Predicting the population-level effects of hypoxia on Atlantic croaker in the northwestern Gulf of Mexico

Sean Creekmore and Kenneth A. Rose
Department of Oceanography and Coastal Sciences
Louisiana State University

Peter Thomas and Md. Saydur Rahman
Marine Science Institute
University of Texas

J. Kevin Craig
Southeast Fisheries Science Center
National Marine Fisheries Service

Rachael Miller-Neilan
Department of Mathematics and Computer Science
Duquesne University

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NCCOS

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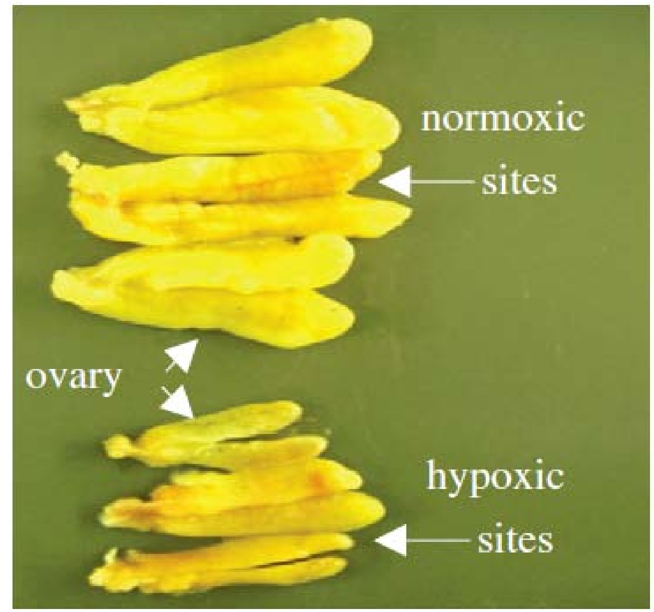
Does hypoxia have population level effects on coastal fish?

- Surprisingly little conclusive evidence for population level effects
- Multiple stressors and compensatory mechanisms make detecting the effects of hypoxia difficult
- Need for populations studies that quantify exposure and separate hypoxia effects from other stressors

What are the long-term effects of hypoxia on Atlantic croaker in the NWGOM?

- Croaker good test case
  - Well studied
  - Mobile, demersal
  - Tolerant to hypoxia
  - Fecundity affected by hypoxia



** Thomas and Rahman 2011*

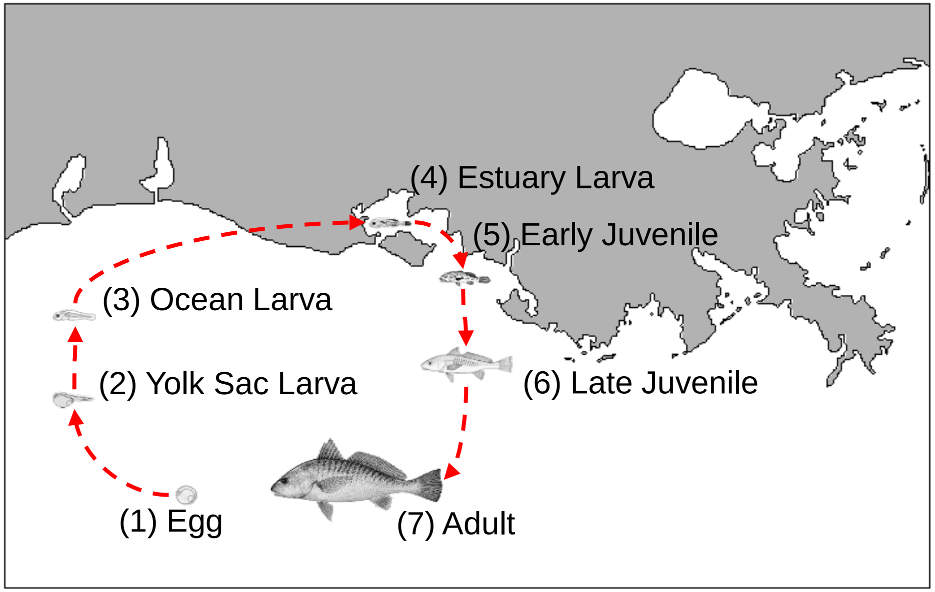
Quantifying Exposure and Determining Effects

- Approach: population model
  - Exposure determined by movement
  - Effects determined by exposure and applied to growth, mortality, and reproduction

