# Overexposure: Using laboratory, field, and modeling approaches to predict hypoxia exposure of estuarine fish

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Civil and Environmental Engineering

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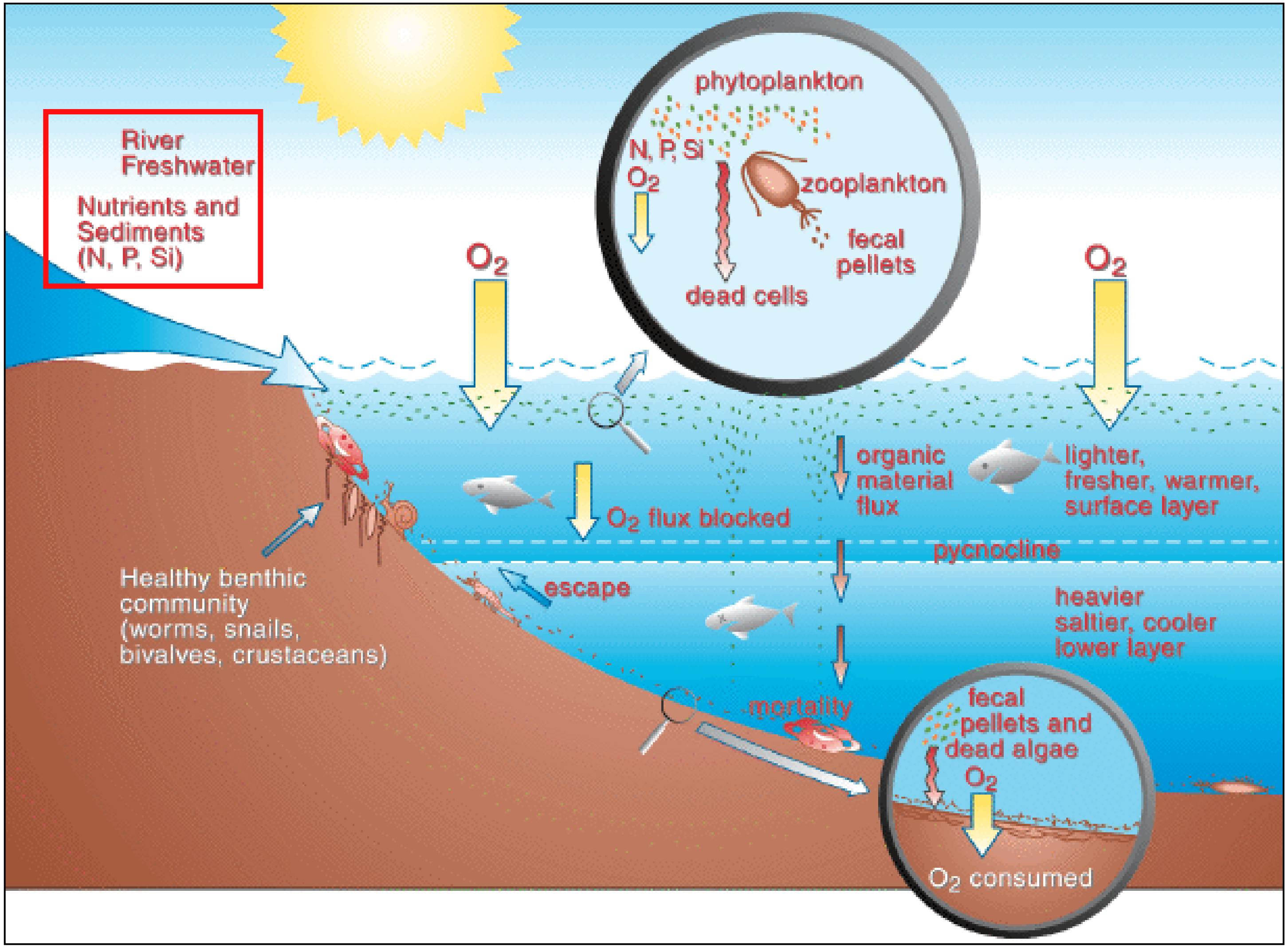
# Outline

- Introduction
  - Estuarine tributaries and estuary-dependent fish
  - Eutrophication and hypoxia
- Factors controlling the temporal and spatial dynamics of diel-cycling hypoxia
- Behavioral responses of estuary-dependent fish to diel-cycling hypoxia
  - Weakfish 
  - Summer flounder 
- Tracking fish in the field in relation to hypoxia using acoustic telemetry
- Water Quality Modeling

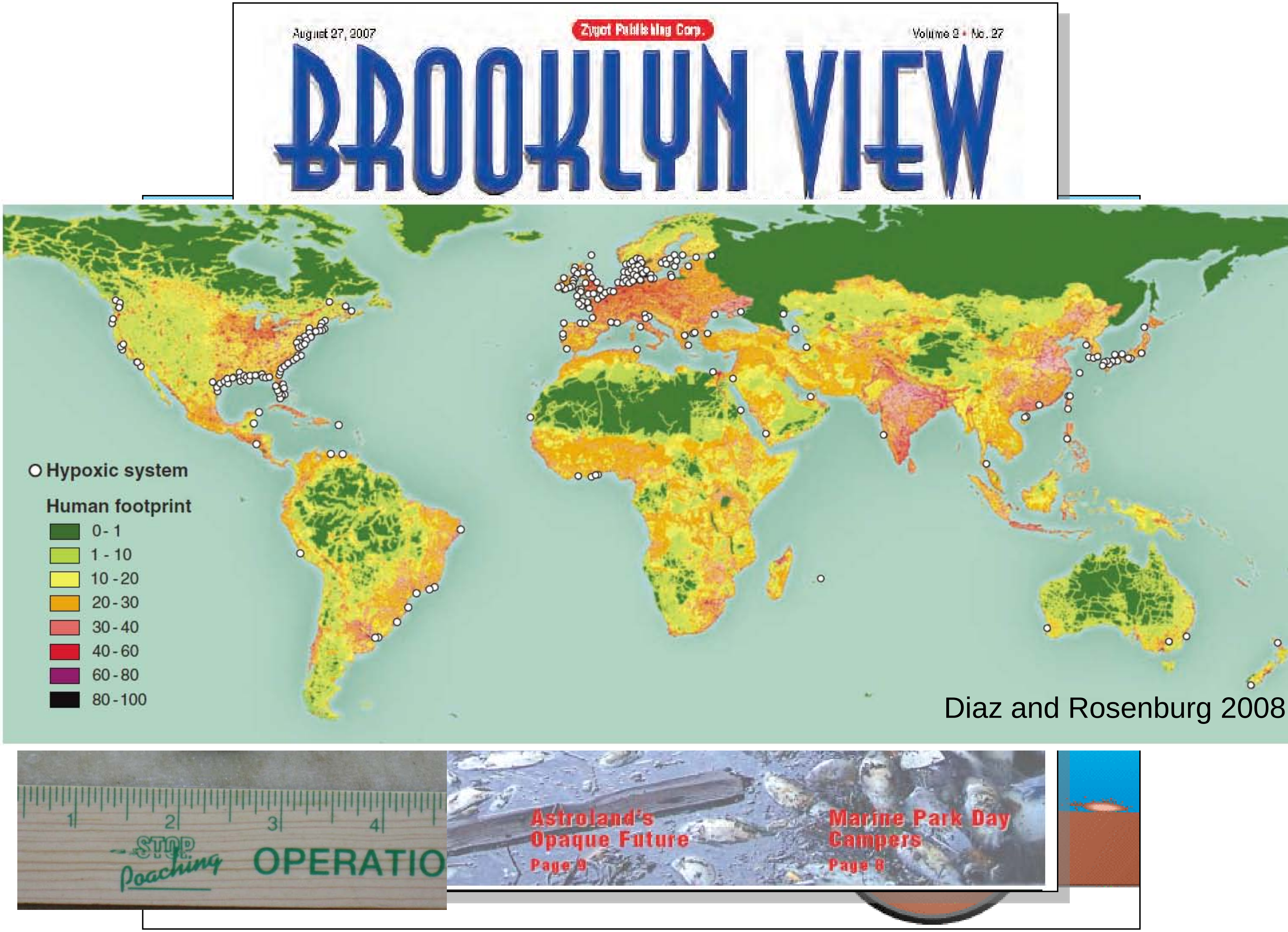
# Importance of Estuarine Tributaries

- Estuaries represent important nursery habitat
- Tributaries are particularly important
  - Higher temperatures
  - Highly productive
  - Less predation
  - Freshwater cue
  - Larval/adult behaviors

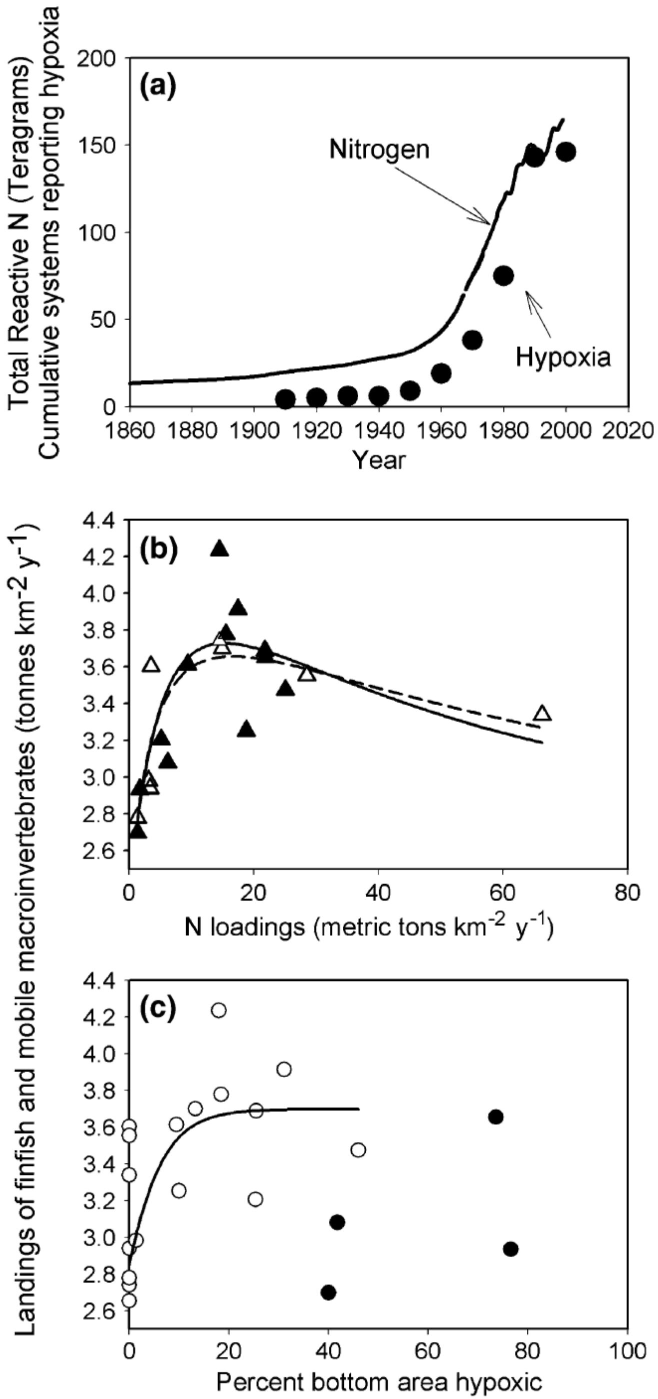
# Eutrophication




August 27, 2007
Zygot Publishing Corp.
Volume 2 • No. 27
BROOKLYN VIEW
Canarsie • Georgetown • Mill Basin • Old Mill Basin • Bergen Beach • Marine Park • Gerritsen Beach • Sheepshead Bay • Gravesend • Manhattan Beach • Brighton Beach
DEAD FISH
Page 10
Astroland's Opaque Future
Page 9
Marine Park Day Campers
Page 8
STOP Poaching
OPERATIO


August 27, 2007
Zygot Publishing Corp.
Volume 2 • No. 27
BROOKLYN VIEW
Hypoxic system
Human footprint
0 - 1
1 - 10
10 - 20
20 - 30
30 - 40
40 - 60
60 - 80
80 - 100
Diaz and Rosenburg 2008
STOP Poaching
OPERATIO
Astroland's Opaque Future
Page 9
Marine Park Day Campers
Page 8

# Hypoxia and Fisheries



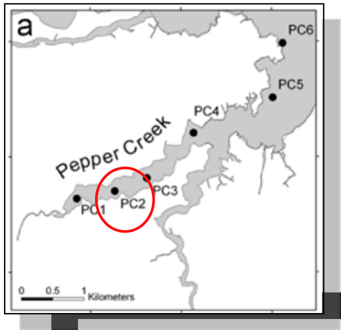

- Non-linear relationship between N-loading, hypoxia, and fisheries
- Behavior plays a large role in mediating these interactions

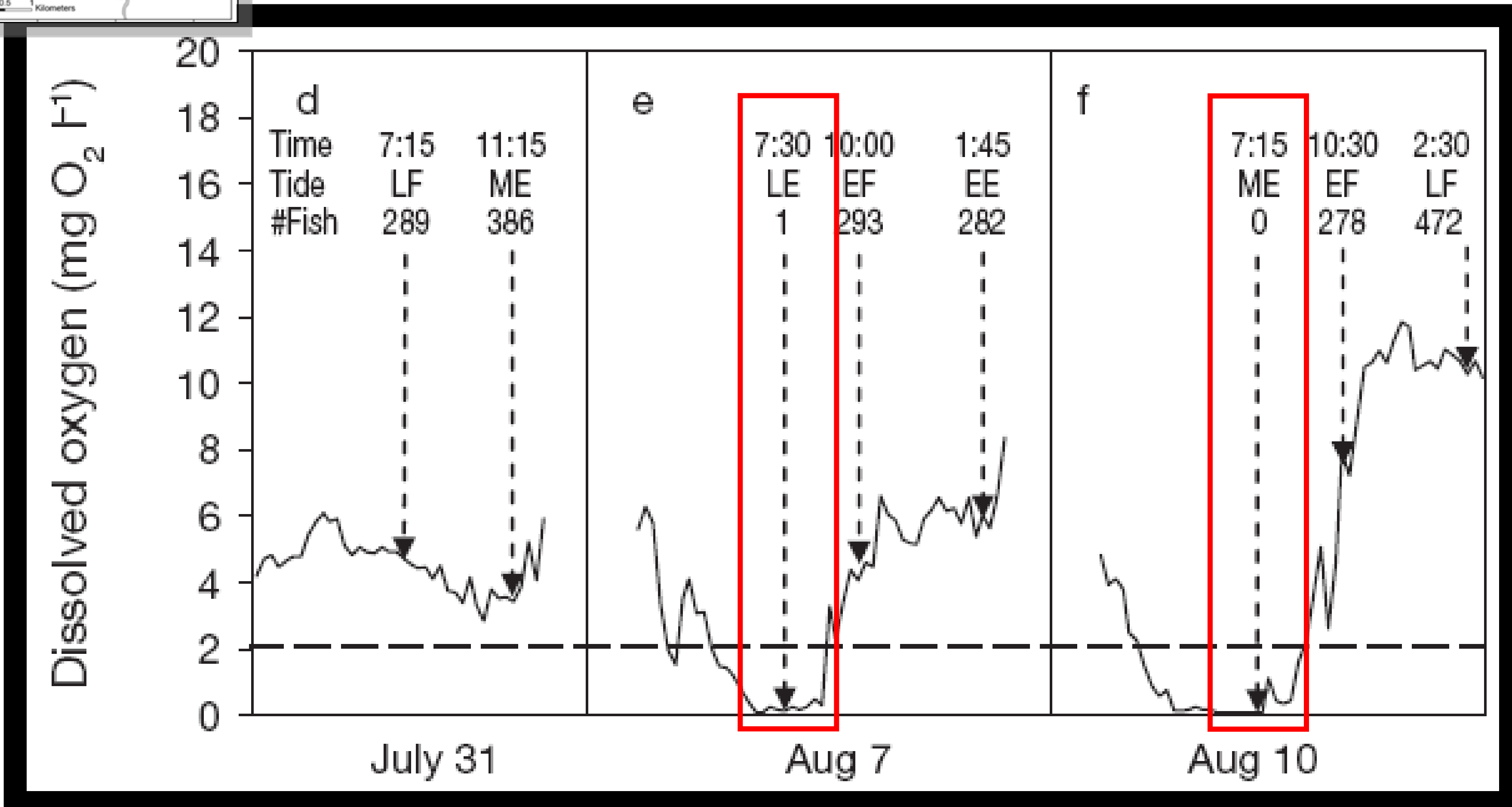
Breitburg, Craig Fulford Rose, Boynton, Brady, et al 2009

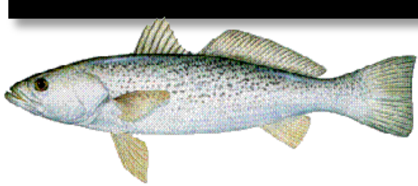
# Diel-cycling Hypoxia

- Increasingly observed in shallow estuarine habitats
  - Bojorquez Lagoon, Mexico (Reyes and Merino 1991)
  - Venice Lagoons, Italy (Sorokin et al. 1996)
  - Waquoit Bay, MA (D'Avanzo and Kremer 1994 and 1996)
  - Elkhorn Slough, CA (Beck and Bruland 2000)
  - Intracoastal Waterways of Hanover County, NC (Hubertz and Cahoon 1999)
  - Maryland Coastal Bays (Kemp and Boynton pers. Comm.)
  - Tributaries of the Chesapeake Bay (Kemp and Boynton pers comm.)
  - The Delaware Coastal Bays (Tyler, Brady, and Targett 2009)

ett



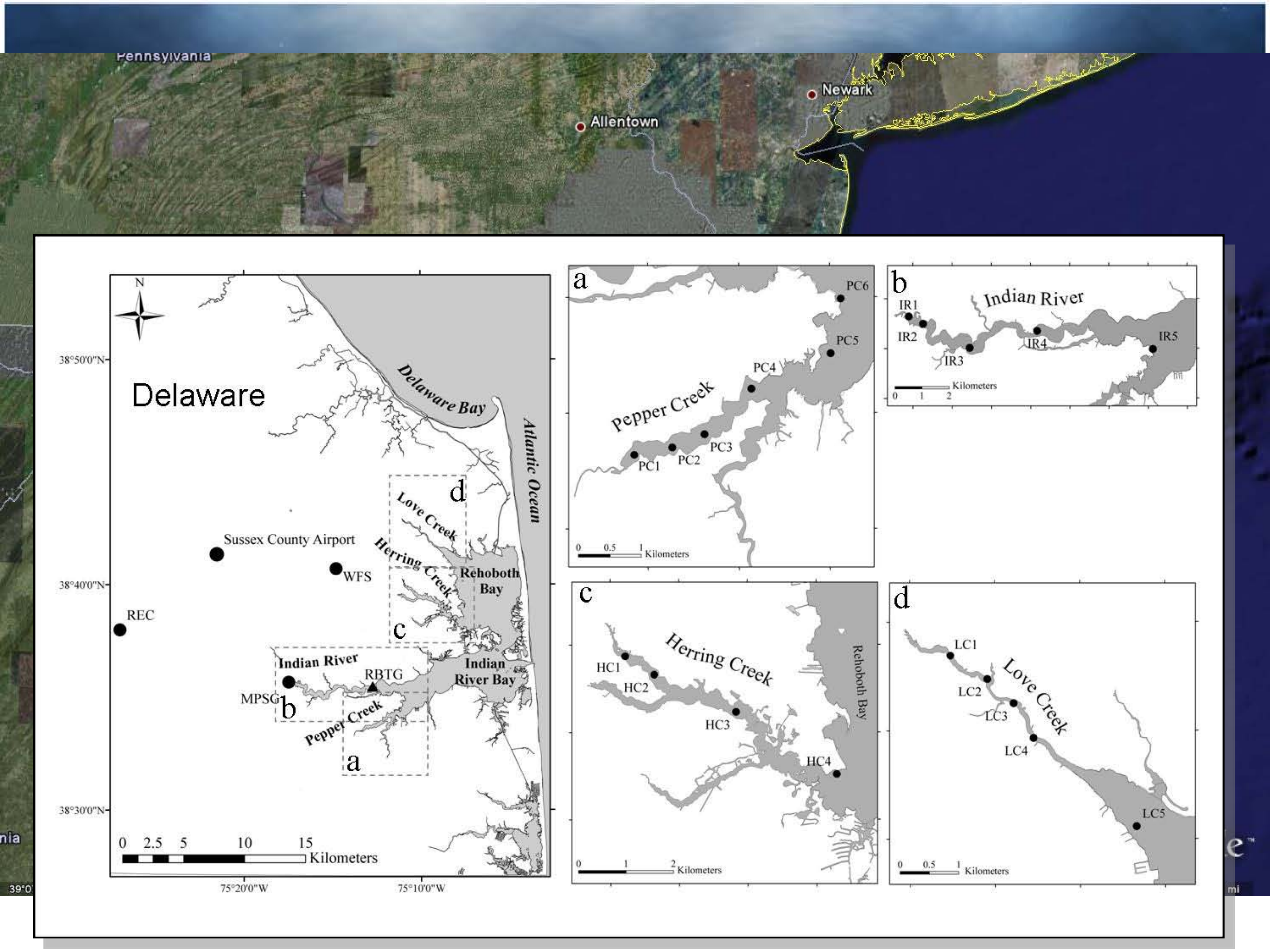



Tyler and Targett 2007

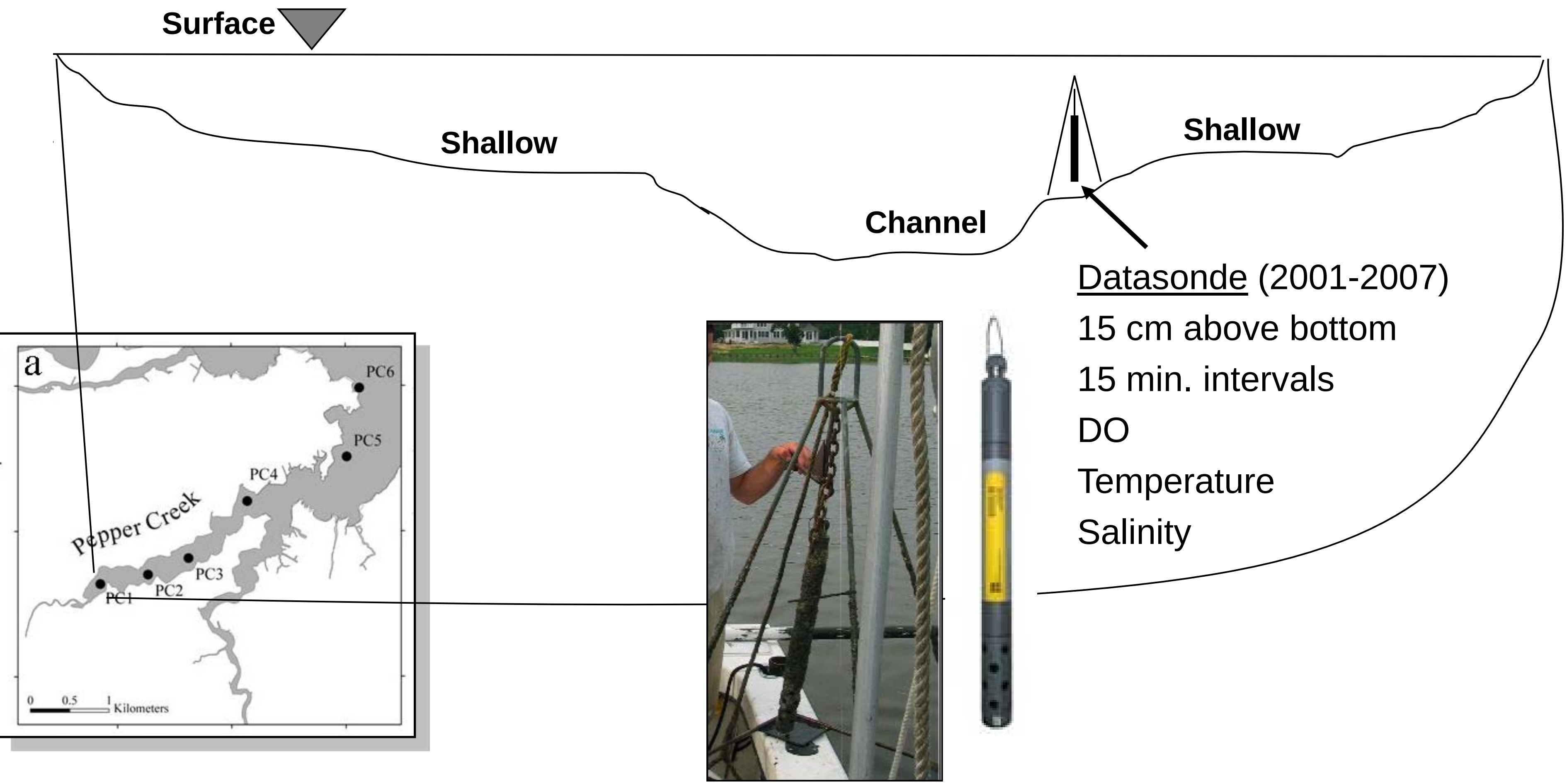
# Exposure

- Direct effects
  - Growth
  - Mortality
- Indirect effects
  - Growth
  - Avoidance
  - Habitat compression/loss
- Exposure
  - Temporal and spatial dynamics of diel-cycling hypoxia
  - Fish behavior

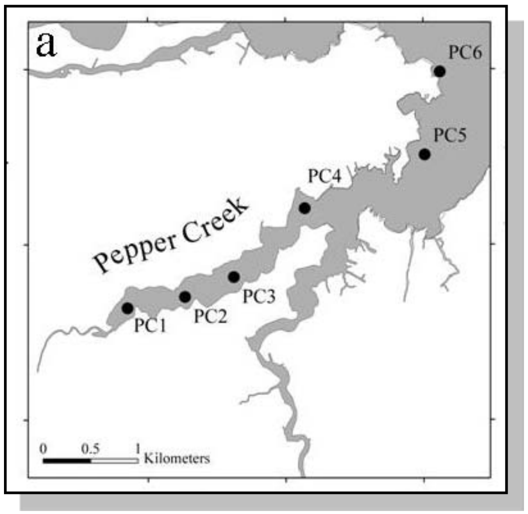


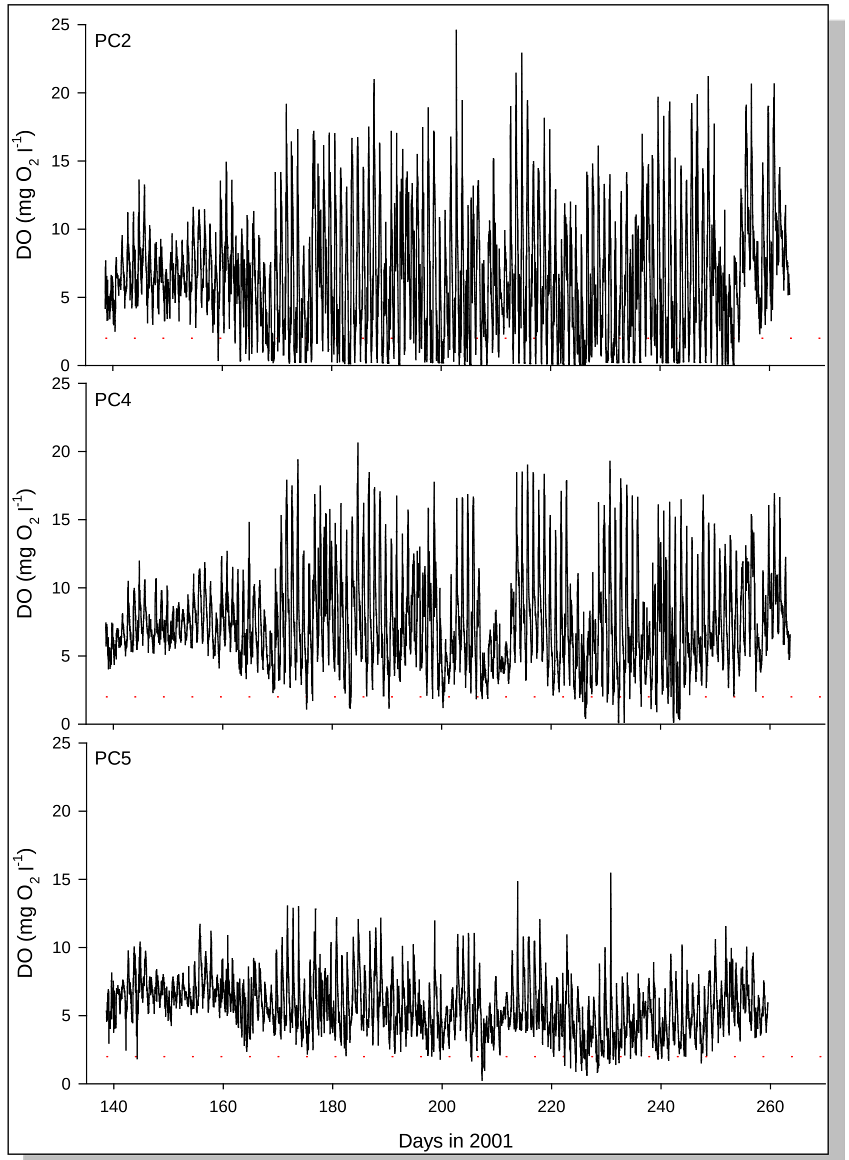
Pennsylvania
Newark
Allentown
N
Delaware
38°50'0"N
38°40'0"N
38°30'0"N
75°20'0"W
75°10'0"W
Delaware Bay
Atlantic Ocean
Love Creek
Herring Creek
Rehoboth Bay
Sussex County Airport
WFS
REC
Indian River
RBTG
Indian River Bay
MPSG
Pepper Creek
a
b
c
d
0 2.5 5 10 15 Kilometers
Pepper Creek
PC1
PC2
PC3
PC4
PC5
PC6
0 0.5 1 Kilometers
Indian River
IR1
IR2
IR3
IR4
IR5
0 1 2 Kilometers
Herring Creek
HC1
HC2
HC3
HC4
Rehoboth Bay
0 1 2 Kilometers
Love Creek
LC1
LC2
LC3
LC4
LC5
0 0.5 1 Kilometers

