Are Population-level Effects of Hypoxia on Fish Truly Small or Larger but Elusive?

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Preface

- Basic question: Does hypoxia affect fish at the population level?
- What I am about to say is based on my collaborations with many people
- However, the opinions are mine and not vetted nor endorsed by my collaborators
- My background and training is fisheries and modeling
  - Optimize death
  - Does not bother me to see dead fish
  - But I rarely touch them
  - Contrast with a conservation philosophy

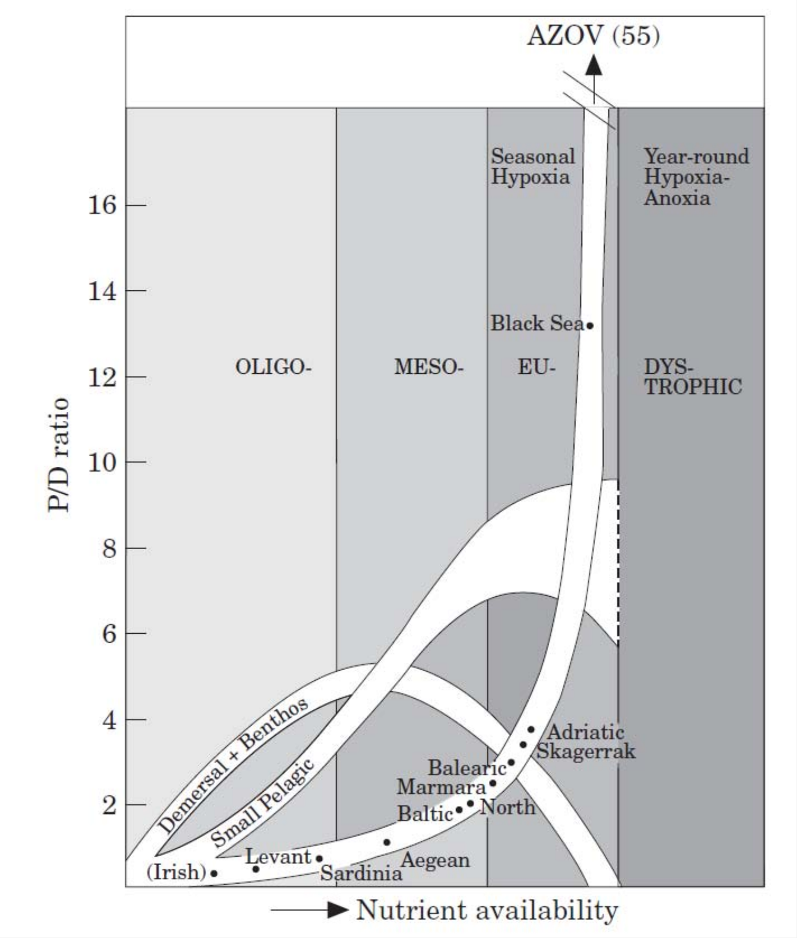
Today

- Preface (done)
- Hypoxia and fish populations
- Why important
- Why field determination is so difficult
- Modeling
- Model-by-model
- View from 10,000 feet
- My conclusions

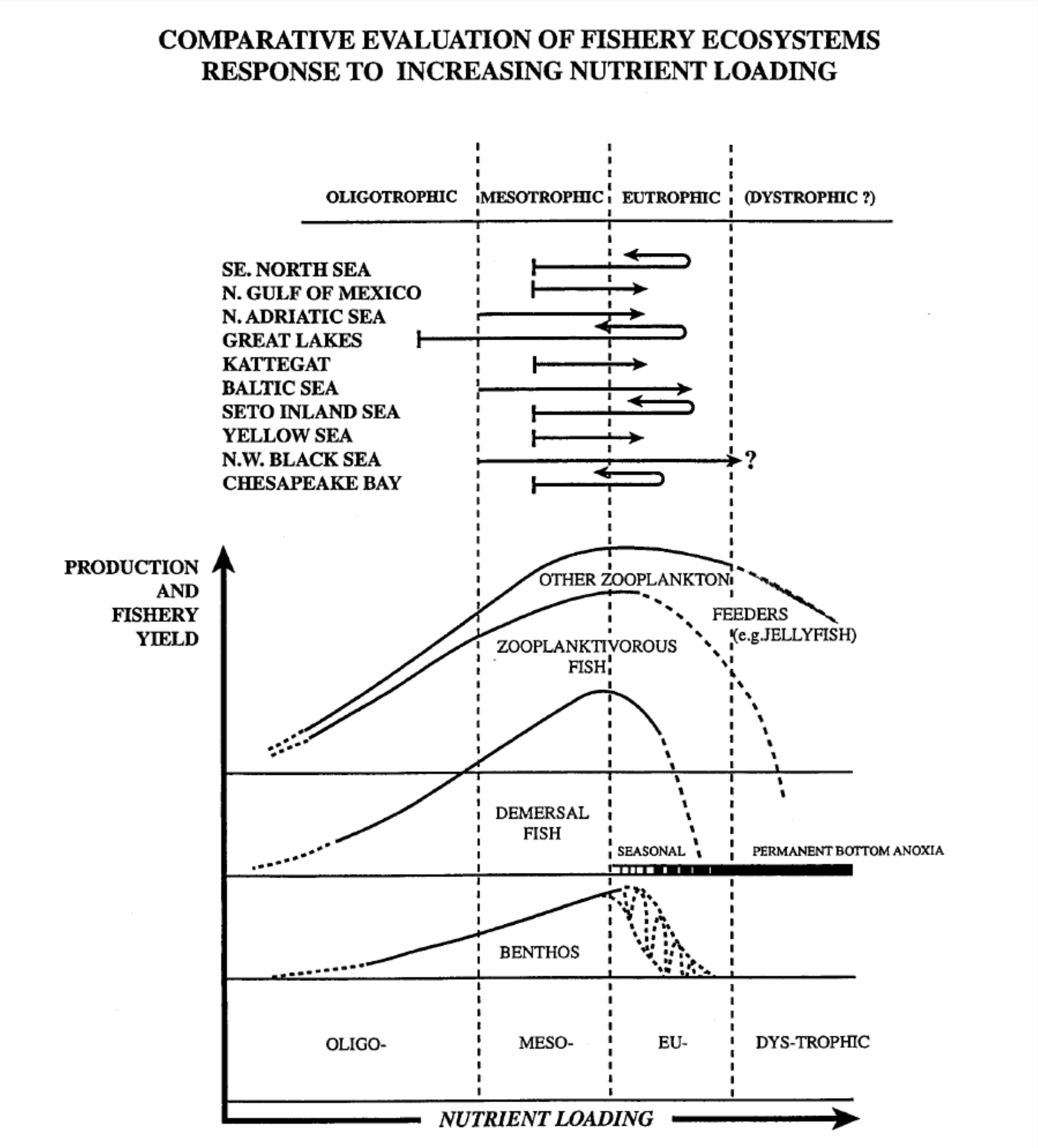
Hypoxia and Fish

- Hypoxia is increasing in coastal waters (Diaz and Rosenberg 2008)
- Indicates potential eutrophication issues
  - Over-enrichment
  - HABs
  - Ecosystem health
- Conceptual models of more nutrients eventually resulting in reduced demersal then pelagic fish

At first, seems fine



Caddy 2000



Diaz 2001, modified and redrawn from Caddy 1993

Hypoxia and Fish

- Cross system comparisons have shown fishery production (catch) increases with increasing nutrient loadings (Caddy 1993; Nixon and Buckley 2002)

- But gets complicated because space for time substitution and no clear link to hypoxia effect (Breitburg et al. 2009)

Starts get murky

Hypoxia and Fish

- Sedentary organisms
  - No doubt they are killed

- Laboratory effects
  - Many experiments
  - Foraging, growth, mortality, avoidance
  - Forced exposure

- Localized effects in nature
  - Habitat compression
  - Displacement

We are still good

Hypoxia and Fish

- Fish kills
  - Visually seems like must have an effect
  - Remember, these are large number populations

- Case studies
  - Baltic, Black, Azov Seas
  - Even these are debated (Daskalov 2003; Oguz, 2005)

- Intuition
  - Maps of massive hypoxia areas must have an effect

Empirical evidence getting weak

Hypoxia and Fish

- Population level effects
- First, definition of population
  - "A group of organisms of one species that interbreed and live in the same place at the same time"
  - Unit stock
  - Management unit
- Hypoxia affects many individuals but not automatic that hypoxia has population impacts
- Conventional wisdom

Houston, we have a problem

Hypoxia brochure from Ecological Society of America which states without references:

"Because hypoxia often occurs in estuaries or near shore areas where the water is poorly mixed, nursery habitat for fish and shellfish is often affected. Without nursery grounds the young animals cannot find the food or habitat they need to reach adulthood. <u>This causes years of weak recruitment to adult populations and can result in an overall reduction or destabilization of important stocks….</u> The most serious effects of hypoxia on fisheries are probably: longterm weakening of species also stressed by overfishing, habitat loss, longterm changes in ecology, and economic losses…. This situation is detrimental not only for ecosystems but for fishermen who rely on these resources for their livelihood and for consumers who look forward to bountiful fish and shellfish harvests."

www.esa.org/education_diversity/pdfDocs/hypoxia.pdf

“A 2008 study found more than 400 dead zones around the world, and the Gulf of Mexico's is one of the largest. Snaking along the Louisiana and Texas coasts, the expanding Gulf Dead Zone has drastically reduced seafood stocks and pushed fishers further out to sea.”

The Gulf of Mexico's Dead Zone is among the world's largest—and corn is one of the culprits
by Chris Kromm, July 7, 2010, INDYweek.com

“While scientists have yet to measure the impact of the zone on fishing yields, fishermen say they already feel its effects as they are forced to travel ever farther to escape the zone's barren limits. "This is a very serious issue," said Jim Giattina, director of the Gulf of Mexico Program office at the Stennis Space Center in Mississippi. Giattina said the gulf boasts an annual catch of 1.7 billion pounds of fish and shellfish, worth $26 billion. "We've seen what can happen in other places in the world," he said. "We don't want to see a collapse of this fishery.“

A 'Dead Zone' Grows in the Gulf of Mexico
by Carol Kaesuk Yoon
Copyright 1998 by The New York Times

O'Connor and Whitall (2007) recently stated in their introduction that ***“hypoxia is now recognized as one of the most significant threats to fisheries production worldwide”.***

Chesney and Baltz (2001) concluded that ***“the exploited nekton are able to tolerate the effects of hypoxia without obvious major consequence for their recruitment, production, or population health”, and that “it is also likely that currently other anthropogenic impacts, such as the direct and indirect effects of fishing, have more significant consequences for the production of nekton populations in the Gulf of Mexico”.***

Why Important?

- Reducing nutrients may be worthwhile
  - Water quality
  - HABs

- No doubt hypoxia has effects
  - On individuals, often many individuals
  - Sessile organisms
  - Lakes and reservoirs

Why Important?

- Presenting the correct reasons and rationale is critical

- Need to know for effective management and planning
  - Determination of remediation actions
  - Effects of fishing and other stressors
  - The public values fish (for better or worse)

Why Field Determination of Effects on Fish is Difficult?

- Complex life cycles means multiple habitats are used, which prevents comprehensive data collection
- Population affected by multiple factors that vary together and have interactive effects
- Offsetting effects across life stages

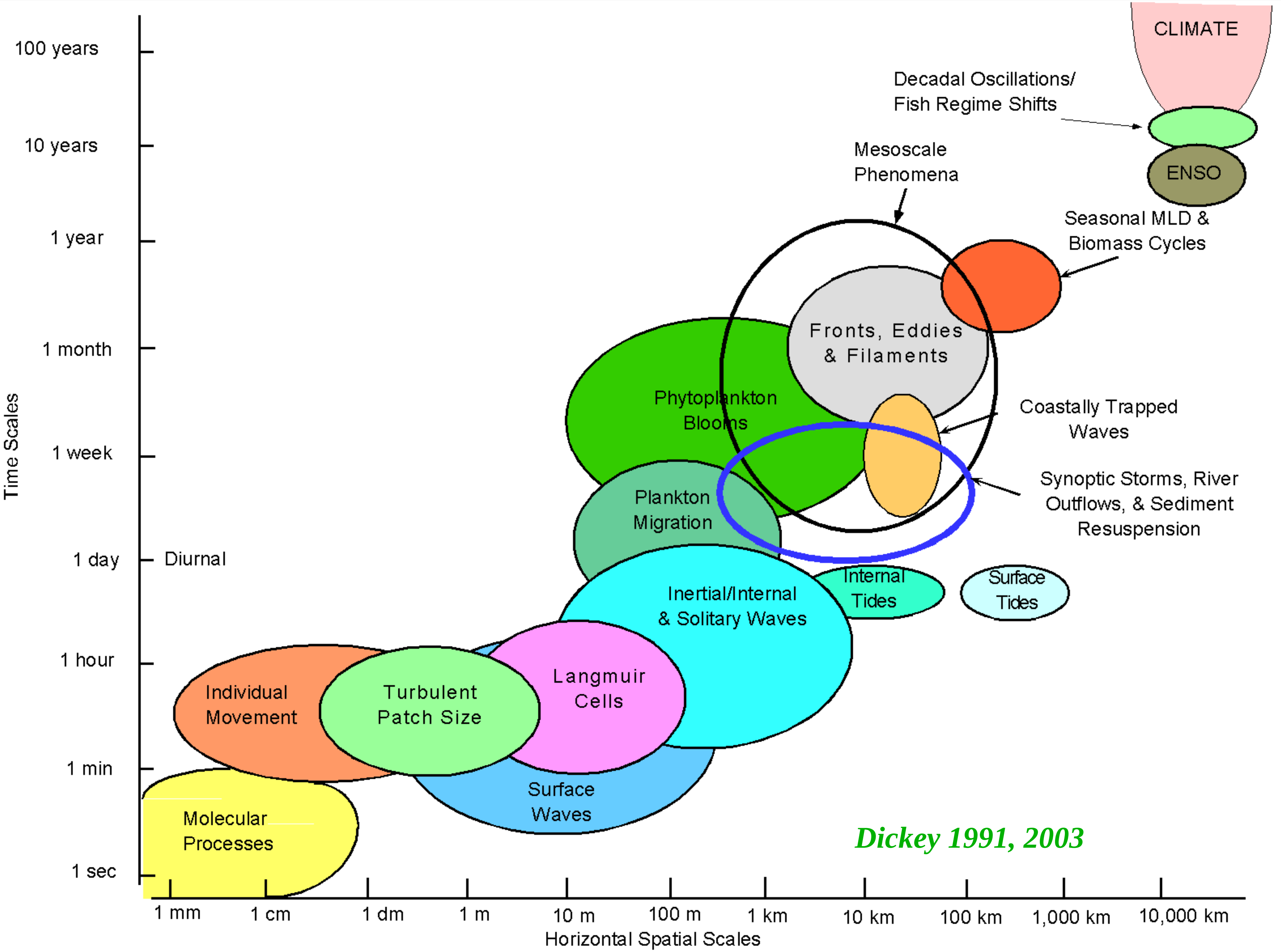
Why Field Determination of Effects on Fish is Difficult?