- Strategy:
  - Keep most things constant
  - No food web interactions

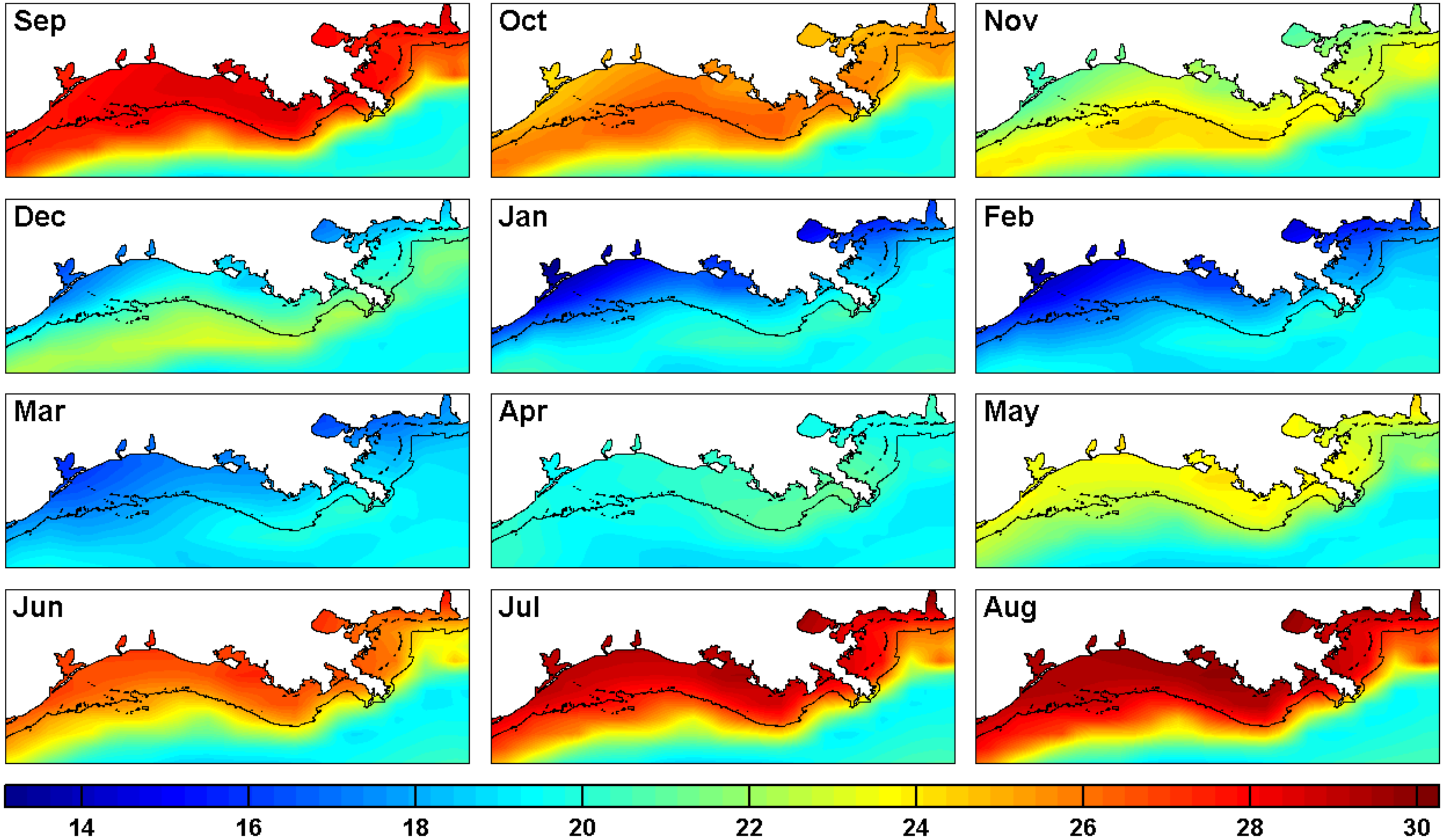
Model Overview

- Spatially explicit, IBM
  - Follows 7 stages to age 8
  - Model year begins Sep. 1
  - Each year 365 days long
- Hourly processes
  - Growth
  - Mortality
  - Reproduction
  - Movement



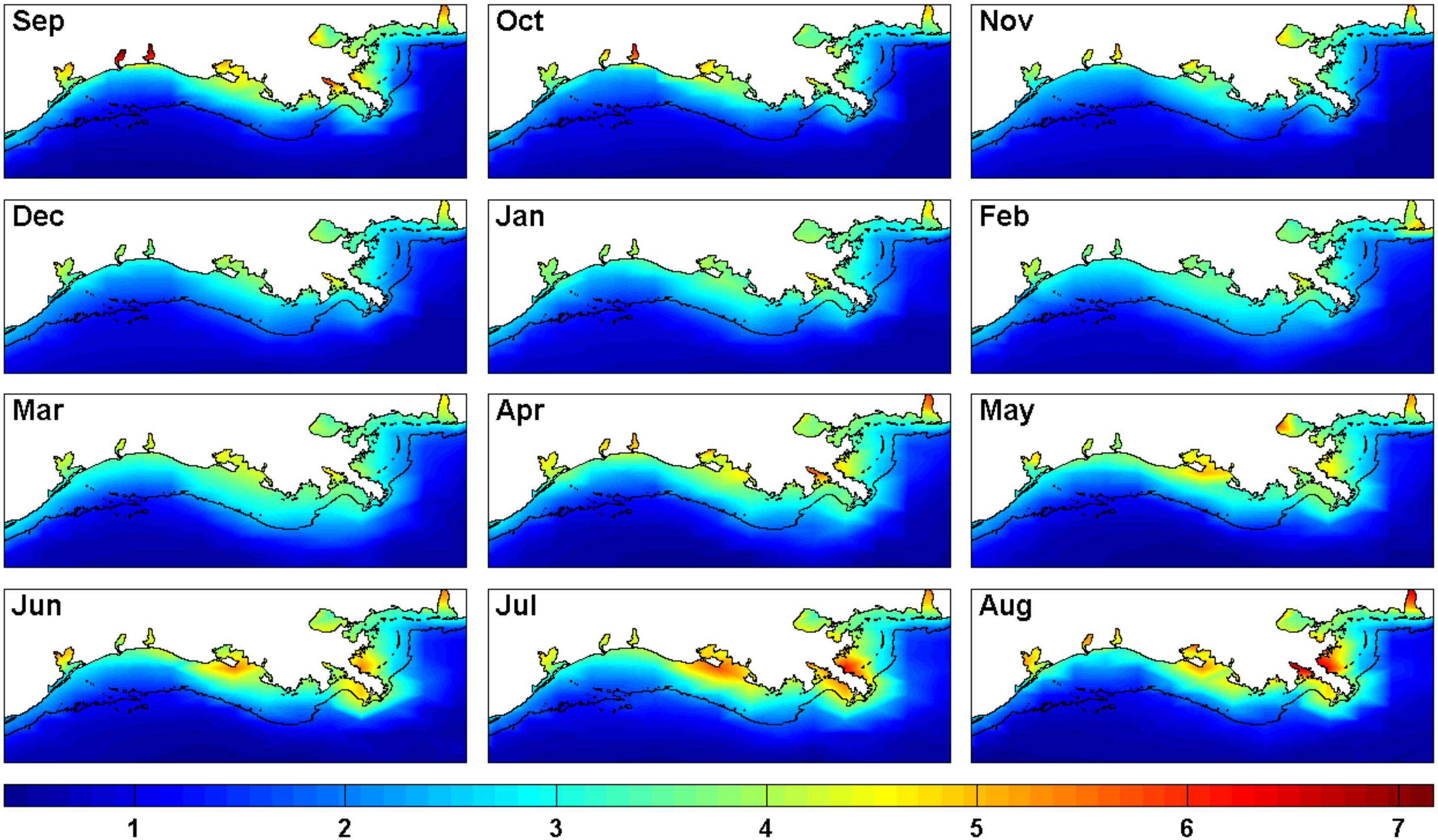
- Environmental conditions simulated on a 2-D spatial grid (1 km resolution)
  - bottom temperature and dissolved oxygen
  - surface chlorophyll

