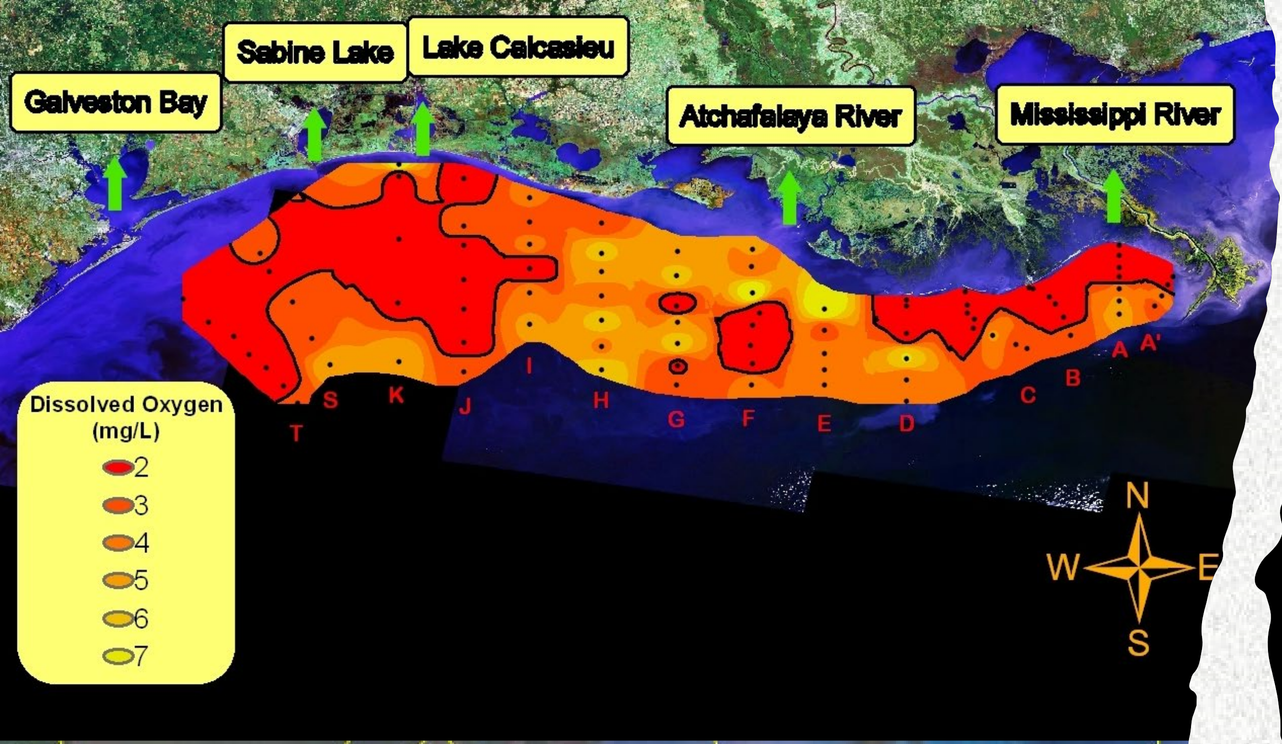
Adding a Spatial Component to Ecosystem Modeling

Kim de Mutsert
School of Ocean Science and Engineering
The University of Southern Mississippi

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

Including Effects of Environmental Factors on Living Resources is a Spatial Issue

- Environmental stressors vary spatially and temporally
- Suboptimal conditions can have sublethal and lethal effects on living resources, and result in movement

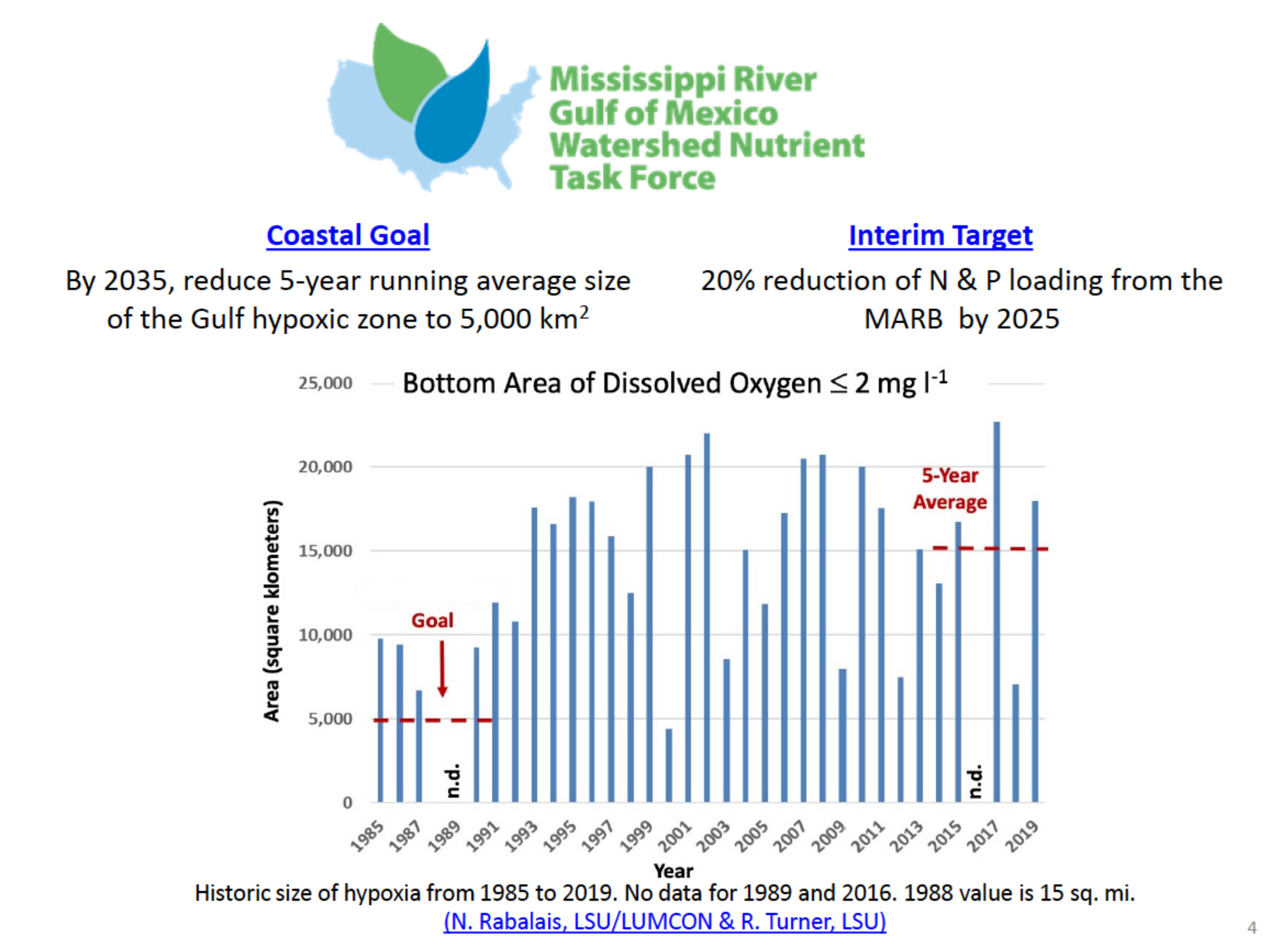


Two Studies Relevant to Gulf Menhaden

- Effects of the hypoxic zone on fish and fisheries
- Effects of large sediment diversions on the estuarine food web

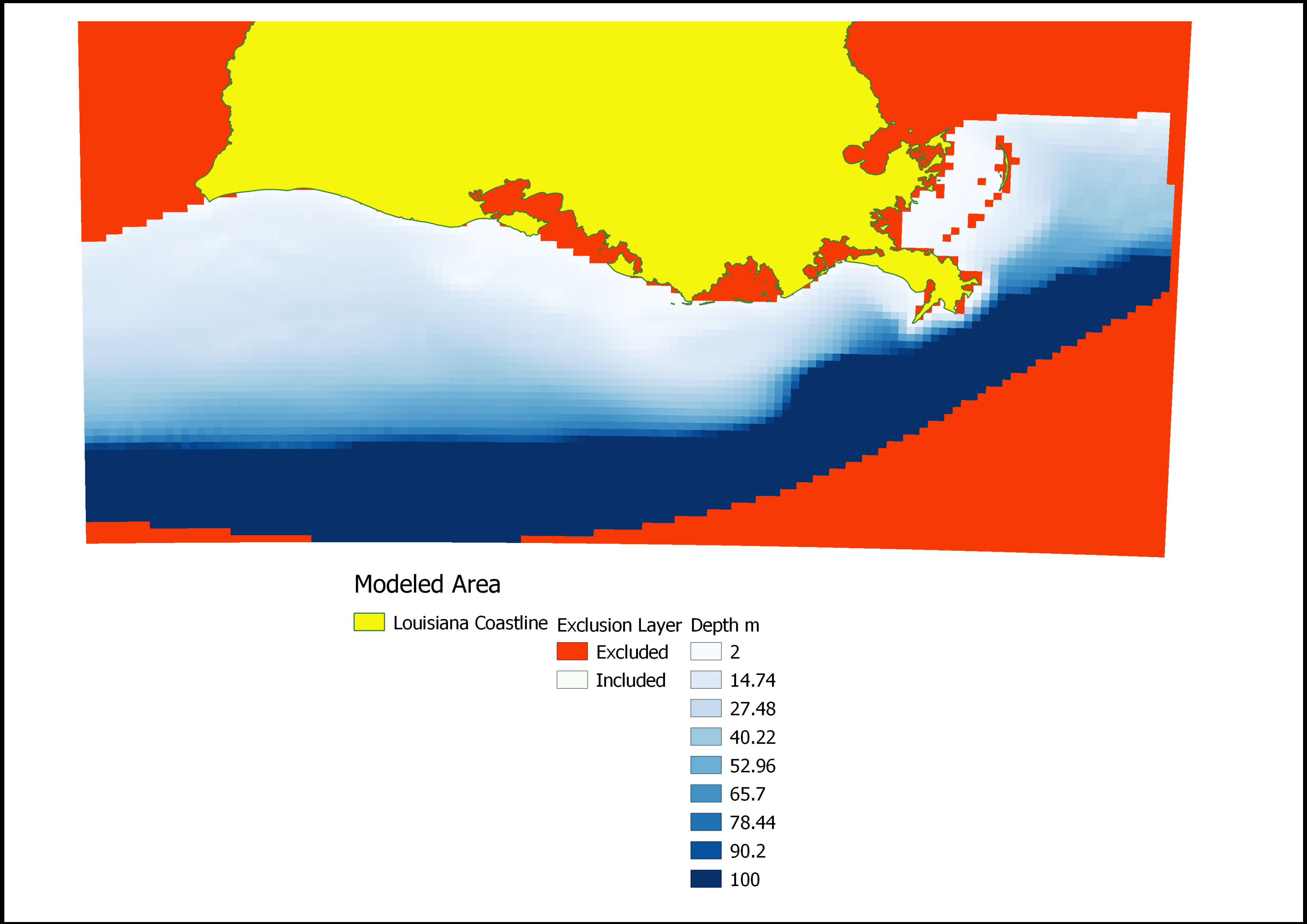
Hypoxia

- What is the effect on living resources of reductions in nutrient loading to reach the goal of the hypoxia task force to reduce the size of the hypoxic zone to 5,000 km^2?



