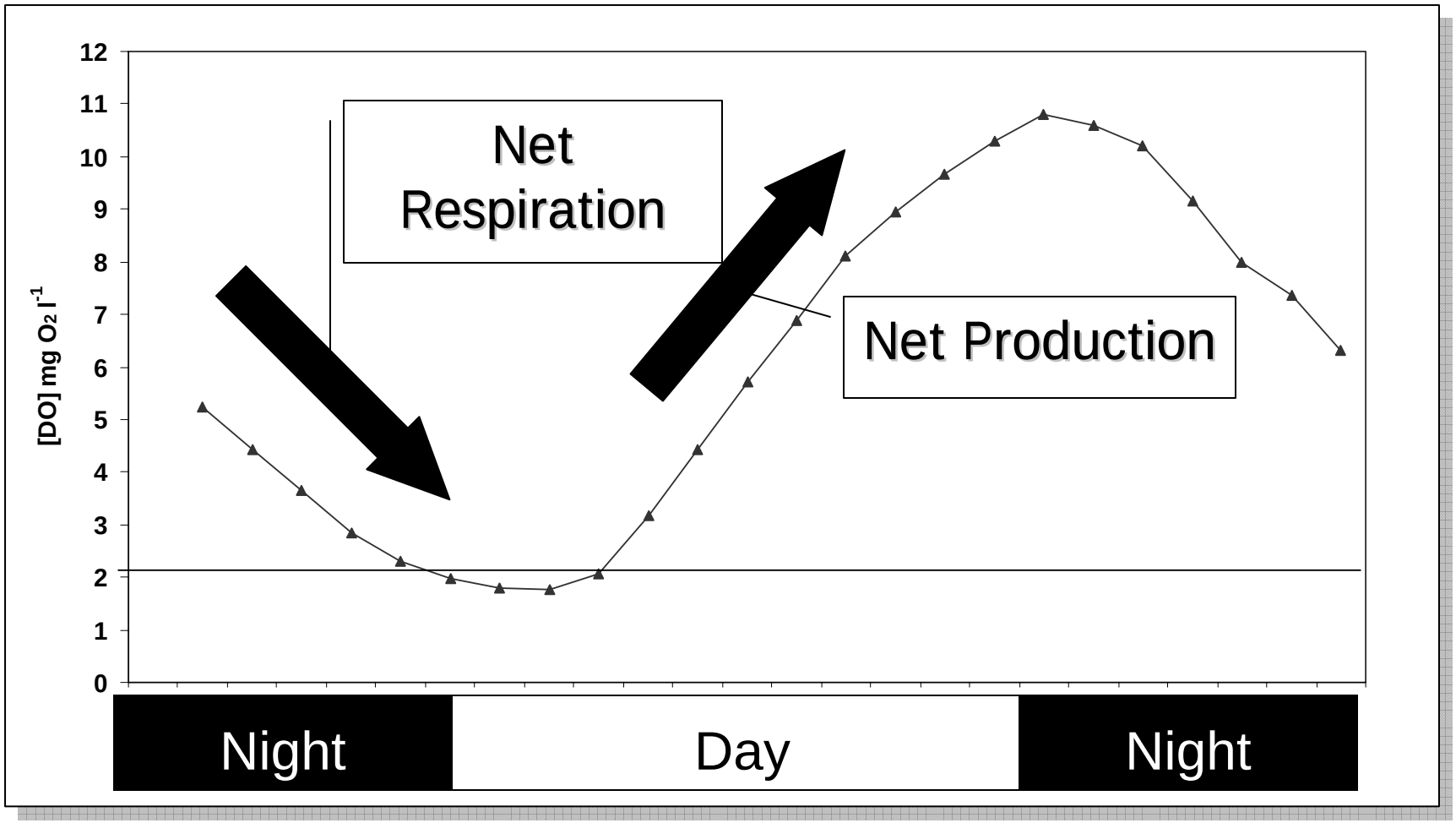
A How To Guide:
for Estuary-Dependent Fish Avoiding Hypoxia in Delaware's Inland Bays

Damian C. Brady
Timothy E.Targett
University of Delaware
Graduate College of Marine Studies

