HAB and Hypoxia Science, Application, and Influence

University of Michigan and Partners

Don Scavia
University of Michigan

4 Primary Grants with 2 “Offshoots”

CHRP – Estuarine Susceptibility to Nutrient Pollution

NGOMEX models (w/Chesapeake Bay models)

Hypoxia Model Transition to Operations

ECOFOR - Lake Erie (w/Lake Erie HAB models)

CHRP - Susceptibility to Nutrient Pollution

with Howarth, Breitburg, Alexander, plus several postdocs and associates

East Coast Estuarine Eutrophication

4 components

Estuarine, fisheries, and 2 watershed models

Significant science contributions in all 4 areas

> 55 Publications

Howarth, R.W., D.P. Swaney, G. Billen, J. Garnier, B. Hong, C. Humborg, P. Johnes, C.-M. Mörth, and R.M. Marino. 2012. Nitrogen fluxes from large watersheds to coastal ecosystems controlled by net anthropogenic nitrogen inputs and climate. ***Frontiers in Ecology and the Environment***. 10(1): 37–43.

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Hong, B., K. Limburg, M. Hall, G. Mountrakis, P. Groffman, K. Hyde, V. Kelly, L. Luo, and S. Myers. 2012. An integrated monitoring/modeling framework for assessing human-nature interactions in urbanizing watersheds: Wappinger and Onondaga Creek watersheds, New York, USA. *Environmental Modelling and Software* 32:1-1...
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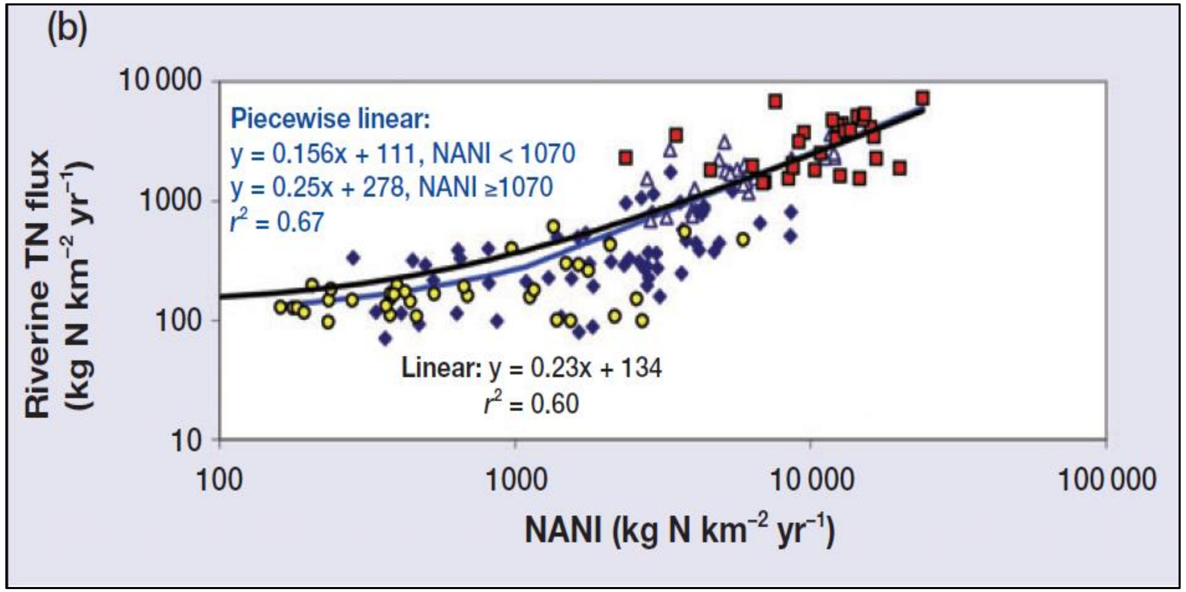
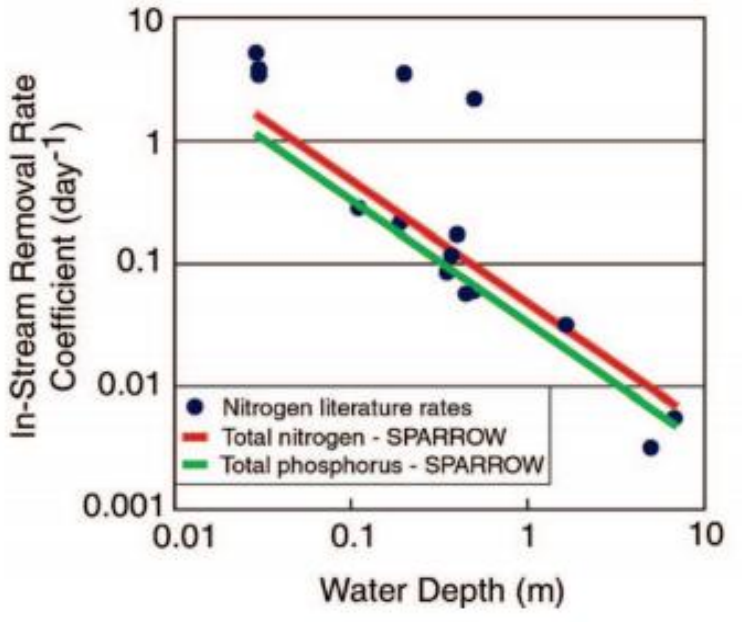
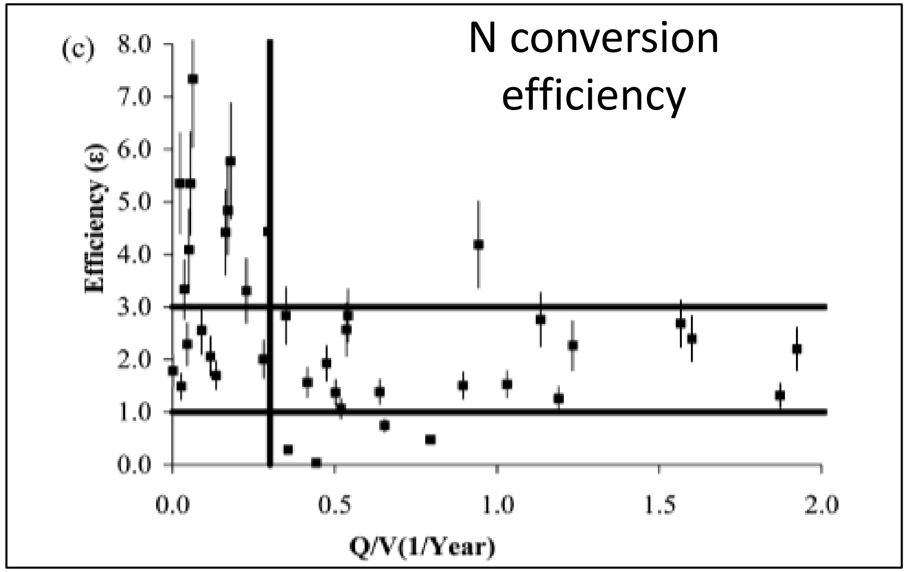
Bob Howarth's team



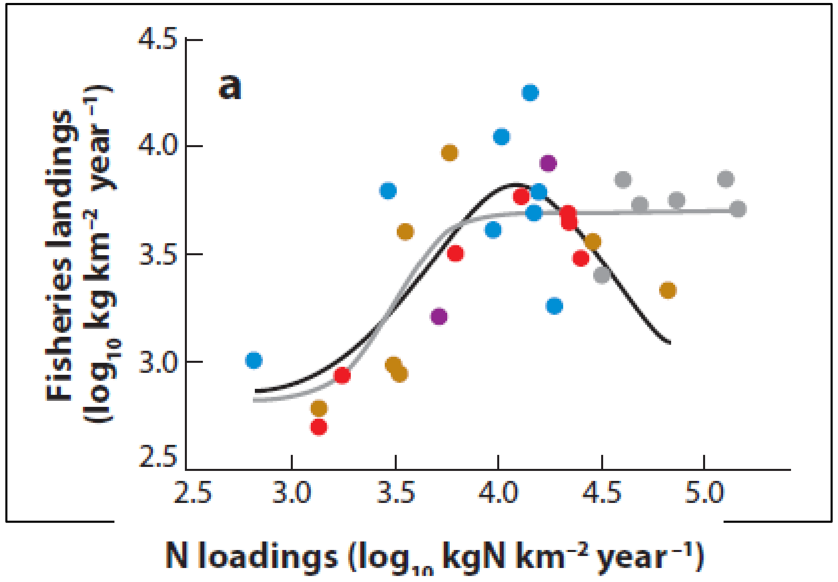
Rich Alexander's Team



Don Scavia's Team



Denise Breitburg's Team



CHRP - Susceptibility to Nutrient Pollution

with Howarth, Breitburg, Alexander, plus several postdocs and associates

East Coast estuarine eutrophication

4 components

Estuarine, fisheries, and 2 watershed models

Significant science contributions in all 4 areas

Important scientific contributions, but integration was a challenge

Large, diverse geography

Significant model mismatches in temporal resolution

Geographically dispersed investigators

Gulf of Mexico models

with Evans, Obenour, Bertani, Liu, Rabalais, Turner

Annual forecasts started in 2002; updated and improved each year

Moved to Bayesian formulation in 2009

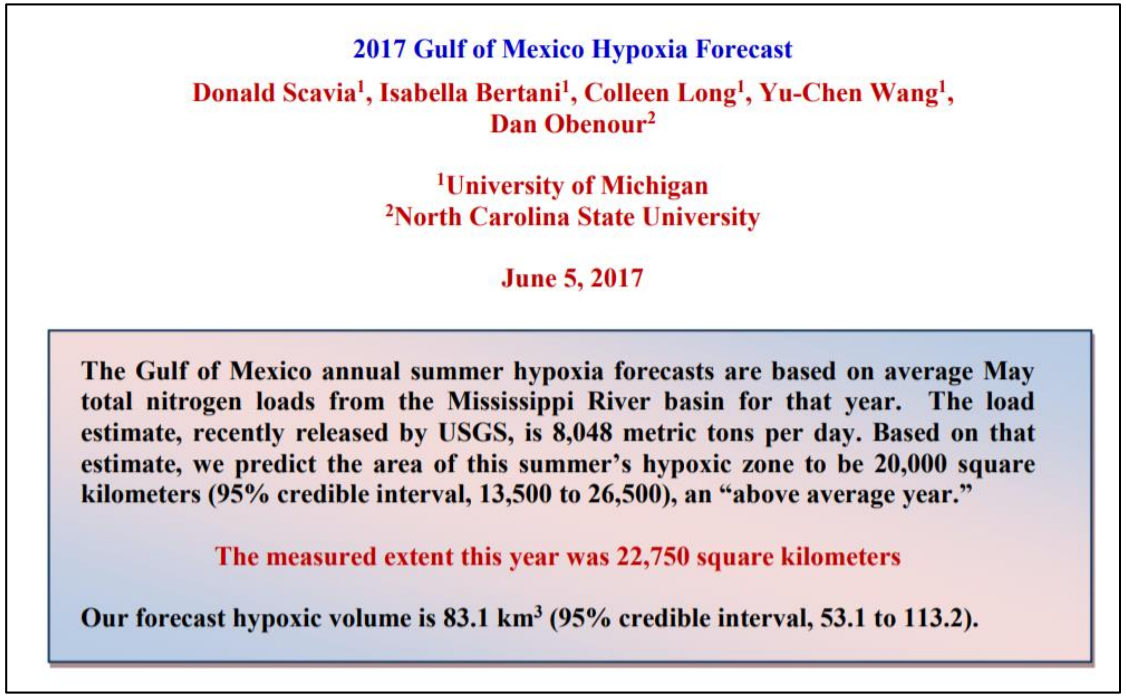
Added hypoxic volume forecasts in 2013

Developed strong track record

Built and added to NOAA's annual ensemble forecasts

Model-based scenarios guided various Gulf Hypoxia Action Plans

Annual Forecasts



2017 Gulf of Mexico Hypoxia Forecast

Donald Scavia[1], Isabella Bertani[1], Colleen Long[1], Yu-Chen Wang[1], Dan Obenour[2]

[1]University of Michigan
[2]North Carolina State University

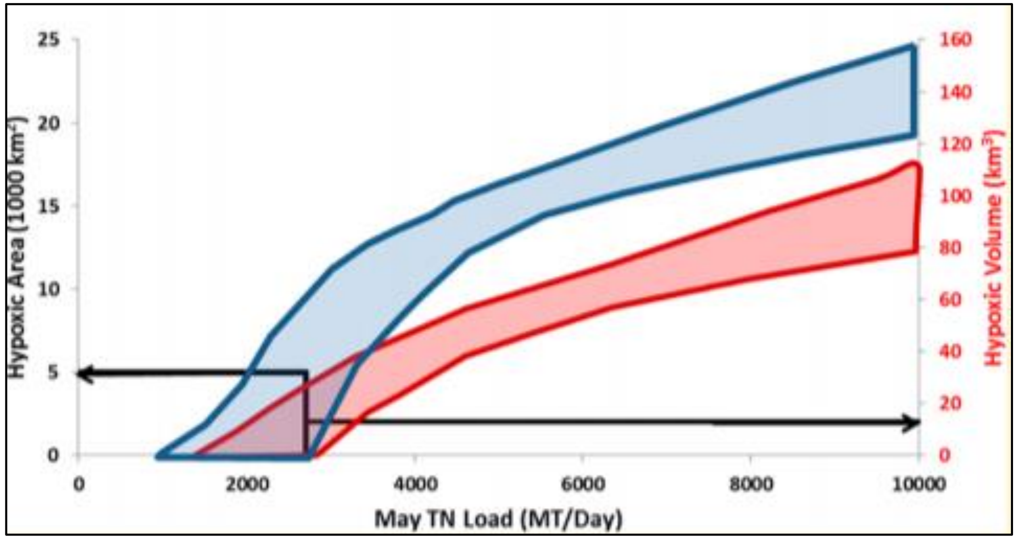
June 5, 2017

The Gulf of Mexico annual summer hypoxia forecasts are based on average May total nitrogen loads from the Mississippi River basin for that year. The load estimate, recently released by USGS, is 8,048 metric tons per day. Based on that estimate, we predict the area of this summer's hypoxic zone to be 20,000 square kilometers (95% credible interval, 13,500 to 26,500), an "above average year."

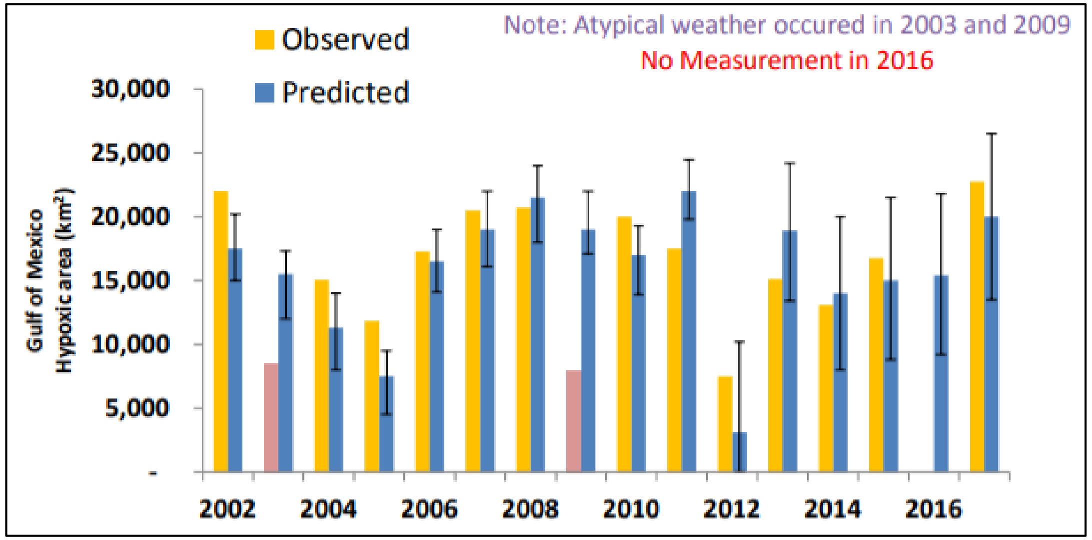
The measured extent this year was 22,750 square kilometers

Our forecast hypoxic volume is 83.1 km³ (95% credible interval, 53.1 to 113.2).

Response Curves for Task Force



Track Record

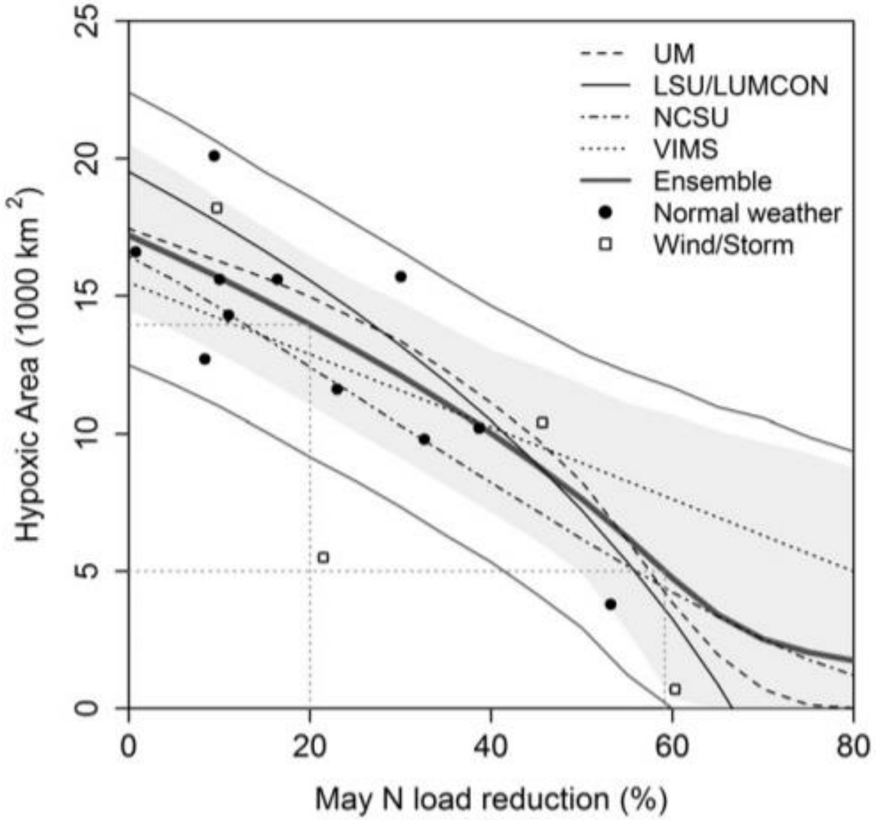


Other Model Uses

Compared to other models (Scavia et al. 2004)
Explored N vs. P control (Scavia and Donnelly 2007)
Explored potential climate impacts (Donner and Scavia 2007)
Predict impacts of oil drilling produced water (Bierman et al. 2007)
Explored increasing sensitivity to N loads (Liu et al. 2010)
Quantify Impacts of stratification and nutrients (Obenour et al. 2012)
Assessing biophysical controls (Obenour et al. 2015)

Ensemble modeling informs hypoxia management in the northern Gulf of Mexico

Donald Scavia[a,b,1], Isabella Bertani[a], Daniel R. Obenour[c], R. Eugene Turner[d], David R. Forrest[e], and Alexey Katin[c]



Formal statistical ensemble

59% N reduction to reduce hypoxia to 5,000 km^2

Interim 20% goal reduces it 18% **over long term**

But, at least 25% reduction needed to be 95% sure of observing **any** reduction between 2 consecutive 5 year assessments.

Chesapeake Bay models

With Bertani, Evans

Built in as adjunct to Gulf grant (similar model)

Forecasts started in 2007

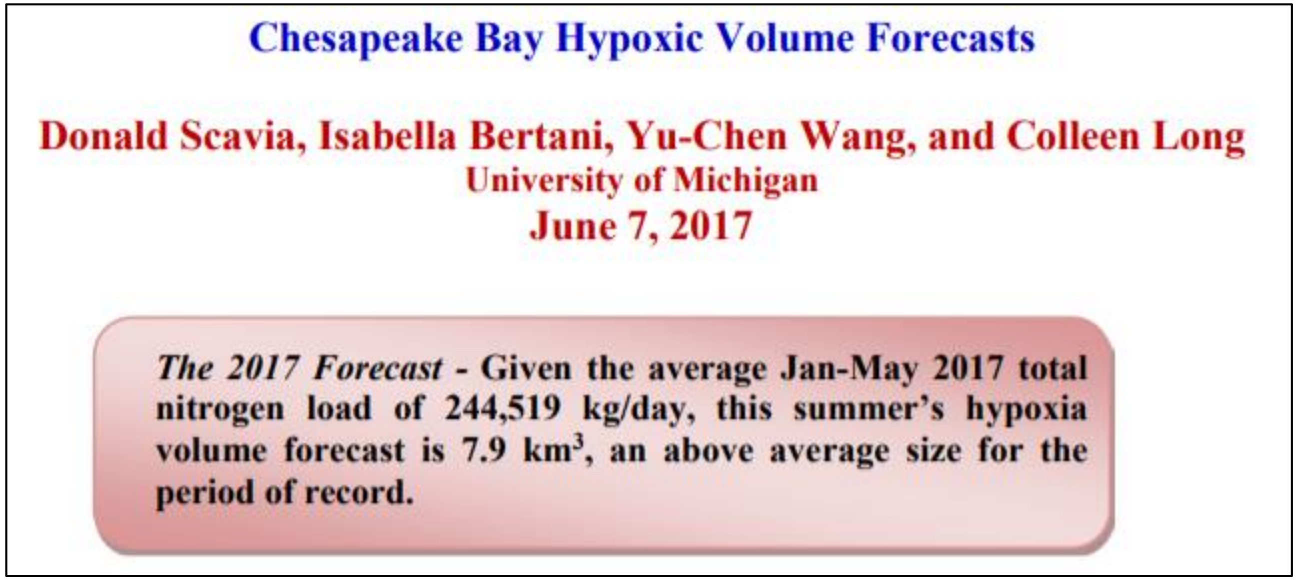
Moved to Bayesian formulation in 2009

Identified regime shift consistent with observations

Tested TMDL impact of main stem hypoxia

***Bioscience* retrospective emphasized model results drove policy attention**

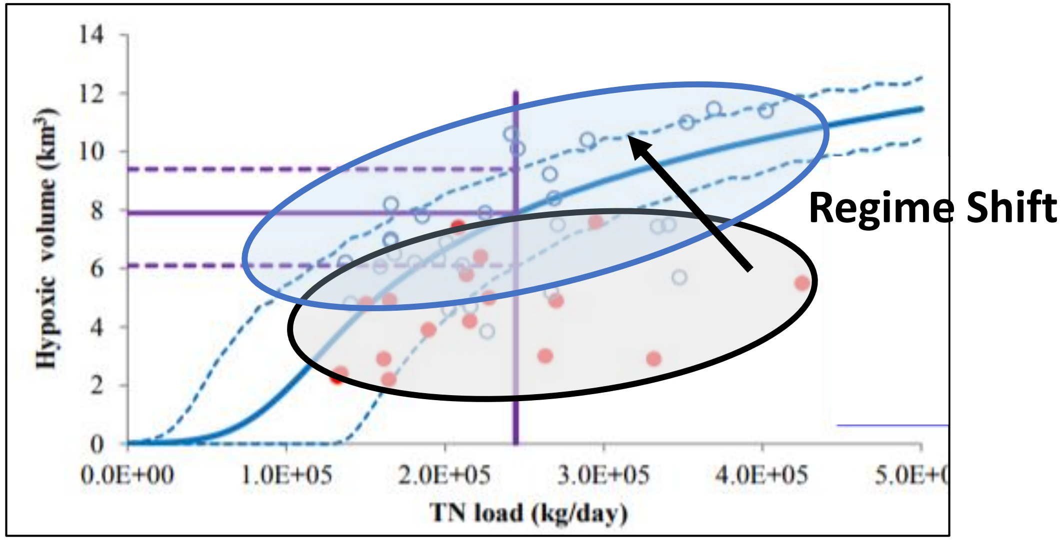
Annual Forecasts


Chesapeake Bay Hypoxic Volume Forecasts

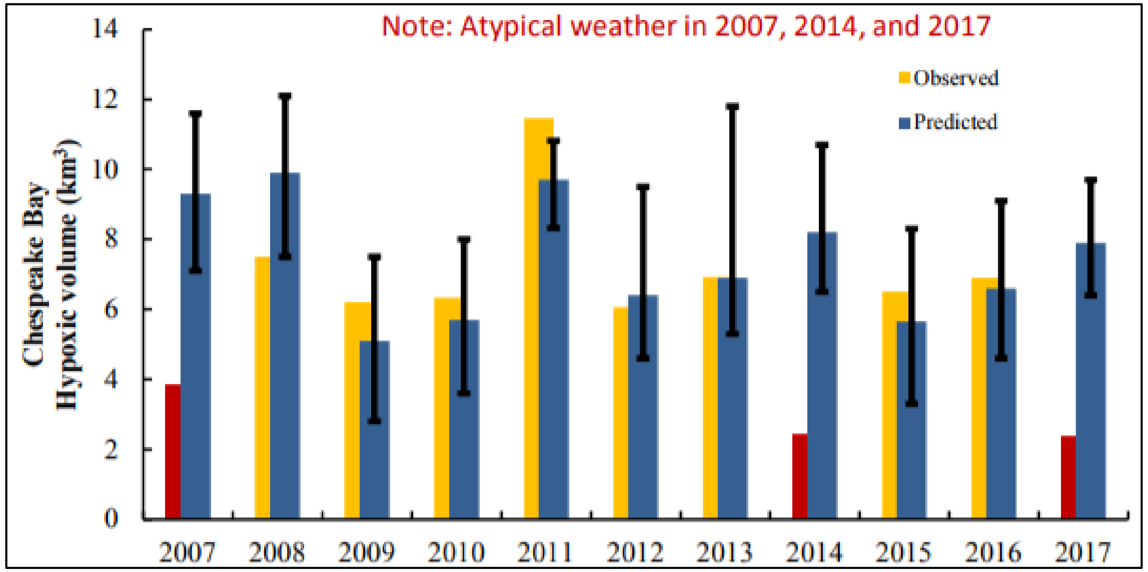
Donald Scavia, Isabella Bertani, Yu-Chen Wang, and Colleen Long
University of Michigan
June 7, 2017

The 2017 Forecast - Given the average Jan-May 2017 total nitrogen load of 244,519 kg/day, this summer's hypoxia volume forecast is 7.9 km³, an above average size for the period of record.

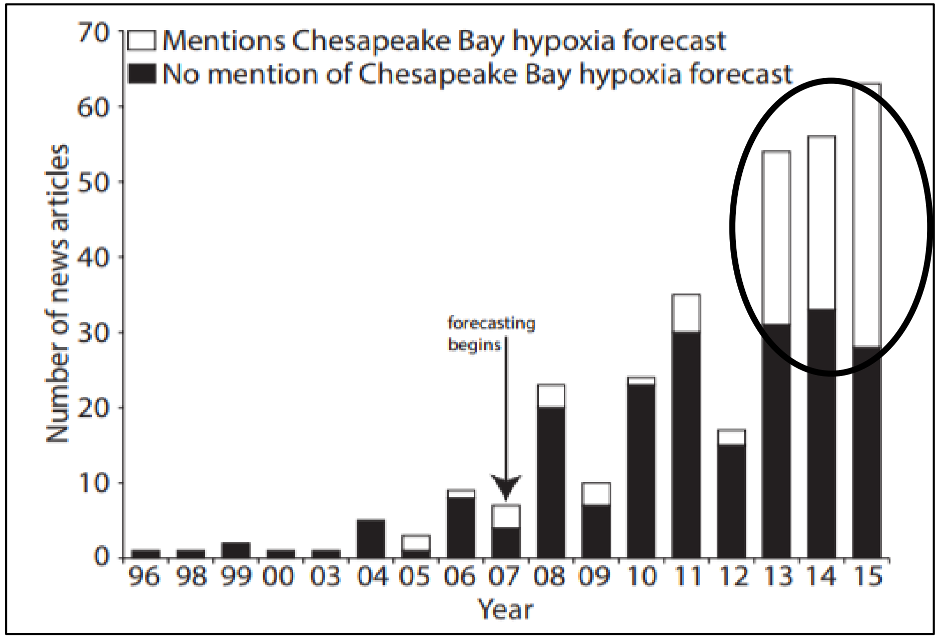
Response Curve



Track Record



Impact on Awareness



Hypoxia Model Transition

with Obenour, Forrest, Testa, Turner

Four Very different <u>Gulf Models</u> (Scavia, Obenour, Forrest, Turner**)**

Worked with NOAA on transition to operations plan

- 2017 forecast successfully done in parallel with NOAA
- Prepared to turn them over to NOAA for 2018
- PNAS article documented approach and scenario application

Two <u>Chesapeake Bay Models</u> (Scavia, Testa**)**

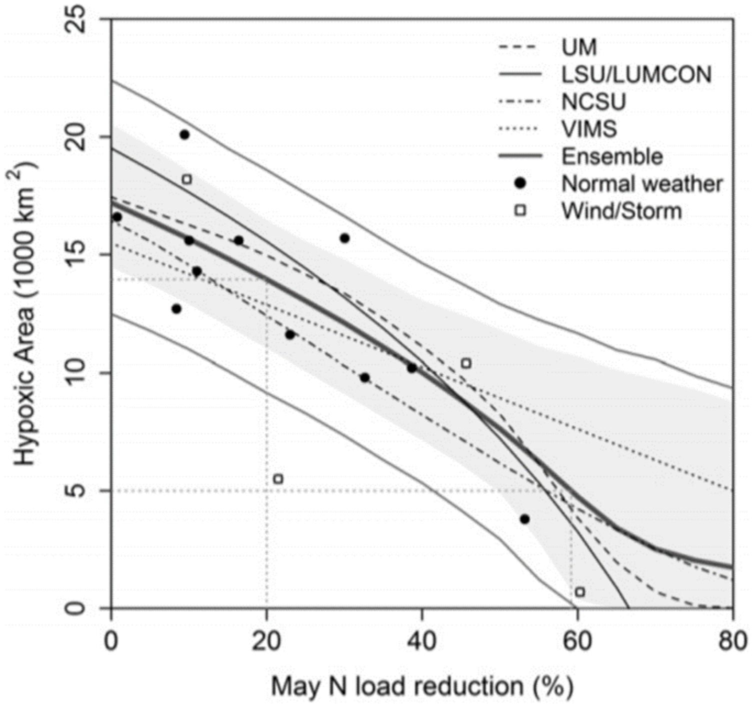
Not yet part of NOAA transition planning

2015 – 2017 hypoxia (Scavia) & anoxia (Testa) forecasts

Progress tracked by Univ. Maryland "EcoCheck" website

Ensemble modeling informs hypoxia management in the northern Gulf of Mexico

Donald Scavia[a,b,1], Isabella Bertani[a], Daniel R. Obenour[c], R. Eugene Turner[d], David R. Forrest[e], and Alexey Katin[c]



ecocheck

How healthy is your ecosystem?

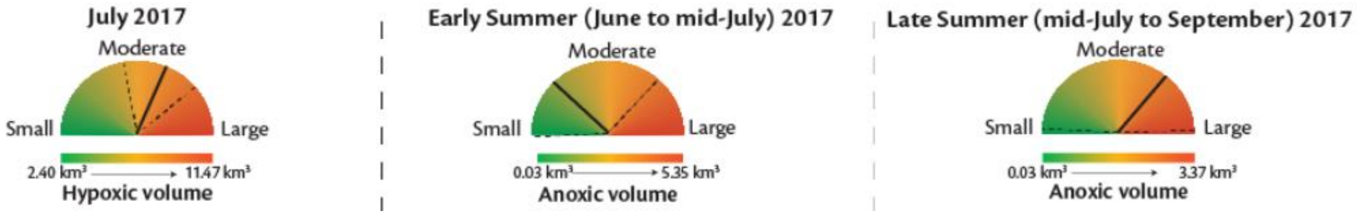
http://ian.umces.edu/ecocheck/

Report Card | Summer Review | Forecast

Home | Overview | July Hypoxia | Early Summer Anoxia | Late Summer Anoxia | FAQ

Chesapeake Bay Summer Forecast: 2017 ▼

Click on the items below for the 2017 summer forecast indicators:



Lake Erie ECOFOR

with Allan, Arend, Bartell, Beletsky, Bosch, Brandt, Briland, Daloğlu, DePinto, Dolan, Evans, Farmer, Goto, Han, Höök, Knight, Ludsin, Mason, Richards, Roberts, Rucinski, Rutherford, Schwab, Sesterhenn, Zhang, Zhou, + many students and other postdocs

Focus: Lake Erie Central Basin hypoxia

3 components: watersheds, lake ecosystem, fisheries

Very significant progress in all three areas

> 60 Publications

Arend, K.K., D. Beletsky, J.V. DePinto, S.A. Ludsin, J.J. Roberts, D.K. Rucinski, D. Scavia, D.J.Schwab, and T.O. Höök. Hypolimnetic Hypoxia in the Central Basin of Lake Erie:Understanding Seasonal and Interannual Effects on Habitat Quality of Important FishSpecies. Freshwater Biology. 56, 366-383.
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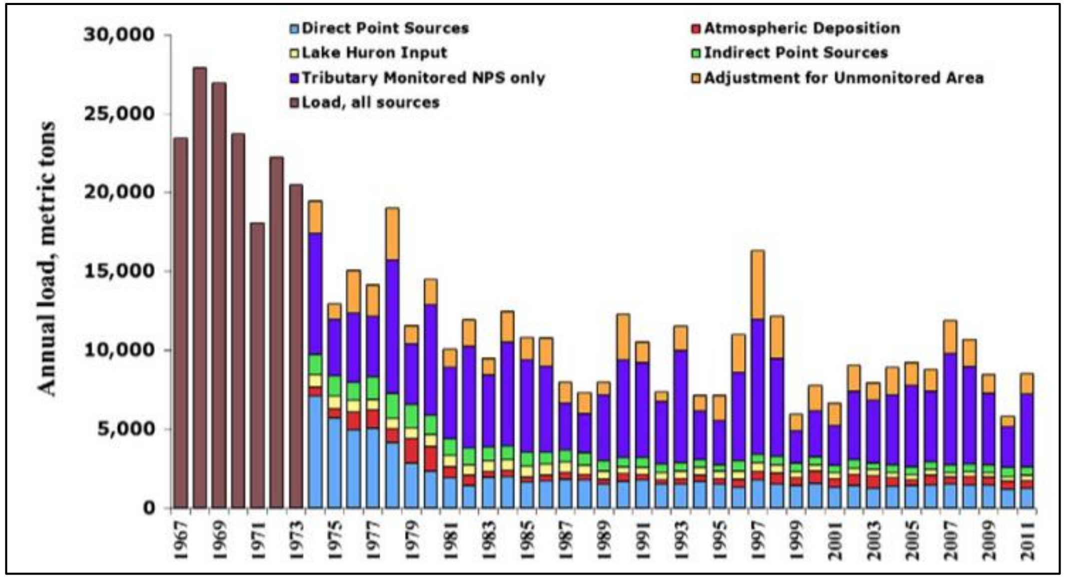
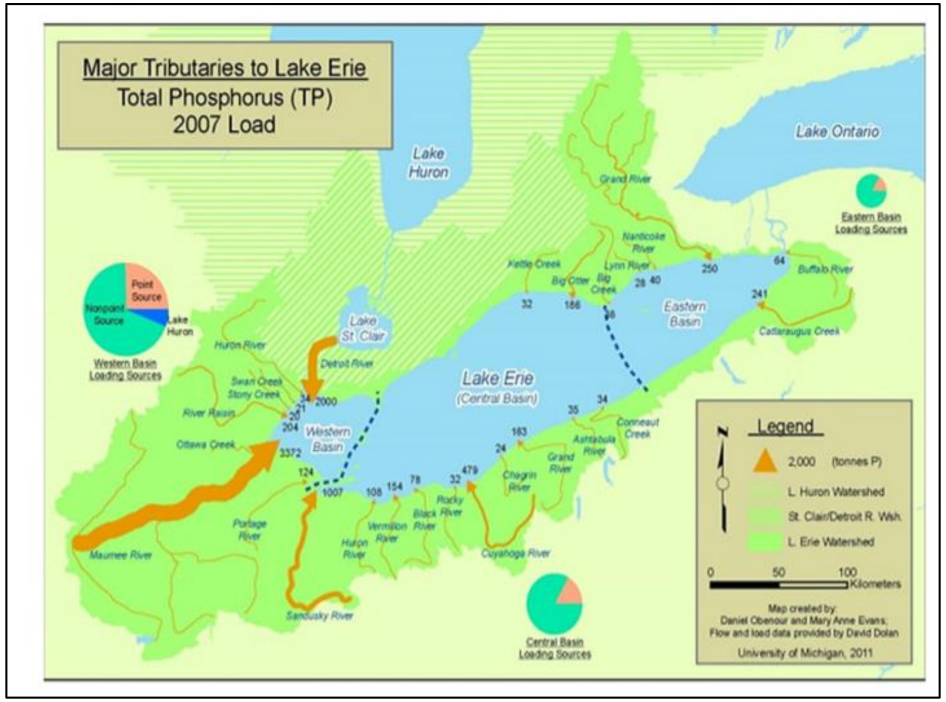
Synthesis: 2014 Best Paper of the Year

Scavia, D., J. D. Allan, K. K. Arend, S. Bartell, D. Beletsky, N. S. Bosch, S. B. Brandt, R. D. Briland, I. Daloğlu, J. V. DePinto, D. M. Dolan, M. A. Evans, T. M. Farmer,D. Goto, H.Han, T. O. Höök, R. Knight, S. A. Ludsin, D. Mason, A. M. Michalak, R. P. Richards, J. J. Roberts, D. K. Rucinski, E. Rutherford, D. J. Schwab, T. Sesterhenn, H. Zhang, Y. Zhou. 2014. **Assessing and addressing the re-eutrophication of Lake Erie: Central Basin Hypoxia**. J. Great Lakes Res. 40: 226–246

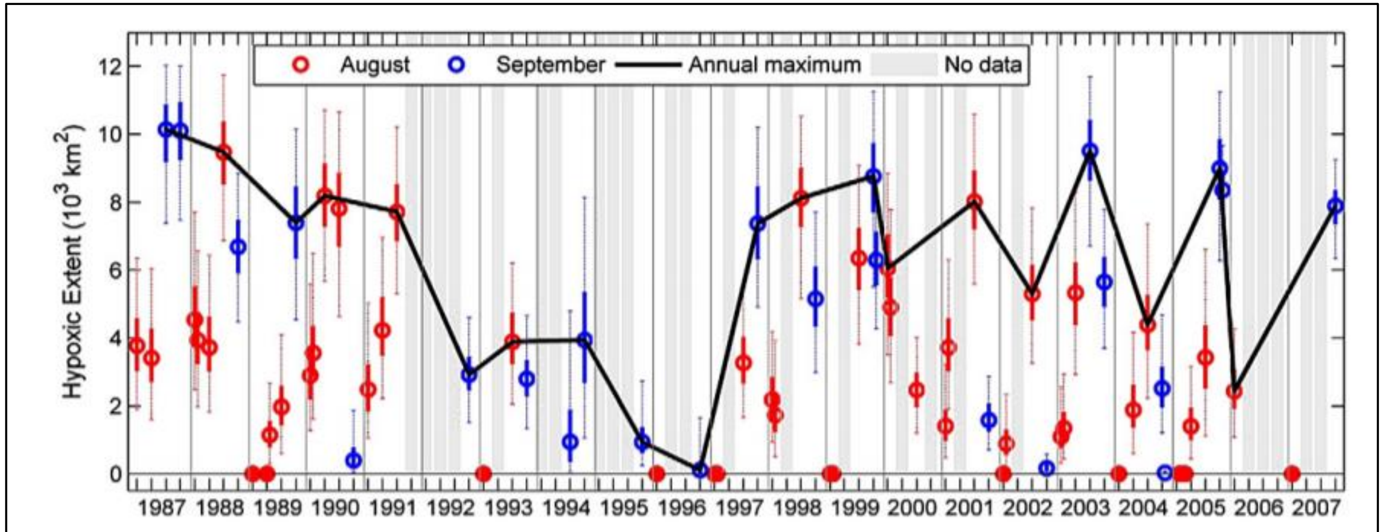
Document Historical Loads (Dolan et al.)