Model Development

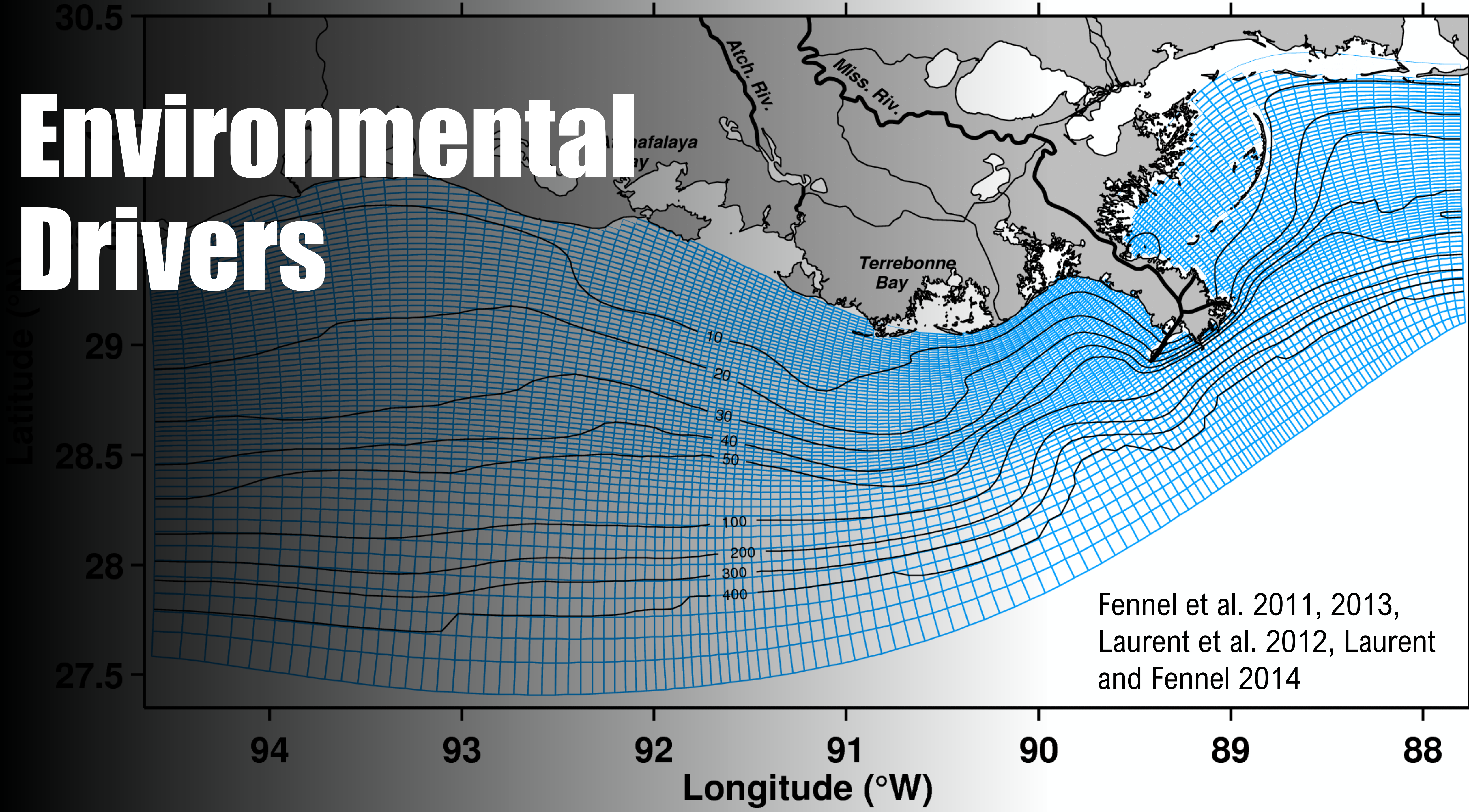
- Ecopath: Mass-balanced "snapshot" of an ecosystem (initial conditions of the model; food web representing the northern Gulf of Mexico with 66 groups)
- Ecosim: Temporal dynamic simulations (used for model calibration)
- Ecospace: Spatial-temporal modeling (framework of the model)



Model Domain

- 5 km^2 grid cells
- 10318 cells
- 2D

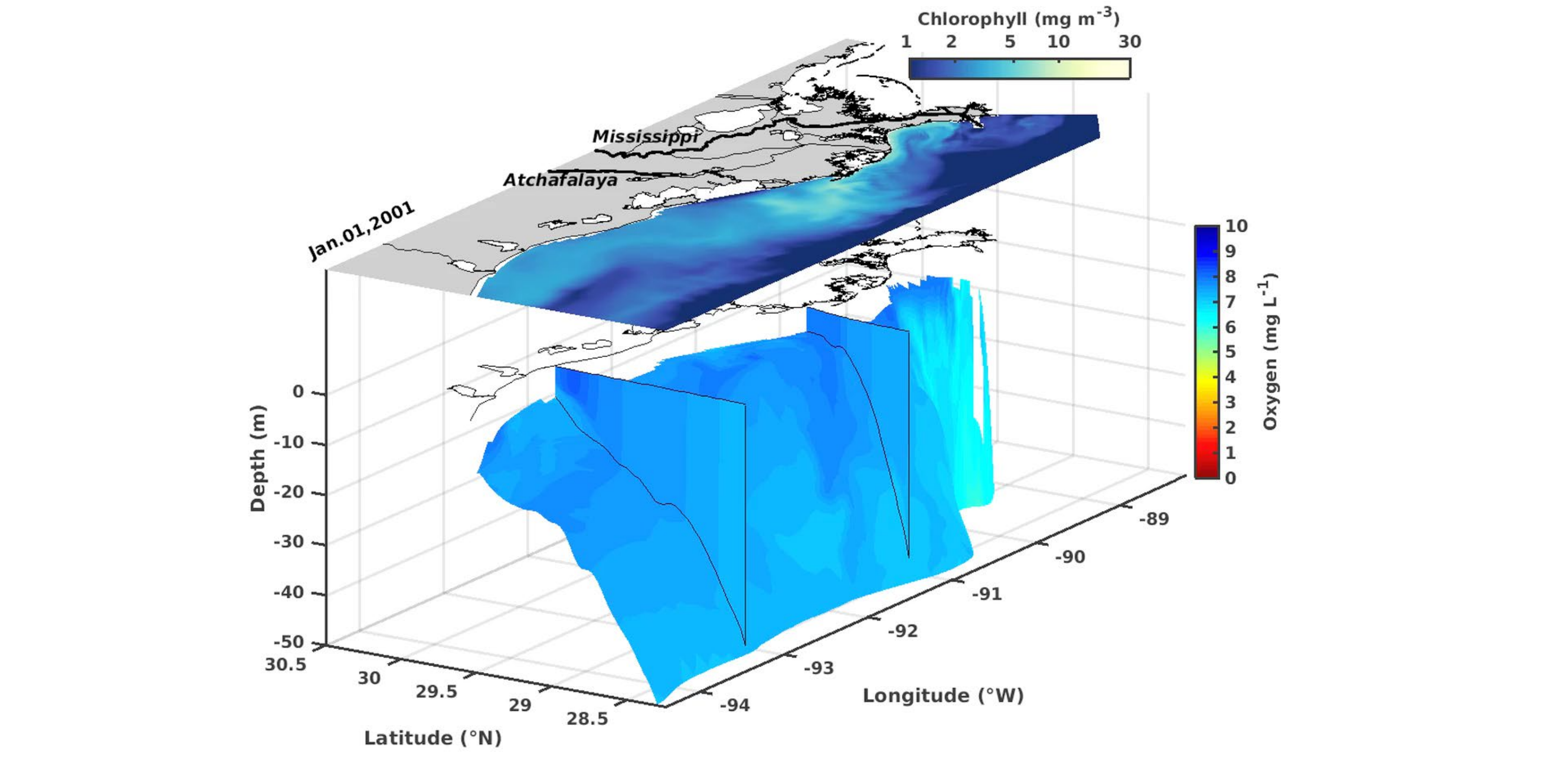
Environmental Drivers



Fennel et al. 2011, 2013, Laurent et al. 2012, Laurent and Fennel 2014

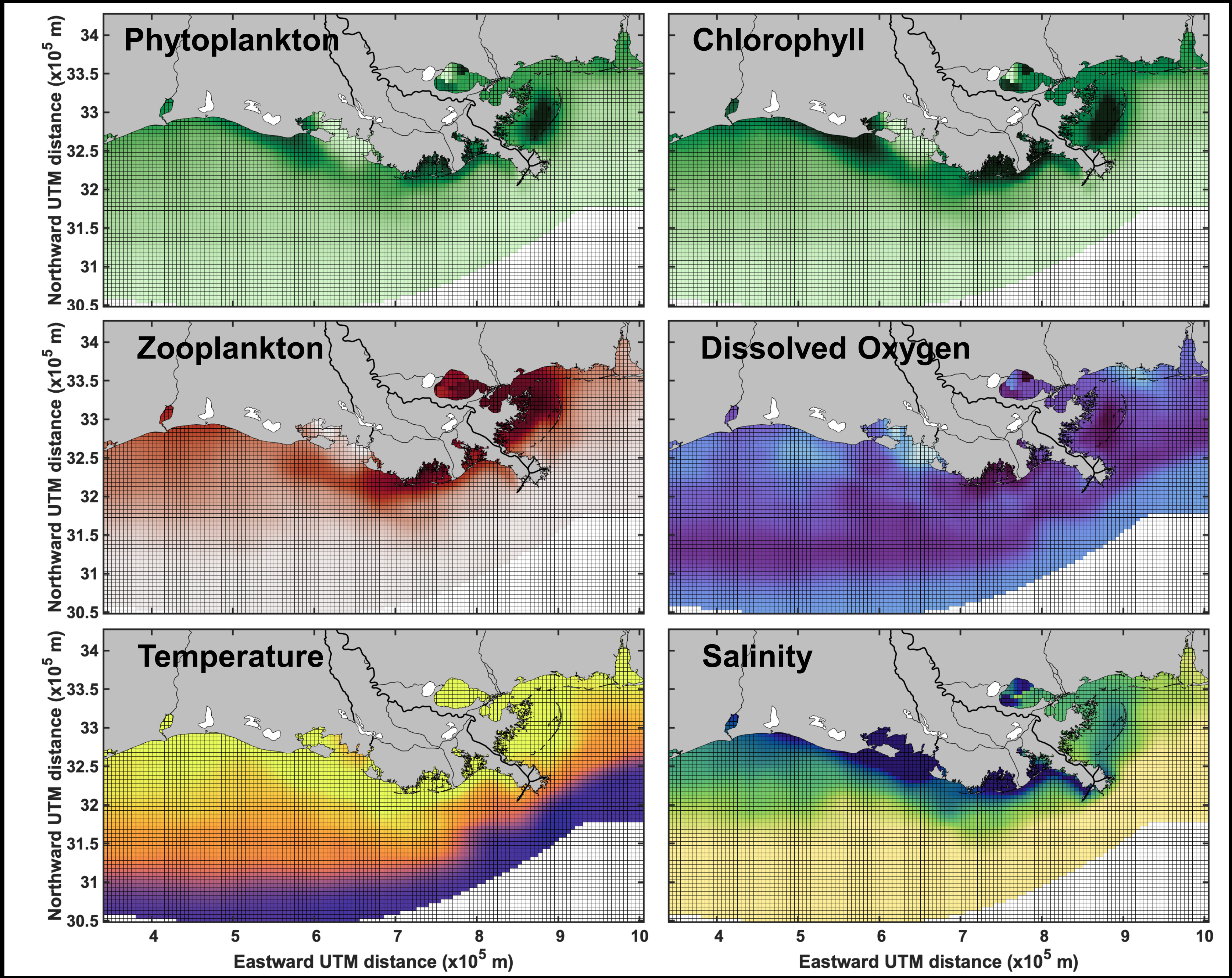
Example year 2001, baseline simulation ROMS-based physical biological model

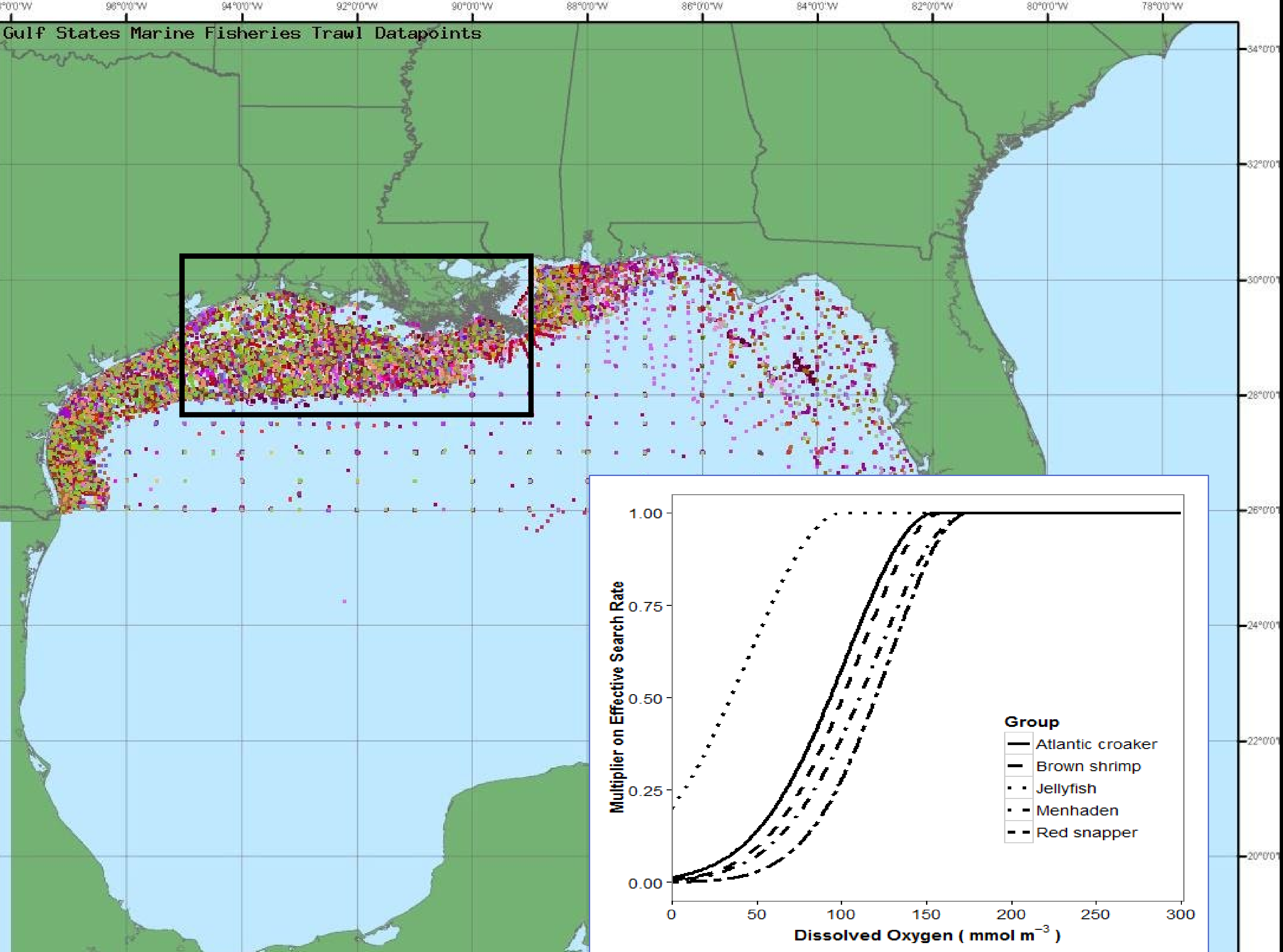
Arnaud Laurent,
Dalhousie University



ROMS → EwE

- Relevant depth layers chosen, e.g. top Chlorophyll, bottom DO
- 3D daily to 2D monthly