# Water Quality Sampling



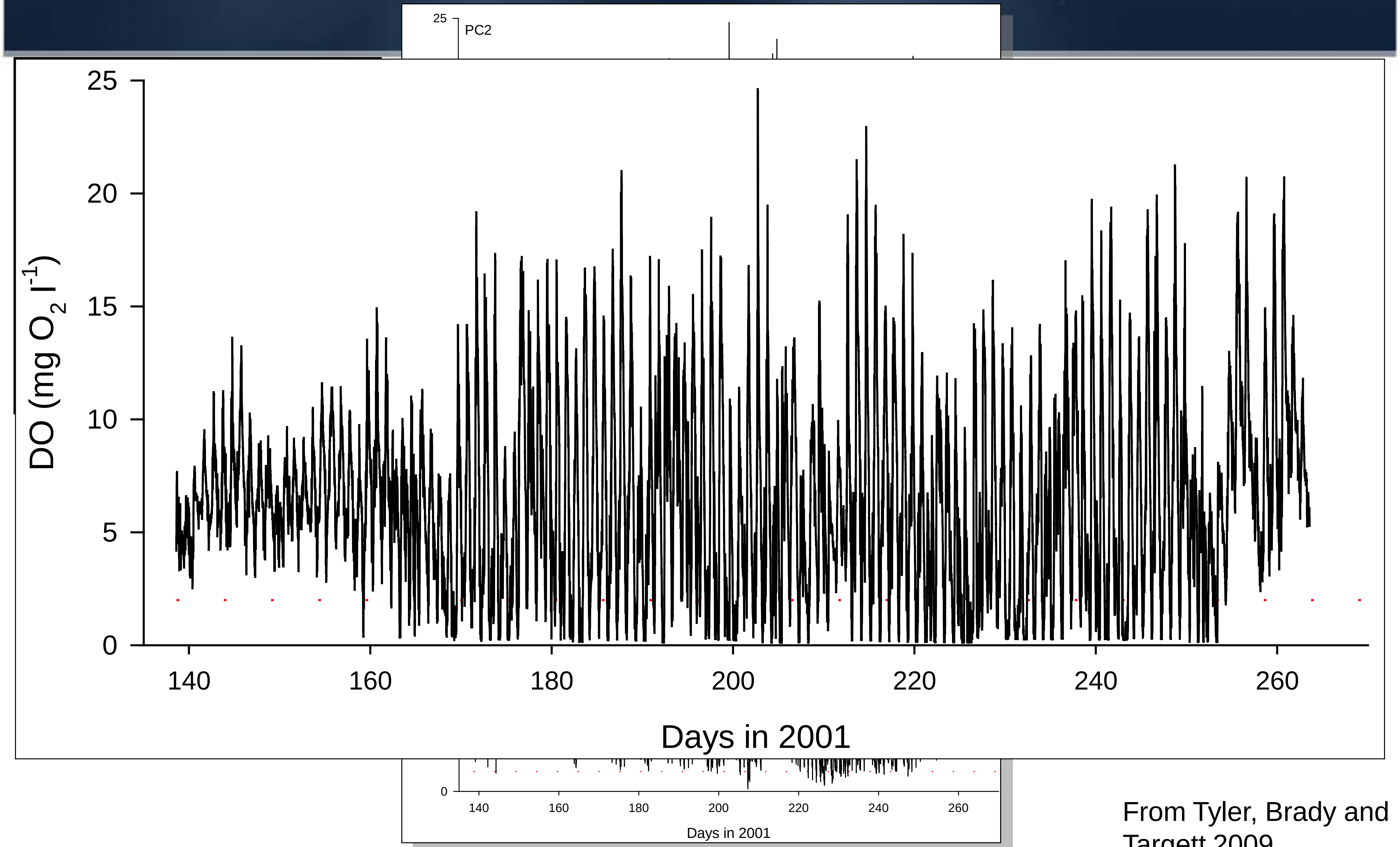

From Tyler 2004



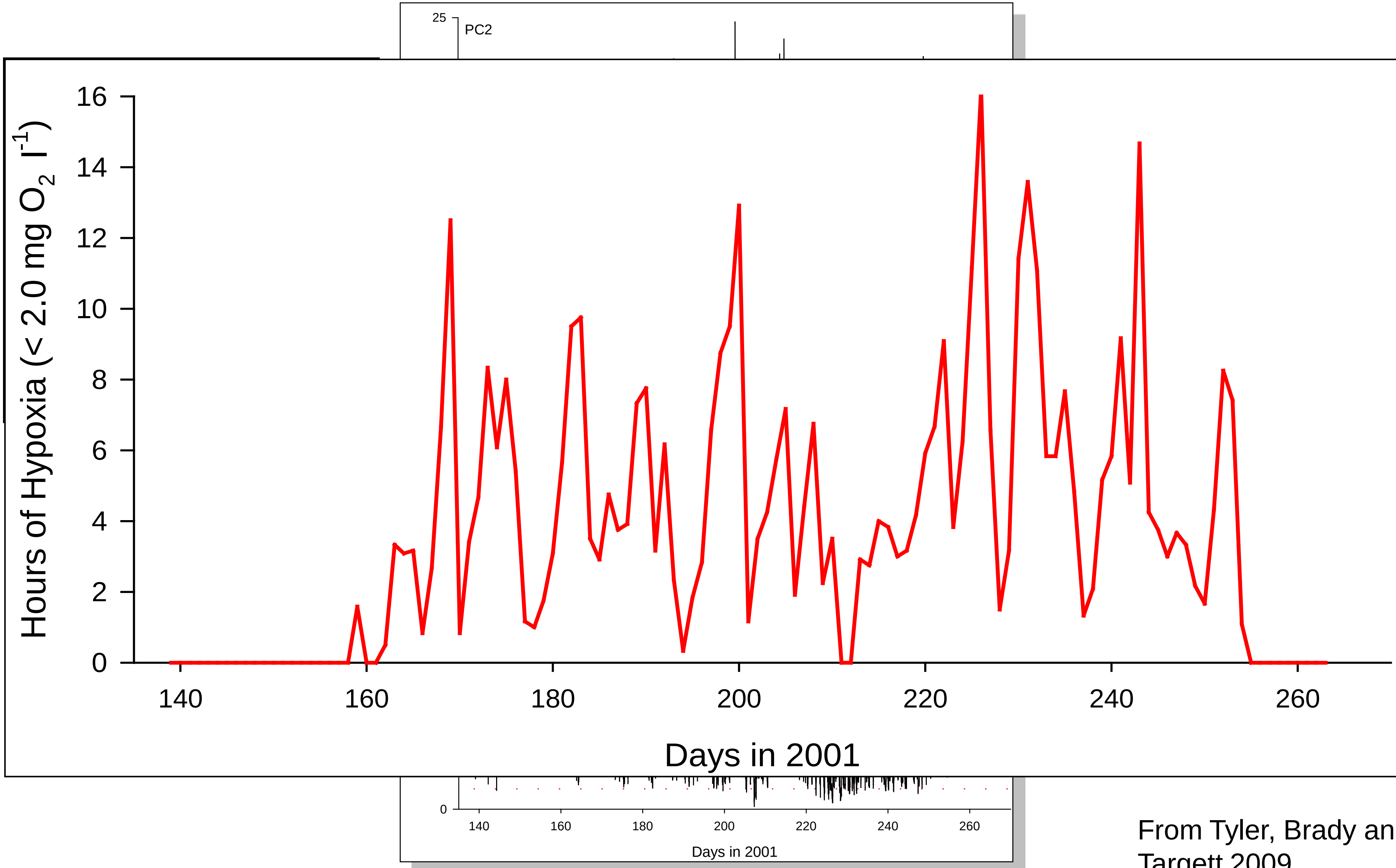




From Tyler, Brady and Targett 2009

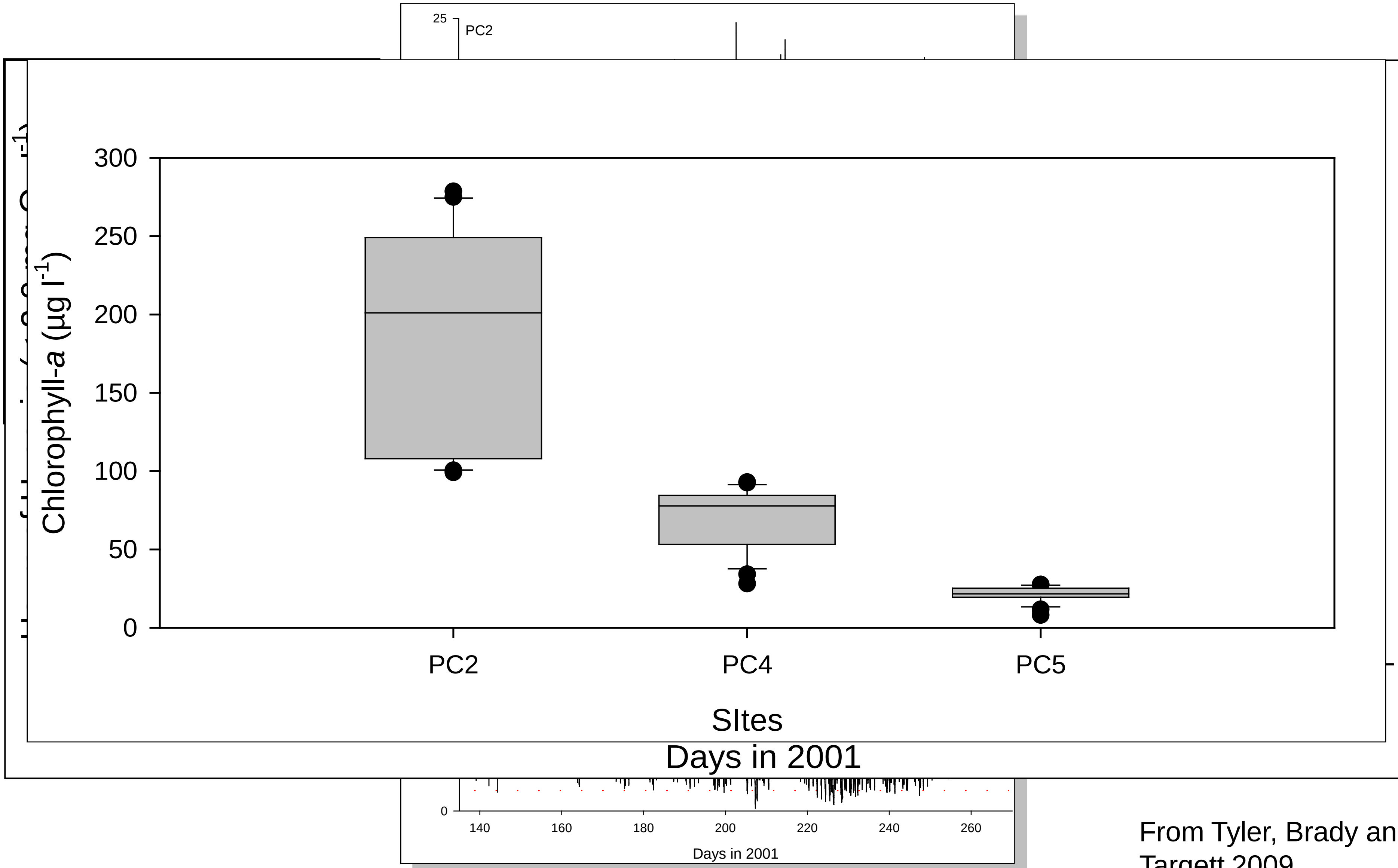
# Temporal and Spatial Dynamics




From Tyler, Brady and Targett 2009

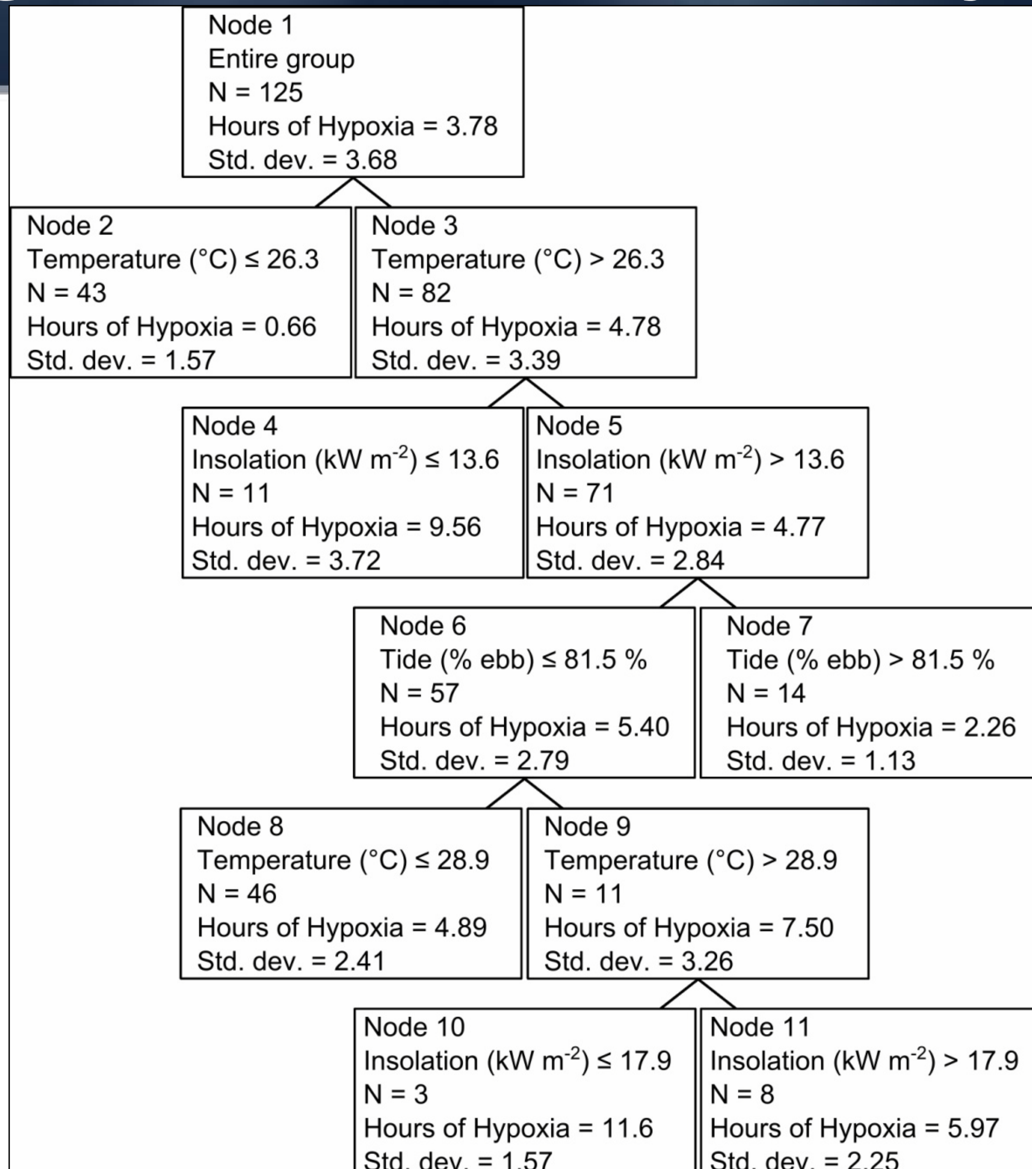



From Tyler, Brady and Targett 2009




From Tyler, Brady and Targett 2009

# Regression Tree Analysis




From Tyler, Brady and Targett 2009

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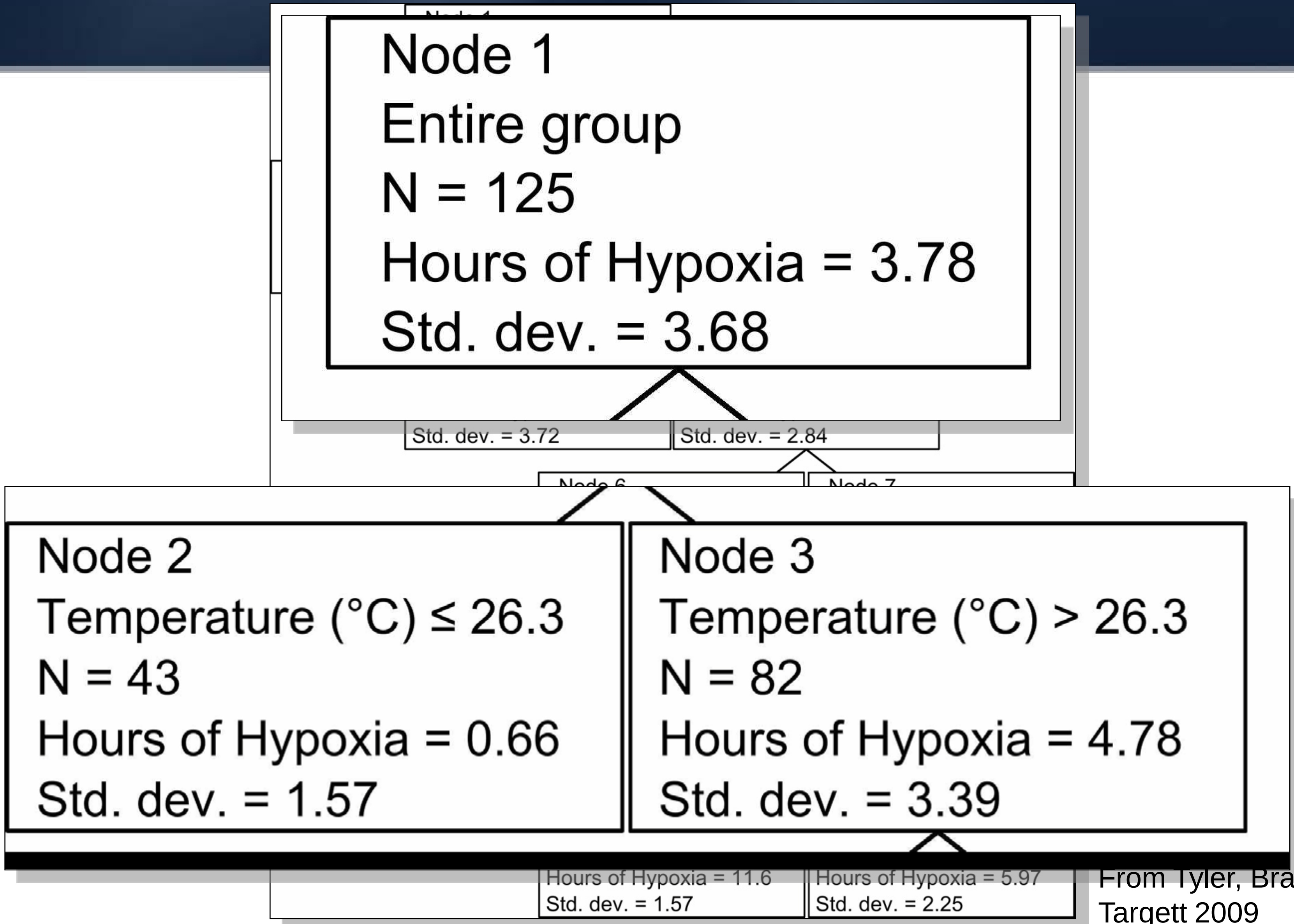
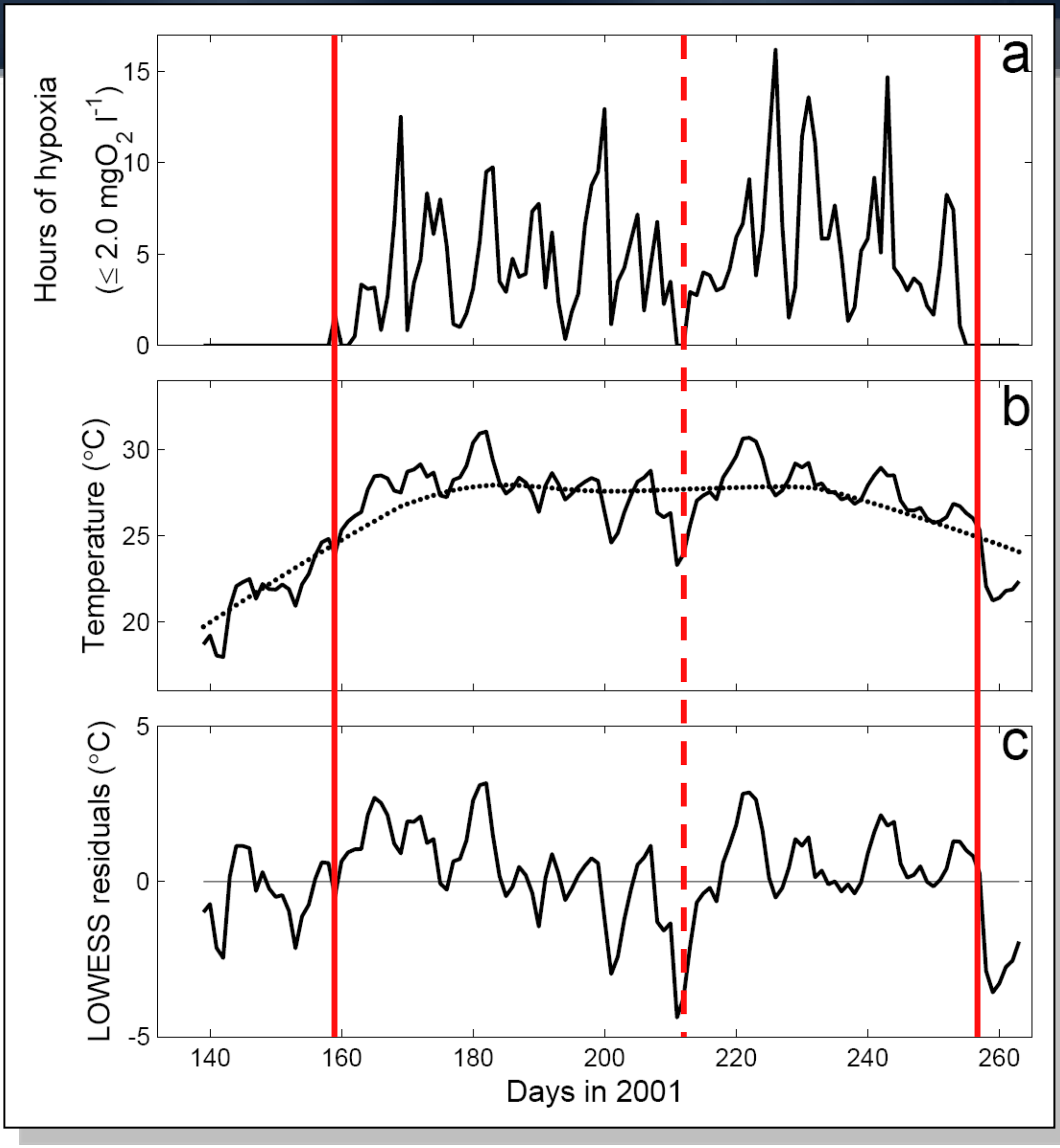