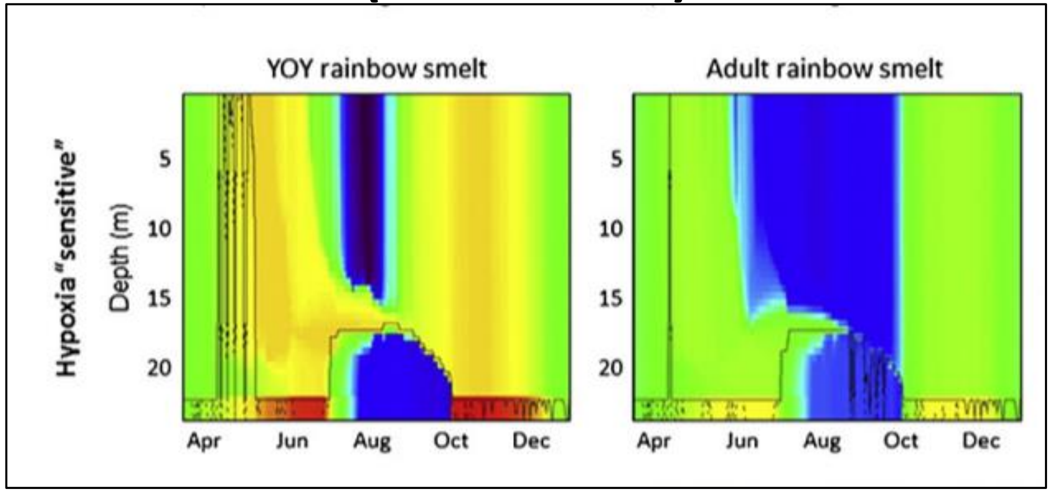
Identify Current Primary P Sources (Scavia Team)



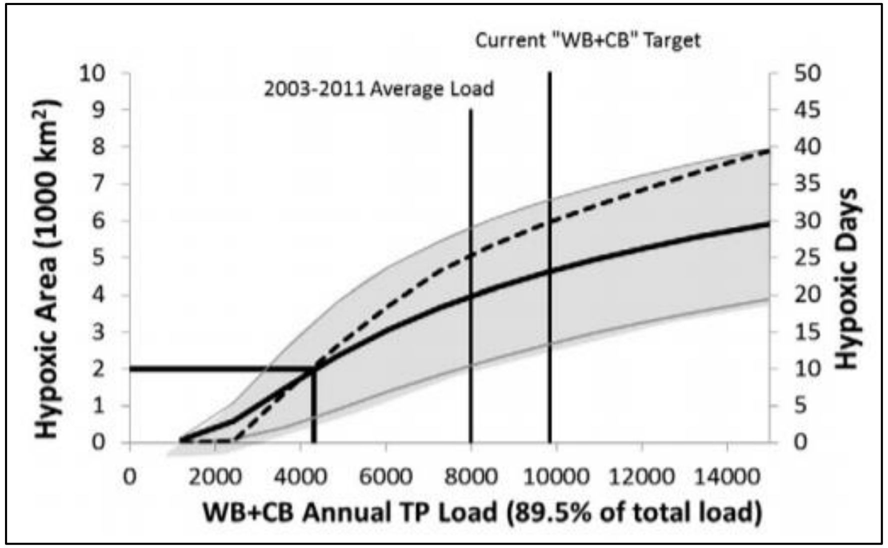
Document 1990s Hypoxia Resurgence (Zhou et al.)



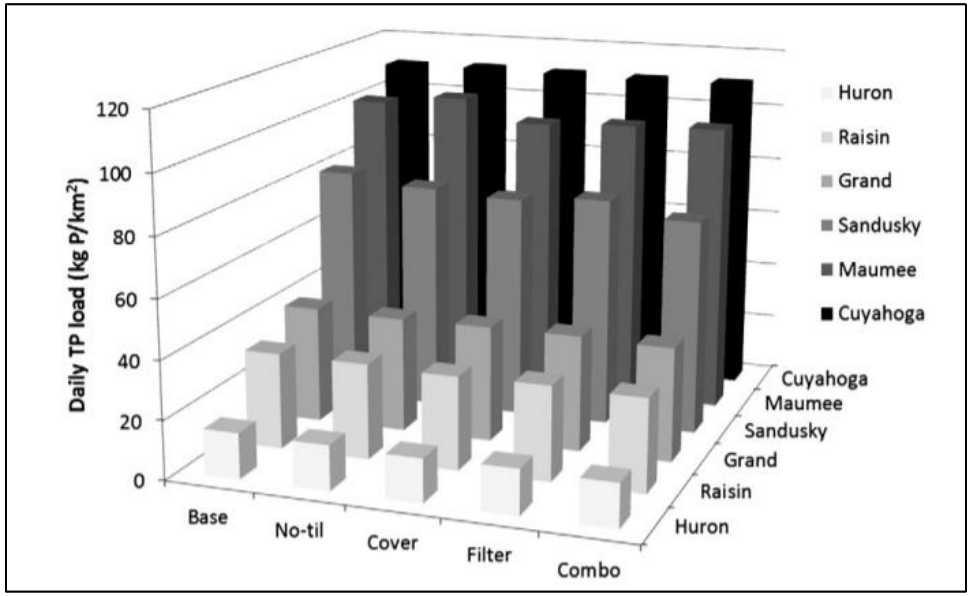
Fisheries Effects: Oxy-Thermal Squeeze (Höök et al.)



Response Curve to Set Targets (Rucinski et al.)



Land-use Load Reduction Strategies (Bosch et al.)



Lake Erie ECOFOR

with Allan, Arend, Bartell, Beletsky, Bosch, Brandt, Briland, Daloğlu, DePinto, Dolan, Evans, Farmer, Goto, Han, Höök, Knight, Ludsin, Mason, Richards, Roberts, Rucinski, Rutherford, Schwab, Sesterhenn, Zhang, Zhou, + many students and other postdocs

Focus: Lake Erie Central Basin hypoxia
3 components: watersheds, lake ecosystem, fisheries
Very significant progress in all three areas (pubs, examples**)**

Integration was easier because it focused on one system and teams were geographically connected

Influence was powerful - New International P load Targets

International Joint Commission – *Lake Erie Priority Report*
Great Lakes Fisheries Commission – *Technical Committees*
EPA, Environment Canada – *GL Water Quality Agreement*
Healing our Waters Coalition – *Great Lakes Advocates*

Lake Erie HAB models

with Obenour, Bertani, Stow, Gronewold

Built as adjunct to ECOFORE

Bayesian hierarchical formulation

- HAB as function of phosphorus load
- First to account for both model and observation error
- First to identify increasing sensitivity to loads

Contributes to NOAA’s annual HAB ensemble forecasts

Used in setting new US-Canada GLWQA phosphorus loads

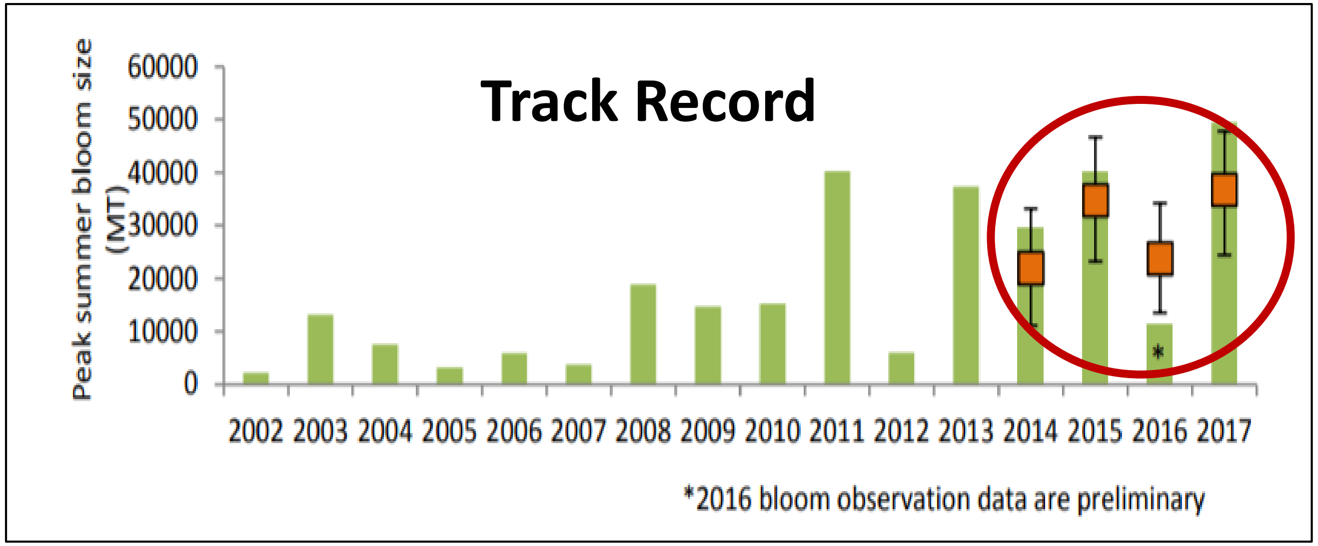
Annual Forecast team feeds NOAA Ensemble

2017 Western Lake Erie Harmful Algal Bloom (HAB) Forecast

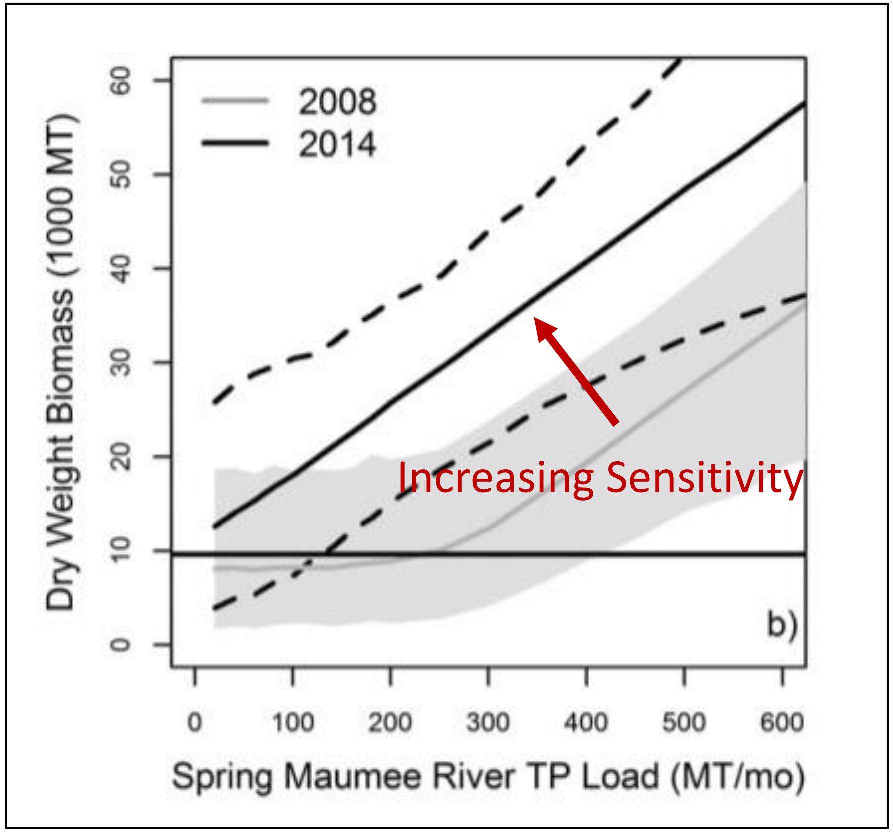
Issued: 13 July 2017

Great Lakes Environmental Research Laboratory

<u>Forecast summary</u>: A cyanobacteria HAB of 36,800 metric tons (MT) is predicted for the western basin of Lake Erie in 2017, with a 95% predictive interval of 24,400 to 47,800 MT. The bloom size over the last decade (2007-2016) has averaged 22,000 MT, such that this year's bloom is likely to be above average. The prediction is based on a probabilistic model developed by a team of researchers at UM, NCSU, and NOAA GLERL. This is one of three models used to develop an ensemble bloom prediction (the other models being developed by LimnoTech and NOAA NCCOS). The measured HAB extent of 49,493 MT.



Response Curves guide GLWQA load targets



ECOFORE Contributions to new GLWQA Nutrient Load Targets
Special Issue of J. Great Lakes Res.

Synthesis

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Central Basin Hypoxia Models

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Bocaniov, S. and D. Scavia 2016 Temporal and spatial dynamics of large lake hypoxia: Integrating statistical and three-dimensional dynamic models to enhance lake management criteria. Water Resources Res. (Supplemental Information) 52: 4247-4263

Western Basin HAB Models

Bertani, I., C. E. Steger, D. R. Obenour, G. L. Fahnenstiel, T. B. Bridgeman, T. H. Johengen, M. J. Sayers, R. A. Shuchman, D. Scavia. 2016. Tracking cyanobacteria blooms: do different monitoring approaches tell the same story? Science of the Total Environment 575: 294-30

Bertani, I, D.R. Obenour, C. E. Steger, C. A. Stow, A. D. Gronewold, D. Scavia 2016. Probabilistically assessing the role of nutrient loading in harmful algal bloom formation in western Lake Erie. J Great Lakes. Res. 42: 1184:1192

Obenour, D.R. A.D. Gronewold, C.A. Stow, and D. Scavia 2014 Using a Bayesian hierarchical model with a gamma error distribution to improve Lake Erie cyanobacteria bloom forecasts. Water Resources Res.

Worth noting

Ecofore began in 2005:

- NCCOS saw an emerging issue and wanted to get ahead of the curve
- At the time, rare for a Federal agency to support competitive GL research
- Ecofore results & capabilities in place <u>two years </u>before the poop hit the fan
- Well positioned for leadership to guide new GLWQA load reductions

Since then, **building on Ecofore,** we have had grants from:

- **NSF** Water, Sustainability, and Climate
- **NSF** SEES: Enhancing sustainability in communities threatened by HABs
- **NOAA/**COCA: Enhancing awareness of Lake Erie climate impacts
- **EPA/Environment Canada:** Multi lake model effort to guide load targets
- **Joyce/Erb Foundations**: Multi watershed model effort to guide reduction actions
- **EPA:** Evaluating Pay for Performance approach in agriculture

Reviewing Results from 4 Pri

with 2 "

CH **olution**

(w/Lake Erie HAB models)

Mexico GOMEX models (w/Chesapeake Bay models)

Hypoxia Model Transitions

Thank you to NOAA and NCOSS
for 10 years of support!

Hypoxia Modeling, Nutrient Reduction Targets, and Stakeholder Engagement (Northern Gulf of Mexico)

Nancy Rabalais
Louisiana State University
Louisiana Universities Marine Consortium

Alan Lewitus
NOAA National Ocean Service
National Centers for Coastal Ocean Science

NCCOS HAB and Hypoxia Portfolio Review

26 February 2018, Silver Spring, MD

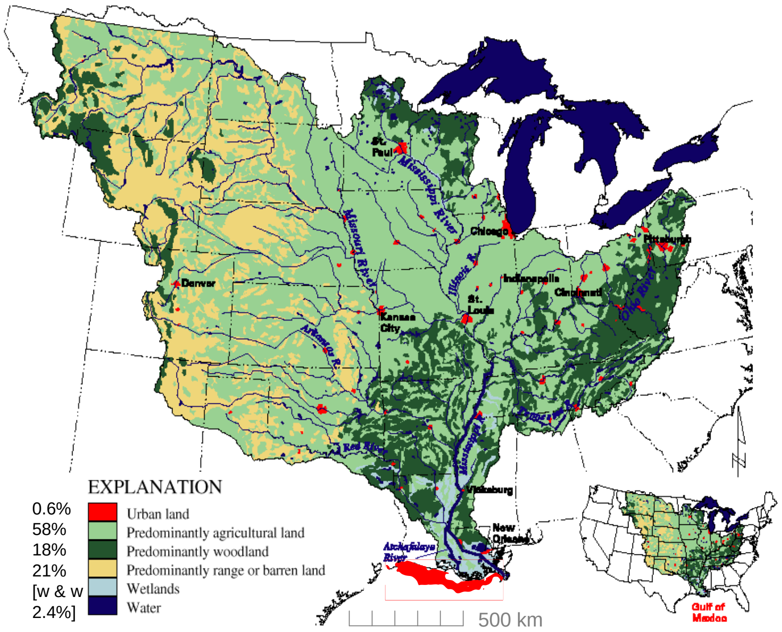
Hypoxia Task Force

5 Federal Agencies and Tribes:

- **US Army Corps**
- **US EPA**
- **USDA**
- **USGS**
- **NOAA**
- **National Tribal Water Council**

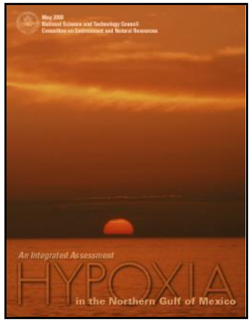
12 State Agencies:

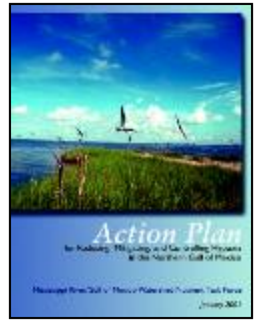
- **Arkansas**
- **Missouri**
- **Iowa**
- **Tennessee**
- **Minnesota**
- **Indiana**
- **Ohio**
- **Louisiana**
- **Illinois**
- **Mississippi**
- **Kentucky**
- **Wisconsin**



Data from Water Resources Inst.

Hypoxia Task Force Action Plans



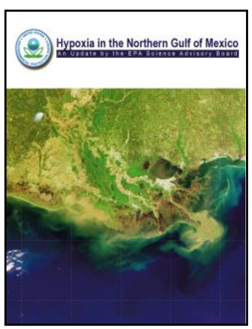


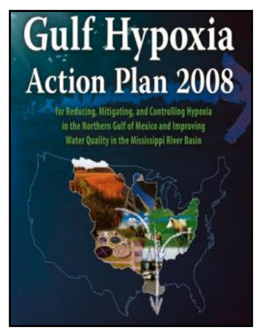
Adaptive Management Framework

2000 CENR state of knowledge report

2001 Hypoxia Action Plan

2004-2008 Science Reassessment





2012-2013 Science Reassessment

2013 Reassessment Report

2008 EPA Science Advisory Board Hypoxia Report

2008 Gulf Hypoxia Action Plan

Workshops to Inform Hypoxia Task Force & other Gulf Management Efforts

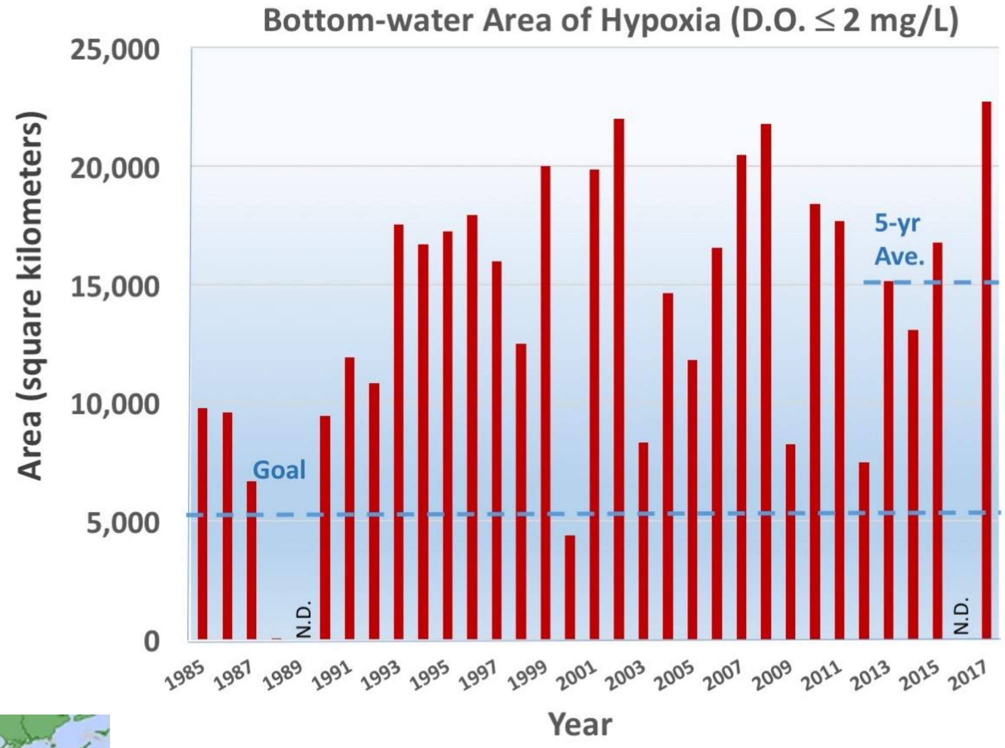
Year	Theme
2006	Gulf Science Symposium – 2007 reassessment of Action Plan
2007	Monitoring
2007	Ecological Impacts
2010*	Fisheries Impacts, Monitoring, Communication
2011*	Monitoring and Modeling
2011	Miss River Diversions
2012*	Living Resource Impacts, Biogeochemical Processing – for Action Plan reassessment
2013*	Glider Applications, Scenario Forecast Modeling
2014*	Miss River Diversions/Hypoxia Interaction
2016*	Monitoring
2018*	Monitoring (CHAMP)
2018	Fisheries Effects

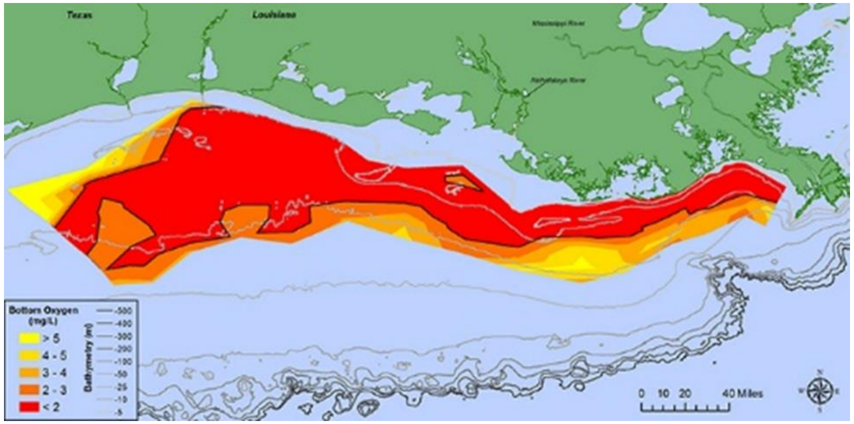
*Annual NOAA/NGI Hypoxia Research Coordination Workshops

Monitoring

Long-term Monitoring of Hypoxic Zone Areal Extent

Coastal Goal: Reduce 5-year running average size of the Gulf hypoxic zone to 5,000 km² by 2035

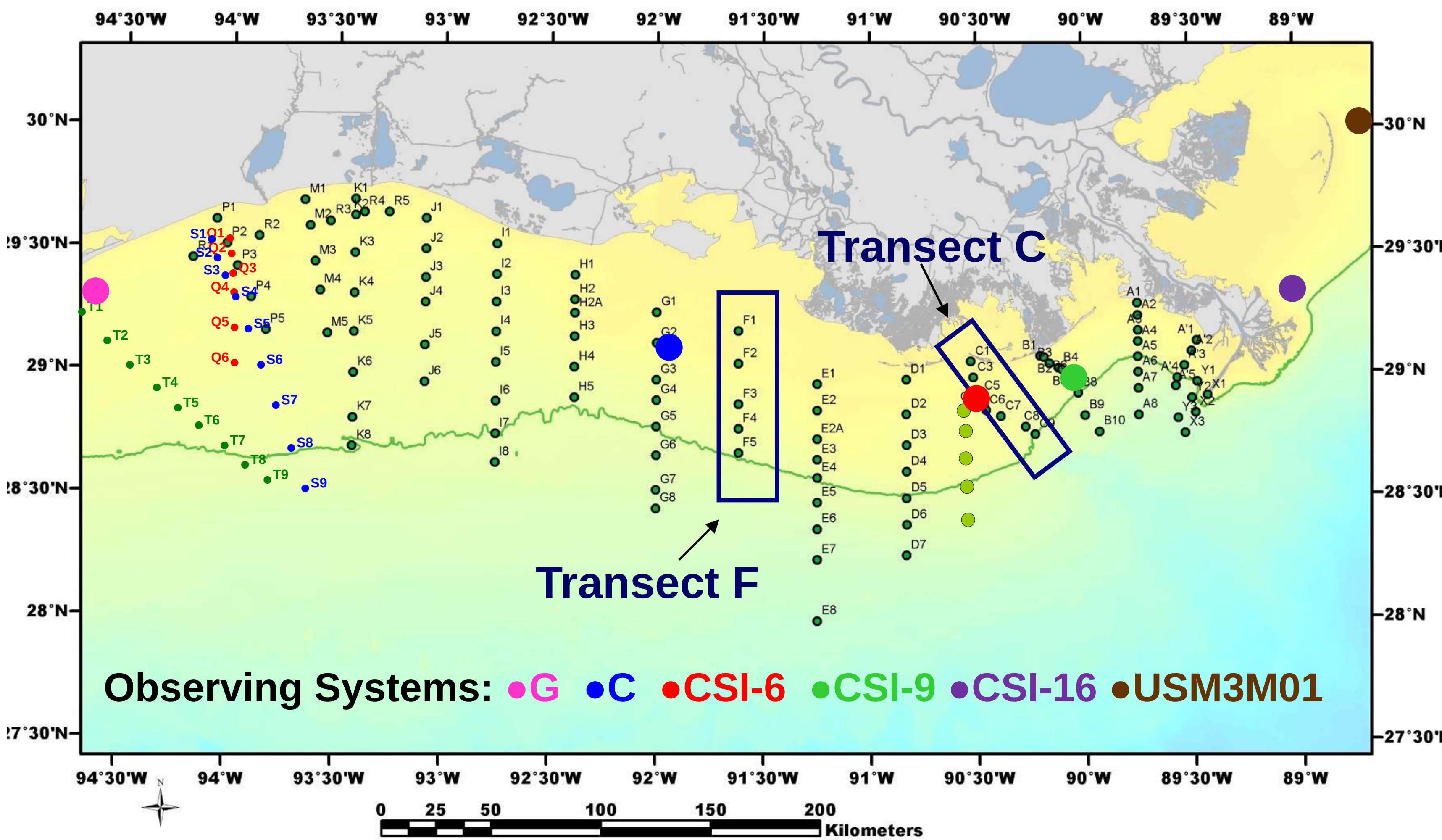




2017 Hypoxic Zone areal extent = 22,720 km^2

From Nancy Rabalais (LSU/LUMCON)

Hypoxic Zone Monitoring Activities in Recent Past



2016 Hypoxic Zone Monitoring Workshop

<u>Goal</u>: Identify and coordinate partner interests for establishing a cooperative sustainable monitoring program for the Gulf hypoxic zone that achieves management-driven objectives.

<u>Core principles</u>:

- **Management Outcomes - monitoring requirements are driven by management needs;**
- **Broad User Community - the monitoring program will extend beyond the hypoxic zone region, and integrate with monitoring programs that target other interrelated issues important to ecosystem conservation and restoration;**
- **Cooperative Support Network – cooperative support from multiple partners with diverse interests is critical to sustainability of a comprehensive and robust monitoring program.**

Management Products Informing Mitigation of Hypoxia

Product 1

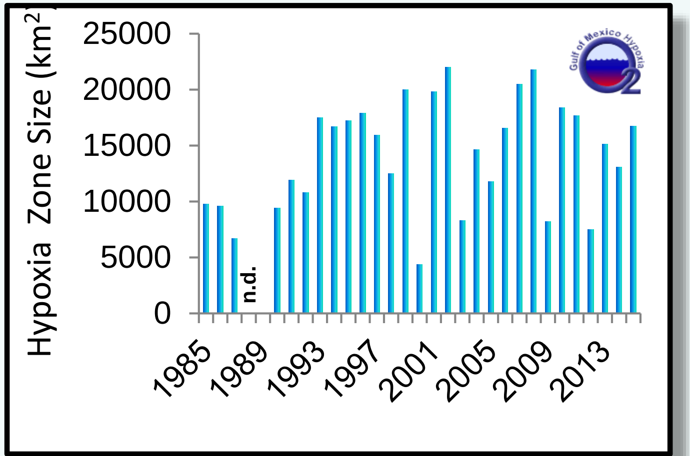
Management Need: Measure progress towards the Coastal Goal of the Hypoxia Task Force Action Plan

-Lumcon

Monitoring Requirement: Mid-summer shelfwide ship survey

Model Integration / Validation

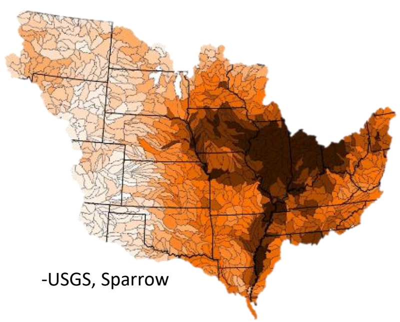
Hypoxic Zone Areal Extent



-adapted from data from Nancy Rabalais (LUMCON) & Eugene Turner (LSU)

Product 2

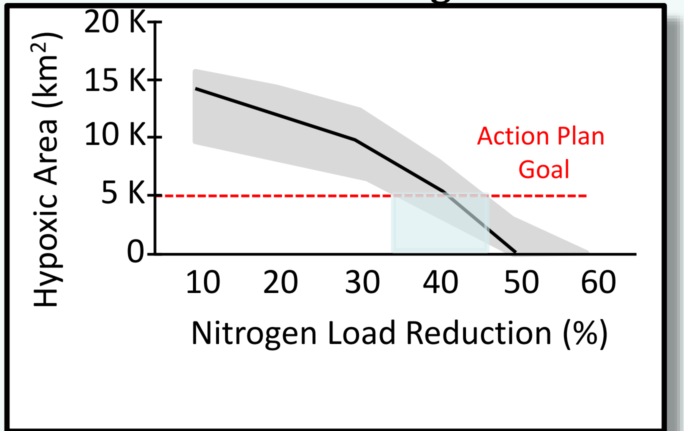
Management Need: Evaluate the overall nutrient reduction required to reduce the hypoxic zone



-USGS, Sparrow

Monitoring Requirement: Riverine nutrient loading and discharge data

Model Guidance on Nutrient Reduction Targets



Adapted from figure by Don Scavia (U Mich)

Monitoring Requirements for Management Products

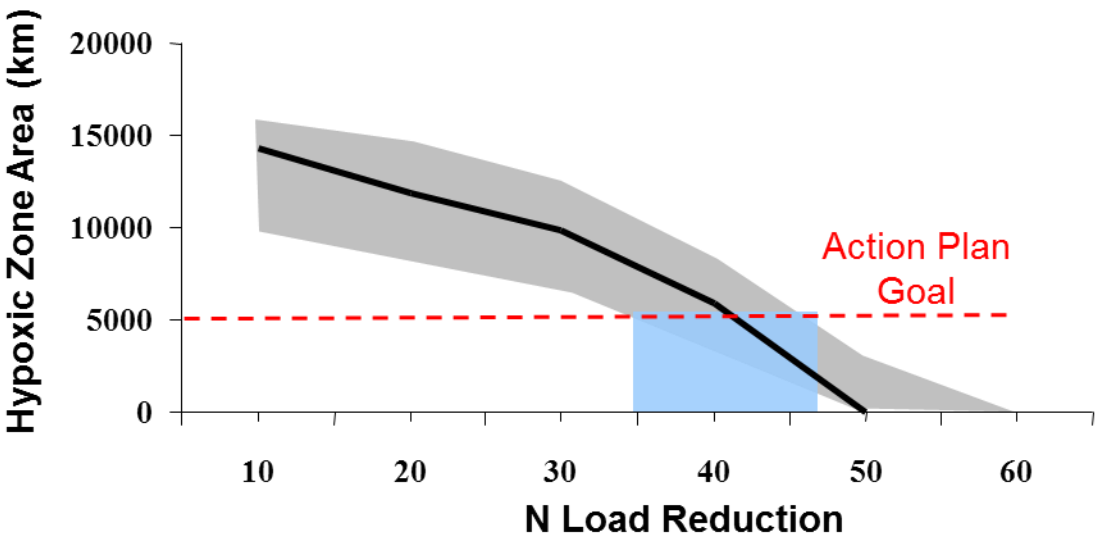
Requirement	Collaborators	Support
Mid-summer shelf-wide ship survey west of Mississippi Delta	LSU/LUMCON	NOAA NCCOS
Nutrient monitoring and annual and spring P and N loading estimates from Miss/Atchafalaya River Basin	USGS	USGS
Daily discharge monitoring	USACE	USACE
Maintain Hypoxia Data Portal	NOAA NCEI IOOS GCOOS	NOAA NCEI IOOS GCOOS

Hypoxia Monitoring Workgroups for the Cooperative Hypoxia Assessment and Monitoring Program (CHAMP)

Workgroup	Lead(s)
Louisiana	Angelina Freeman (LA CPRA), Dubravko Justić (LSU)
Mississippi/Alabama	Steve Ashby (MSU/NGI), Stephan Howden (USM), Brian Dzwonkowski (DISL)
Texas	Steve DiMarco (TAMU)
Autonomous Vehicles	Steve DiMarco (TAMU)
Fisheries	Kevin Craig (NOAA), Chris Brown (NOAA)
Hypoxia Task Force	Katie Flahive (EPA), Danny Wiegand (EPA)
Ocean Acidification	Barb Kirkpatrick (GCOOS), Nancy Rabalais (LSU/LUMCON), Steve DiMarco (TAMU)
Gulf Restoration	Steve Giordano (NOAA), Becky Allee (NOAA)

Scenario Forecast Modeling

See Don Scavia presentation



Nutrient reduction targets in 2001 and 2008 HTF Action Plans informed by scenario forecast models

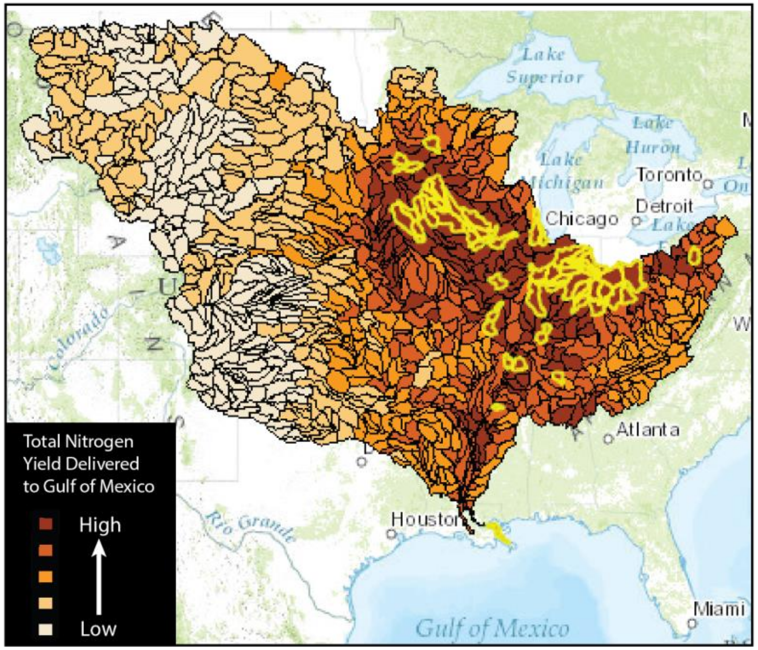
Task Force Goals

- **Coastal Goal: reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 (1,928 mi^2) by 2035;**

- **an Interim Goal of a 20% reduction of N and P loading by 2025 is a milestone for immediate planning and implementation actions…**

Watersheds contributing the highest nitrogen yields to the Gulf

Total Nitrogen Yields Delivered to Gulf of Mexico



USGS SPARROW MAPPER

Scenario Forecast Modeling

See Don Scavia presentation

Model Type	Modelers
Statistical regression	Gene Turner (LSU)
Streeter-Phelps adaptation	Don Scavia (U. Michigan)
Bayesian biophysical	Dan Obenour (NCSU)
Statistical regression	David Forrest (VIMS)

Scenario Forecast Modeling

Model Type	Modelers
Statistical regression	Gene Turner (LSU)
Streeter-Phelps adaptation	Don Scavia (U. Michigan)
Bayesian biophysical	Dan Obenour (NCSU)
Statistical regression	David Forrest (VIMS)
Hydrodynamic/biogeochemical	Katja Fennel (Dalhousie) Rob Hetland (TAMU) Dubravko Justić (LSU)

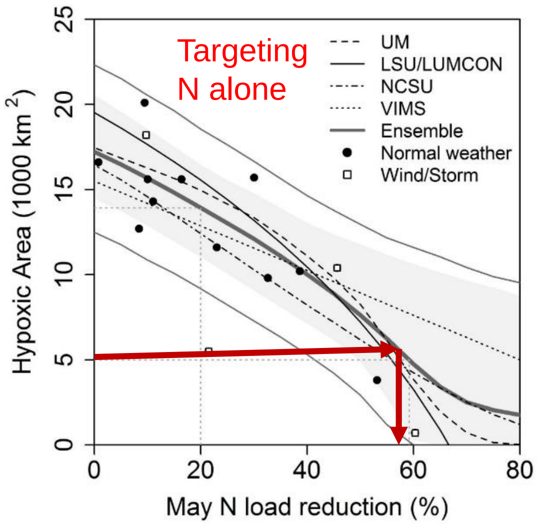
Nutrient Reduction Guidance from Ensemble of Scenario Forecast Models

Question 1: What reductions in N and P loading are needed to shrink the Dead Zone to 5,000 km² (Coastal Goal)?