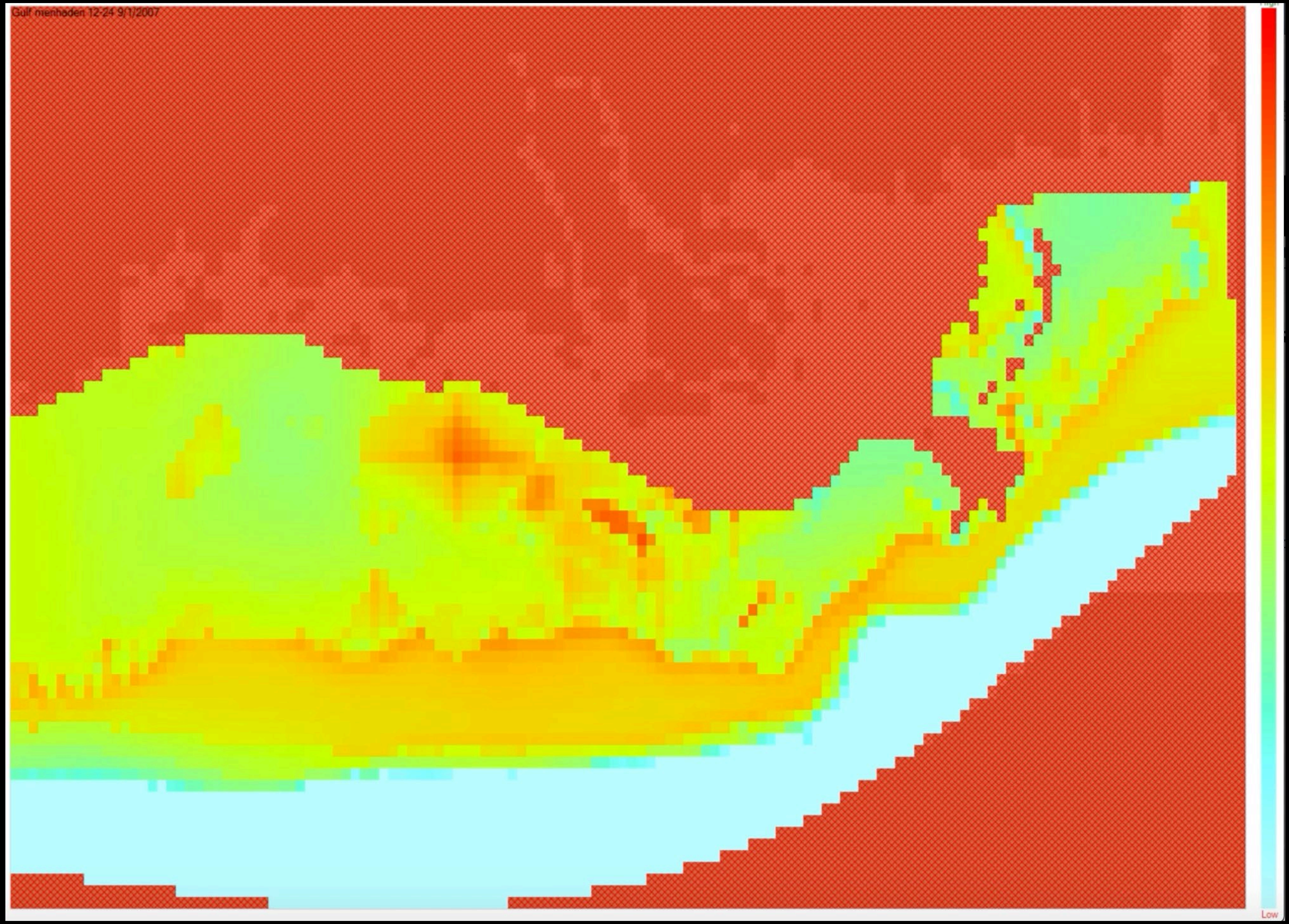


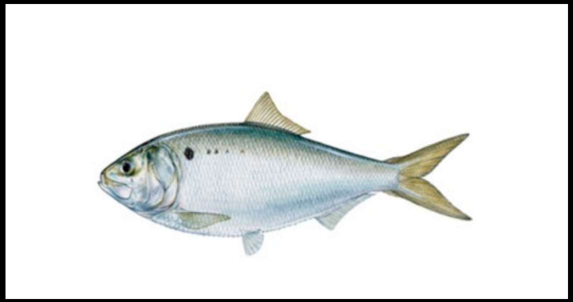


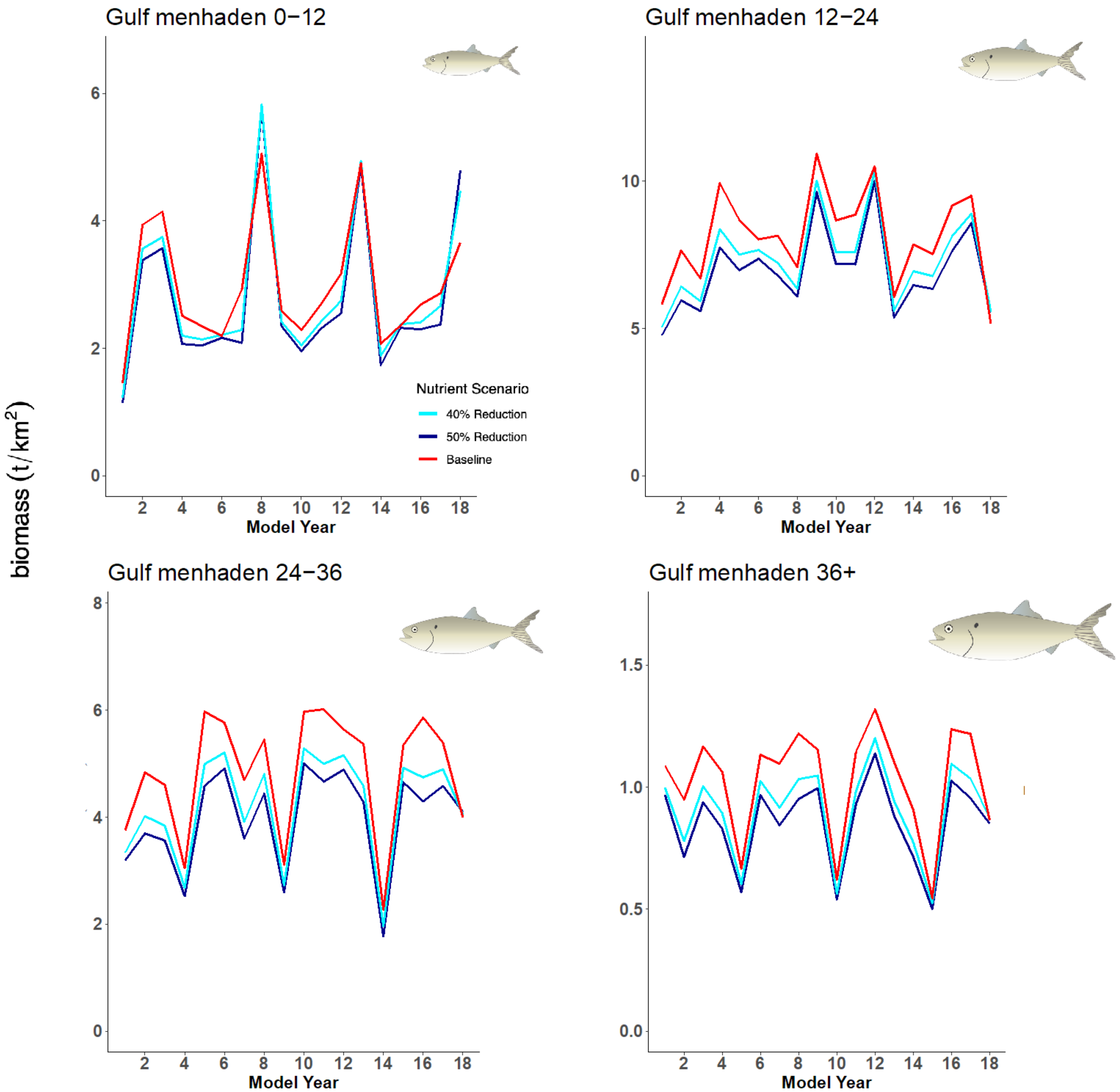
Response Curves

- Species-specific
- SEAMAP surveys measure water quality when collecting fish

Menhaden biomass: Response to baseline run 2000-2016

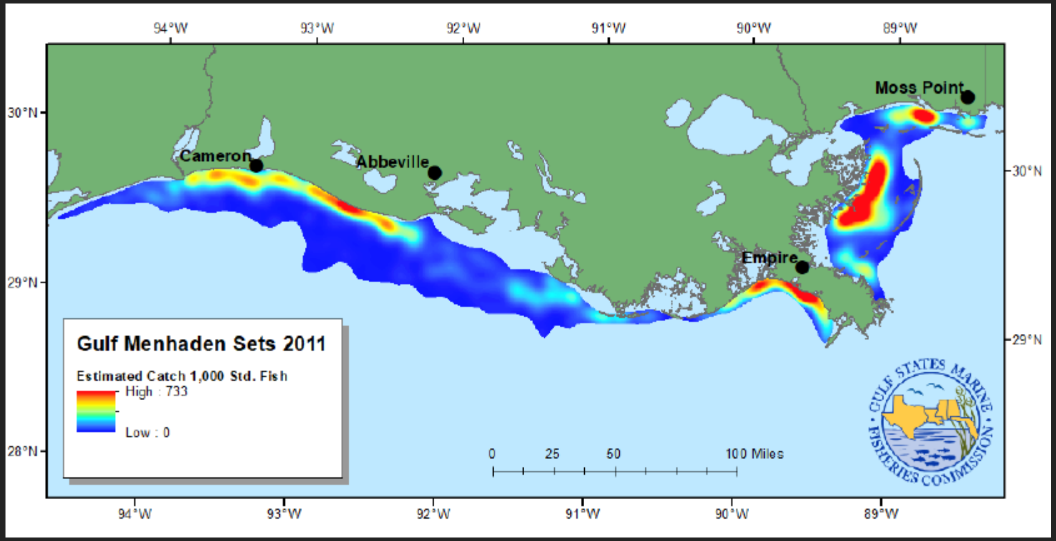






Effects of nutrient reductions on Gulf Menhaden biomass

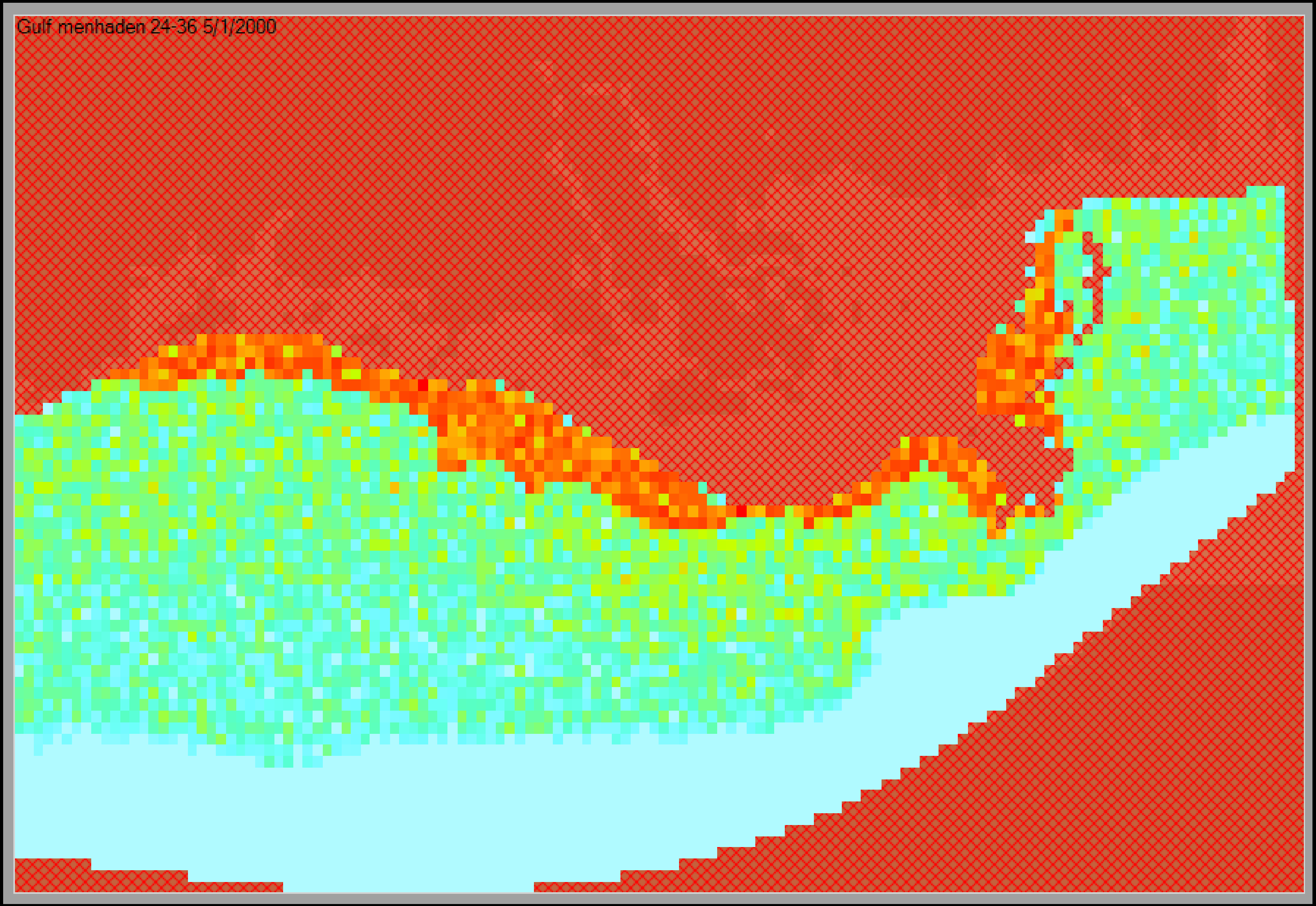
- Both nitrogen and phosphorus from MS River outflow are reduced by 40 and 50%
- This encapsulates the nutrient reductions necessary to reduce to hypoxic zone to 5000 km^2

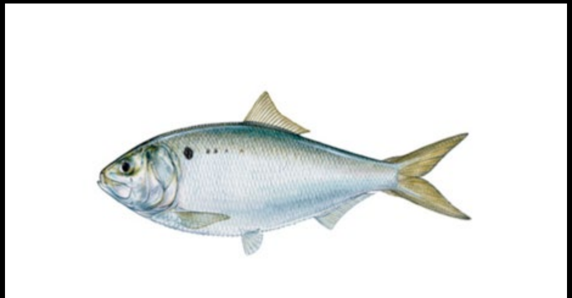


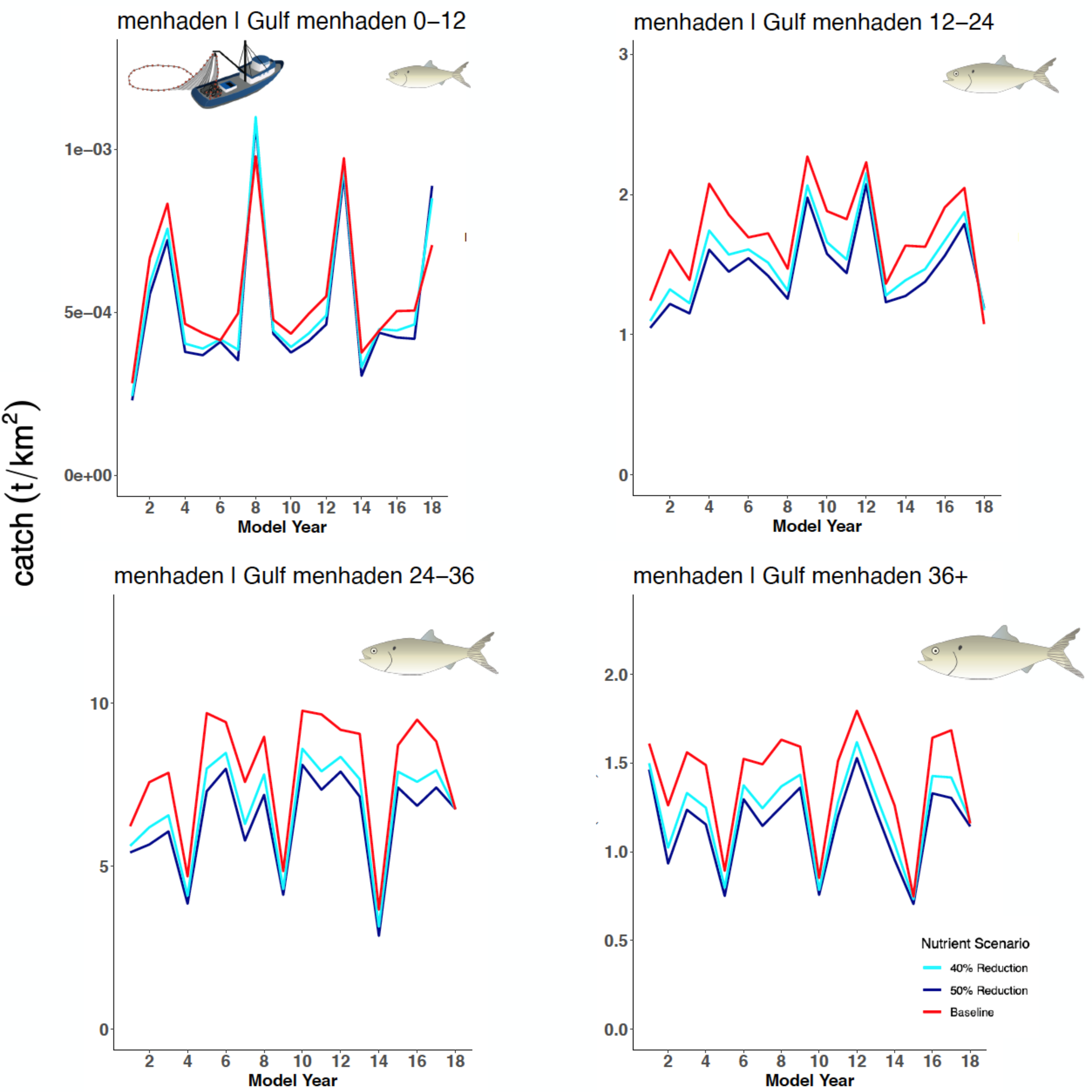
Menhaden fishing in the model

- Fleets are included in Ecopath
- Fishing effort in Ecospace occurs where highest revenue occurs (highest target species biomass, low sailing cost)