- Separation of hypoxia effects from other factors is difficult
- [Rose's] Uniqueness principle in ecology
  - Each study, location, and year are special cases
- Thus, we turn to modeling…….

Modeling

- Allows for systematic evaluation of multiple factors in a controlled world

- But, also relies heavily on:
  - Judgment in model building (scaling, processes)
  - Calibration and validation
  - Spatial aspects (e.g., movement)
  - Modelers dilemma: “can never validate a model because if truly did then no need for the model”

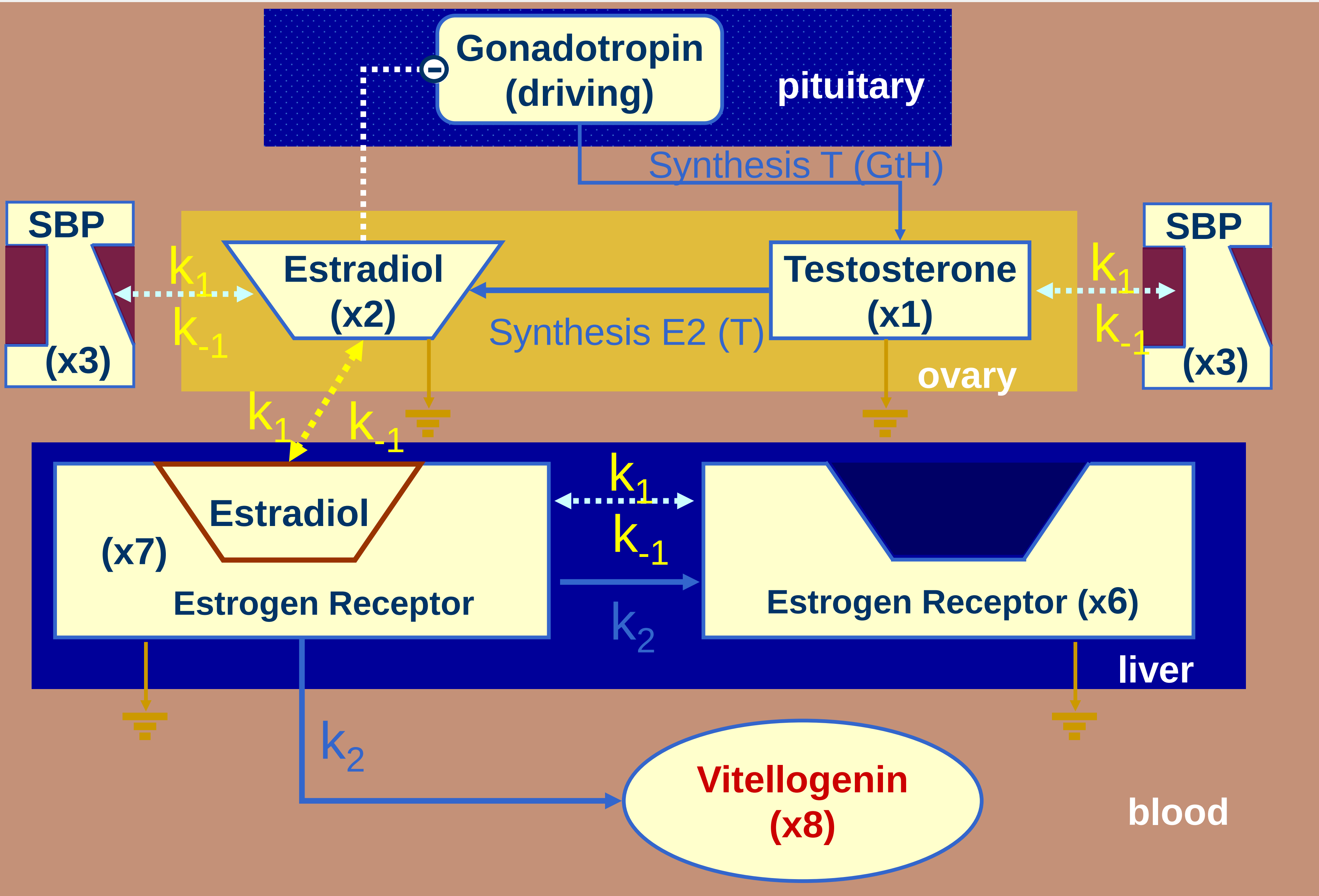

CLIMATE
Decadal Oscillations/
Fish Regime Shifts
ENSO
Mesoscale
Phenomena
Seasonal MLD &
Biomass Cycles
Fronts, Eddies
& Filaments
Phytoplankton
Blooms
Coastally Trapped
Waves
Synoptic Storms, River
Outflows, & Sediment
Resuspension
Plankton
Migration
Internal
Tides
Surface
Tides
Inertial/Internal
& Solitary Waves
Diurnal
Langmuir
Cells
Individual
Movement
Turbulent
Patch Size
Surface
Waves
Molecular
Processes
Dickey 1991, 2003
100 years
10 years
1 year
1 month
1 week
1 day
1 hour
1 min
1 sec
Time Scales
1 mm
1 cm
1 dm
1 m
10 m
100 m
1 km
10 km
100 km
1,000 km
10,000 km
Horizontal Spatial Scales

	Scales			DO Effects	Hypoxia	Response
	Biological	Temporal	Spatial			
A	One individual	Hourly 6 months	One box	Gonadotropin suppression	Forced 2.7 10 weeks	Yolk production
B	Eggs, larvae 1-5 d cohorts	Daily June, July	3 layers	Move; M and G	~2 bottom layer	Survival
C	Juvenile individuals	2 hour summer	2-D grid 100 m2	M on prey; C, M, move	0.5 to 5 Normoxic perimeter	Survival Biomass
D	Food web Larvae, zoop, cteno	12 h (d/n) summer	3 layers	Move; M and G	1.5 bottom 3 pycnocline	Laval survival
E	6-species food web	Hourly One yr	2-D 1 m	Move; G, M, and Fec	2-4 lower	Production by species
F	Individual Population	Minutes 10 yrs	3-D Hydro/WQ	M on zoop; Move; M and G	20-40% decrease in volume	YOY survival Pop biomass
G	Individual Population	Hourly 140 yrs	2-D 1 km	Move; Fec, G, and d-d M	Low, medium, severe maps	Size at age Fecundity Abundance

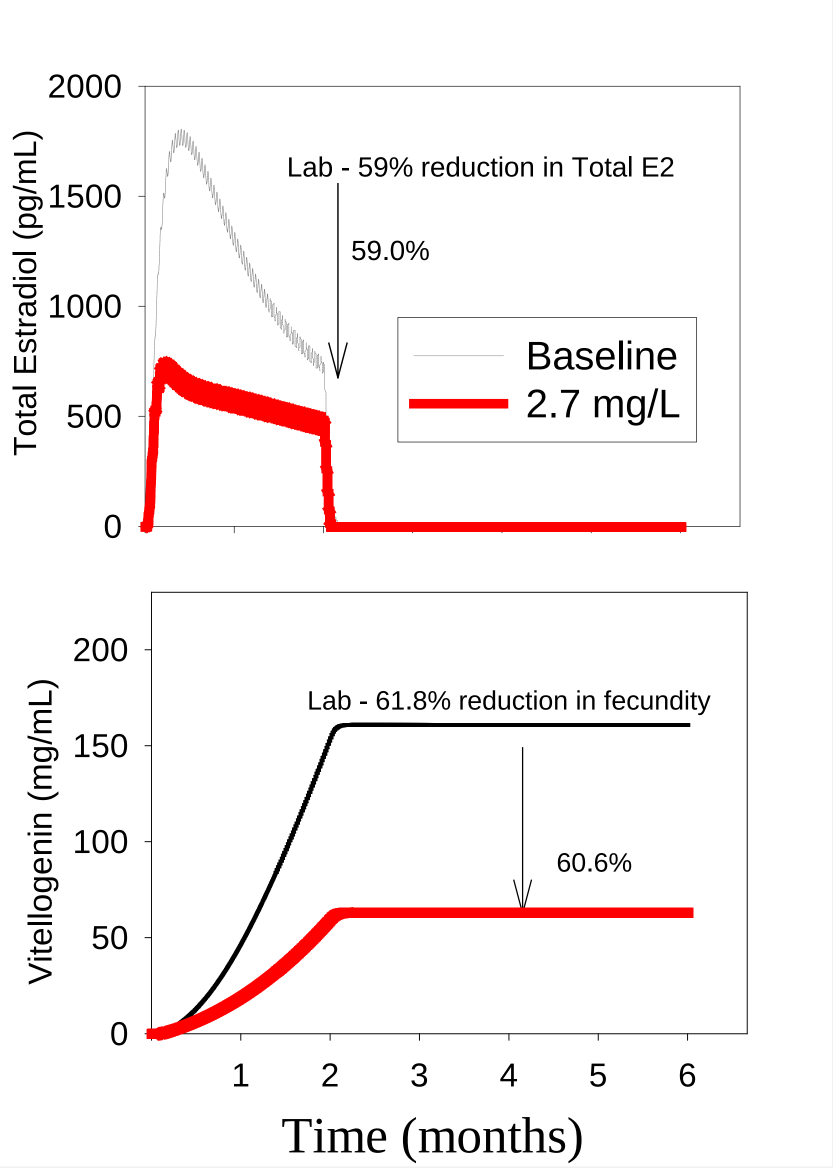
Model: Sources

	Sources
A	Murphy, Rose, Rahman, and Thomas (2009) Testing and applying a fish vitellogenesis model to evaluate lab and field biomarkers of endocrine disruption in Atlantic croaker exposed to hypoxia. Environ Toxic Chem 28: 1288–1303.
B	Adamack, Rose, Breitburg, Nice, and Lung (in press) Simulating the effect of hypoxia on bay anchovy egg and larval mortality using coupled watershed, water quality, and individual-based predation models. MEPS.
C	Craig, Rose, and Rice (in prep.)
D	Sarah E. Kolesar (2006) The effects of low dissolved oxygen on predation interactions between *Mnemiopsis leidyi* ctenophores and larval fish in the Chesapeake Bay ecosystem. PhD dissertation, University of Maryland. Kolesar, Rose, and Breitburg (draft) Hypoxia effects within an intraguild predation food web of *Mnemiopsis leidyi* ctenophores, larval fish, and copepods.
E	Shaye Sable (2007) A comparison of individual-based and matrix projection models applied to fish population and community dynamics. PhD dissertation, LSU. Sable and Rose (draft) An individual-based model of a tidal marsh community: model description, corroboration, and application for scaling individual-level effects to population-level responses.
F	Aaron Adamack (2007) Predicting water quality effects on bay anchovy (*Anchoa Mitchilli*) growth and production in Chesapeake Bay: linking water quality and individual-based fish models. PhD dissertation, LSU.
G	Sean Creekmore (2011) Modeling the population effects of hypoxia on Atlantic croaker (*Micropogonias undulatus*) in the Northwestern Gulf of Mexico. MS thesis, LSU.
A-F	Rose, Adamack, Murphy, Sable, Kolesar, Craig, Breitburg, Thomas, Brouwer, Cerco, and Diamond (2009) Does hypoxia have population-level effects on coastal fish? Musings from the virtual world. J Exp Marine Biol Ecol 381: S188–S203.

Model-by-Model (A)



Model-by-Model (A)



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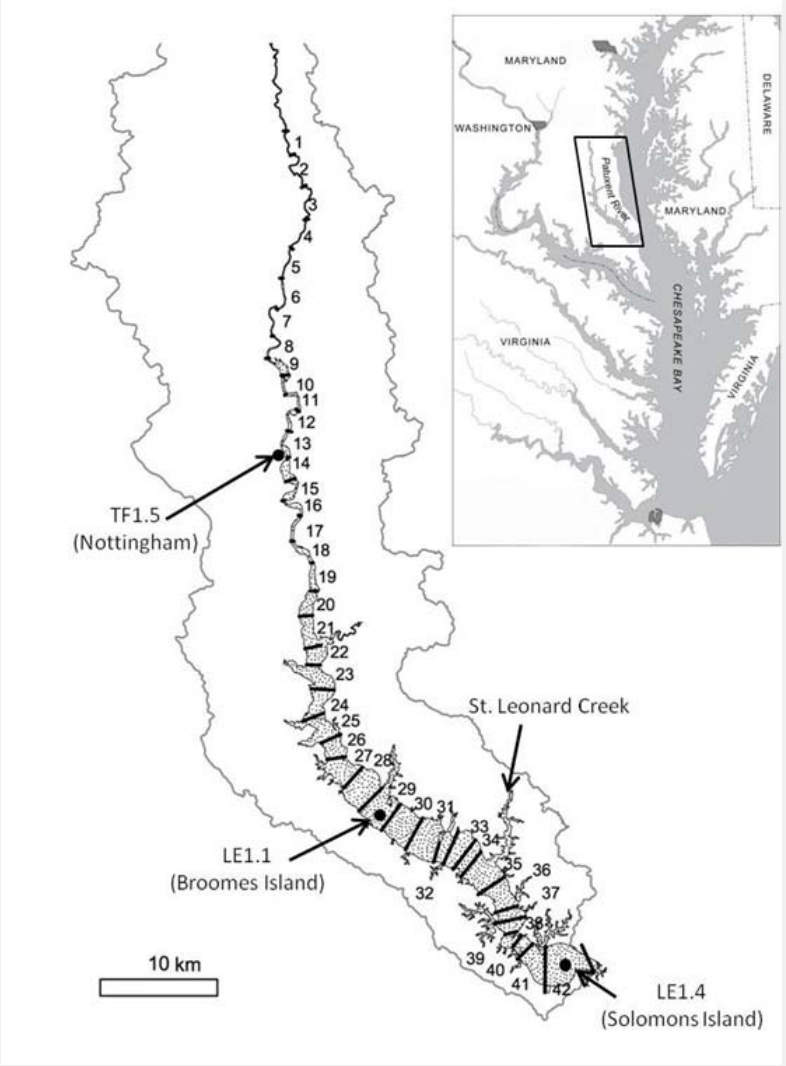