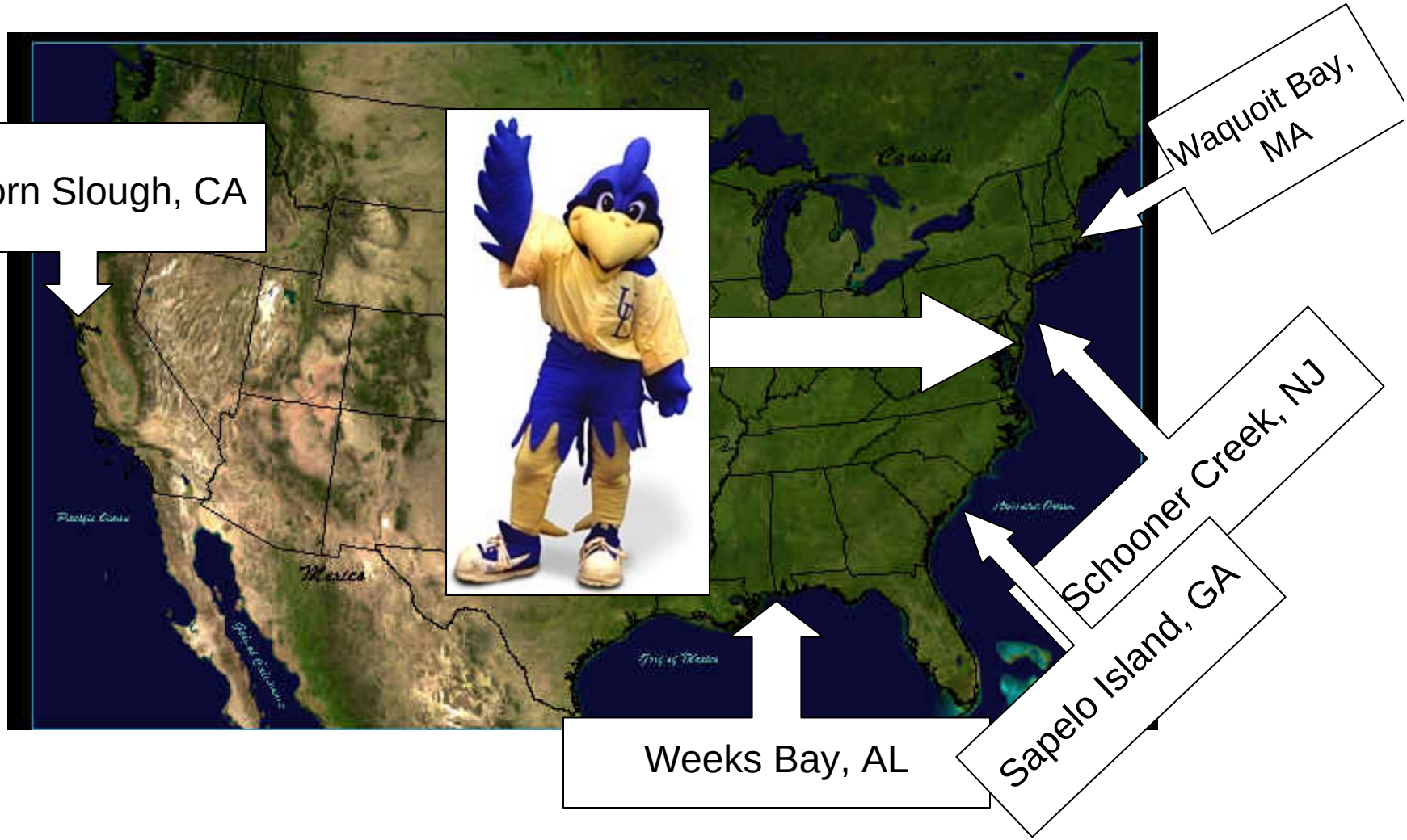
Outline

- Diel-cycling Hypoxia
  - Delaware's Inland Bays in particular
- What mechanisms do fish use to cope with hypoxia?
- Can we "see" these mechanisms in the field?
- What's next and what is the future for affected areas as nursery grounds?