- Three plants included as ports in Ecospace: Abbeville, Empire and Moss Point

Menhaden catch distribution





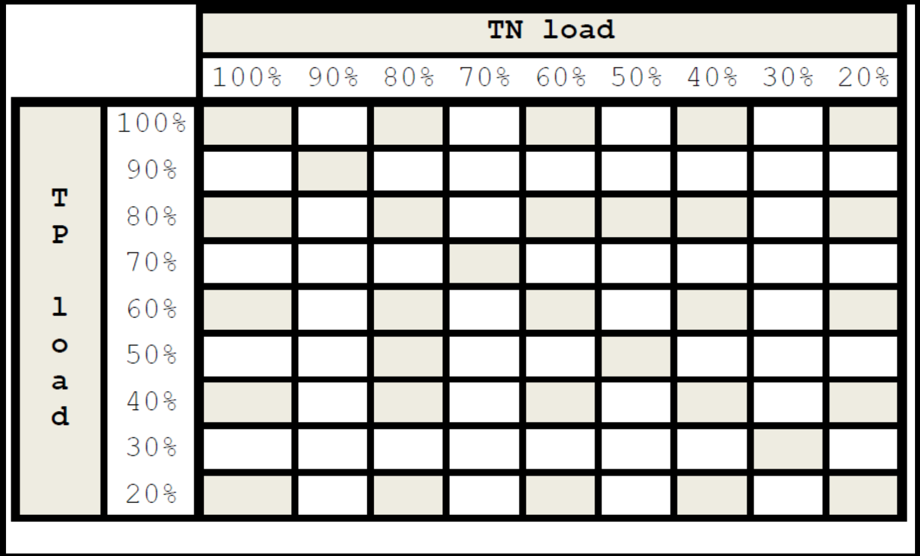


Effects of nutrient reductions on Gulf Menhaden catch

- Both nitrogen and phosphorus from MS River outflow are reduced by 40 and 50%
- This encapsulates the nutrient reductions necessary to reduce to hypoxic zone to 5000 km^2

Conclusions

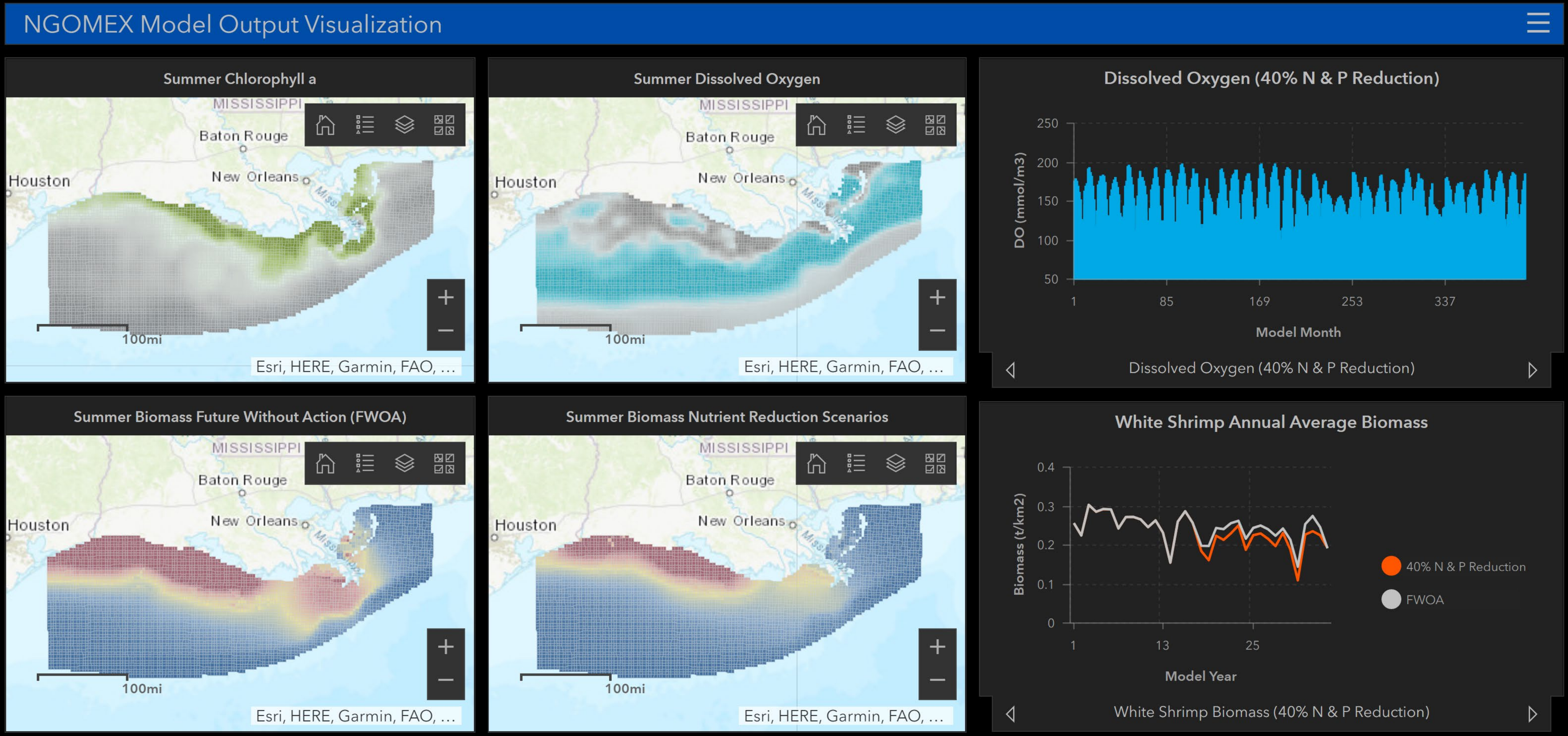
- Nutrient reductions reduce bottom-up energy flow into the food web, reducing secondary production
- Associated hypoxia reductions have small positive effects on fisheries species and most other groups in the food web
- Net effect of nutrient reductions on living marine resource biomass is small and species-specific
- For menhaden this results in a small net loss in most years