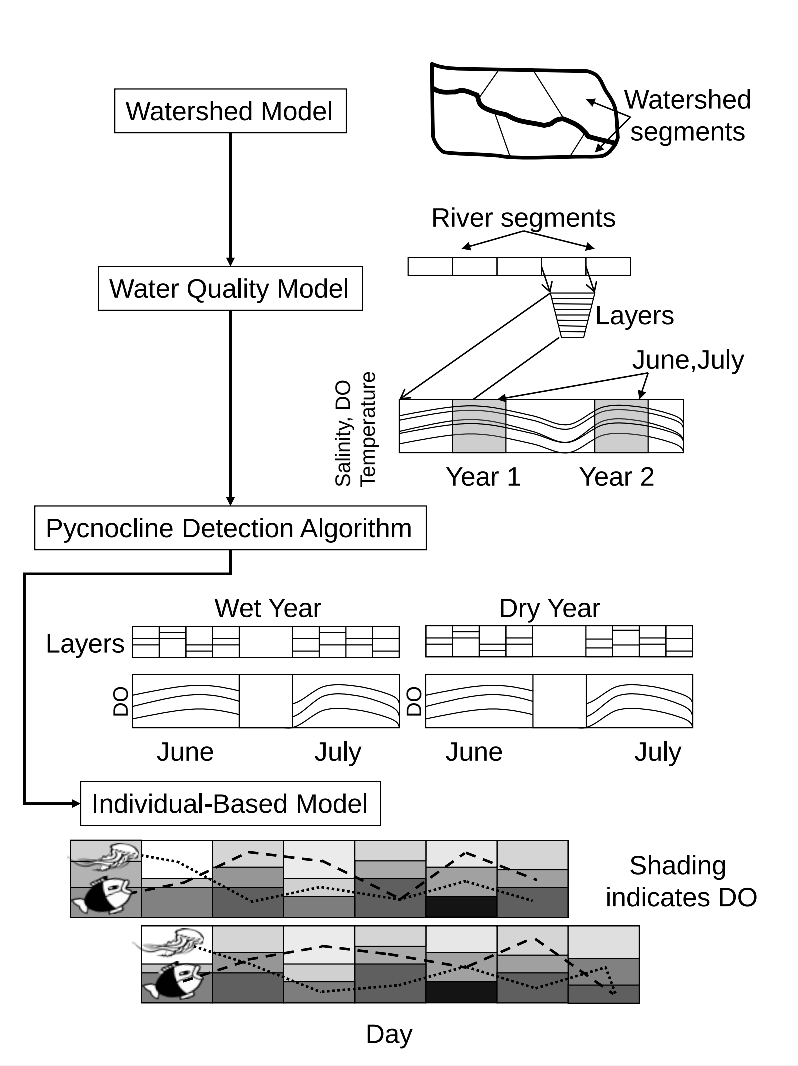

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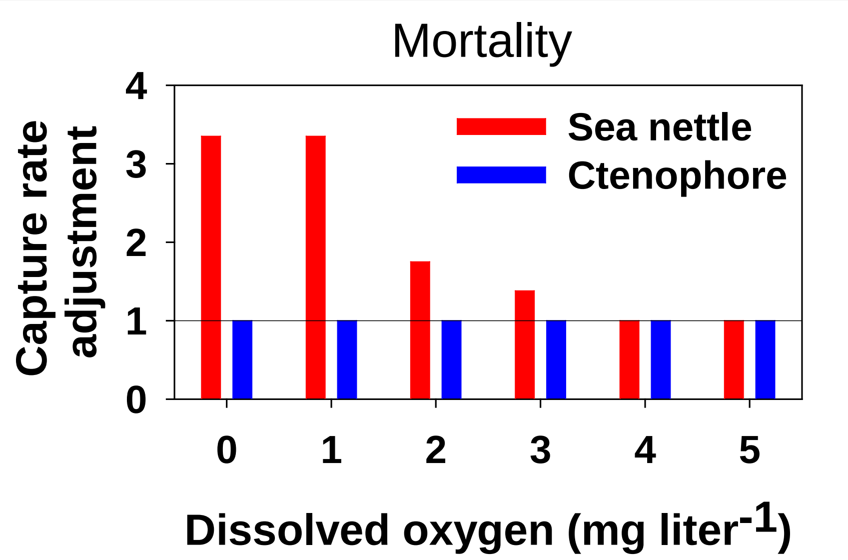

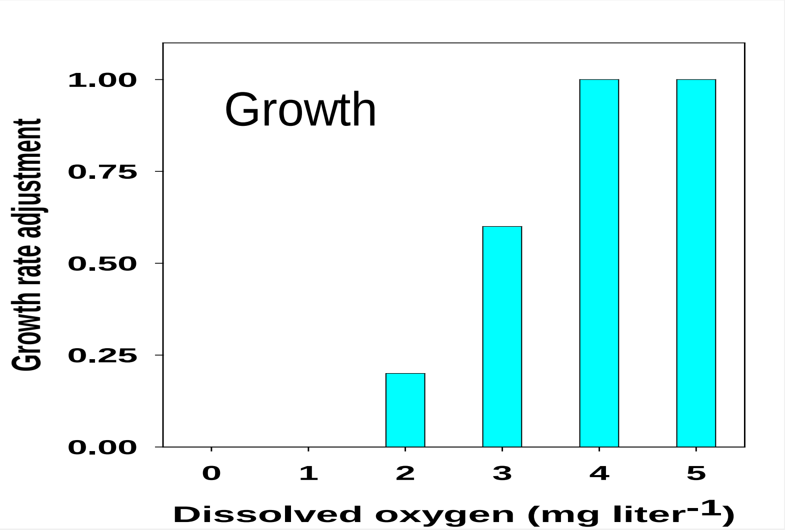

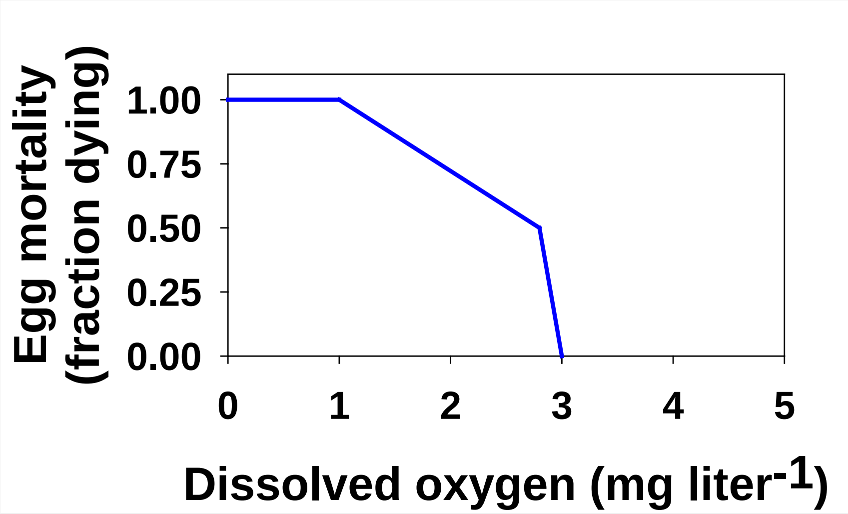

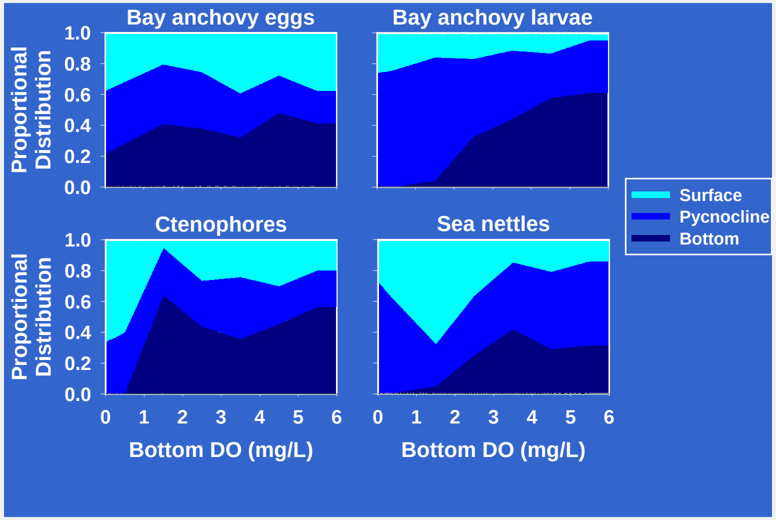

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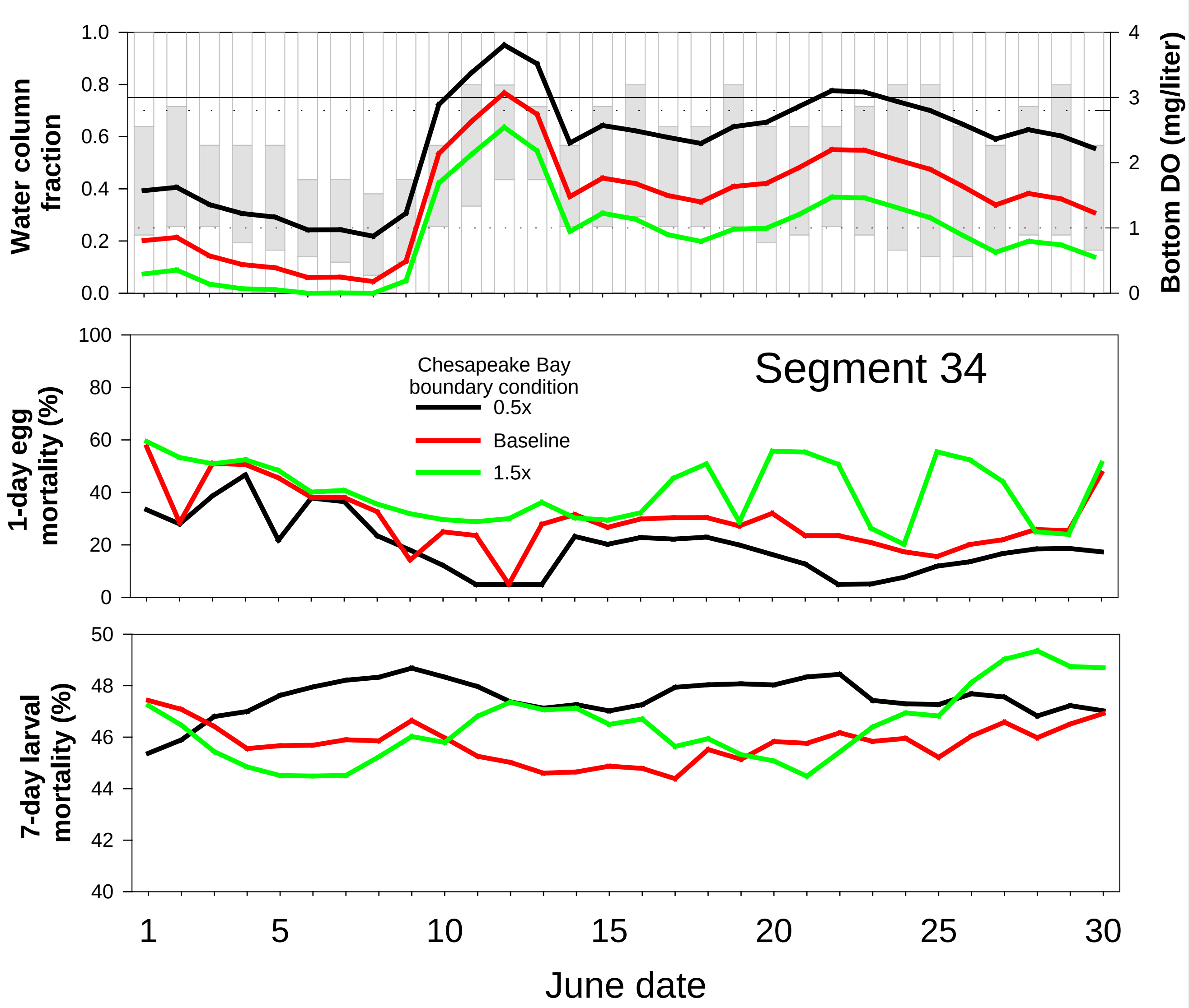
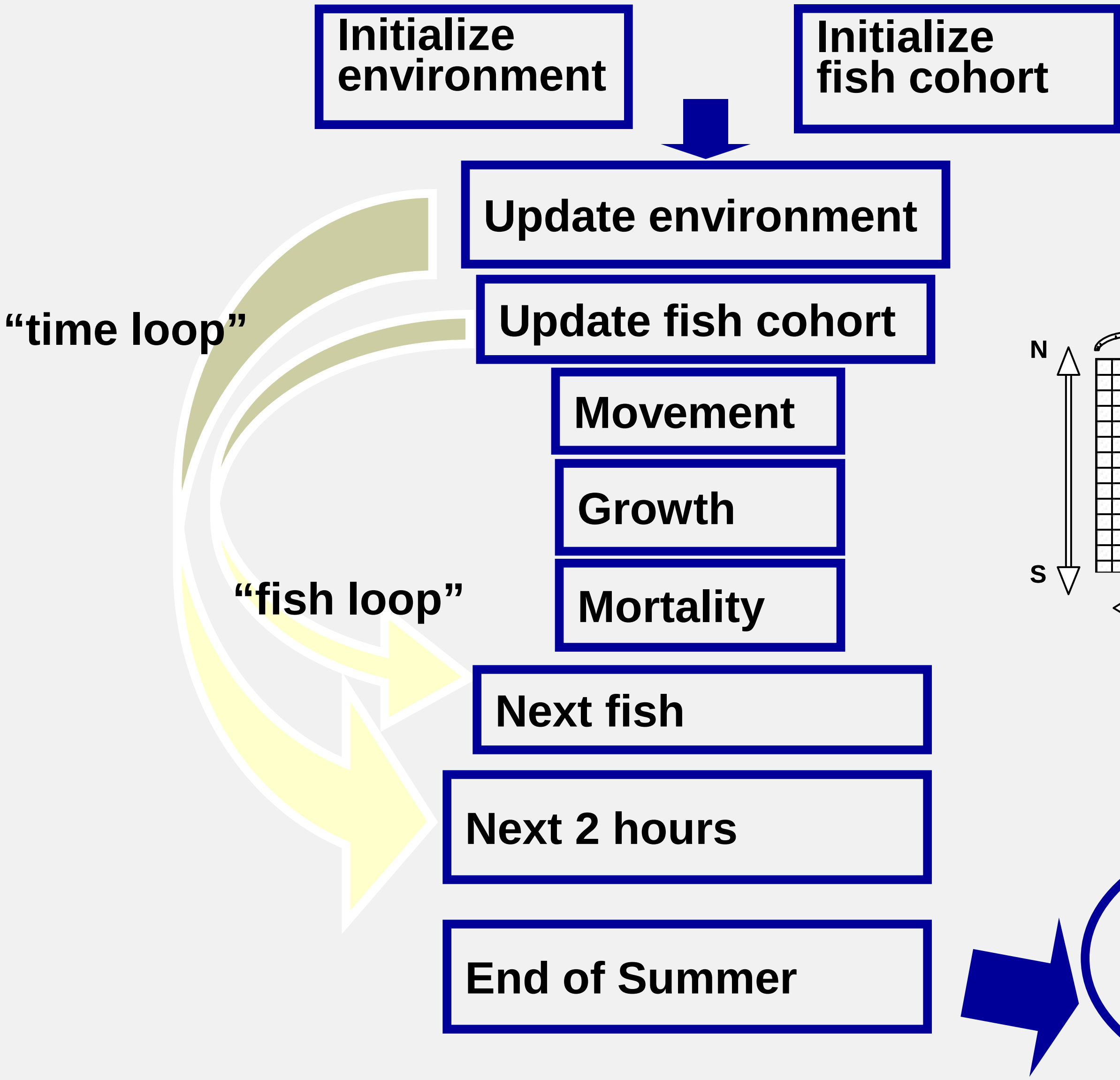
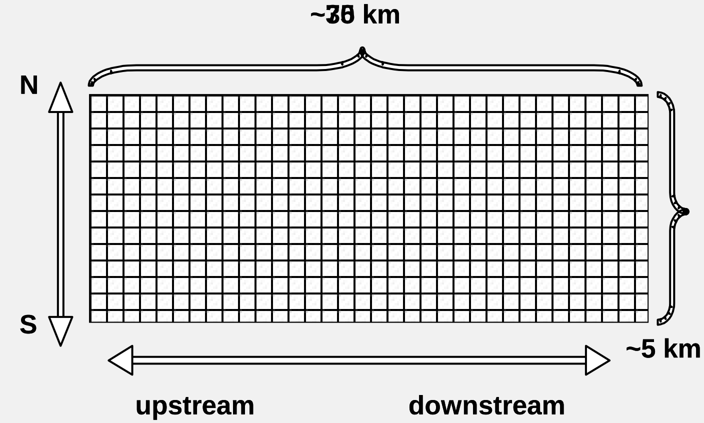


