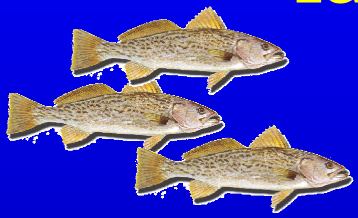
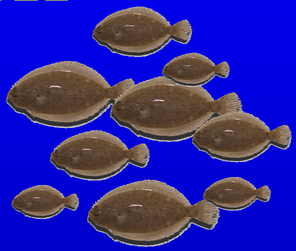
Growth responses of fish to hypoxia in estuarine nursery habitat: results from the laboratory and Pepper Creek



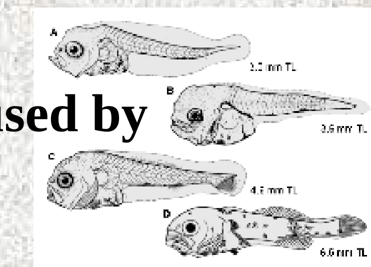


Delaware Center for the Inland Bays
STAC meeting
Lewes, DE
Jan. 13, 2006

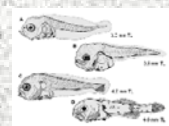
T.E.Targett and K.L. Stierhoff*
University of Delaware
Graduate College of Marine Studies
Lewes, DE
***** **Present address: NMFS, Santa Cruz, CA**

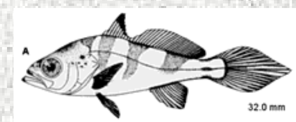
Early life history ecology of fishes:

- **Critical period concept --**
  - Variability in the recruitment of fish populations is caused by processes during the early life history stages

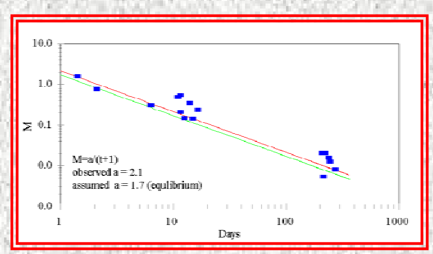


- **Environment, growth rate, and mortality --**
  - Subtle variability in the environment can have substantial effects on growth and survival of young fishes





- **Growth and mortality in juvenile fishes --**
  - Mortality processes (e.g. predation) during the juvenile stage are largely size-dependent



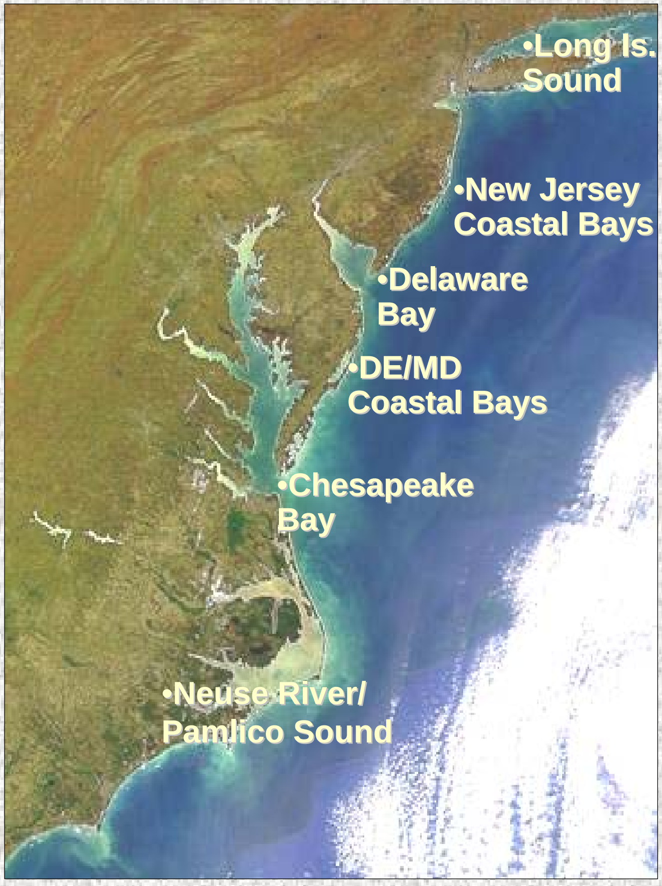
Rapid growth is critical to the survival of young fishes

Essential fish habitat and nurseries:

- **Habitat: where an organism lives**
- **<u>E</u>ssential <u>F</u>ish <u>H</u>abitat (EFH) (Sustainable Fisheries Act 1996)**
  - **"Those waters and substrata necessary for the successful feeding, breeding, and growth to maturity"**
- **Four levels of EFH (NMFS 1997)**
  - **Presence/absence**
  - **Abundance**
  - **Habitat-specific growth ("bigger is better")**
  - **Habitat-specific production**
- **'Nursery habitat' (Beck et al. 2001)**
  - **A subset of all available juvenile habitats that disproportionately contribute to survival and recruitment for a species**

Estuaries as nursery habitats:

- **Coastal ecosystems are important to juveniles of estuarine-dependent fishes**
- **Estuarine-dependency**
  - Adults spawn in or near estuaries
  - Larvae and juveniles reside in estuaries
- **Estuaries as EFH**
  - High productivity (1° and 2°)
  - Reduced predation
  - Promote rapid growth and high survival of juvenile fishes
- **Dynamic physicochemical regimes**
  - Temperature
  - Salinity
  - Dissolved oxygen (DO)



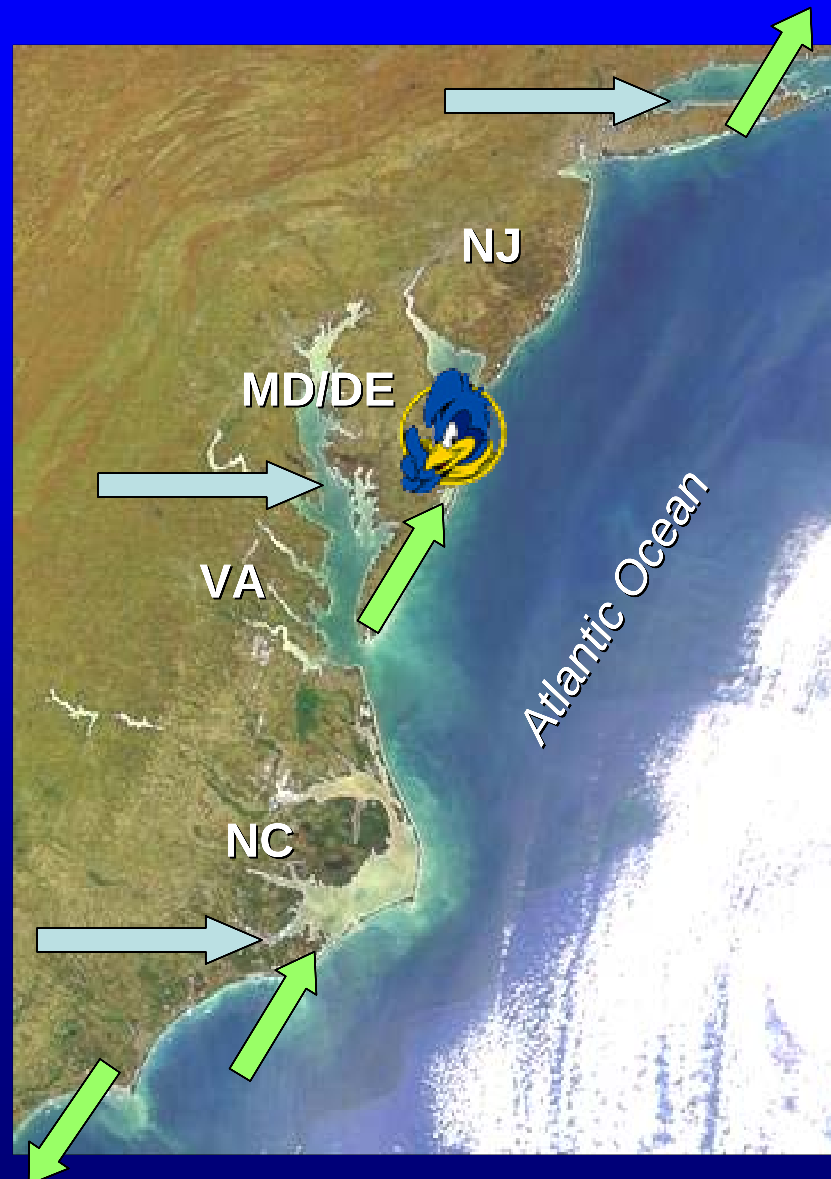
Hypoxia in Estuaries

- Eutrophication (NO_3, NH_4, PO_4)
- Increased frequency and severity of low DO events worldwide

United Nations Environment Programme (2003)