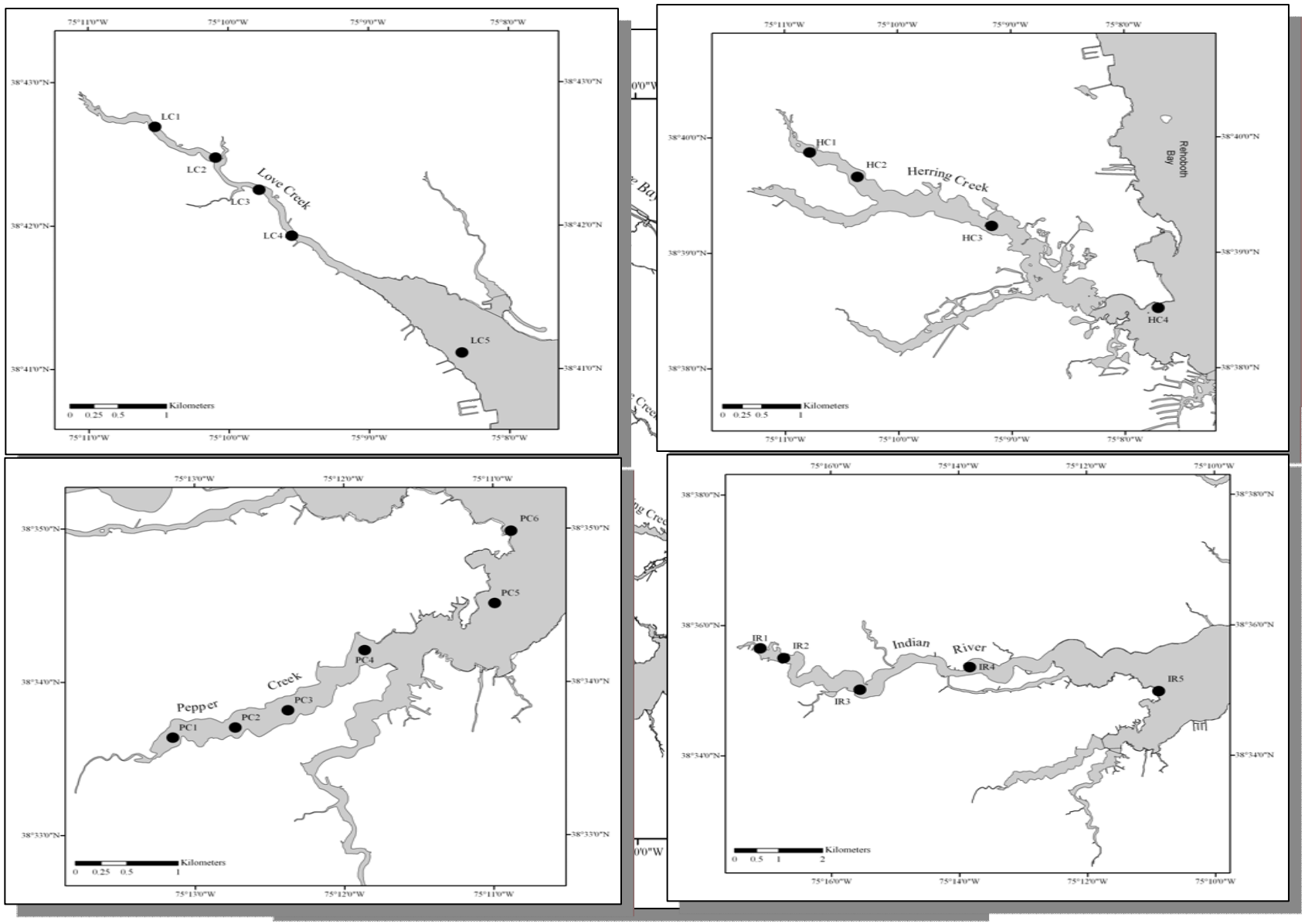
Diel-cycling Hypoxia



Increasingly Widespread



Study Area

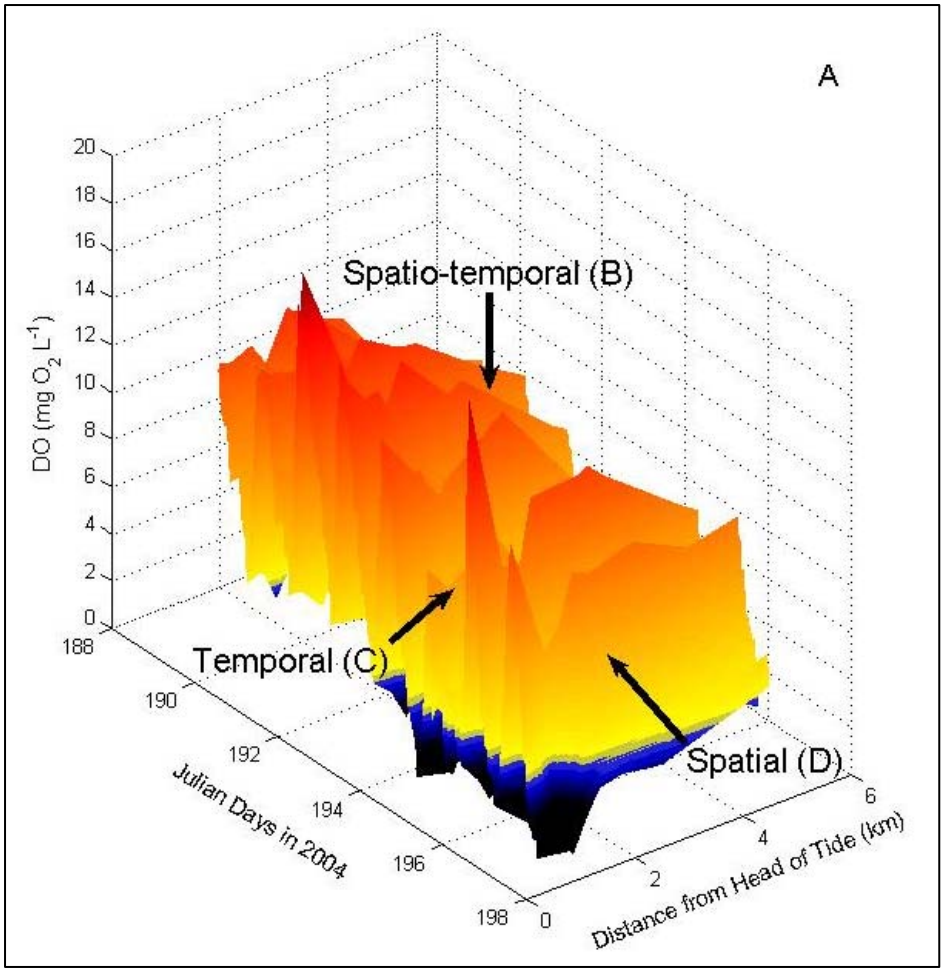

LC1
LC2
LC3
LC4
LC5
Lowe Creek
HC1
HC2
HC3
HC4
Herring Creek
Rehoboth Bay
PC1
PC2
PC3
PC4
PC5
PC6
Pepper Creek
IR1
IR2
IR3
IR4
IR5
Indian River
Kilometers