Further Work

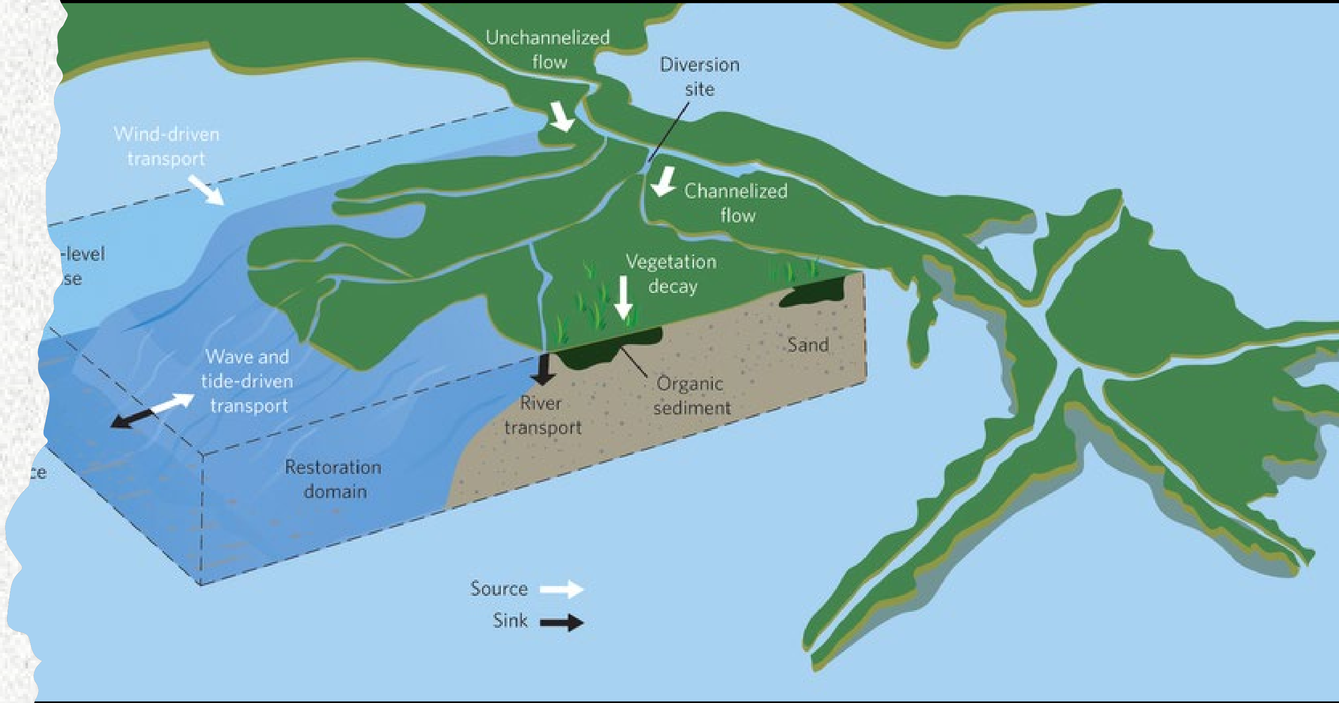
- Including menhaden (and other model groups) as individual agents using an individual-based model inside the Ecospace simulation is now possible by increased computing power; this improves the model by better accounting for local conditions of each fish
- Further model improvements include spatial calibration, validation, and uncertainty analysis
- Simulating a suite of nutrient reduction scenarios will be simulated so that trade-offs can be evaluated of different levels of nitrogen and phosphorus reductions
- Development of decision support tool

Output visualization decision support tool (ArcGIS Dashboard)



Mississippi River Delta Management Study

- How do a select combination of large sediment diversions affect fish and shellfish in the receiving basins?



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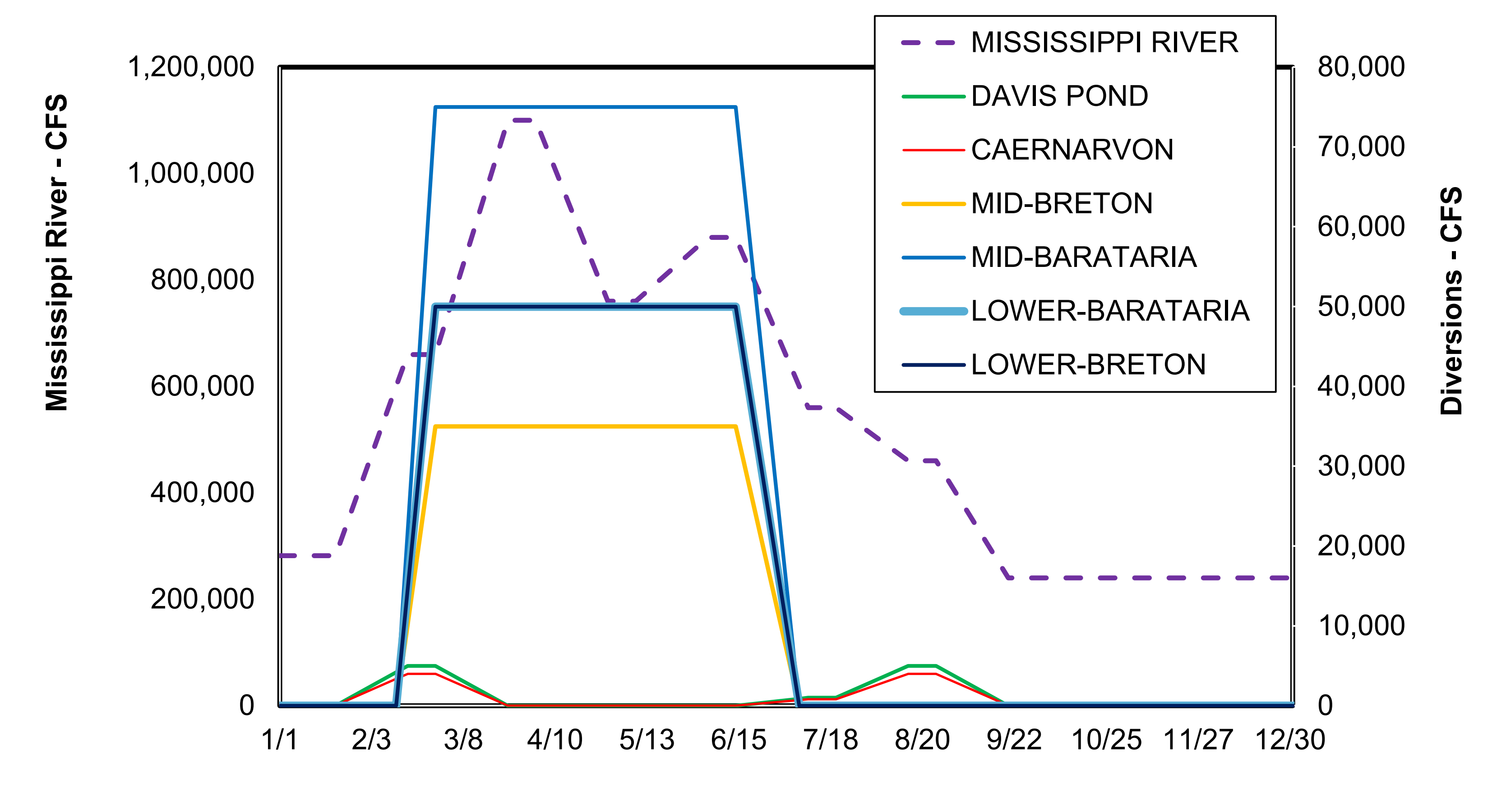
COASTAL PROTECTION AND RESTORATION AUTHORITY
CPRA

Model Domain and evaluated diversion locations

- Finer resolution Ecospace model with 500 m^2 grid cells

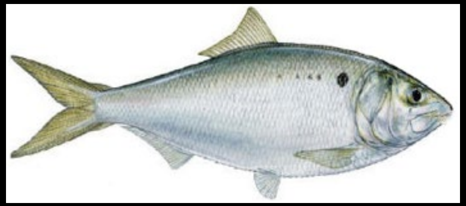
Operation scenario

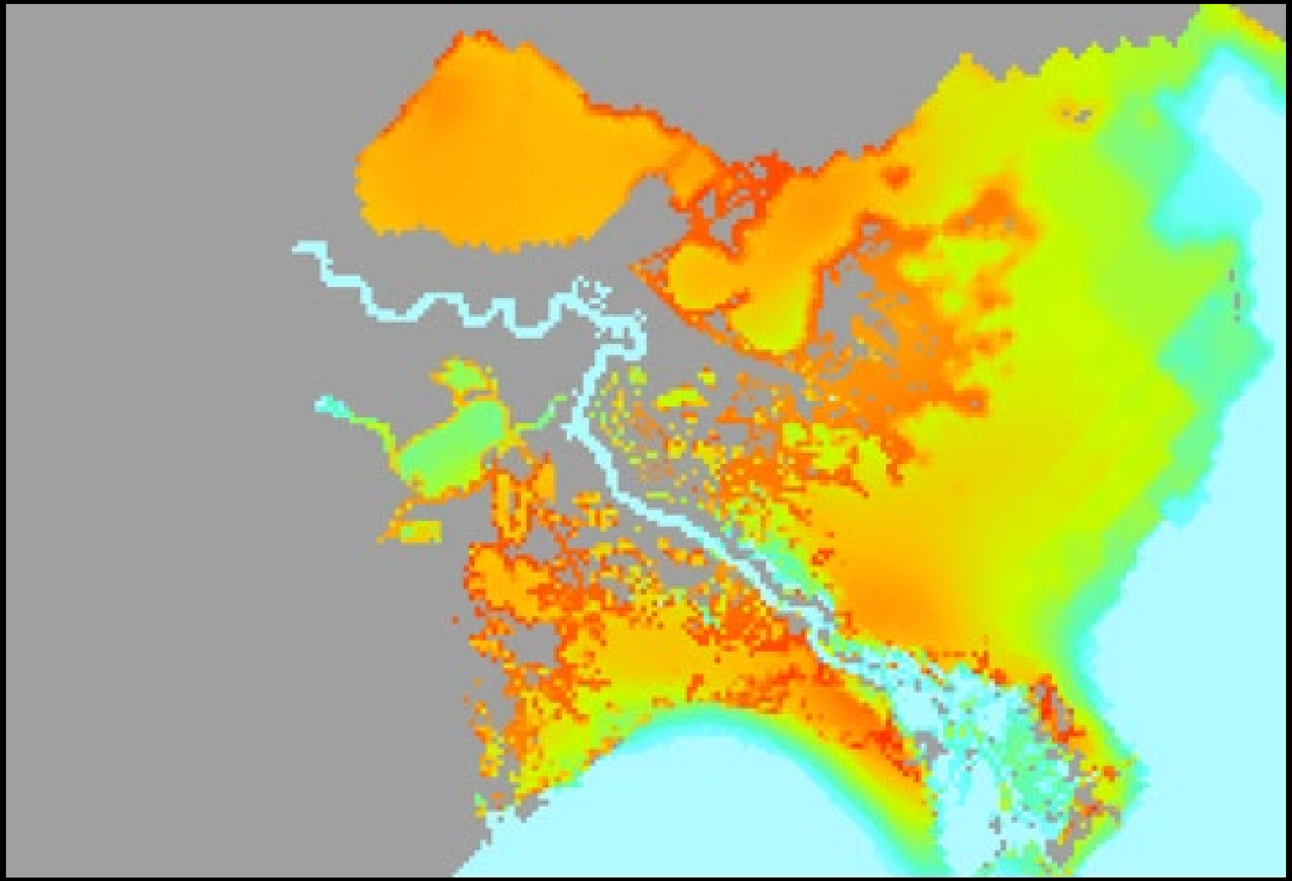
- Open four sediment diversions for 50 year (opening triggered by 600,000 CFS in the river)
- Compare with Future Without Action