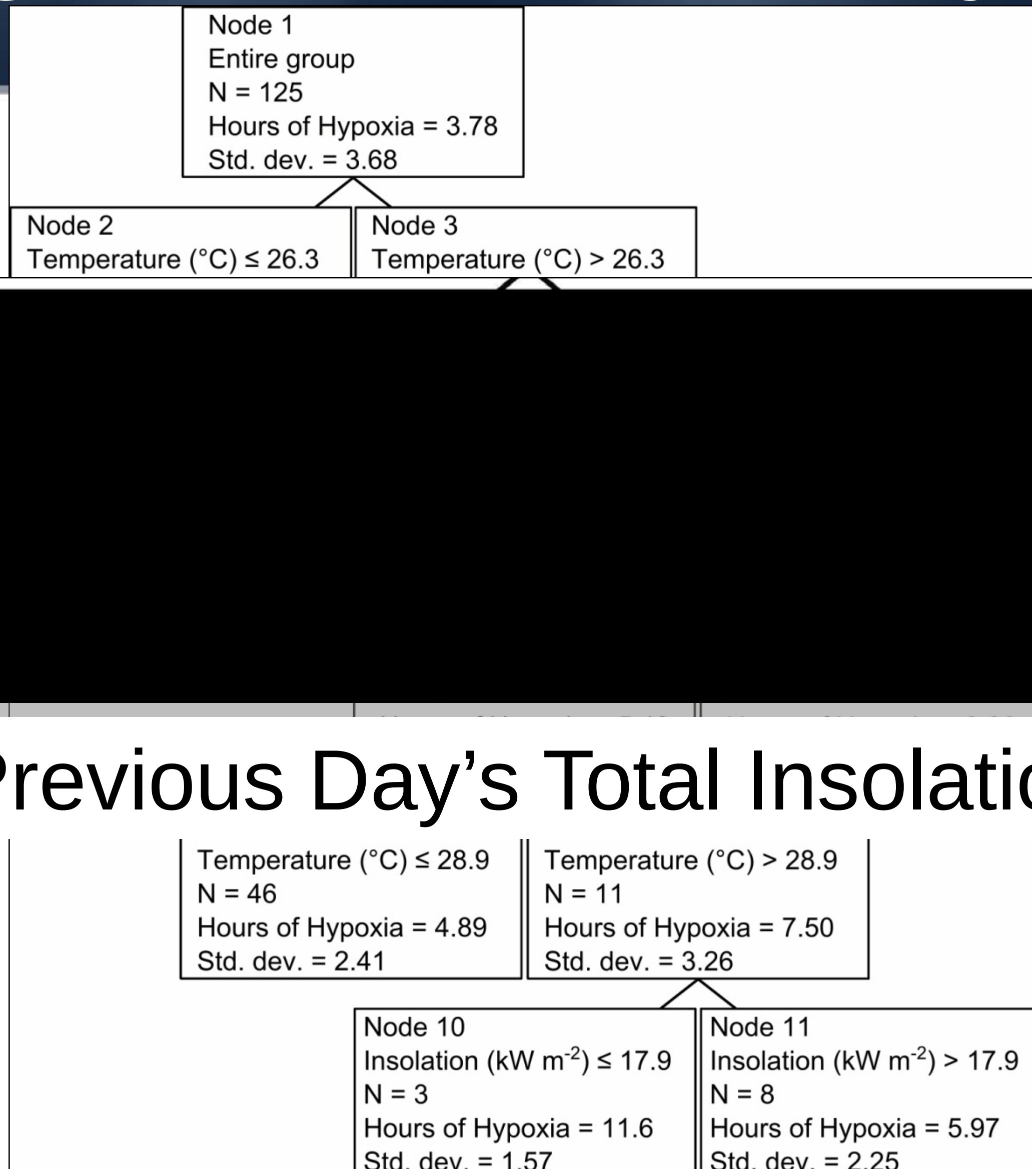

From Tyler, Brady and Targett 2009

# Temperature




From Tyler, Brady and Targett 2009

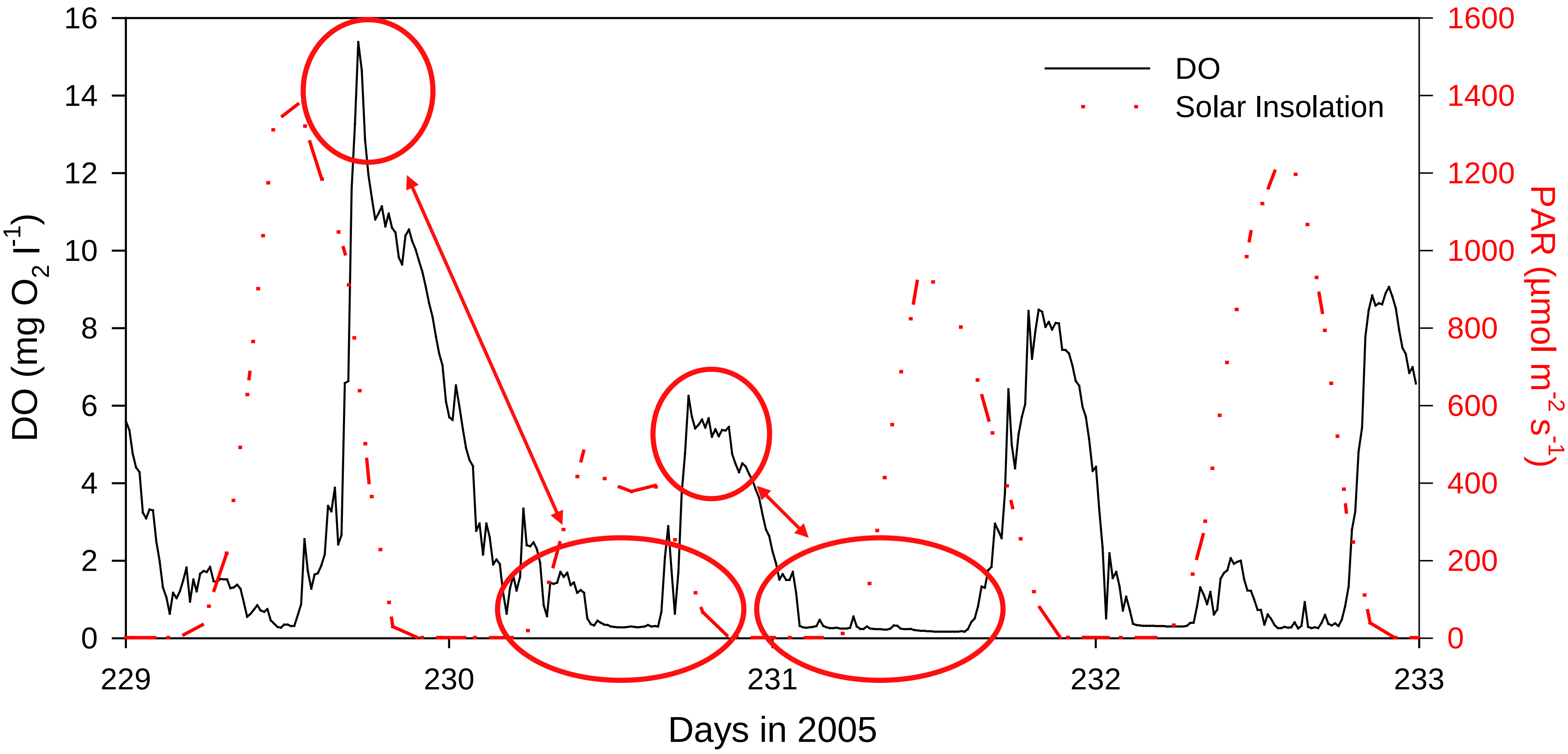
# Regression Tree Analysis




Previous Day’s Total Insolation

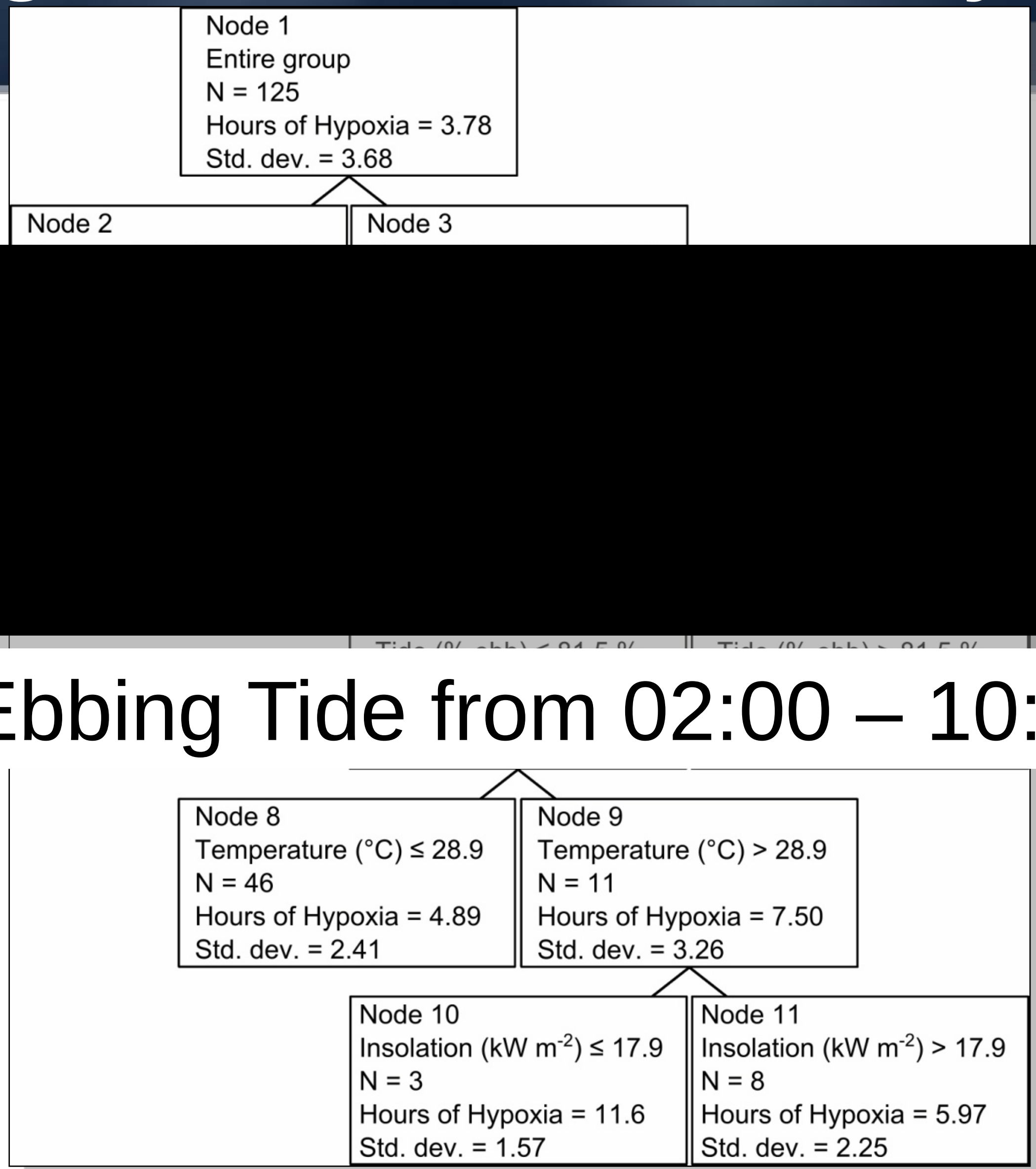
From Tyler, Brady and Targett 2009

# Insolation




From Tyler, Brady and Targett 2009

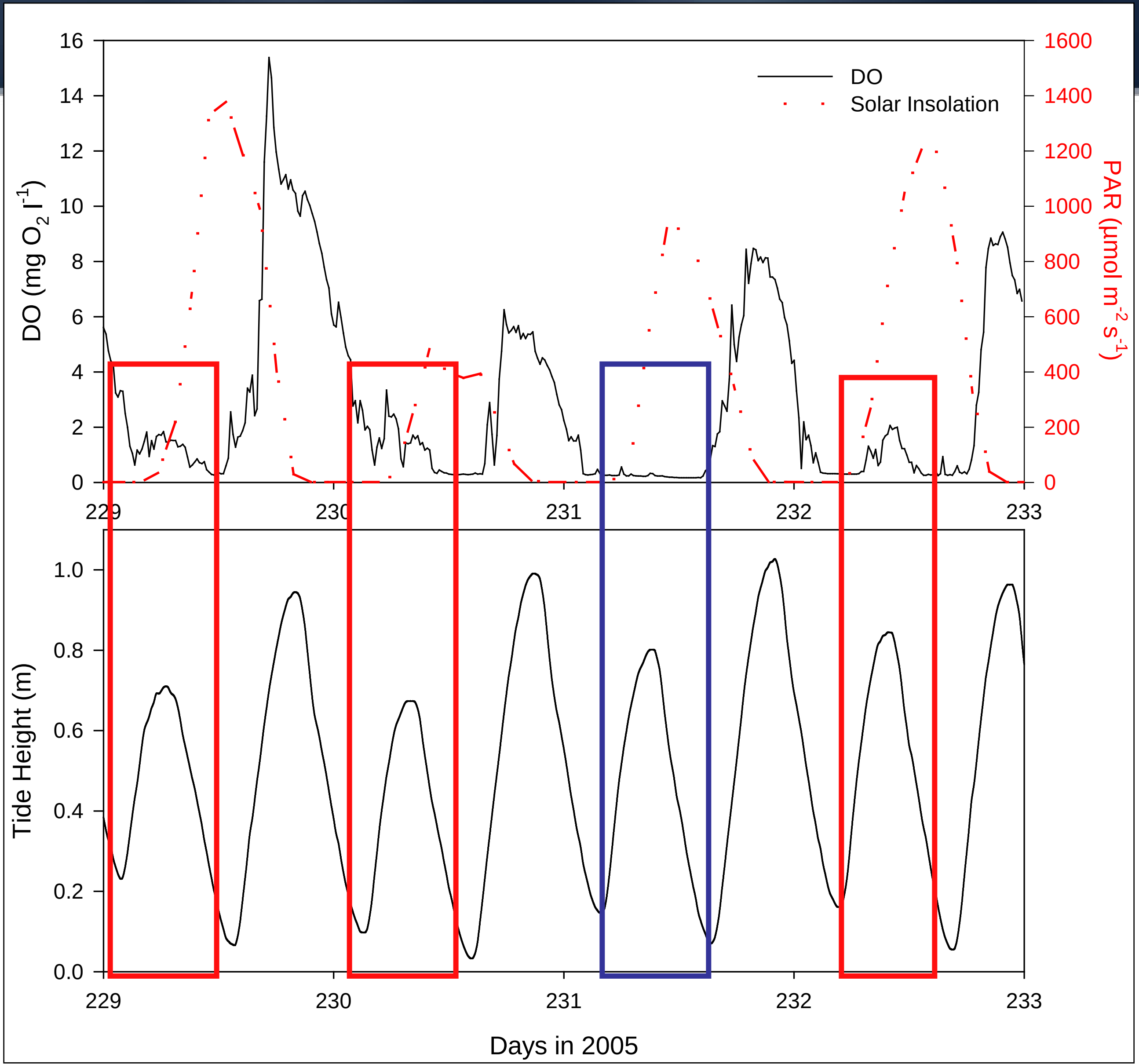
# Regression Tree Analysis



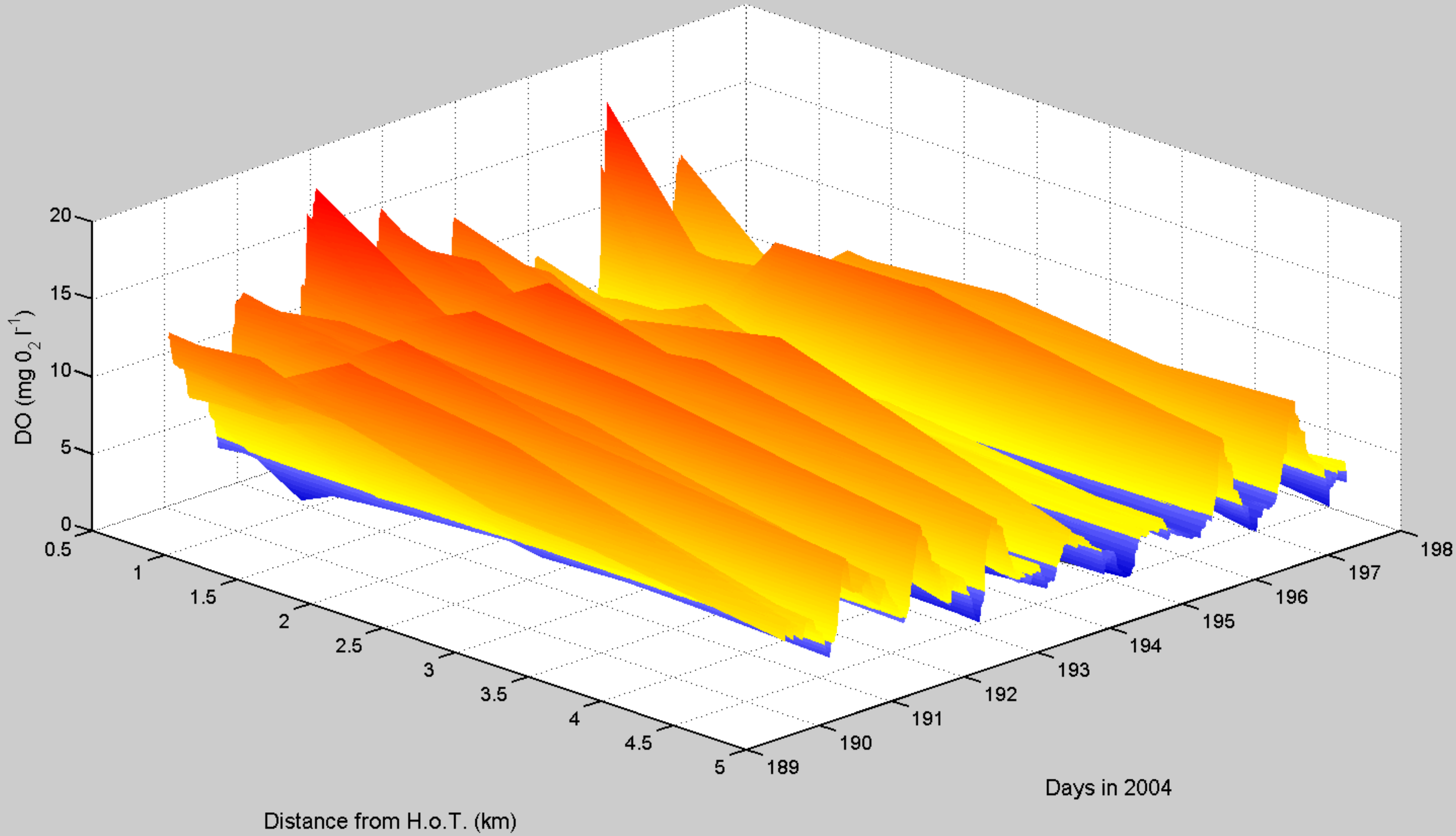

% Ebbing Tide from 02:00 – 10:00

From Tyler, Brady and Targett 2009

# Tidal Interactions

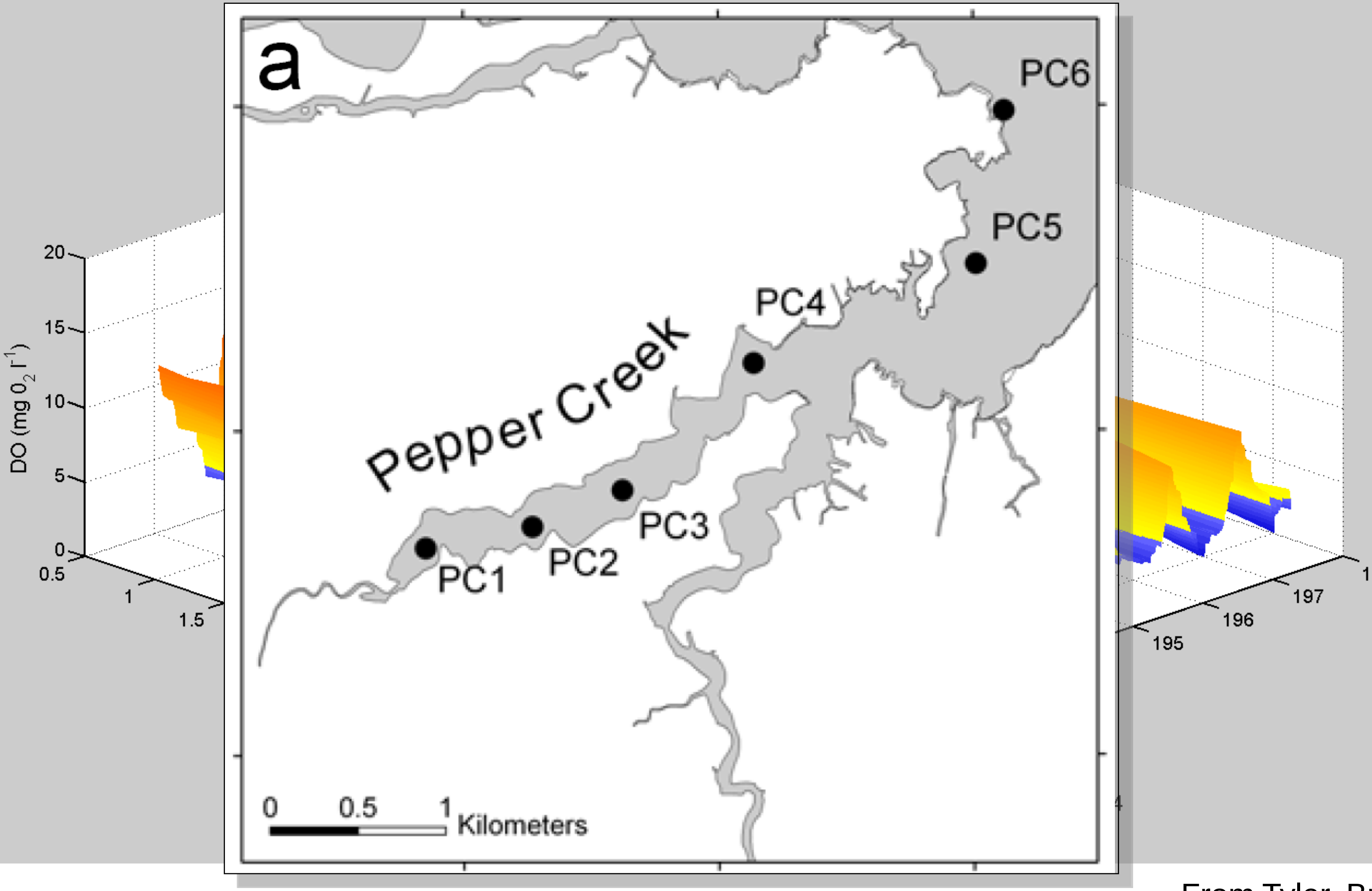


# Spatial Variability

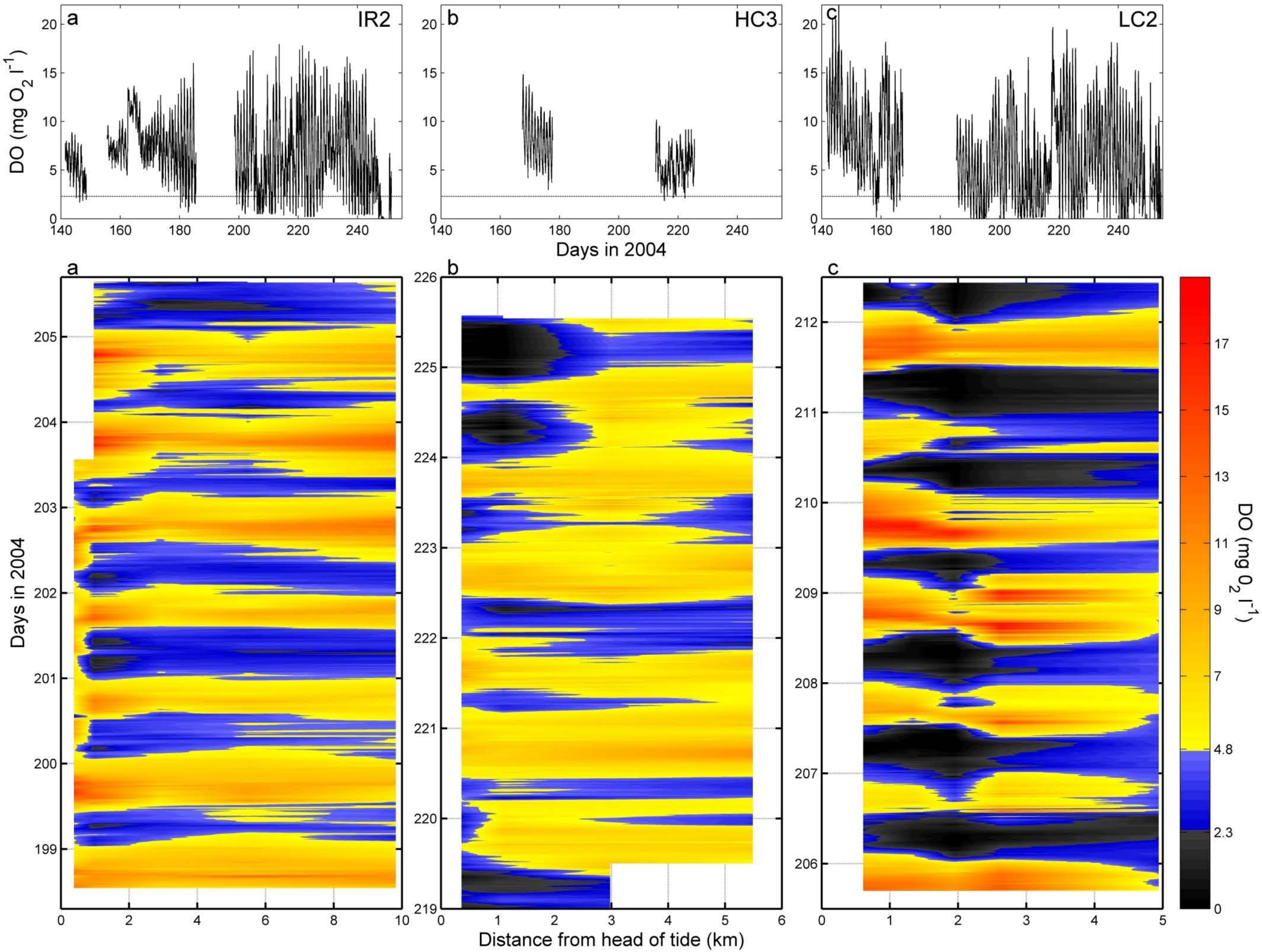



From Tyler, Brady and Targett 2009

# Spatial Variability




From Tyler, Brady and Targett 2009



a
IR2
b
HC3
c
LC2
DO (mg O2 l-1)
Days in 2004
Days in 2004
Distance from head of tide (km)
DO (mg 02 l-1)

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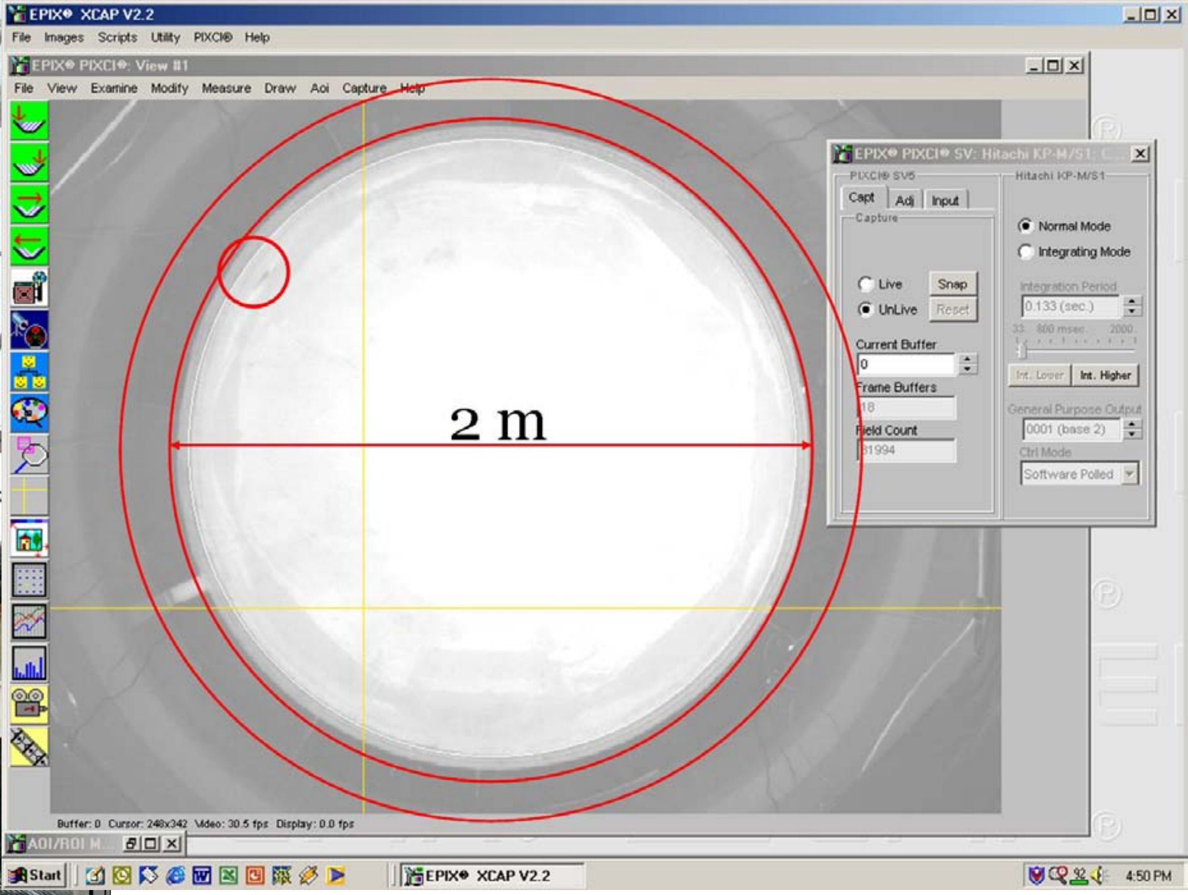
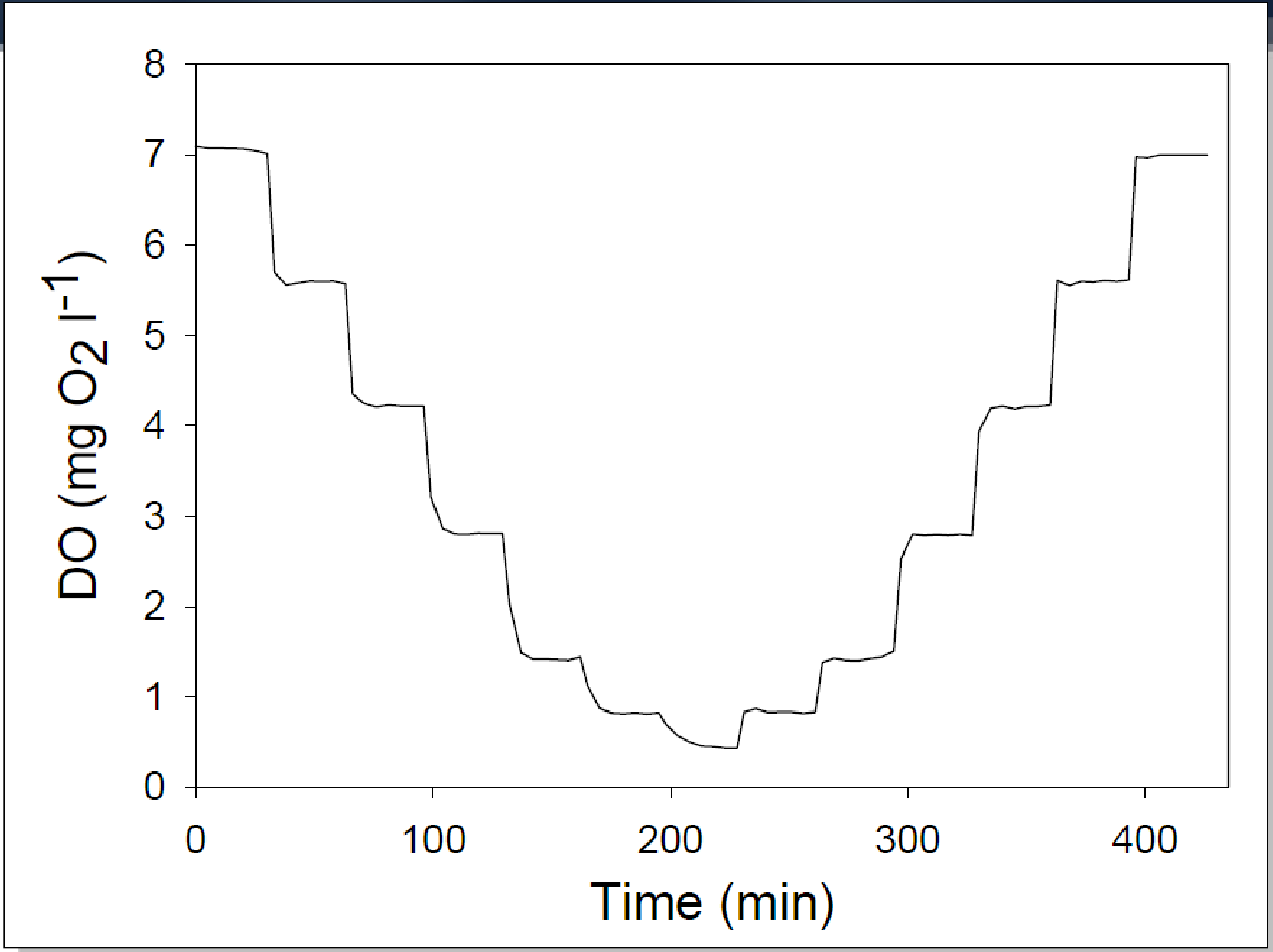
# Mesocosm