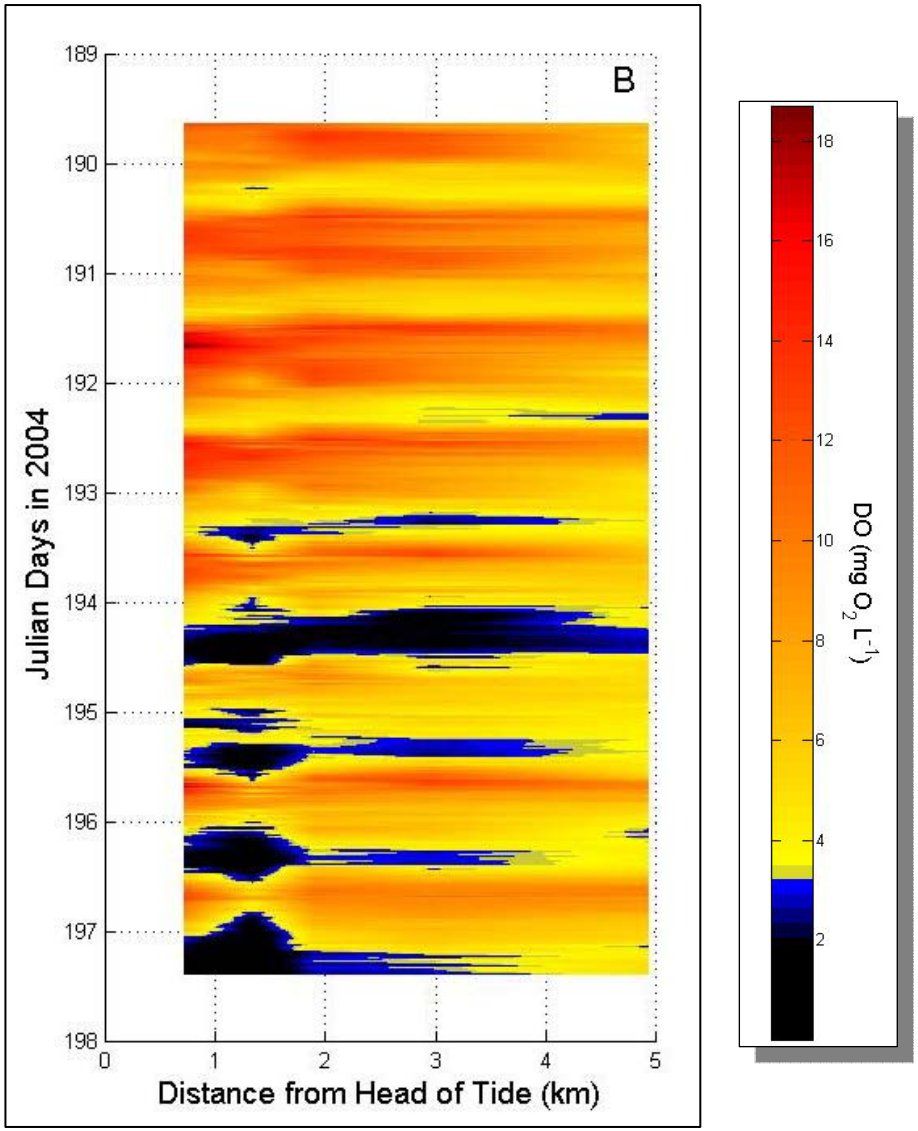
Importance of Tidal Creeks

- Biotic Factors
  - Less predation
  - More prey
- Abiotic Factors
  - Selective Tidal Stream Transport
  - Enviroregulation