Environmental Variables: Temperature

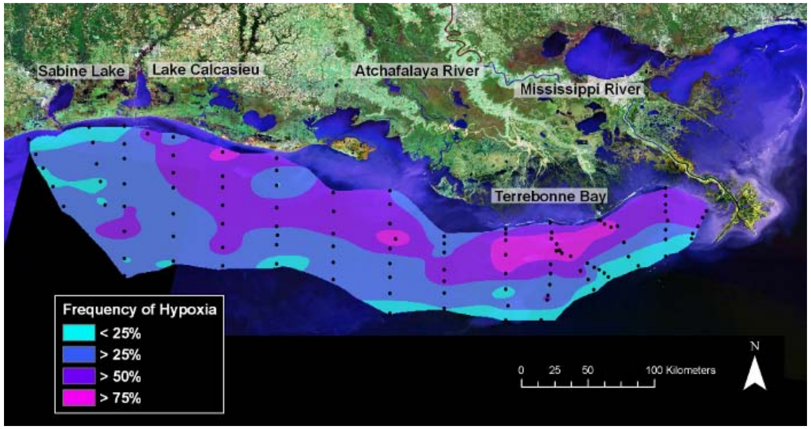


Environmental Variables: Chlorophyll-a

(mg/m^3, sqr-transformed)

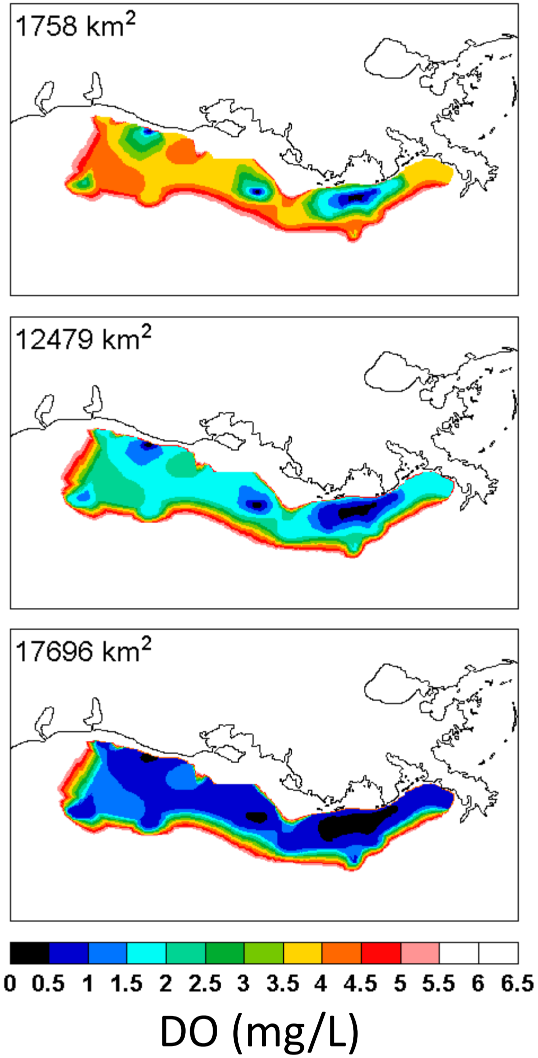


Environmental Variables: Oxygen



www.gulfhypoxia.net

- Baseline: normoxic all year
- Hypoxia
  - June1-7, DO in hypoxic zone declines from 8 mg/L to specified local minimum
  - low DO from June to August
- Scenarios: mild, intermediate, & severe



Model Processes

- Growth
  - Development of early stages proportional to averaged daily °C
  - For juvenile and adults, bioenergetics model with weight, cell C and cell Chl-a (index of food) as inputs
- Reproduction
  - 1:1 sex ratio
  - September to March spawning season
- Mortality
  - Stage-specific
  - Late juvenile stage density dependent
- Movement (juveniles and adults)
  - If DO > 2.0 mg/L, response to cell temperature (kinesis)
  - If DO ≤ 2.0 mg/L, search 80 surrounding cells for best °C and DO