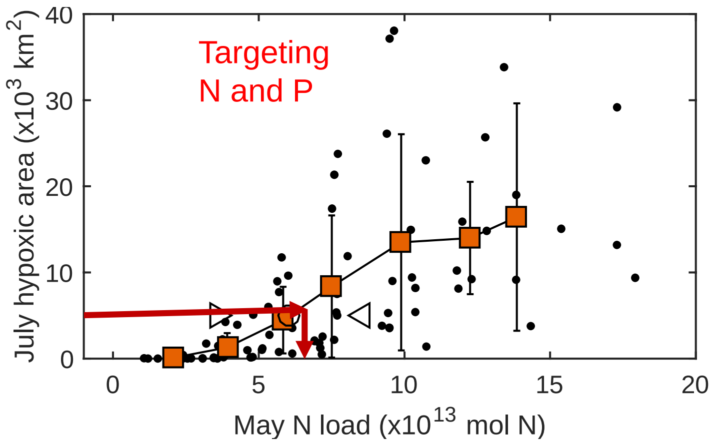
Models confirmed the importance of a <u>dual nutrient reduction strategy</u>:

– Targeting N alone would require a ~60% reduction to reach 5,000 km² goal;

– Targeting both N and P would require a 48% reduction of each nutrient, close to the 45% reduction recommended in 2008 Action Plan.



Scavia et al. 2017 PNAS 114:8823-8828

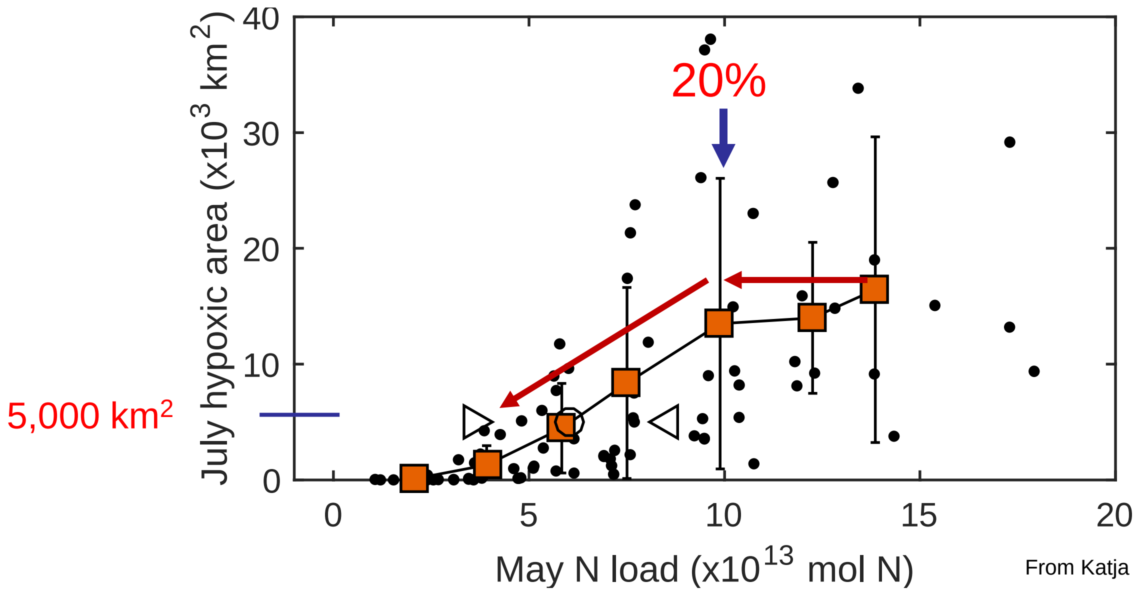


From Katja Fennel and Arnaud Laurent (Dalhousie)

Nutrient Reduction Guidance from Ensemble of Scenario Forecast Models

Question 2: How much will 20% reductions in N and P loading shrink the zone (Interim Goal)?

- **3D Model simulations showed that the sensitivity of changes in hypoxia to nutrient load reductions is variable – reaching the 20% interim nutrient reduction goal will not reduce hypoxia significantly, but will bring us closer to the point where the amount of hypoxia reduction per unit nutrient reduction increases - i.e. moving beyond 20% reduction will have an impact on the size of the hypoxic zone**



From Katja Fennel and Arnaud Laurent (Dalhousie)

3D Time Variable Models

Applications:

- **HTF guidance on nutrient reduction goals**
- **Hypoxic zone annual characterization presented to HTF**
- **Effect of Miss River Diversions on nutrient loading/hypoxia**
- **Ecological impacts**
- **Future projections of climate effects**

Model Simulations of 2017 Hypoxic Zone Dynamics

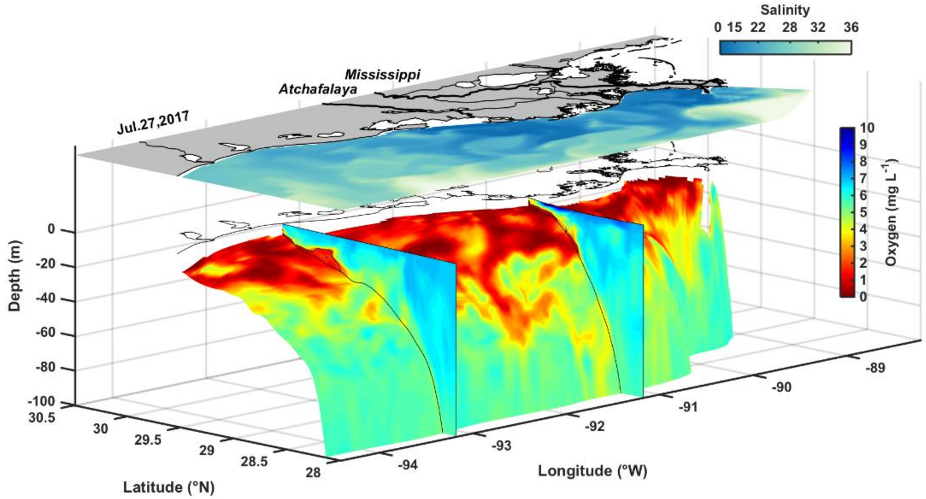
NOAA supported modelers:
- Katja Fennel (Dalhousie U)
- Dubravko Justić (LSU)
- Robert Hetland (Texas A&M)

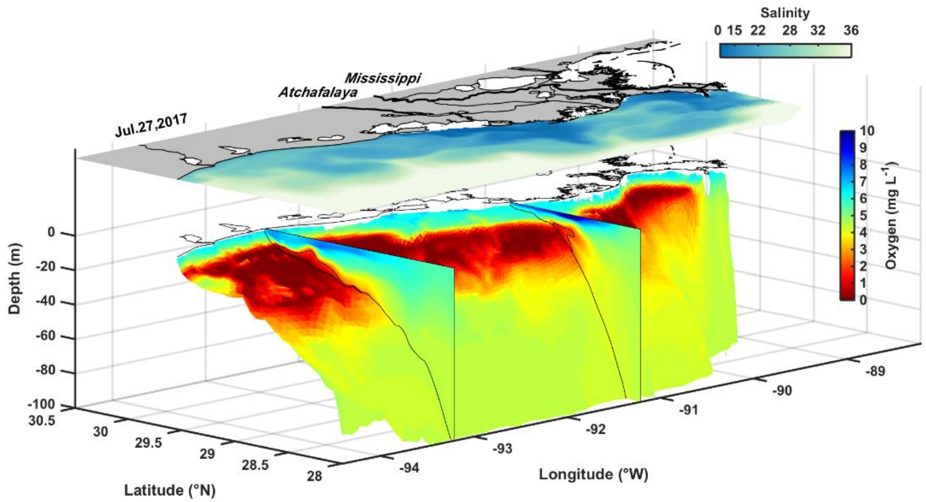
Biogeochemical model coupled to:

1. **ROMS Hydrodynamic Model**

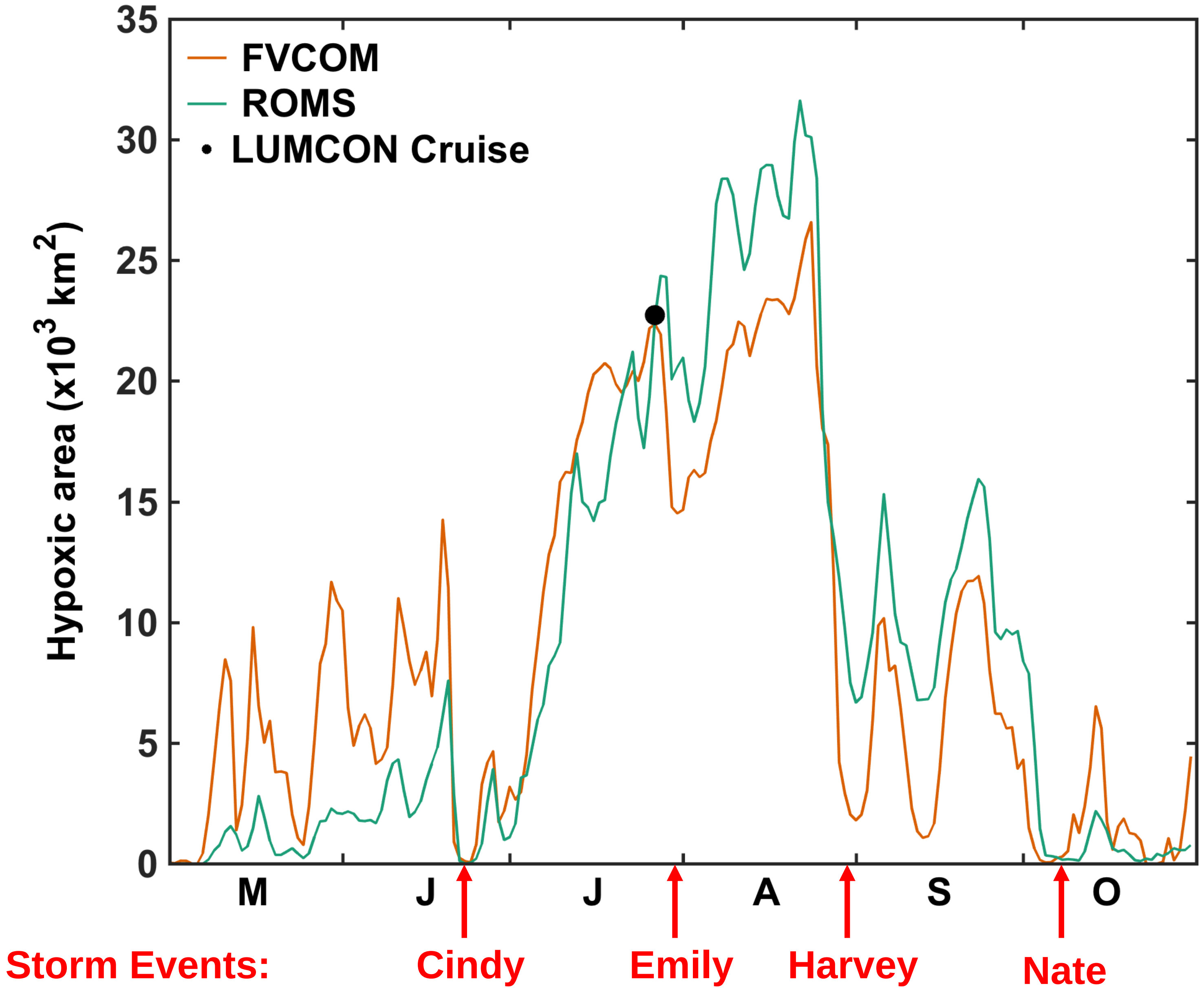
2. **FVCOM Hydrodynamic Model**

Simulated 3D view at midpoint of July 2017 ship survey





Model Simulations of 2017 Hypoxic Zone Dynamics



-- June 20, 2017 –

NOAA, USGS and partners predict third largest Gulf of Mexico summer 'dead zone' ever

Federal scientists forecast that this summer's Gulf of Mexico dead zone – an area of low to no oxygen that can kill fish and other marine life – will be approximately 8,185 square miles [21,199 square kilometers], or about the size of New Jersey.

-- August 2, 2017 –

Gulf of Mexico 'dead zone' is the largest ever measured

Scientists have determined this year's Gulf of Mexico "dead zone," is 8,776 square miles [22,720 square kilometers], an area about the size of New Jersey. It is the largest measured since dead zone mapping began there in 1985.

Press Releases of Forecast and Measured Size

Page Title	Pageviews	Avg. Time on Page	Bounce Rate
Homepage	6,052,199	0:03:50	11.63%
East Coast storm born from 'bombogenesis'. It's less scary than it sounds.	39,112	0:01:50	67.12%
2017 was 3rd warmest year on record for U.S.	18,289	0:02:25	72.97%
NOAA: 2017 was 3rd warmest year on record for the globe	18,137	0:02:29	70.75%
Snow squall warnings to begin this winter	14,383	0:02:01	78.23%
NOAA kicks off 2018 with massive supercomputer upgrade	13,754	0:02:29	86.47%
U.S. Winter Outlook: NOAA forecasters predict cooler, wetter North and warmer, drier South	10,589	0:02:32	81.25%
How do snowflakes form? Get the science behind snow	7,654	0:06:19	84.51%
Globe had 3rd warmest year to date and 5th warmest November on record	5,196	0:01:49	64.71%
Extremely active 2017 Atlantic hurricane season finally ends	5,145	0:04:32	79.70%
New storm surge watches and warnings saved lives	5,078	0:01:22	73.85%
NOAA's GOES-16, now at GOES-East, ready to improve forecasts even more	4,356	0:01:14	75.23%
Gulf of Mexico 'dead zone' is the largest ever measured	3,578	0:06:43	78.12%
Q&A: Winter weather forecasts, from our national centers to your neighborhood	2,740	0:01:25	73.37%
Photo story: Rescued seals make it home for the holidays	2,205	0:01:48	80.14%
6 tools our meteorologists use to forecast the weather	2,192	0:07:47	73.87%
Scientists: Strong evidence that human-caused climate change intensified 2015 heat waves	1,939	0:05:19	91.41%
Whale science on the high seas	1,485	0:02:03	65.22%
Deepwater Horizon oil spill settlements: Where the money went	1,484	0:10:38	75.92%
What is a harmful algal bloom?	1,270	0:06:52	81.13%

Summary

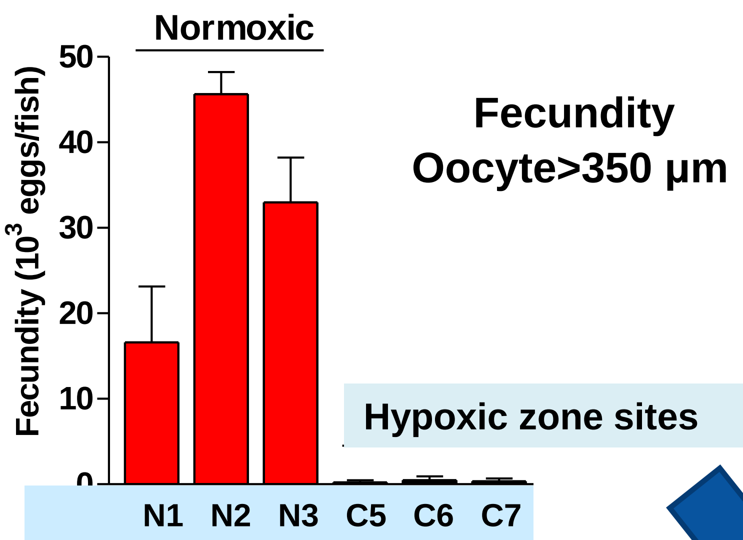
- **Providing management guidance built on years of research that developed a series of linked statistical, two-dimensional and three-dimensional models and supportive field efforts that:**
  - **couple the Mississippi River watershed with the northern Gulf of Mexico,**
  - **explain diverse synergistic influences on the physical and biological factors in the northern Gulf that control the development of hypoxia, and**
  - **provide improved forecasting tools to inform hypoxia mitigation strategies.**

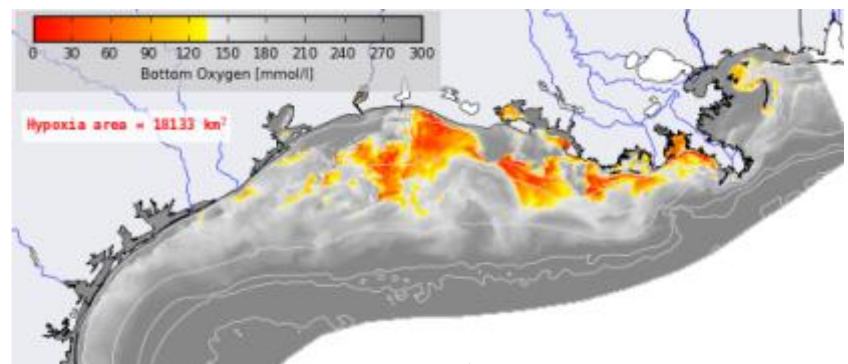
- **Recent emphasis on transitioning of monitoring requirements and modeling tools to operations**

- **Strong network of researchers, managers, and stakeholders, and extensive outreach at multiple levels**

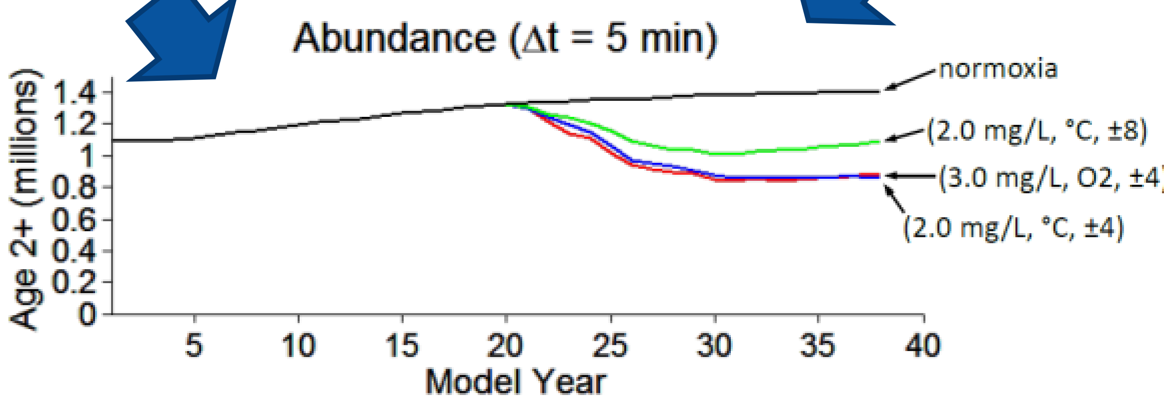
Ecological Impacts – Kevin Craig Talk

Coupling between hydr/biogeoch models and ecological models is needed to capture environmental forcings of hypoxia and its effects;





Atlantic Croaker Population Trend Scenarios



The End

- **Next up –**

Don Scavia (University of Michigan). ***Hypoxia modeling, relationship with nutrient loading, water quality targets, and transition planning (Chesapeake Bay, Lake Erie, Gulf of Mexico)***

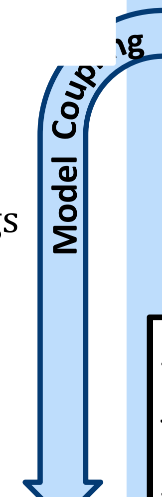
Monitoring Requirements are driven by Management Products

Product 3

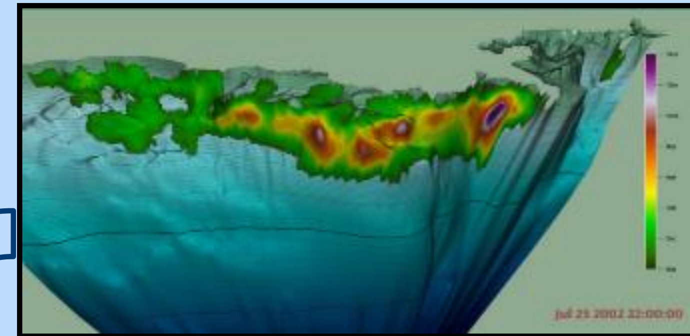
Management Need: Provide comprehensive space/time characterization of hypoxic zone and controlling factors

- NOAA)

Monitoring Requirement: Cruises, Gliders, Moorings



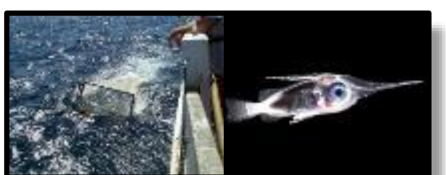
3-D Time Variable Hypoxic Zone Characterization



-Dubravko Justic

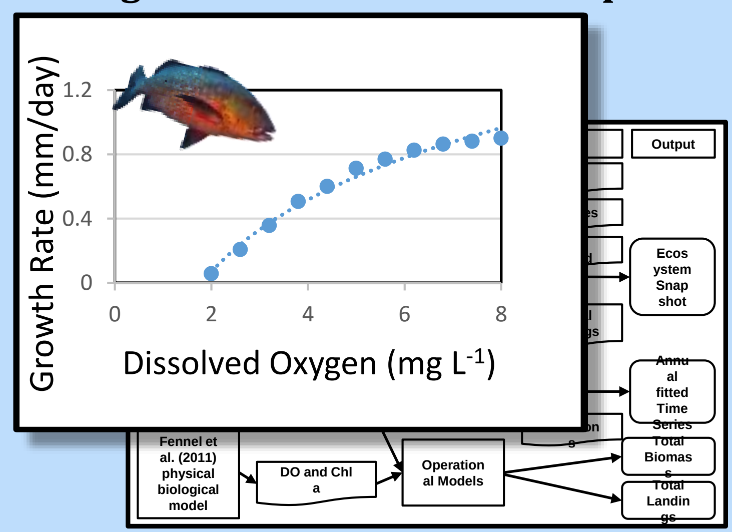
Product 4

Management Need: Determine impacts of hypoxia on Gulf of Mexico living resources, habitats, fisheries, economies



- NOAA)

Living Resource and Habitat Impacts

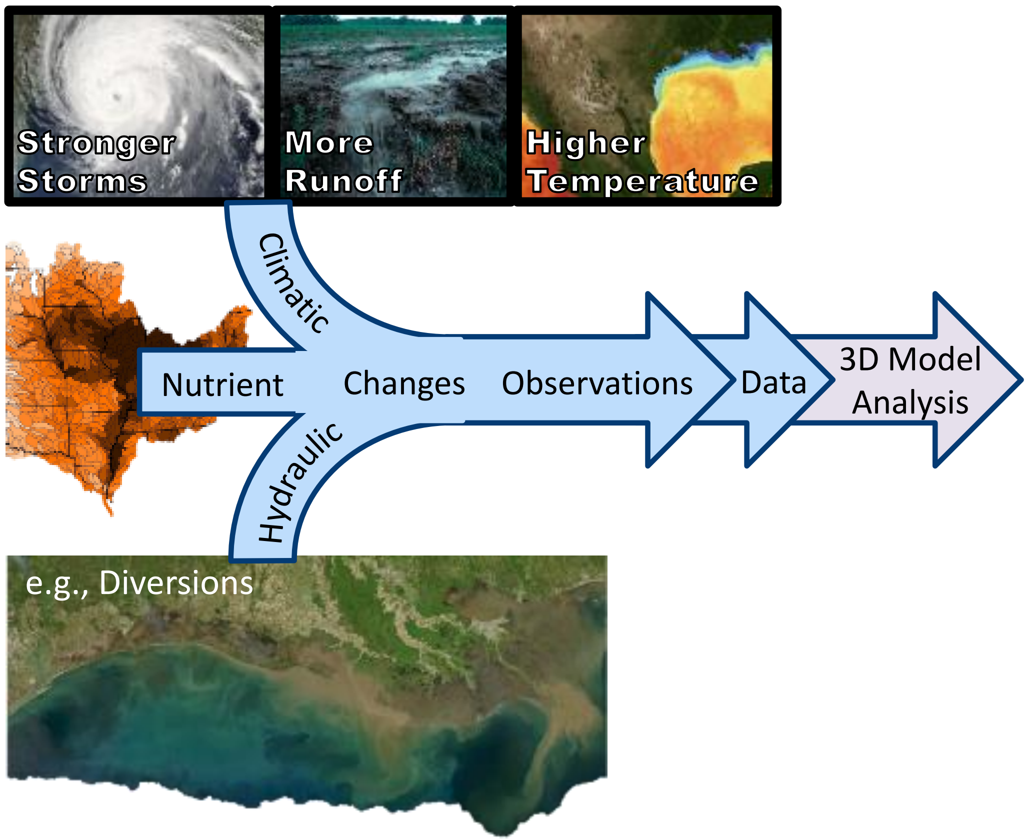


- Kim De. Mutsert et al. (Ecopath/Ecosim)

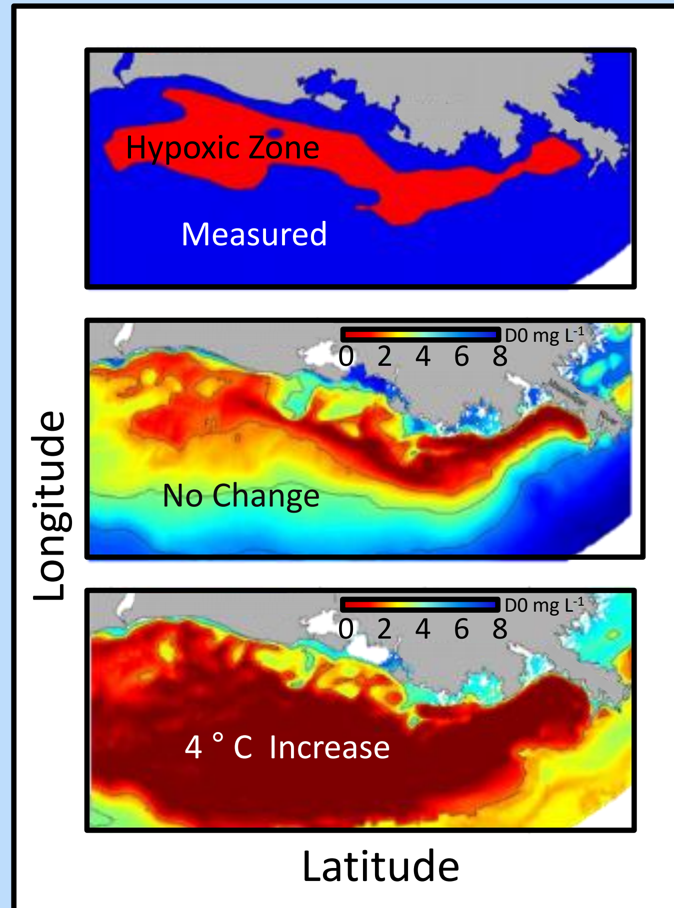
Monitoring Requirements are driven by Management Products

Product 5

Management Need: Evaluate strategic management questions related to nutrient reductions including timing, input location, nutrient type, and impacts of climate change



Scenario Forecasts that include interactive ecosystem stressors



- Dubravko Justic

Progression of Forecast Models

Year	Modeler	Predicted Areal Extent (km^2)	Observed Areal Extent (km^2)
2007	Turner	22,127	20,480
2008	Turner & Scavia	22,404	21,764
2009	Turner & Scavia	19,325 - 21,935	8,240*
2010	Turner & Scavia	16,861 - 20,233	18,400
2011	Turner & Scavia	22,049 - 24,438	17,680
2012	Turner & Scavia Turner (sediment legacy effect)	3,371 16,117	7,480
2013	Turner & Scavia	18,900 - 22,207	15,120

*Persistent westerly winds for weeks before cruise “piled up” hypoxic water along SE LA shelf

Progression of Forecast Models

Year	Modeler	Predicted Areal Extent (km^2)	Observed Areal Extent (km^2)
2014	Turner & Scavia & Forrest	12,018 - 14,807	13,080
2015	Turner & Scavia & Forrest & Obenour	14,201	16,760
2016	Turner & Scavia & Forrest & Obenour	15,276	*
2017	Turner & Scavia & Forrest & Obenour	21,199	22,720

***2016: model simulations of mid-summer areal extent were 13,900 km^2 (ROMS) and 21,100 km^2 (FVCOM)**

Project

CHRP: Observations and Modeling of Narragansett Bay Hypoxia and Its Response to Nutrient Management

Observed and modeled responses of Narragansett Bay to managed nutrient load reductions under an engaged stakeholder process

Candace Oviatt and Daniel Codiga
Graduate School of Oceanography
University of Rhode Island

February 26, 2018
NCCOS Science Review
Silver Spring, MD

Project Investigators

- Candace Oviatt, GSO
- Daniel Codiga, GSO
- James Kremer, UCONN
- Jaime Vaudrey, UCONN
- Mark Brush, VIMS
- Scott Nixon, GSO
- Chris Kincaid, GSO
- David Ullman, GSO
- Warren Prell, Brown University
- David Murray, Brown University

Project Goals

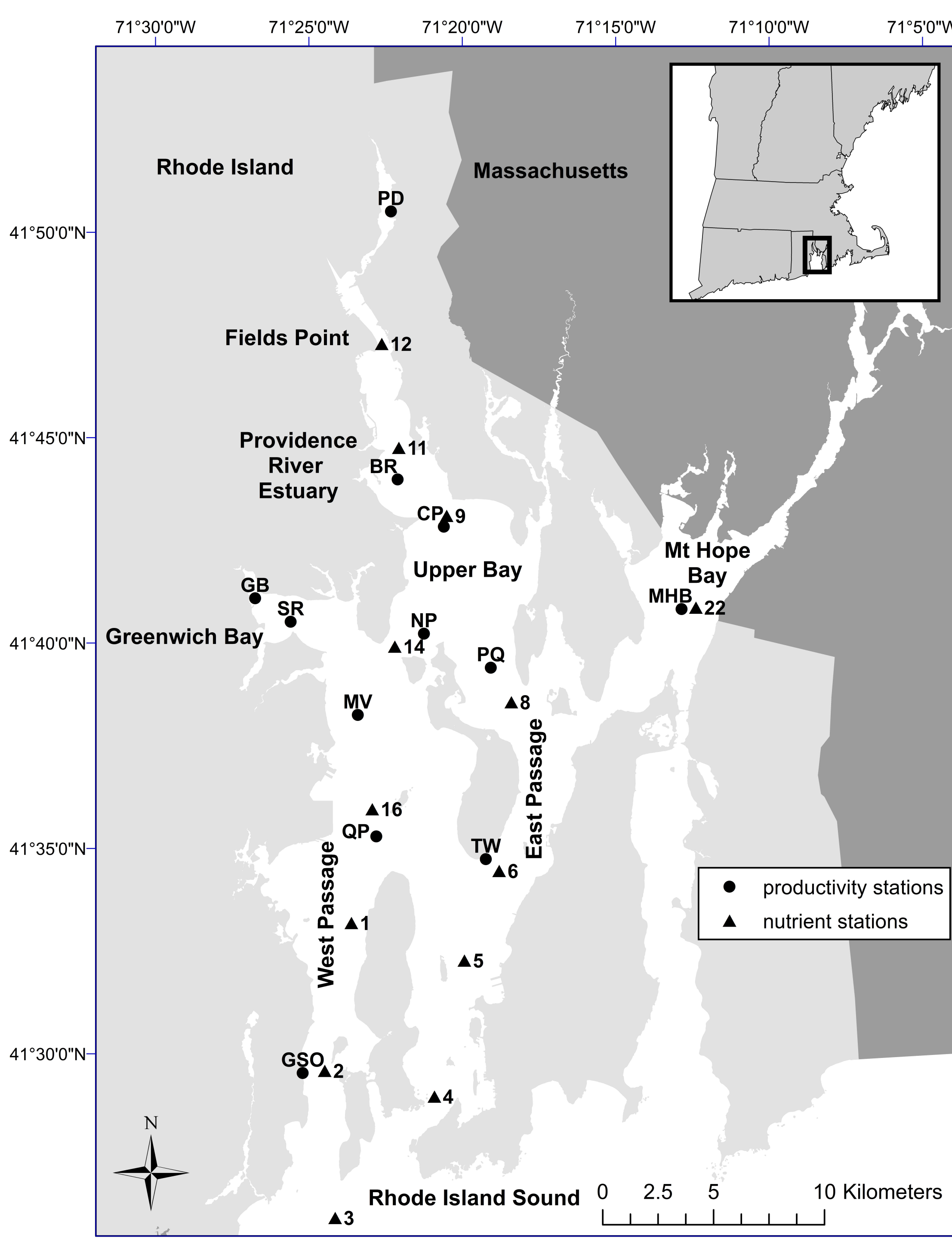
- Advance understanding of nutrient loading and circulation processes that dictate Narragansett Bay hypoxia, and assess their relative importance;

- Implement multiple modeling approaches to develop tools for (i) evaluating the response of hypoxia to alternative management scenarios and climate change, and (ii) enhanced predictive capabilities.

- Engage all stakeholder and make all information and tools available to them on a regular basis.