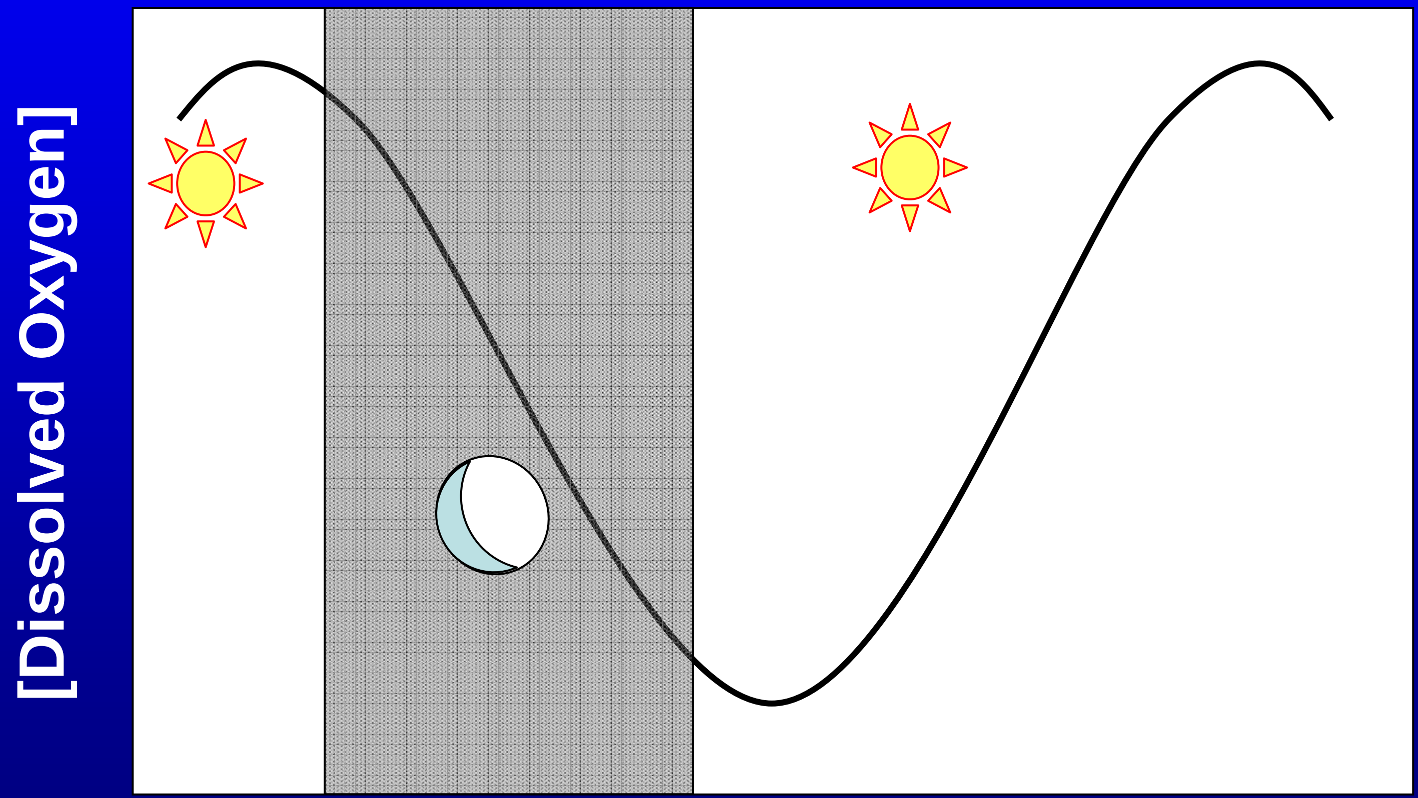
Hypoxia in Estuaries

-
  - Chesapeake Bay
  - W. Long Island Sound
  - Neuse River, NC
- **Diel-cycling hypoxia**
  - Waquoit Bay, MA
  - NC Coastal Bays
  - MD Coastal Bays
  - GA Marsh Creeks
  - Delaware Coastal Bays



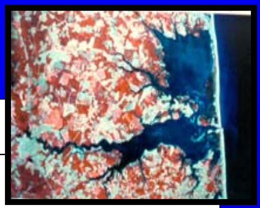
Dissolved Oxygen in Shallow Coastal Ecosystems

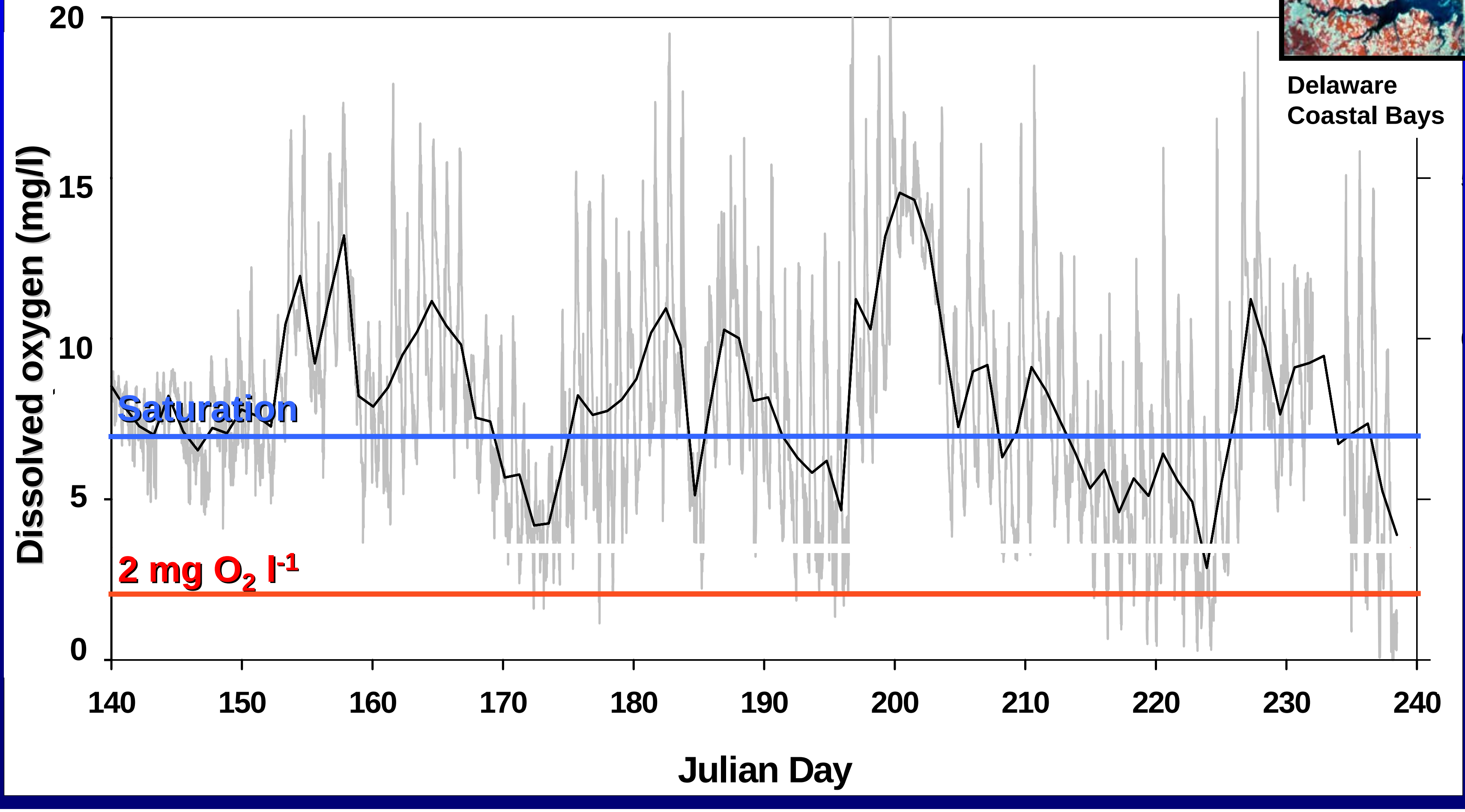
Diel P/R cycles of phytoplankton and macroalgae



Dissolved Oxygen in Shallow Coastal Ecosystems

Diel P/R cycles of phytoplankton and macroalgae



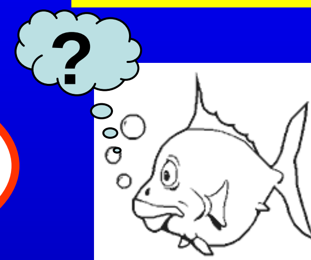


Hypoxia in Estuaries

Fish Kills

Sub-lethal Effects

Physiological Ecology



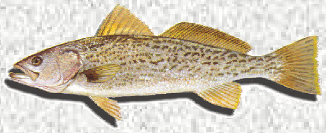
Behavior

Questions:

Does hypoxia impact the <u>quality of estuaries nursery areas</u> by limiting growth of juvenile estuary-dependent fishes?

Summer flounder
Paralichthys dentatus

Winter flounder
Pseudopleuronectes americanus



Weakfish
Cynoscion regalis

1. **What are the effects of constant and diel-cycling hypoxia on growth rates of juvenile estuary-dependent fishes in the laboratory?**
   - **Are there interactions between hypoxia and other environmental factors?**
   - **Can these fishes adapt to hypoxia exposure?**
2. **What are their behavioral avoidance thresholds – and how do these DO levels relate to growth limiting [DO]?**

3. **Are the growth rates of free-ranging juvenile fishes impacted by hypoxia in estuarine nurseries?**
   - **Can RNA:DNA be used to measure growth rates in dynamic habitats?**
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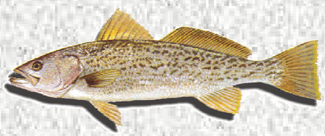