Direct Effects of Low DO

- June-August
- Only imposed on late juveniles, age-1 adults, and age-2 adults
- Exposure-effects sub-models (Neilan and Rose, in prep), calibrated and tested using 10 lab experiments on constant and fluctuating DO, used to follow 3 state variables:
  - reproductive vitality (Vr), affected by *last 10 weeks* when DO < **4.0 mg/L**
  - growth vitality (Vg), affected when G was positive and DO < **3.0 mg/L**
  - survival vitality (Vs), affected when DO < **1.25 mg/L**

$$Vg, Vr, or\ Vs = \begin{cases} 1 - \alpha \dfrac{(DO - DO_{NE})^2}{(DO - DO_{NE})^2 + \beta^2} & \text{if } DO < DO_{NE} \\ 1 & \text{if } DO \geq DO_{NE} \end{cases}$$

- Vg and Vs are reset to 1.0 on Sep 1; Vr not reset until Jun 1

Design of Simulations

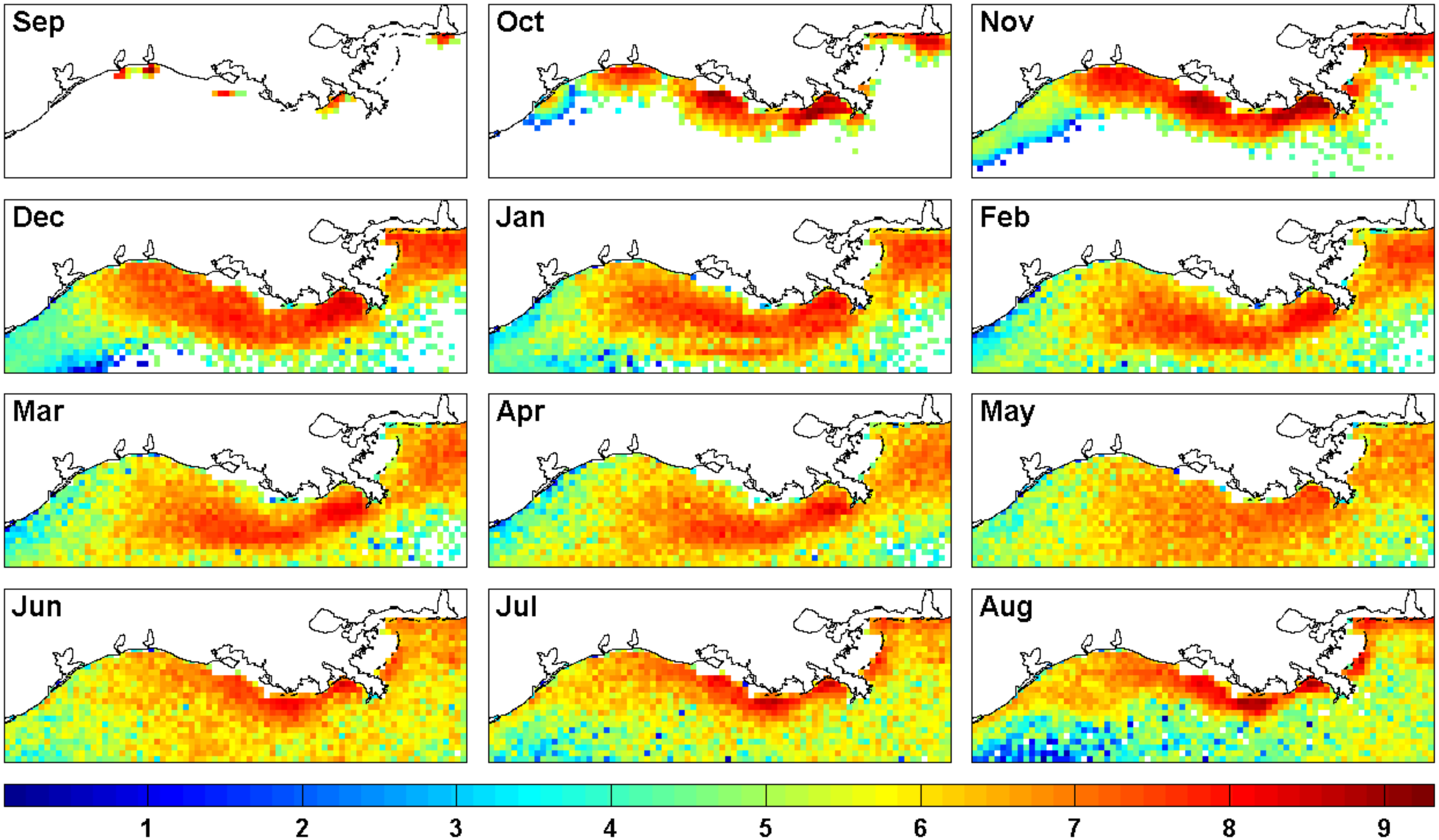
- Calibration of baseline (not shown)
- 100 years simulated in each run, first 20 years ignored
- Hypoxia effects simulations (3)
  - Repeated years of either mild, intermediate, or severe hypoxia
- Time series simulation (12 replicate runs)
  - Each year had a 0.12, 0.40, and 0.38 probability of being either mild, intermediate, or severe
- Some sensitivity analysis (replicate #6)
  - If DO < 1.5mg/L, individuals search 24 cells for best °C and DO
  - Combinations of each of the 3 vitality sub-models set to 1.0

Model Outputs

- Hypoxia Effects
  - Average age 2+ total abundance (years 61-100)
  - Hourly percent exposure
  - Hourly vitality values
  - Percent exposure on September 1
  - Growth, mortality, and reproduction