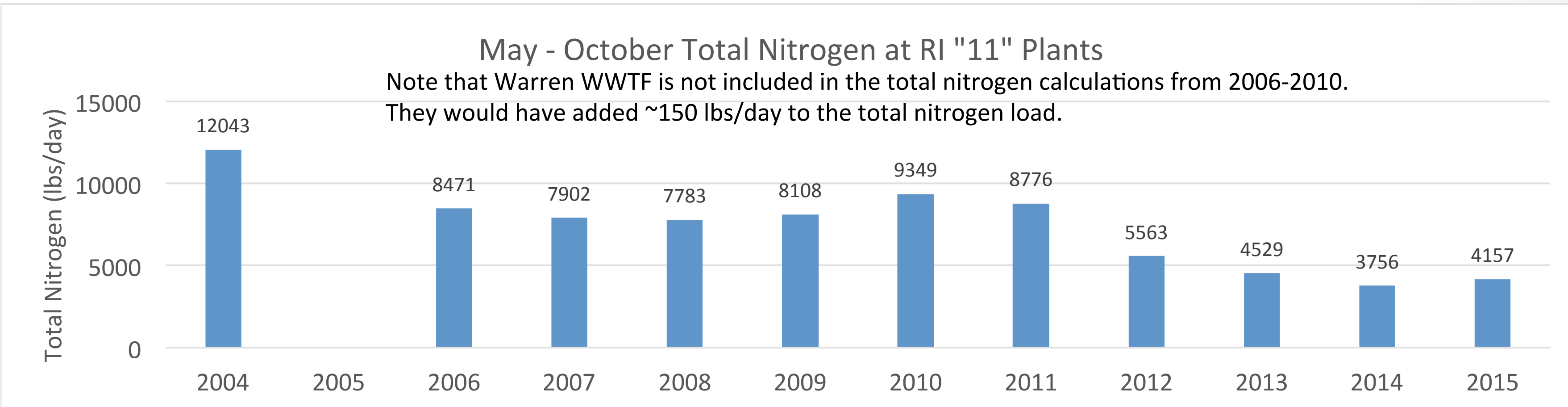
Observational Program

- Document the nutrient reduction by measuring standing stock concentrations of nutrients in the surface waters of Narragansett Bay;
- Document ecosystem productivity and hypoxia changes to nutrient reduction;
- Measure physical parameters such as currents and vertical mixing to improve the ROMS circulation model for Narragansett Bay.

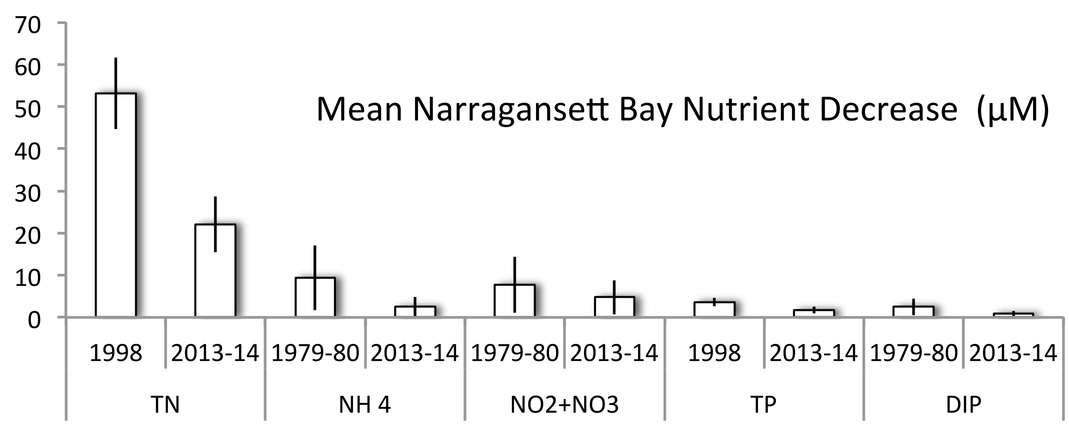

71°30'0"W
71°25'0"W
71°20'0"W
71°15'0"W
71°10'0"W
71°5'0"W
41°50'0"N
41°45'0"N
41°40'0"N
41°35'0"N
41°30'0"N
Rhode Island
Massachusetts
PD
Fields Point
12
Providence
River
Estuary
11
BR
CP
9
Upper Bay
Mt Hope
Bay
MHB
22
GB
SR
Greenwich Bay
NP
14
PQ
8
MV
East Passage
16
QP
TW
6
West Passage
1
5
GSO
2
4
N
Rhode Island Sound
3
0
2.5
5
10 Kilometers
productivity stations
nutrient stations

Results Observations

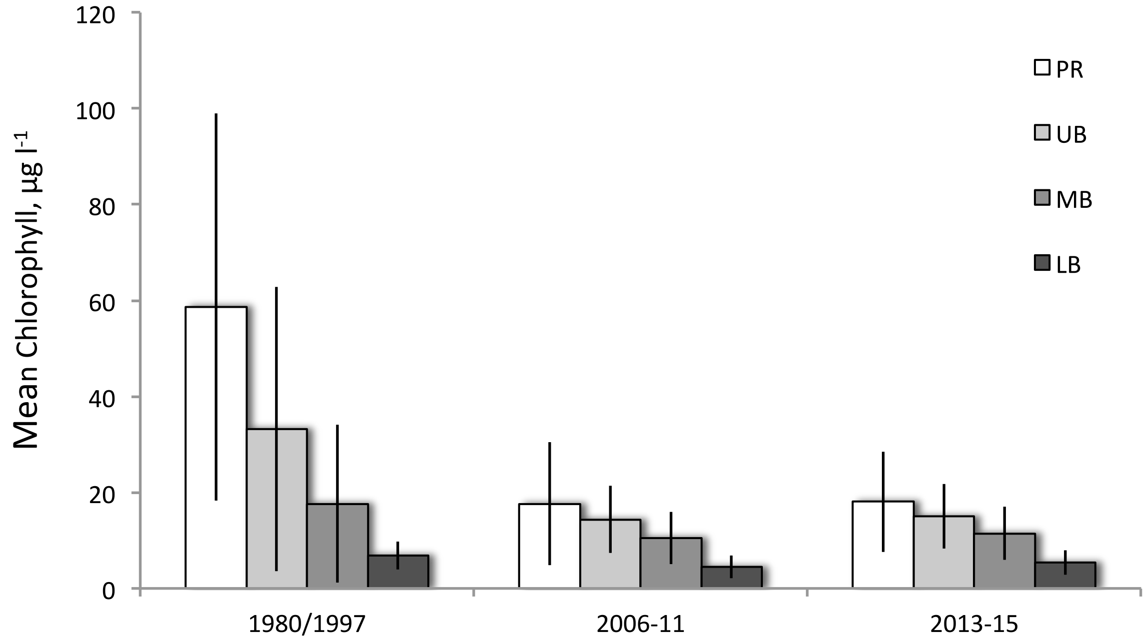
A.

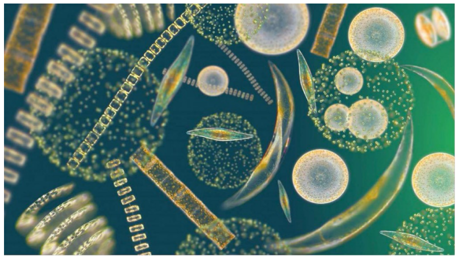


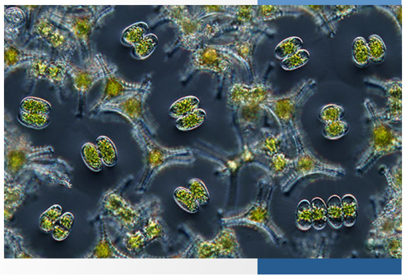
B.



Decrease in Summer Chlorophyll







Primary production patterns in the Bay change with nitrogen reduction.

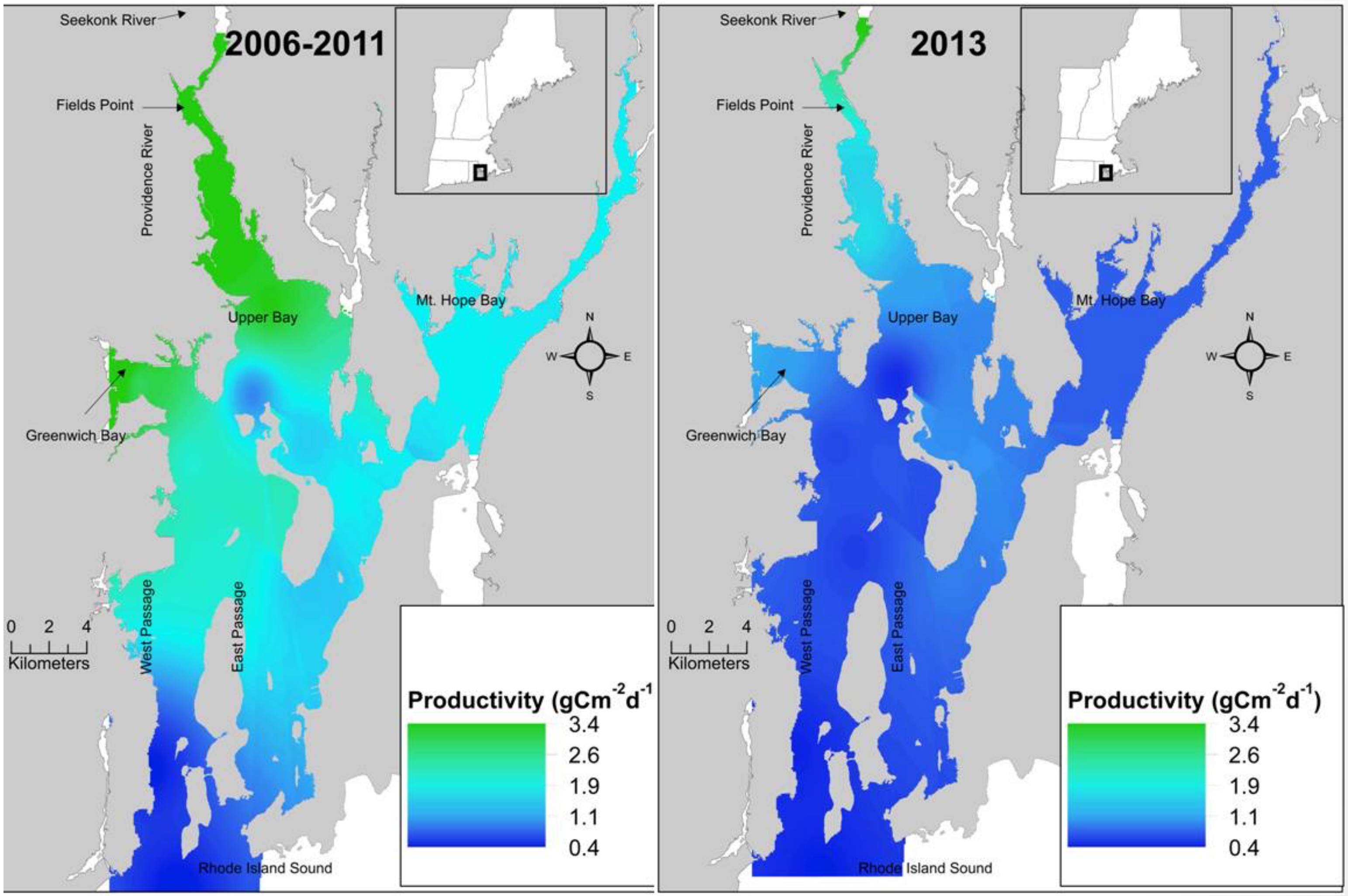
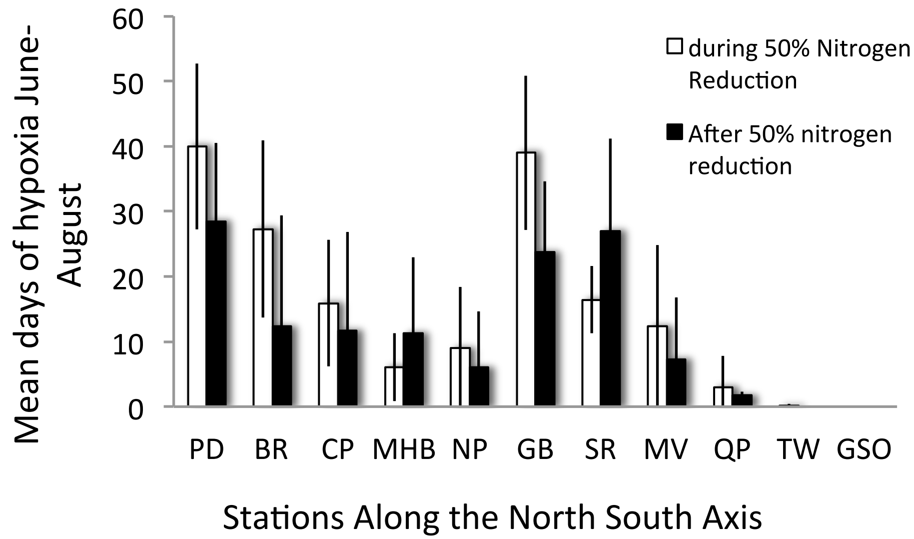
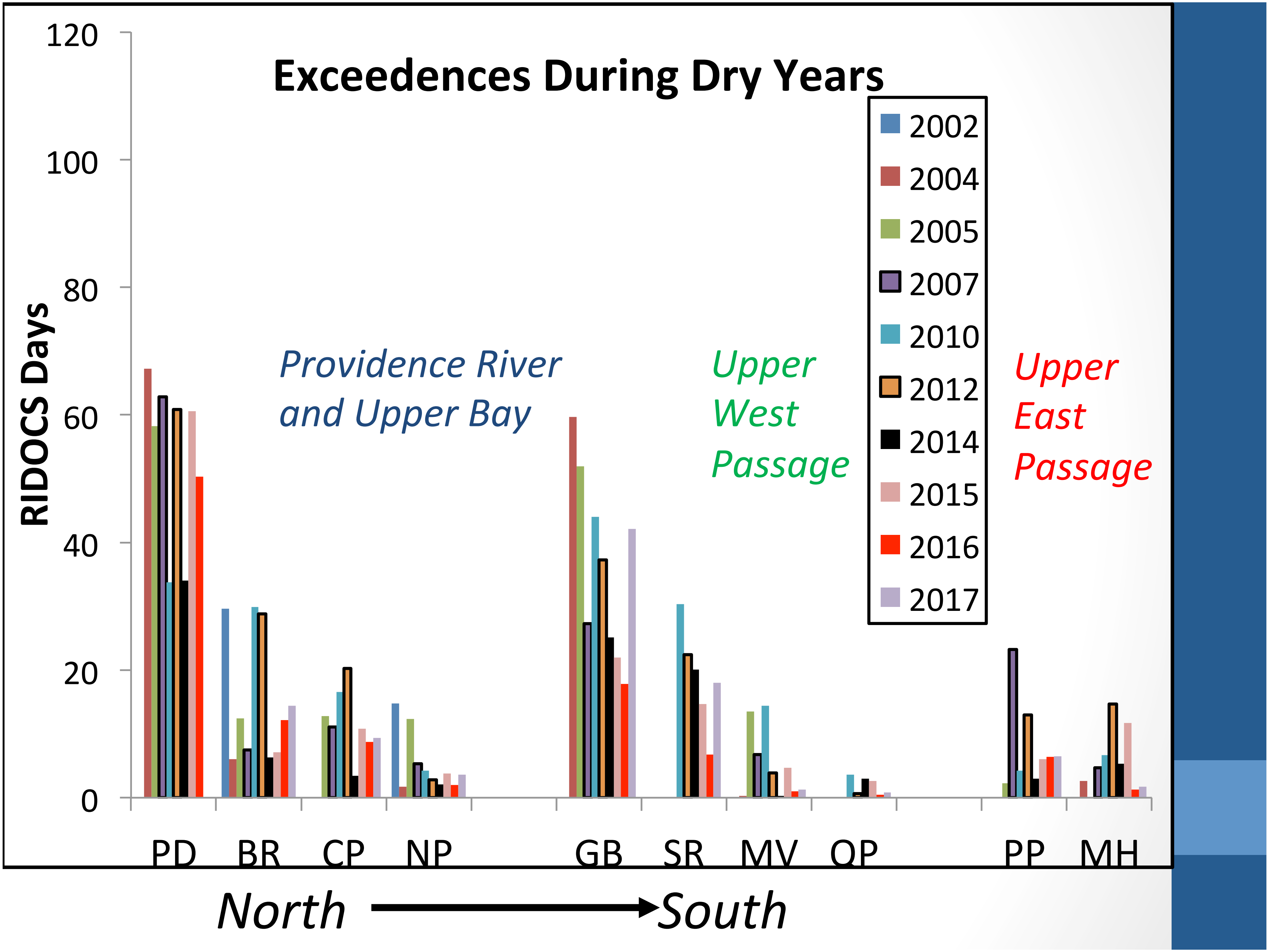


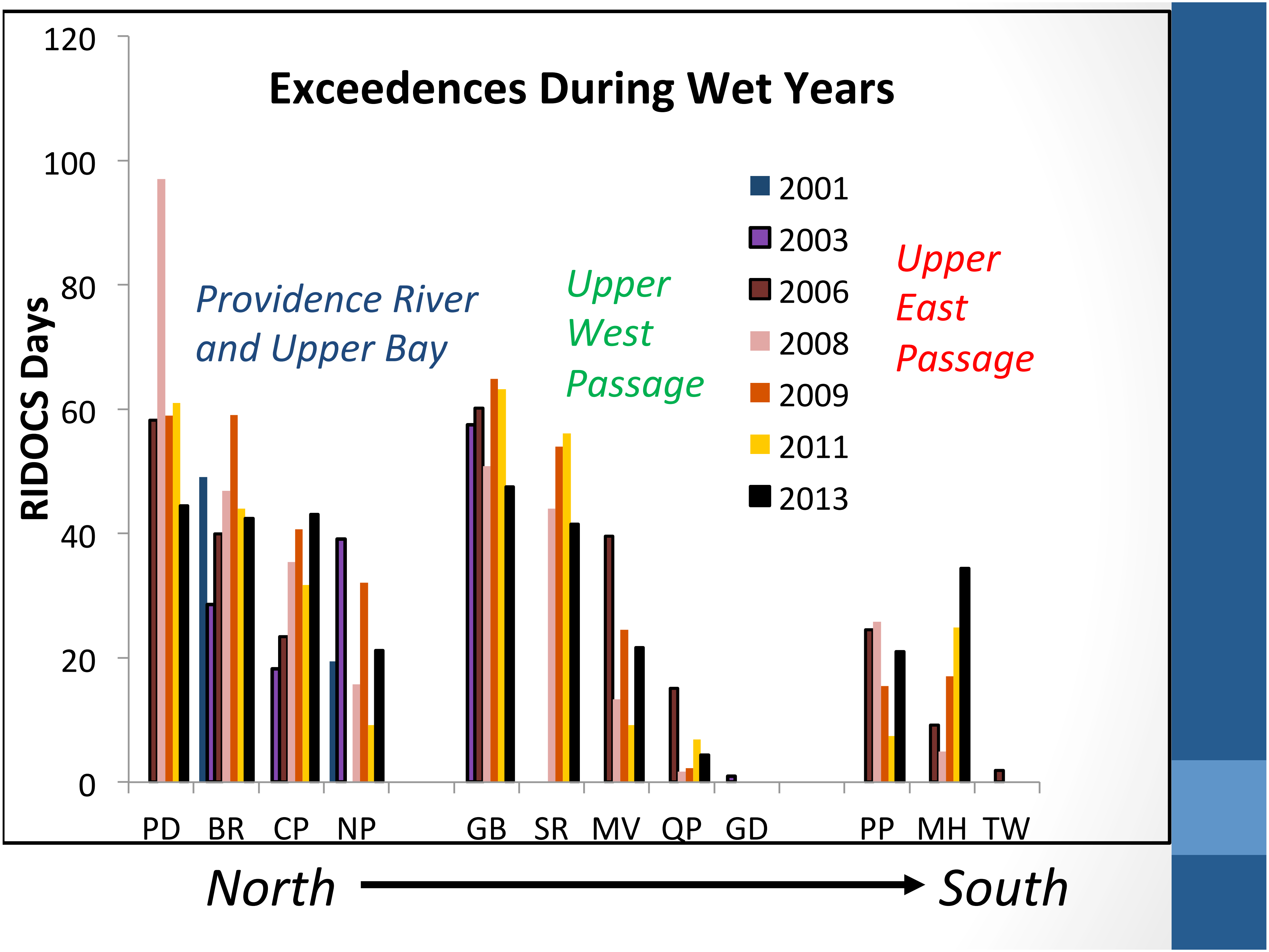
Figure from Jason Krumholz.

Continued periods of low oxygen in the Bay

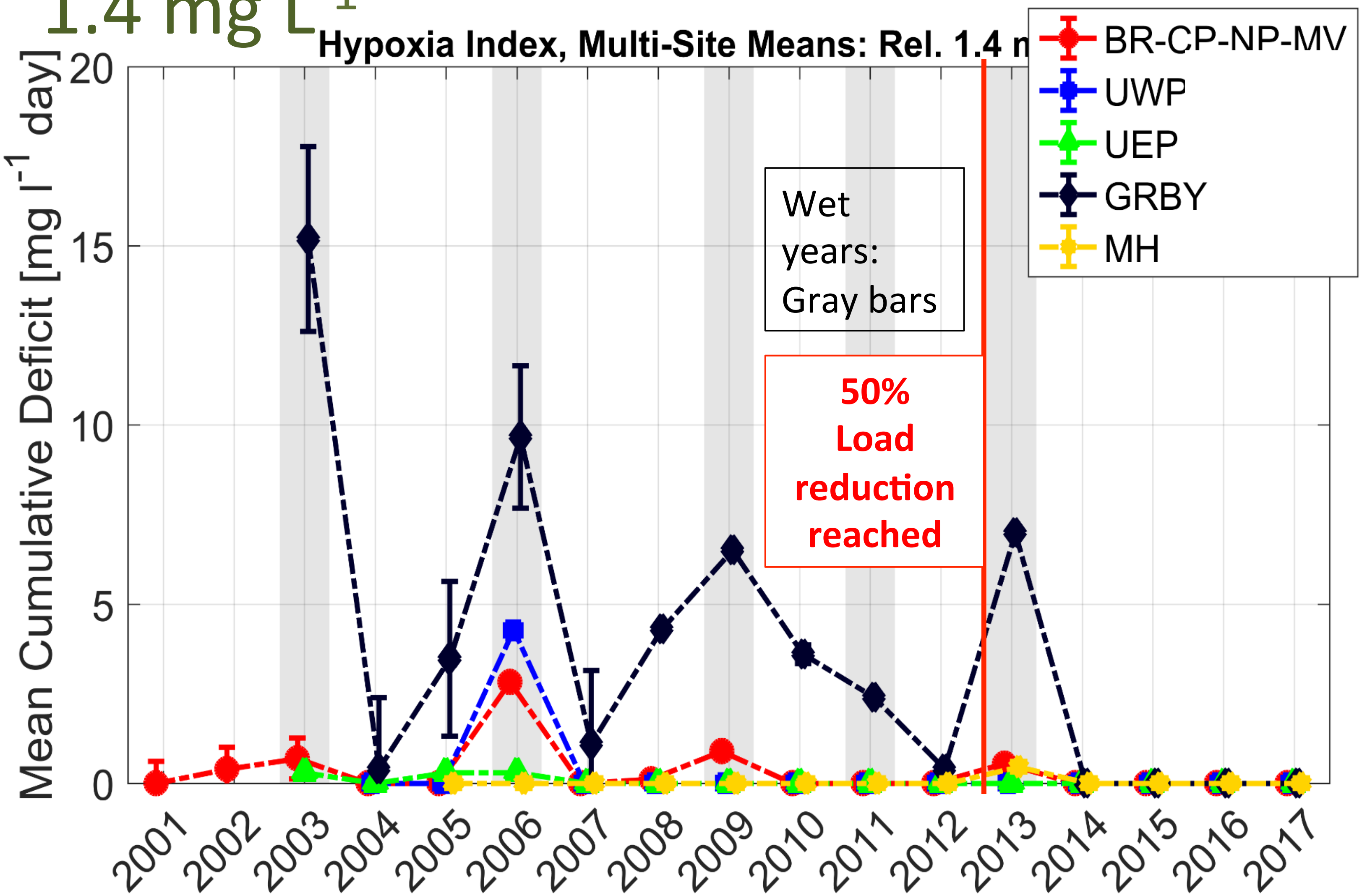




Exceedences During Dry Years
RIDOCS Days
120
100
80
60
40
20
0
Providence River and Upper Bay
Upper West Passage
Upper East Passage
2002
2004
2005
2007
2010
2012
2014
2015
2016
2017
PD
BR
CP
NP
GB
SR
MV
QP
PP
MH
North
South


Exceedences During Wet Years
RIDOCS Days
120
100
80
60
40
20
0
Providence River
and Upper Bay
Upper
West
Passage
Upper
East
Passage
2001
2003
2006
2008
2009
2011
2013
PD
BR
CP
NP
GB
SR
MV
QP
GD
PP
MH
TW
North
South

1.4 mg L^{-1}



Most severe hypoxia mostly limited to Greenwich Bay

Modeling Program

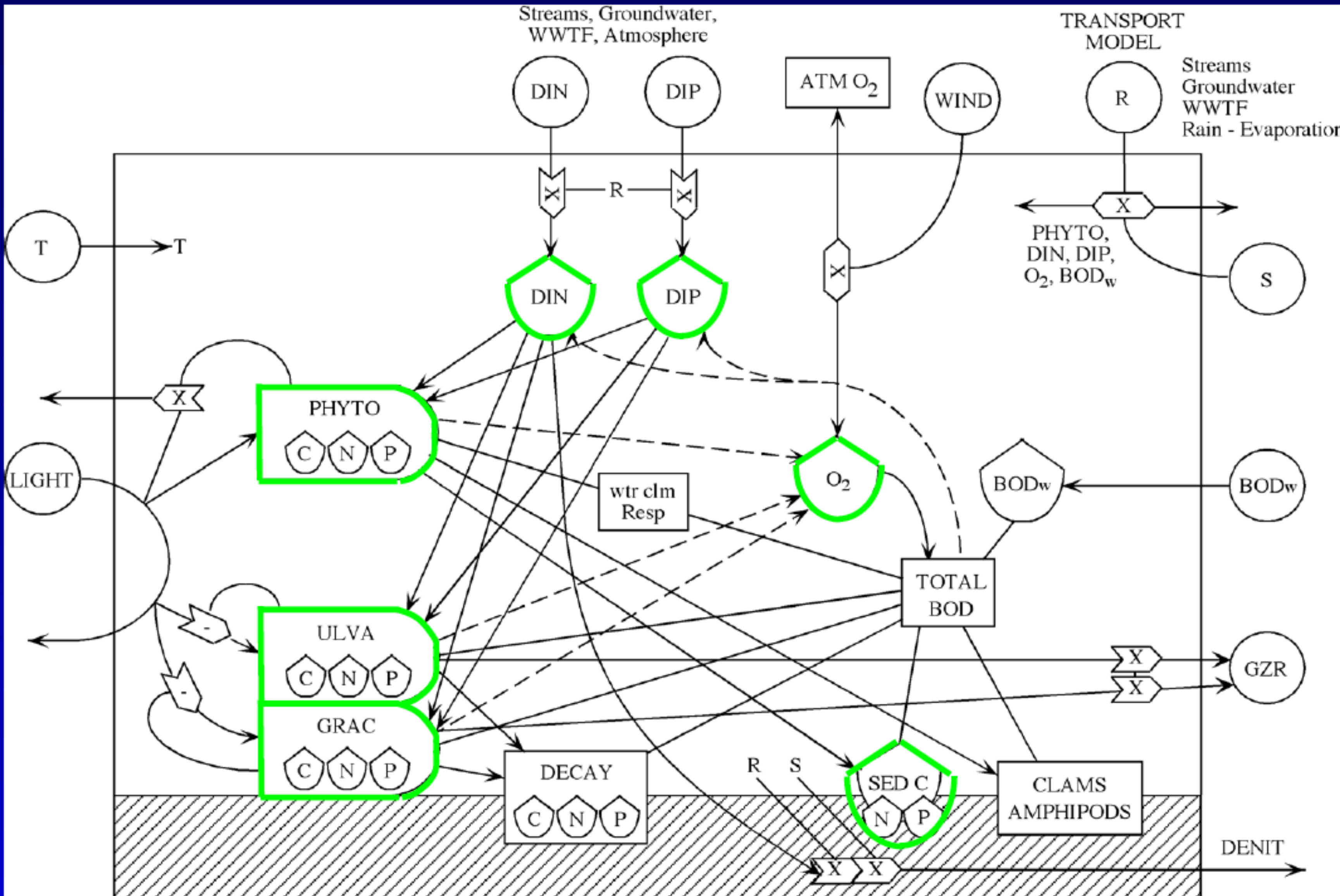
- Empirical modeling
- Refine material exchange methods in two ecological models using 1) the ROMS circulation model and 2) a box model for circulation;
- Validate the General Ecosystem Model and the Ecosystem Box Models;
- Model Management and climate scenarios and develop user-friendly version of the model for use by managers.

Empirical modeling

- Using time series D.O. obs. (Codiga et al. 2009)
- Multiple linear regressions with observed biological/physical parameters
  - Temp, riverflow, spring/neap, stratification
- Conclusion: Spring/neap weakly important
- Conclusion: River flow (stratification) is strongest driver of inter-annual variability

Simulation Modeling: Two Approaches

Estuarine Eutrophication Model



MODEL RESULTS

Panel A – EcoGEM results ***Panel B – RIDOCS results***

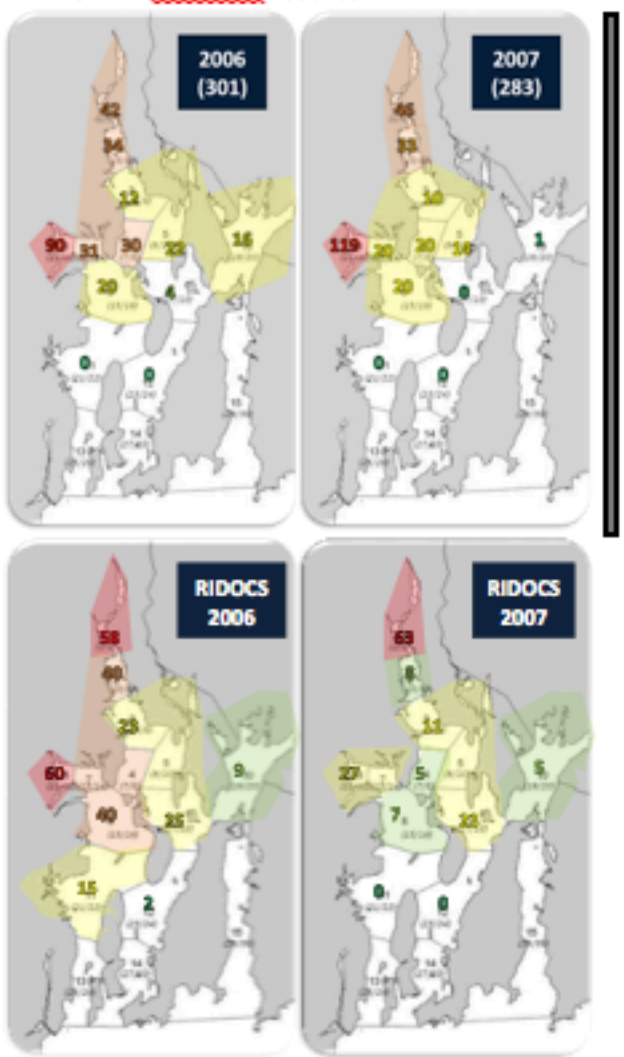
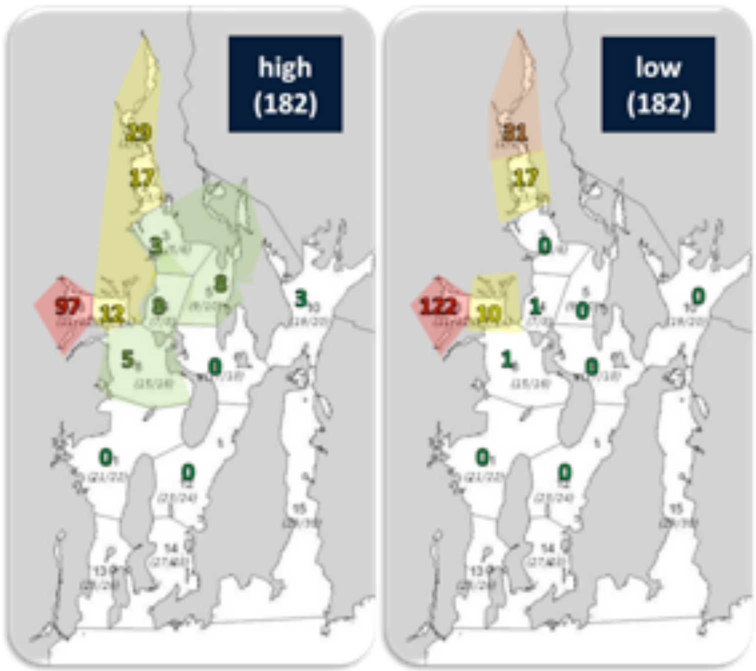
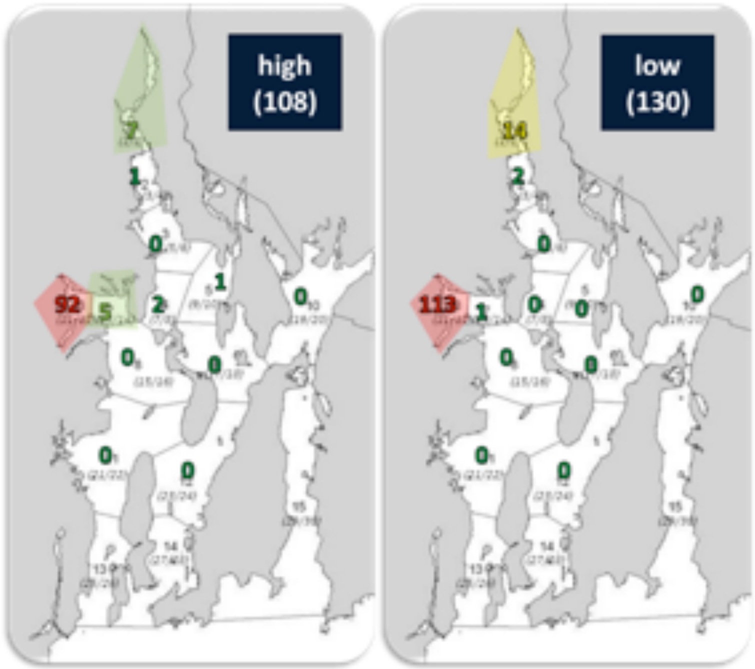


Figure V8: (Panel A) Number of days predicted by the EcoGEM model where the bottom water oxygen predicted minimum value is less than 2.9 mg/L. Model was run using the 2006 and 2007 nutrient inputs. (Panel B) RIDOCS values for 2006 and 2007. The RIDOCS results is a more complex formula involving multiple criteria beyond the < 2.9 mg/L. Both figures use the same color scheme: 0-3 dark green; 4-9 light green; 10-29 yellow; 30-49 orange; >50 red.



50%
reduction
from
WWTF,
relative to
1995

Figure V9: Projected number of days where instantaneous dissolved oxygen in bottom water is less than 2.9 mg/L. This scenario is the predicted results of target nitrogen reductions goals from WWTFs of 50% relative to 1995, achieved in 2013. The two panels provide a high and low estimates of number of days below 2.9 mg/L.



75% reduction from WWTF, relative to 1995

Figure V10: Projected number of days where instantaneous dissolved oxygen in bottom water is less than 2.9 mg/L. This scenario is the predicted results of target nitrogen reductions goals from WWTFs of 75% relative to 1995. The two panels provide a high and low estimates of number of days below 2.9 mg/L. This is an additional 25% reduction over what was achieved in 2013. While modeled as reductions to WWTF nitrogen inputs, these reductions could also be achieved in combination with non-point source reductions.