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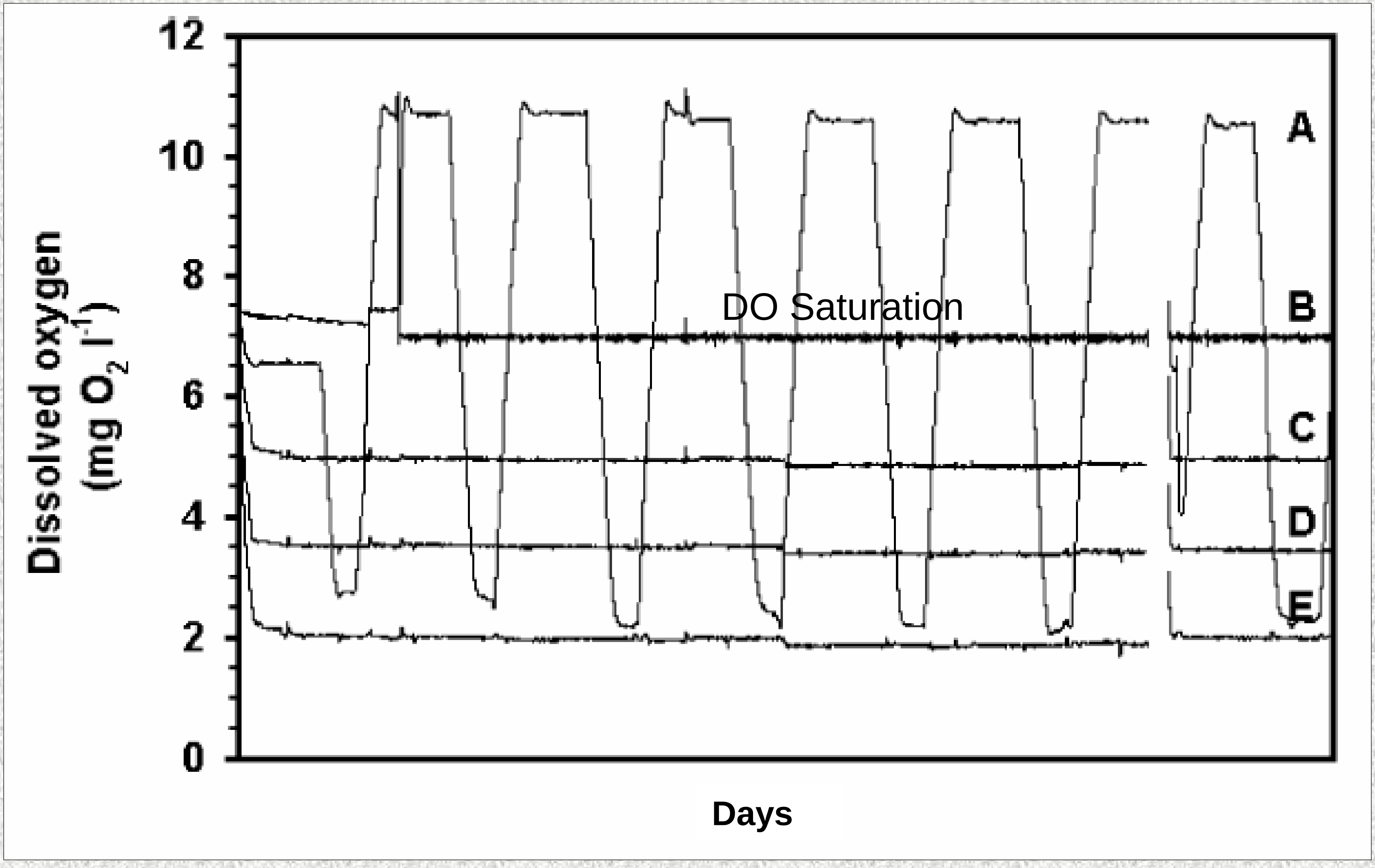
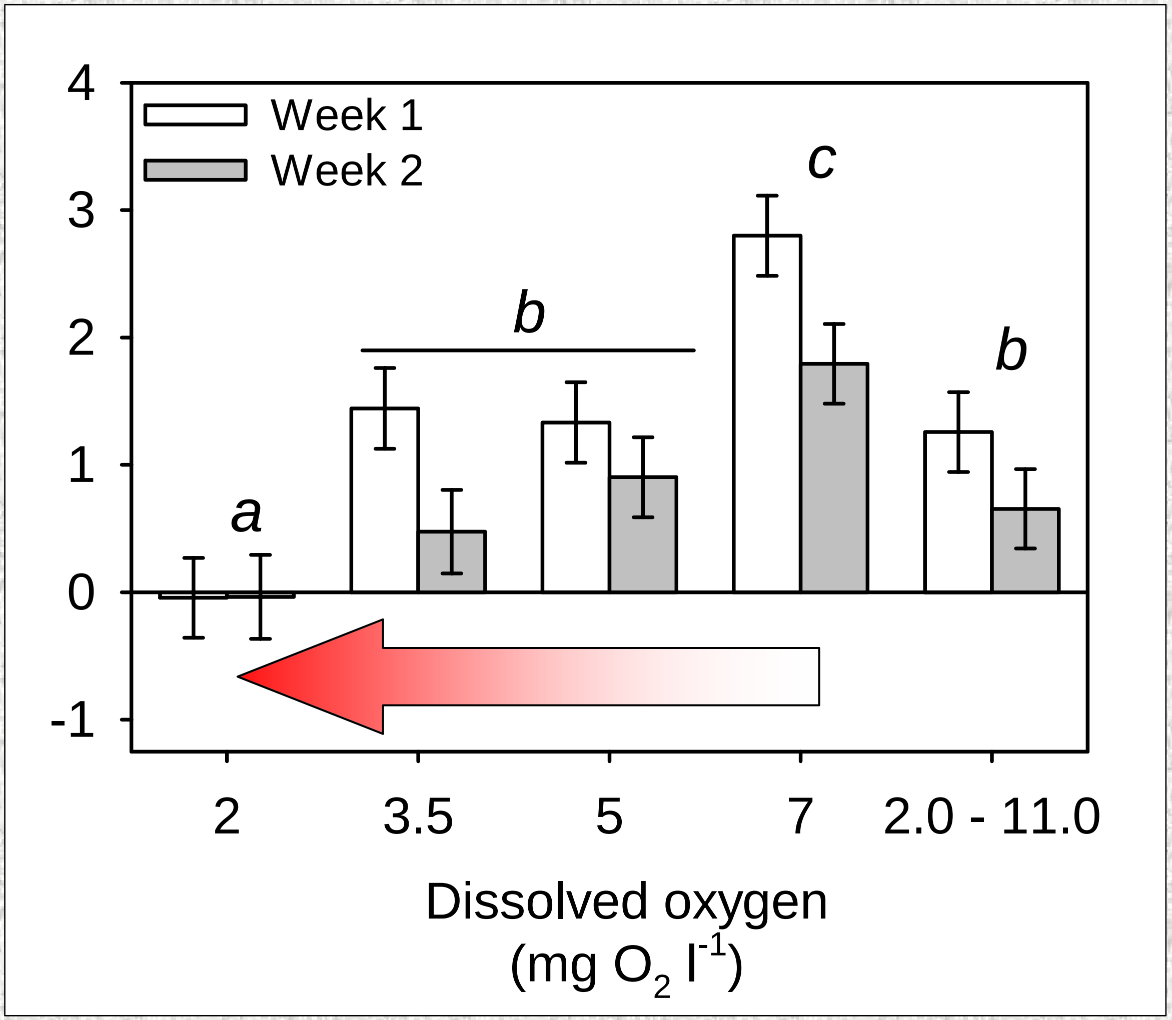
Laboratory Growth Studies