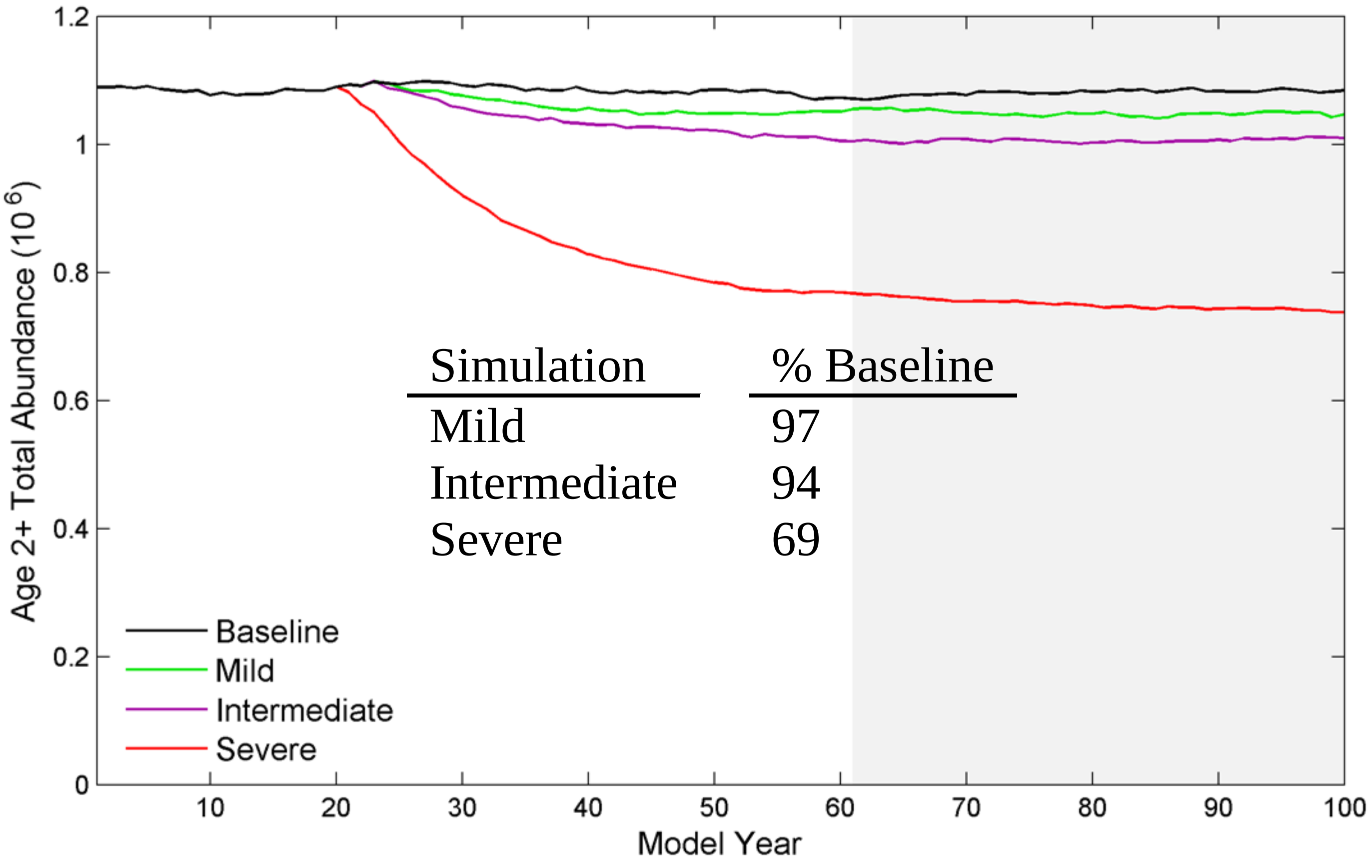
- Sensitivity Analysis
  - % change from baseline age 2+ abundance (years 61-100)

Baseline Age-1 Adult Distribution



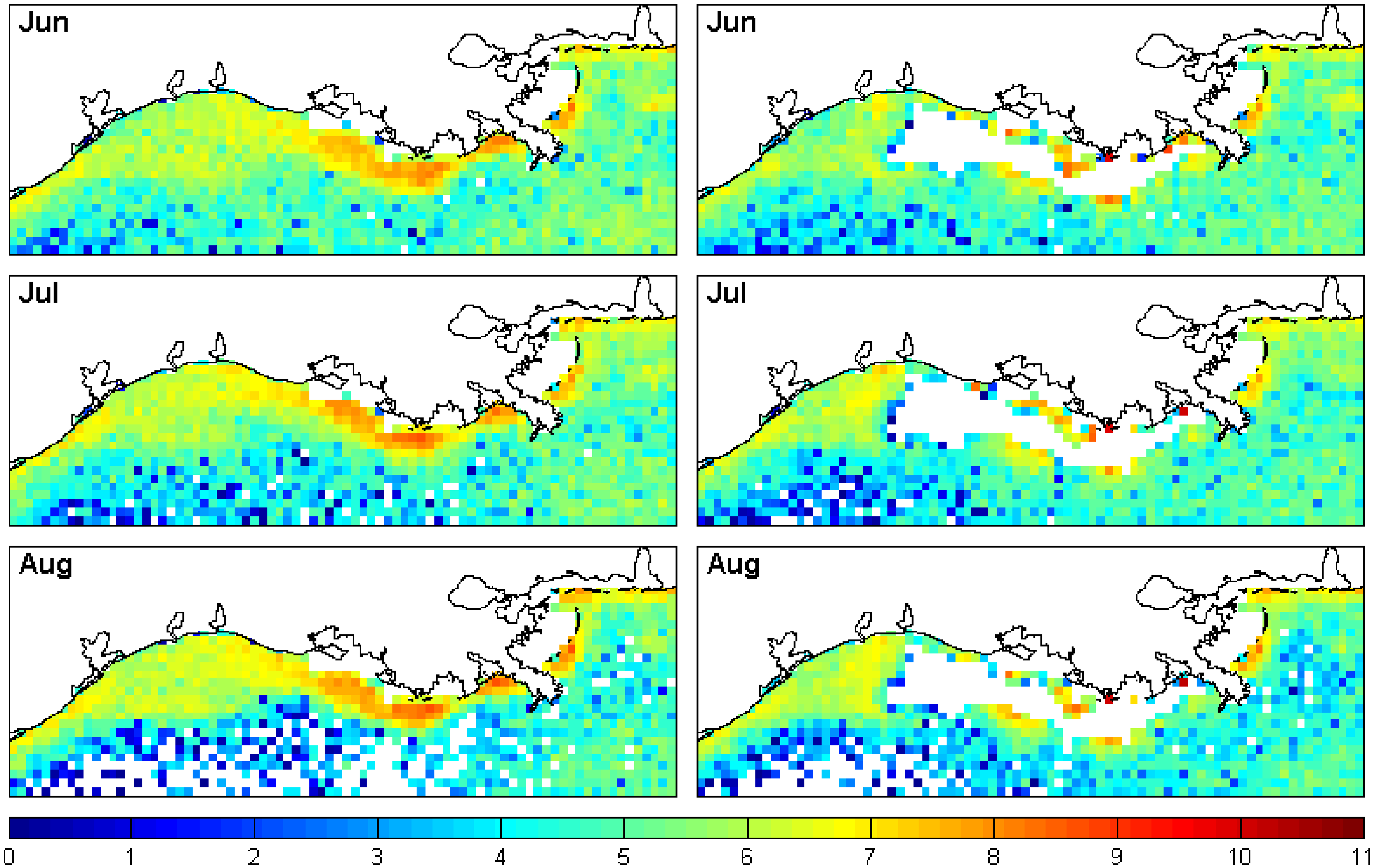
(fish / 10 km^2, ln-transformed)