Comparison of Output from EcoGEM and EcoOBM

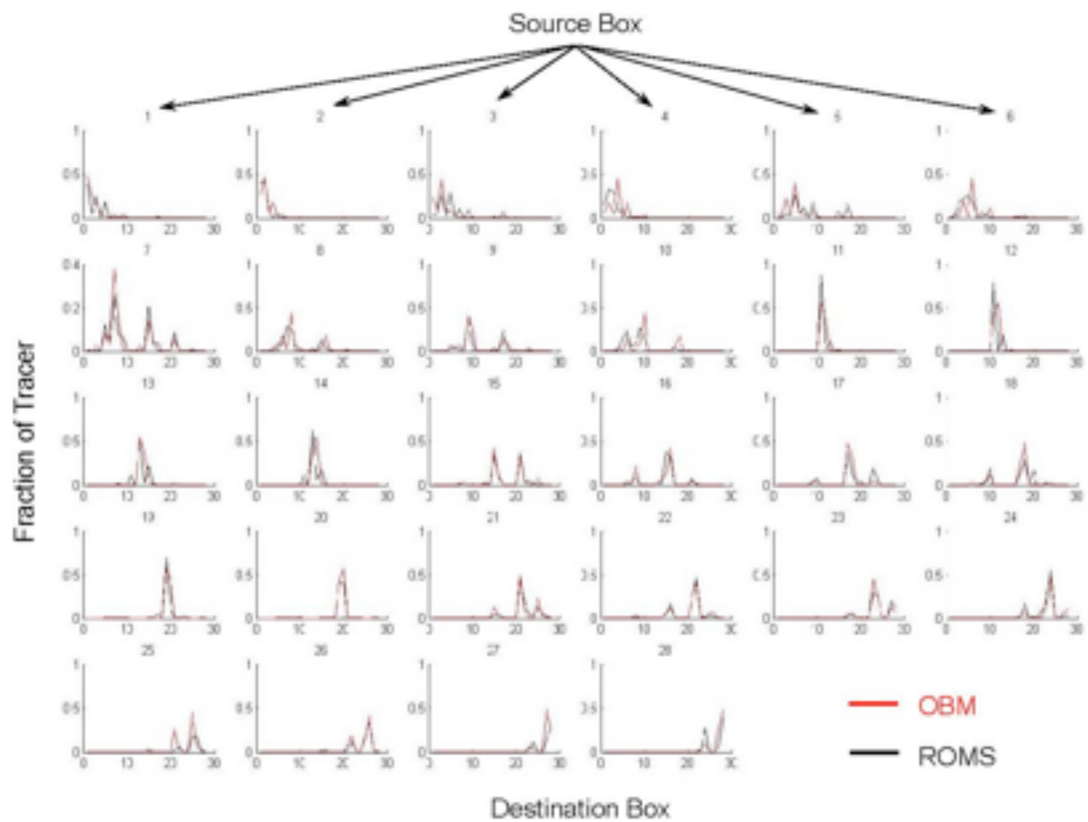


Fig. 1. Example tracer distributions by model element after a 24 hour simulation in EcoGEM, using exchanges from ROMS (black) and the OBM (red), provided by J. Vaudrey. Plots show the fraction of tracer starting in a given element ('Source Box', numbers across the top), present in each model box after 24 hours ('Destination Box', x-axis). Box numbering is that used in EcoGEM.

EcoOBM Verification

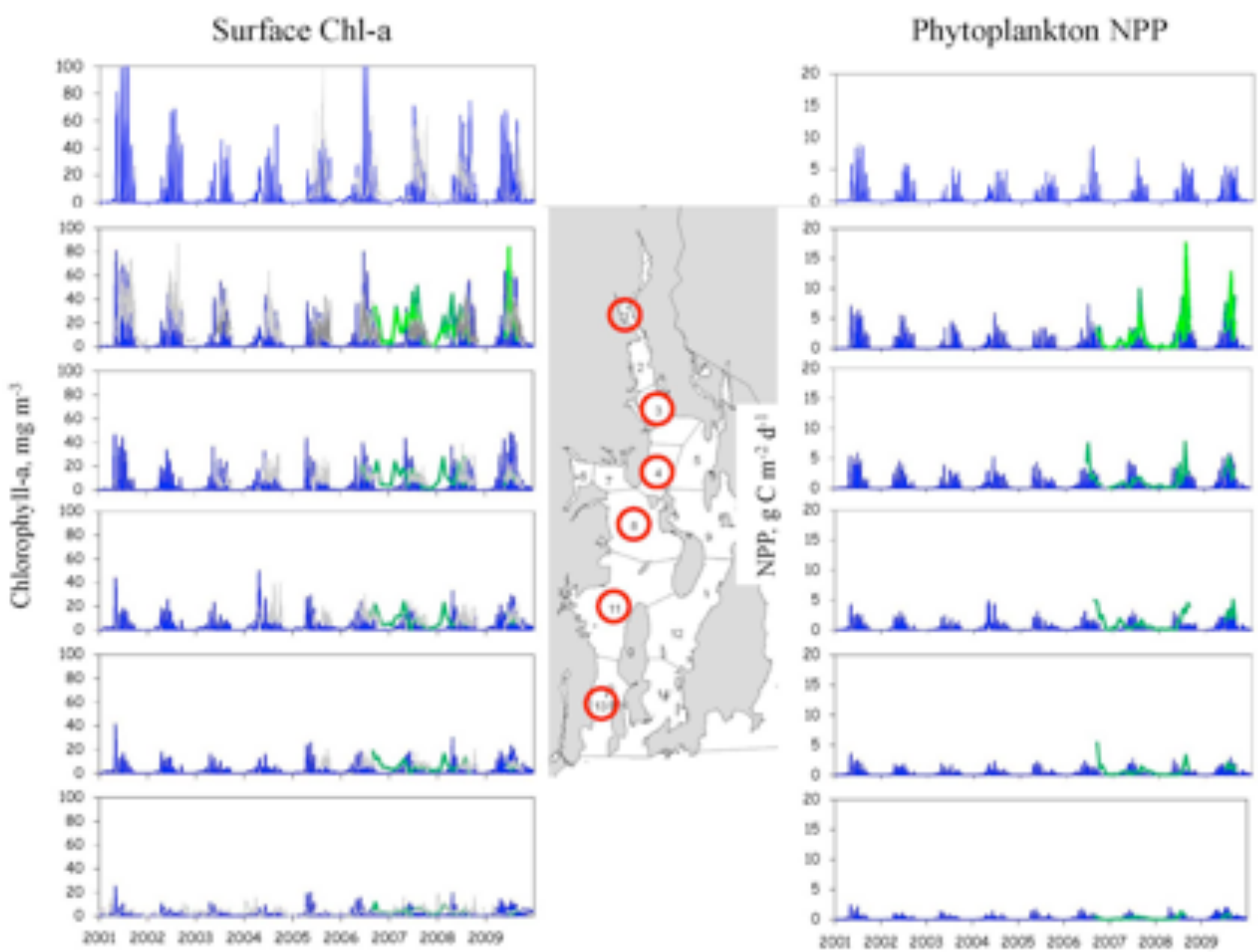


Fig. 2. Example EcoOBM output for surface chl-a and phytoplankton NPP for the 2001-09 period along a transect down the Providence River and West Passage. Model output is in blue, data from Smith & Oviatt are in green (two stations in Box 3), and NBFSMN (buoy) data are in grey, with the exception of Box 13 which is the long-term time series maintained by MERL at the GSO pier.

EcoOBM: Predicted decrease in low oxygen events with different levels of nutrient reduction.

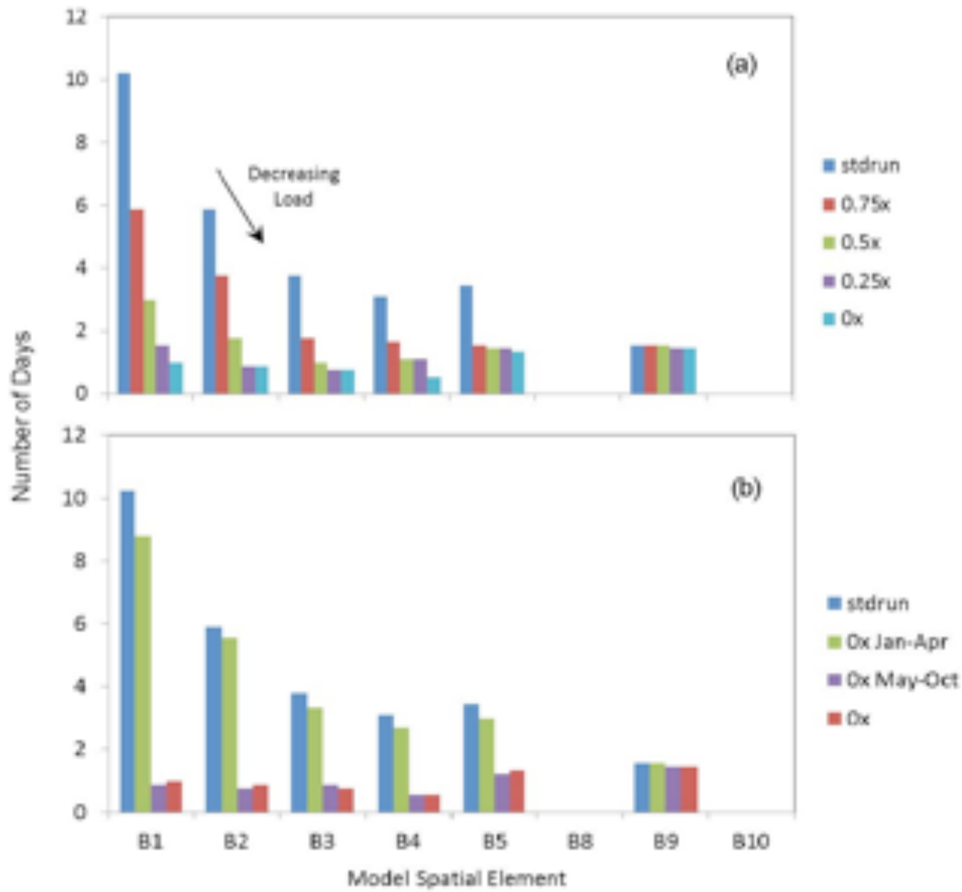


Fig. 5. EcoOBM scenario analysis results with changes in nutrient loading from rivers and WWTFs. Graphs show the predicted number of days with $O_2 < 4.8$ mg l^{-1} in the bottom layer of boxes in the upper bay. (a) Effect of decreasing loads year-round from current values (stdrun) to 0, 0.25, 0.5, and 0.75 times current values. (b) Effect of removing riverine and WWTF loads in January through April vs. May through October, compared to removing loads year-round (0x) and current conditions (stdrun).

Stakeholder Program

- Conduct targeted meetings with Environmental Mangers;
- Conduct an annual workshop to announce findings of the project and engage advice from the stakeholder community.

Hypoxia Workshop October 2, 2006
Graduate School of Oceanography, URI

Organization	Visitor's Name	Email
AE	Hittingerr, Rich	Rhittinger@AllianceEnvironmentalGroup.com
ASA	Swanson, Craig	cswanson@appsci.com
Brown	Murray, David	dmurray@brown.edu
Brown	Prell, Warren	warren_prell@brown.edu
Brown	Pryor, Don	Donald_pryor@brown.edu
CT DEP	O'Brien-Clayton	kate.obrien-clayton@po.state.
CT DEP	Layman, Matthew	Kristin@nbnerr.org
EPA	Adler, Rob	adler.robert@epa.gov
EPA	Cote, Mel	cote.mel@epa.gov
EPA	Latimer, Jim	latimer.jim@epa.gov
EPA-LISO	Tedesco, Mark	Tedesco.Mark@epa.gov
GSO	Aleszczyk, Michelle	michelle@gso.uri.edu
GSO/URI	Codiga, Dan	D.Codiga@gso.uri.edu
GSO	Fulweiler, Wally	wally@gso.uri.edu
GSO	LaSota, Nicole	Nicola@gso.uri.edu
GSO	Nixon, Scott	swn@gso.uri.edu
GSO	Pfeiffer-Herbert, Anna	annaph@gso.uri.edu
GSO	Reguintina, Edwin	edwinr@gso.uri.edu
GSO	Rogers, Justin	jmrogers@gso.uri.edu
GSO	Smith, Leslie	leslie.smith@gso.uri.edu
GSO	Stoffel, Heather	stoffelh@hotmail.com
GSO	Ullman, Dave	d.ullman@gso.uri.edu
MCZN	Callaghan, Todd	Todd.Callaghan@state.ma.us
MWRA	Taylor, David	dtaylor@mwra.state.ma.us
NBEP	Deacutis, Chris	deacutis@gso.uri.edu
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NBC	Kelly, Jim	jkelly@narrabay.com
NBC	Walker, Catherine	Catherine.walker@narrabay.com
NBNERR	Comeau, Christine	chris@nbnerr.org
NBNERR	Raposa, Kenny	Kenny@nbnerr.org
NBNERR	Stankelis, Bob	Bob.Stankelis@dem.ri.gov
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RIDEM	Scott, Elizabeth	Elizabeth.scott@dem.ri.gov
RIDEM	Travers, Heidi	heidi.travers@dem.ri.gov
RIDEM	Zalewsky, Brian	brian.zalewsky@dem.ri.gov
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RI Sea Grant	Pierce, Barry Costa	bcp@gso.uri.edu
Save the Bay	Ekberb, Marci Cole	mcole@savebay.org
STB	Pastore, Dick	rplngri@cox.net
UCONN	Kremer, Jim	jkremer@uconn.edu
UCONN	Vaudrey, Jamie	jamie.vaudrey@uconn.edu
USEPA	Pryor, Margherita	pryor.margherita@epa.gov

Summary

Data observations indicate the 50% managed nutrient reduction was achieved and resulted in a 30% reduction in primary production. A trend of a 30% reduction in hypoxia is not yet statistically significant.

Two models have been developed to predict the summer low oxygen events in Narragansett Bay. One uses the detailed circulation dynamics of the ROMs model to predict oxygen during a wet and a dry year with different nutrient levels. The other uses a coarse box model to predict circulation and can easily run annual oxygen predictions with different nutrient levels. Both models have been inter-compared, data verified and exhibit acceptable skill levels. Both models indicate that some hypoxia will continue at a 50% reduction in nutrients and that a 75% reduction will be necessary to further decrease hypoxia.

R I DEM managers have access to both models but for the time being prefer observations to models. Thus we have the contract from RI DEM to maintain the DEM portion of the monitoring network and manage data from the monitoring network of fixed sites and buoys to assess water quality oxygen levels.

DEM continues to evaluate the impacts of the 50% nutrient reduction and faces criticism From fishing industry interests for making the Bay “too clean”.

.

Evaluation Criteria for the Narragansett Bay CHRP program (2005-2016)

Quality: 48+ presentations; 28 publication; 6 PhD dissertations; 3 Master's Theses;

EcoGem User's Guide, Jaime Vaudrey

Online EcoOBM, Mark Brush

Relevance:

1-Up-to-date information on nutrient concentrations, primary production, water clarity, bay circulation, and summer hypoxia distribution, intensity and duration.

2-Two ecological and circulation models able to predict oxygen concentration spatially and temporally in Narragansett Bay.

Performance:

Continuing stakeholder engagement (NOAA, NBEP, Baird Symposium, RI C-AIM program, RI DEM).

Hypoxia Impacts on Living Resources and Implications for Management

J. Kevin Craig

NOAA Southeast Fisheries Science Center
Beaufort Laboratory

Projects and Peer-Reviewed Papers

NGOMEX 2009: Effects of Hypoxia on Harvest Dynamics and Economics of the Shrimp Fishery in the Northwestern Gulf of Mexico.

CHRP 2005: Linking Hypoxia-induced Habitat Degradation to Fishery Outcomes: A Bioeconomic Approach Based on Brown Shrimp

FATE 2012: (leveraged): Effect of Shelf Hypoxia on the Gulf Menhaden Fishery and Implications for Stock Assessment.

- PIs and Collaborators: Martin Smith (Duke), Kevin Craig (FSU), Lori Bennear (Duke), James Nance (NOAA SEFSC)

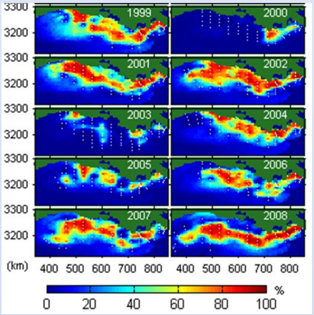
- 18 peer-reviewed papers since 2010

NGOMEX 2009: Modeling Reproductive and Population Impacts of Hypoxia in the Northern Gulf of Mexico.

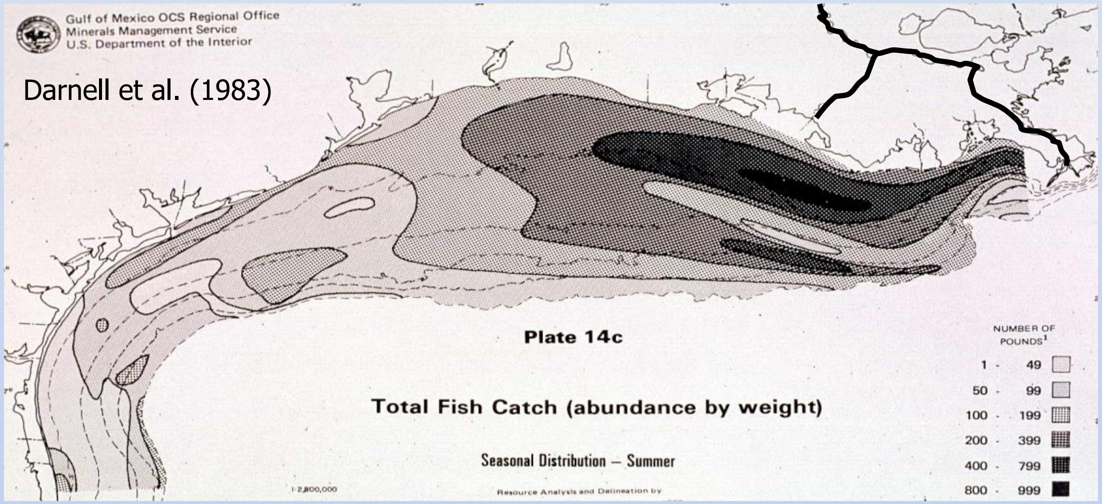
- PIs and Collaborators: Peter Thomas, (UT), Kenneth Rose (LSU), Dubravko Justic (LSU), Kevin Craig (FSU), Thomas Grothues (Rutgers).

- 24 peer-reviewed papers since 2011

Making the Link to Living Resources



Demersal fish and crustacean biomass
'pre-hypoxia' (1961-1965)



- Gulf hypoxic zone overlaps in time and space with:
  - Region of highest productivity of fish and invertebrates
  - Highest valued fishery in the Gulf (penaeid shrimp)
  - Highest biomass fishery in the Gulf (Gulf menhaden)

- Little research on potential effects on managed resources (i.e., fisheries) prior to early to mid-2000s

General Approach

Spatial responses to hypoxia
(avoidance, spatial distn)

Effects on population vital rates
(growth, reproduction, mortality)

Population-Level Effects

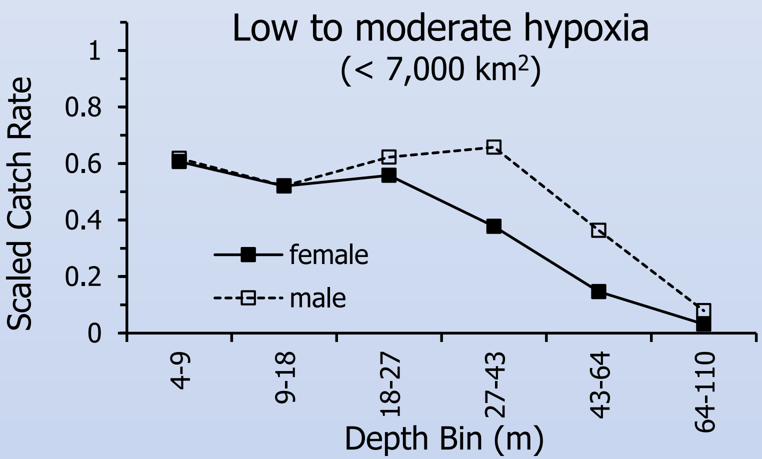
Economic Effects

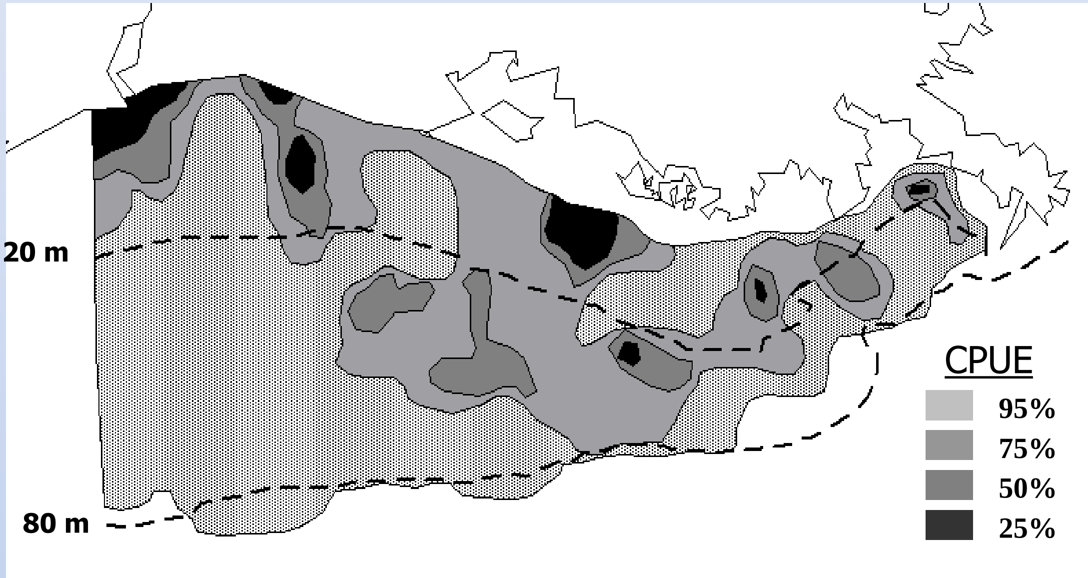
Fisheries Assessment

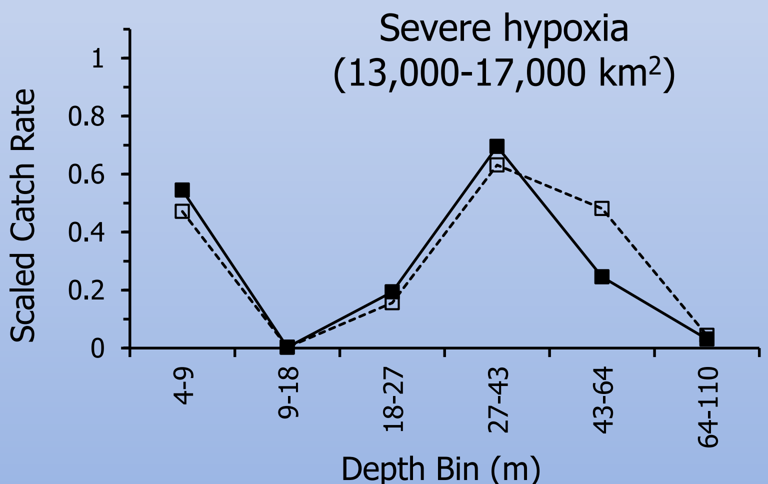
Management Applications

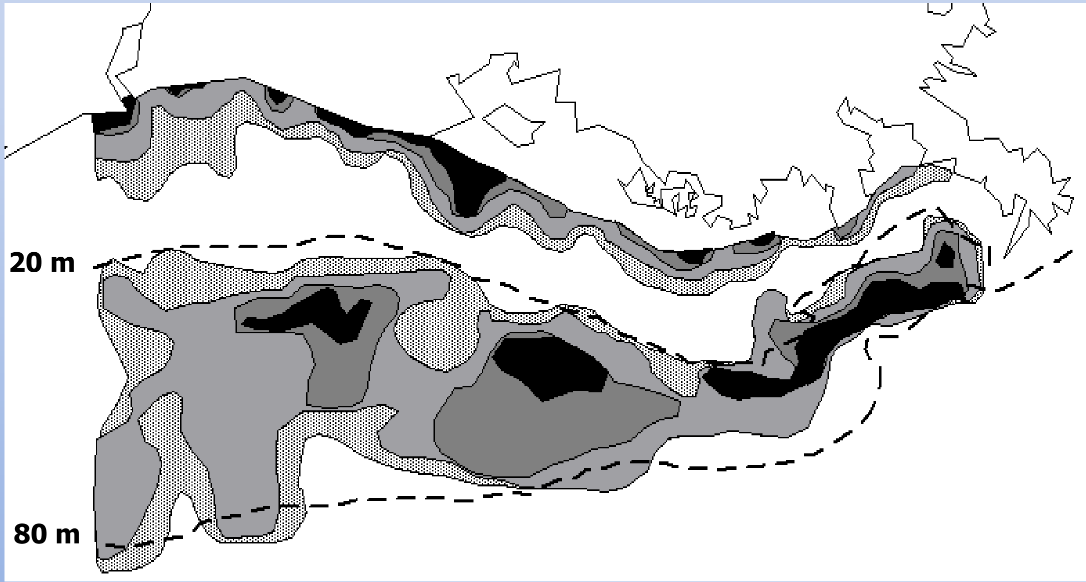
Brown Shrimp Spatial Distribution

Fishery-Independent SEAMAP Survey (June-July)

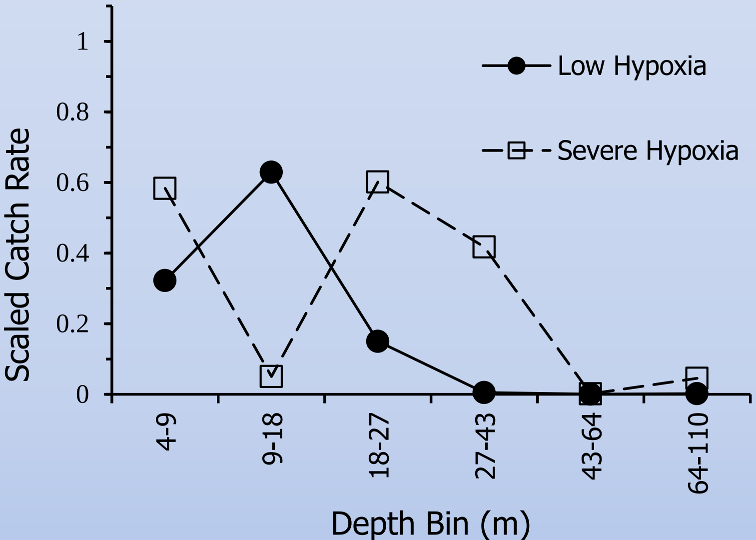




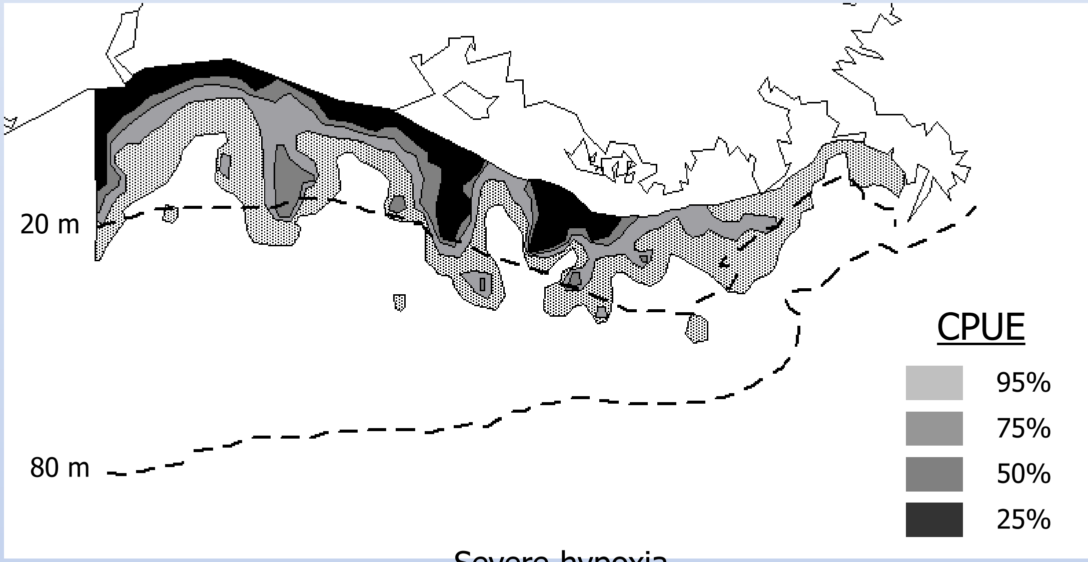




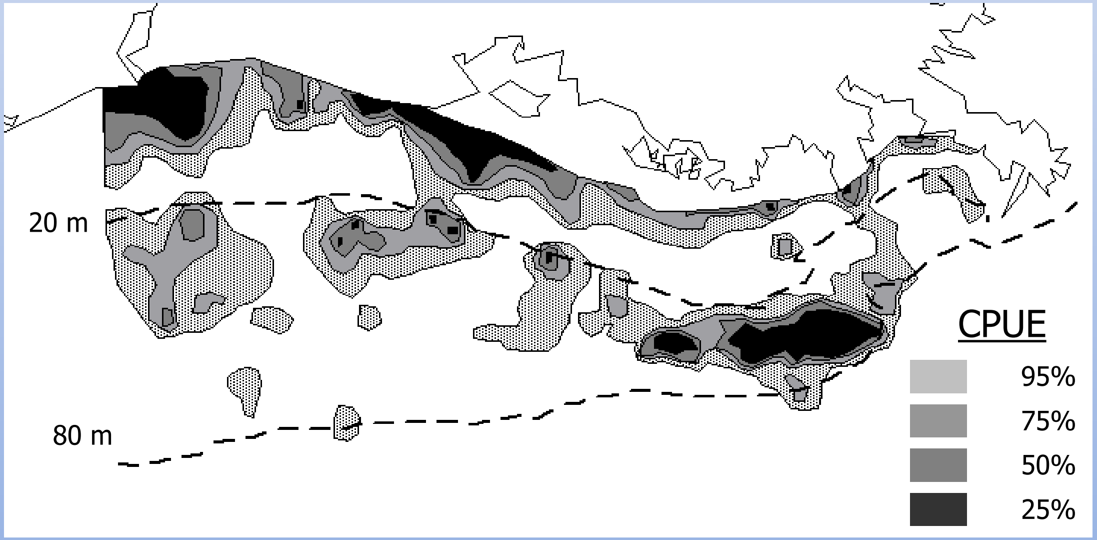
Atlantic Croaker Spatial Distribution



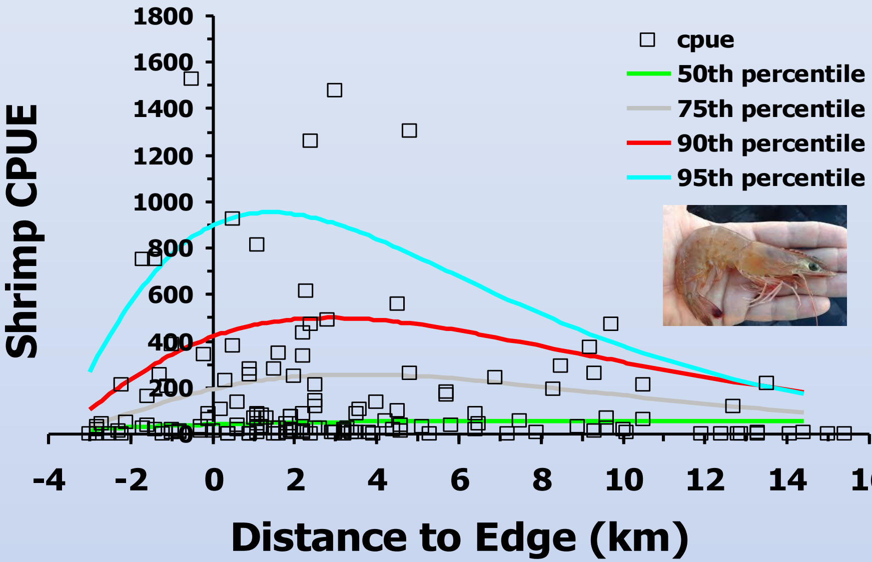
Low to moderate hypoxia
(< 7,000 km^2)

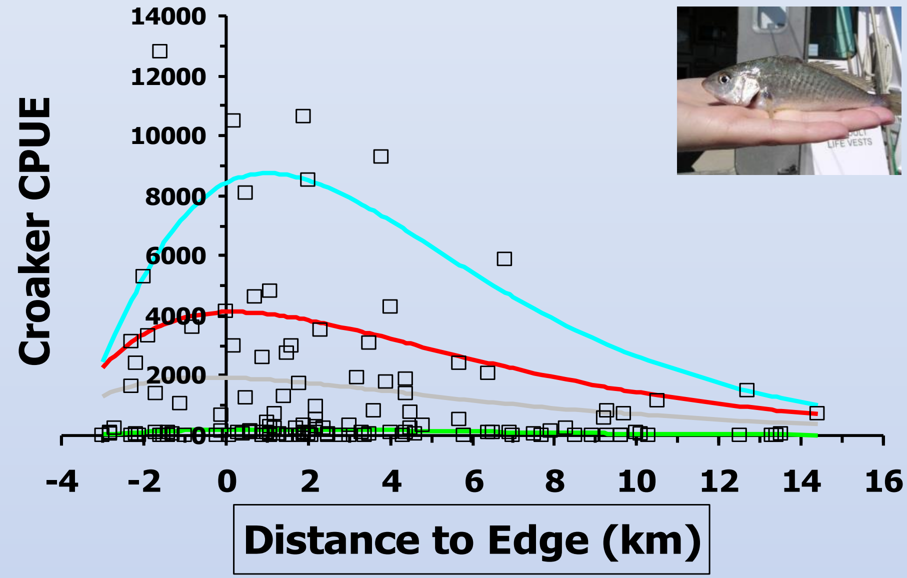


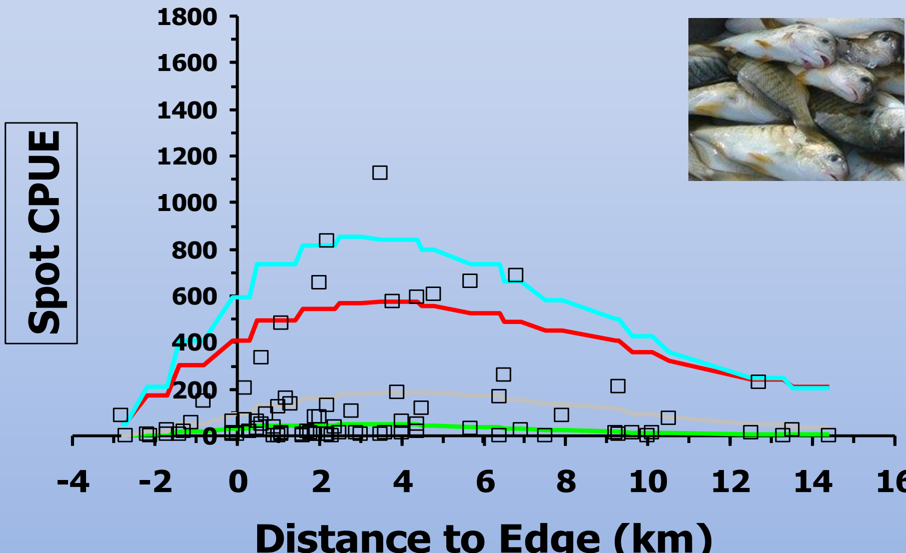
Severe hypoxia
(13,000-17,000 km^2)

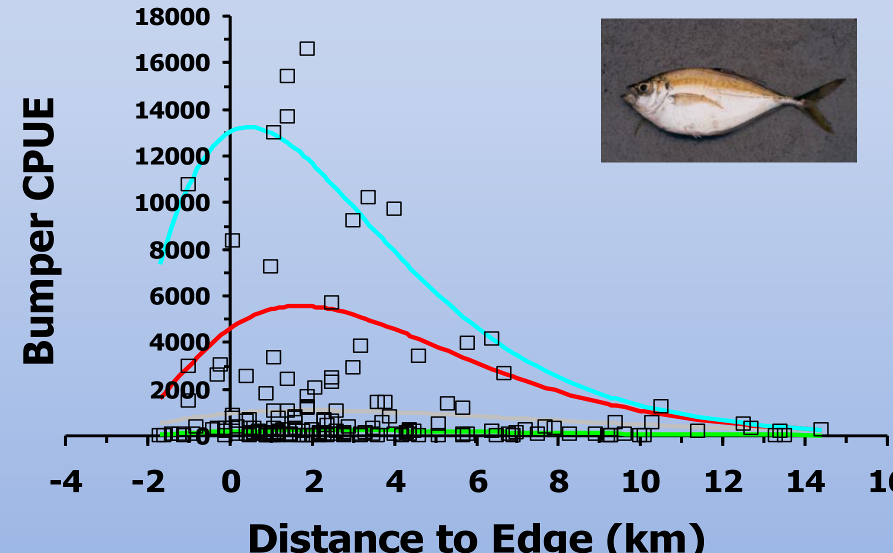


Aggregation Near Hypoxic Edge









Spatial Responses to Hypoxia

- Mobile organisms effectively avoid low DO
  - Field-estimated avoidance thresholds range from 1-2 mg L^{-1} across species
  - Avoidance thresholds are above laboratory-based lethal thresholds

- Sub-lethal and indirect effects are important
  - Organisms occupy moderately low DO (2-4 mg L^{-1}) in the field
  - Occupy DO levels where sub-lethal effects observed in lab
  - Habitat loss induces strong aggregations near hypoxic edges

- Primary Limitation
  - Based mostly on point-in-time surveys
  - Spatio-temporal dynamics of organism (and fishery response) to seasonally dynamic oxygen conditions not well-known

Craig et al. (2010, 2012, 2013)

General Approach

Spatial responses to hypoxia

Effects on population vital rates
(croaker reproduction)