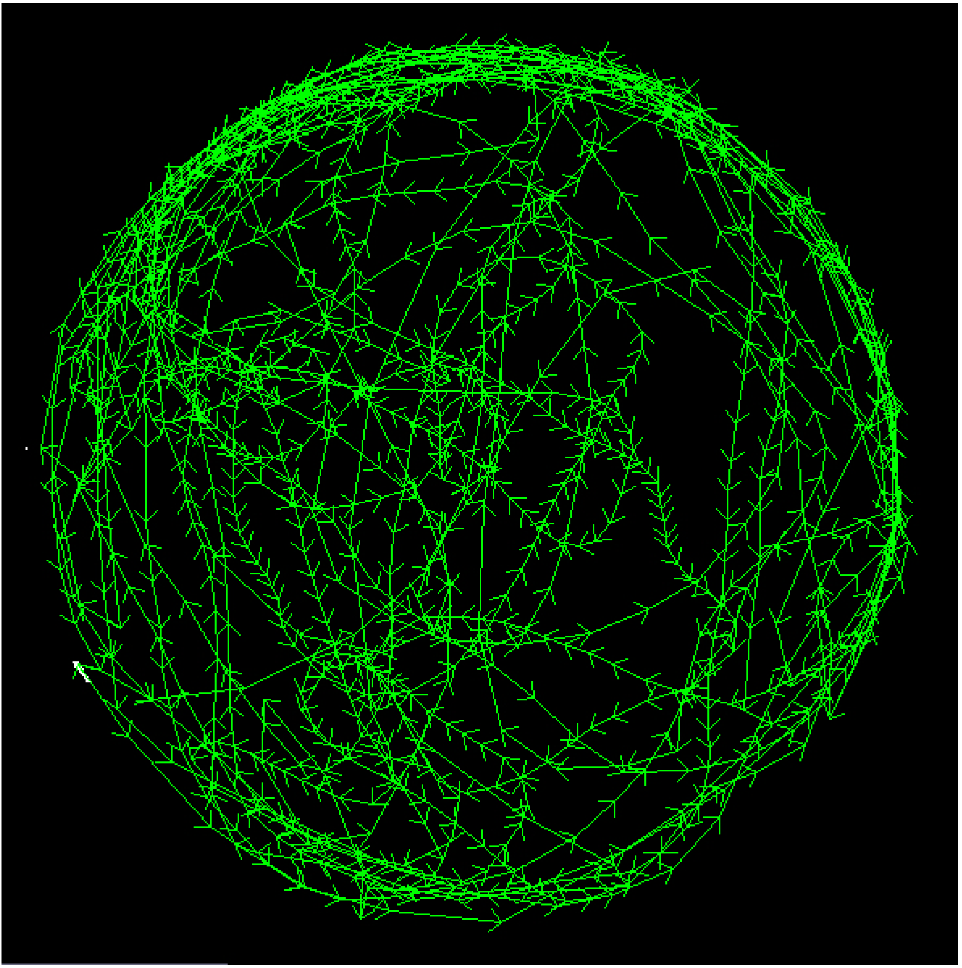

EPIX® XCAP V2.2
File Images Scripts Utility PIXCI® Help
EPIX® PIXCI®: View #1
File View Examine Modify Measure Draw Aoi Capture Help
2 m
EPIX® PIXCI® SV: Hitachi KP-M/S1
PIXCI® SV5
Capt Adj Input
Capture
Live
UnLive
Snap
Reset
Current Buffer
0
Frame Buffers
18
Field Count
Hitachi KP-M/S1
Normal Mode
Integrating Mode
Integration Period
0.133 (sec.)
Int. Lower
Int. Higher
General Purpose Output
0001 (base 2)
Ctrl Mode
Software Polled
Buffer: 0 Cursor: 248x342 Video: 30.5 fps Display: 0.0 fps
Start
EPIX® XCAP V2.2
4:50 PM