Model-by-Model (C)





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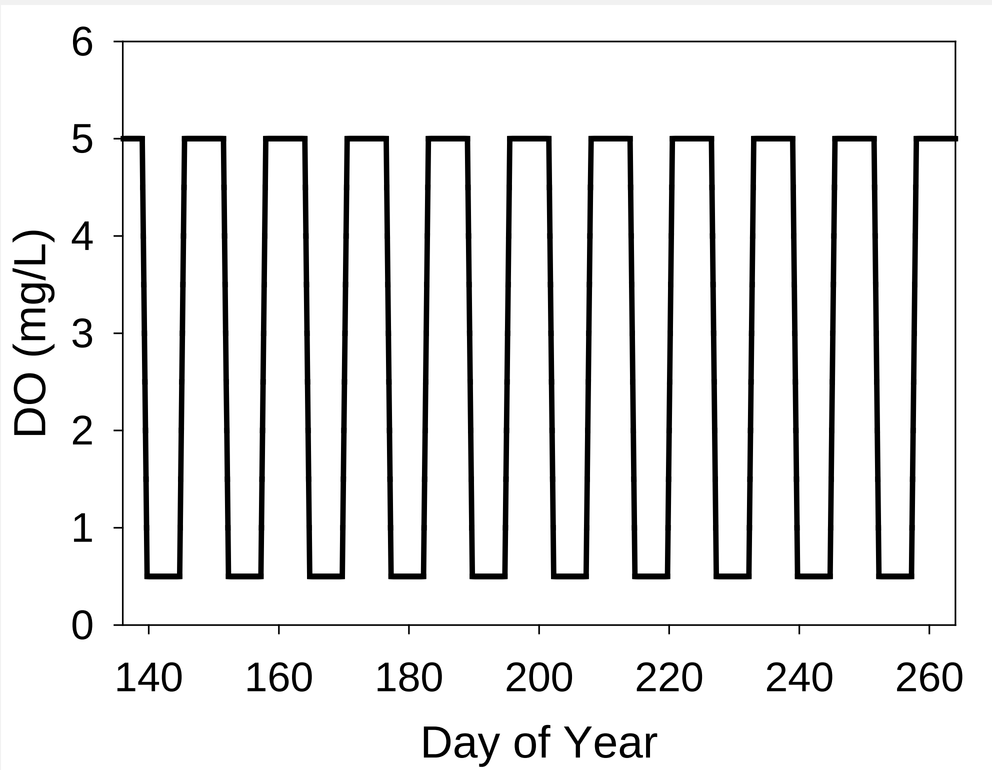
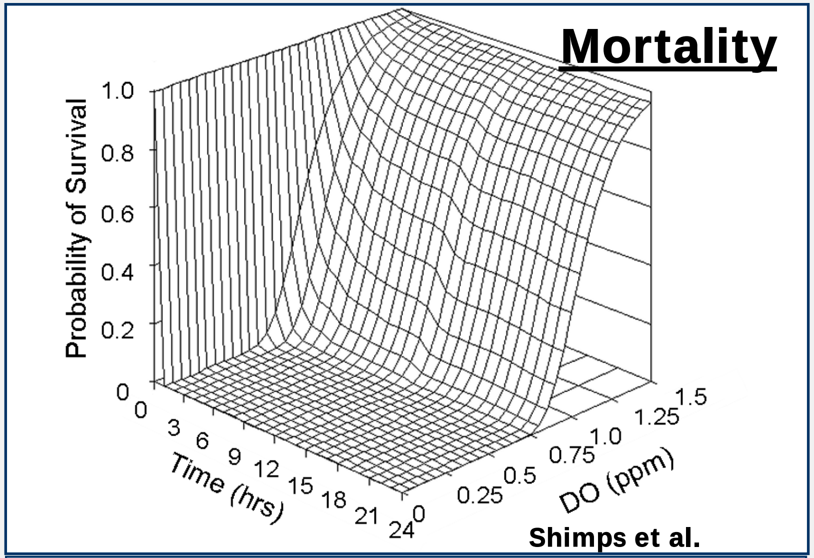
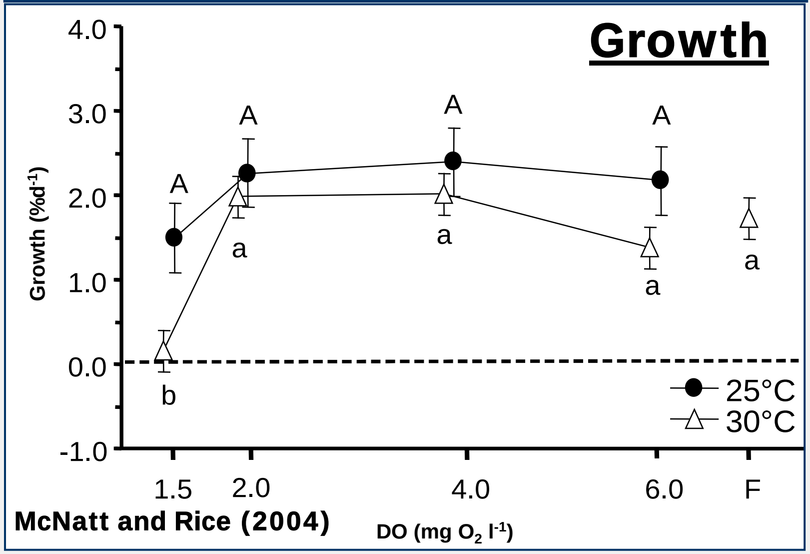
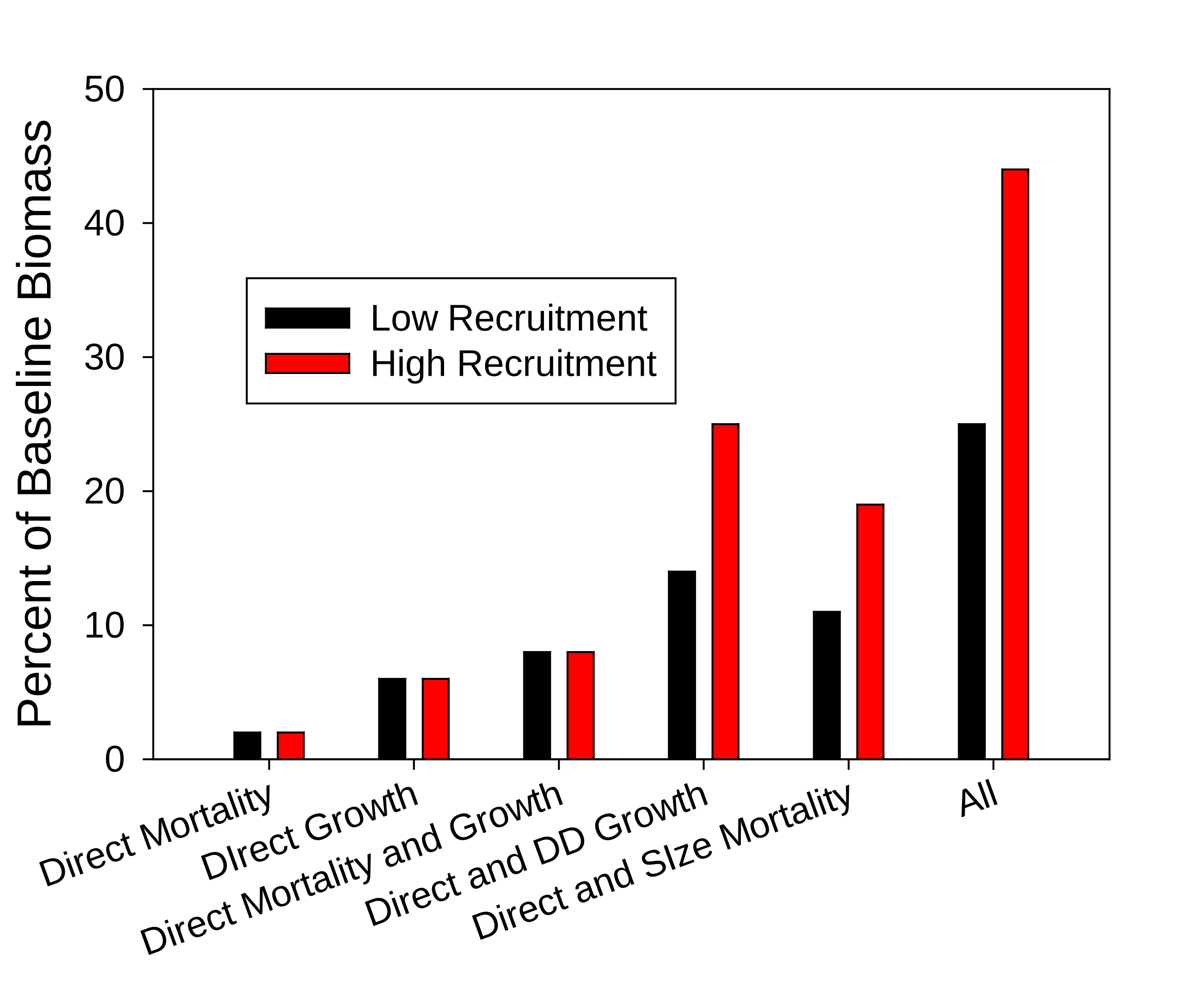


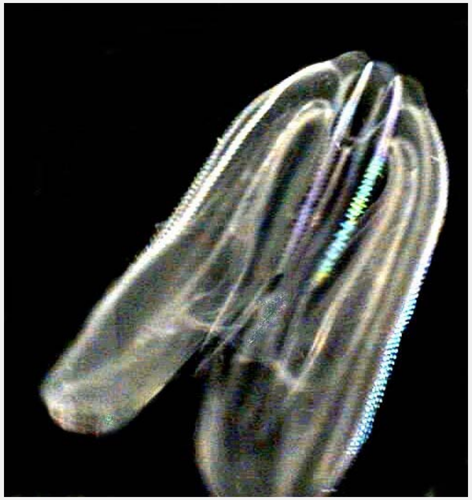




Model-by-Model (C)



Model-by-Model (D)



Ctenophores

100% survival

DO ≥ 0.5 mg / L

72 h

Fish Larvae

LC_{50} = 1 – 2 mg / L

Zooplankton

Acartia tonsa

LC_{50} = 0.95 – 1.4 mg / L

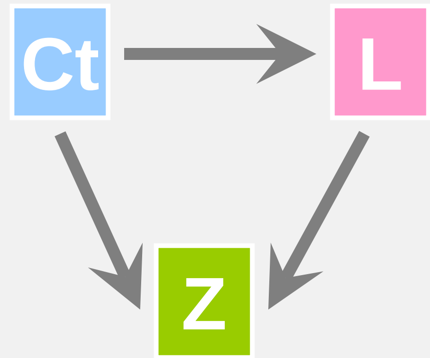
Surface 6 mg/L

Pycnocline 3

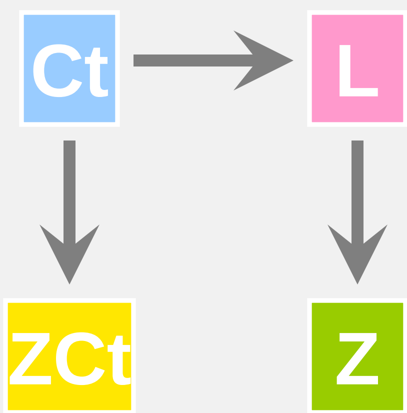
Bottom 1.5

Model-by-Model (D)