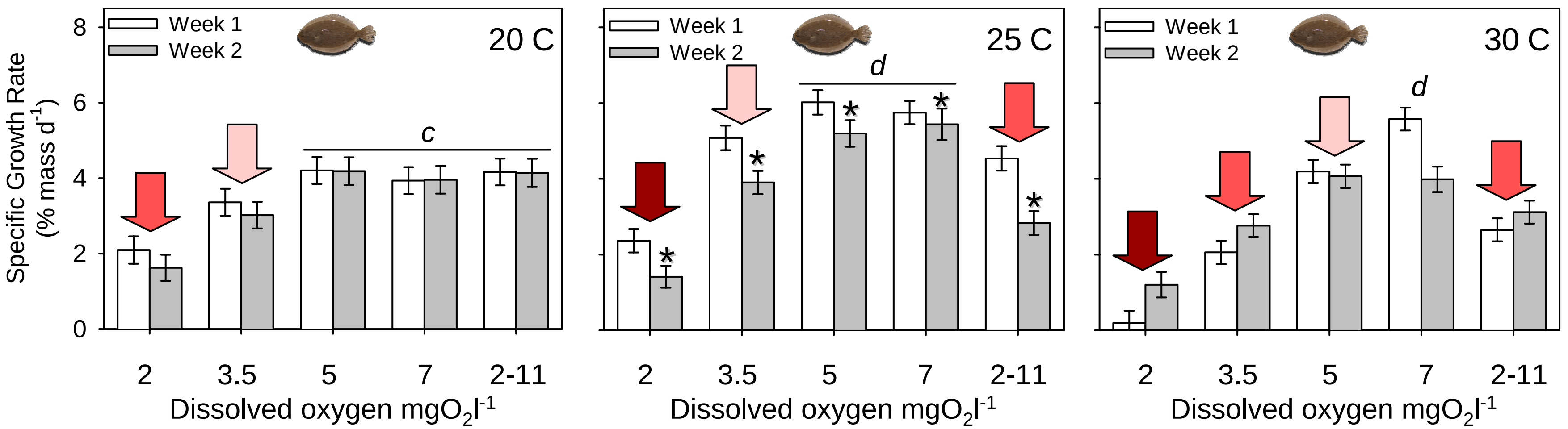
Results

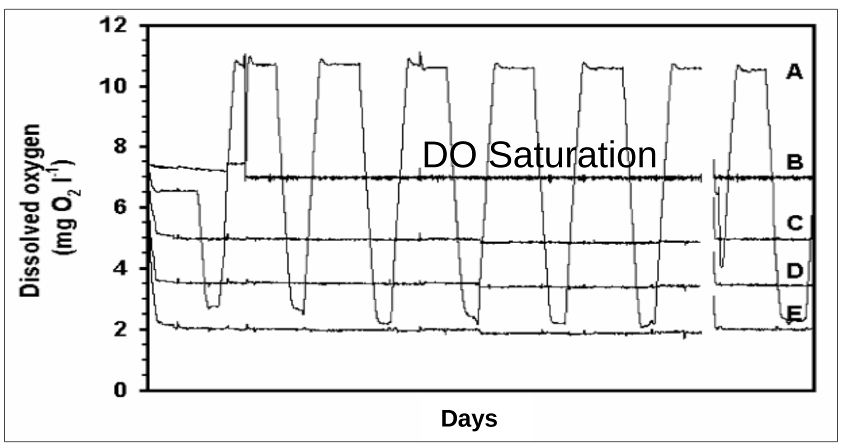
Laboratory Growth Studies



Results – Laboratory Growth Studies

Summer Flounder

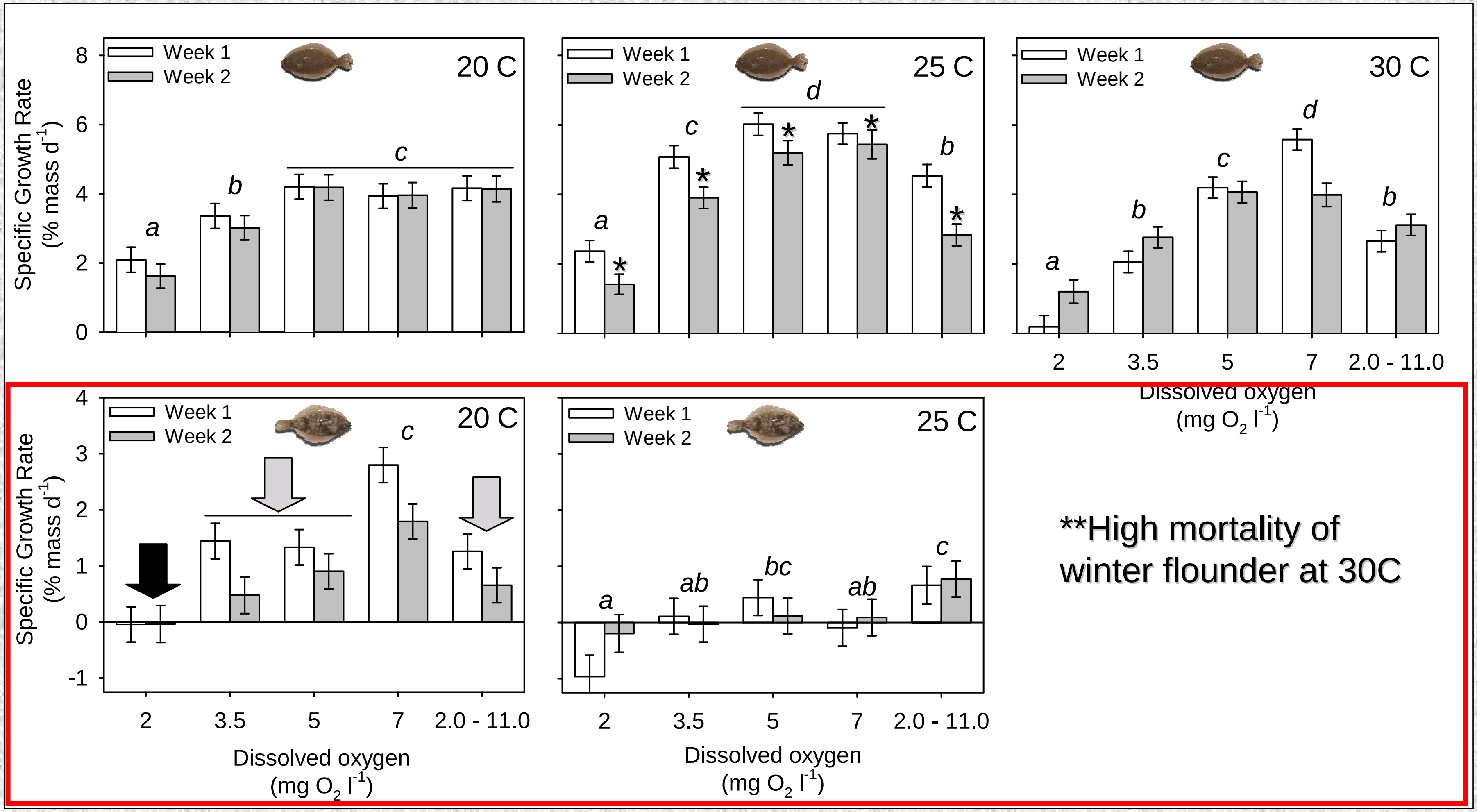




Little evidence of growth acclimation to hypoxia exposure

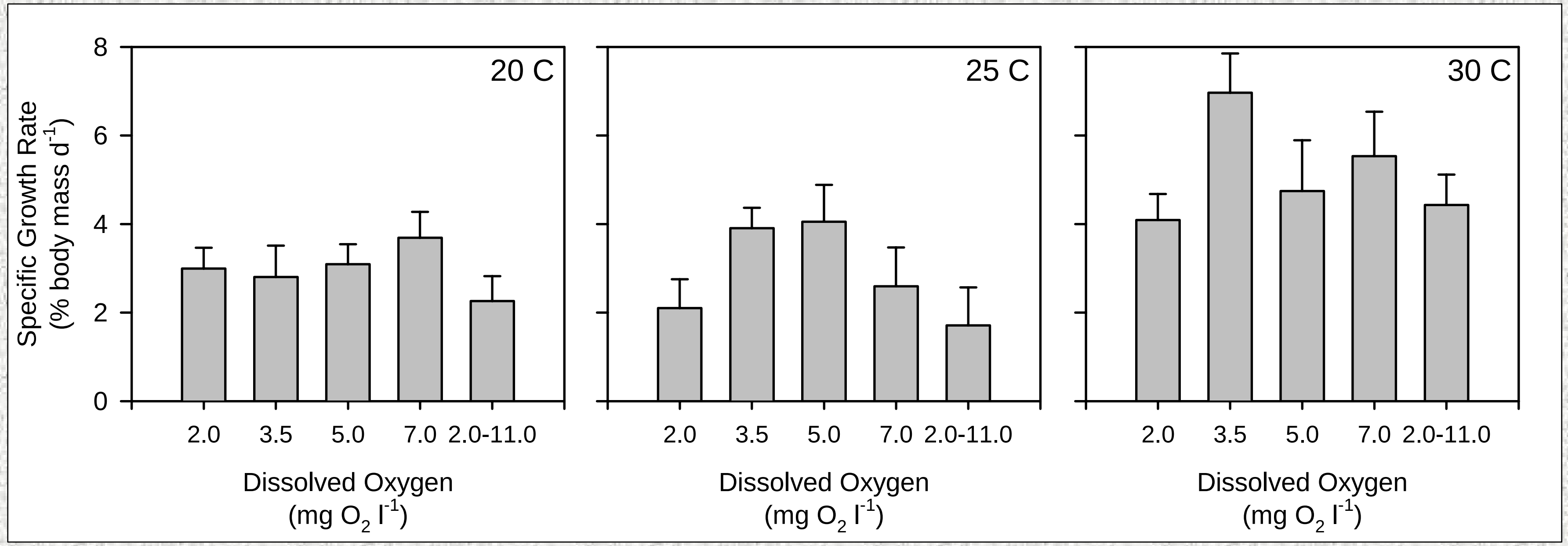
Results - Summer and winter flounder

Laboratory hypoxia studies



Results – Laboratory Growth Studies

Weakfish



- Increase in SGR with temperature but no statistical effect of DO on growth at levels tested

Conclusions - Laboratory Growth Studies

- Moderate hypoxia negatively impacts growth of juvenile summer flounder
- The effect of hypoxia on growth of both flatfishes is exacerbated at higher temperatures
- Growth limitation is caused largely by reduced feeding
- Growth of weakfish was insensitive to hypoxia over a range of temperatures
- Low mortality in summer flounder and weakfish even at DO as low as $2 mgO_2 l^{-1}$

Questions:

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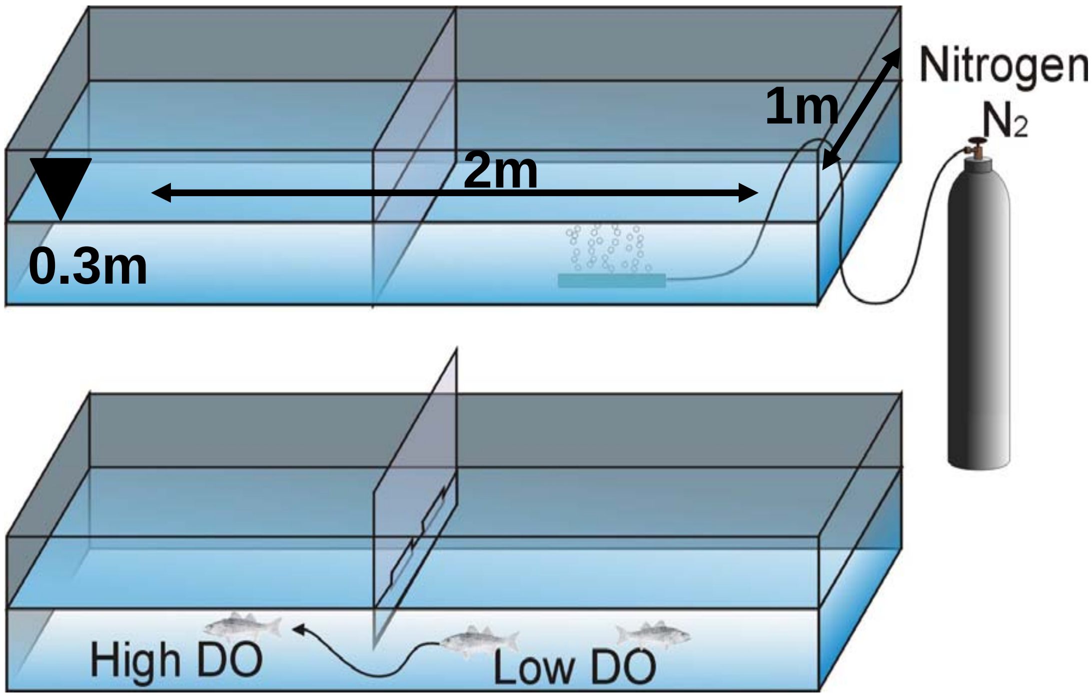
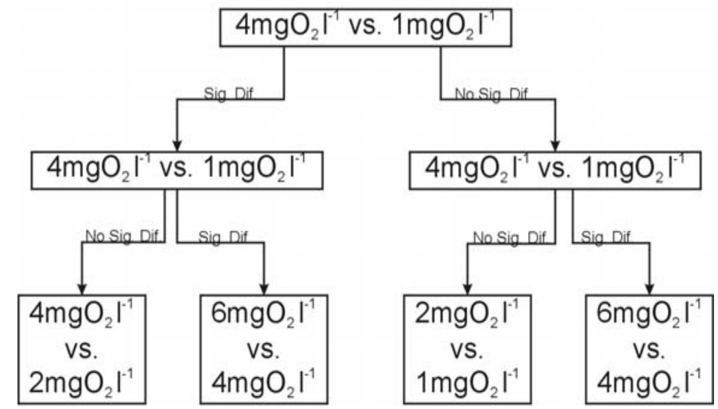
Behavioral Avoidance Studies



30-40 min trials



Dissolved oxygen avoidance trial tree used to determine avoidance response. Note, to further resolve each species' avoidance behavior, additional trials with alternate DO concentrations were performed.

After Wannamaker & Rice (2000) J. Exp. Mar. Biol. Ecol.

Results – Behavioral Avoidance Studies

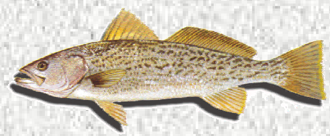
- Both juvenile summer flounder and weakfish avoid $1 mgO_2l^{-1}$ but demonstrated no avoidance in these trials for dissolved oxygen values $\geq 2 mgO_2l^{-1}$

- For summer flounder, then, the DO avoidance threshold established here is below that which causes growth limitation in the laboratory… This suggests fish in the field would experience growth detriment under moderate hypoxia

Questions:

Does hypoxia impact the quality of estuaries nursery areas by limiting growth of juvenile estuary-dependent fishes?

Summer flounder
Paralichthys dentatus



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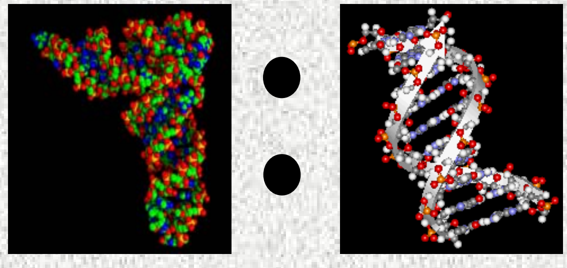
Nucleic acids as indices of fish growth

- Nucleic acids and protein synthesis
  - [DNA] remains relatively constant
  - [RNA] changes relative to protein synthesis rates