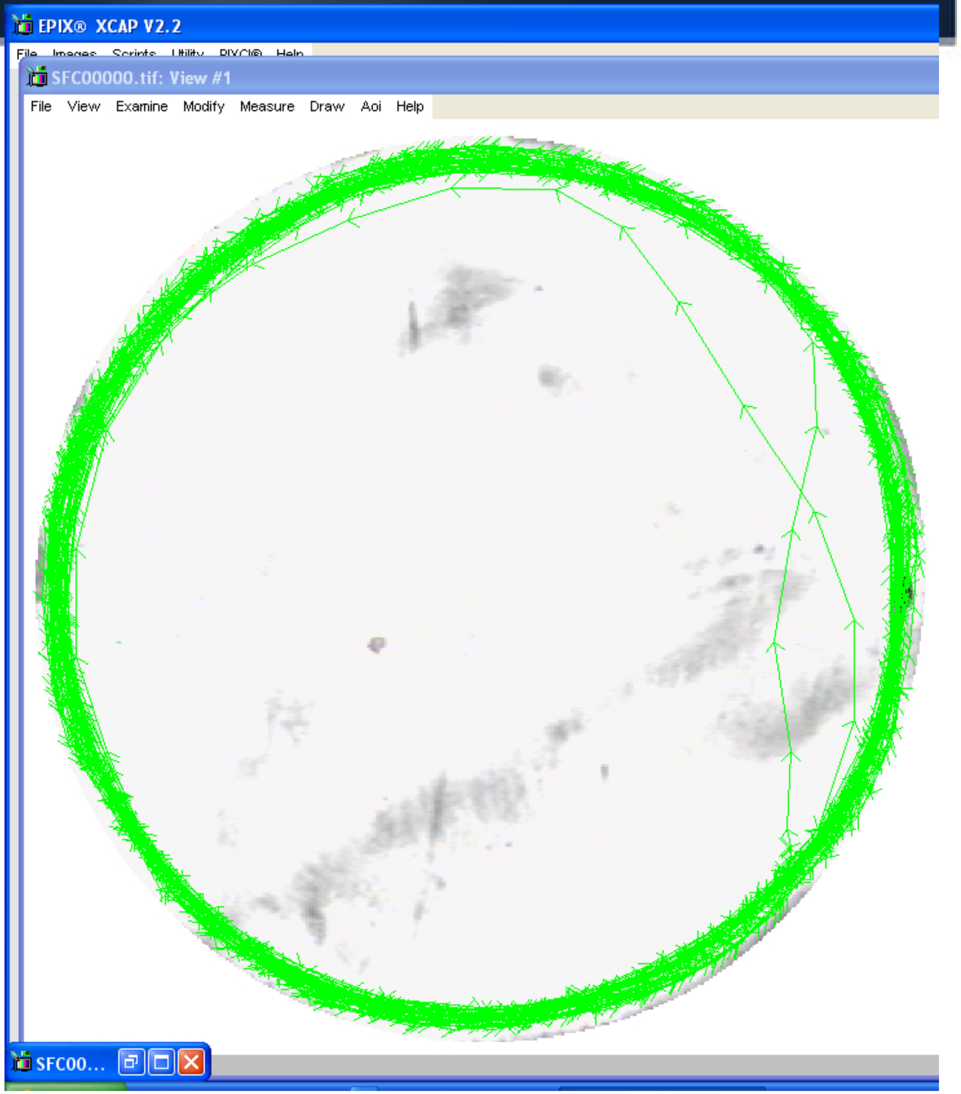
# DO Exposure

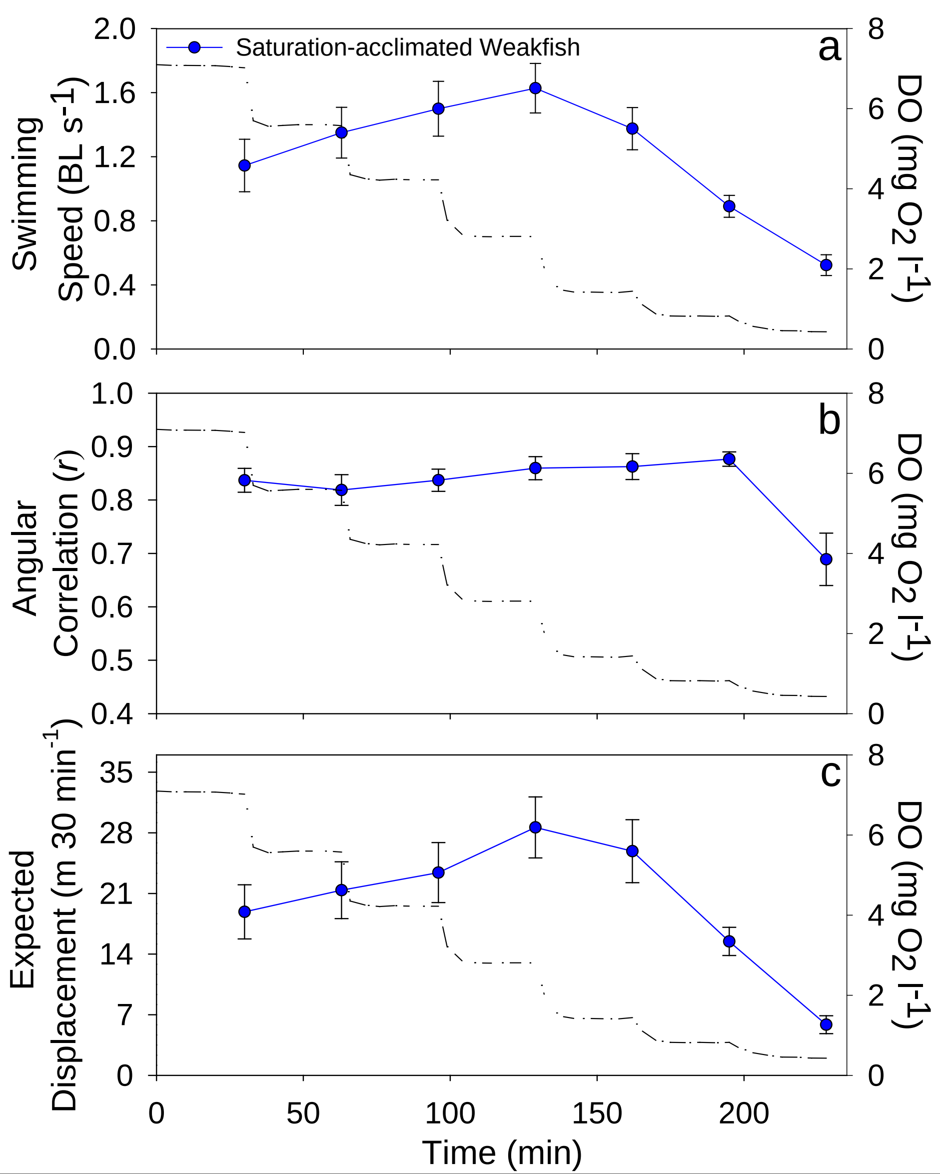


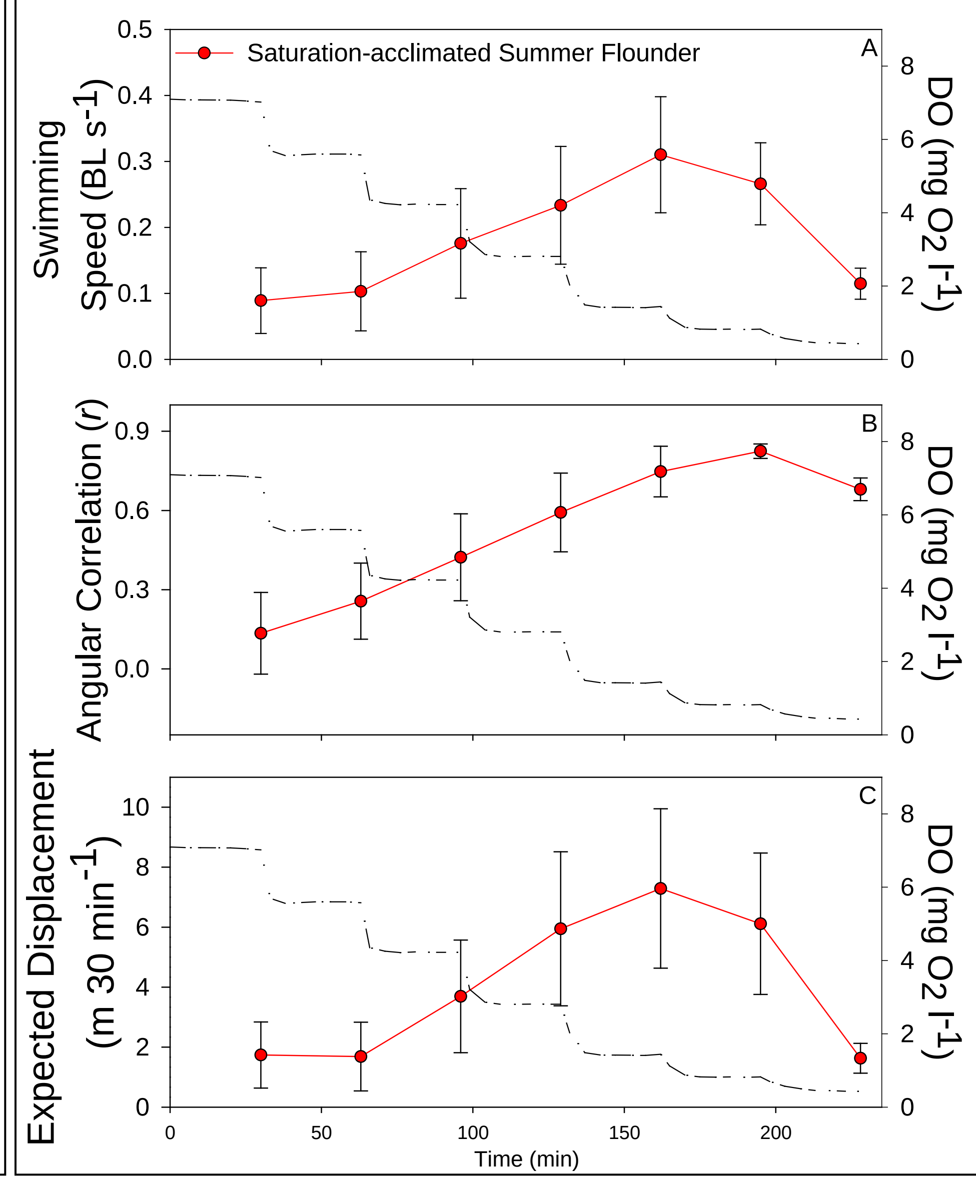

Brady and Targett 2009

# Behavioral Experiments

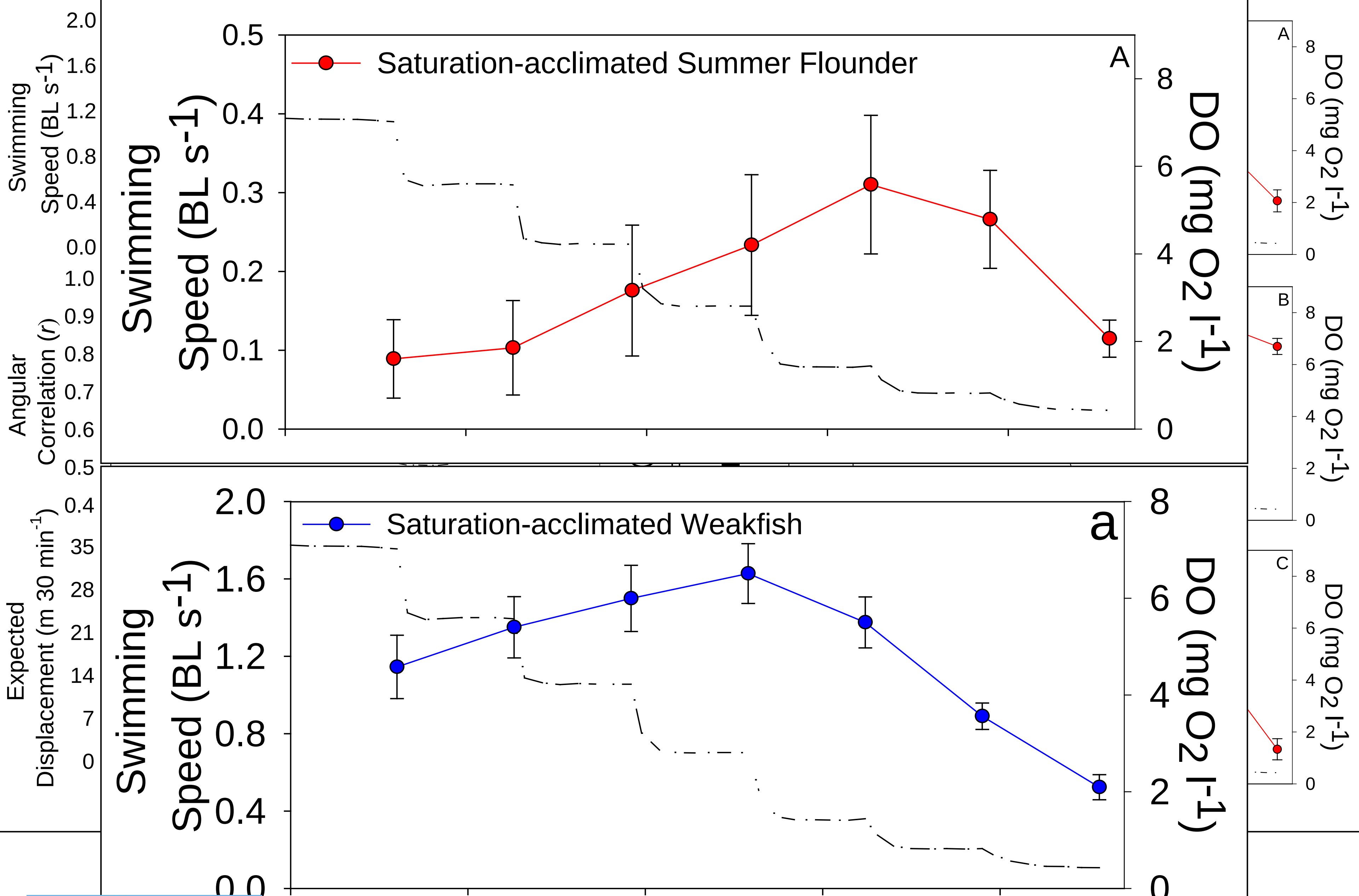




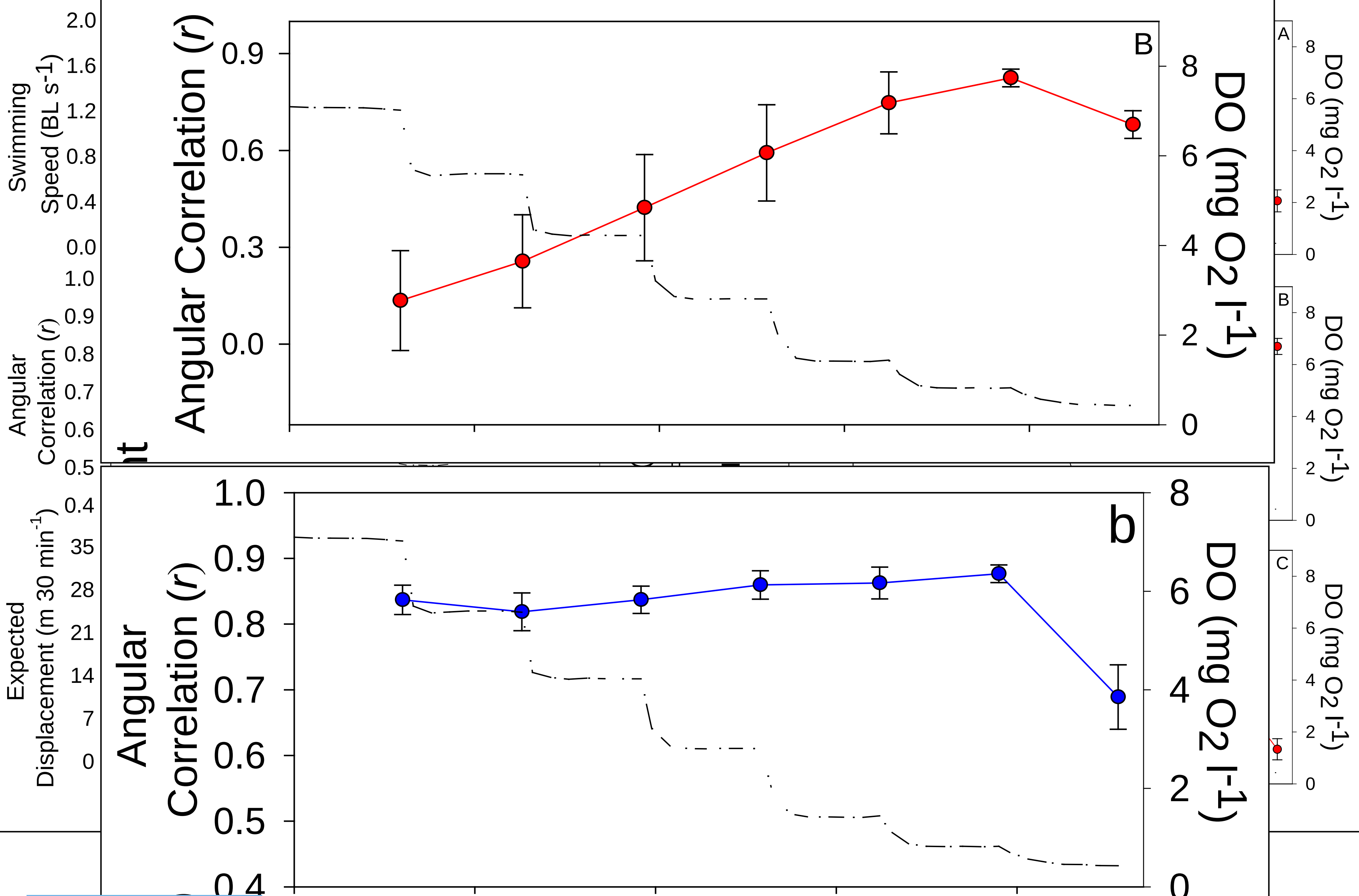


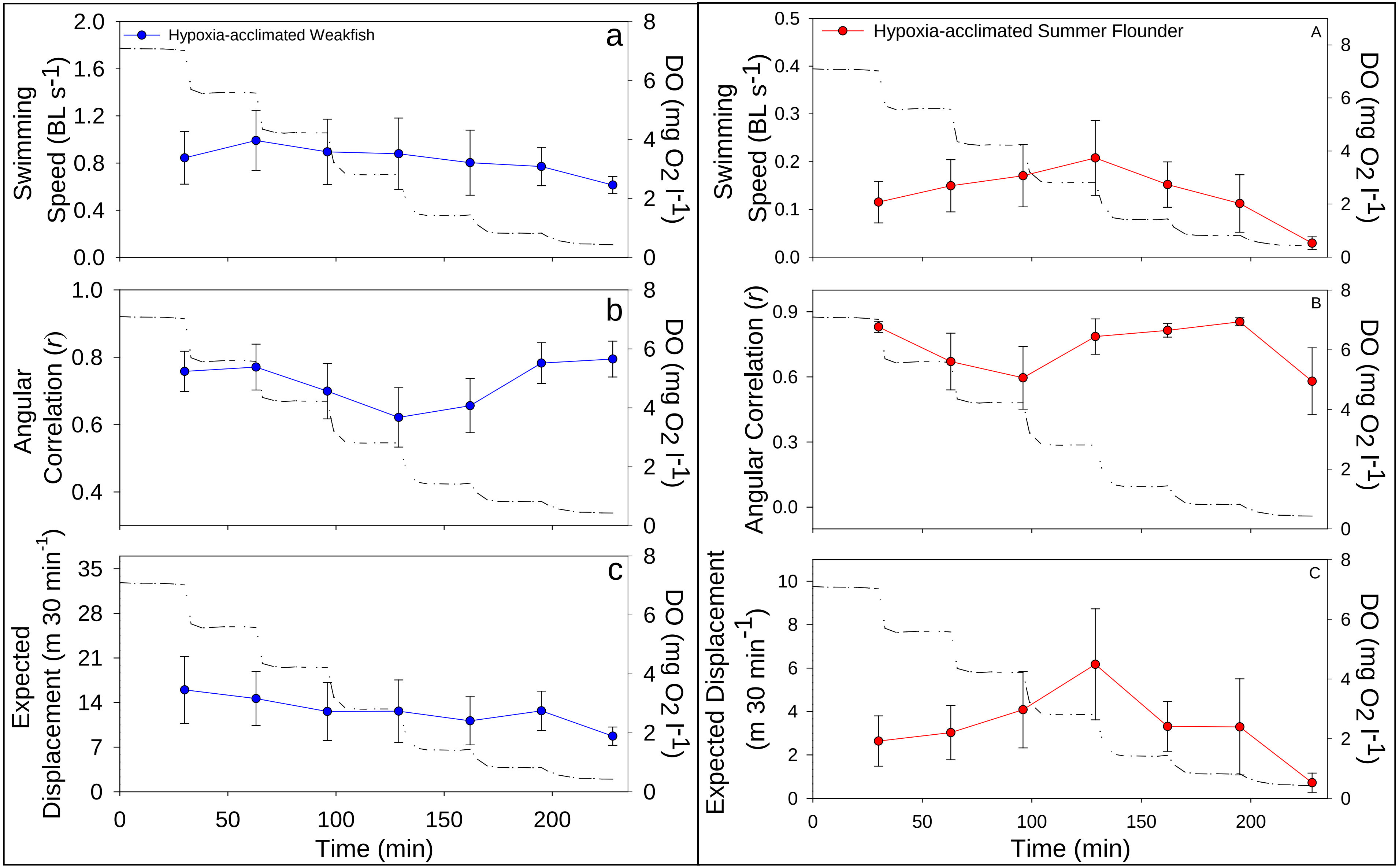

Brady and Targett 2009
Brady and Targett 2010



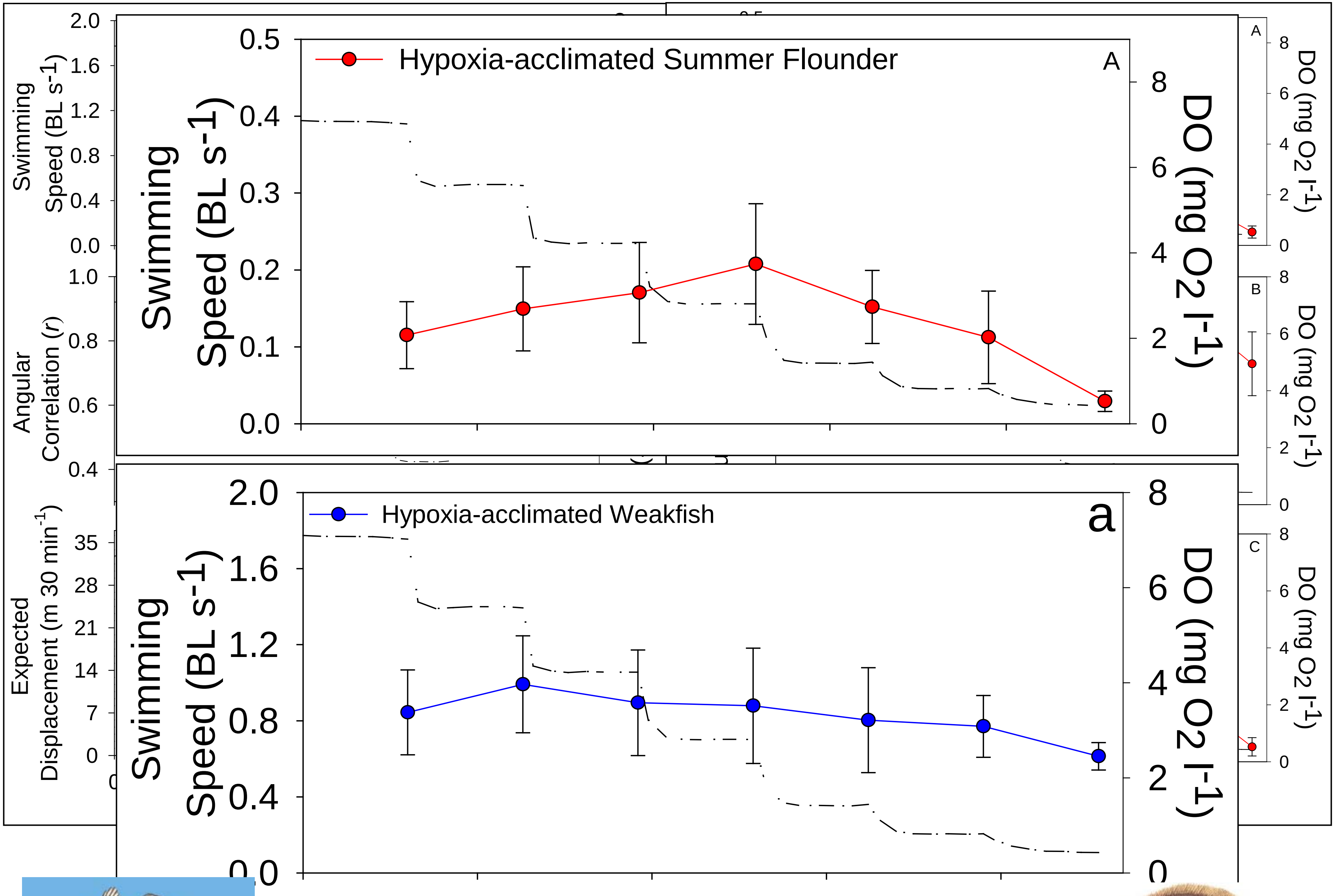

Brady and Targett 2009
Brady and Targett 2010




Brady and Targett 2009
Brady and Targett 2010

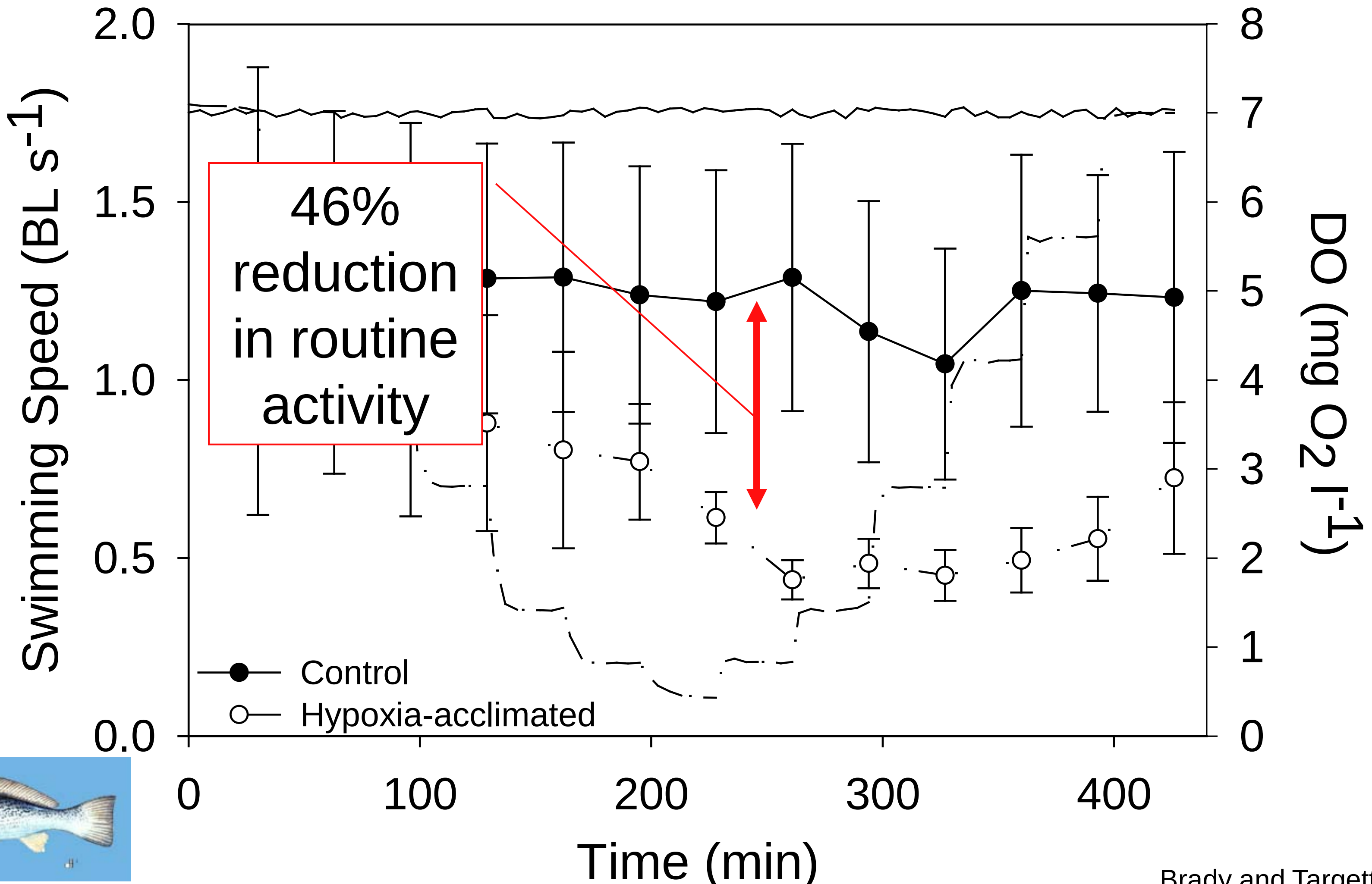



Brady and Targett 2009
Brady and Targett 2010




Brady and Targett 2009
Brady and Targett 2010

# Hypoxia-Acclimation




Brady and Targett 2009

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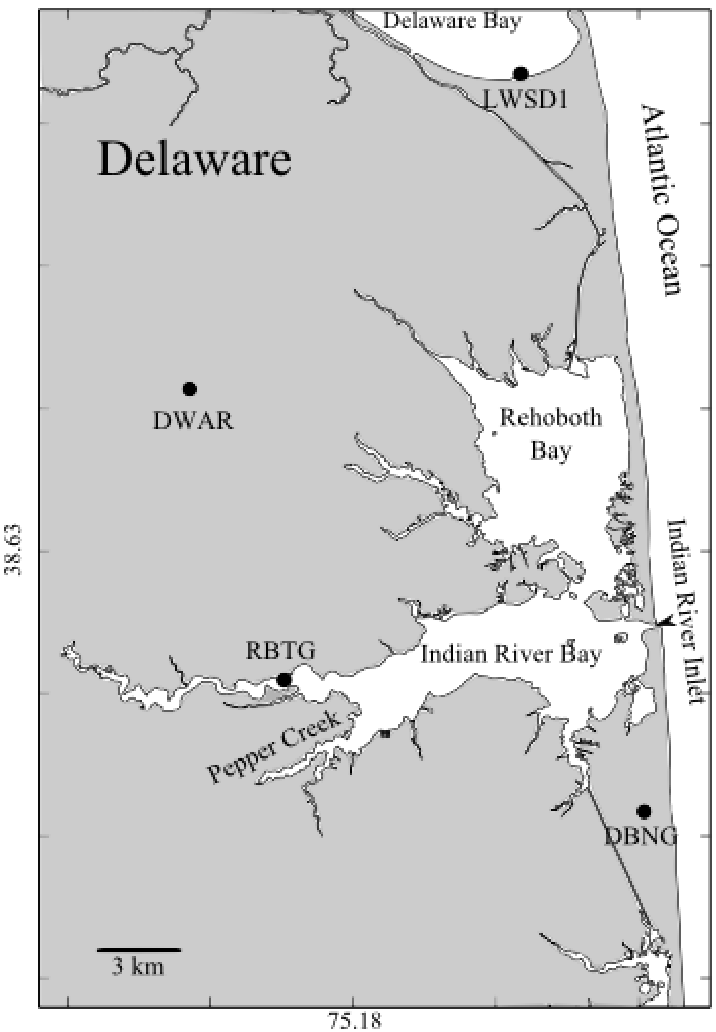
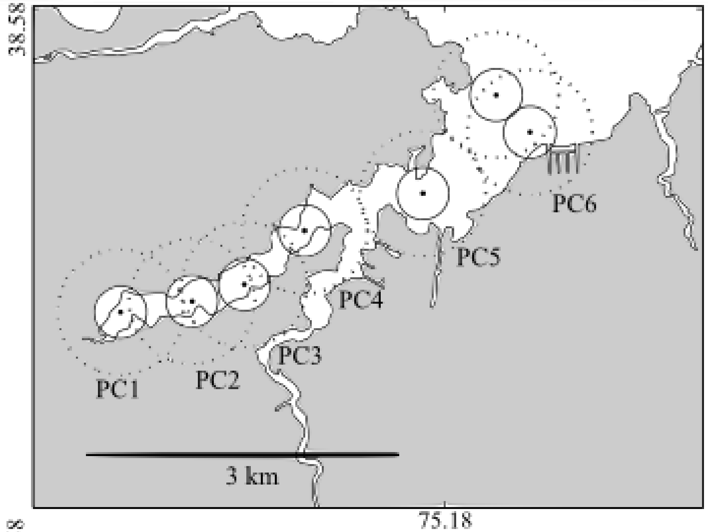
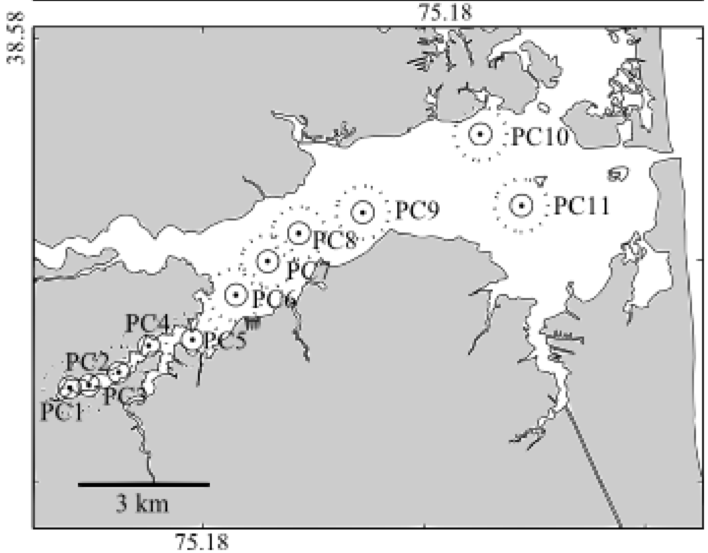
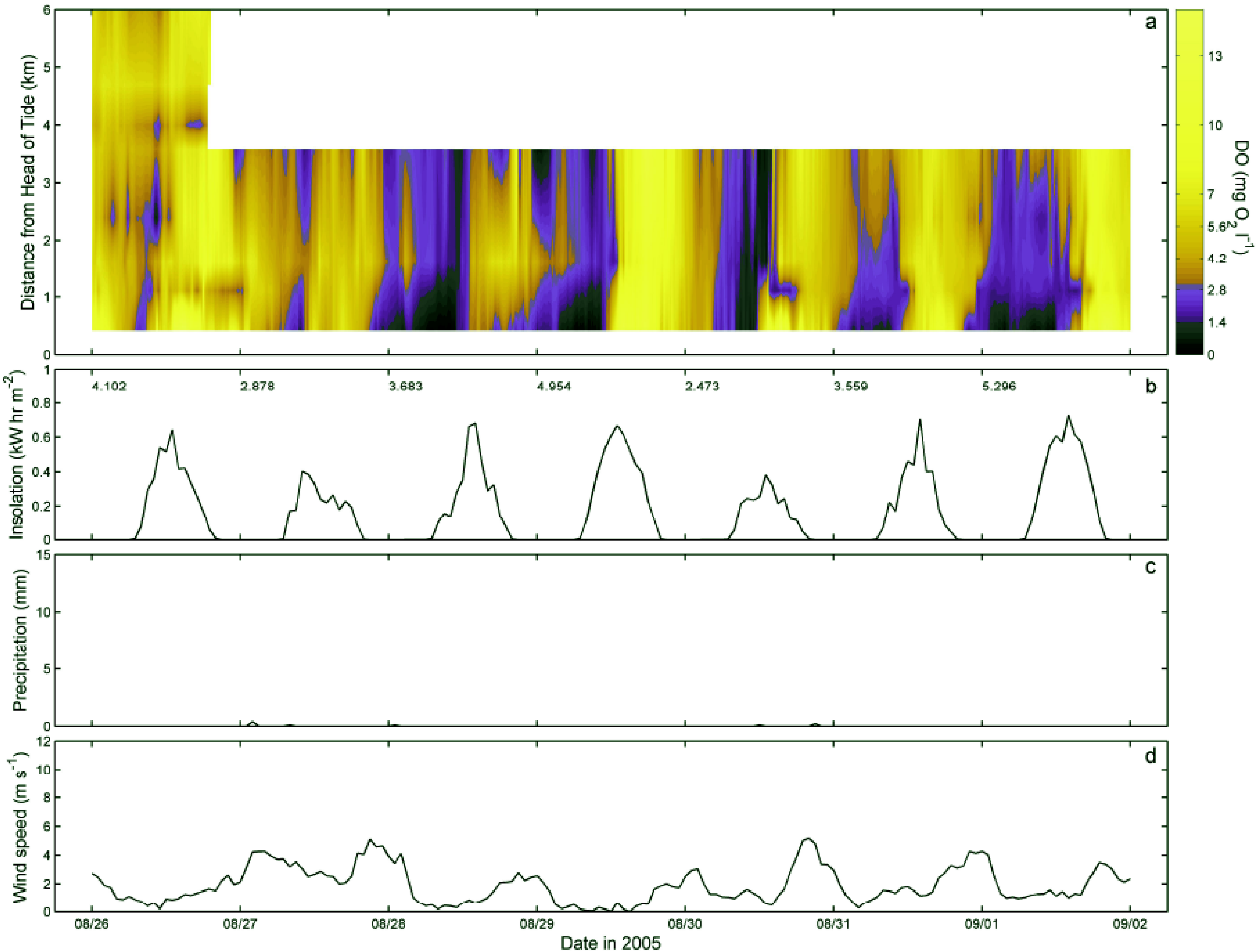
# From the Laboratory to the Field



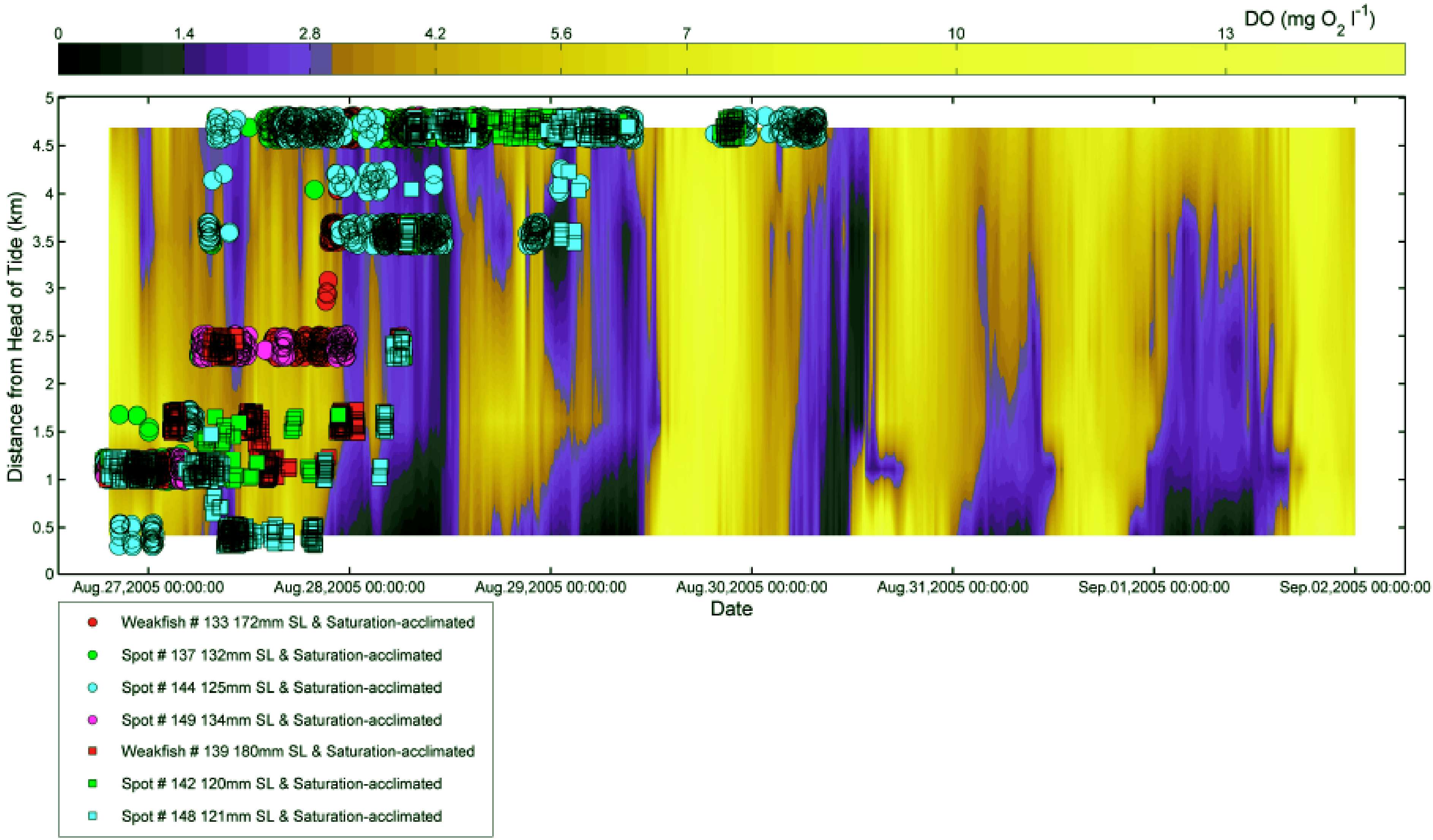



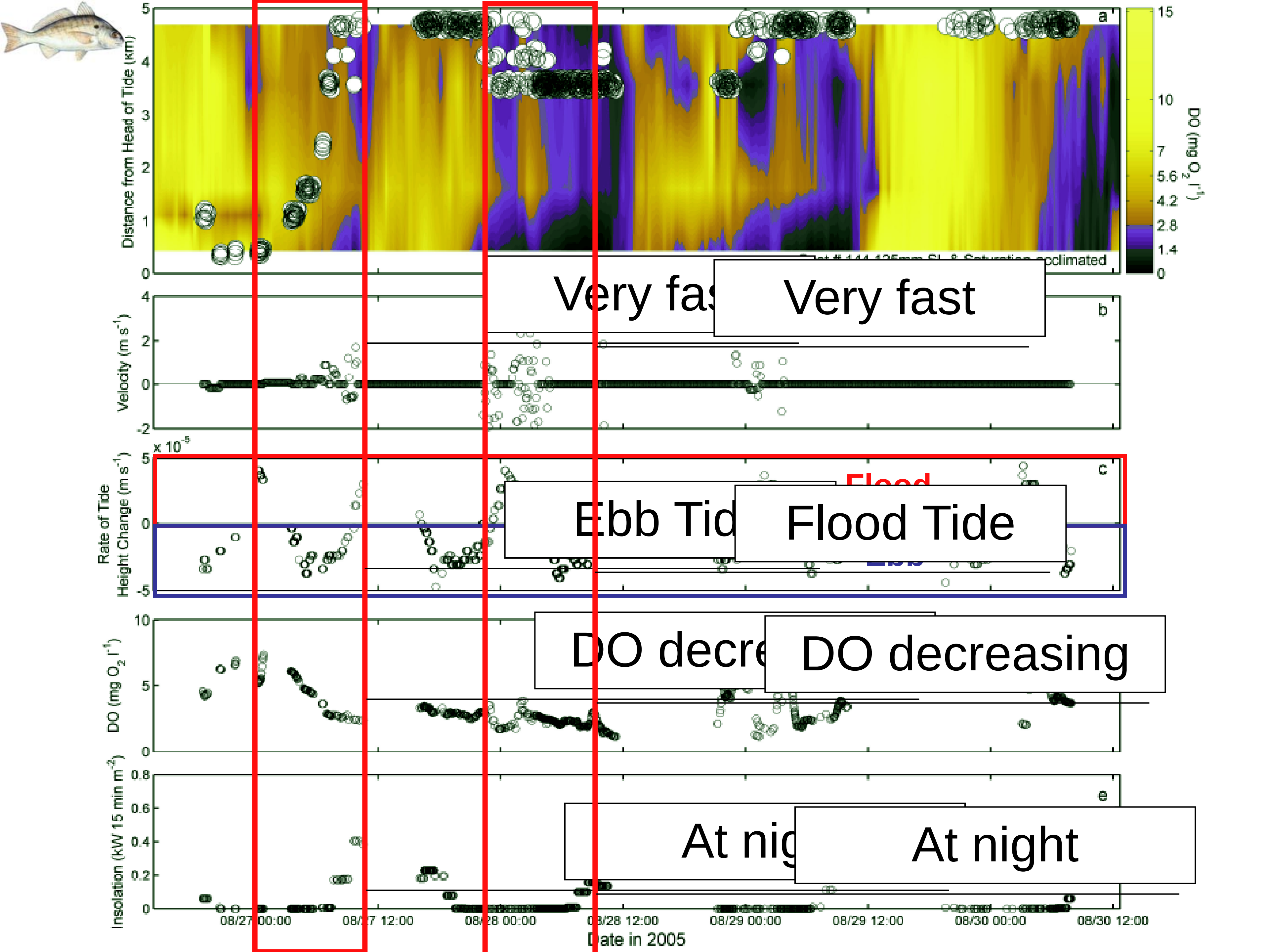




a
b
c
d
Distance from Head of Tide (km)
DO (mg O2 l-1)
13
10
7
5.6
4.2
2.8
1.4
0
Insolation (kW hr m-2)
4.102
2.878
3.683
4.954
2.473
3.559
5.296
Precipitation (mm)
Wind speed (m s-1)
08/26
08/27
08/28
08/29
08/30
08/31
09/01
09/02
Date in 2005