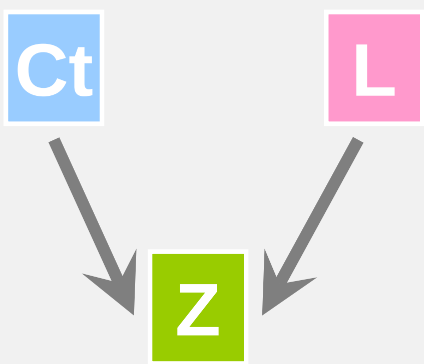
Intraguild Predation



Relaxed Competition



Relaxed Predation



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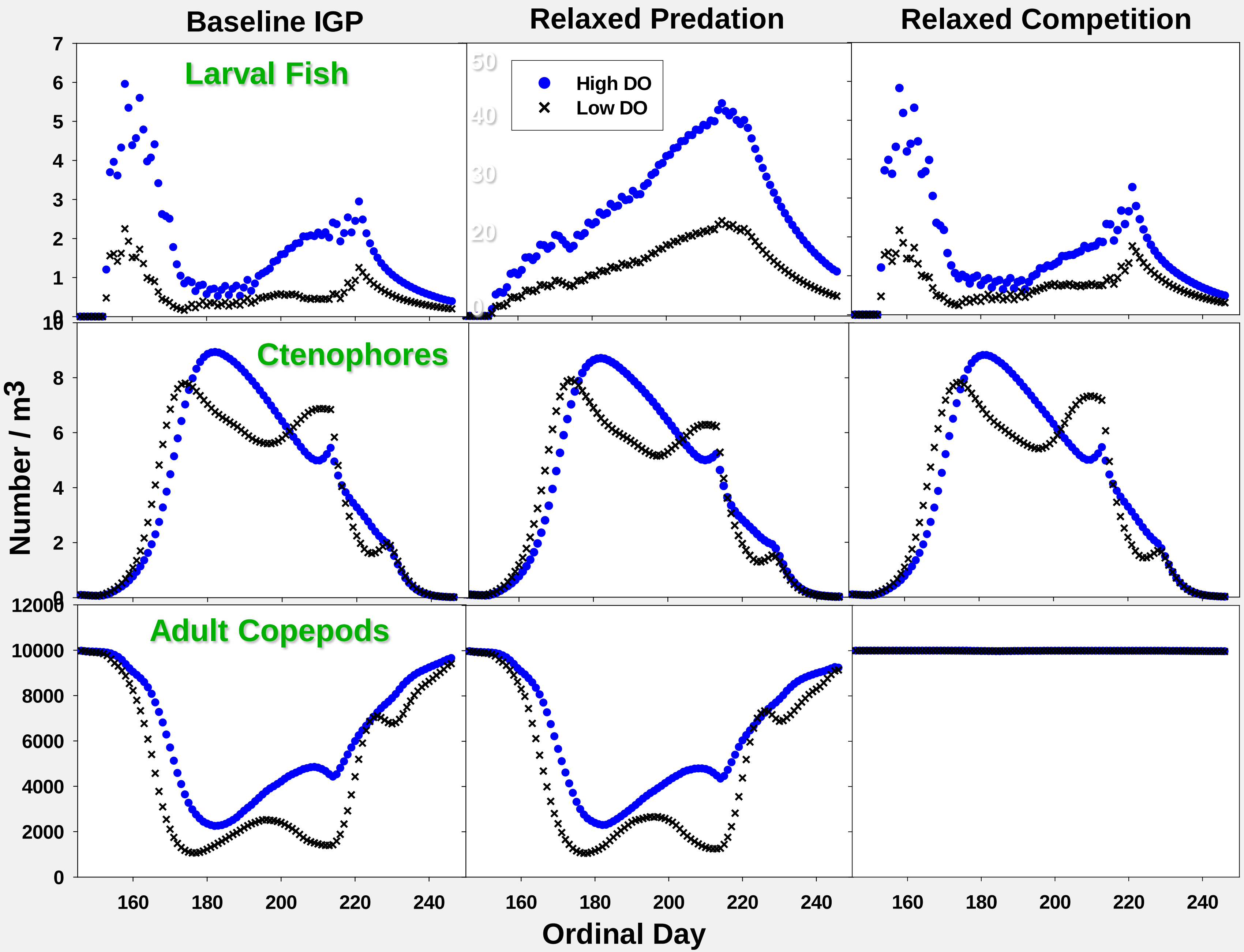

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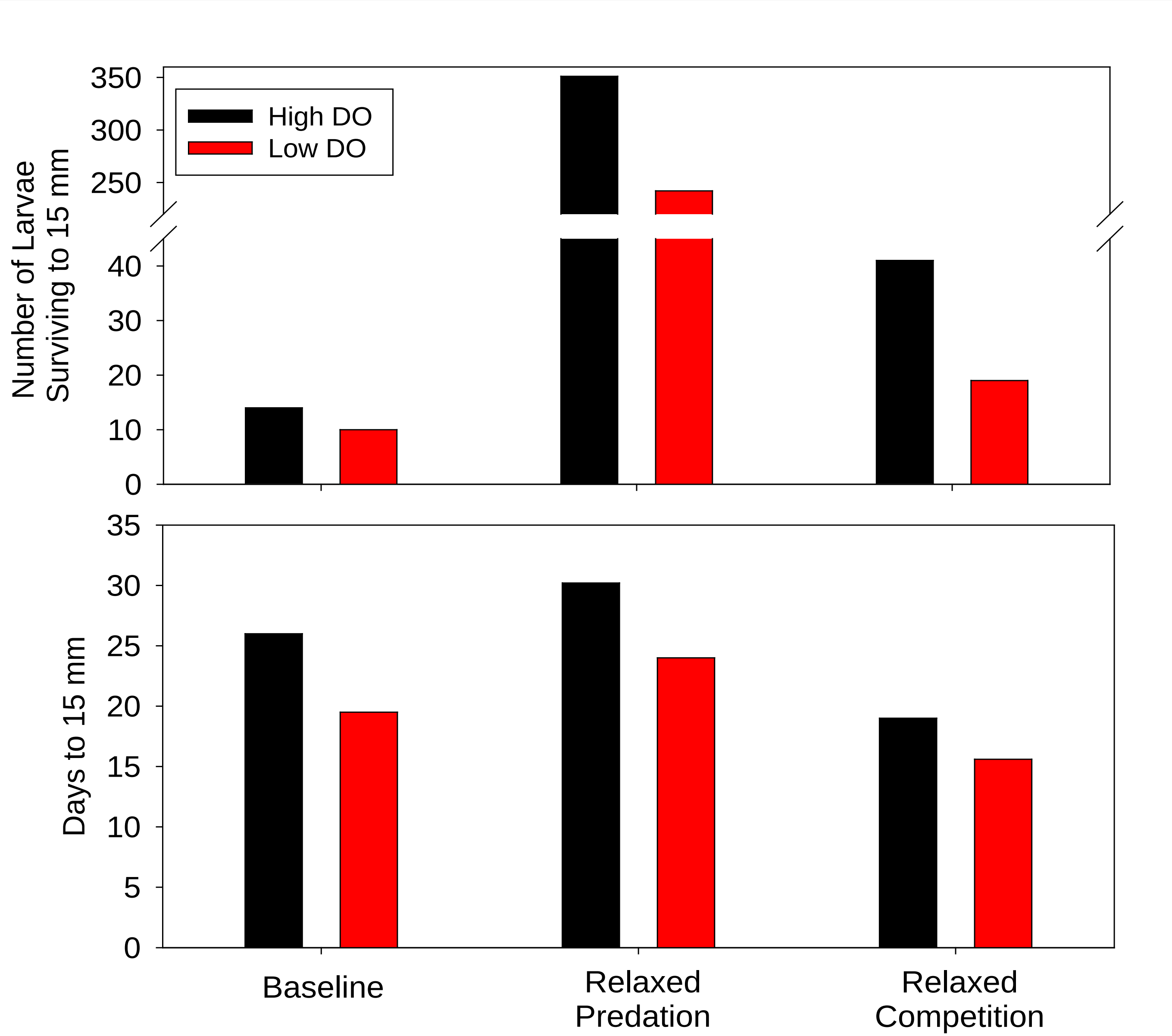
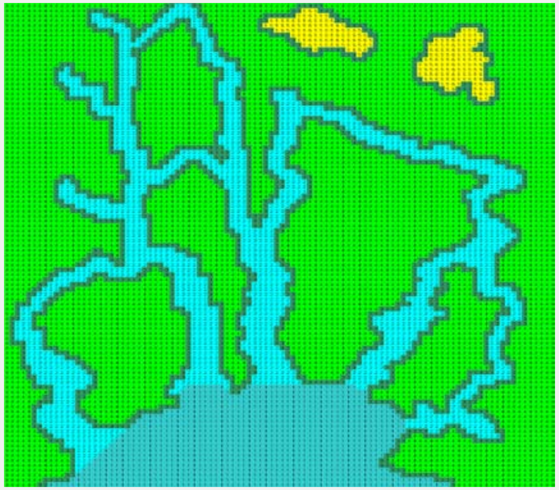
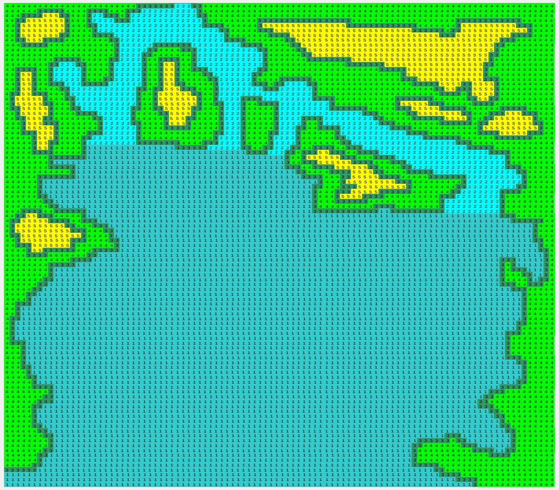
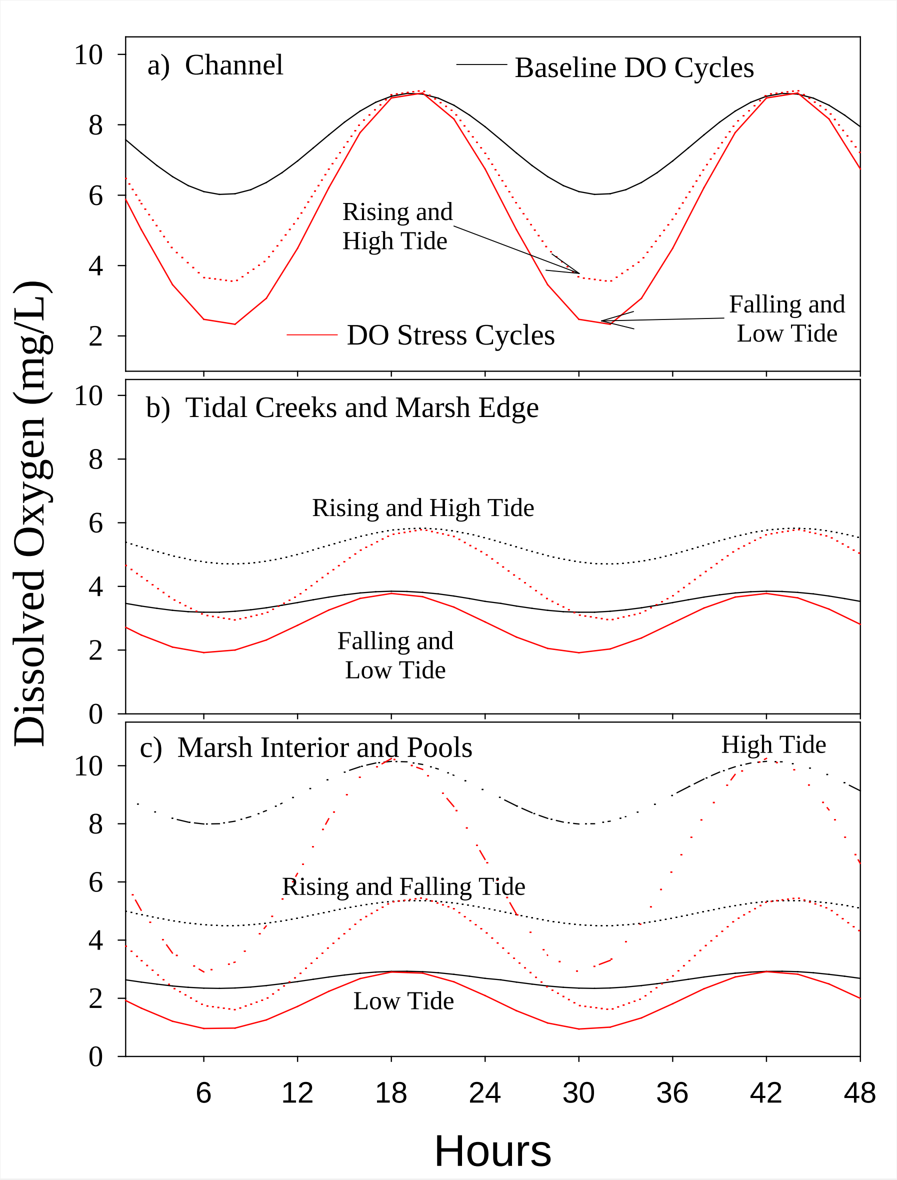


Model-by-Model (E)