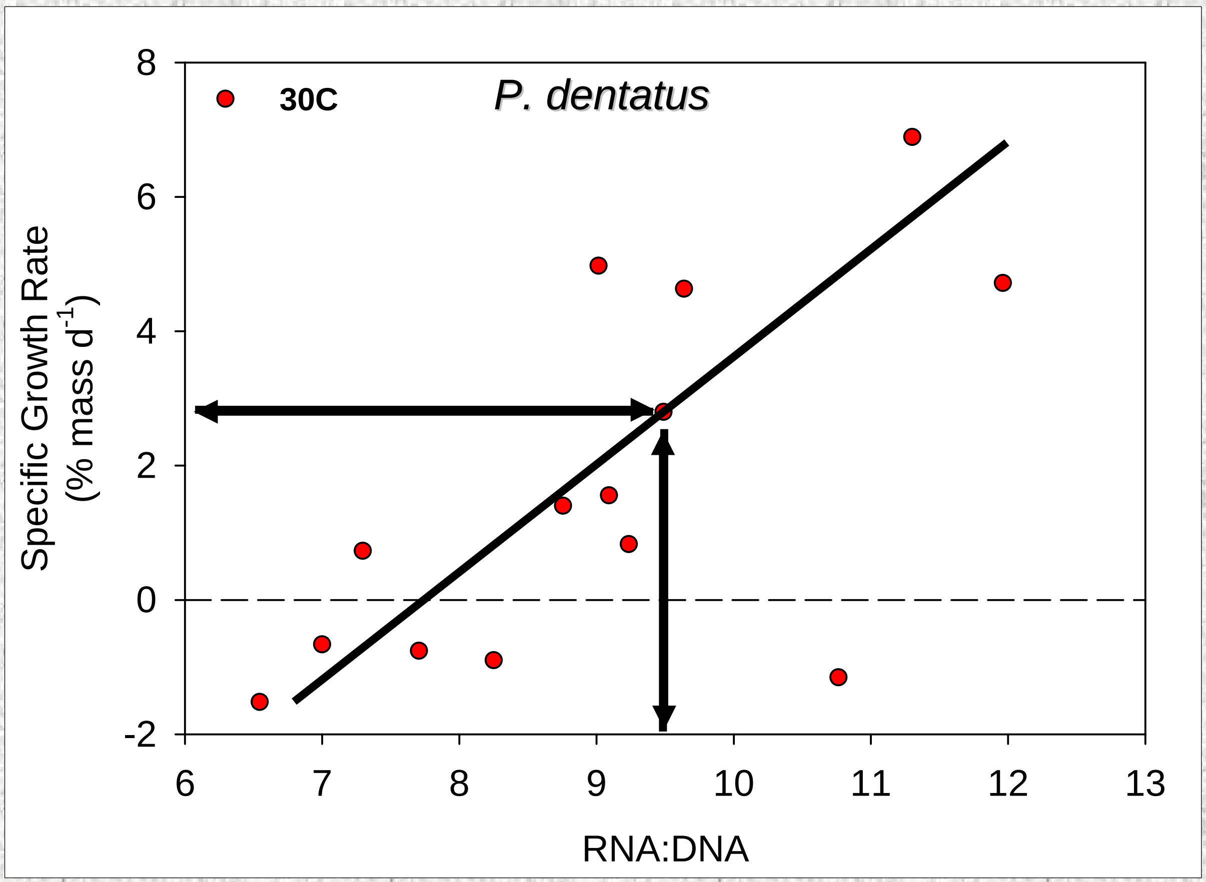


RNA DNA

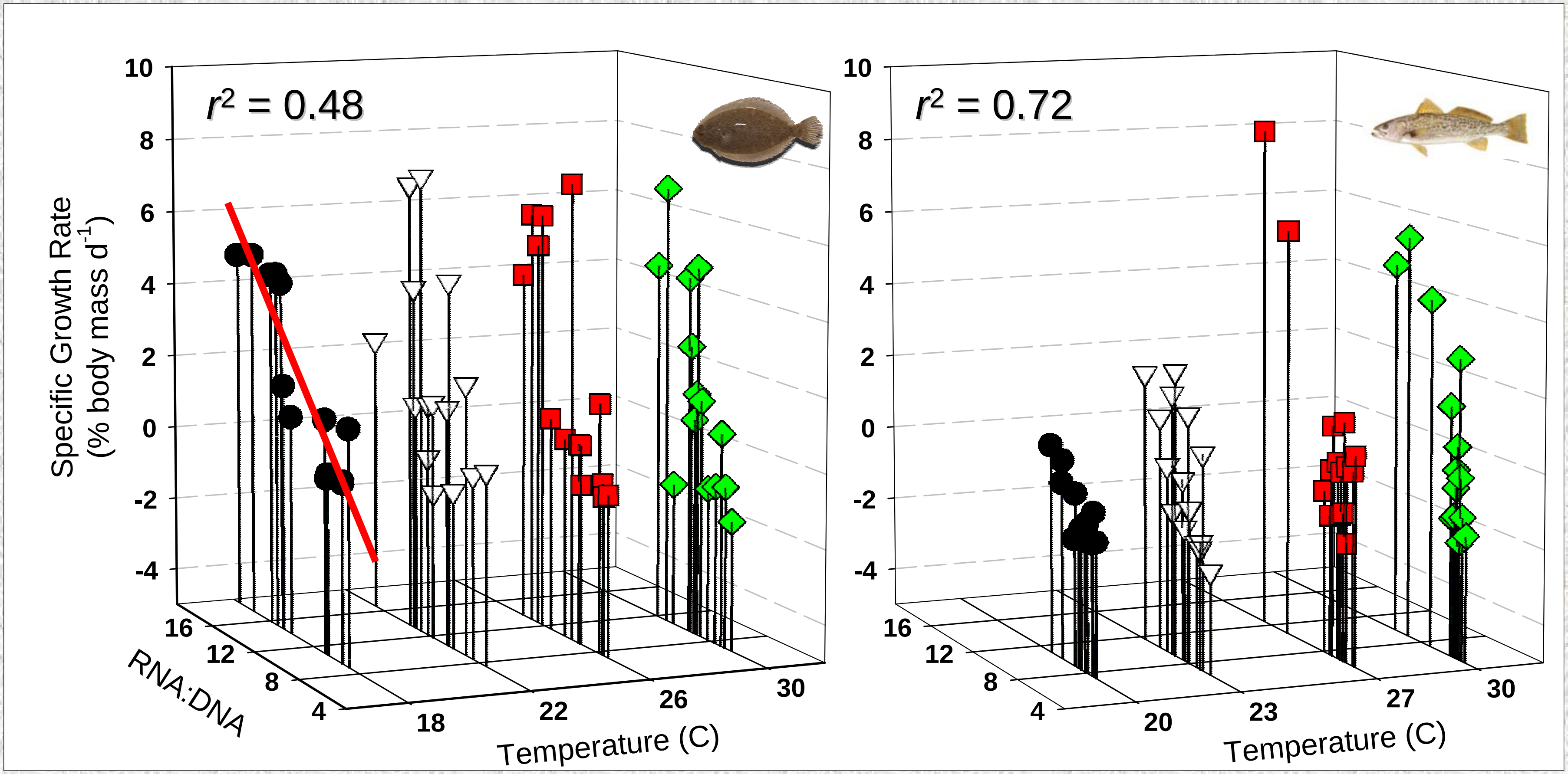
- RNA:DNA responds rapidly to changes in feeding
- <u>May be useful for linking environmental variation to growth in **dynamic** habitats like estuaries</u>

Establishing the Technique (A)

- 4 temperatures (18-30 °C)
- 3 ration levels (starved, low, *ad libitum*)
- n = 60 fish total

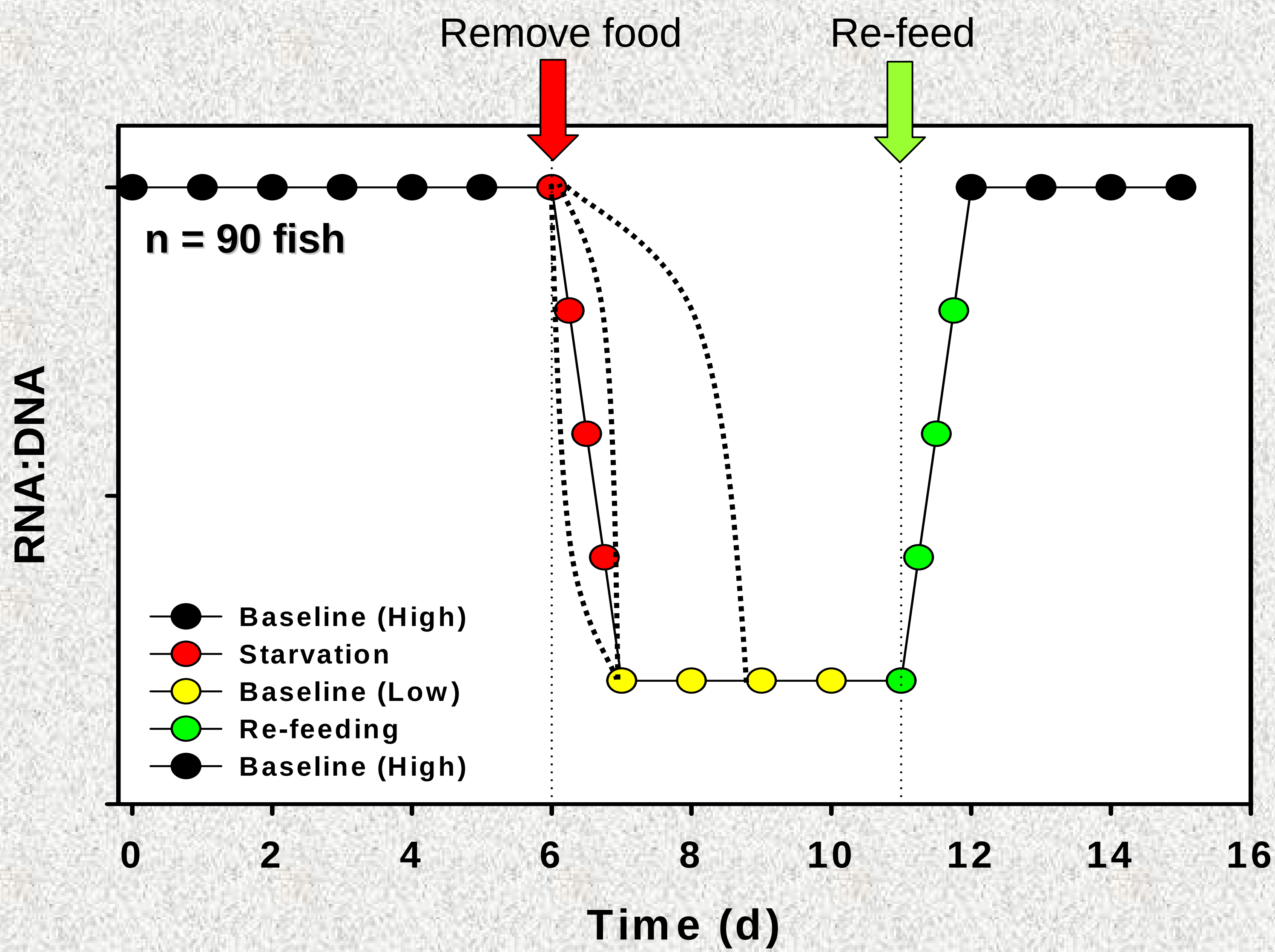


Results – Establishing the Technique (A)