Juvenile Gulf Menhaden

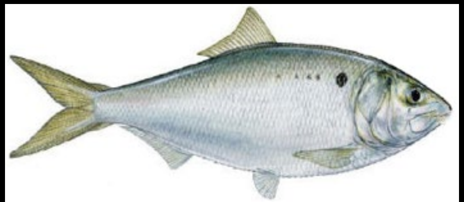
- June Year 50
- FWOA

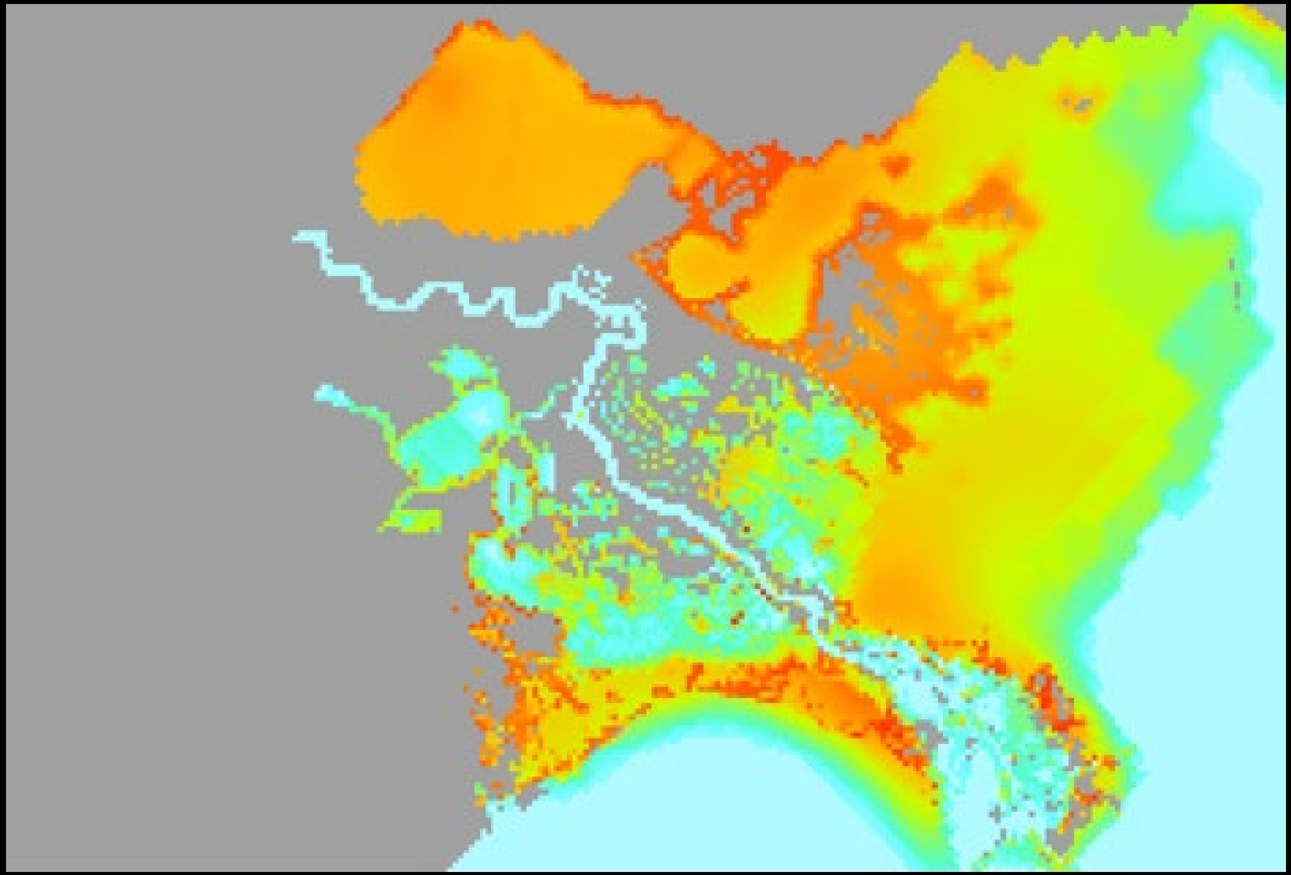




Juvenile Gulf Menhaden

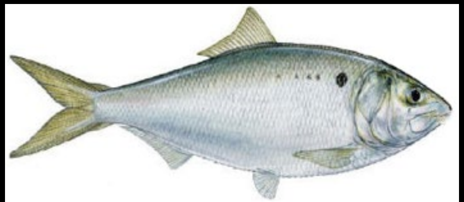
- June Year 50
- Diversions

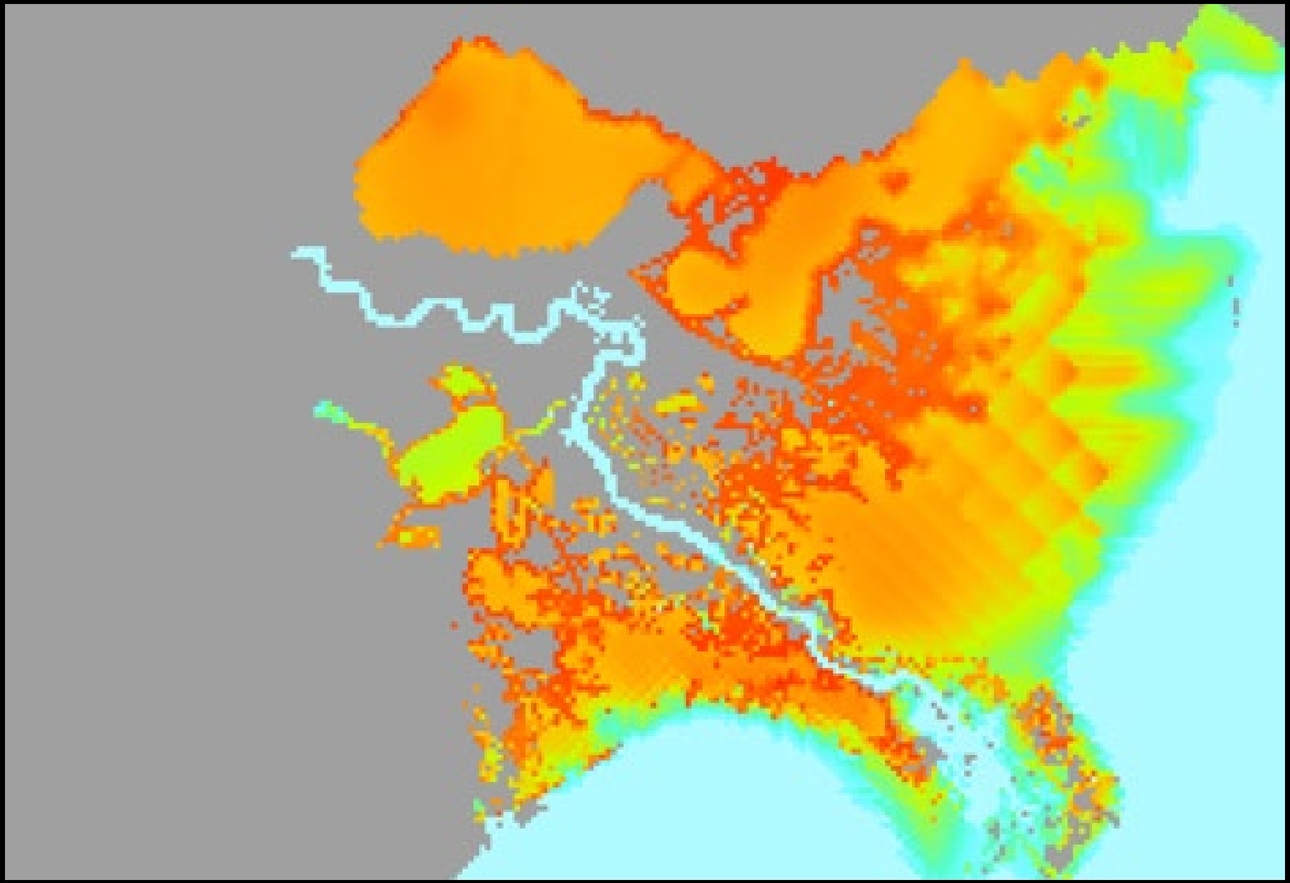




Juvenile Gulf Menhaden

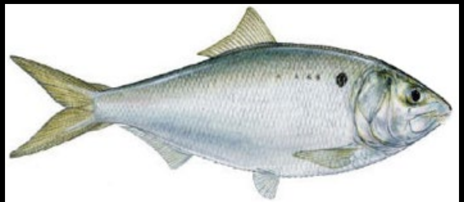
- October Year 50
- FWOA

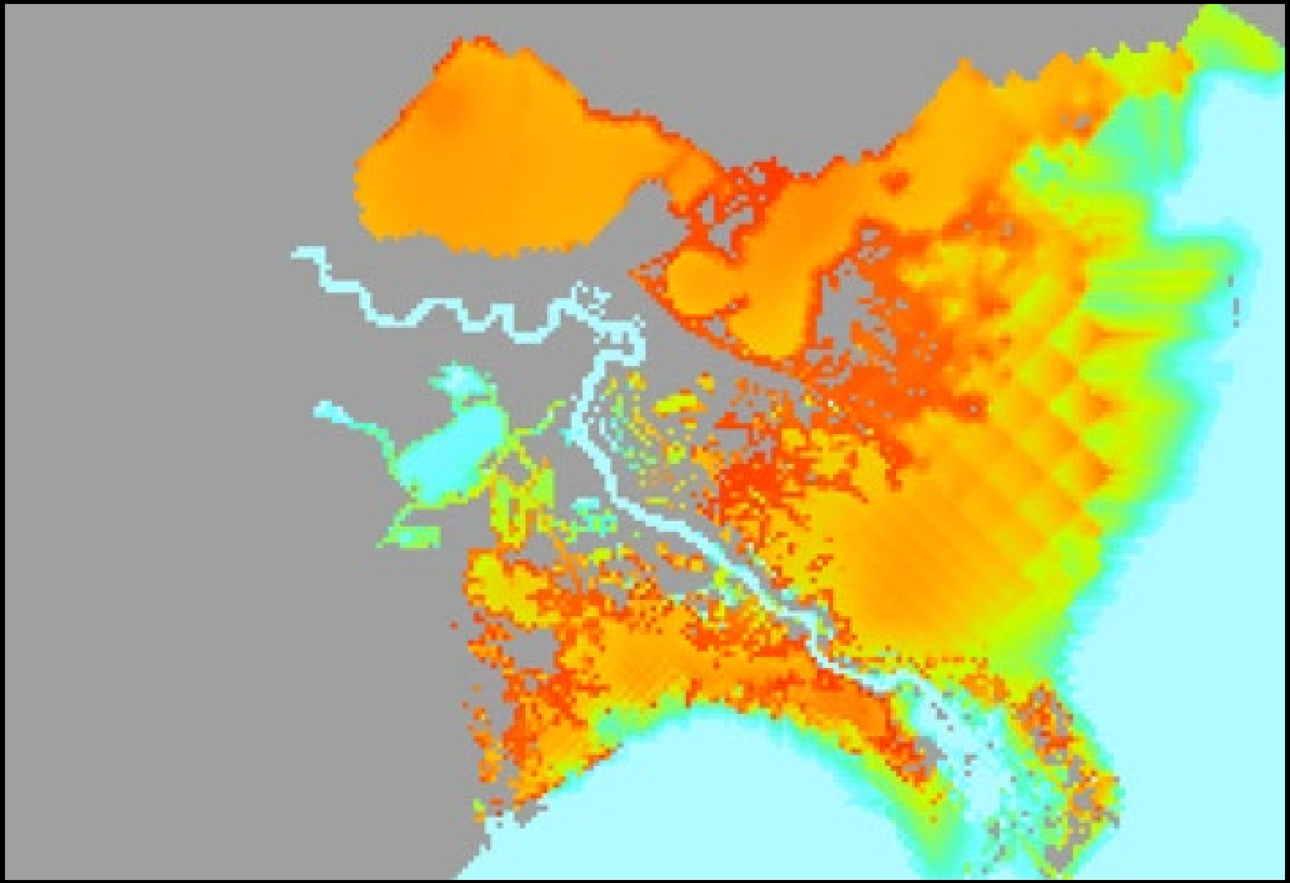




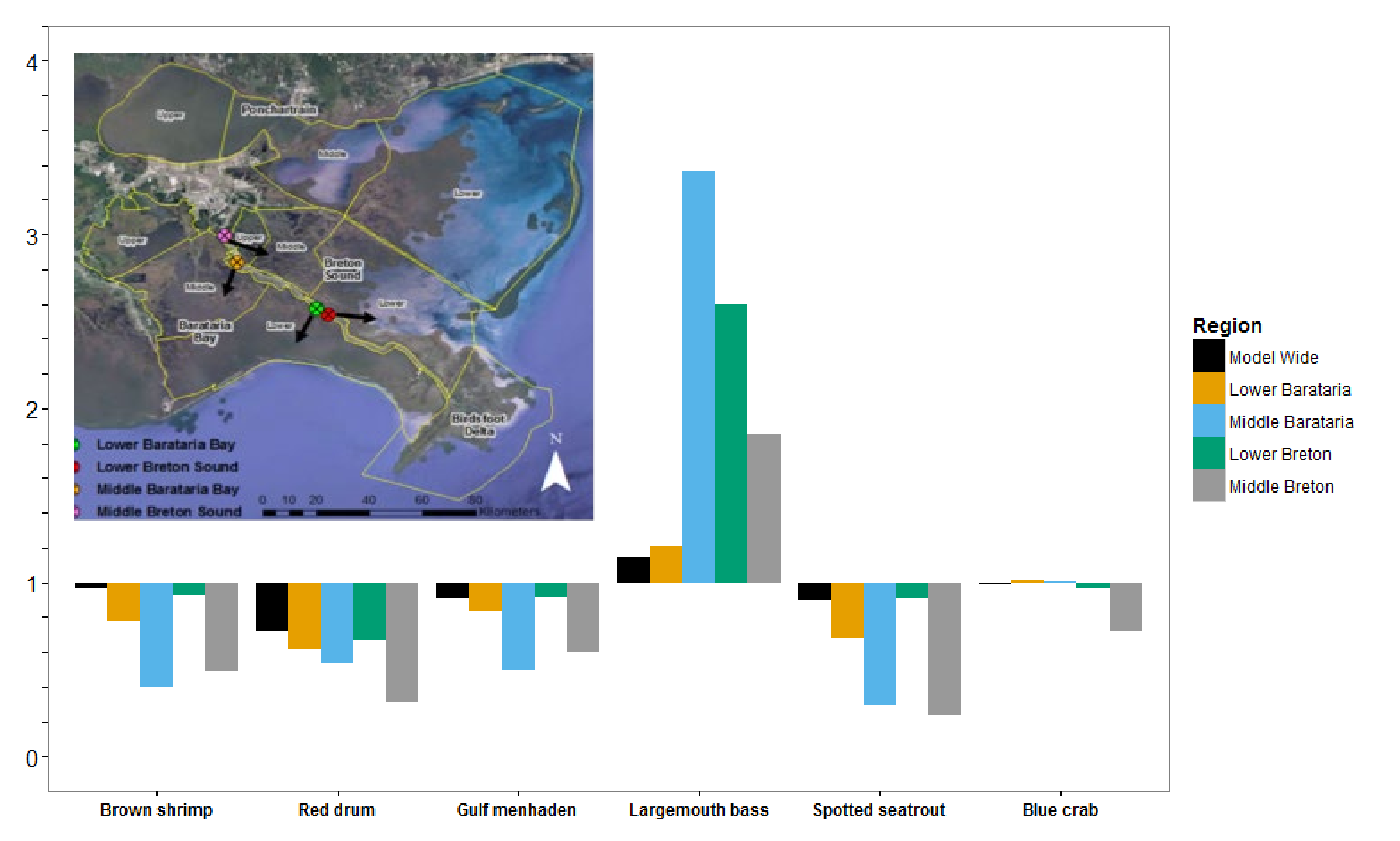
Juvenile Gulf Menhaden

- October Year 50
- Diversions

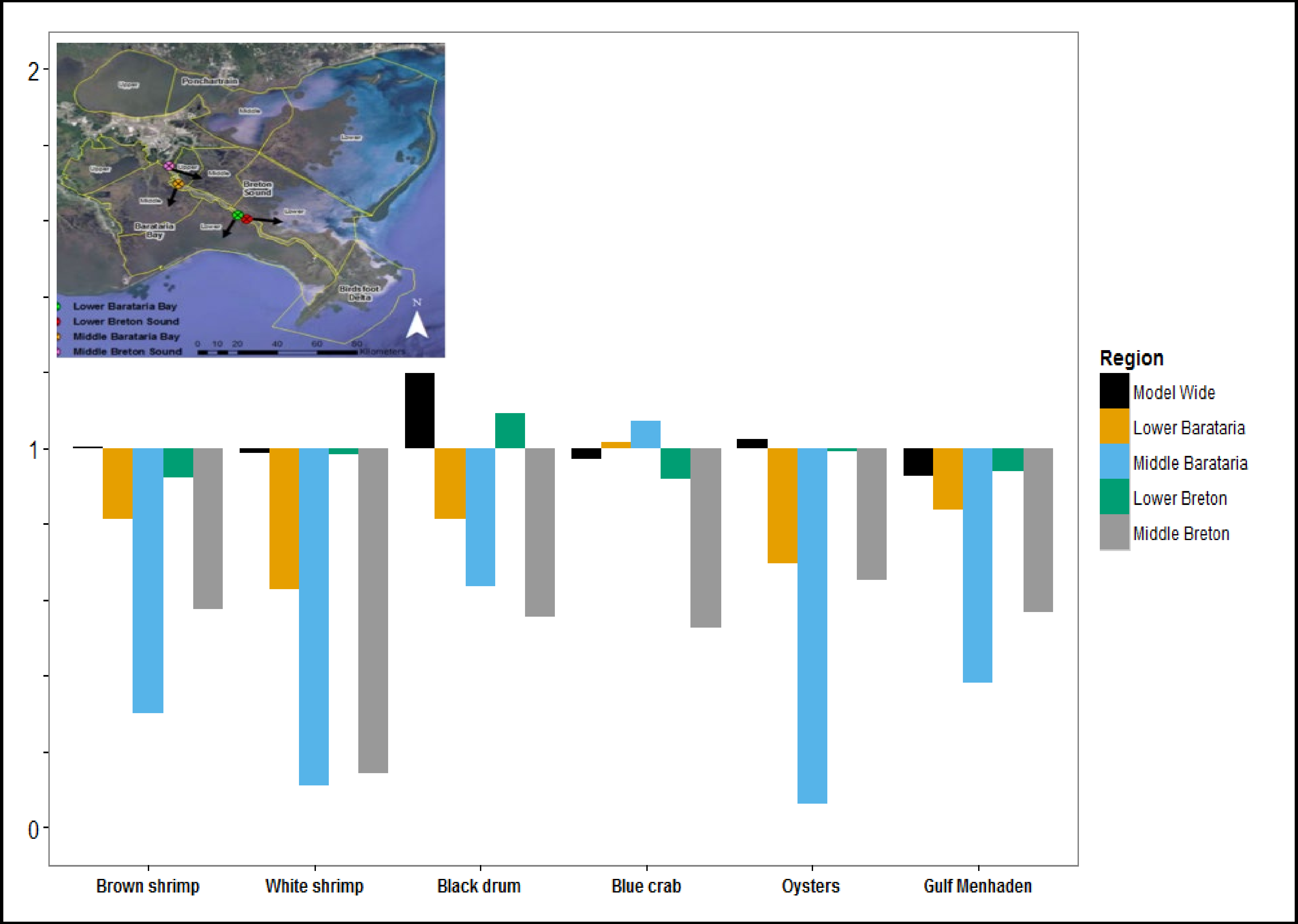




Year 50 biomass relative to FWOA



Year 50 catch relative to FWOA



Scenario summary

Decreases in species that prefer higher salinities on a sub-basin level, increases in (few) species that prefer lower salinities

Magnitude of change dampened on a larger spatial scale:

- Redistribution of species
- Large *relative* change in areas with low biomass doesn’t contribute much to total biomass change

Two lower diversions mostly responsible for total biomass change

Management Application

- In combination with other models: Provides ability to evaluate trade-offs between land-building capacity benefits and biomass losses