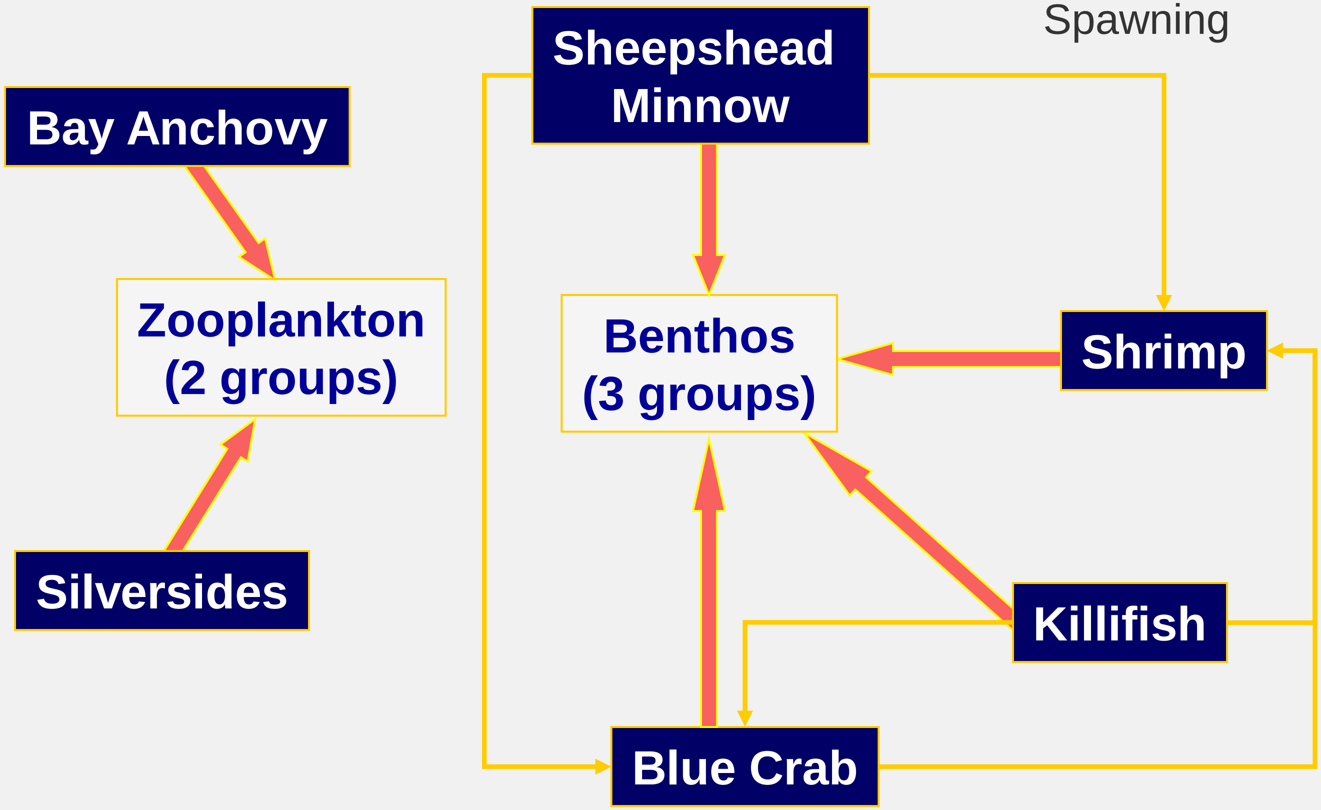


Model-by-Model (E)

Growth rates of all species
Fecundity of resident species

Individual Processes
Growth
Movement
Mortality
Spawning

Conditions
Dissolved O_2
Temperature
Tidal stage
Prey density
Predator density
Individual size



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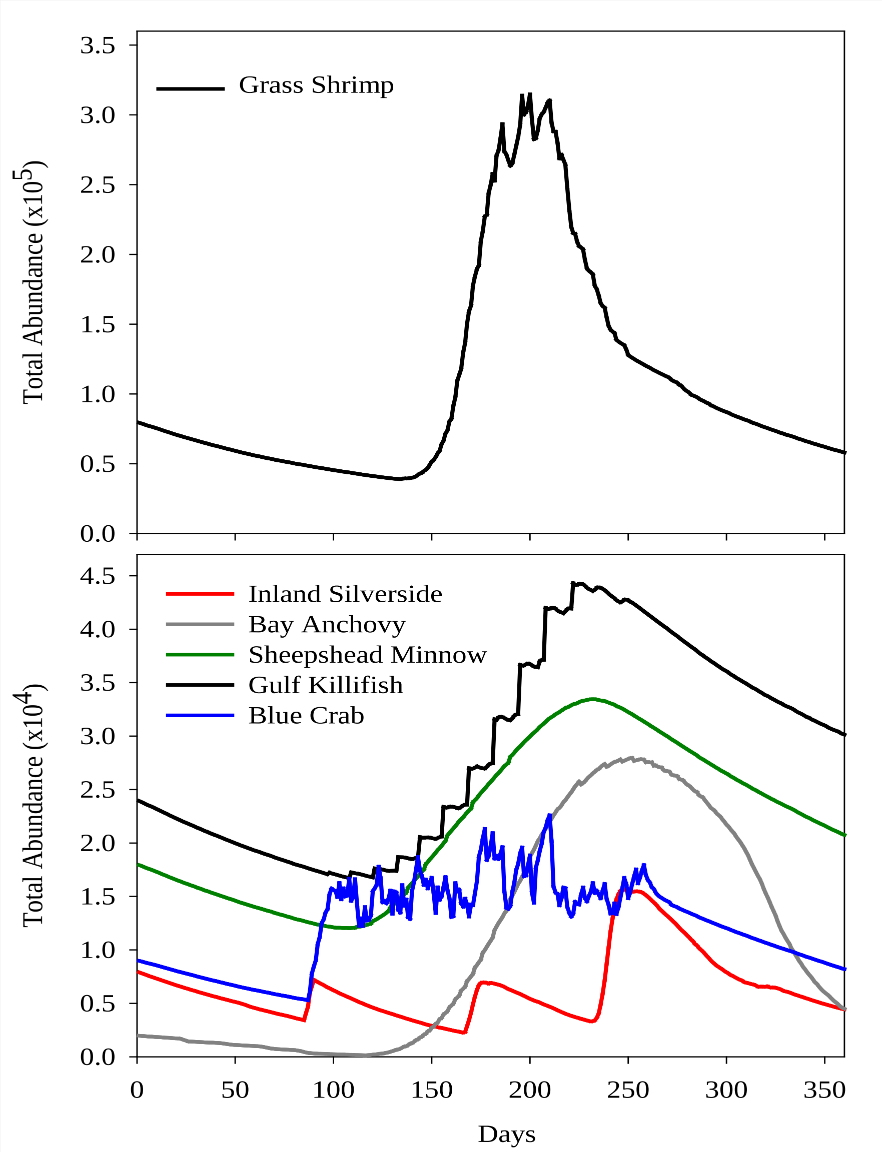
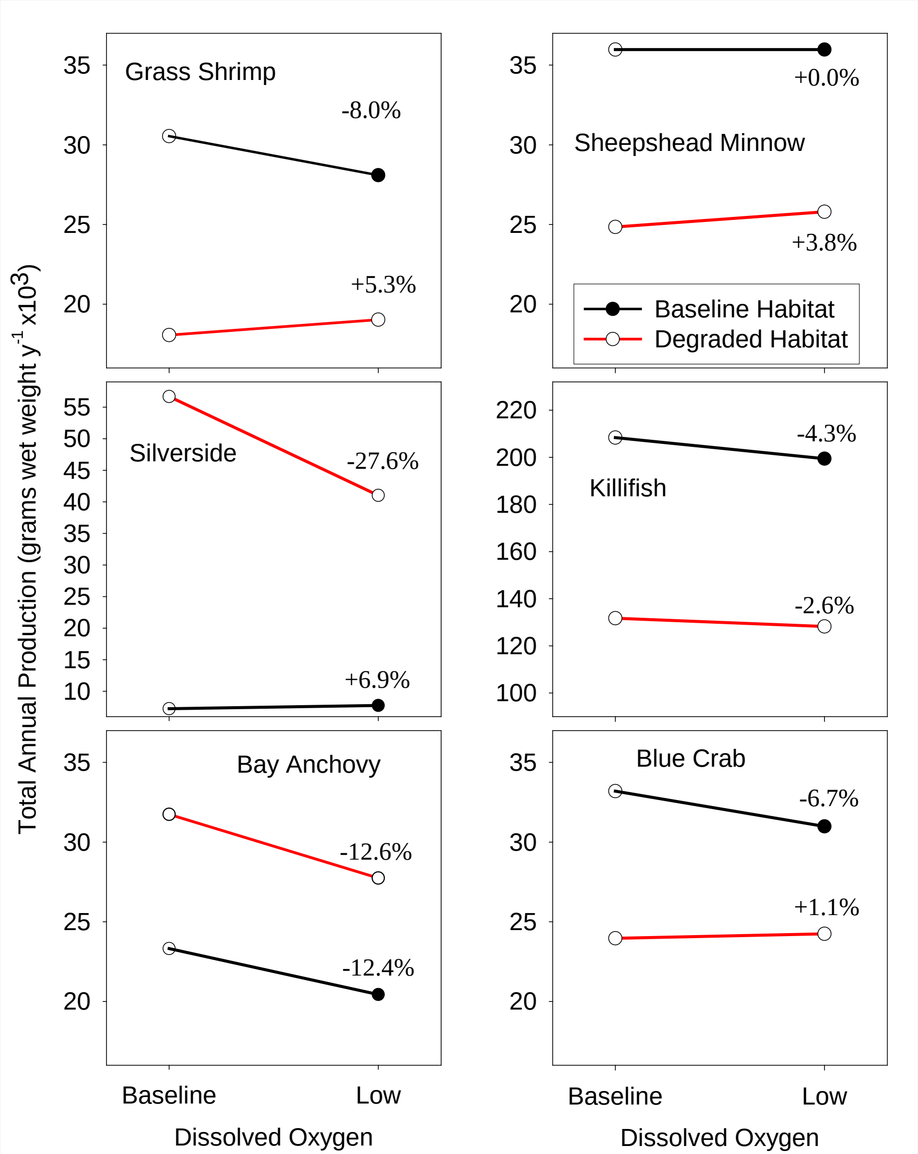
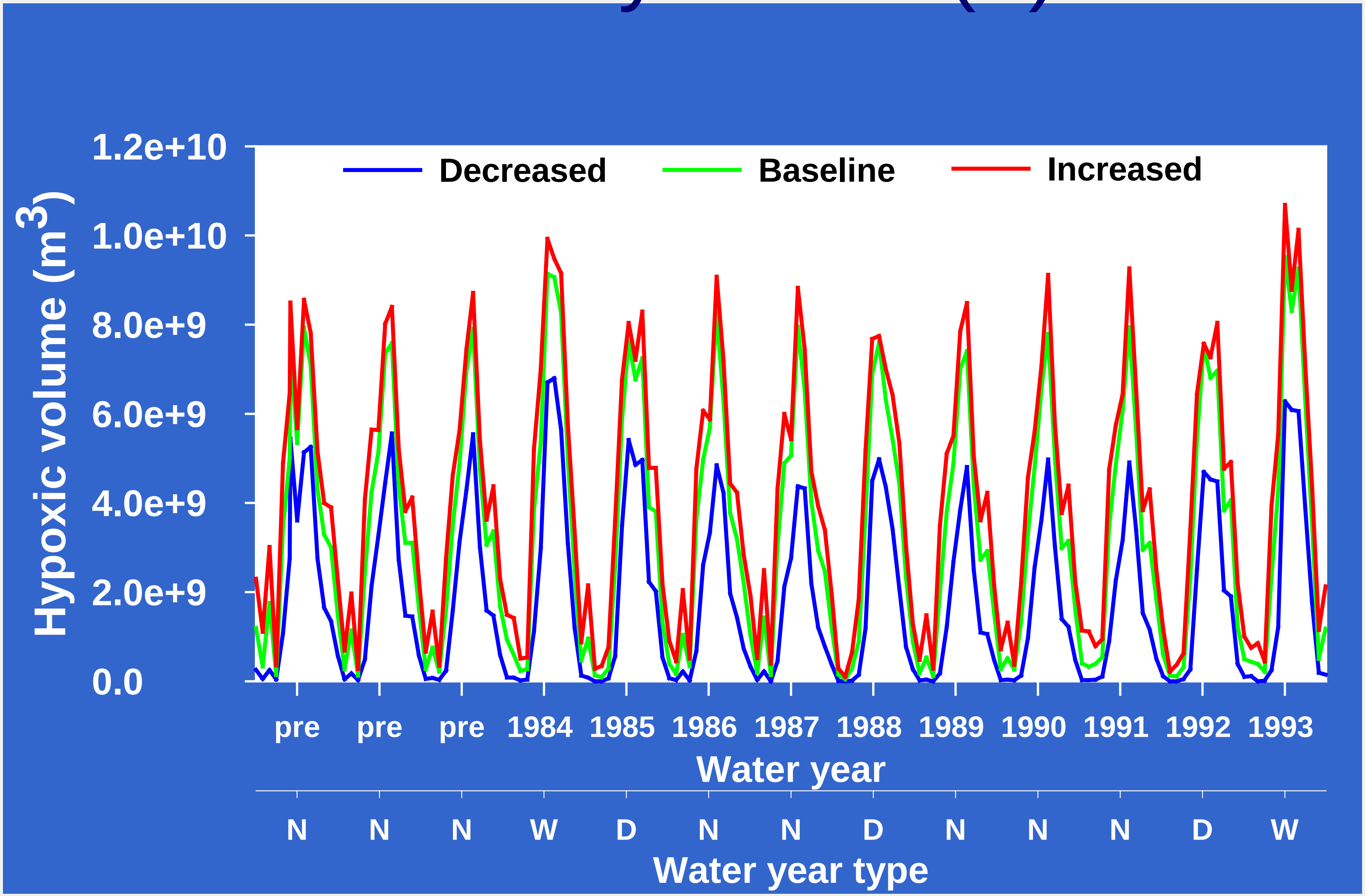