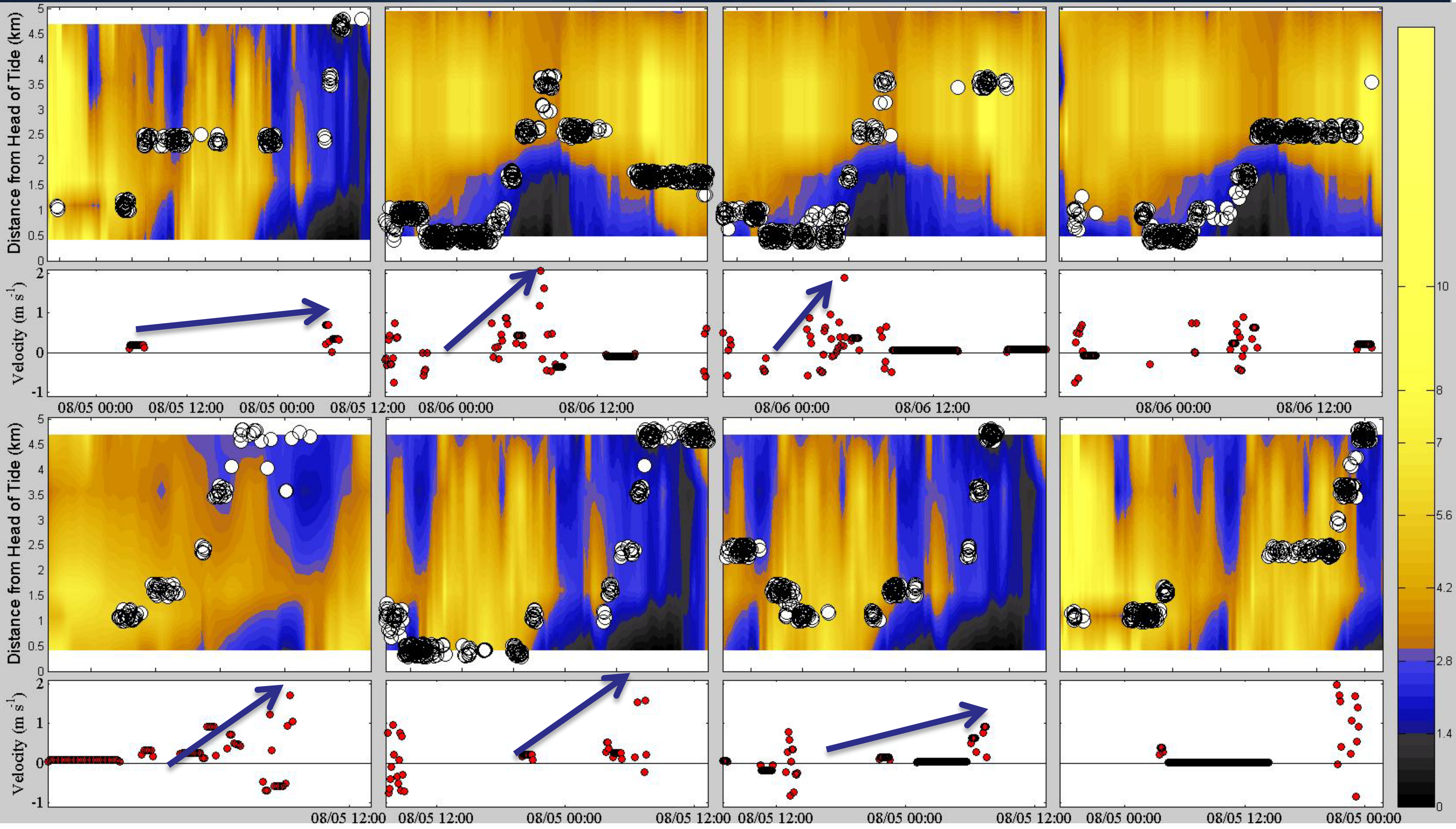


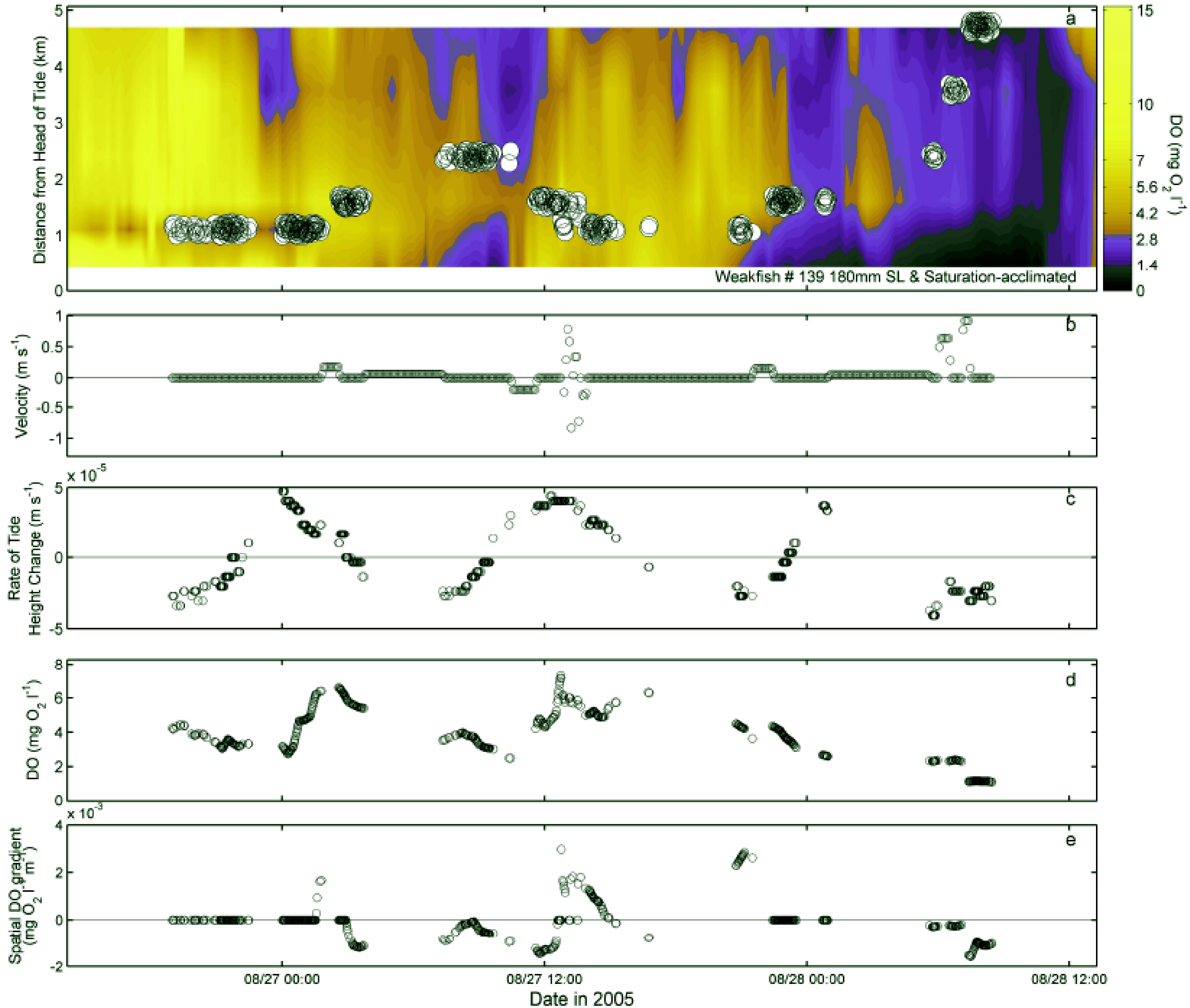

Brady and Targett 2010

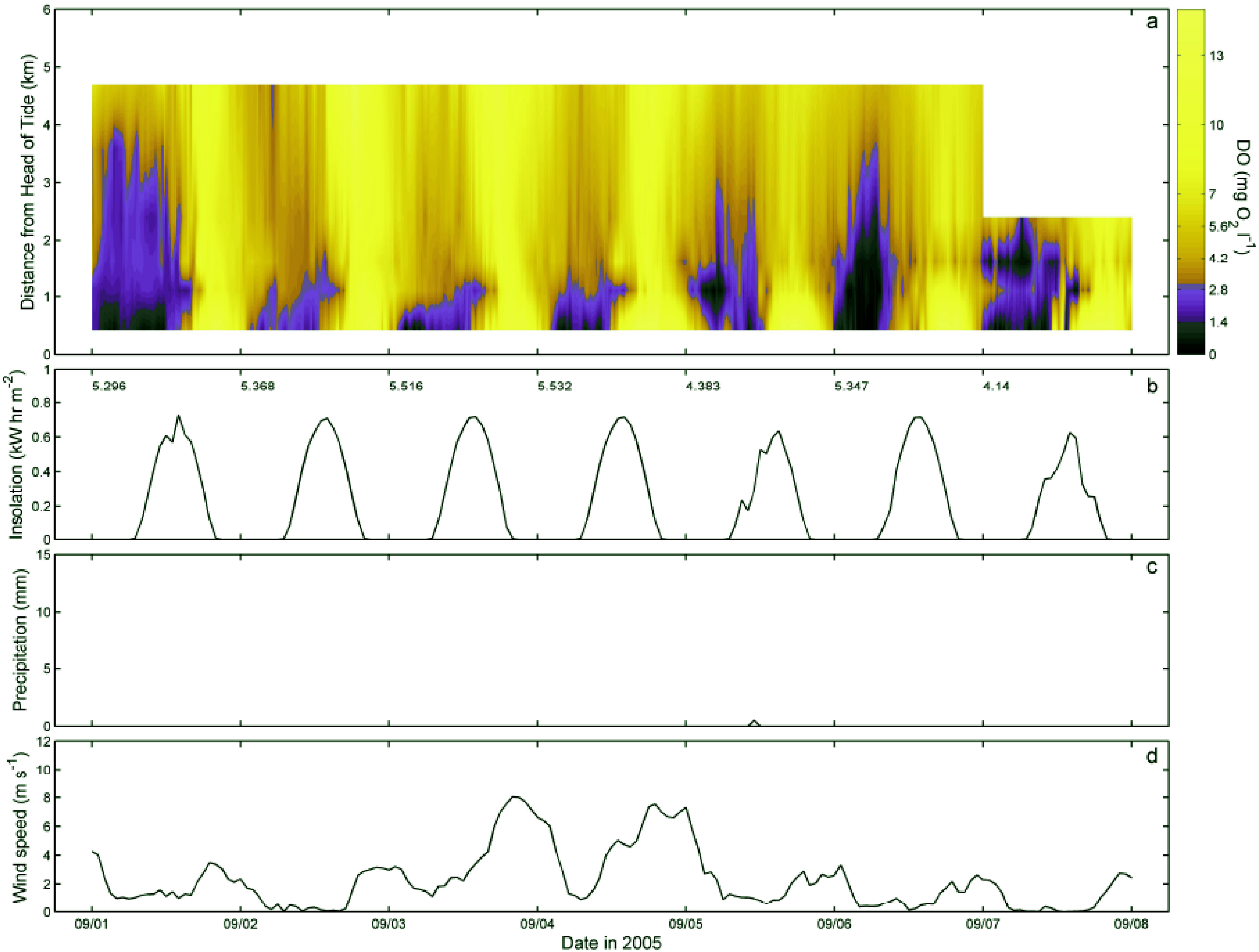


a
b
c
e
Distance from Head of Tide (km)
DO (mg O2 l-1)
Velocity (m s-1)
Rate of Tide Height Change (m s-1)
x 10-5
DO (mg O2 l-1)
Insolation (kW 15 min m-2)
Very fast
Very fast
Ebb Tide
Flood Tide
Flood
Ebb
DO decreasing
DO decreasing
At night
At night
08/27 00:00
08/27 12:00
08/28 00:00
08/28 12:00
08/29 00:00
08/29 12:00
08/30 00:00
08/30 12:00
Date in 2005

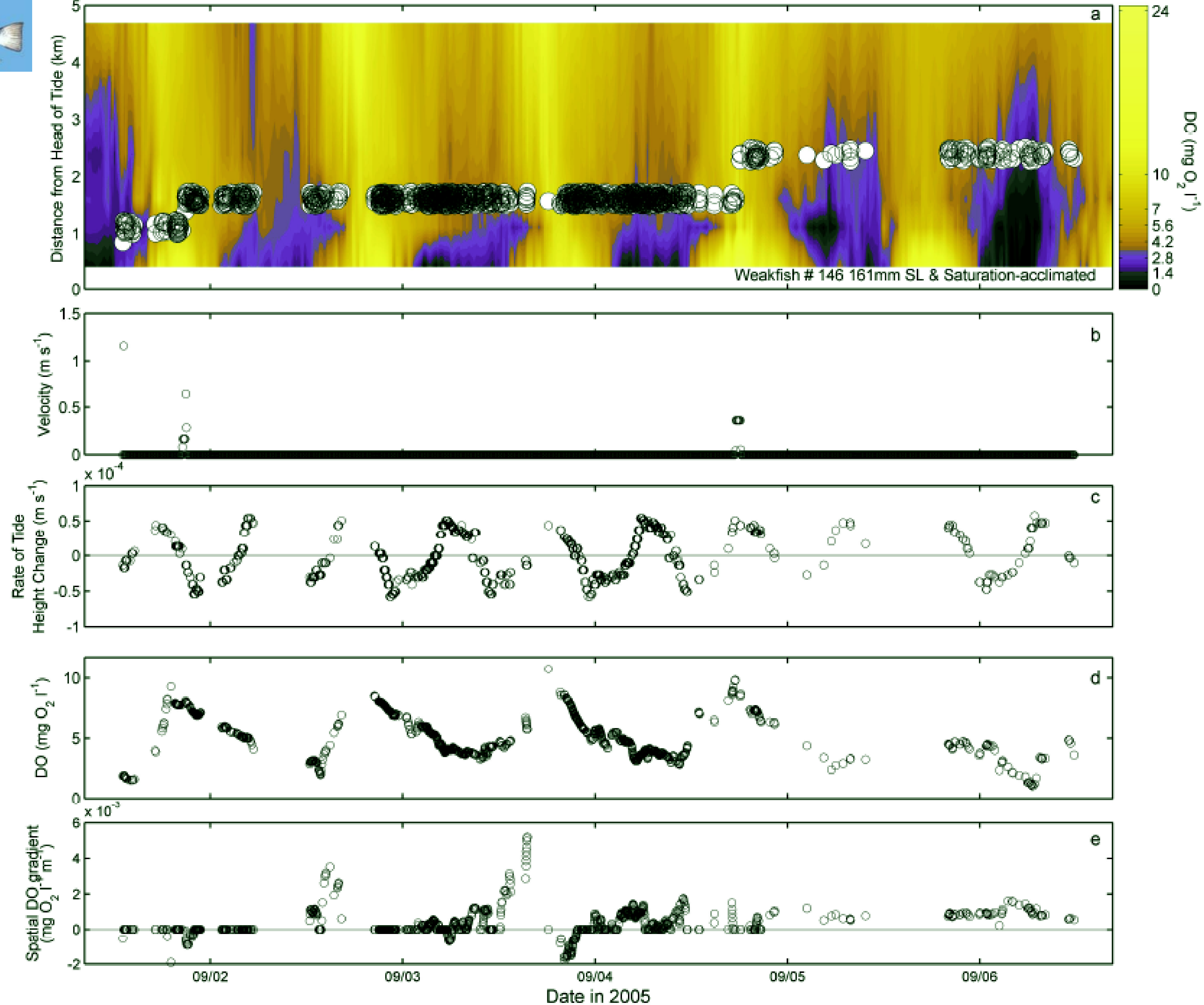
# Speed of Avoidance




Distance from Head of Tide (km)
DO (mg O$_2$ l$^{-1}$)
15
10
7
5.6
4.2
2.8
1.4
0
a
Weakfish # 139 180mm SL & Saturation-acclimated
b
Velocity (m s$^{-1}$)
c
x 10$^{-5}$
Rate of Tide Height Change (m s$^{-1}$)
d
DO (mg O$_2$ l$^{-1}$)
e
x 10$^{-3}$
Spatial DO gradient (mg O$_2$ l$^{-1}$ m$^{-1}$)
08/27 00:00
08/27 12:00
08/28 00:00
08/28 12:00
Date in 2005

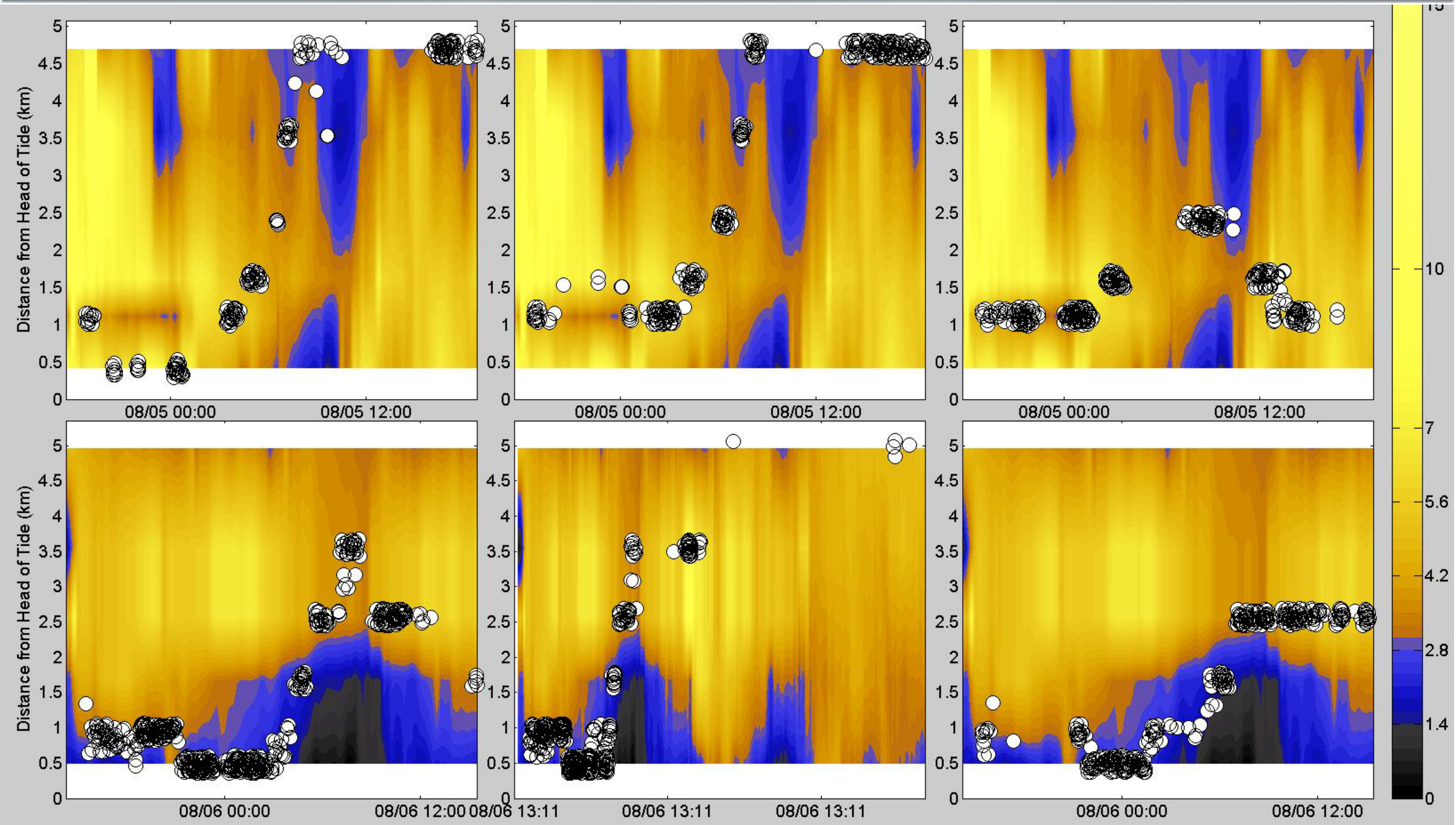


a
b
c
d
Distance from Head of Tide (km)
DO (mg O2 l-1)
0
1.4
2.8
4.2
5.6
7
10
13
5.296
5.368
5.516
5.532
4.383
5.347
4.14
Insolation (kW hr m-2)
Precipitation (mm)
Wind speed (m s-1)
09/01
09/02
09/03
09/04
09/05
09/06
09/07
09/08
Date in 2005

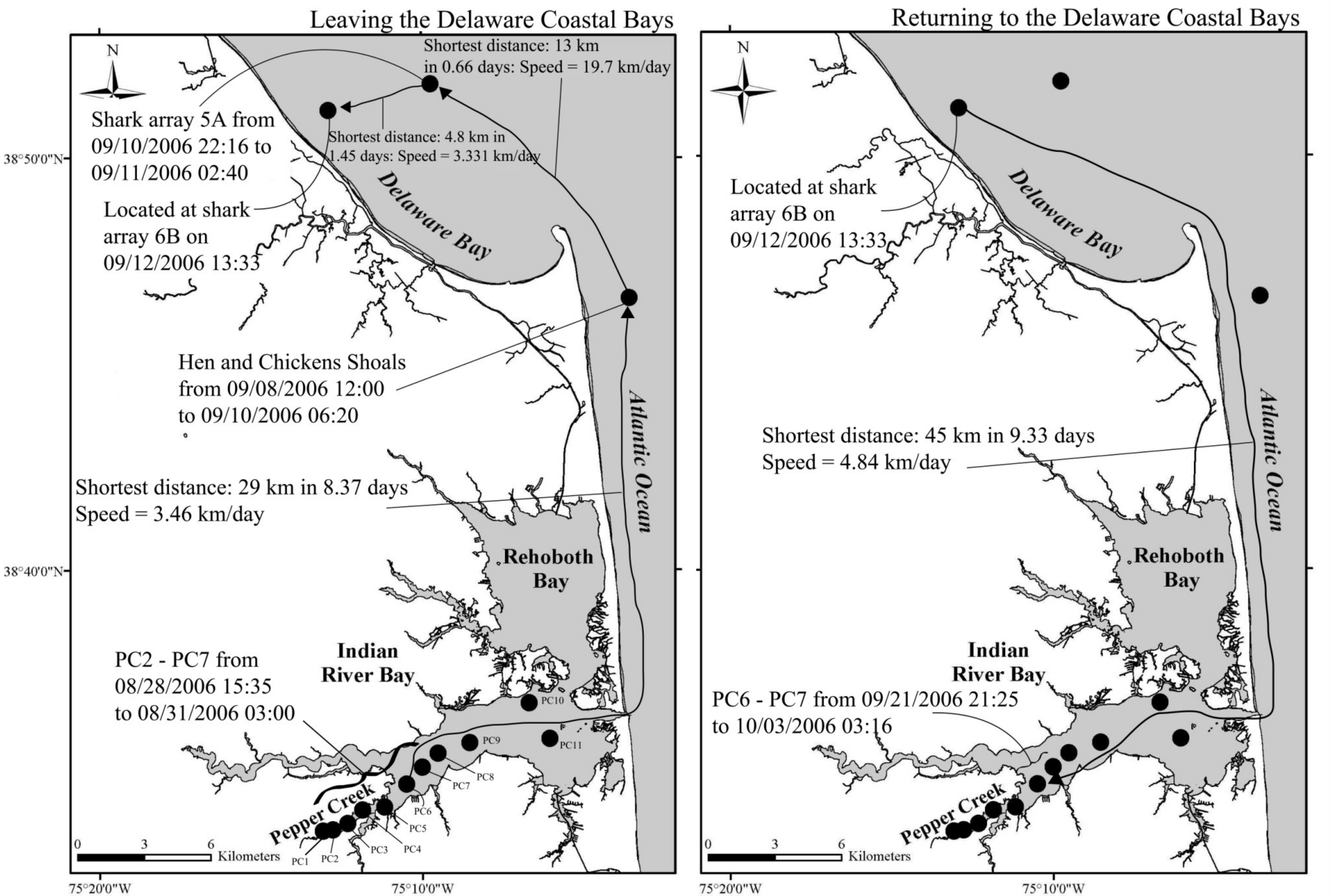


a
Distance from Head of Tide (km)
DO (mg O2 l-1)
24
10
7
5.6
4.2
2.8
1.4
0
Weakfish # 146 161mm SL & Saturation-acclimated
b
Velocity (m s-1)
c
x 10-4
Rate of Tide Height Change (m s-1)
d
DO (mg O2 l-1)
e
x 10-3
Spatial DO gradient (mg O2 l-1 m-1)
09/02
09/03
09/04
09/05
09/06
Date in 2005

# Hypoxia-Acclimation



# A Long Strange Trip...



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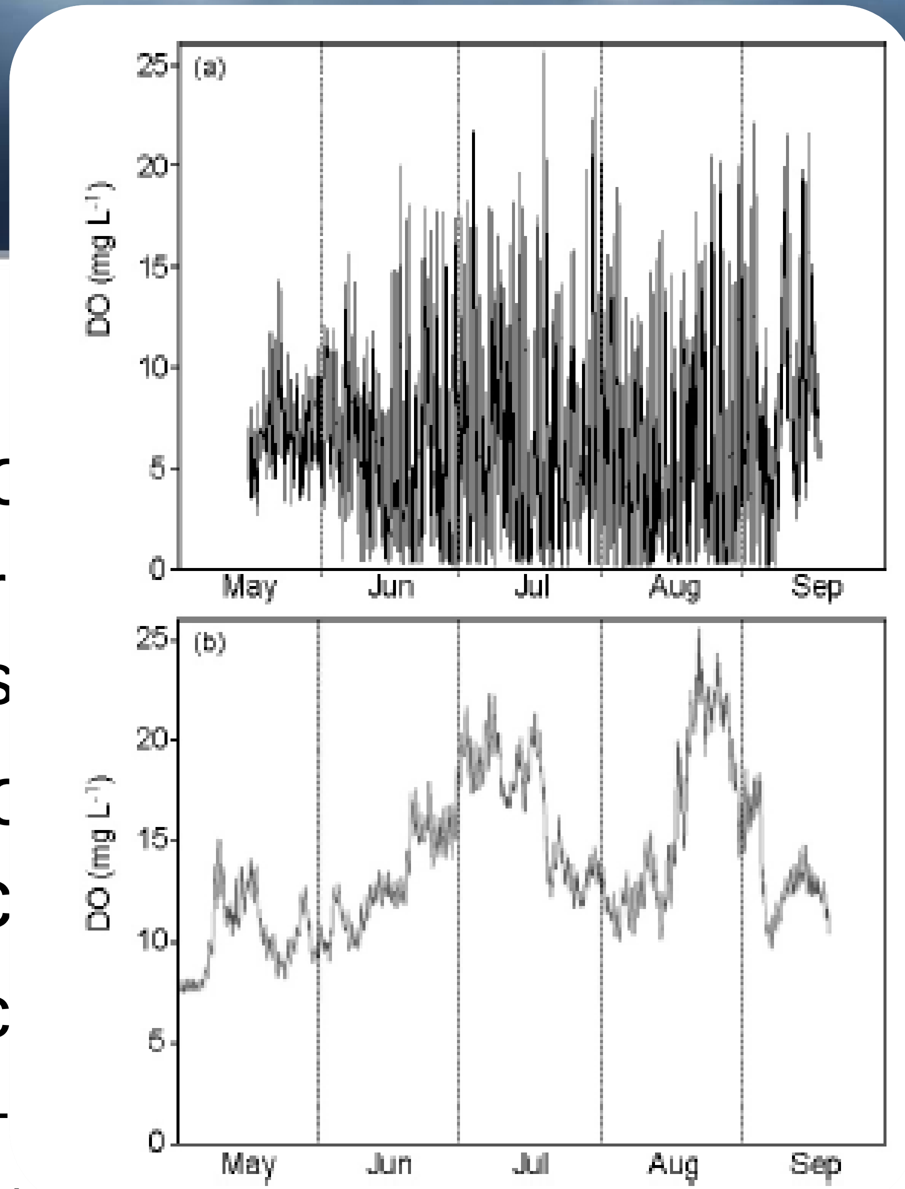
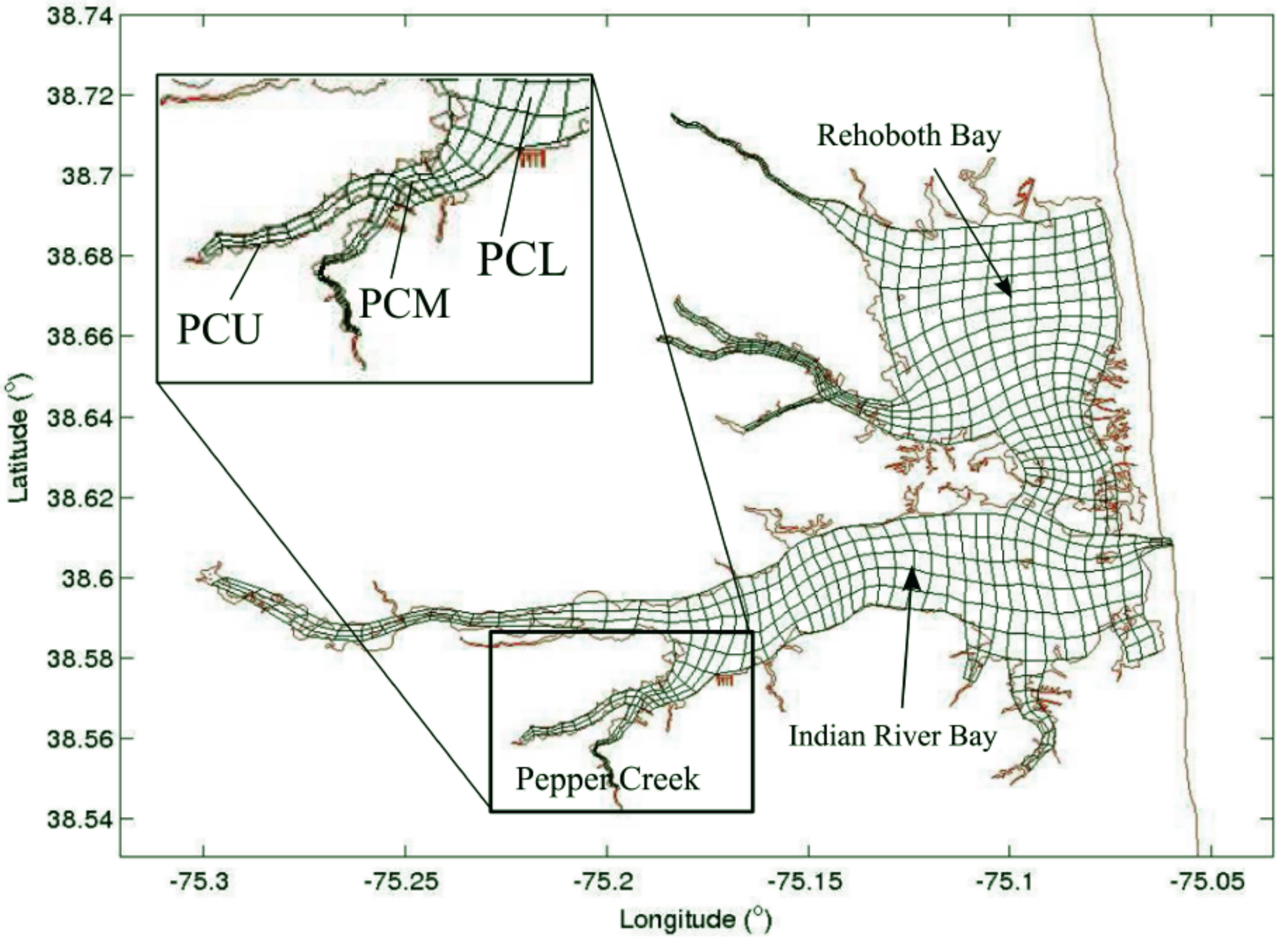
# Models