Population-Level Effects

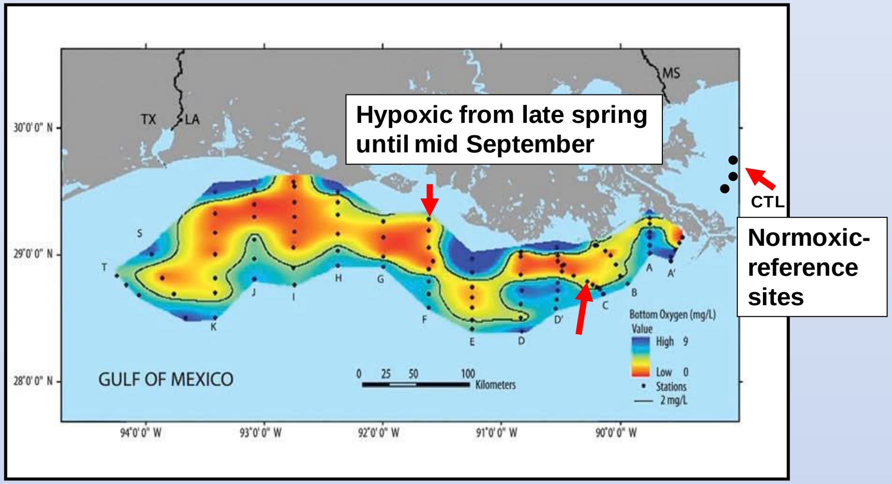
Economic Effects

Fisheries Assessment

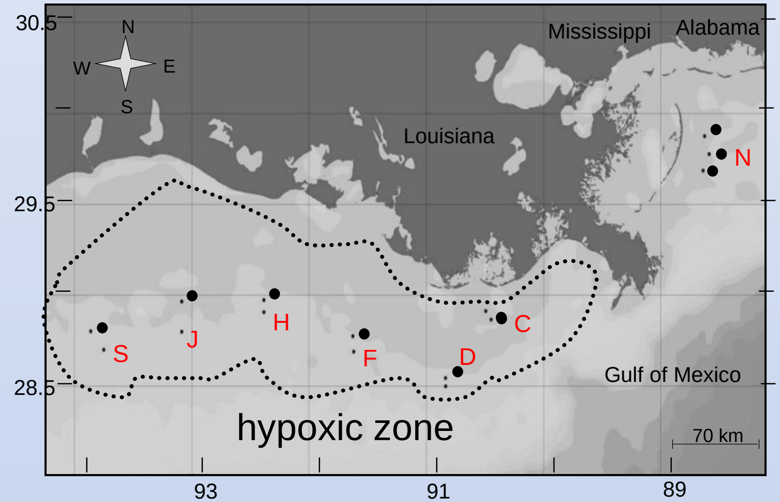
Management Applications

Reproductive Impairment of Atlantic Croaker

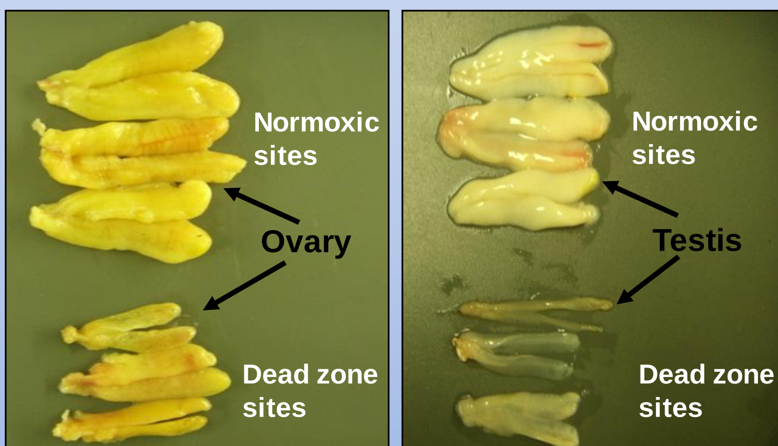
October 2007



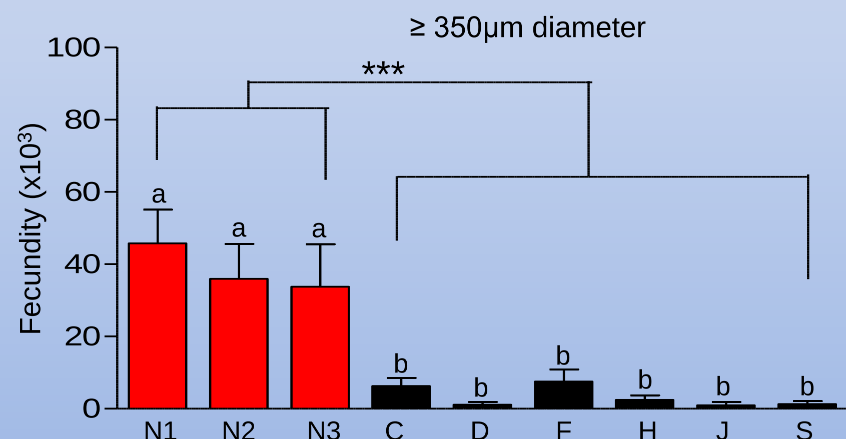
October 2010



Gonads smaller at hypoxic sites



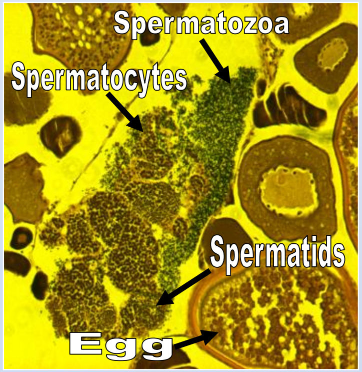
Marked decrease in fully developed oocytes

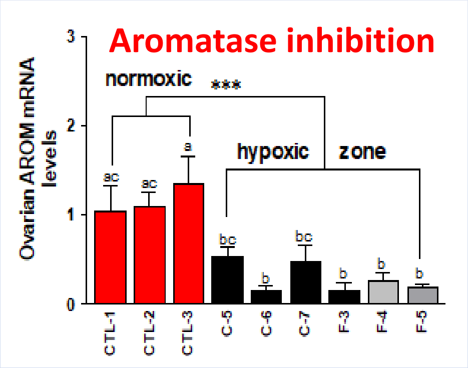


Thomas et al. (2011, 2015)

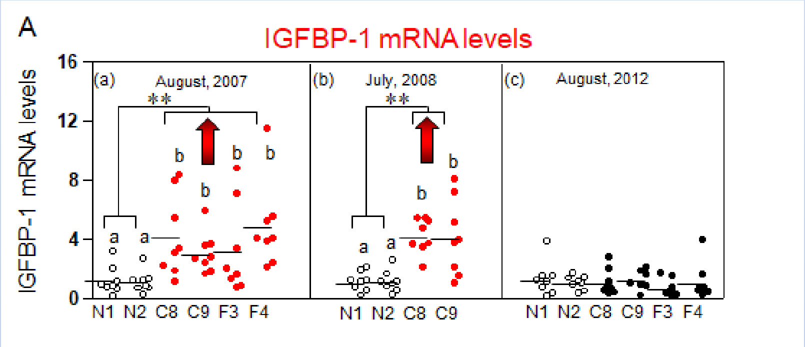
Hypoxia Effects on Croaker Reproduction & Growth

- Masculinization of females
  - Sperm detected in 25% ovaries
  - Decrease in aromatase activity
  - Thomas and Rahman (2011)

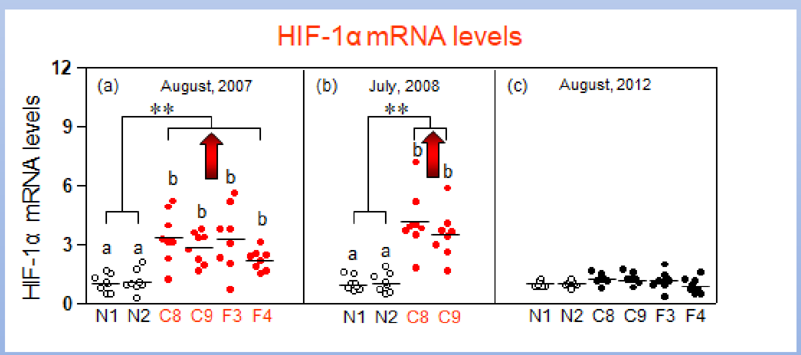




- Growth impairment
  - Elevated growth inhibitors (IGF binding protein (IGFBP-1, IGFBP-2)
  - IGFBP increased and growth decreased over 20 wks hypoxia exposure in the lab
  - Rahman and Thomas (2018)



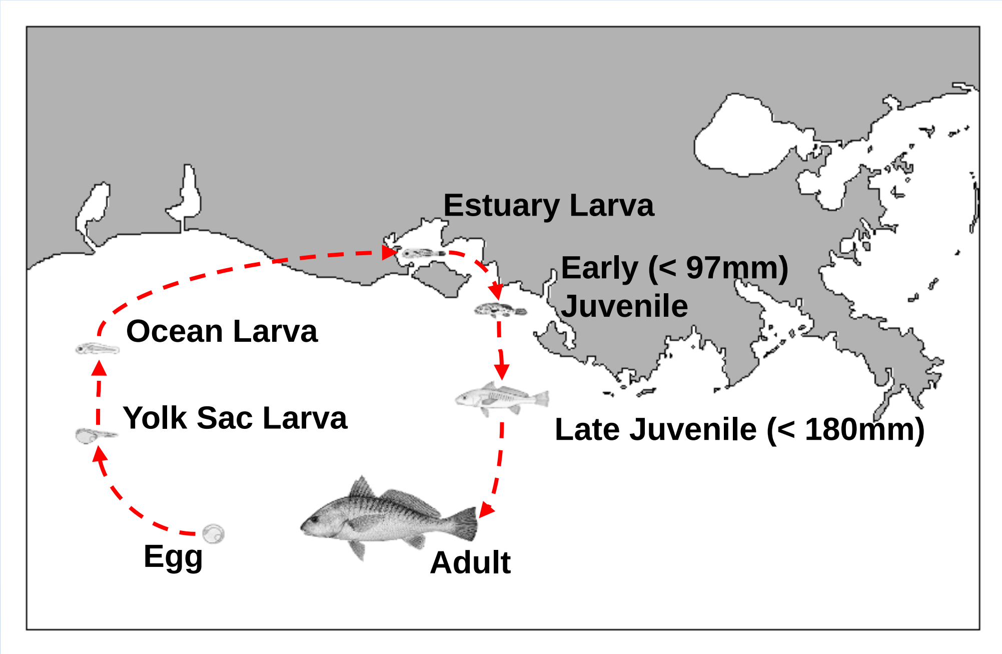
- Hypoxia exposure biomarkers elevated
  - Hypoxia-Inducible Factor (HIF-α) an oxygen sensitive transcription factor- regulates metabolic adaptation to hypoxia
  - Rahman and Thomas (2018)



Atlantic Croaker Population Model

Project long-term popn consequences of hypoxia exposure

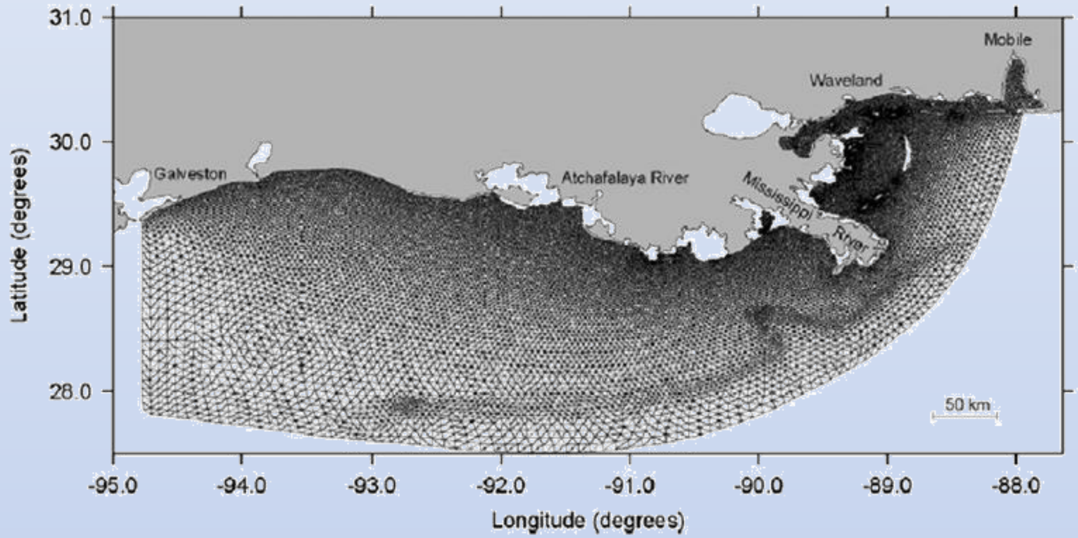
- Spatially explicit, IBM
  - Follows 7 stages to age 8
  - September 1 birthday
  - Model year begins Sept. 1
  - Each year 365 days long
- Hourly processes
  - Growth
  - Mortality
  - Reproduction
  - Movement (routine & avoidance)



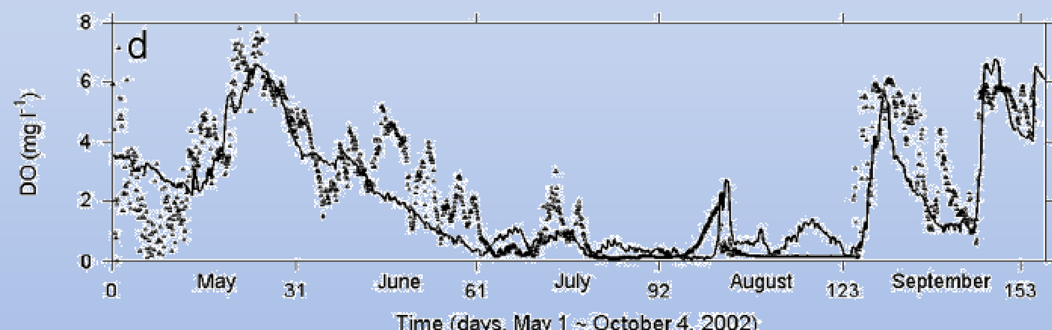
- Environmental conditions simulated on a 2-D spatial grid
  - Climatological temperature
  - Climatological surface Chl-a
  - Dissolved oxygen from 3-D hydrodynamics-WQ model

Dissolved Oxygen

- Grid encompasses La. and N. Texas coast
- 3-D coupled hydrodynamic-water quality model
  - FVCOM + WASP
  - 1-10 km horizontal
  - 0.2-2.0 m vertical

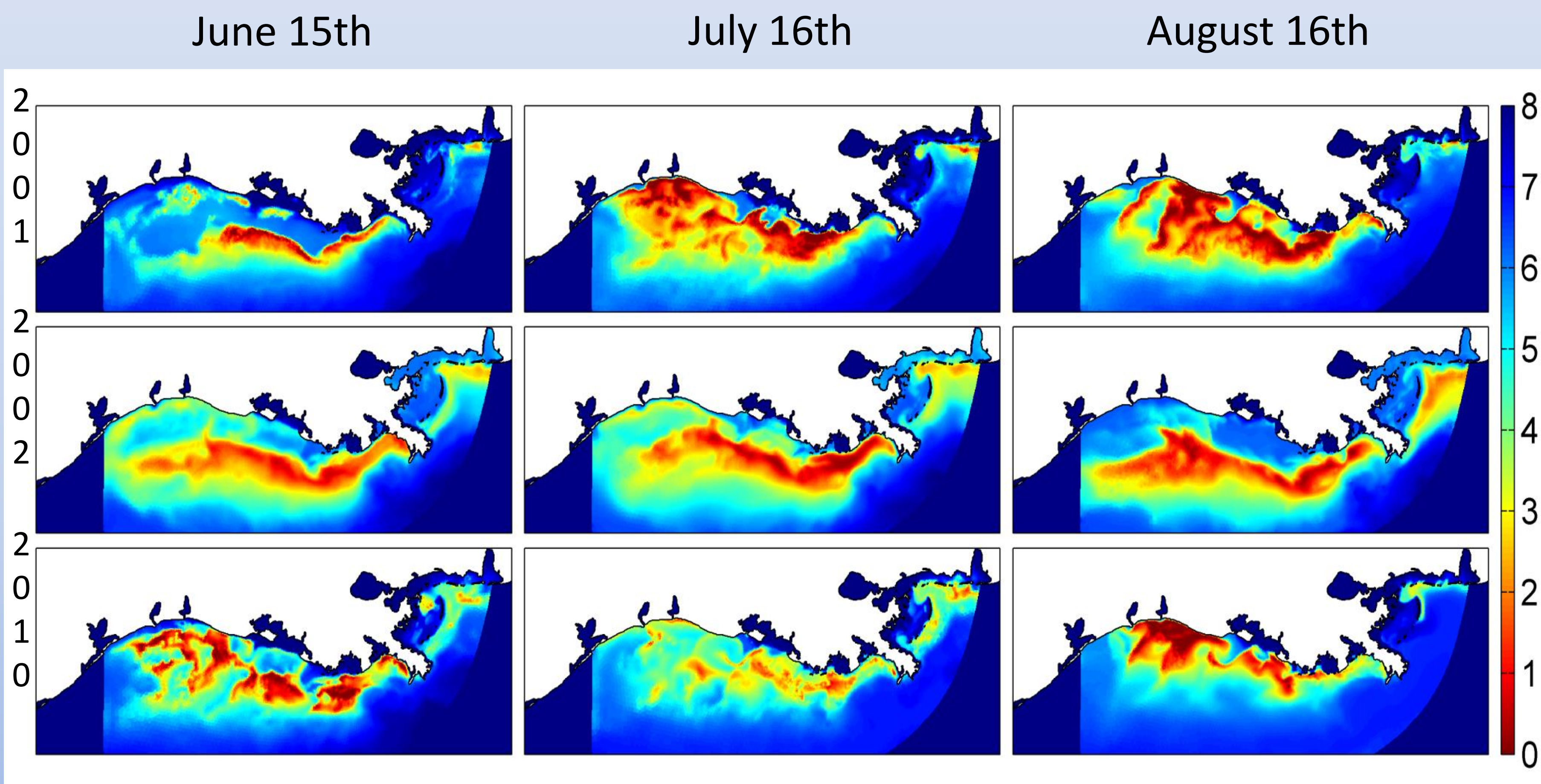


- Calibrated and assessed using multiple independent data sources for 2002



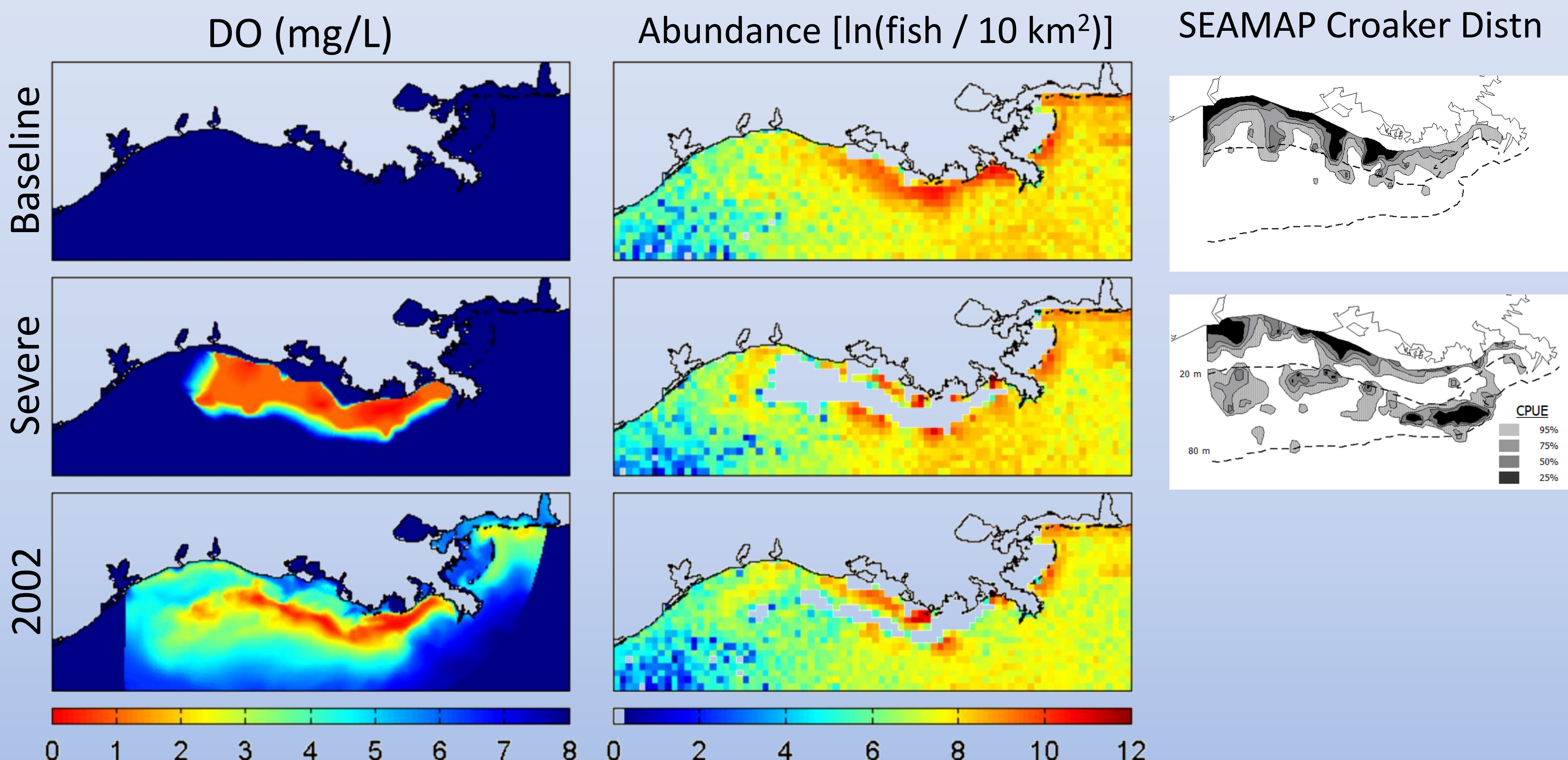
Justic and Wang. 2014. Continental Shelf Research

Midyear snapshots of predicted bottom DO
(FVCOM interpolated to the IBM grid)

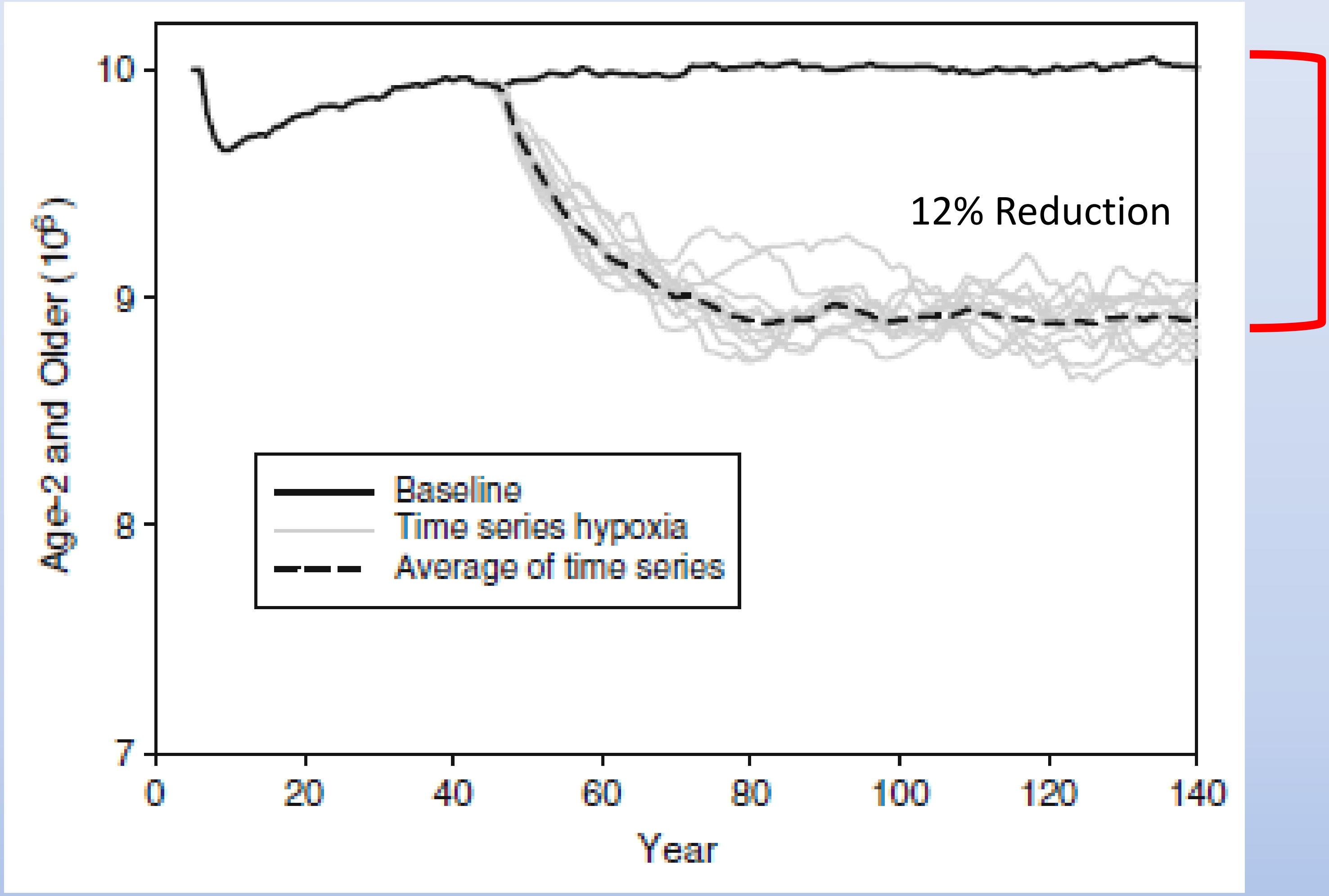


Croaker Avoidance

(July 16th)



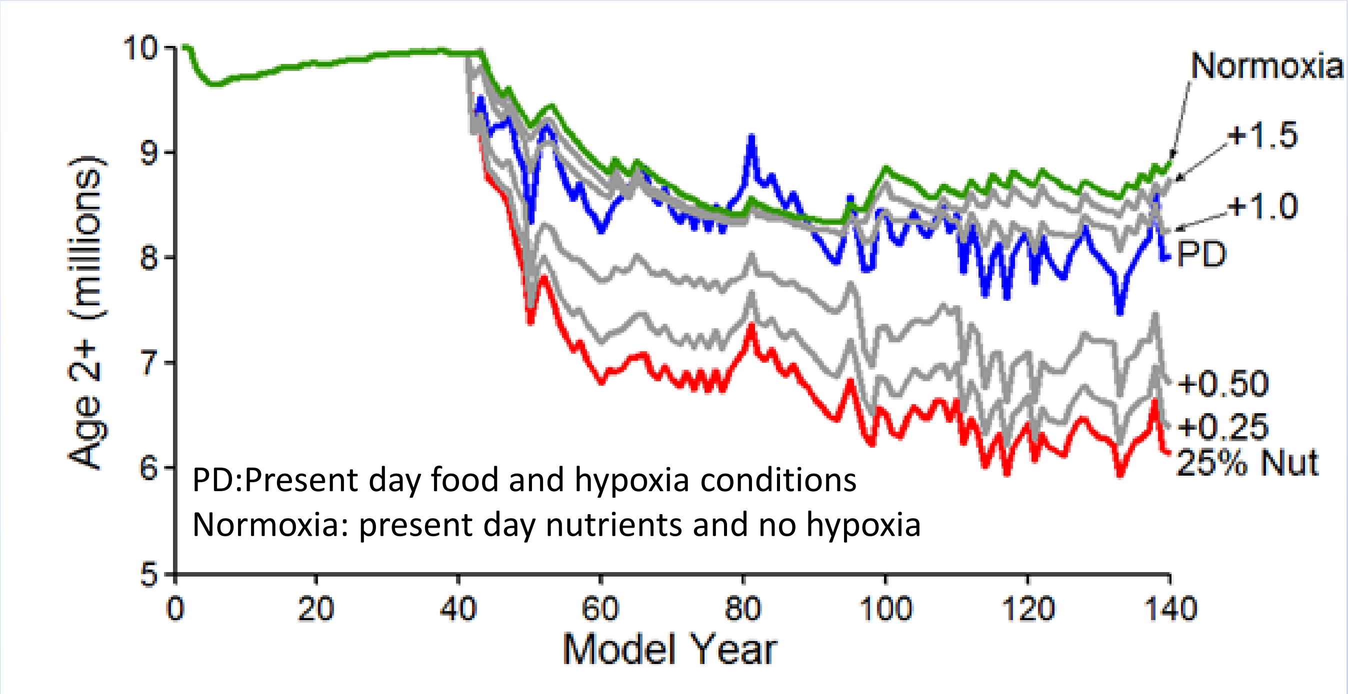
Hypoxia Effect on Long-Term Population Abundance



- Random times series of idealized 'severe,' 'moderate,' and 'mild' hypoxic years in proportion to their historical occurrence
- Response dominated by the effect of reduced fecundity

Rose et al. (2017a)

Nutrient-Hypoxia Tradeoffs



increase DO due to reduced nutrients

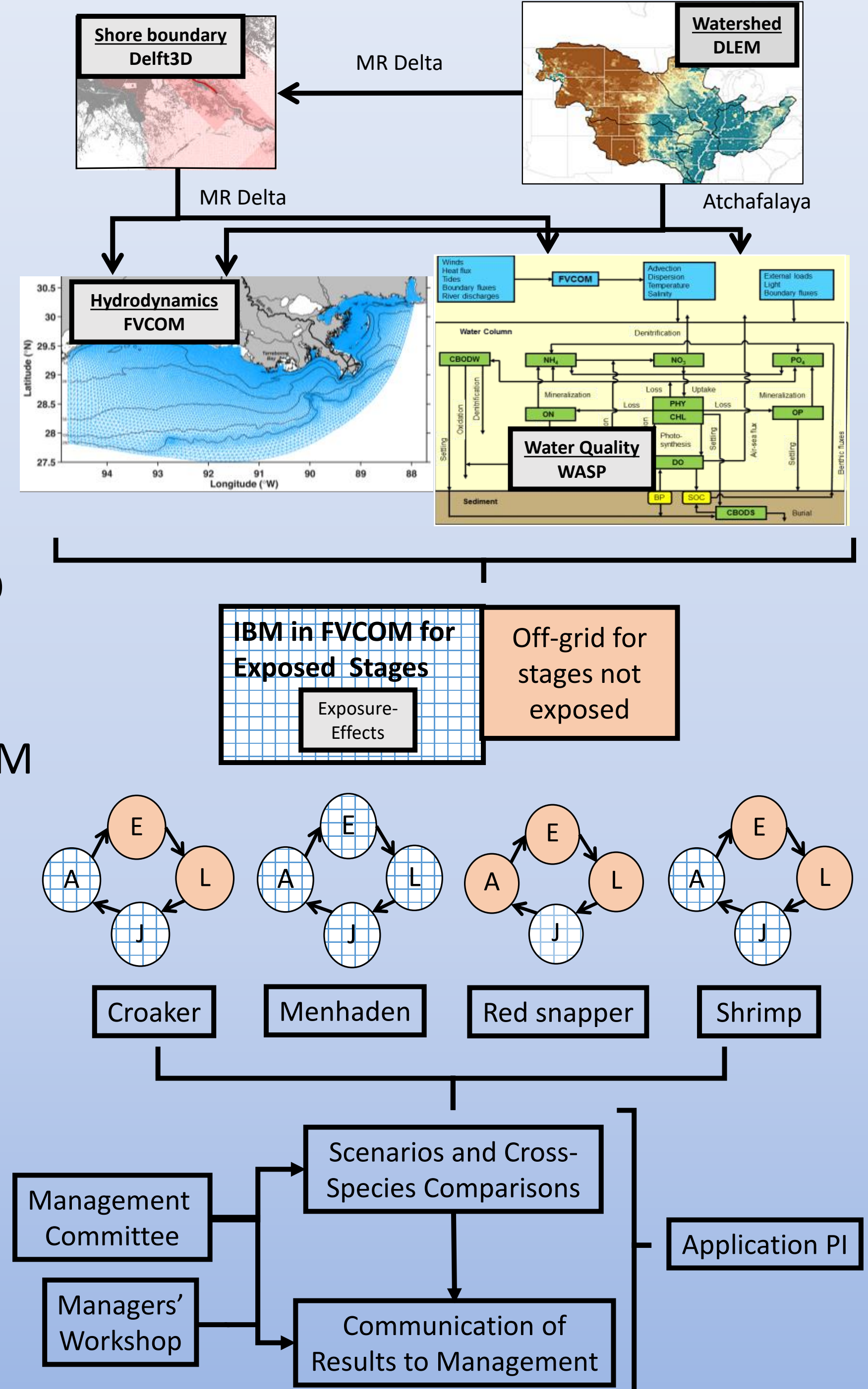
- Magnitude of hypoxia effect is larger (~25% decline) with the more realistic DO (blue)
- Reductions in nutrients result in further croaker declines due to decreased food (red)
- These reductions in food availability can be offset by relatively modest increases in DO associated with the lower nutrients (gray lines)
- Pos. effect of reduced hypoxia outweighs neg effect of reduced food (preliminary conclusion)

Rose et al. (2017b)

NGOMEX 2016 (new)

D. Justic (LSU), K. Rose (UMCES), E. Meselhe (Water Institute), H. Tian (Auburn), J. Xu (LSU), L. Huang (LSU), K. Craig (SEFSC)

- Link IBM to 3D FVCOM and WASP models
  - Predictions of Chl (food availability) and DO
  - Potential for vertical movement
- Link watershed and river diversion models (DLEM and Delft 3D) to FVCOM
  - supply nutrients and water flow to FVCOM
  - Evaluate diversion scenarios
- Coupled models allow for more seamless evaluation of nutrient-hypoxia tradeoffs
- Expand to additional species (Gulf menhaden, brown shrimp, red snapper)



General Approach

Spatial responses to hypoxia

Effects on population vital rates
(fishing mortality)

Population-Level Effects

Economic Effects

Fisheries Assessment

Management Applications

How do Fisheries Respond to Hypoxia?