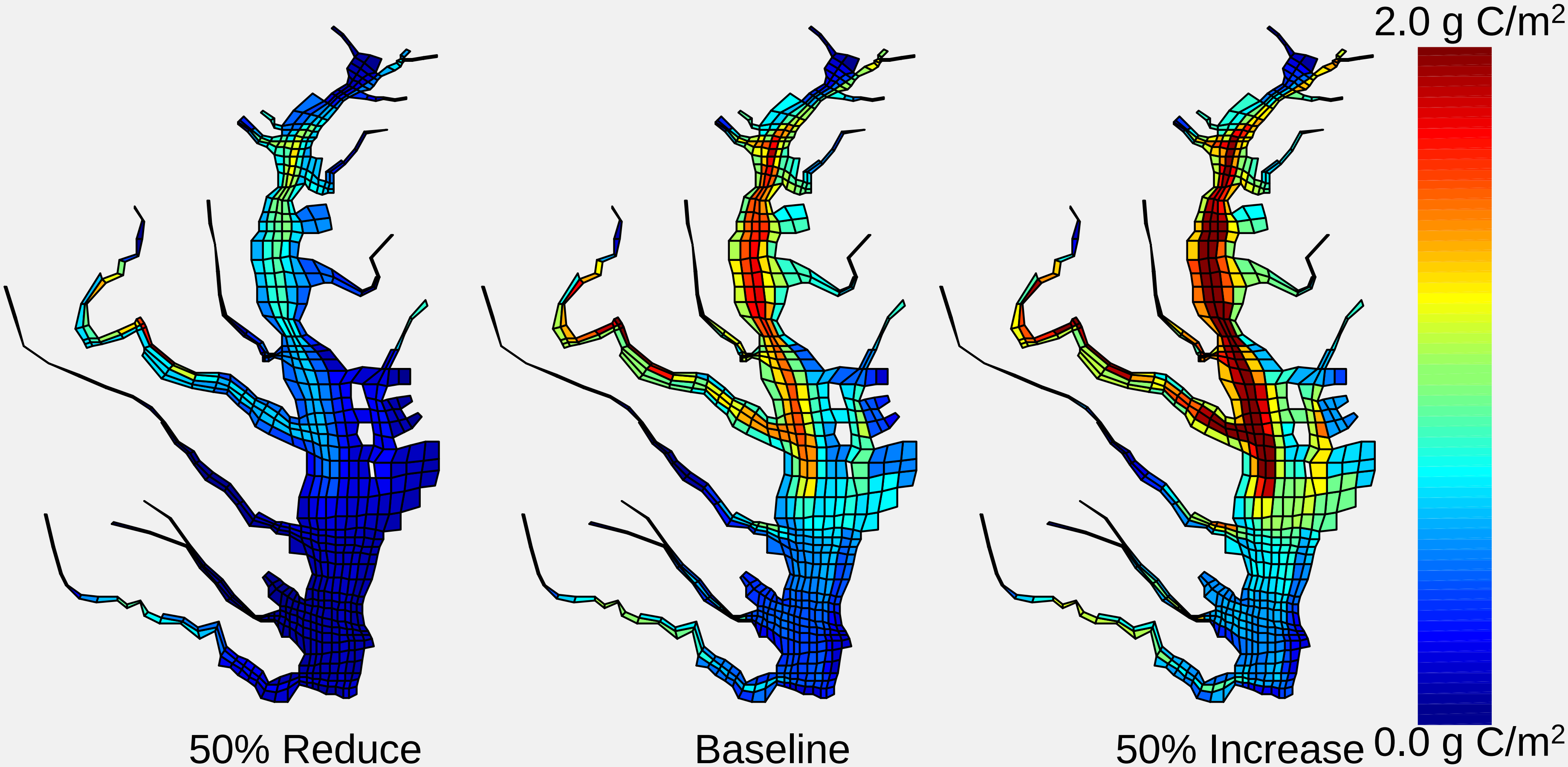
Model-by-Model (F)

- 3D hydrodynamic model (CH3D), eutrophication model (CE-QUAL-ICM), and sediment diagenesis model
- Simulates 24 constituents
  - Forms of N, P, and Si
  - Algae and zooplankton
  - DO and temperature
- Bay is divided into 4073 cells
  - 729 surface cells
  - Minimum 2 layers thick
  - Maximum 15 layers thick

Model-by-Model (F)



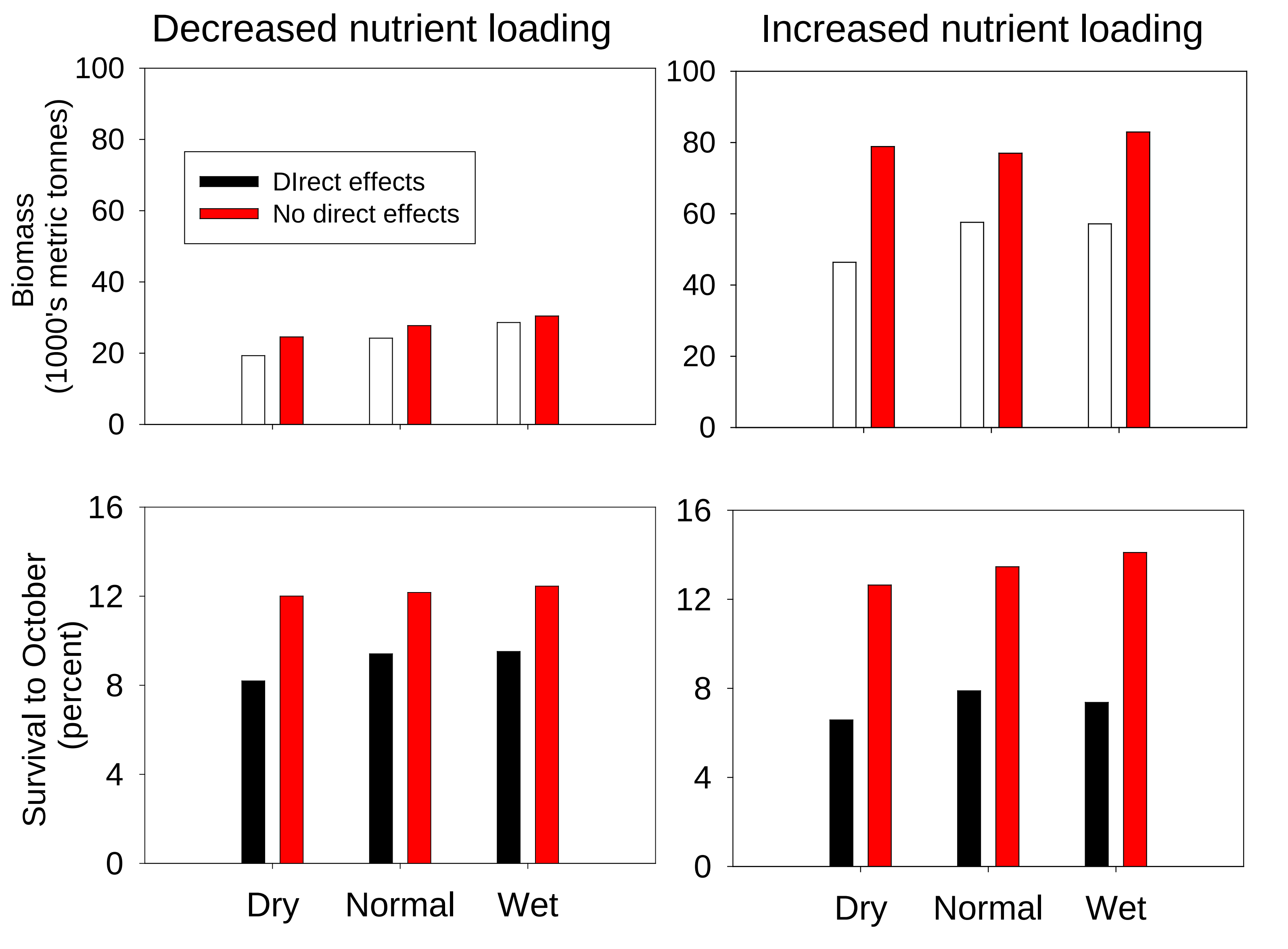
Model-by-Model (F)



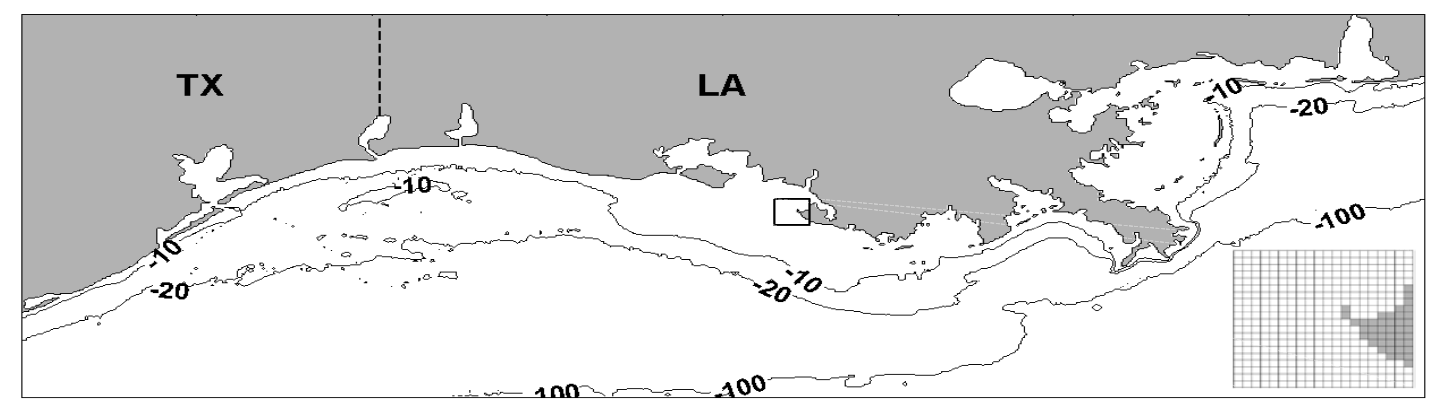
Zooplankton

(Normal Year, July, high recruitment)

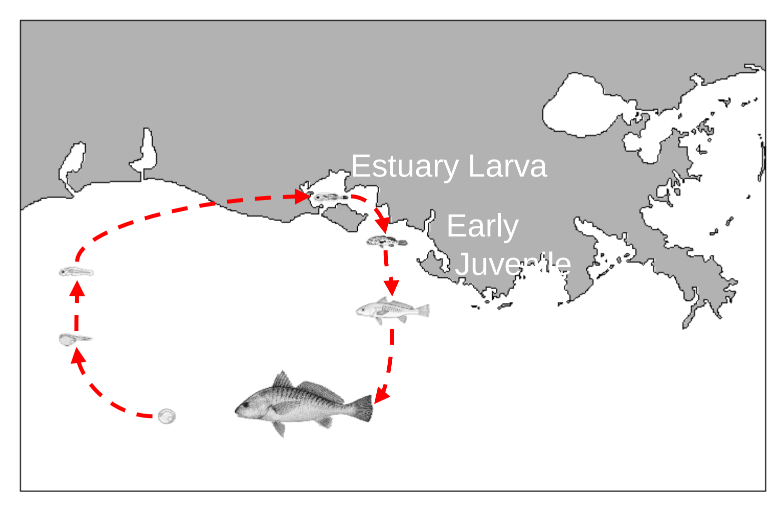
Model-by-Model (F)



Model-by-Model (G)



- Full life cycle
- Hourly processes
  - Growth
  - Mortality
  - Reproduction
  - Movement
- Daily temperature, chlorophyll-a, DO