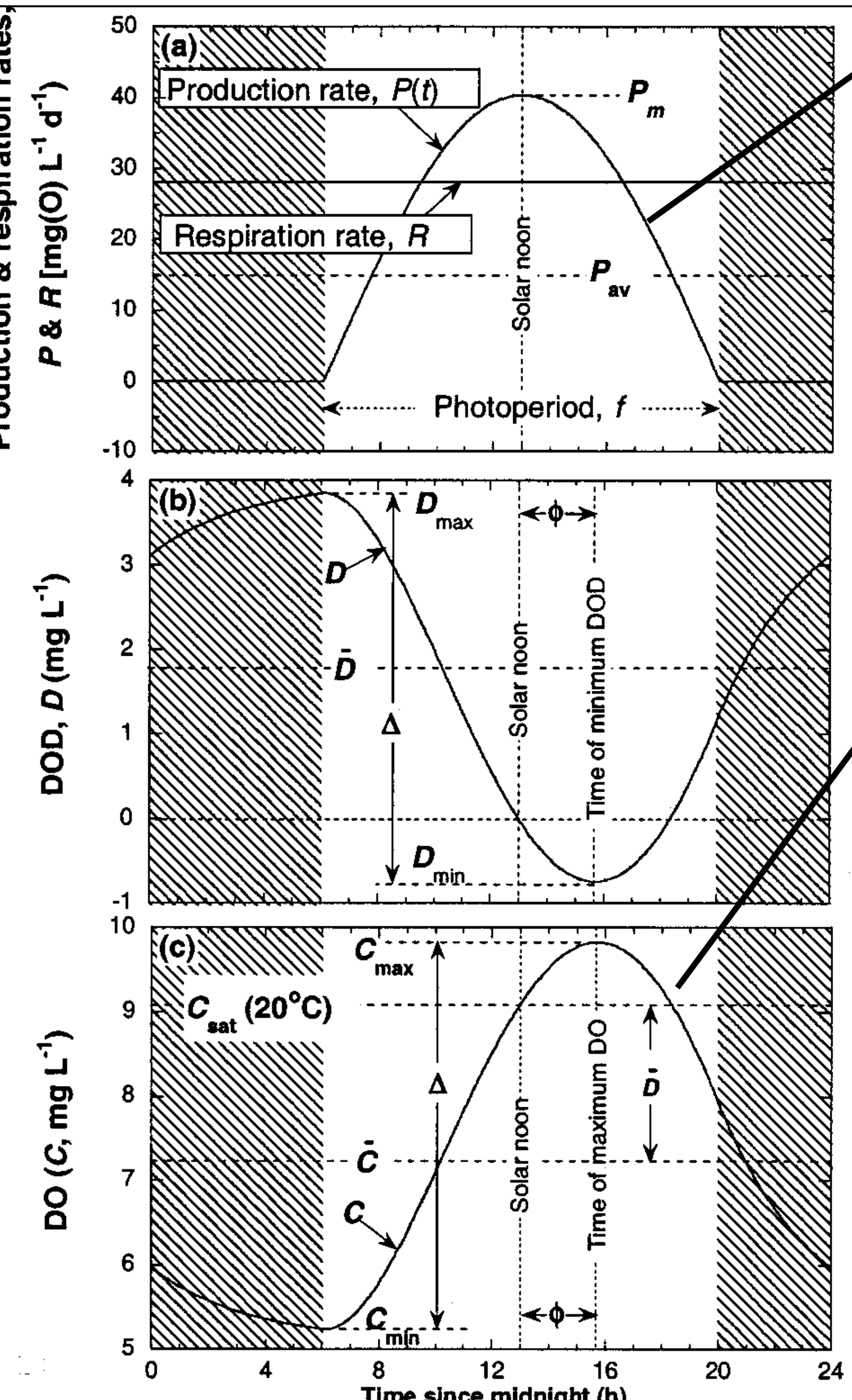
- ECOMSED/ROMS – fully integrated three-dimensional hydrodynamic model
  - Tide, freshwater discharge, wind stress, and water surface heat exchange
- RCA (Row Column AESOP (Advanced Ecological Systems Operating Program))
  - Production – Respiration
    - DO – Photosynthesis, respiration, reaeration
  - Full Eutrophication Kinetics

- ECOMS … ated three-dimensio … el
  - Tide, fr … tress, and water s
- RCA (Ro … vanced Ecologic … rogram))
  - Produc
    - DO – … eration
  - Full Eutrophication Kinetics



# ECOMSED Model Domain






$$I_{surf}(t) = \frac{\pi I_{tot}}{2f} \sin\left[\frac{\pi\left(t_d - t_{sunrise}\right)}{f}\right]$$

$$I_0(H) = I_{surf}\exp\left(-k_e H\right)$$

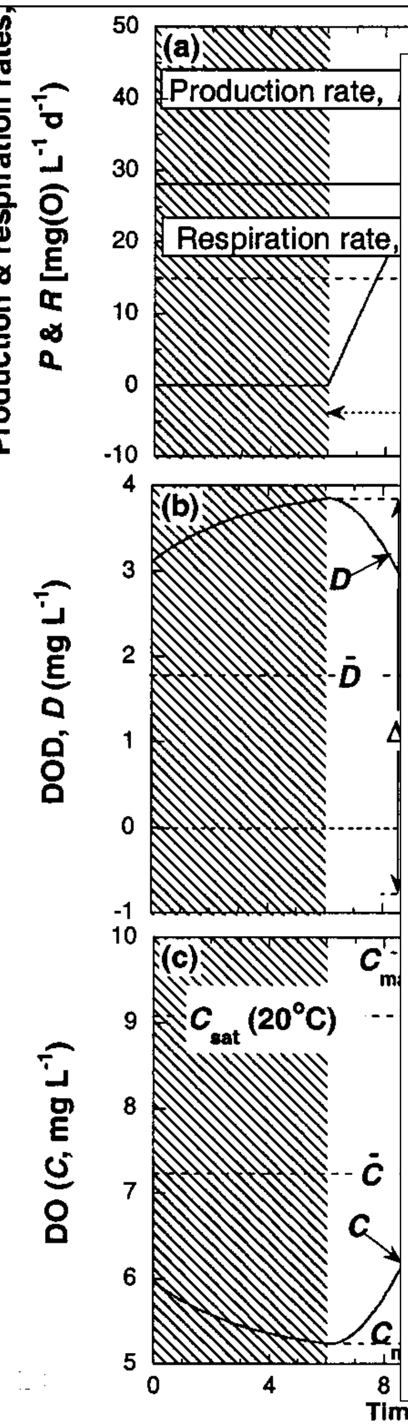
$$G_I(I) = \frac{e}{k_e H}\left[\exp\left(\frac{-I_0(t)}{I_s}e^{-k_e H}\right) - \exp\left(\frac{-I_0(t)}{I_s}\right)\right]$$

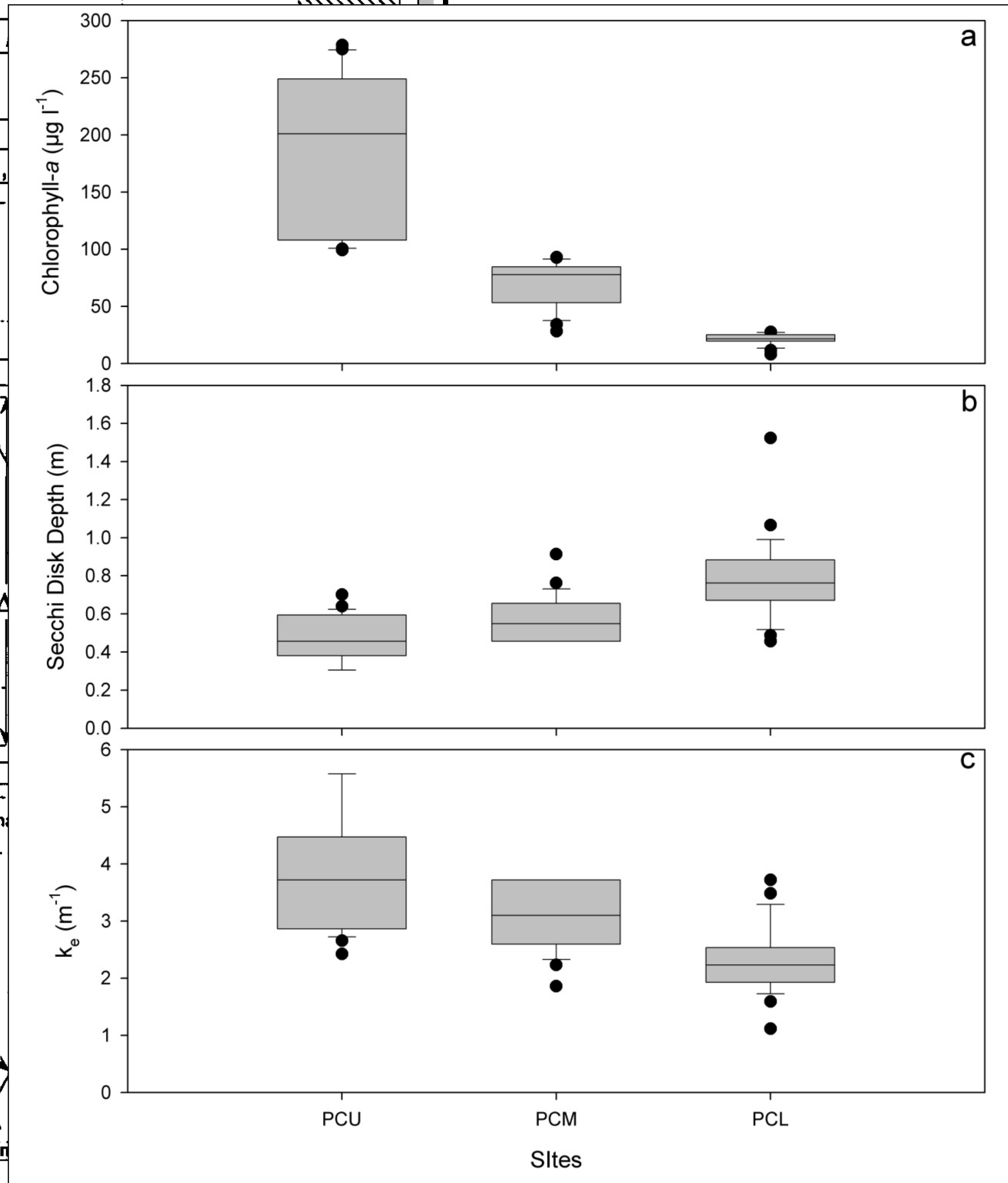
$$P = P_m \theta_{P,T}^{T-20} G_I$$

$$R = R_T \theta_{R,T}^{T-20}$$

$$Re = k_a \theta_{Re,T}^{T-20}\left(O_s - O\right)$$

from Chapra and Di Toro 1991
and McBride and Chapra 2005




$$t_d - t_{sunrise}) \over f$$

$$(-k_e H)$$

$$- \exp\left(\frac{-I_0(t)}{I_s}\right)\Big]$$

$$^{20} G_I$$

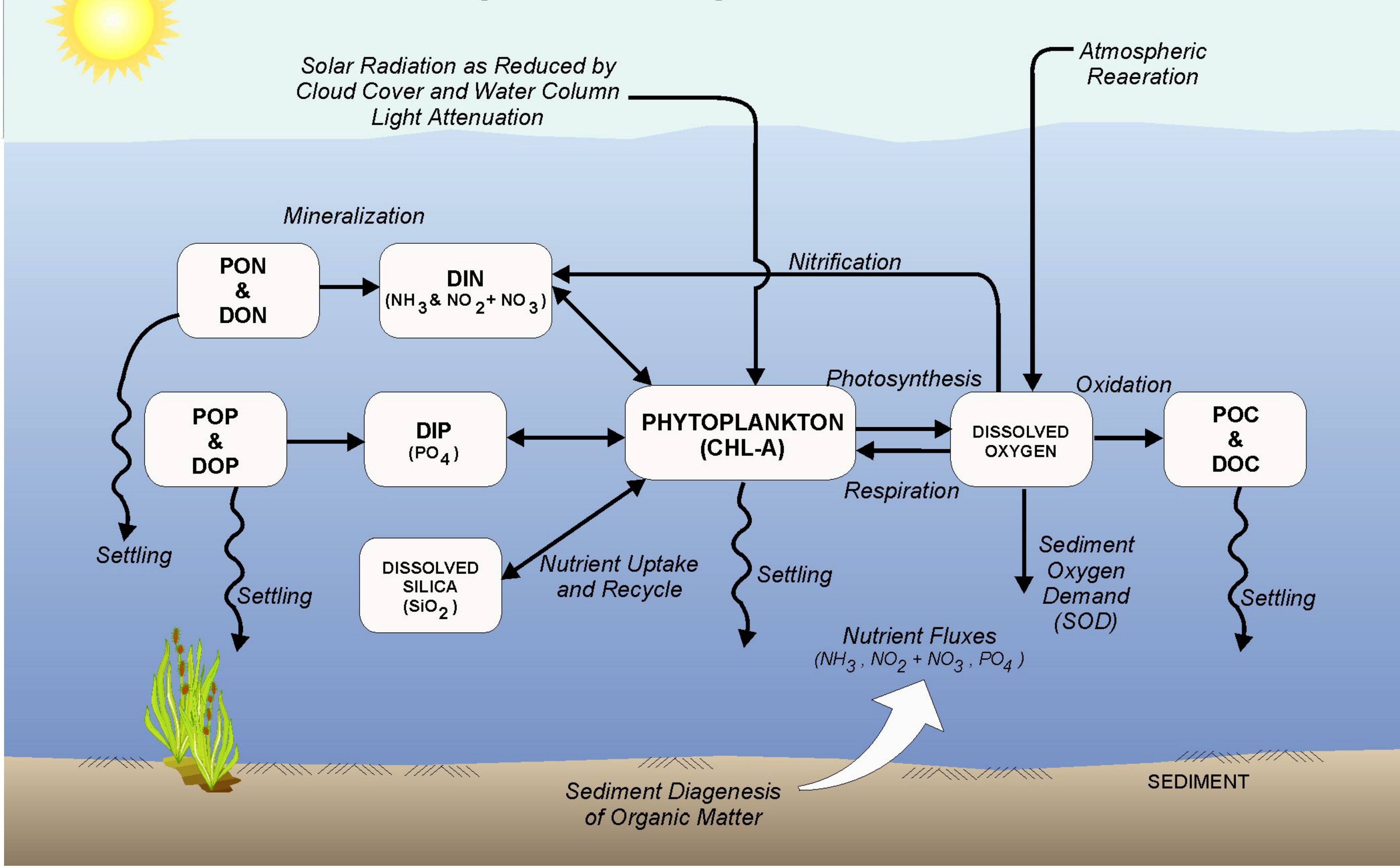
$$T-20$$

$$,T$$

$$O_s - O)$$

hapra and Di Toro 1991
and McBride and Chapra 2005

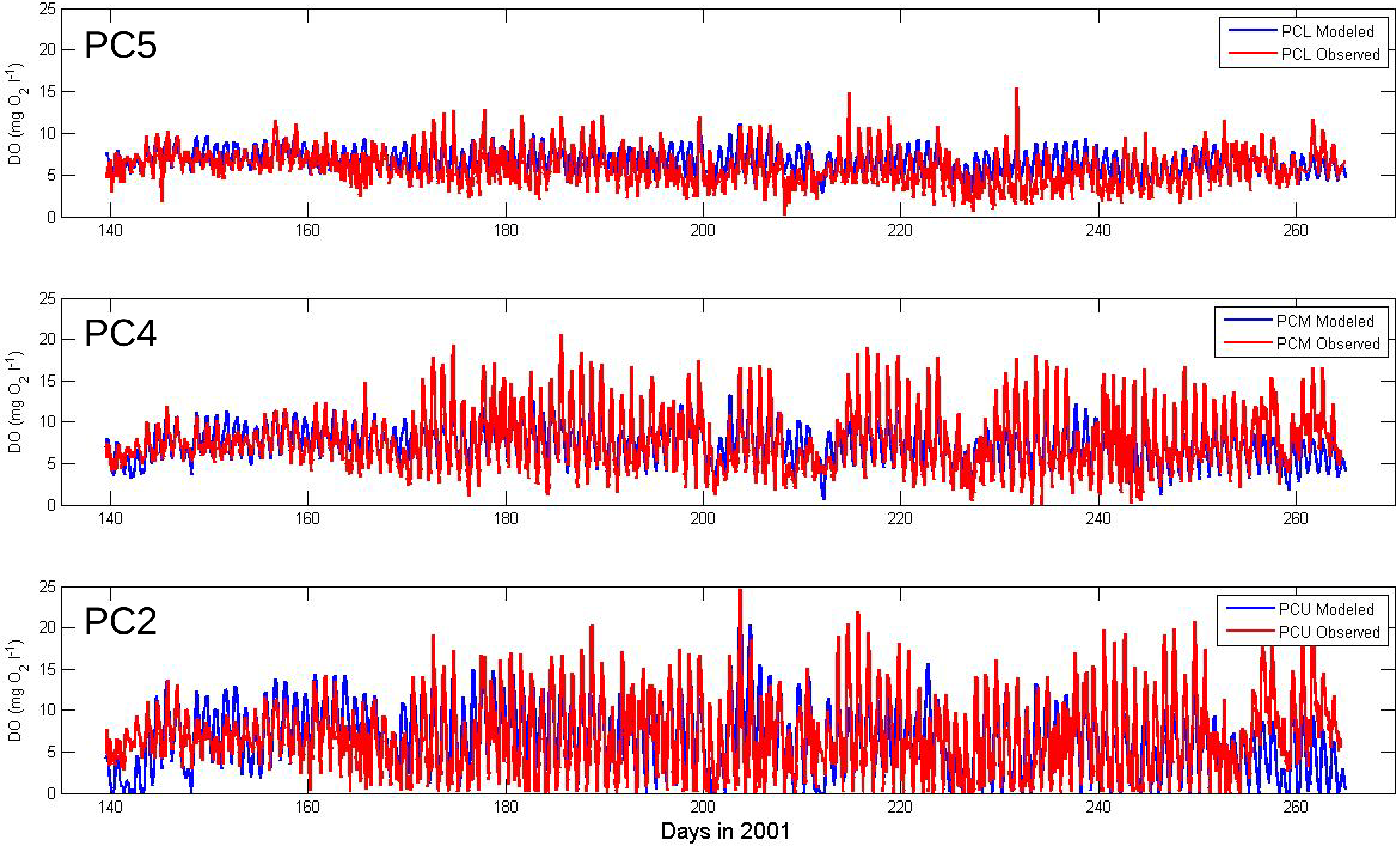
# Water Quality Model Phytoplankton Kinetics



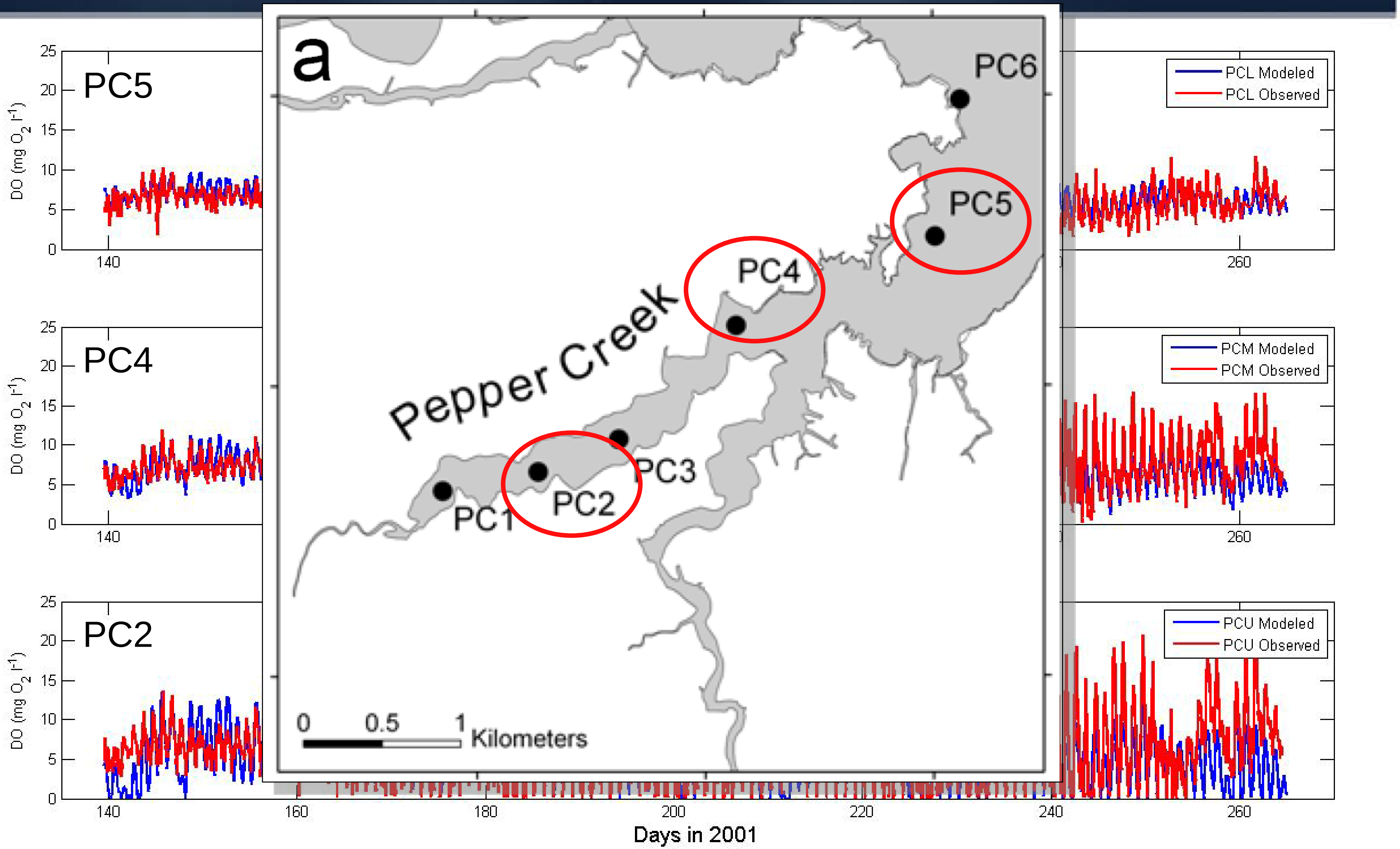
State variables used in the eutrophication model.

| Number | System | Number | System |
|---|---|---|---|
| 1 | Salinity | 13 | Ammonia |
| 2 | Phytoplankton – diatoms | 14 | Nitrate + Nitrate |
| 3 | Phytoplankton – summer groups | 15 | Biogenic Silica |
| 4 | Particulate Organic Phosphorus – refractory | 16 | Dissolved Silica |
| 5 | Particulate Organic Phosphorus – labile | 17 | Particulate Organic Carbon – refractory |
| 6 | Dissolved Organic Phosphorus – refractory | 18 | Particulate Organic Carbon – labile |
| 7 | Dissolved Organic Phosphorus – labile | 19 | Dissolved Organic Carbon – refractory |
| 8 | Inorganic Dissolved Phosphorus | 20 | Dissolved Organic Carbon – labile |
| 9 | Particulate Organic Nitrogen – refractory | 21 | Dissolved Organic Carbon – reactive |
| 10 | Particulate Organic Nitrogen – labile | 22 | Dissolved Organic Carbon – algal exudate |
| 11 | Dissolved Organic Nitrogen – refractory | 23 | Dissolved Sulfide |
| 12 | Dissolved Organic Nitrogen – labile | 24 | Dissolved Oxygen |