Mine existing fisheries datasets:

- Electronic logbook data on shrimp vessel tow locations
  - Maintained by NOAA SEFSC Galveston Lab (2005-2010)
  - Random sample of vessels with recorded trawl set locations over the fishing season (April to October)
  - 17,843 – 53,242 individual shrimp trawl locations per year

- Gulf Menhaden Coastal Logbook Program
  - Maintained by NOAA SEFSC Beaufort Lab
  - 100% catch and effort reporting since 2006
  - 75,132 purse seine set locations (2006-2009)

- Merge with survey or model estimates of dissolved oxygen
  - Brown Shrimp: SEAMAP survey estimates of bottom DO
  - Gulf Menhaden: WQ model output (Fennel et al. 2013)

- Test for effects on fishery response variables (e.g., effort, catch, CPUE) using geospatial regression models

Two Key Finding

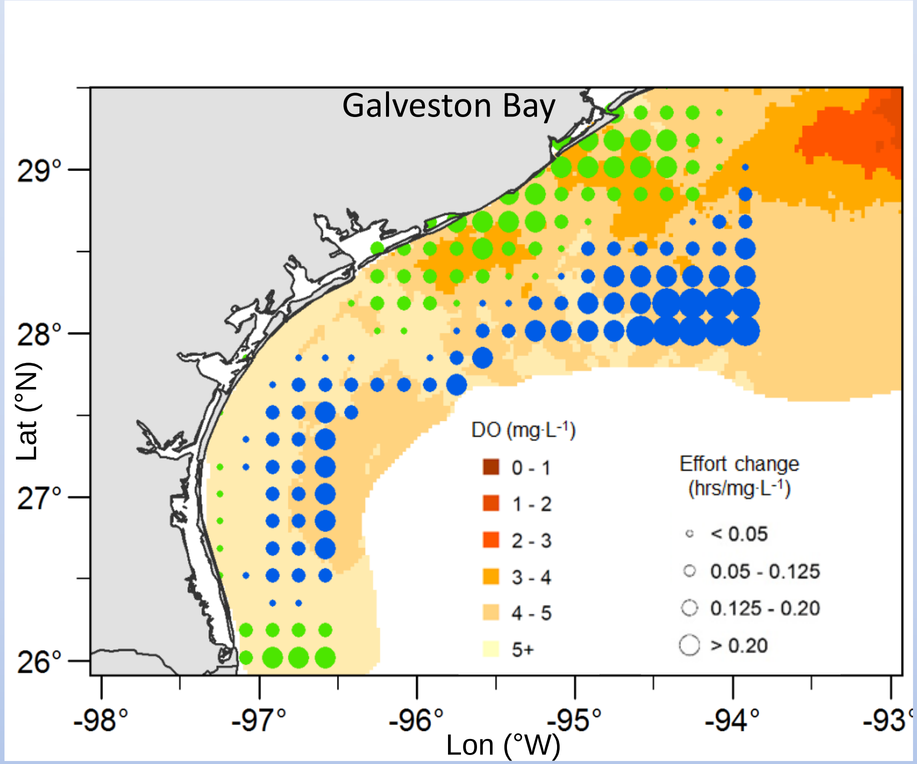
- Fishing fleets are responsive to hypoxia (or hypoxia-induced effects on target species)

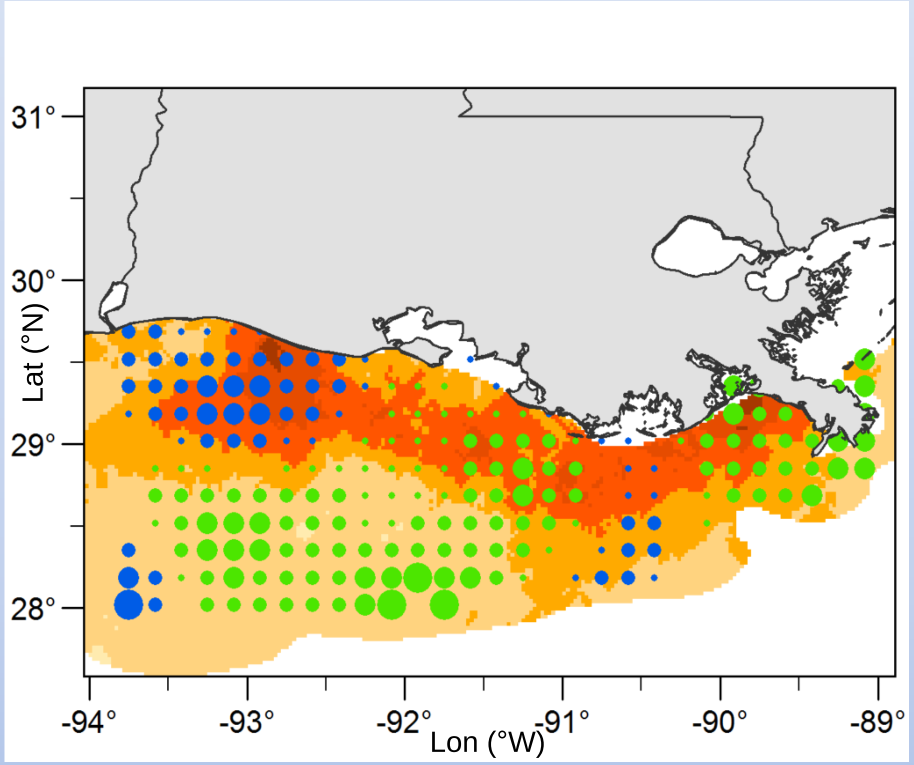
- These shifts in spatial distribution influence catchability (q), or the proportion of the stock harvested by a given unit of fishing effort—key parameter of stock assessment models

Hypoxia Effects on the Shrimp Fishery

(Results from Geospatial Regression Model)

Texas Shelf (reference site) 2005-2010 Louisiana Shelf (treatment site)





<u>Slope of Spatially Varying DO Effect</u>

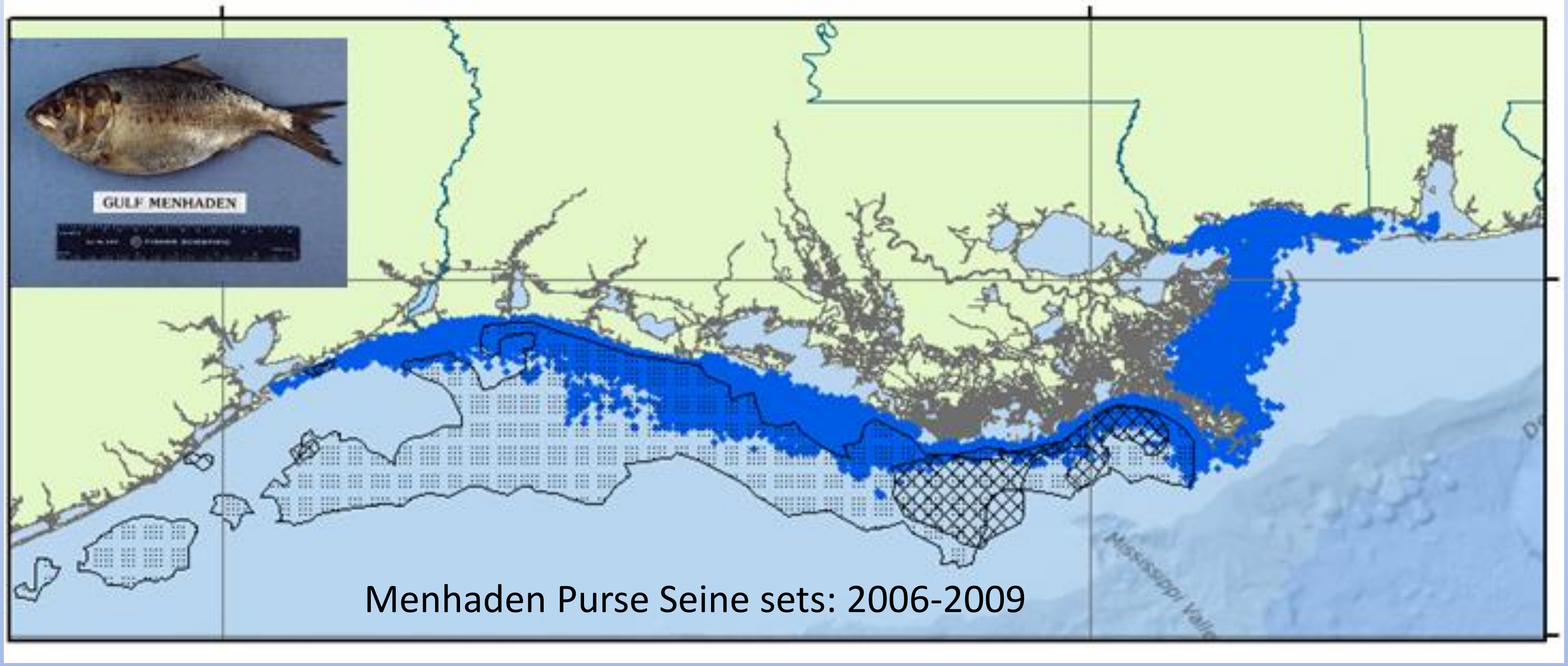
Green: Decrease in effort when DO is low (positive slope)

Blue: Increase in effort when DO is low (negative slope)

Purcell et al. (2017)

Gulf Menhaden Fishery

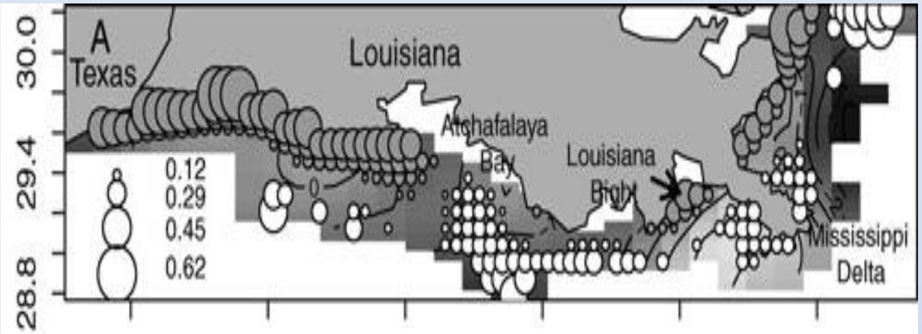
- Second largest US fishery by weight (0.5 million metric tons annually)
- Fishery extends from April to November but peaks in June-July
- Mostly prosecuted close to shore (within 5 miles)
- Merged with DO predictions from coupled hydrographic-biogeochemical model (Fennel et al. 2013)



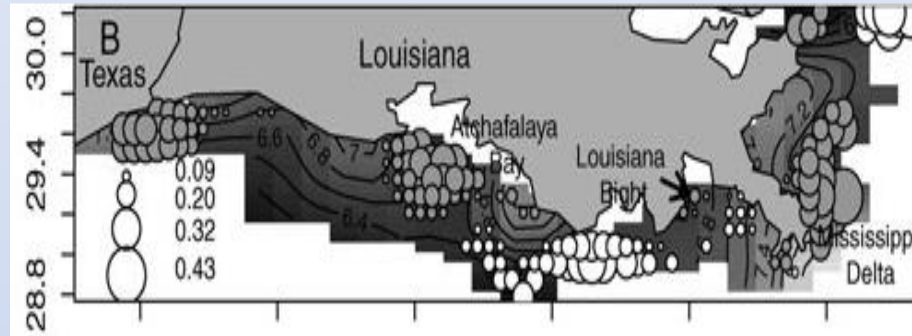
Menhaden Purse Seine sets: 2006-2009

Shift in Spatial Distribution of the Menhaden Fishery

P(fishing)

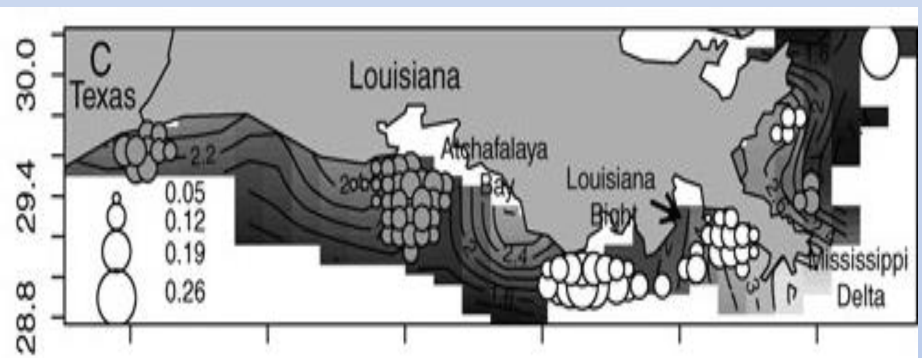


Catch

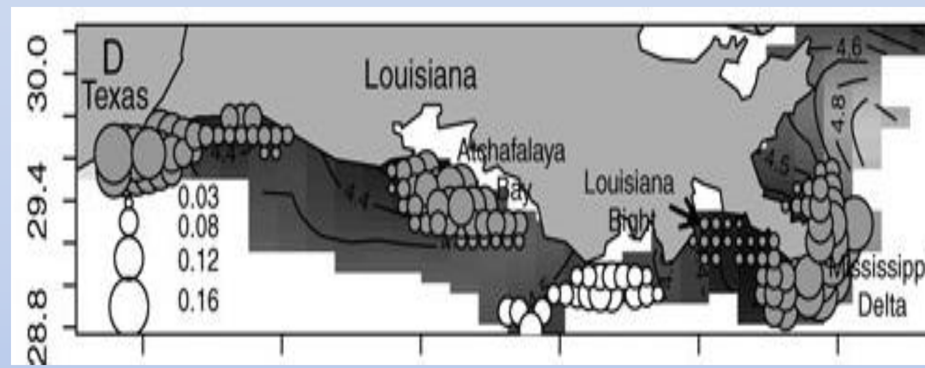


increase in response variable with declines in DO

Effort



Catch-per-unit-effort (CPUE)



Under low DO conditions:

- Decrease in catch and effort in regions typically experiencing chronic hypoxia
- Fleet shifts westward, inshore, and eastward when hypoxia is severe

Langseth et al. 2014)

What are the economic consequences to the shrimp fishery?

Shrimp Bioeconomic Modeling

Led by Marty Smith (Duke)

Brown shrimp life history

$$N_{0,j,y} = \widetilde{N}(1+\varepsilon_{j,y})\theta_j$$ Recruitment

$$N_{t,j,y} = N_{0,j,y}e^{\sum_s -m_s + \sum_s -f_s}$$ Survival

$$m_t = \beta(L_t)^\rho$$ Natural Mortality

$$f_t = qE_t$$ Fishing Mortality

$$L_t = L_\infty(1-e^{-\delta t})$$ Growth

$$w_t = \omega(L_t)^\gamma$$ Allometric (length to weight)

$$H_t = \frac{f_t}{f_t + m_t}(1-e^{-f_t})w_t N_t$$ Harvest

Hypoxia Adjustments

$$\widetilde{m_t} = (1+\Delta_m)m_t$$

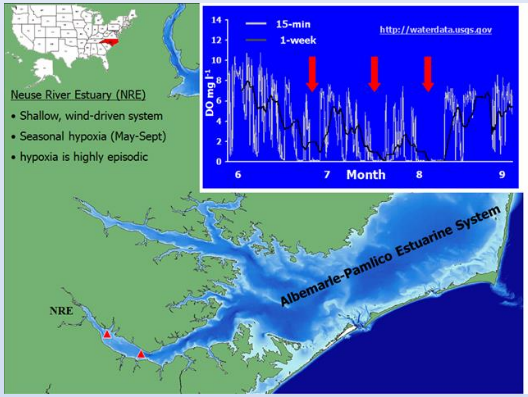
$$\widetilde{q_t} = (1+\Delta_q)q$$

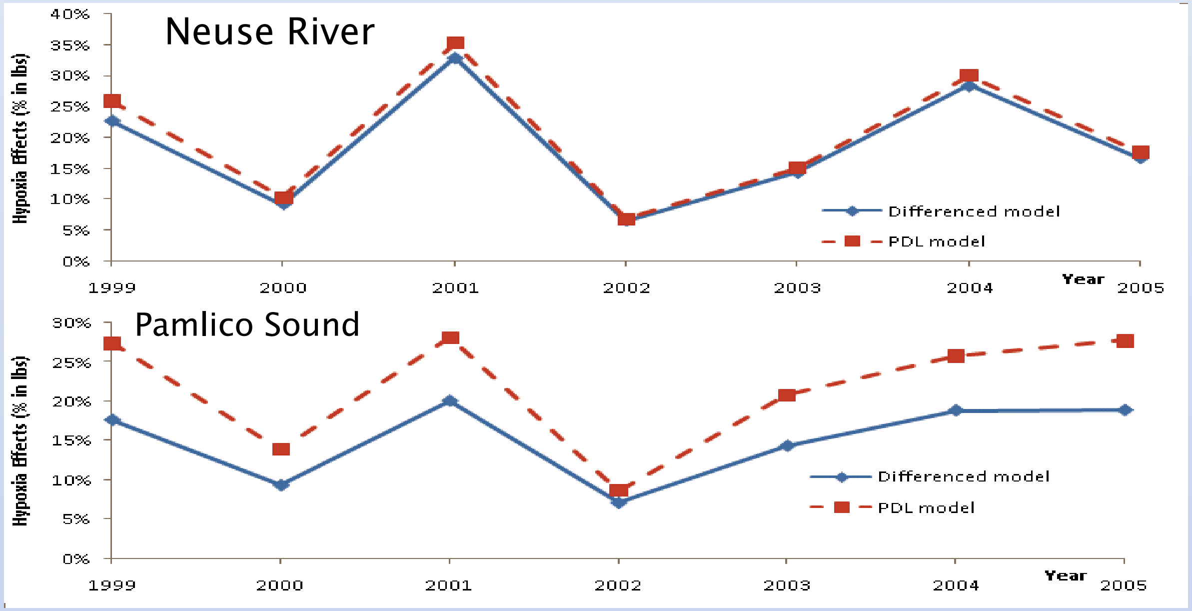
$$\widetilde{\delta_t} = (1-\Delta_\delta)\delta$$

Microdata:

- Requires high resolution data on shrimp catches and environmental conditions over the course of a fishing season

Main Results from North Carolina





- Daily shrimp catches (NCDMF trip ticket program)
- Daily DO (USGS moorings)

Harvest losses from hypoxia (1999-2005):

- Avg losses of 13-21% across the range of models considered (compared to no hypoxia)
- For Neuse-Pamlico system \$1.2 million in lost annual revenues
- Modeling fisher participation (respond to abundance and price) suggests behavioral adjustments can partially mitigate this loss
  - 4% annual loss in revenue (\$0.3 million annually)

Huang et al. (2010, 2012)

Is this approach transferable to the Gulf?

No….resolution of catch and DO data not sufficient

Key findings from <u>spatially dynamic</u> bioeconomic model:

1. Net effect of all three processes (q, growth, mortality) on total catch can be pos or neg and vary depending on when in the season the system is observed

2. Even with perfect info., detecting hypoxia effects in catch data would be difficult

3. No counterfactual (i.e., control)--What would happen in the absence of hypoxia?
   - Shrimp fleet highly mobile and trips can extend over several weeks
   - Contamination of potential controls (e.g., Texas fishery)

(Smith et al. 2014. Marine Resource Economics 29:111-131)

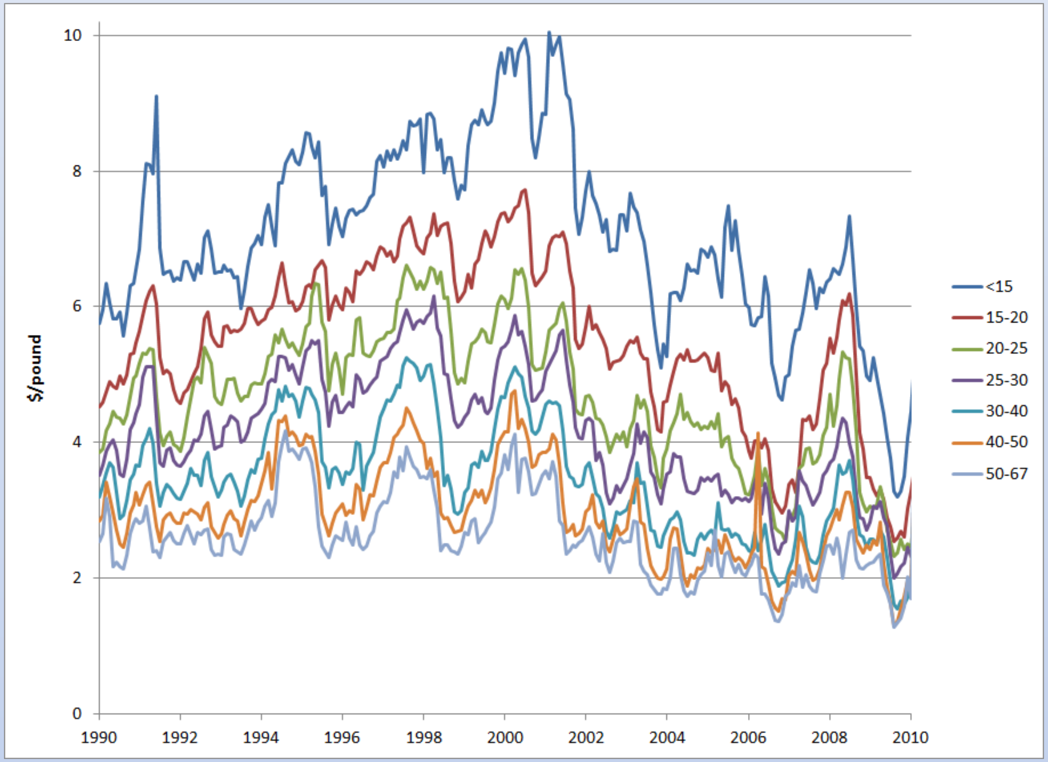
==============================

Expect increased harvest of small relative to large shrimp

Catchability, growth, and mortality skew size distn to smaller sizes

Do size-based shrimp prices contain info. on the effects of hypoxia?

Size-Based Prices of Brown Shrimp



- Shrimp are sold in size-based categories based on the number of shrimp per pound
- Price per pound of large shrimp is higher than for small shrimp (different economic value)
- Relative size-based prices are stable in the long-term so that short-term deviations in relative price should be random in the absence of intervening effects
- Shrimp prices provide a market-based counterfactual against which to test effects of hypoxia

Smith et al. (2017)

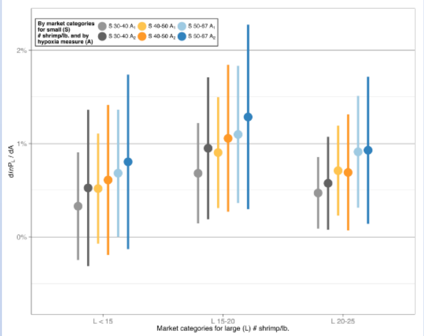
Seafood prices reveal impacts of a major ecological disturbance

January 2017

Martin D. Smith[a,b,1], Atle Oglend[c], A. Justin Kirkpatrick[a], Frank Asche[c,d], Lori S. Bennear[a,b,e], J. Kevin Craig[f], and James M. Nance[g]

[a]Nicholas School of the Environment, Duke University, Durham, NC 27708; [b]Department of Economics, Duke University, Durham, NC 27708; [c]Department of Industrial Economics, University of Stavanger, 4036 Stavanger, Norway; [d]Institute for Sustainable Food Systems, School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611-0240; [e]Sanford School of Public Policy, Duke University, Durham, NC 27708; [f]National Marine Fisheries Service, Southeast Fisheries Science Center, National Oceanic and Atmospheric Administration, Beaufort Laboratory, Beaufort, NC 28516; and [g]National Marine Fisheries Service, Southeast Fisheries Science Center, National Oceanic and Atmospheric Administration, Galveston Laboratory, Galveston, TX 77551

Demonstrated effect of hypoxia on a major commercial fishery



➢ Main result:

- When hypoxia is severe, prices of large shrimp increase relative to small shrimp (growth overfishing is a key mediating process)

- Result is consistent with known or hypothesized mechanisms: catchability, growth, and mortality skew size distributions to smaller sizes so that fewer large shrimp are available

- Cannot separate out the relative importance of alternative mechanisms with this analysis

- Magnitude of the effect is unknown, but regression model suggests 1000 km^2 increase in area hypoxia triggers a 1% increase in the relative price of large shrimp

Effects on the Gulf Menhaden Stock Assessment

Key Result: Hypoxia may bias management advice from stock assessment models
(Underestimate fishing mortality and overestimate stoc biomass)

Simulate the Gulf Menhaden Stock Assessment

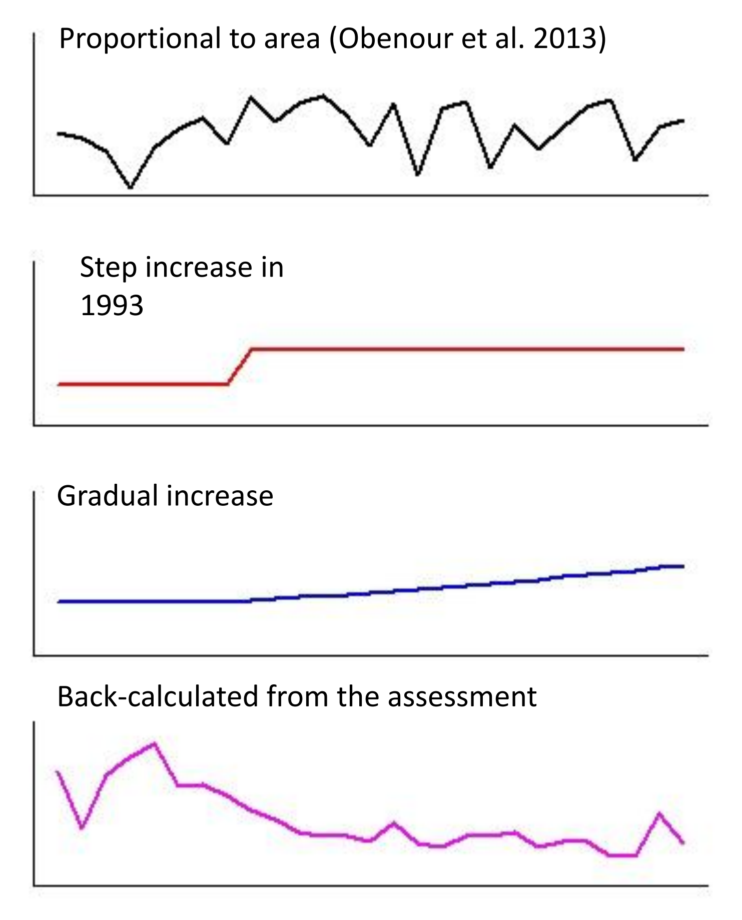
Catchability (q):

- Avg proportion of a stock harvested by a given unit of fishing effort
- Key parameter of stock assessment models used to set catch limits

Operating model
"Create Truth"
(2013 assessment)

Generate data

4 patterns in q



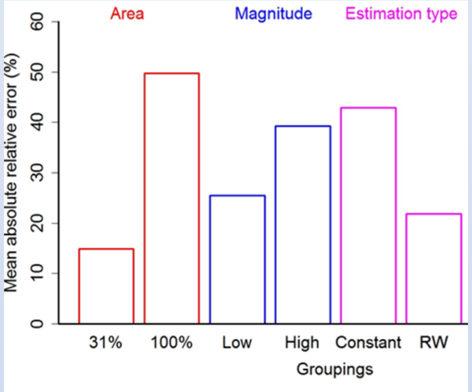
% Fleet affected:

- 31% (Langseth et al. 2014)
- 100% (max effect)

Estimation model
assume constant q
as in current assessment

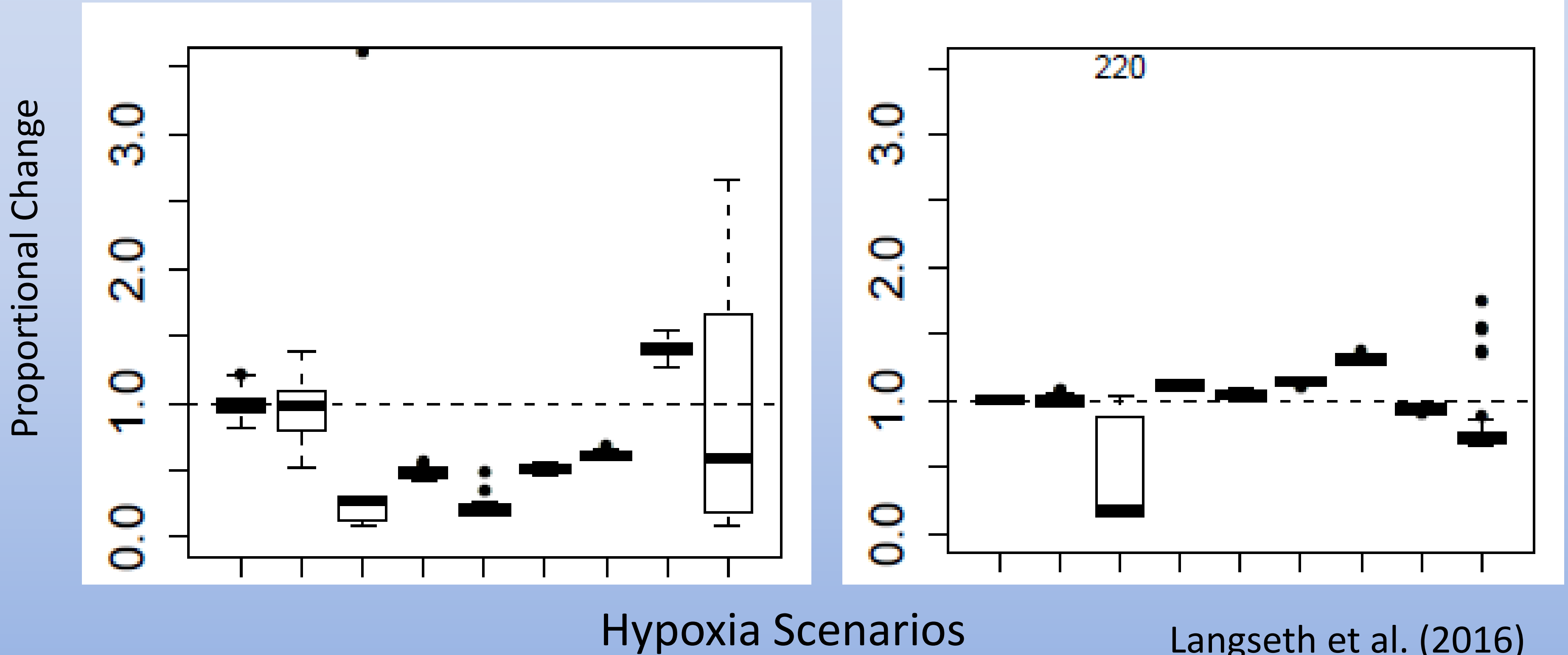
Effects on Fishing and Biomass Reference Points

- Not accounting for effects of hypoxia:
  - Fishing mortality (F) biased low
  - Spawning biomass (SSB) biased high
  - Magnitude of effect is highly uncertain
- Potential leads to risk-prone management advice



F30% reference point

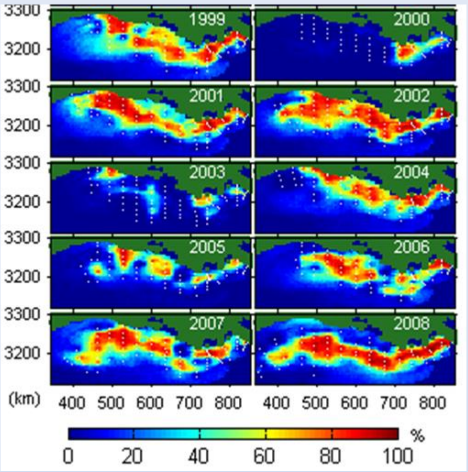
SSB30% reference point



Langseth et al. (2016)

NGOMEX 2016 (new)

D. Obenour (NCSU), K. Craig (SEFSC)



- Primary limitation to understanding hypoxia effects on fisheries is the lack of empirically-based, high resolution DO data

- Objectives:

- Geostatistical modeling of available DO data to generate within-season spatial maps of DO
- Fusion of geostatistical and mechanistic model results to develop optimal estimates of hypoxia through time and over multiple sections of the Louisiana-Texas Shelf
- Re-evaluate hypoxia effects on the Gulf Menhaden assessment model
- Extend approach to the Brown Shrimp assessment

General Approach

Spatial responses to hypoxia

Effects on population vital rates

Population-Level Effects

Economic Effects

Fisheries Assessment

Management Applications

Stock Assessment Process for Federally-Managed Species

SEDAR (Southeast Data, Analysis, Review)

Data — Data Workshop: Assemble, QA/QC, Discuss/Summarize

Analysis — Indices of abundance, life history (growth curves, maturity ogives), natl mortality

Assessment — Assessment Workshop: Stock Assessment Modeling (Catch-age models, Production models, data-limited)

Report — Summarize Results

Review — Review Workshop and SSC review

Management

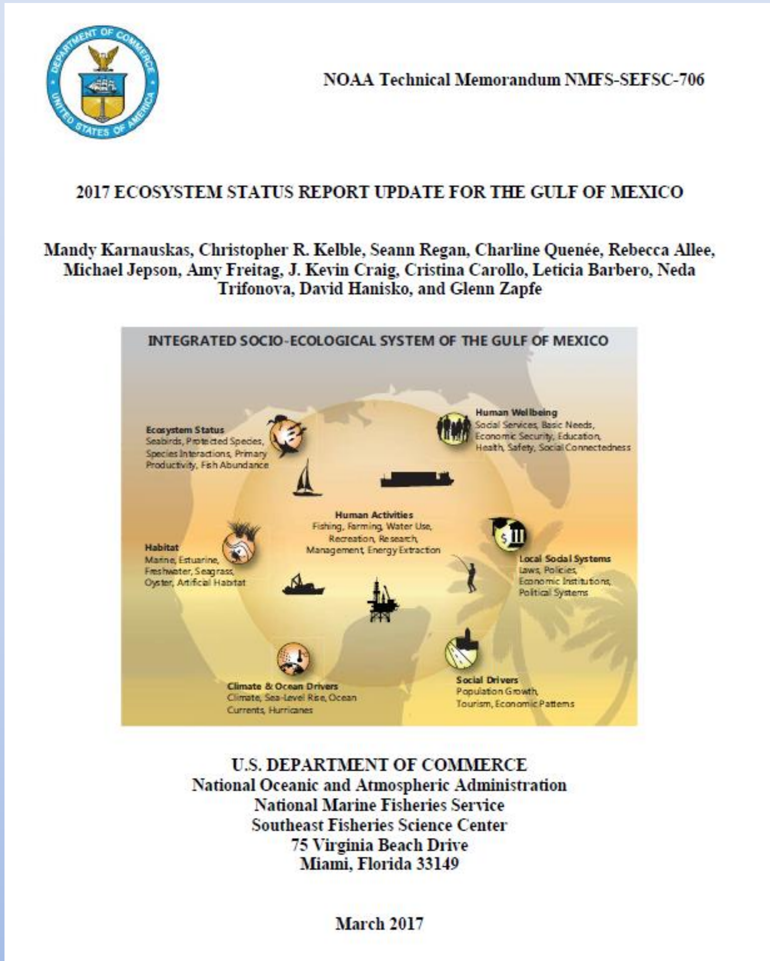
SEDAR Process:

- Takes about one year
- Highly structured
- Currently does not consider hypoxia
- Purpose:
  - Determine stock status (overfished, overfishing)
  - Establish re-building plans
  - Set short term (1-3 year) catch levels
- See http://sedarweb.org/

Menhaden simulation study led to alternative modeling approach that implicitly accounts for hypoxia effects

Gulf of Mexico Ecosystem Status Report (ESR)

ESR develops and tracks ecosystem drivers, pressures, and state across multiple components of the ecosystem



NOAA Technical Memorandum NMFS-SEFSC-706

2017 ECOSYSTEM STATUS REPORT UPDATE FOR THE GULF OF MEXICO

Mandy Karnauskas, Christopher R. Kelble, Seann Regan, Charline Quenée, Rebecca Allee, Michael Jepson, Amy Freitag, J. Kevin Craig, Cristina Carollo, Leticia Barbero, Neda Trifonova, David Hanisko, and Glenn Zapfe

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149

March 2017

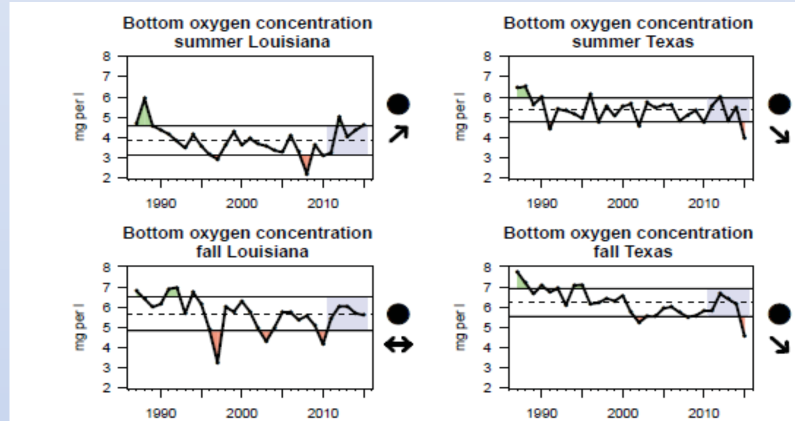


Figure 5.2. Average annual dissolved oxygen concentration values for the Louisiana (left) and Texas (right) coastal shelf, in summer (top) and fall (bottom).