Hypoxia Effects: Mild, Intermediate, Severe



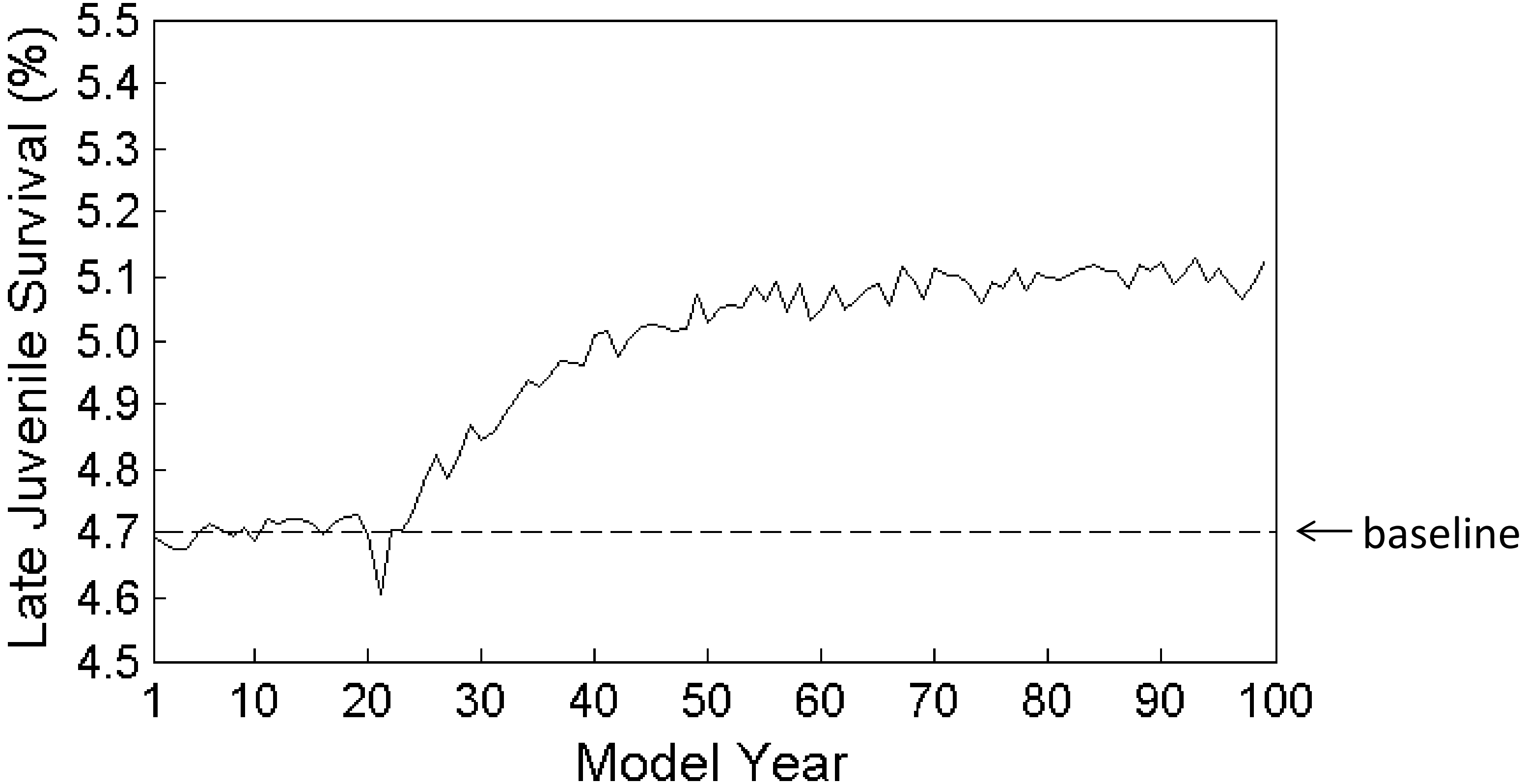
Simulation	% Baseline
Mild	97
Intermediate	94
Severe	69