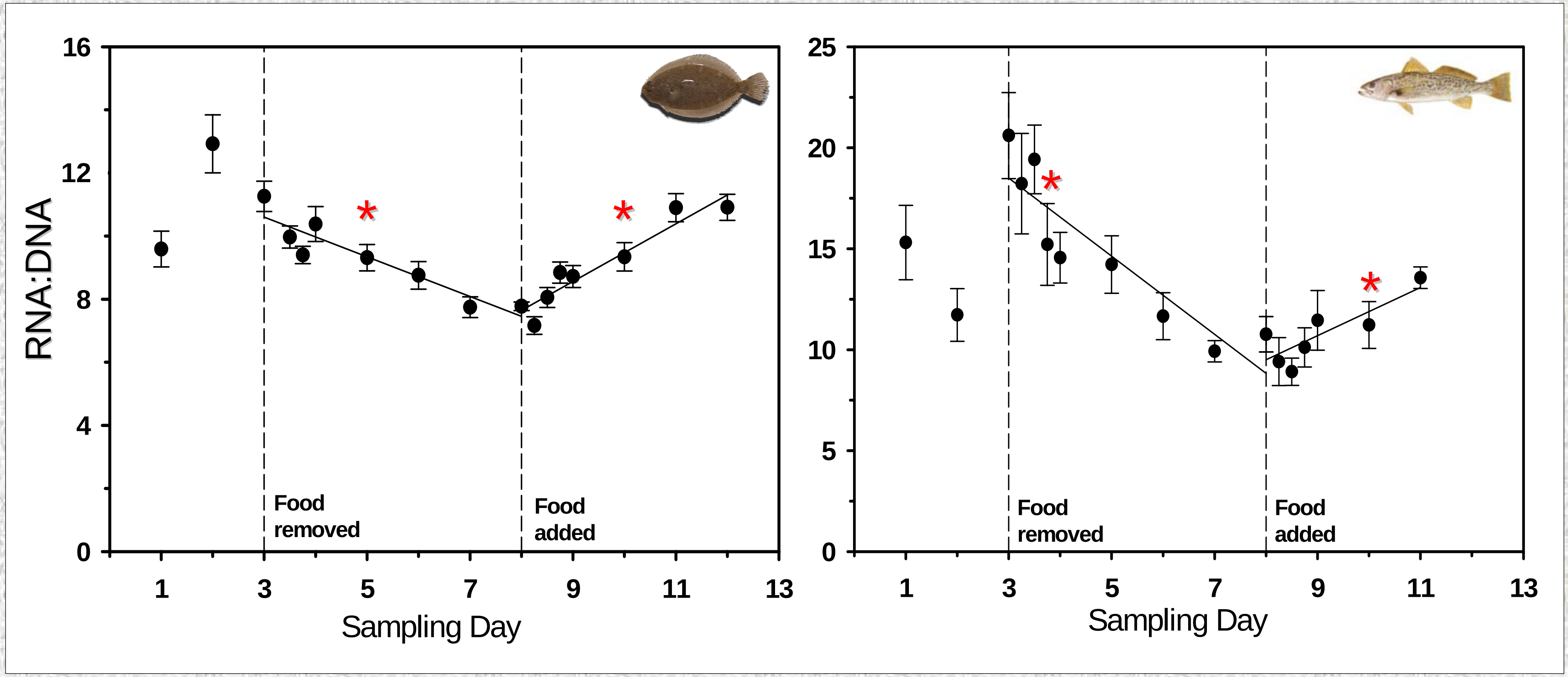


Specific growth rate = a_1 (RNA:DNA) + a_2 (TEMP) + a_3 (MASS)

Establishing the Technique (B): temporal response



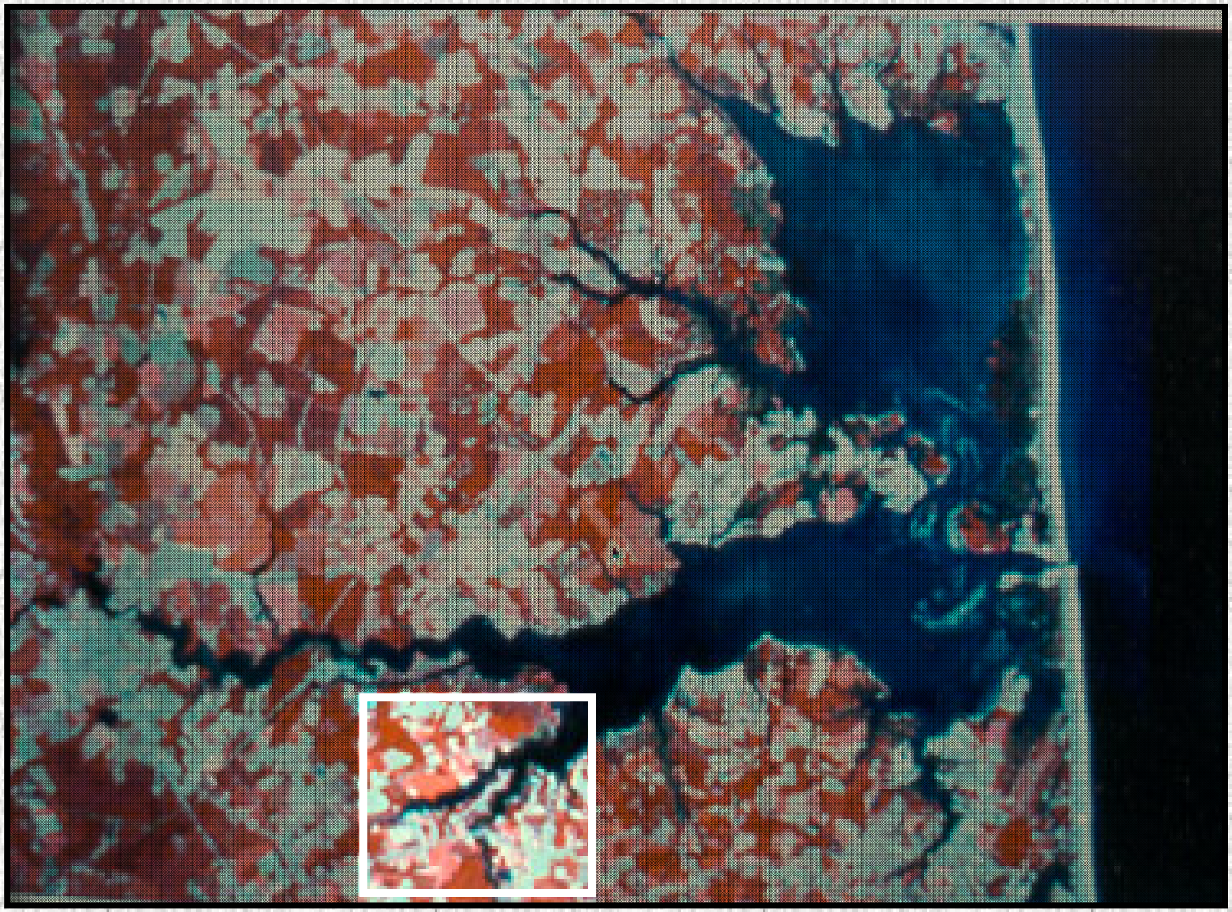
Results – Establishing the Technique (B): temporal response



- Rapid, linear response of RNA:DNA to changes in feeding
- Significant changes in 18 - 48 h
- Rapid enough to estimate short-term growth rates in the field

Growth Rates in Pepper Creek (DE Coastal Bays)

- Shallow tributary to Indian River Bay
- Routinely experiences diel-cycling hypoxia
- High abundance of summer flounder and weakfish



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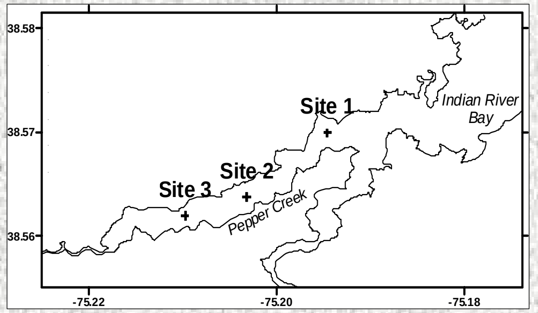
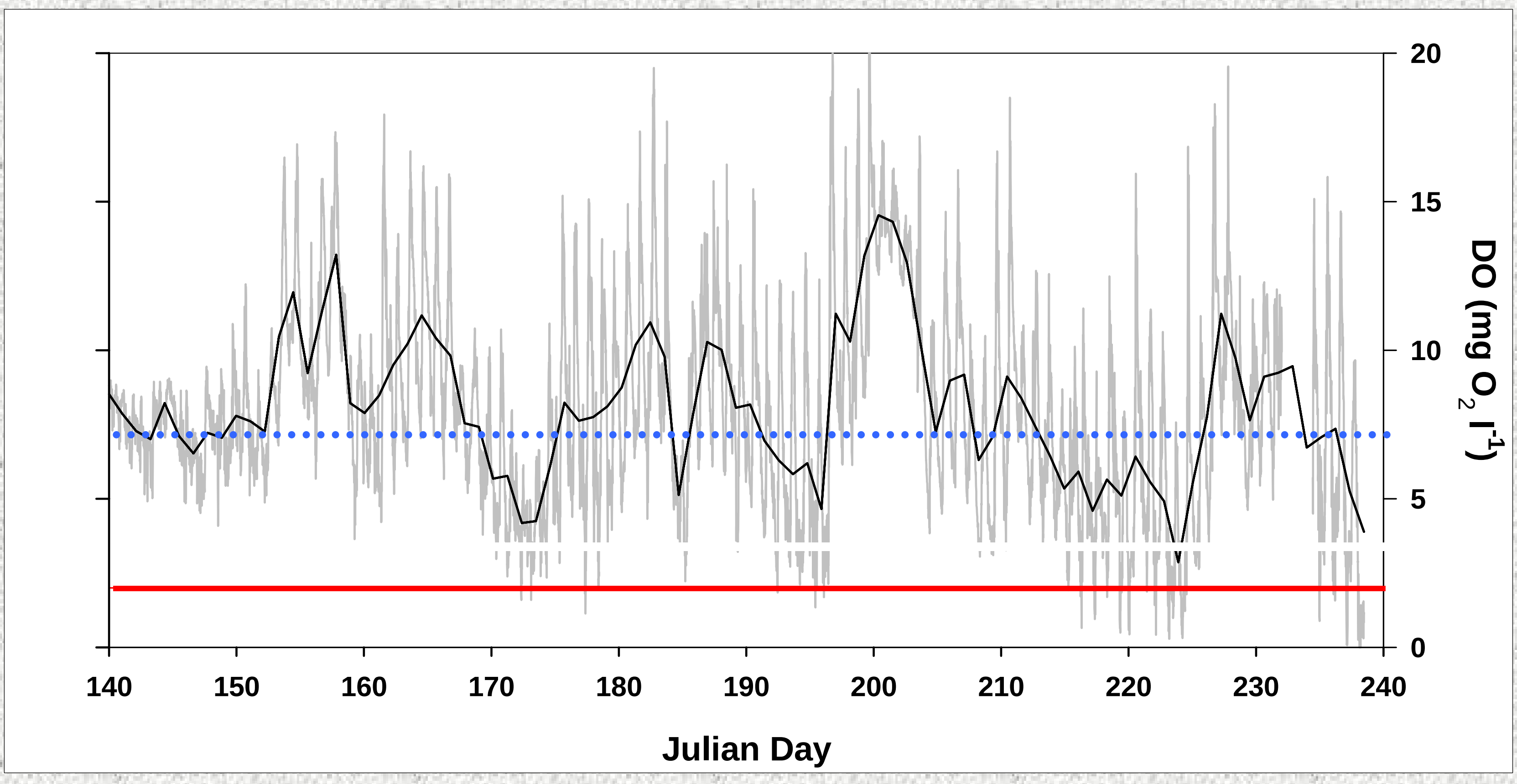
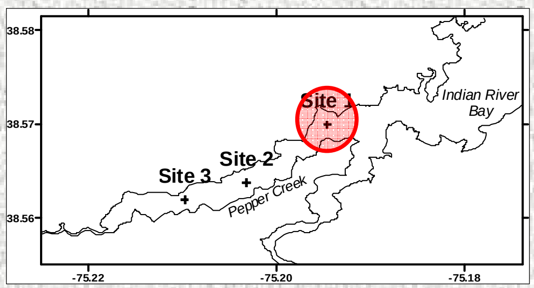


