attainment for All Tidal Waters
1985-2012
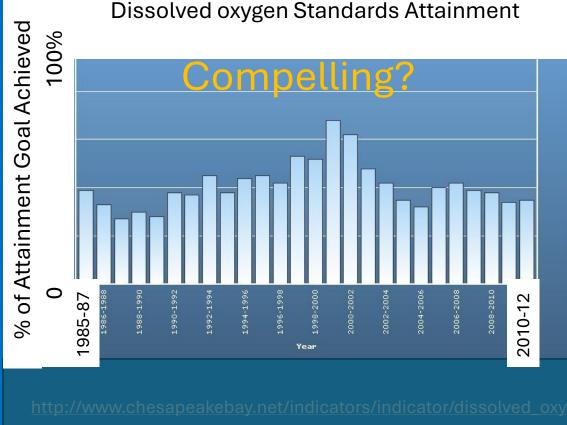## This is roughly what we show the public on Chesapeake Progress and how we describe it

Dissolved oxygen Standards Attainment

% of Attainment Goal Achieved

100%

0

1985-87 1986-1988 1988-1990 1990-1992 1992-1994 1994-1996 1996-1998 1998-2000 2000-2002 2002-2004 2004-2006 2006-2008 2008-2010 2010-12

Year

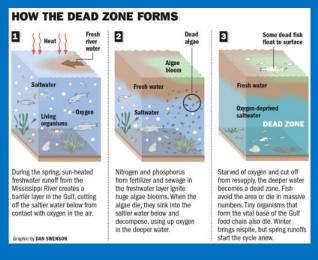# Make the issue of low oxygen relatable to the public?

Call it a **Dead Zone**

2022 Chesapeake Bay Dead Zone Report Released

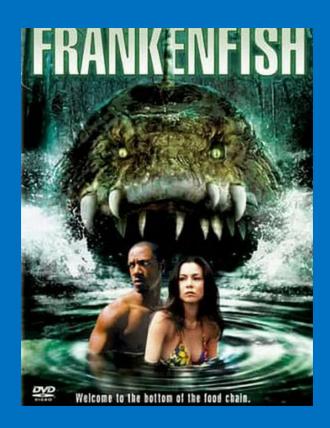NOVEMBER 16, 2022 – ANCHOR QEA AND THE VIRGINIA INSTITUTE OF MARINE SCIENCE

Chesapeake Bay, the largest estuary in the United States and the third largest in the world, is particularly vulnerable to human impacts. In recent decades, low dissolved oxygen and changing acidification have severely affected the Bay's ecosystem. A dead zone—an area of water with little to no oxygen—can form when excess nutrients, such as nitrogen and phosphorous from fertilizer, wastewater, and urban runoff, enter the water. Scientists refer to these oxygen-poor waters as "hypoxic," meaning the oxygen concentration is less than 2 milligrams per liter, which is too low for aquatic life to thrive.

In collaboration with the **Virginia Institute of Marine Science (VIMS)**, Anchor QEA operates the **Chesapeake Bay Environmental Forecast System (CBEFS) computer model**, which both predicts dissolved oxygen concentrations and forecasts environmental conditions in the Bay every day. Anchor QEA and VIMS recently released a 2022 Chesapeake Bay Dead Zone Report that summarizes the severity of the dead zone during the summer of 2022 and compares these findings to data collected from 1985 to 2021, with a focus on the previous 5 years.

Capture public attention:

National Geographic
https://www.nationalgeographic.com › ...

Pictures: Wasps Turn Ladybugs Into Flailing "Zombies"

Killer bees are spreading across the US – and are being drawn to northern states because of warming temps

Story by Erin Keller • 5h • ⏱ 2 min read   💬 Summarize

Africanized honey bees, infamously known as "killer bees," are rapidly spreading across the United States, having already been confirmed in 13 states from California and Arizona to Florida, Georgia, and as far east as Alabama.