Hypoxia Effects: Severe



(fish / 10 km², ln-transformed)

Hypoxia Effects: Severe

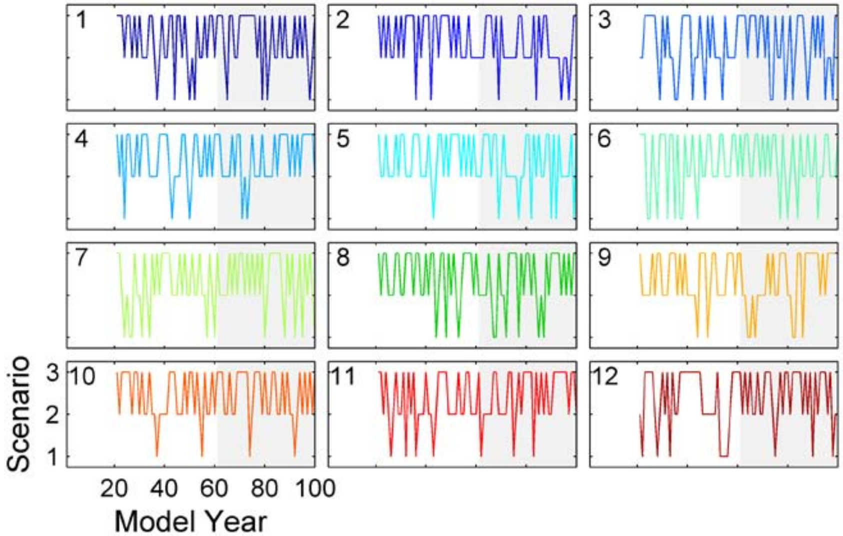


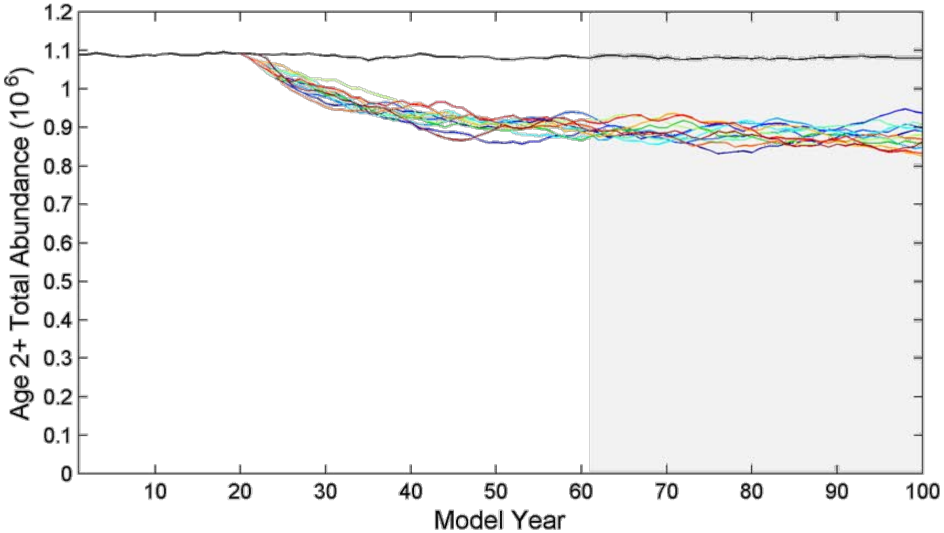
Hypoxia Effects: Severe

- Percent of surviving age-1 and age-2 individuals on Sep. 1 ever exposed to DO < 4.0 mg/L the previous summer was 23% and 60% for years 61-100
- 1% of incoming late juveniles and 2% of incoming age-1 and age-2 individuals died from hypoxia each year …
- No detectable change (<2%) in beginning weight-at-age …
- Eggs per gram (EPG) and eggs per individual (EPI) for ages 1 and 2 decreased by 5% …

Age	Baseline			Severe		
	SSB	EPG	EPI	SSB	EPG	EPI
1	25.5	93.8	6416	18.6	93.5	6507
2	57.7	96.5	19717	40.9	92.0	18814
3	64.7	97.0	32826	44.6	93.4	31397
4	57.0	97.3	43927	39.3	97.2	43605
5	44.6	97.4	52647	30.8	97.4	52278
6	32.6	97.4	59209	22.5	97.4	58859
7	22.9	97.4	64030	15.8	97.4	63721

Time Series





*scenario: 1 = mild, 2 = intermediate, and 3 = severe

- Average age 2+ abundance for model years 61-100 ranged from 87-89% of baseline abundance

Sensitivity Analysis: Some Outcomes

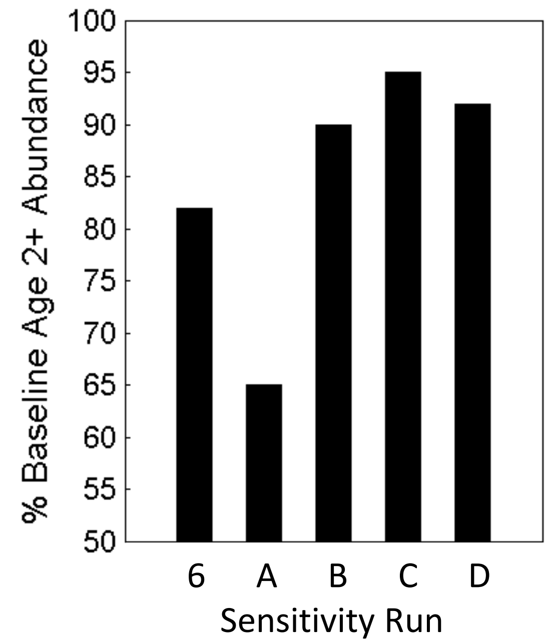
6. Age 2+ abundance was 82% of baseline in replicate 6