- Focus on constructing two upper diversions (Mid-Barataria and Mid-Breton), lower diversions put on hold
- Spatial re-distribution output allows for estimating change in habitat use
    - Helps preparing for change

“The Louisiana coast is in a state of crisis that demands immediate and urgent action to avert further damage to one of our most vital resources”

Gov. Edwards (2017)

a sediment diversion is granted fast-track permitting

January 2017, Nola.com

Mid-Breton included on Federal permitting dashboard in 2019

Permitting process includes an Environmental Impact Statement

Diversion work publication (aim phone camera)

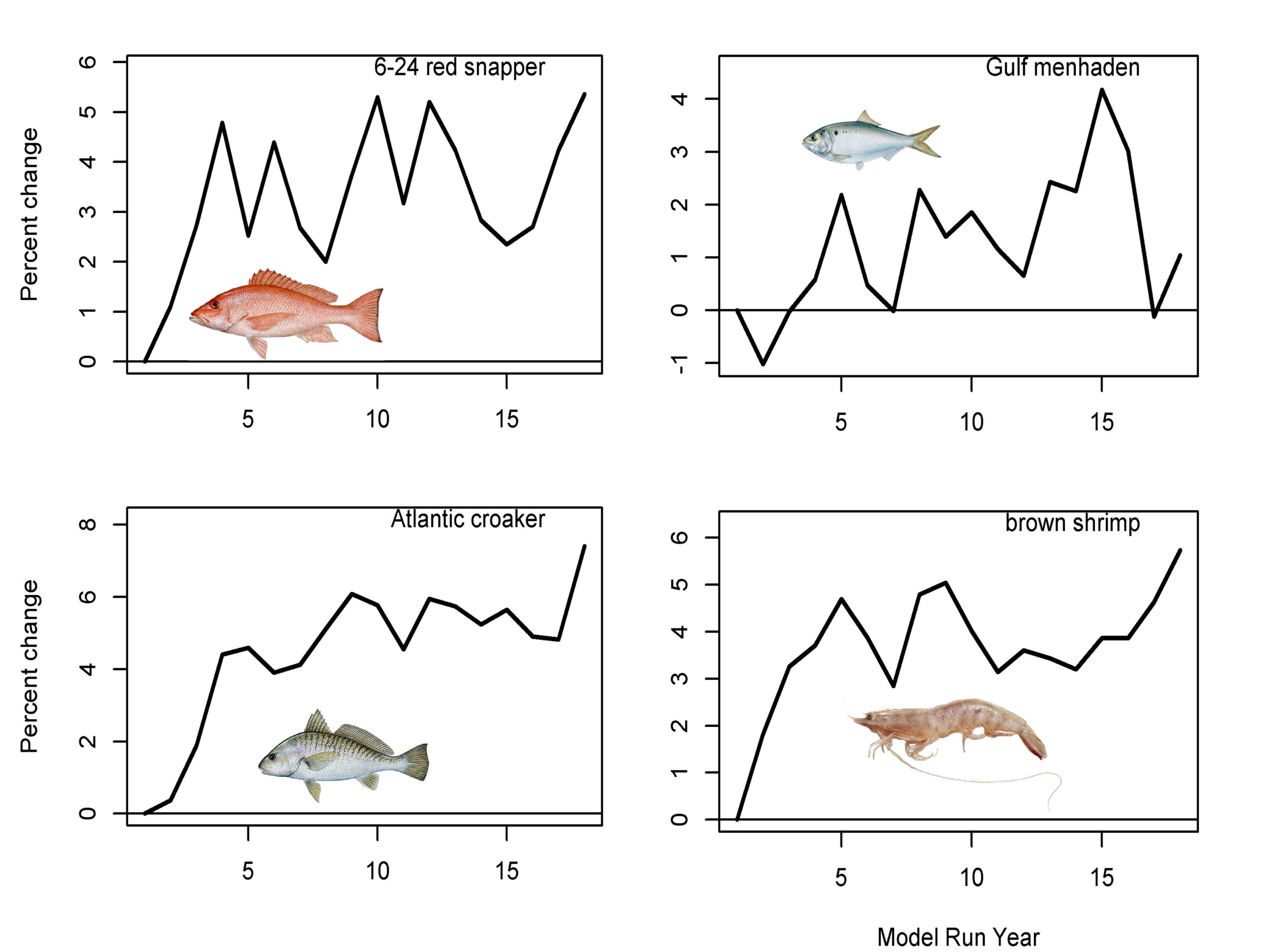
Thank You

I would like to acknowledge the following sponsors and collaborators:

- Sponsors: NOAA National Centers for Coastal Ocean Science (Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program and the NOAA RESTORE Science Program), The Louisiana Coastal Protection and Restoration Authority, The Water Institute of the Gulf
- Collaborators: Arnaud Laurent, Joe Buszowski, Kristy Lewis, Jeroen Steenbeek, Steve Brandt, Matt Campbell, Cynthia Sellinger, Cassie Glaspie, Alex Van Plantinga, Sara Marriott, Dave Chagaris, Skyler Sagarese, Ehab Meselhe, Scott Milroy, Jim Cowan.