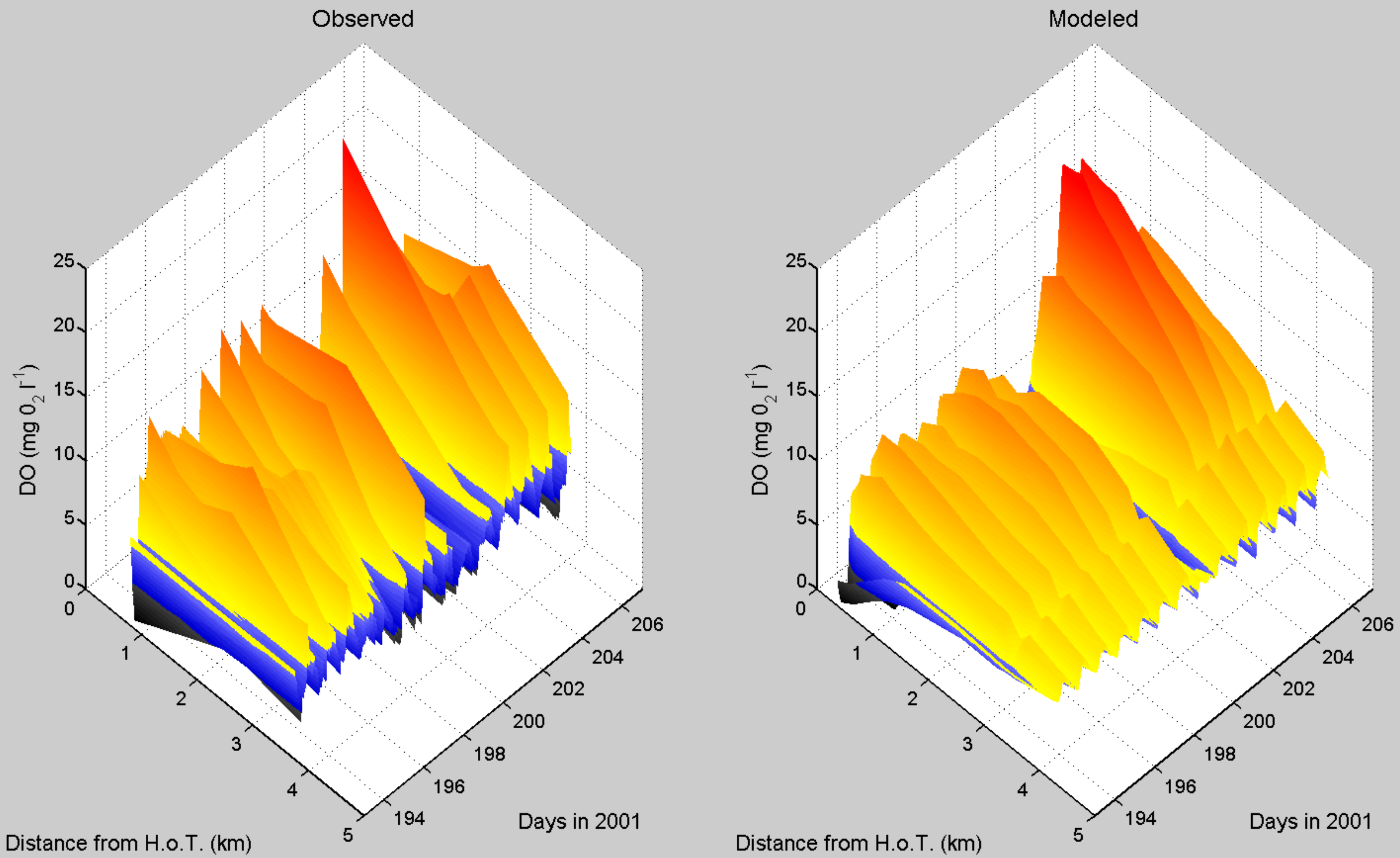
# Model Performance



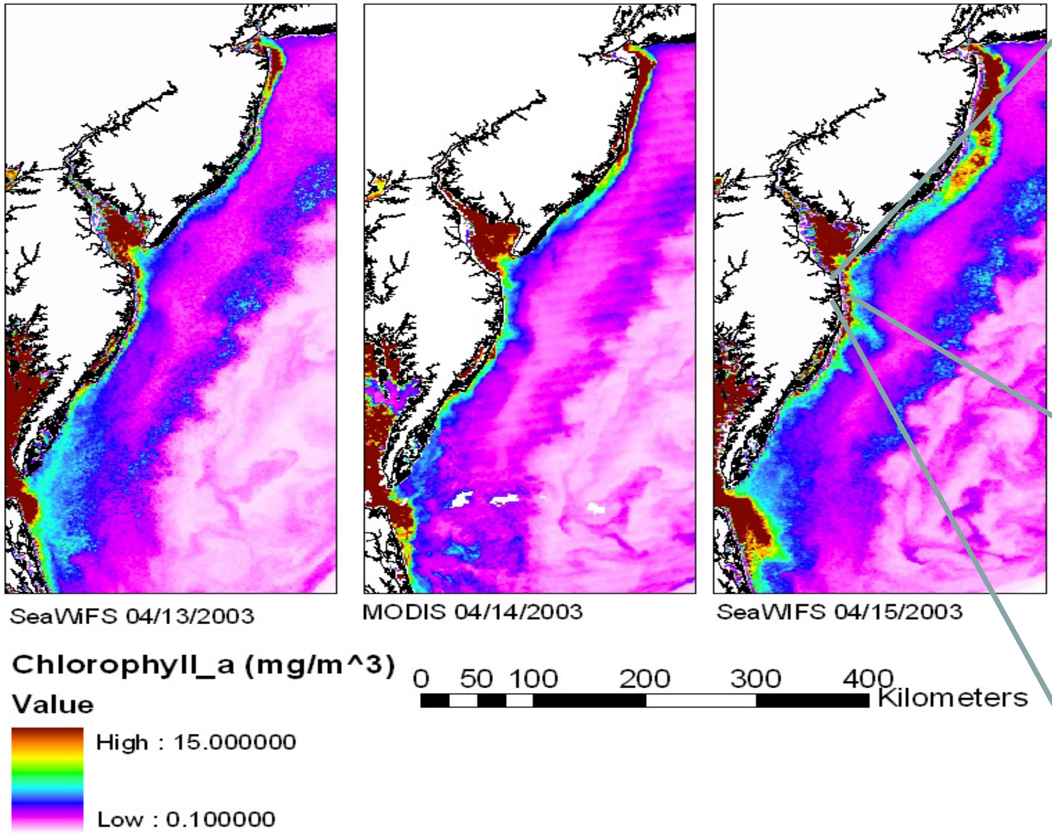
# Model Performance



# Model vs Observed



# NASA EPSCoR




Sea Surface Temperature, CHL and Land Use

Boundary Conditions Offshore

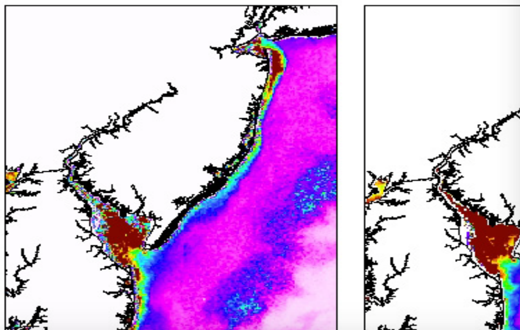
Phosphorus

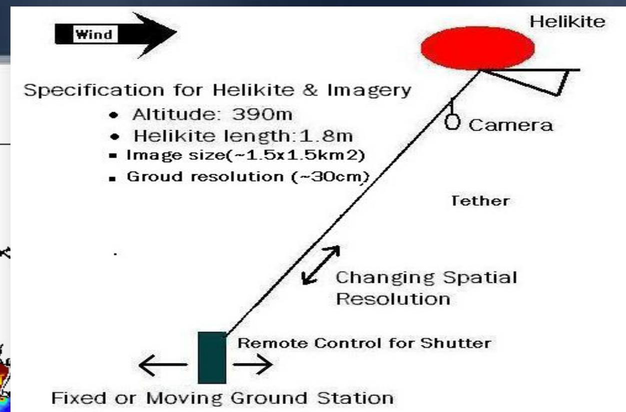
Feature Tracking

CHL

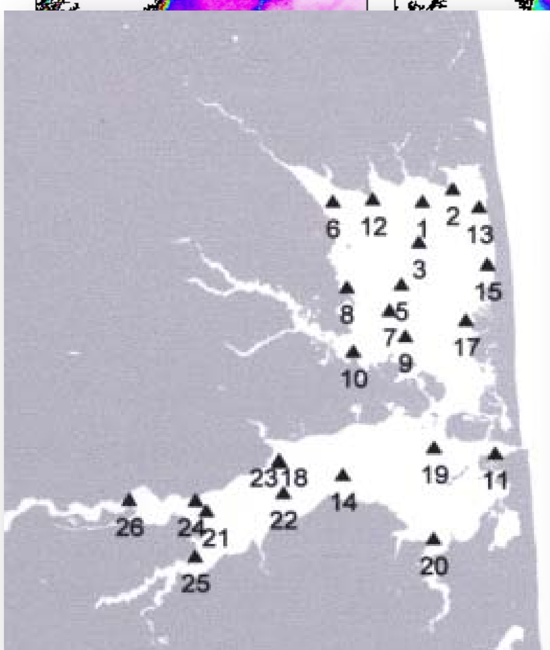
CHL

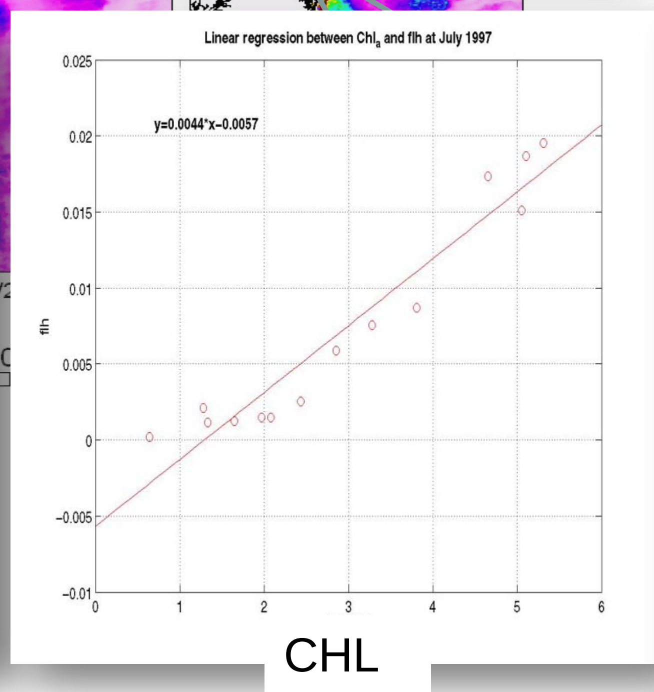
# NASA EPSCoR

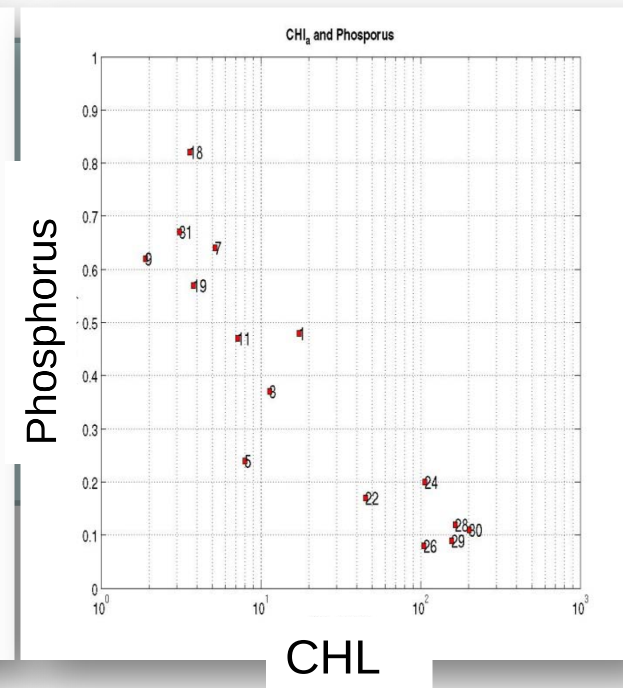


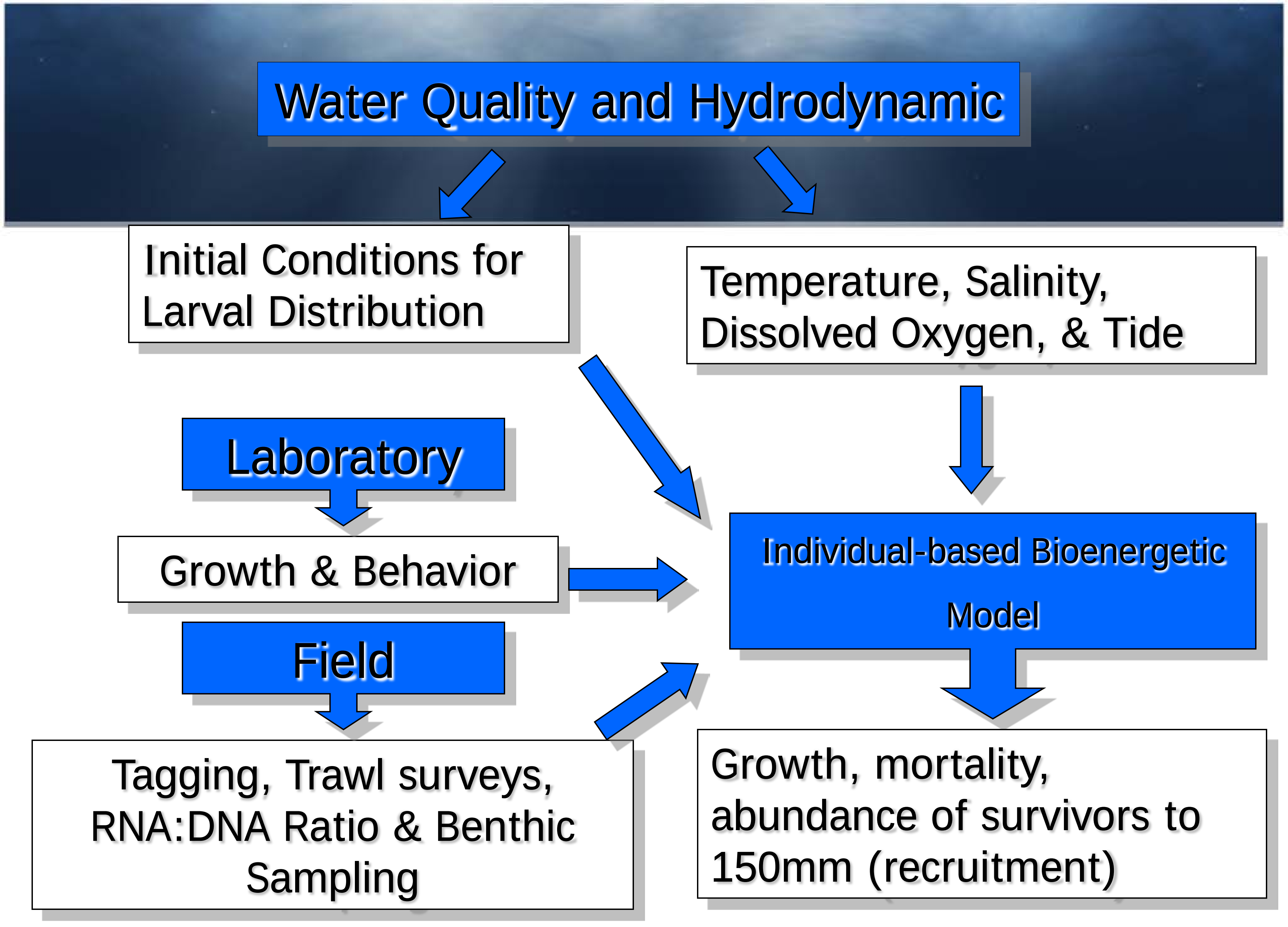


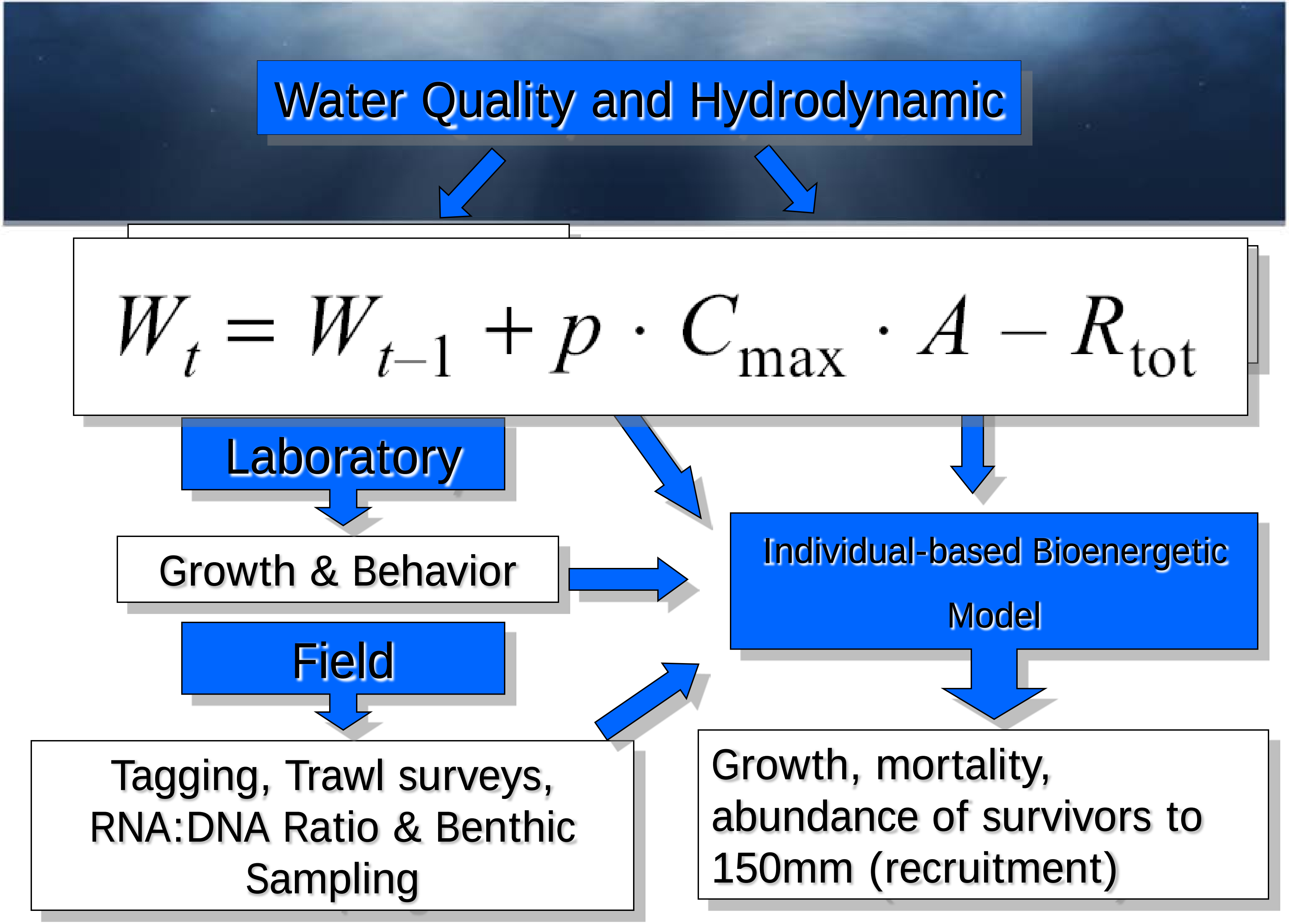

Sea Surface Temperature, CHL and Land Use



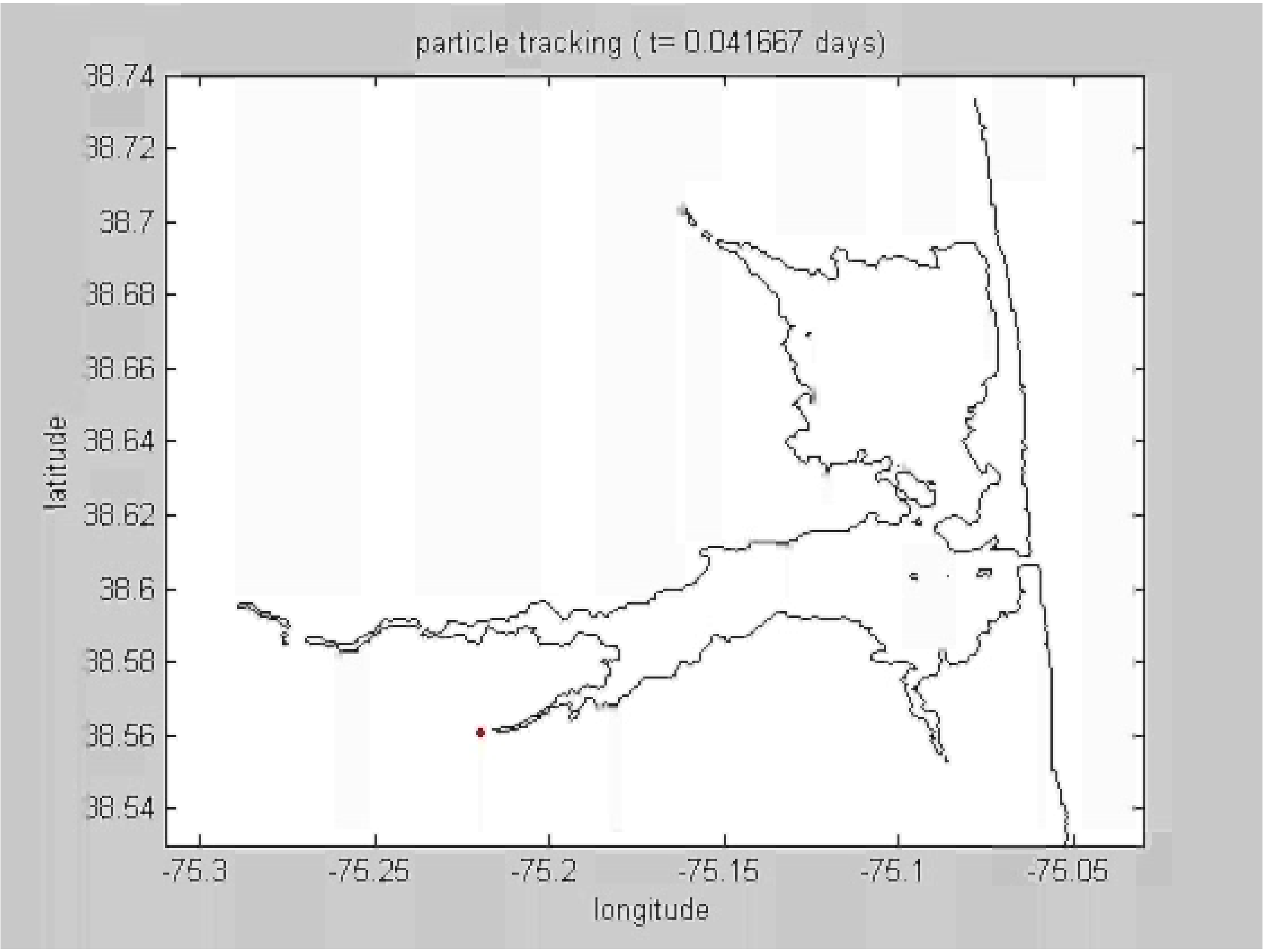



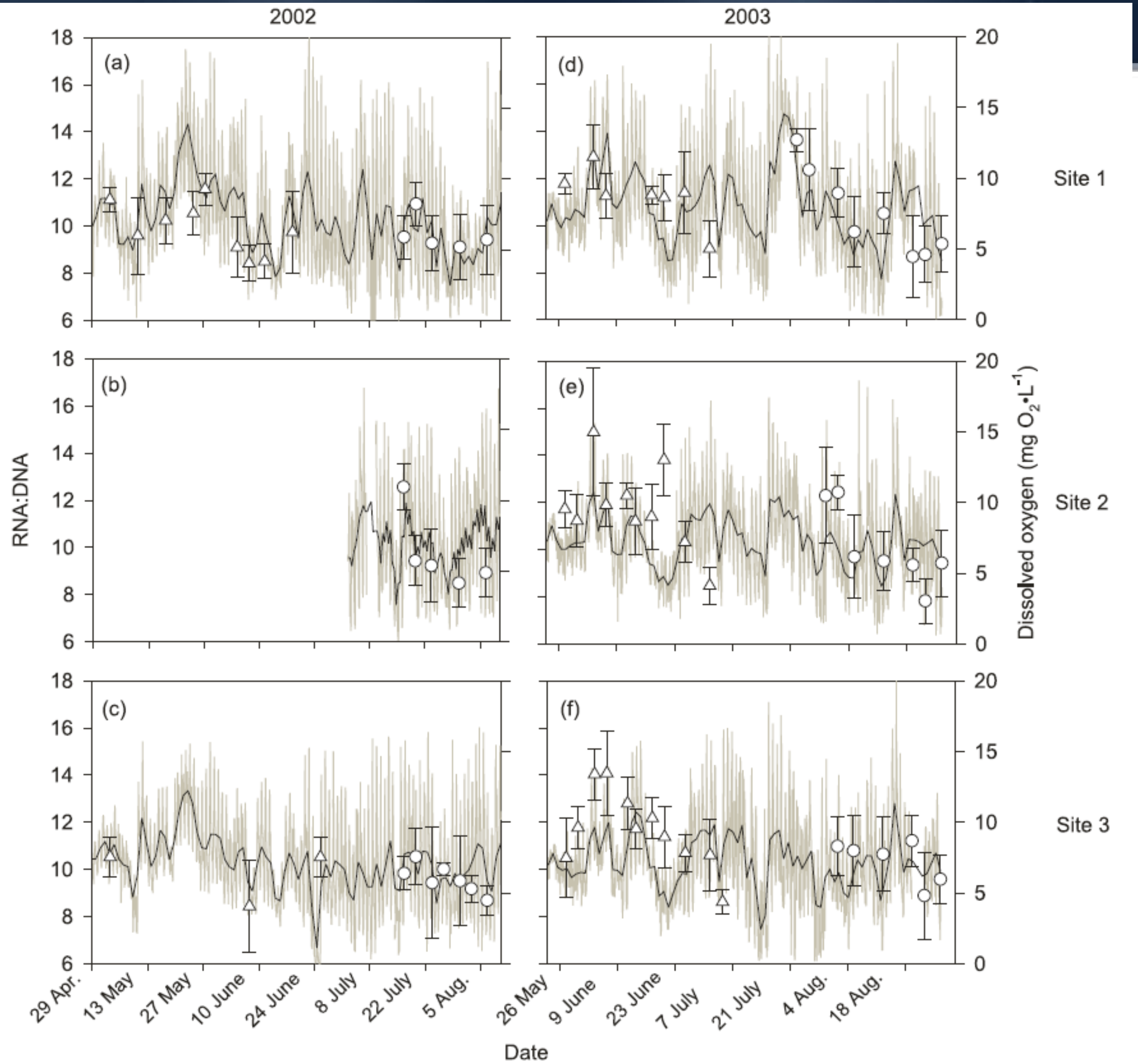

Water Quality and Hydrodynamic
Initial Conditions for Larval Distribution
Temperature, Salinity, Dissolved Oxygen, & Tide
Laboratory
Growth & Behavior
Field
Tagging, Trawl surveys, RNA:DNA Ratio & Benthic Sampling
Individual-based Bioenergetic Model
Growth, mortality, abundance of survivors to 150mm (recruitment)


Water Quality and Hydrodynamic
$W_t = W_{t-1} + p \cdot C_{\max} \cdot A - R_{\mathrm{tot}}$
Laboratory
Growth & Behavior
Field
Tagging, Trawl surveys, RNA:DNA Ratio & Benthic Sampling
Individual-based Bioenergetic Model
Growth, mortality, abundance of survivors to 150mm (recruitment)

# Particle Tracking

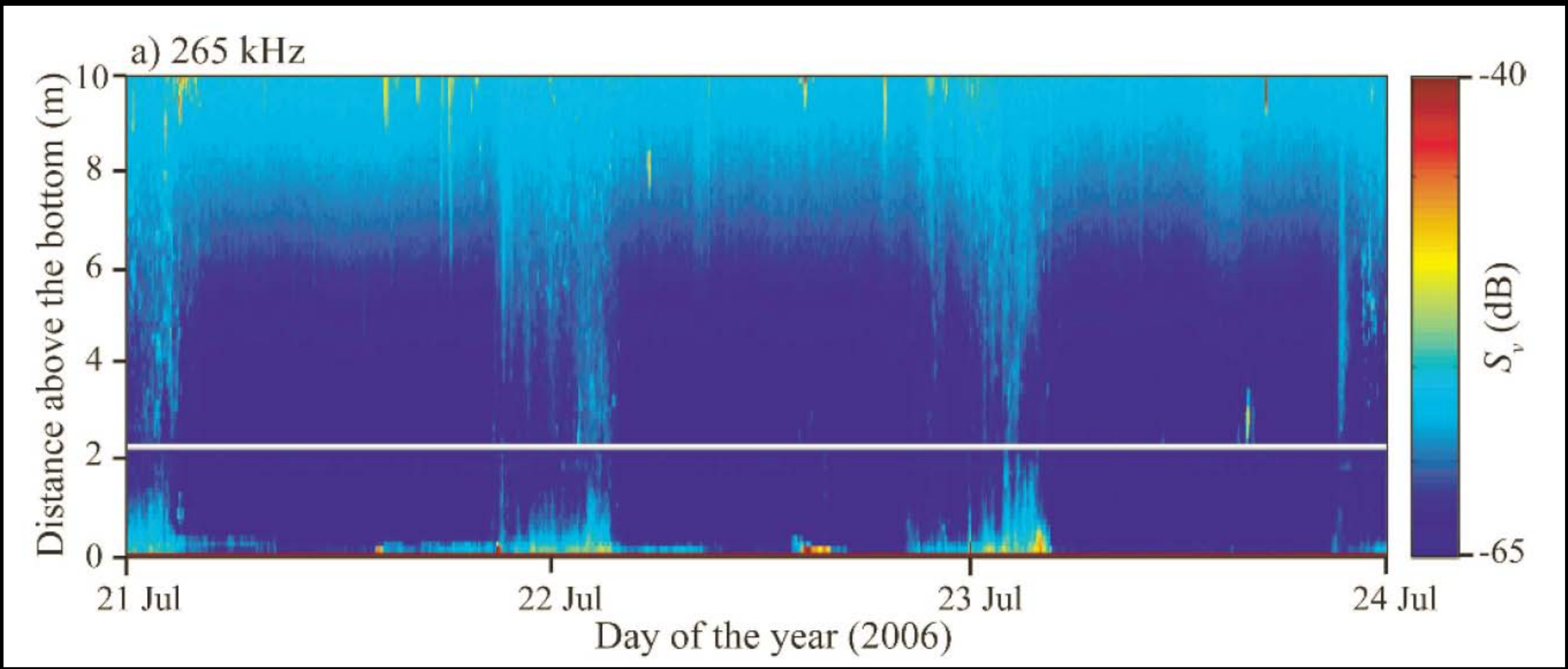


# Growth Rate Validation




From Stierhoff *et al* 2009

# Future Objectives




- 2 multifrequency echo sounders
- Monitor fish and benthos simultaneously

From Sato and Jumars 2008

# Acknowledgements

NCCOS
Center for Sponsored Coastal Ocean Research
Science Serving Coastal Communities

Sea Grant
Delaware

Sea Grant
National Sea Grant Office

NASA

NASA EPSCoR

Delaware EPSCoR

*Improving Delaware's environment and economy through research and education*