A. Age 2+ abundance was 65% of baseline when both the trigger for avoidance was reduced from 2.0 mg/L to 1.5 mg/L and the size of the search area was reduced from 80 cells to 24 cells

B. Vs alone caused a 10% reduction in age 2+ abundance

C. Vr alone …8% reduction

D. Vg alone …5% reduction



Summary: Effects of Hypoxia

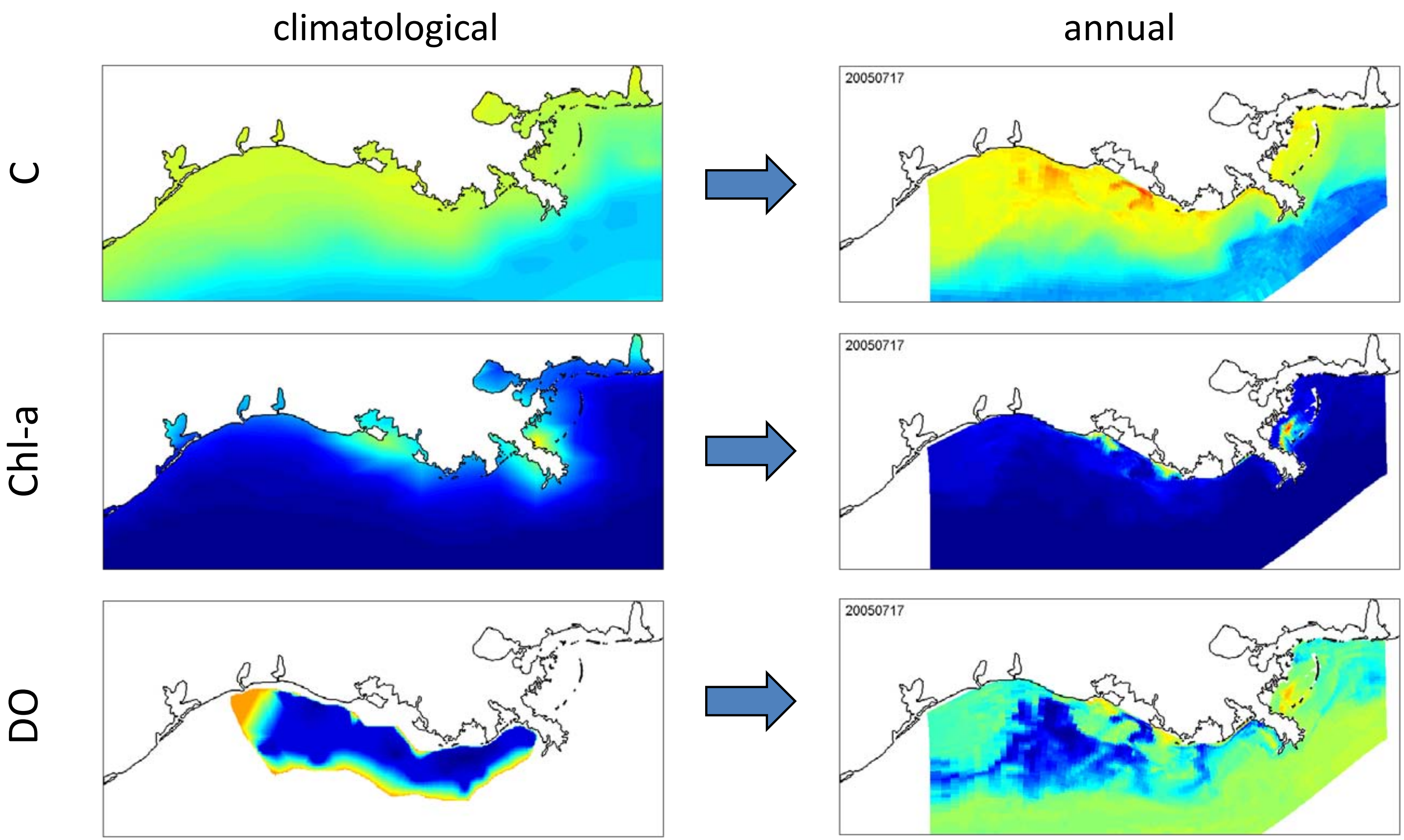
- Under repeated environmental conditions, 80 years of severe seasonal hypoxia caused a 31% reduction in long-term abundance.

- Under more realistic hypoxia conditions, the model predicted an 11-13% decrease in long-term abundance

- Predicted declines in abundance were primarily due to direct effects operating on mortality and reproduction

- Model predictions were sensitive to assumptions concerning avoidance behavior

Ongoing Analyses: Daily Conditions from 3D Hydrodynamics Model (2004-2009)



Output provided by: K. Fennel – Dalhousie University, Halifax, Nova Scotia
R. Hetland, Y.Feng, and S. DiMarco – Texas A&M, College Station

Next Steps

- Incorporate empirical data (scanfish) on fine scale spatial variability in DO
- Better quantify exposure using "smart particle" tracking experiments
- Corroborate exposure and effects estimates using data from laboratory and field studies
  - Hypoxia-inducible factor (HIF)
  - SEAMAP data
  - Shelf-wide fecundity surveys
- Reassess strength of density dependence and stage(s) at which it occurs