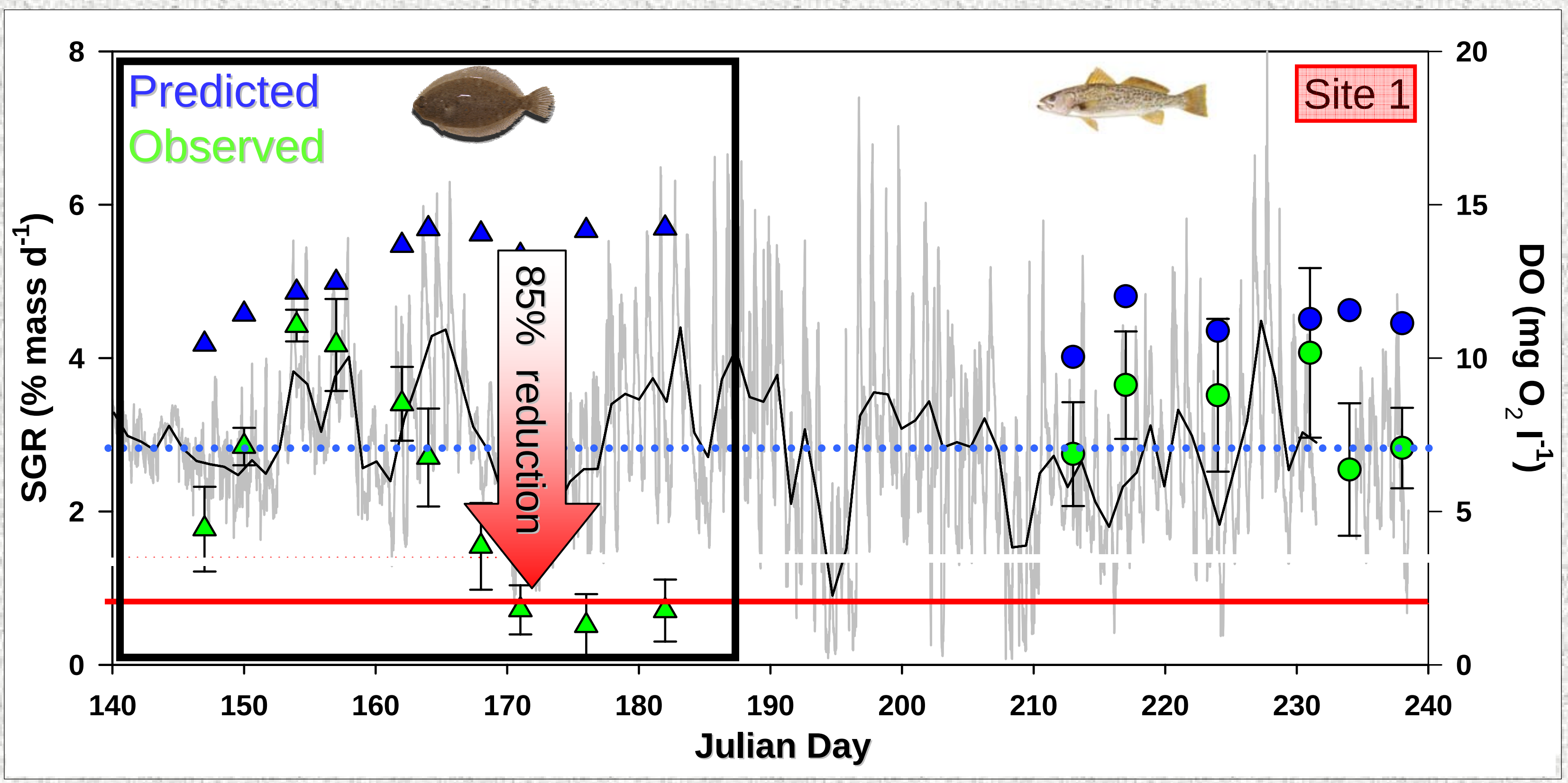
- Three sites sampled bi-weekly
- May through September 2002 and 2003



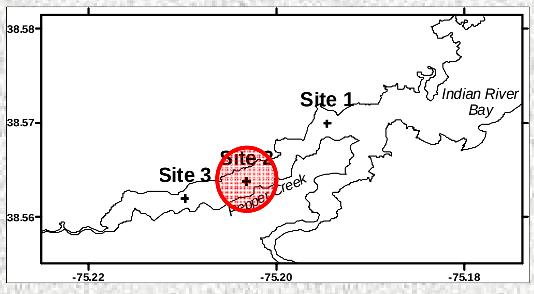
Results – Growth Rates in Pepper Creek (DE Coastal Bays)



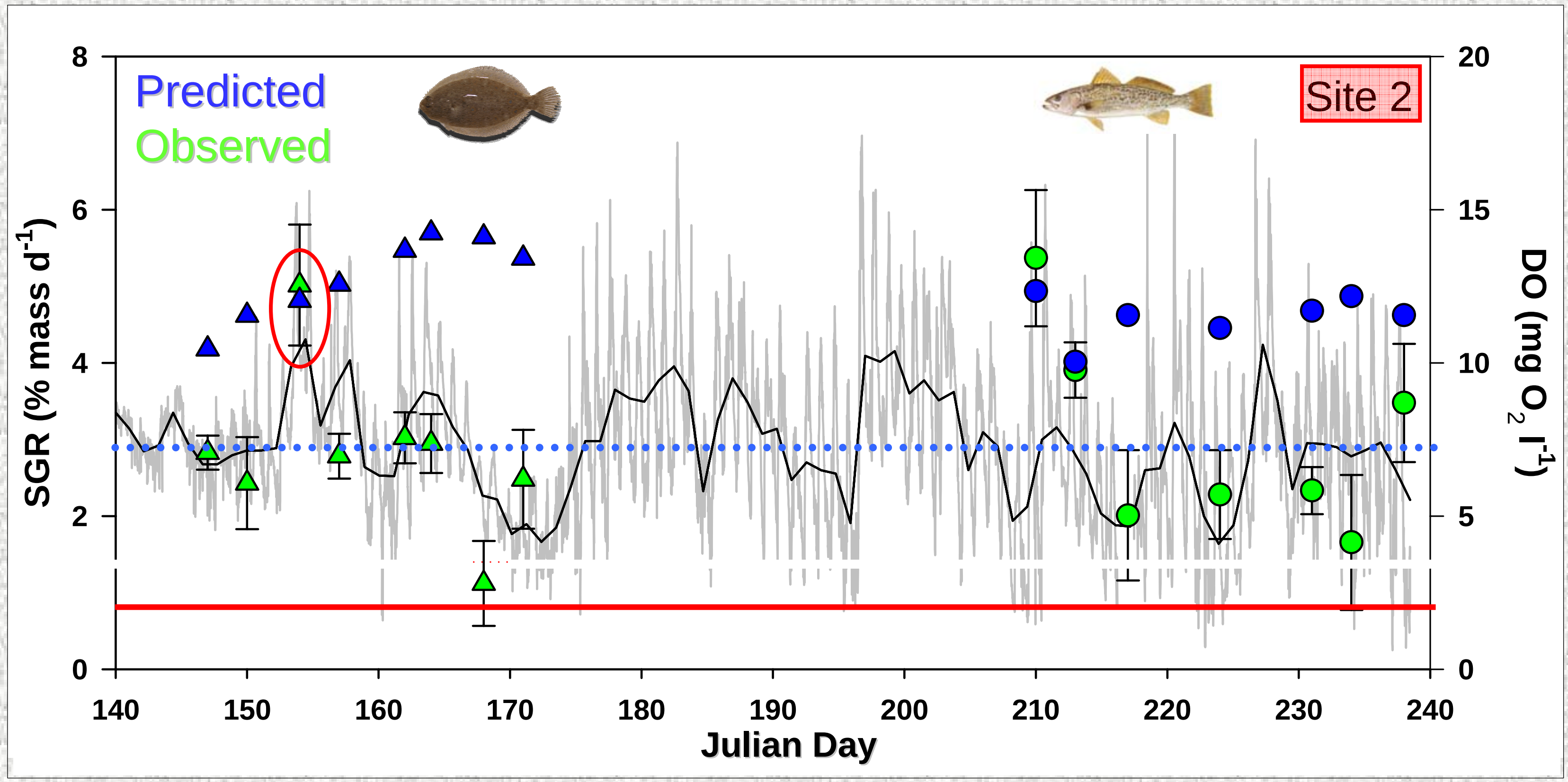
- Striking correlation between SGR of summer flounder and DO dynamics
- Specific growth rate (SGR) of both species less than predicted maximum, even under highest DO conditions



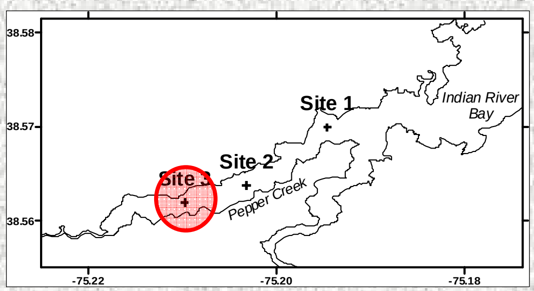
Results – Growth Rates in Pepper Creek (DE Coastal Bays)