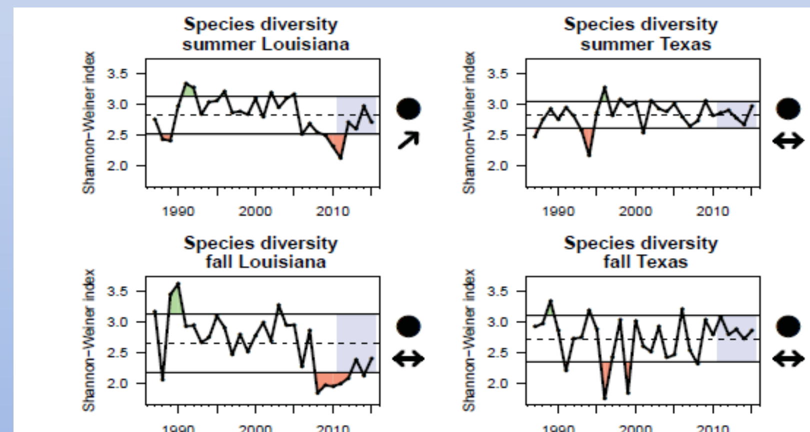


Figure 8.2. Species diversity metrics calculated from the SEAMAP survey. Metrics are reported separately for Louisiana (left) and Texas (right) waters and for summer (top) and fall (bottom) surveys.

http://www.aoml.noaa.gov/ocd/ocdweb/ESR_GOMIEA/

Gulf Integrated Ecosystem Assessment (IEA)

The Ecosystem Status Report is one product of the Gulf IEA

INTEGRATED ECOSYSTEM ASSESSMENT

Provide analytical frameworks to implement ecosystem-based management

- Is a decision-support process that synthesizes and analyzes diverse data and ecosystem model outputs
- Is modular, iterative, scaleable, and adaptable
- Shares a common national framework, yet with regional variation in implementation
- Provides assessments of the ecosystem across and within multiple ocean-use sectors
- http://www.aoml.noaa.gov/ocd/ocdweb/gomiea.html

Movement toward EBFM in the Gulf

NOAA Ecosystem-Based Fisheries Management Policy Statement (published May 2016)

- Defines EBFM and its benefits
- Establish relationship to current legal authorities (e.g., MSA, MMPA, ESA, NEPA)
- Articulate guiding principles

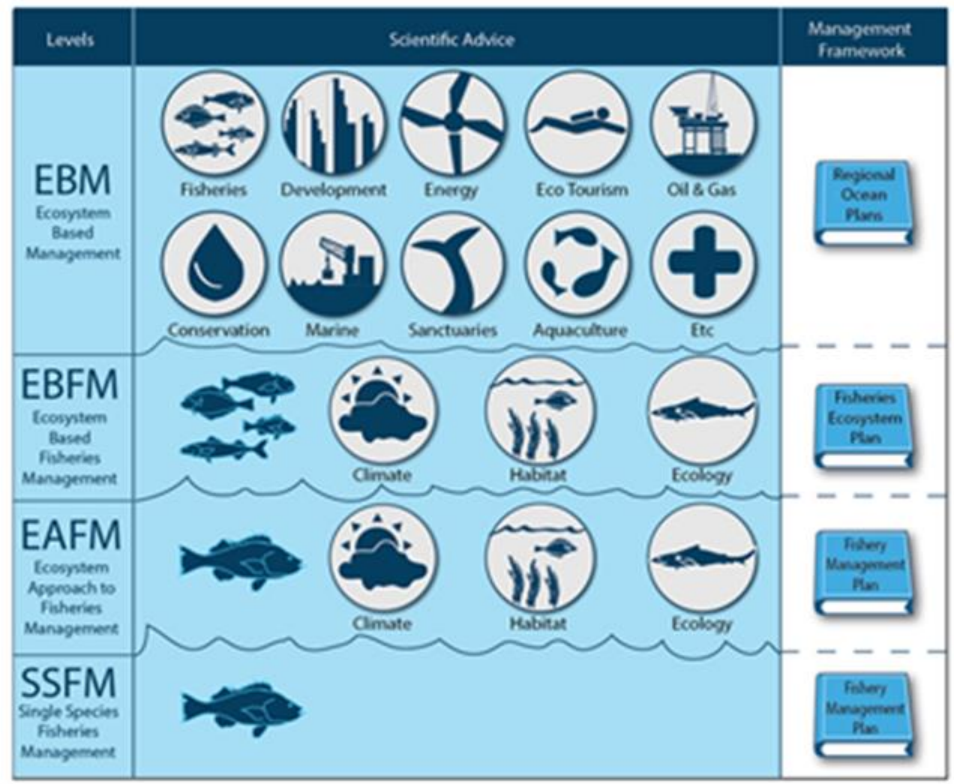
NOAA Fisheries Ecosystem-Based Fisheries Management Road Map (published November 2016)

Gulf of Mexico Ecosystem-Based Fisheries Management Road Map Implementation Plan (currently in review)

Thank You

Levels of Ecosystem-Based Management

Increasing interest in



Provide analytical frameworks to implement ecosystem-based management

- Is a decision-support process that synthesizes and analyzes diverse data and ecosystem model outputs
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PROCEEDINGS OF THE ROYAL SOCIETY B

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Published online

Extensive reproductive disruption, ovarian masculinization and aromatase suppression in Atlantic croaker in the northern Gulf of Mexico hypoxic zone

Peter Thomas* and Md. Saydur Rahman

The University of Texas at Austin, Marine Science Institute, 750 Channel View Drive, Port Aransas, TX 78373, USA

Journal of Experimental Marine Biology and Ecology 381 (2009) S38–S50

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

ELSEVIER

Biomarkers of hypoxia exposure and reproductive function in Atlantic croaker: A review with some preliminary findings from the northern Gulf of Mexico hypoxic zone

Peter Thomas *, Md. Saydur Rahman

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Marine Environmental Research 69 (2010) S59–S62

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

ELSEVIER

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Peter Thomas *, Md. Saydur Rahman

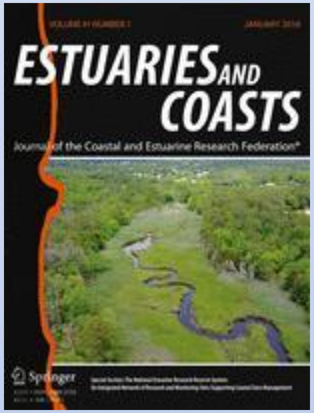
University of Texas at Austin, Marine Science Institute, 750 Channel View Drive, Port Aransas, Texas 78373, USA

Estuaries and Coasts (2018) 41:233–254
DOI 10.1007/s12237-017-0266-6

CrossMark

Modeling the Population Effects of Hypoxia on Atlantic Croaker (*Micropogonias undulatus*) in the Northwestern Gulf of Mexico: Part 1—Model Description and Idealized Hypoxia

Kenneth A. Rose[1,2] · Sean Creekmore[1] · Peter Thomas[3] · J. Kevin Craig[4] ·
Md Saydur Rahman[5] · Rachael Miller Neilan[6]



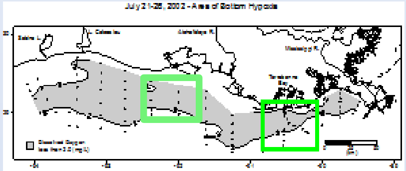
Estuaries and Coasts (2018) 41:255–279
DOI 10.1007/s12237-017-0267-5

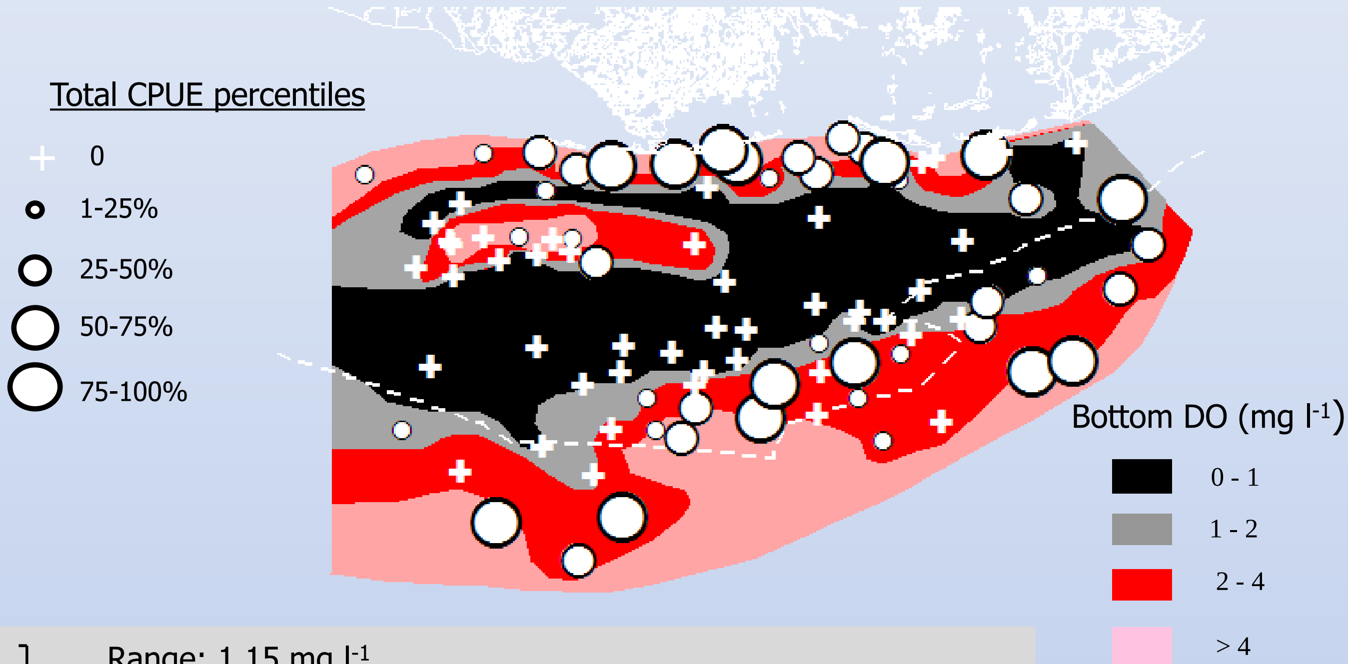
CrossMark

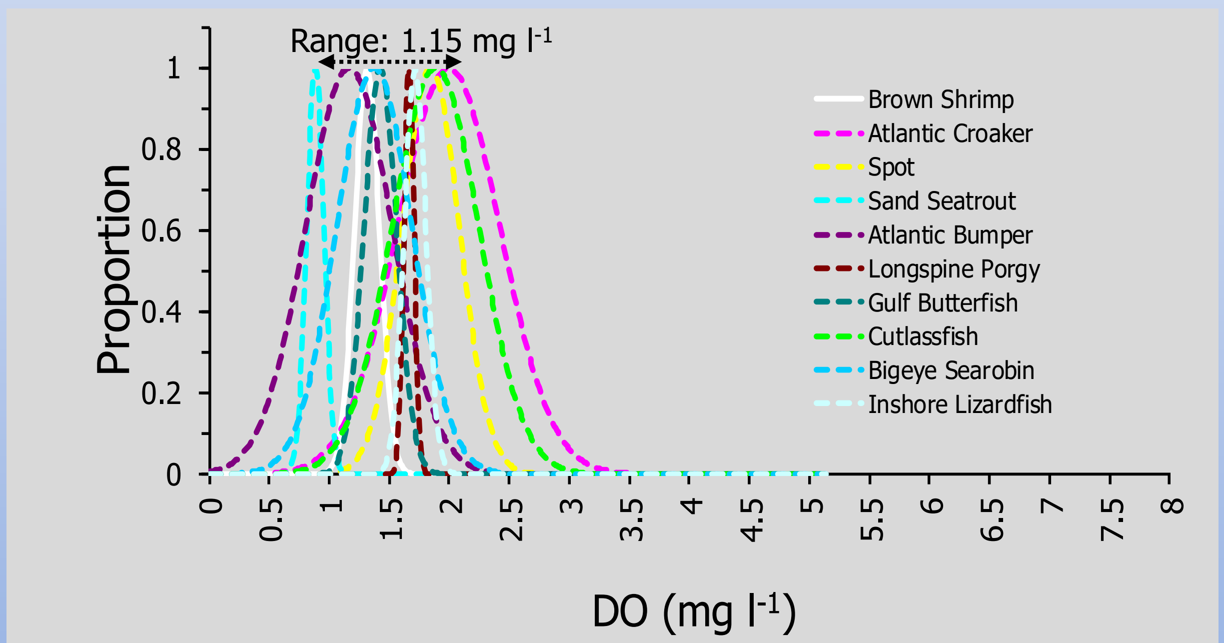
Modeling the Population Effects of Hypoxia on Atlantic Croaker (*Micropogonias undulatus*) in the Northwestern Gulf of Mexico: Part 2—Realistic Hypoxia and Eutrophication

Kenneth A. Rose[1,2] · Sean Creekmore[1] · Dubravko Justić[1] · Peter Thomas[3] ·
J. Kevin Craig[4] · Rachael Miller Neilan[5] · Lixia Wang[1] · Md Saydur Rahman[6] ·
David Kidwell[7]

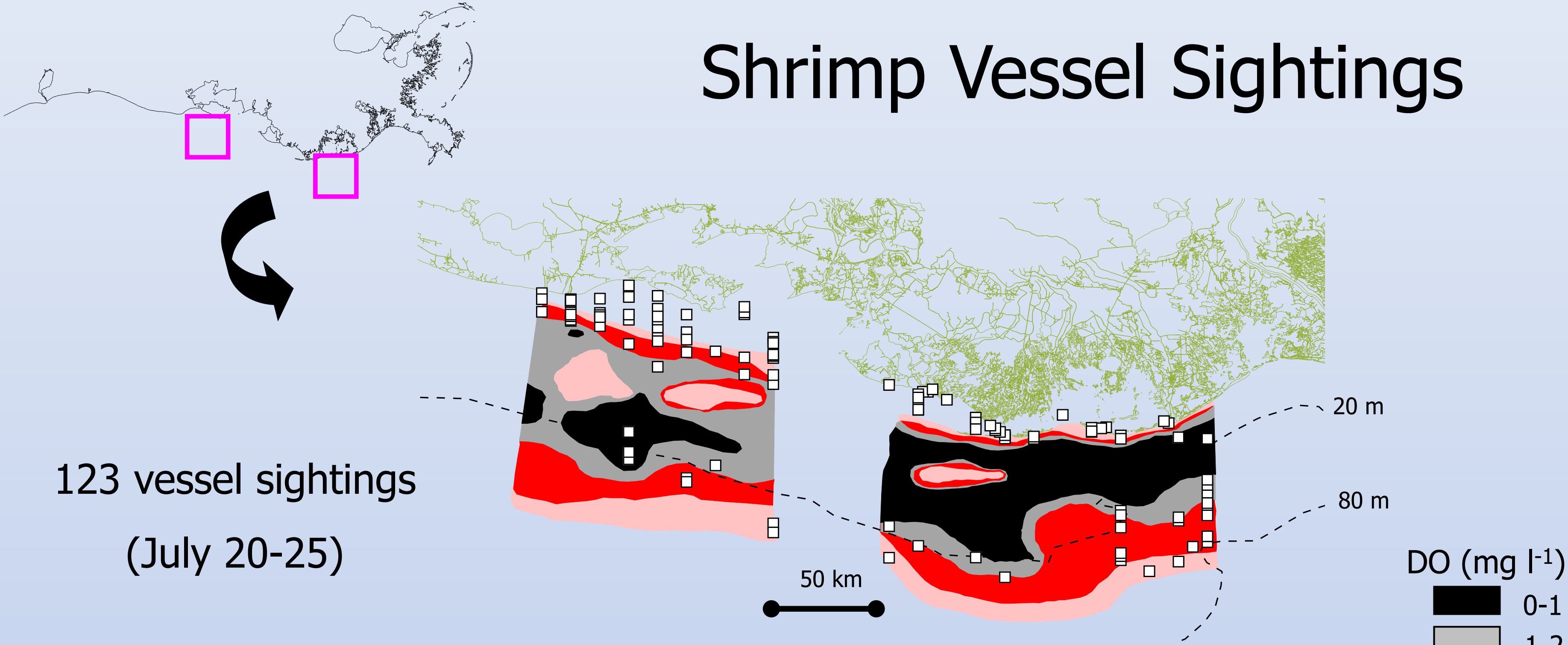
Hypoxia Avoidance Thresholds





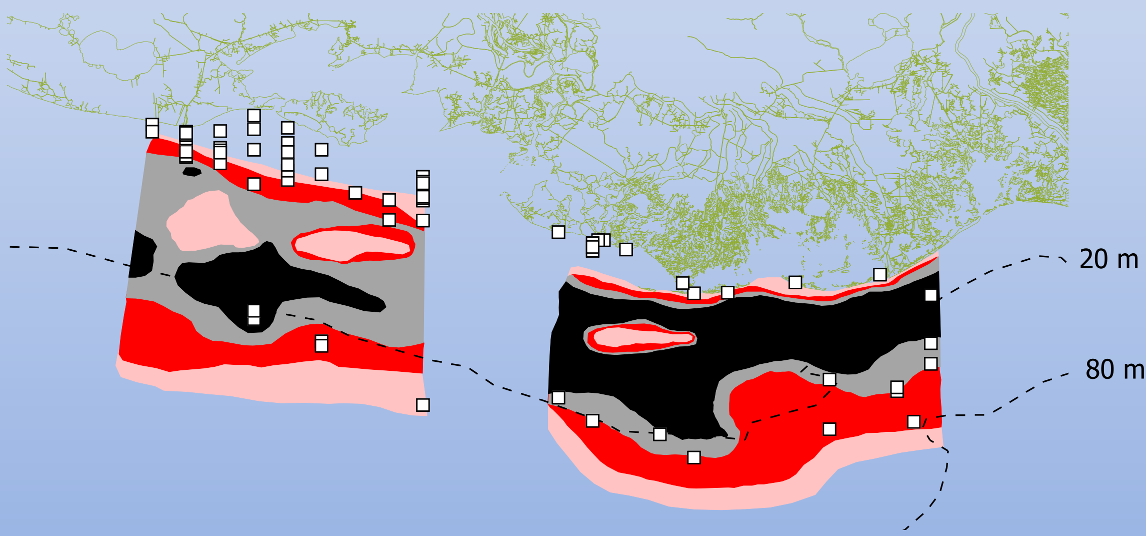


Shrimp Vessel Sightings



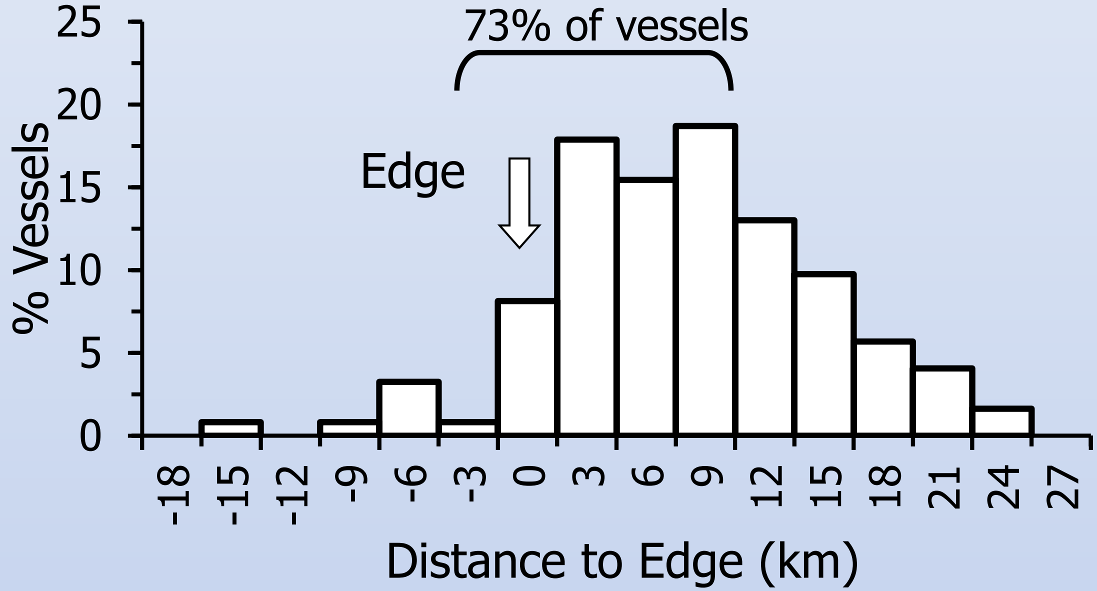
123 vessel sightings

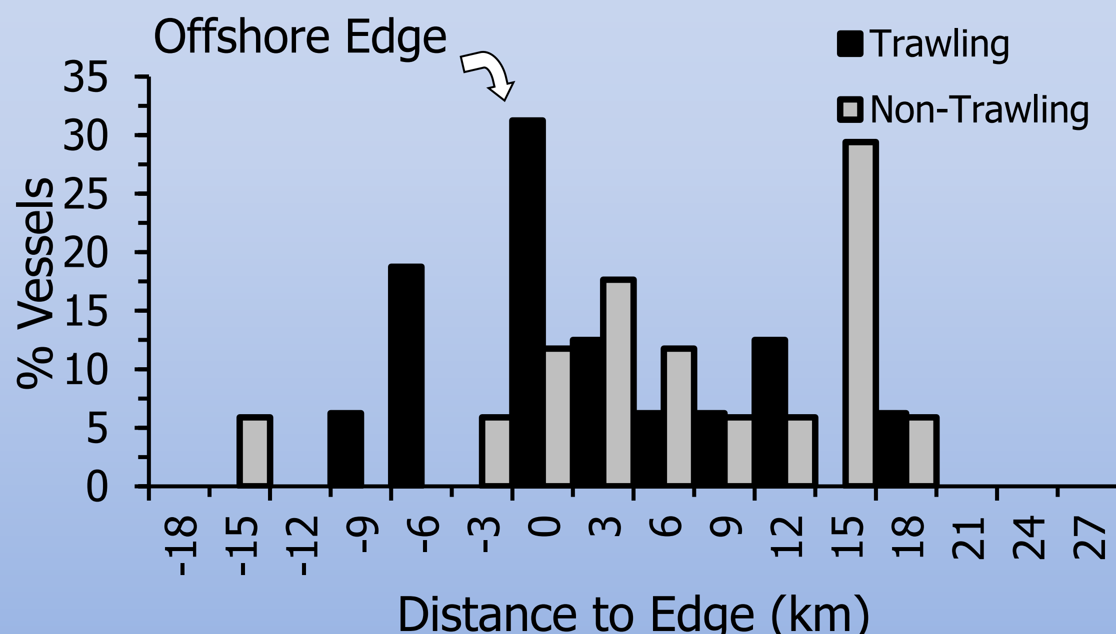
(July 20-25)



Trawling Vessels
(65%)

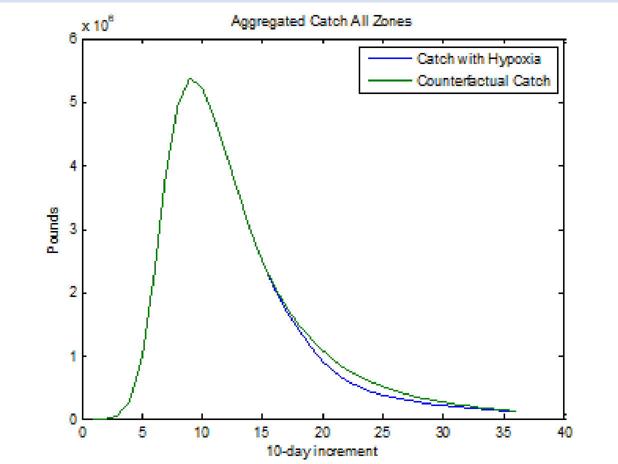
Shrimpers Target Hypoxic Edges



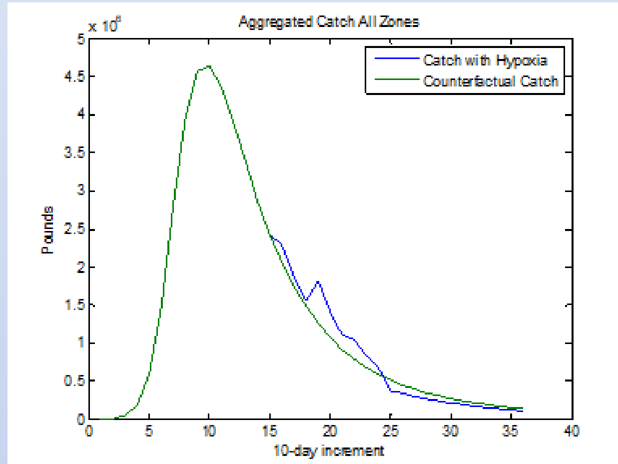


Example-1 yr Simulations

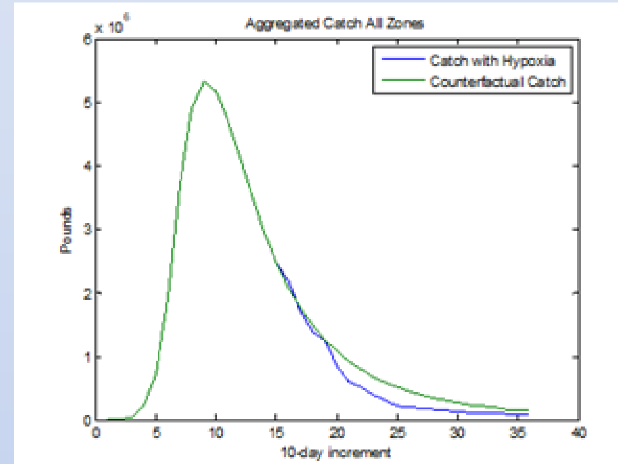
Growth only
(Dynamic, nonlinear, subtle)



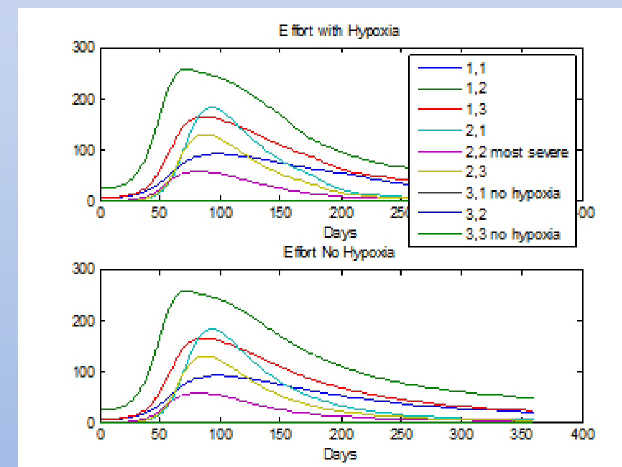
Catchability only
(Non-monotonic)



Growth, mortality and catchability



Contamination of controls



- Net effect of hypoxia can be positive or negative
- Direction and magnitude of effect varies over the season
- Mobility of shrimp fleet contaminants (nonhypoxic) controls

Key Lesson: Detecting hypoxia effects from perfect catch data would be difficult

Time Series Modeling of Brown Shrimp Prices

Hypothesis: Relative price of large to small shrimp increases with increasing hypoxia severity

$$\frac{P_{L,t}}{P_{S,t}} = \alpha + \beta H_{k,t} + \gamma(P_{s,t}) + \boldsymbol{X_t}(\boldsymbol{\theta}) + \epsilon_{L,t}$$

$\text{Price}_{\text{large shrimp}}$ / $\text{Price}_{\text{small shrimp}}$ = hypoxia severity + covariates

<u>Data</u>

- Monthly sizes-based prices (1990-2010; 252 observations)

<u>Covariates</u>

- Hypoxic area and volume
- Diesel fuel price (influences effort--major driver of variable costs)
- Sea surface temperature (could influence supply, i.e., via recruitment)
- Monthly dummy variables

<u>Permutations</u>

- 3 separate large shrimp categories (<15, 15-20, 20-25 count)
- 3 separate (reference) small shrimp categories (30-40, 40-50, 50-67 count)
- Hypoxia area and volume via two alternative interpolation methods

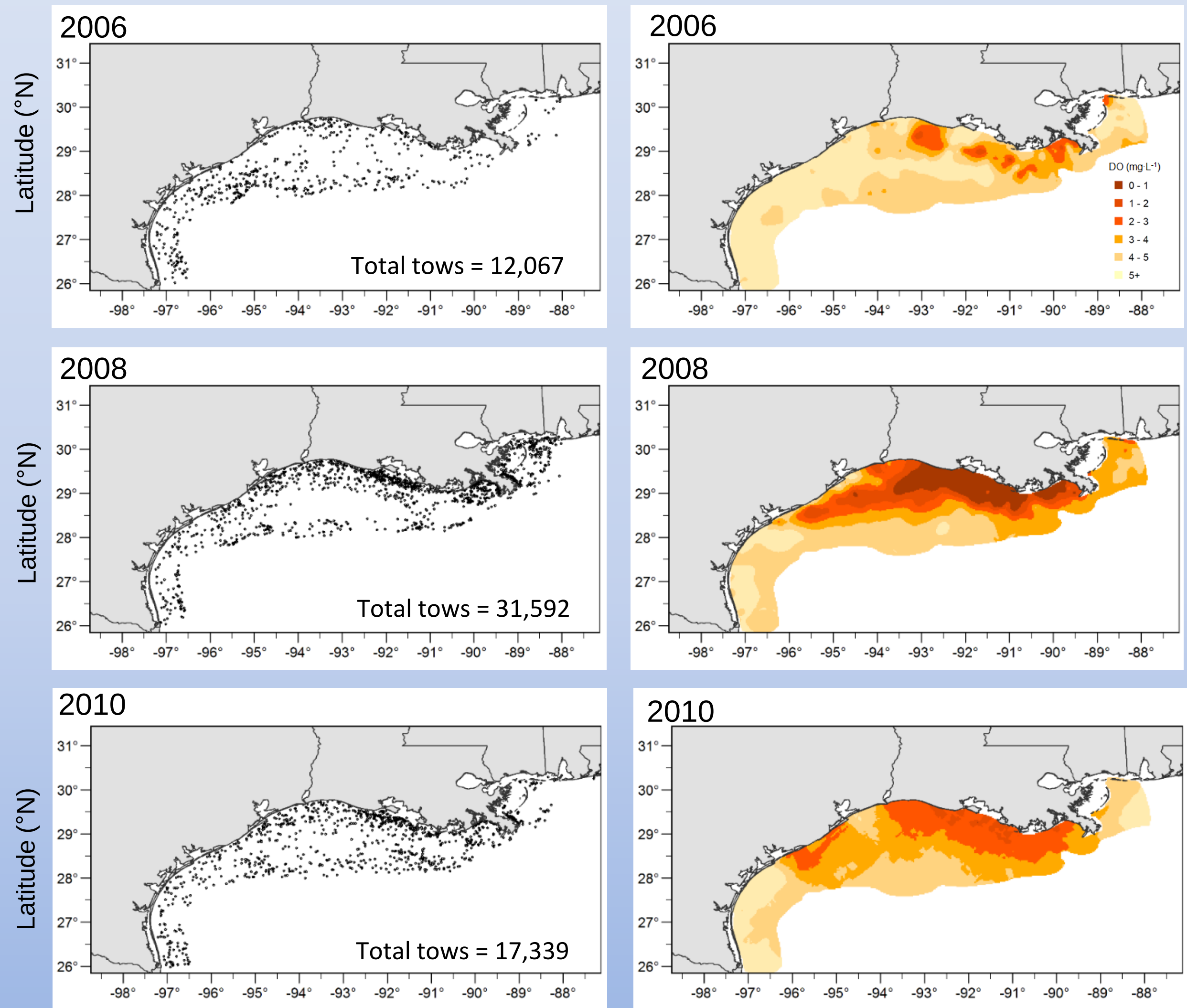
Shrimp Fishery Electronic Logbooks

Merged with bottom DO from SEAMAP trawl and hydrographic survey

- FI trawl and hydrographic survey (~300 stations/ yr)
- Interpolate bottom DO from annual SEAMAP surveys (June-July)
- Censor ELB data to match temporal scale of DO interpolation
- Smooth interpolated surface to account for uncertainty in DO data and trawl path
- Aggregate tow and DO data to 10 min x 10 min grid
- Synoptic on a scale of 1-2 weeks and 30-40 km

Randomly selected 10% of ELB tows

Interpolated bottom DO (SEAMAP)



Longitude (°W)

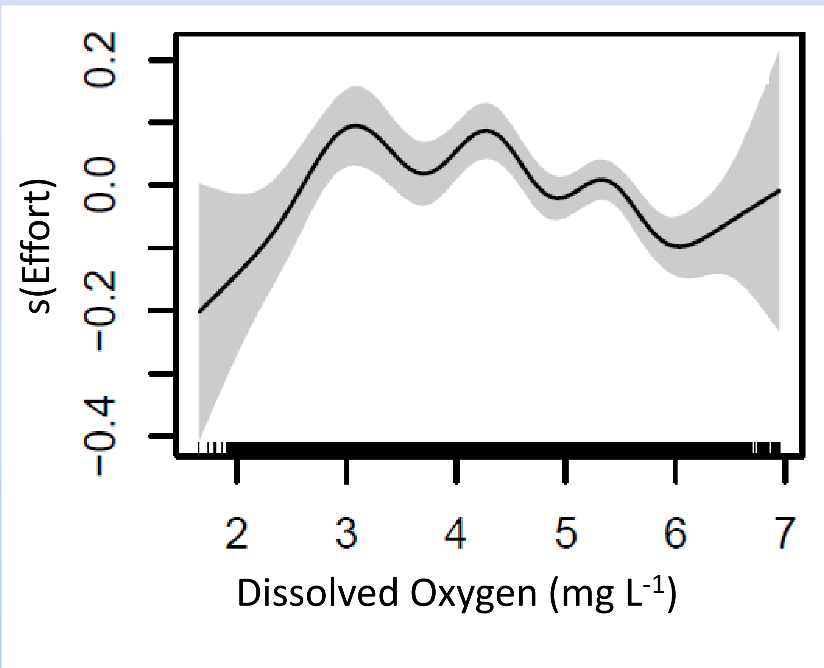
Longitude (°W)

Partial Effect of DO on Shrimping Effort

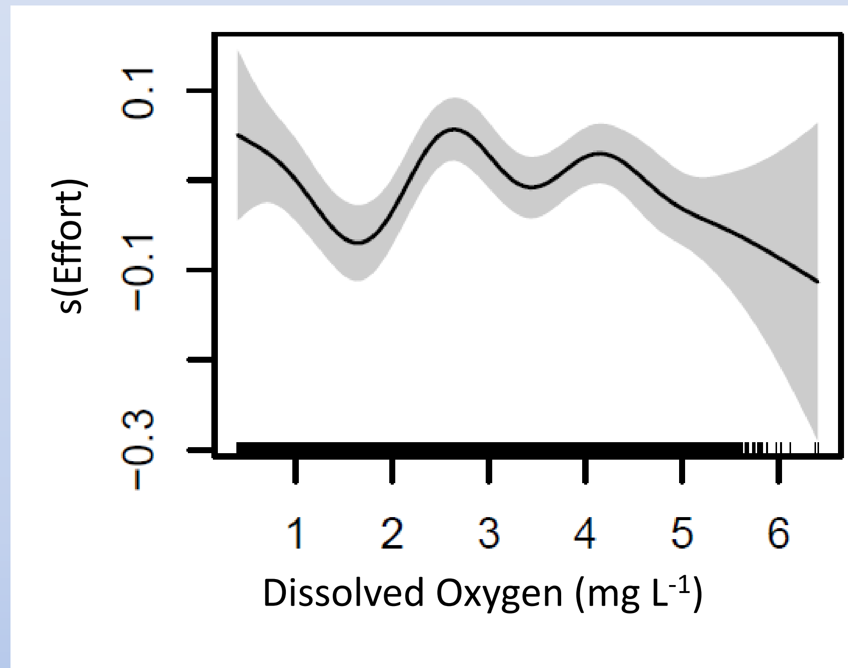
(averaged over space)

Texas Shelf

2005-2010



Louisiana Shelf



Avoidance of limited areas of low DO

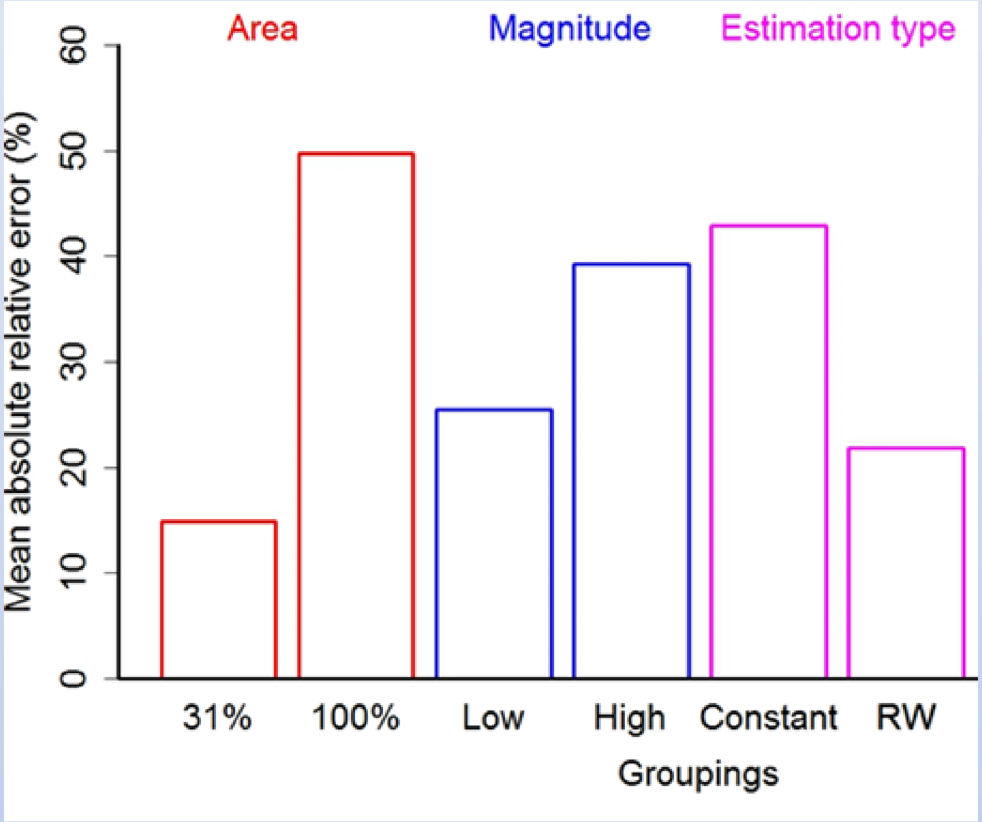
- Mouths of major estuaries
- Extension of Miss. Plume west

Some avoidance of low DO

- Hypoxia extends over most of shrimping grounds
- Shrimpers active in and around low DO water

Purcell et al. (2017)

Hypoxia Effects on Fishing Mortality Reference Points



Langseth et al. (2016)

- Magnitude of the effect is highly uncertain
- Maximum estimates of bias assuming effects persist over the entire fishing season (May-Sept)
- Depends strongly on the proportion of the fleet affected by hypoxia
- Need better understanding of within-season spatio-temporal dynamics of hypoxia and the fishing process