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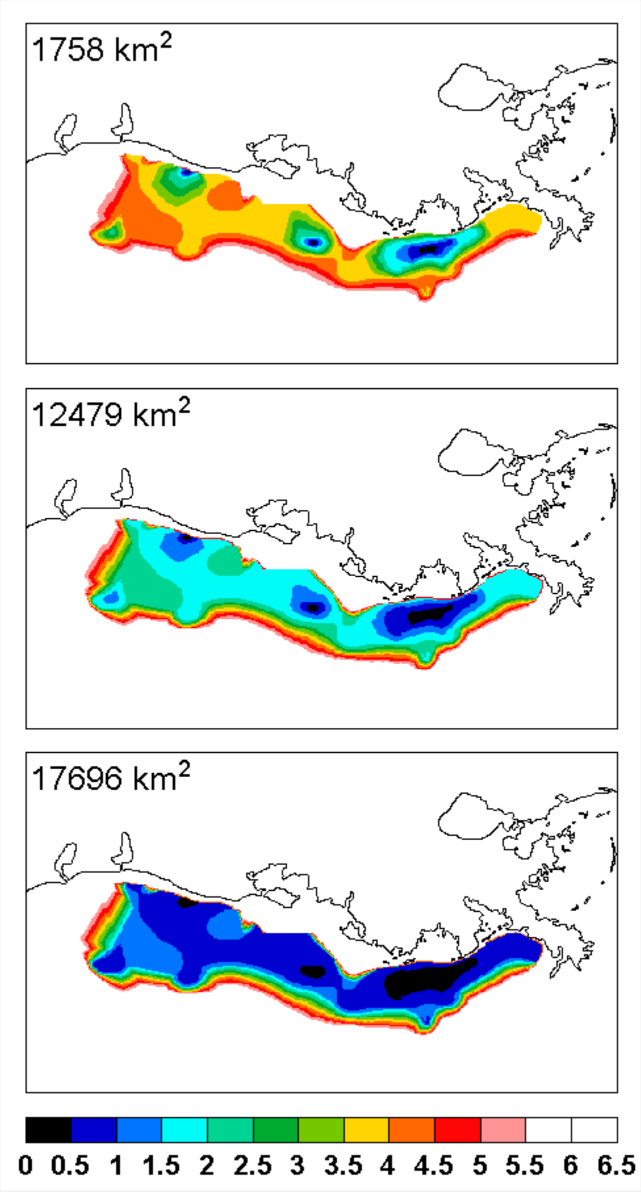
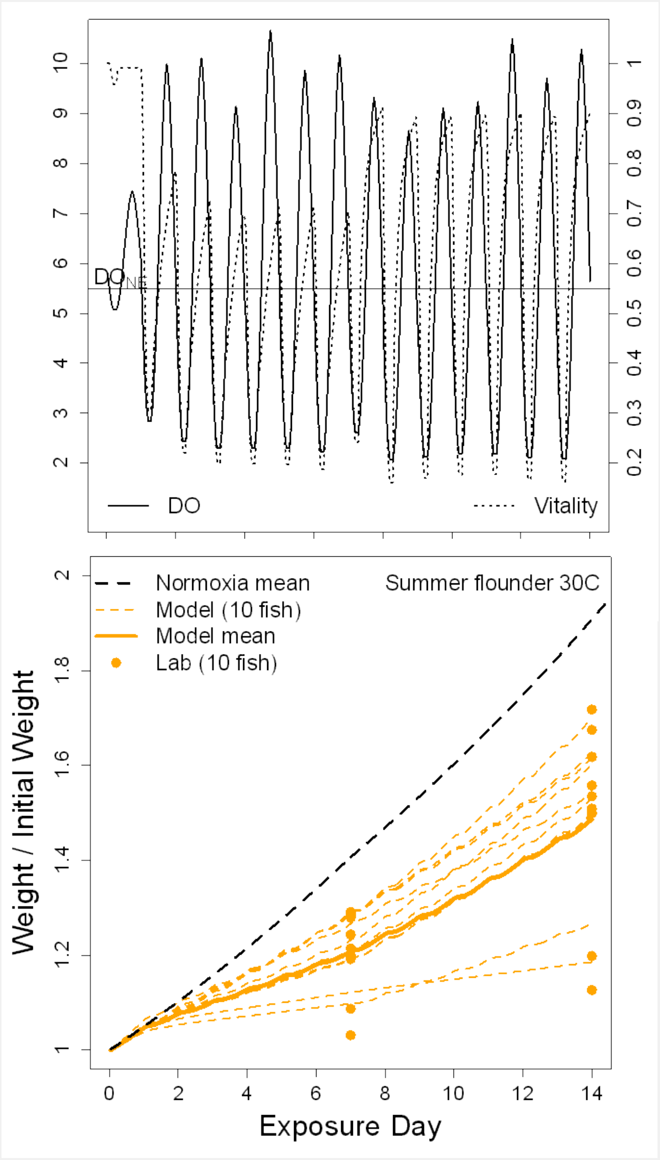
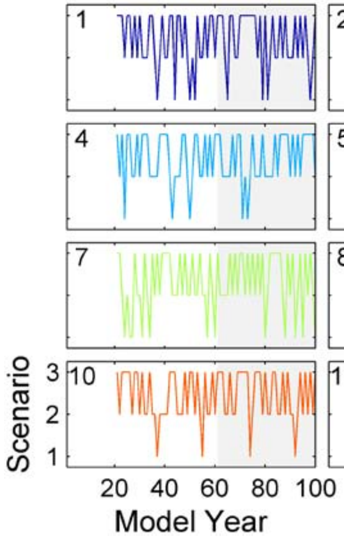
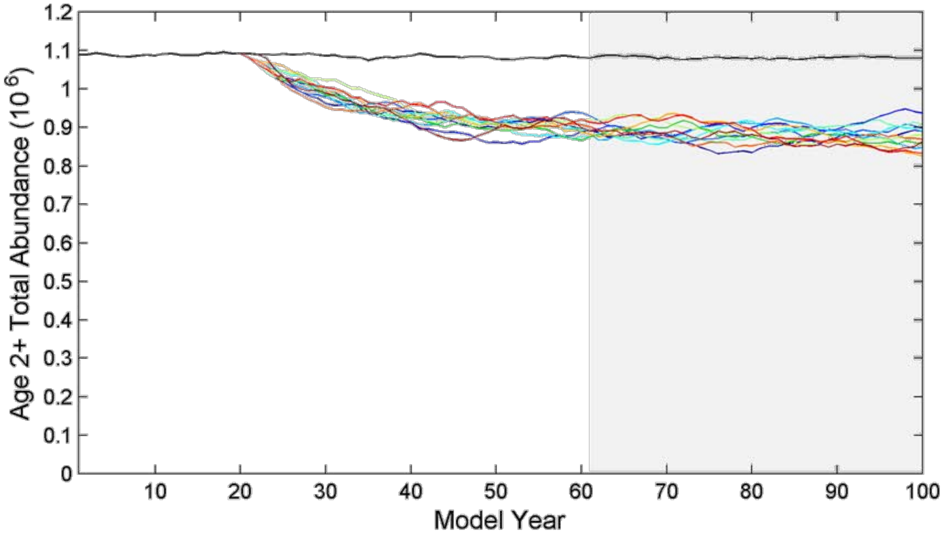




Data from Stierhoff et al. (2006)

Model-by-Model (G)





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

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

Model-by-Model (G)

- A 31% reduction in average long-term abundance
- Many exposed a little
  - 23% of age-1 and 60% of age-2 individuals on Sept 1 were ever exposed to DO < 4.0 mg/L for at least one hour
- Very few exposed a lot
  - On any hour, a maximum of 5% exposed, and usually <1%
- Small effects on processes
  - <3% of incoming age-1 and age-2 died from hypoxia
  - Eggs per gram and per individual decreased by <5%
  - No detectable change (<2%) in weight-at-age

View from 10,000 Feet

- Reponses larger in simpler models
  - Forced exposure on one fish (A)
  - 1-day egg and 7-day larval cohorts (B)
  - Once add avoidance, responses smaller
  - “flexibility” results in small responses

- More feedbacks and indirect pathways, the smaller the main effects but larger the interaction and indirect effects

View from 10,000 Feet

- Indirect and interaction effects
- Offsetting effects across life stages (egg vs larva in B)
- Form of growth and mortality (DD and size in C)
- Hypoxia effects amplified by other conditions (recruitment in C), but not always (competition and predation in D)
- Multi-species food web (winners and losers in E)

View from 10,000 Feet

- Masked by other factors
  - Higher production with worse hypoxia (hidden foregone production in F)
- Accumulation of subtle effects
  - Widespread low exposure but very low percent high exposure and small changes in growth and fecundity (G)
  - Required decades to accumulate (G)

Other Models

- My look at other modeling analyses either supports or does not contradict these conclusions
- For example, growth rate potential (Brandt and Mason 2003; Constanini et al 2008; Ludsin et al 2009)
- NOAA’s CHRP and NGOMEX

My Conclusions

- Exposure is critical
  - Behavior
  - Avoidance
  - Fluctuating DO
  - Many individuals exposed a little (precision)

- Consequences of being forced to move to less optimal habitat
  - Community ecology has failed us

My Conclusions

- On a typical year, hypoxia generally has small effects on coastal fish populations
  - Notable exceptions but they are exceptions

- Population effects can be moderate to large under certain conditions

- Arise from indirect accumulated effects

My Conclusions

- Often, effects are masked by variation in other factors (detectability versus presence)

- Wrong to infer hypoxia effects can be ignored

- Indeed, very important to quantify the effects
  - “hidden costs”
  - Lost year-classes
  - Distort population responses, especially when large episodic effects

Where do we go from here?

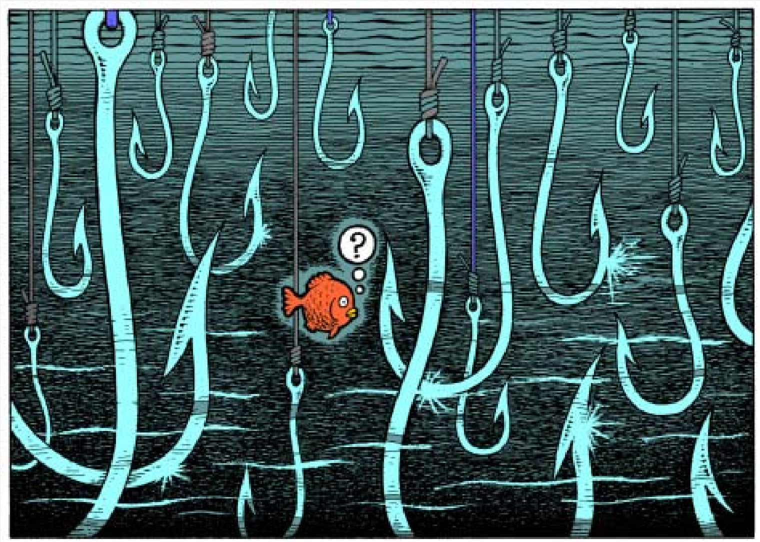
- We (Thomas, Creekmore, Rahman, Craig) are continuing the modeling and data collection for (G)
- Diurnal DO effects in Chesapeake Bay (Breitburg et al. CHRP)
- Others (e.g., Roman et al. NGOMEX)

Where do we go from here?

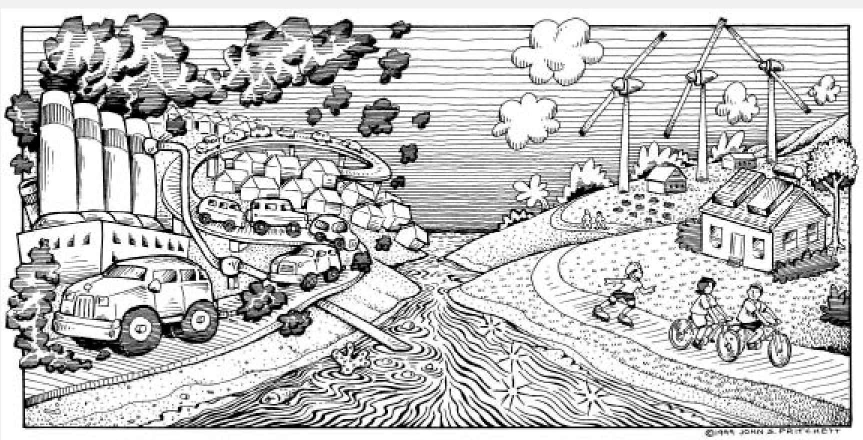
- Modeling Summit
  - First, the modelers – devil in the details
  - Then everyone
  - Previous workshops focused on other topics

- Time for a synthesis paper on population level effects of hypoxia on coastal species

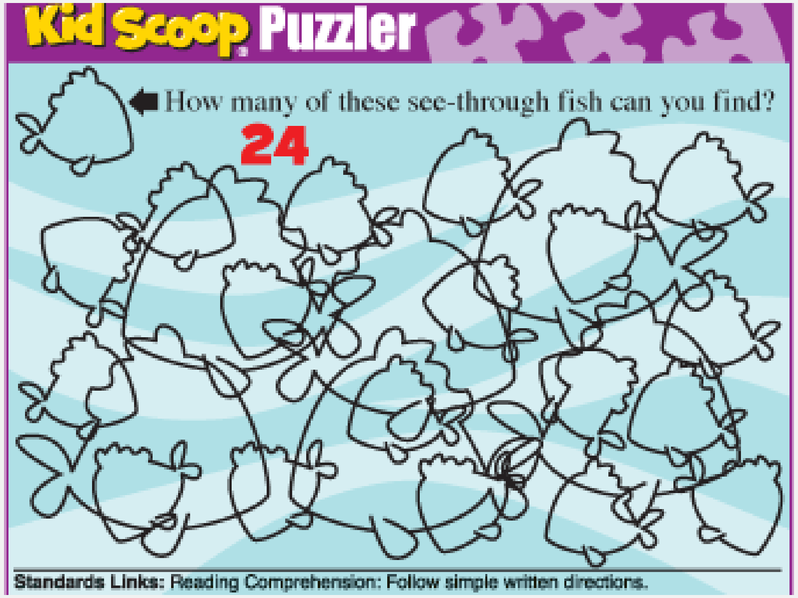
Preparation documents sent to review panel members for the Gulf of Mexico Red Snapper stock assessment



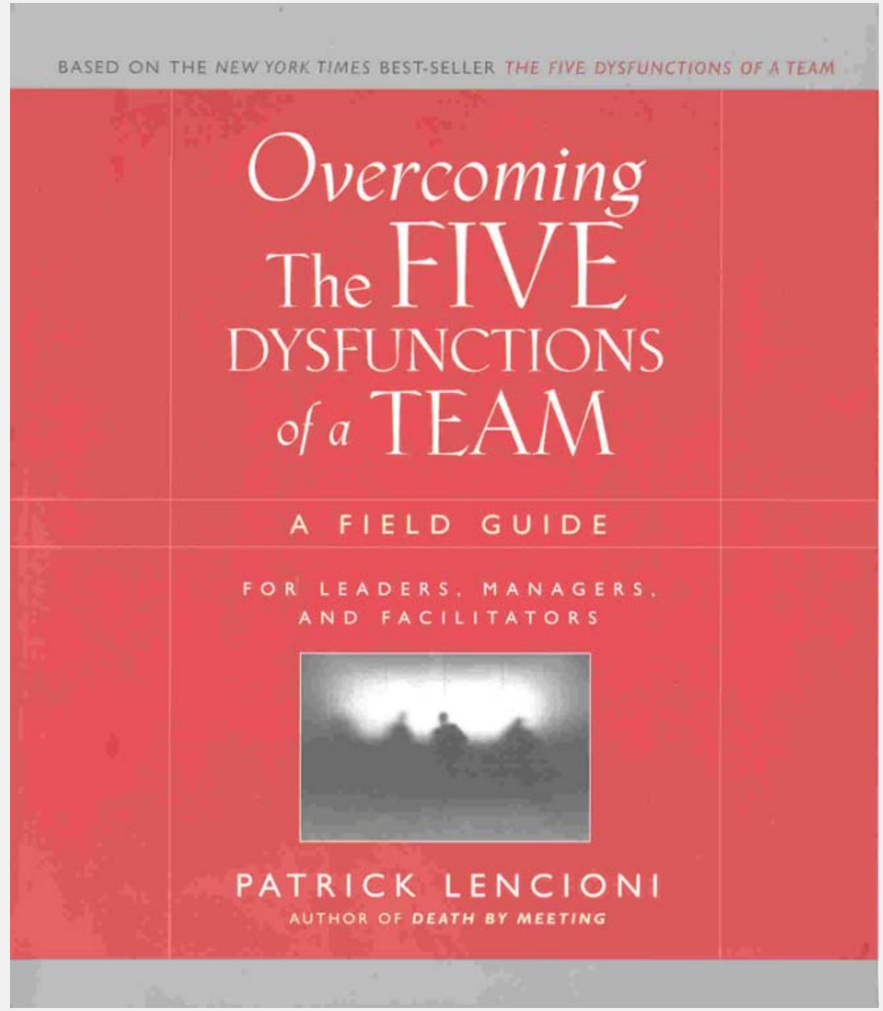
“Mr. Osborne, may I be excused? My brain is full.”



"You should check your e-mails more often. I fired you over three weeks ago."


Kid Scoop Puzzler
How many of these see-through fish can you find?
24
Standards Links: Reading Comprehension: Follow simple written directions.


WATER
COMMISSION


BASED ON THE NEW YORK TIMES BEST-SELLER THE FIVE DYSFUNCTIONS OF A TEAM
Overcoming The FIVE DYSFUNCTIONS of a TEAM
A FIELD GUIDE
FOR LEADERS, MANAGERS, AND FACILITATORS
PATRICK LENCIONI
AUTHOR OF DEATH BY MEETING

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