Hypoxia work publication (aim phone camera)

Hypoxia reduction only (40%)



Taxa in the NGOMEX ecosystem model

Marine Mammals
Tunas
Carangidae
Birds
Atlantic Cutlassfish
Lizardfish
Sharks
King Mackerel
Spanish Mackerel
Sea Trout
Red Snapper
Serranidae
Other Snappers
Red Drum
Rays & Skates
Flounders
Atlantic Bumper

Scad
Atlantic Croaker
Catfish
Gulf Butterfish
Spot
Squid
Pinfish
Porgies
Anchovy
Gulf Menhaden
Other Clupeids
Mullet
Sea Turtles
Small Forage Fish

Jellyfish
Blue Crab
Brown Shrimp
White Shrimp
Pink Shrimp
Other Shrimp
Benthic Crabs
Benthic Invertebrates
Zooplankton
Benthic Algae
Phytoplankton
Detritus

66 groups

Life stages included

Model balancing

- Solving:

$$\left(\frac{P_i}{B_i}\right) \cdot B_i \cdot EE_i - \sum_{j=1}^{n} B_j \cdot \left(\frac{Q_j}{B_j}\right) \cdot DC_{ji} - Y_i - E_i - BA_i = 0$$

- This is a mass balance assumption at the base of Ecopath
- We’ve provided everything but EE – Ecotrophic Efficiency
- EE of species *i* describes what proportion of this species is used in the system, and cannot exceed 1
- In cases where biomass is uncertain EE is provided:
    - (other) clupeids and ‘small forage fish’: 0.8
    - Benthic crabs and benthic invertebrates: 0.85

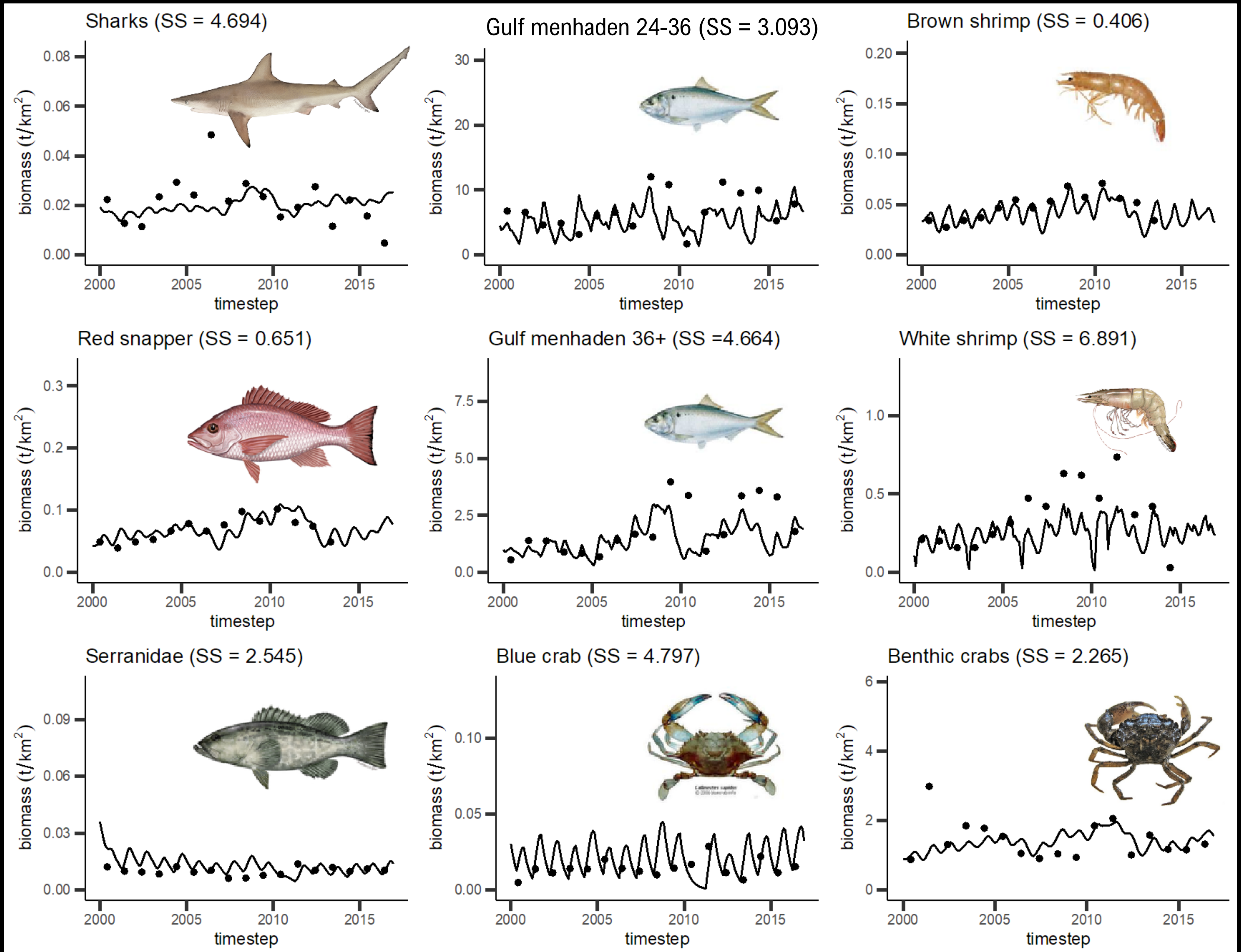
Fishery

- ‘Fleets’ included in the model:
  - Shrimp trawl
  - Menhaden
  - Recreational
  - Snapper/grouper (commercial)
  - Other commercial finfish
- Landings – NOAA’s landings query, MRIP, stock assessment
- Discards – stock assessment

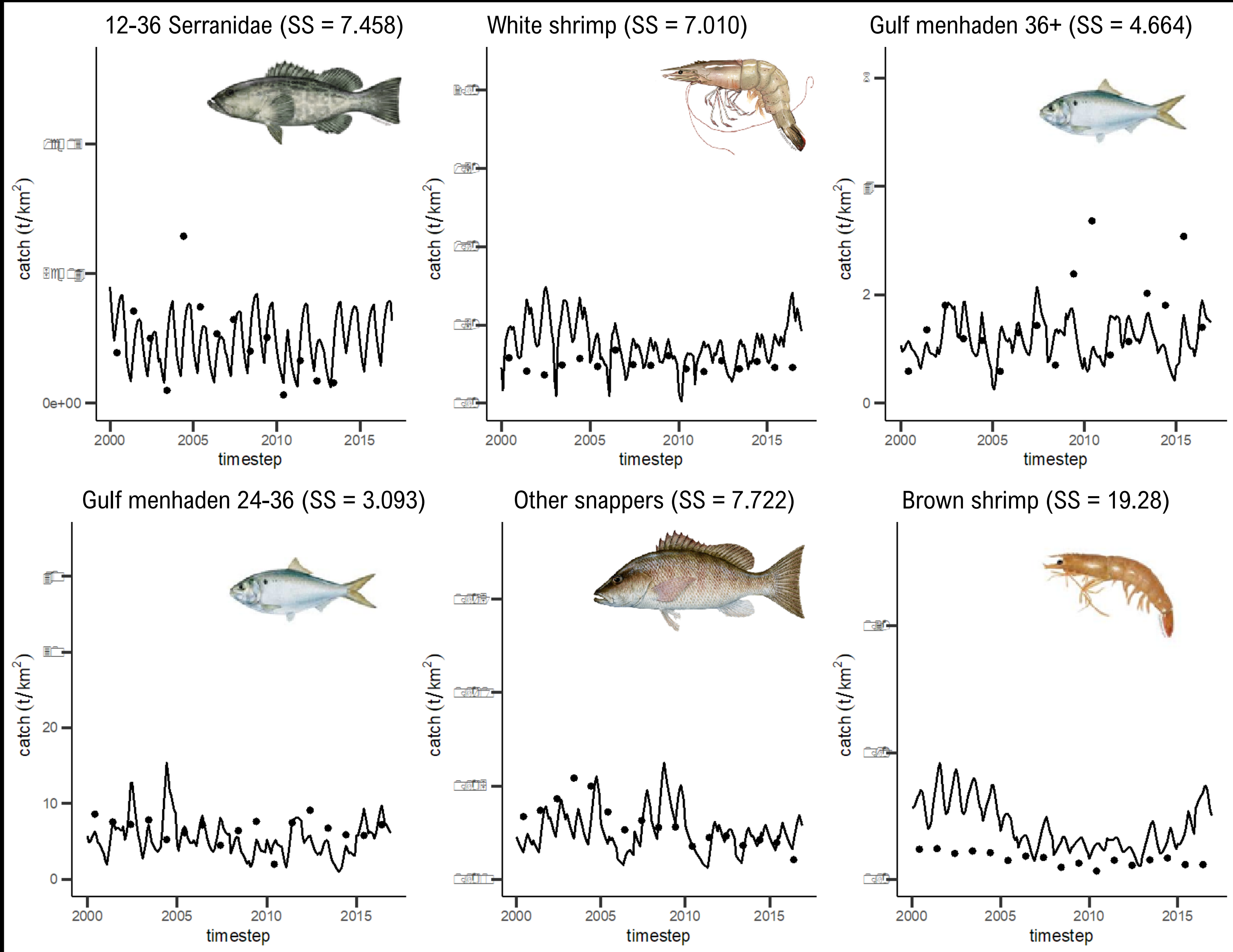
Time series

- Sixty-one time series with observations loaded to calibrate the model
- Calibration period: 2000-2016 (time period for which coupled model output is available)
- Catches – stock assessment, NOAA landings query, MRIP (for recreational-only available until 2013)
- Biomass – stock assessment, SEAMAP
- Fishing mortality – stock assessment (driver that determines fishing effort per species)

Calibration - Biomass



Calibration - Catch



Groups in the Delta Management model

Fish

Atlantic Croaker[1]
Bay Anchovy[1]
Black Drum[1]
Blue Catfish[1]
Coastal sharks[1]
Gizzard Shad[1]
Grey Snapper[1]
Gulf Menhaden[1]
Gulf Sturgeon[1]
Killifishes
Largemouth Bass[1]
Pinfish[1]
Red Drum[1]
Sand Seatrout[1]
sea catfishes[1]
Sheepshead[1]

Fish

Silver Perch[1]
silversides
Southern Flounder[1]
Spot[1]
Spotted Seatrout[1]
Striped Mullet[1]
Sunfishes[1]
Threadfin Shad[1]

Invertebrates

Benthic crustaceans
Blue Crab[1]
Brown Shrimp[1]
Eastern Oyster[2]
Grass Shrimp
Mollusks

Invertebrates

Mud crabs
Other shrimp
Oyster Drill
White Shrimp[1]
Zoobenthos
Zooplankton

Primary producers

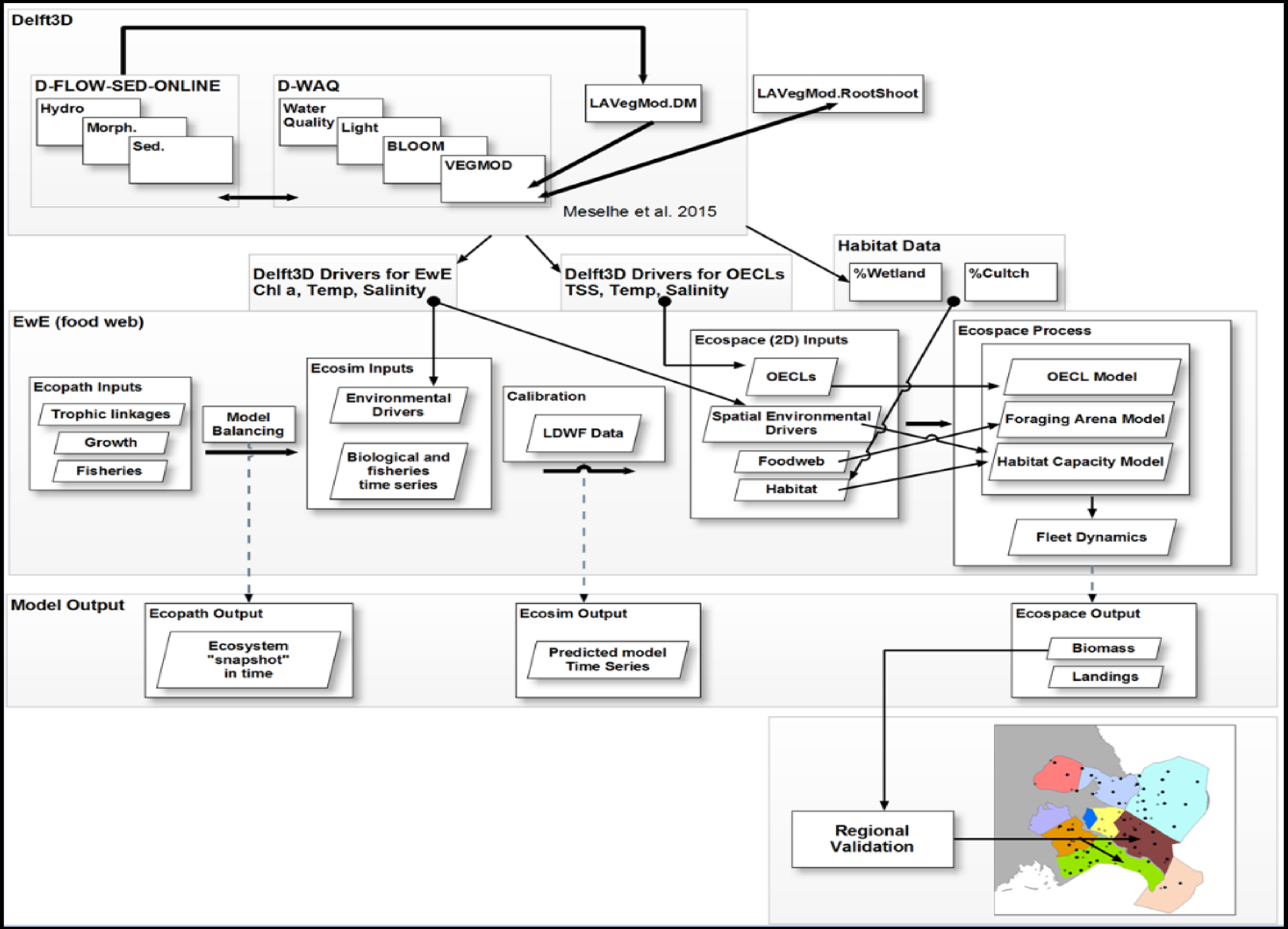
Phytoplankton
SAV[3]
Benthic algae

Other

Kemp Ridley sea turtle
Dolphins
Detritus
Seabirds

[1]Juvenile and adult, [2]spat, seed, and sack, [3]submerged aquatic vegetation

Delta Management Model Coupling



De Mutsert et al. 2017