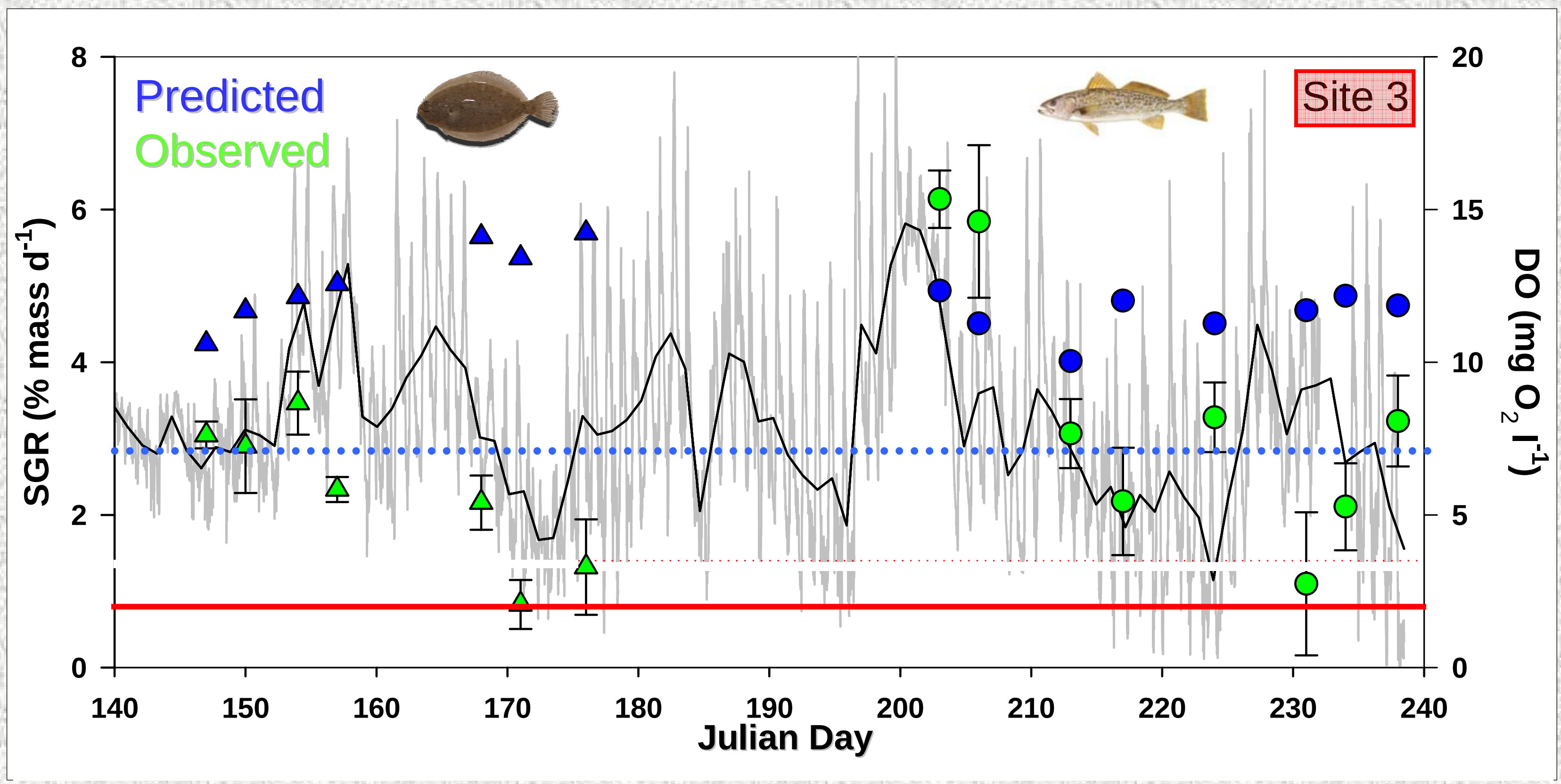
- Again, correlation between SGR and DO
- Potential for both species to grow near capacity under very high DO conditions



Results – Growth Rates in Pepper Creek (DE Coastal Bays)



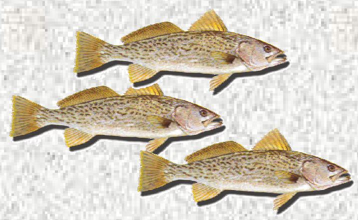
- Striking correlation between SGR and DO for both species
- Negative impacts associated with even moderate hypoxia

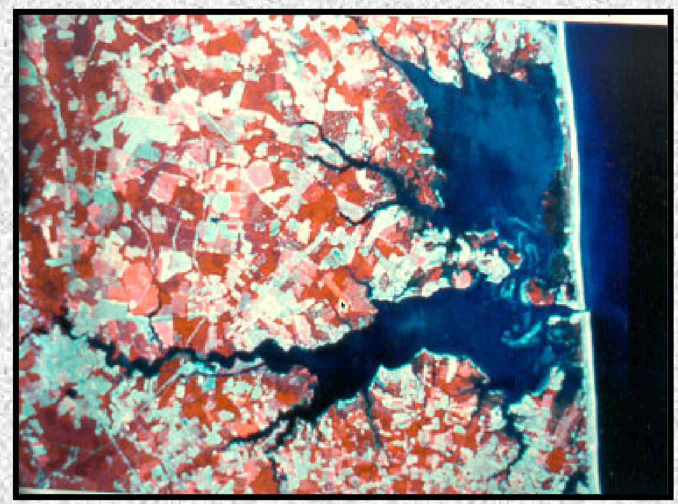


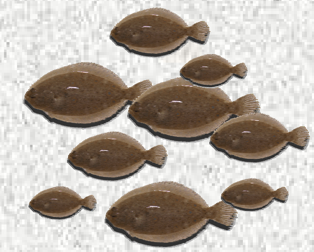
Conclusions

- RNA:DNA ratios are a robust index for estimating growth rate
- Describe short-term growth dynamics in the field
  - Rapid response appropriate for dynamic environments
- Hypoxia affects growth of young fishes in estuarine habitats
  - Growth rate – striking correlation with DO
  - First demonstrated effects in free-ranging fishes
- Lower than expected growth rates in field
  - Maximum growth rates in the field are generally < laboratory predictions
  - Growth rates impacted by moderate hypoxia and appear more sensitive to hypoxia in the field than in the laboratory

Questions







– Are we underestimating the impact of sublethal hypoxia on fish nursery habitat quality based on laboratory data?

– Does decreased swimming activity of fishes acclimated to hypoxic conditions cause decreased feeding (and the observed poorer growth) in the field??

Acknowledgements

-- Coauthor: Kevin Stierhoff

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Simon Brown
Kerri-Lynn Miller

-- Colleagues Jim Rice (NCSU) and Kenny Rose (LSU)

T. TARGETT LAB

Sea Grant National

Sea Grant University of Delaware

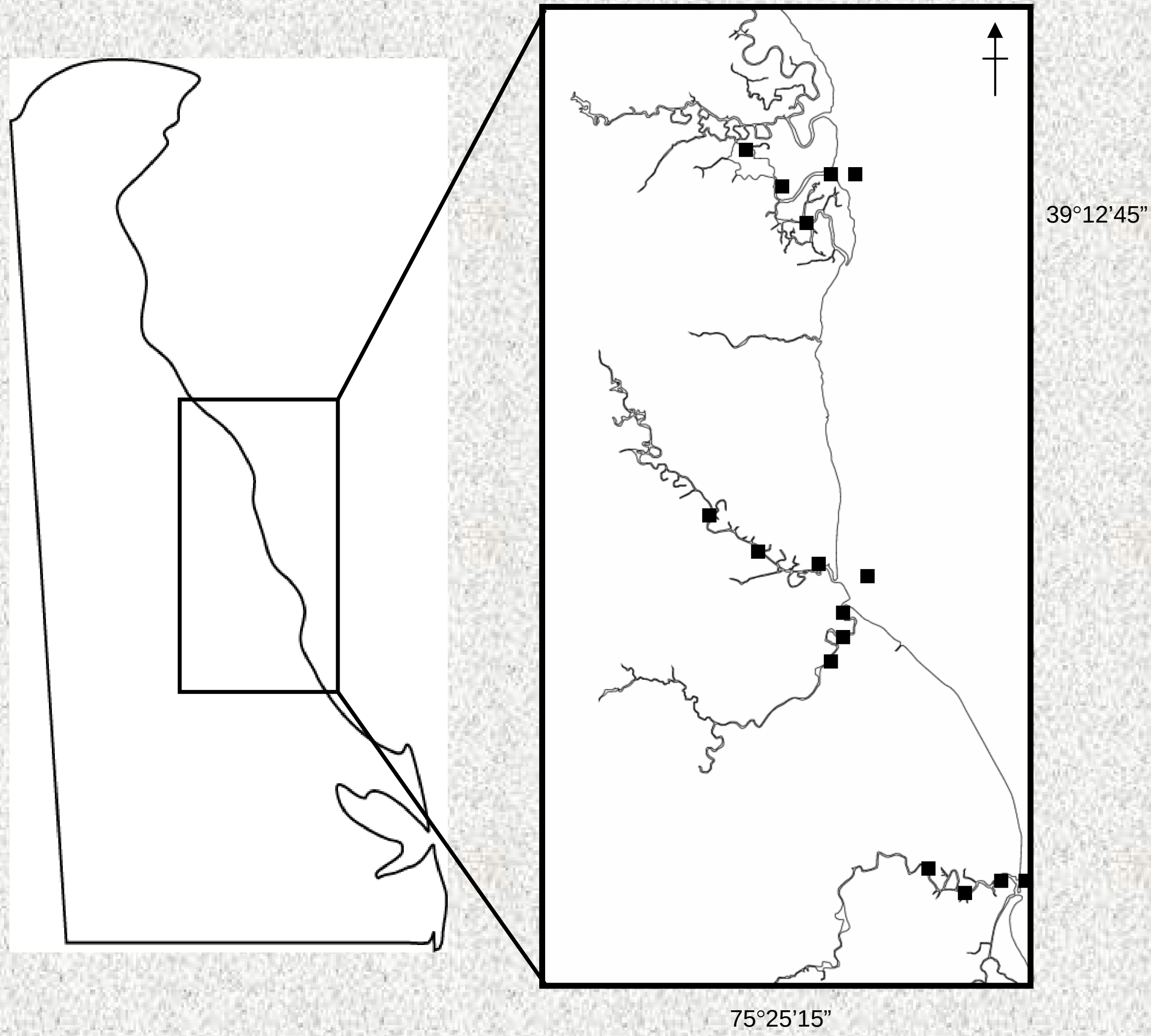

Figure 1: Delaware Bay and tidal tributary sampling stations (top to bottom: Simons River, Mahon River (1 site only), St. Jones River, Murderkill River and Mispillion River). Sampling stations marked with squares.