Water Quality Monitoring

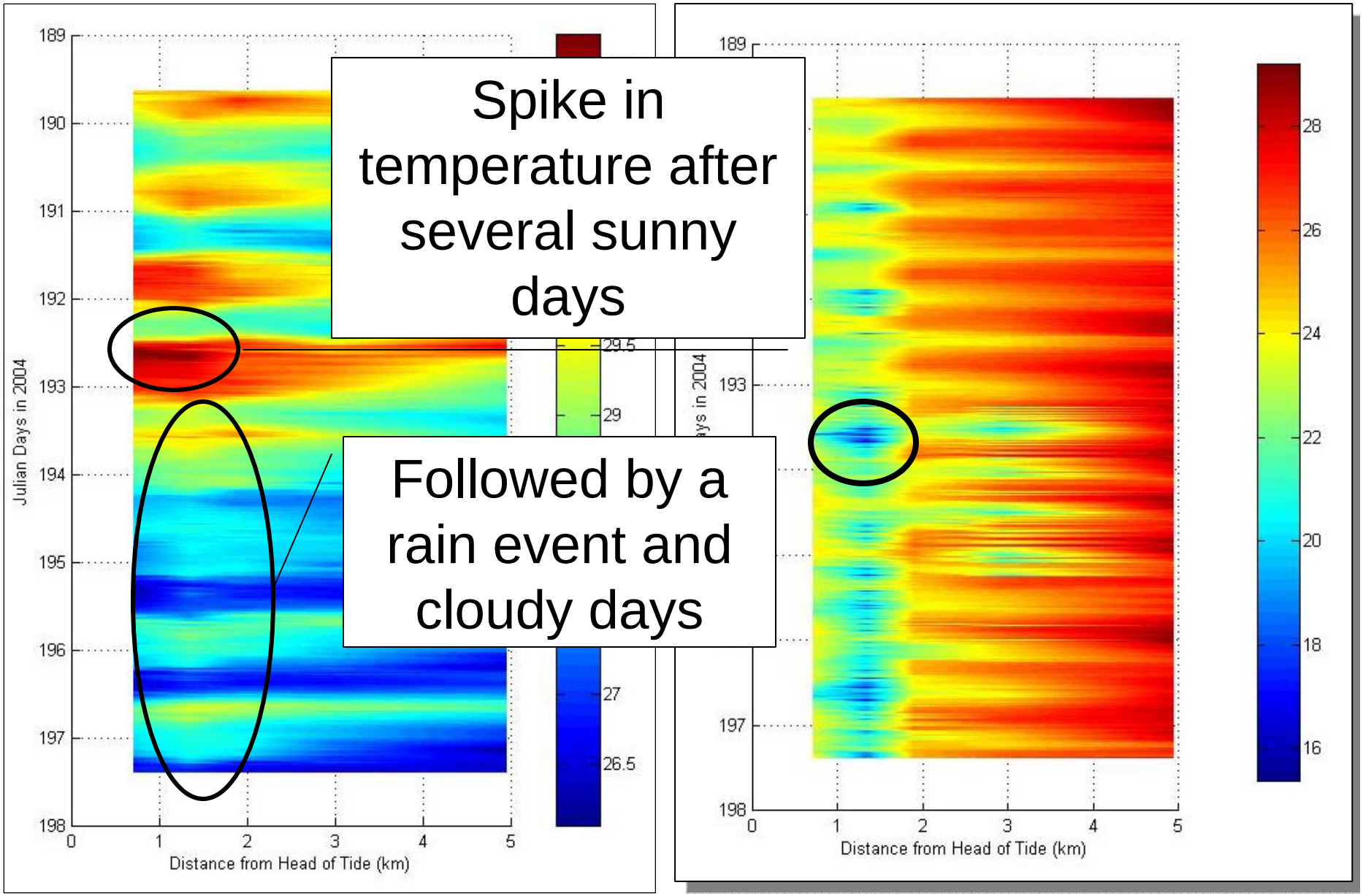
Spatio-temporal Mosaics



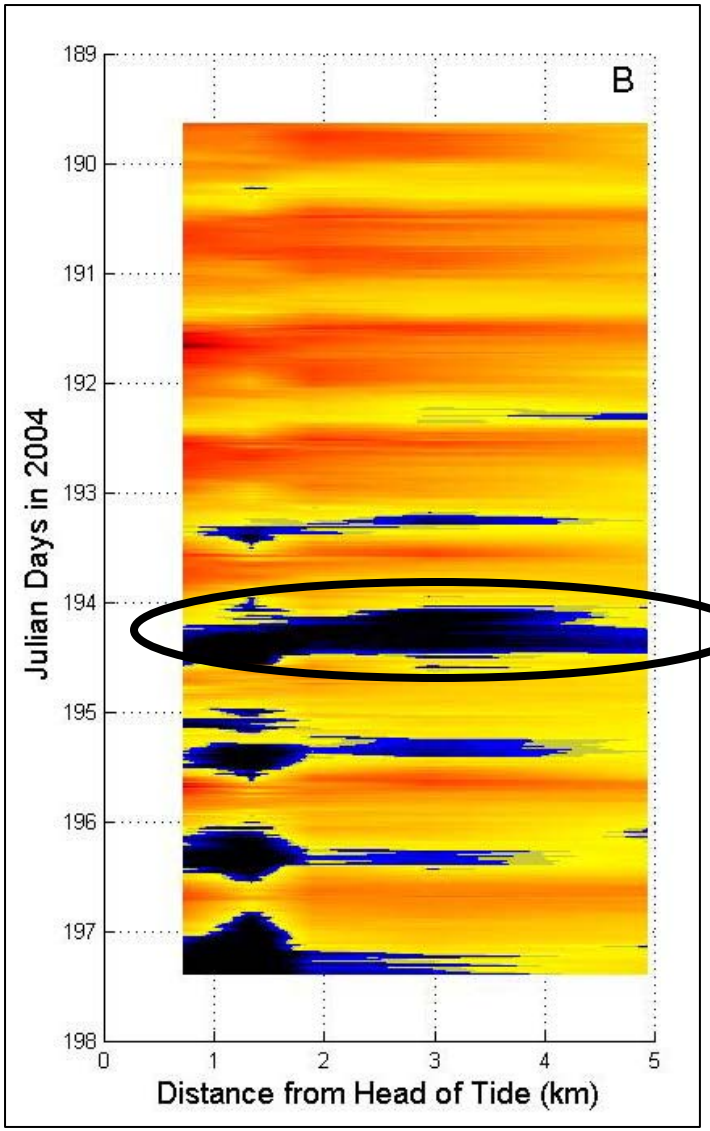


Temperature

Salinity

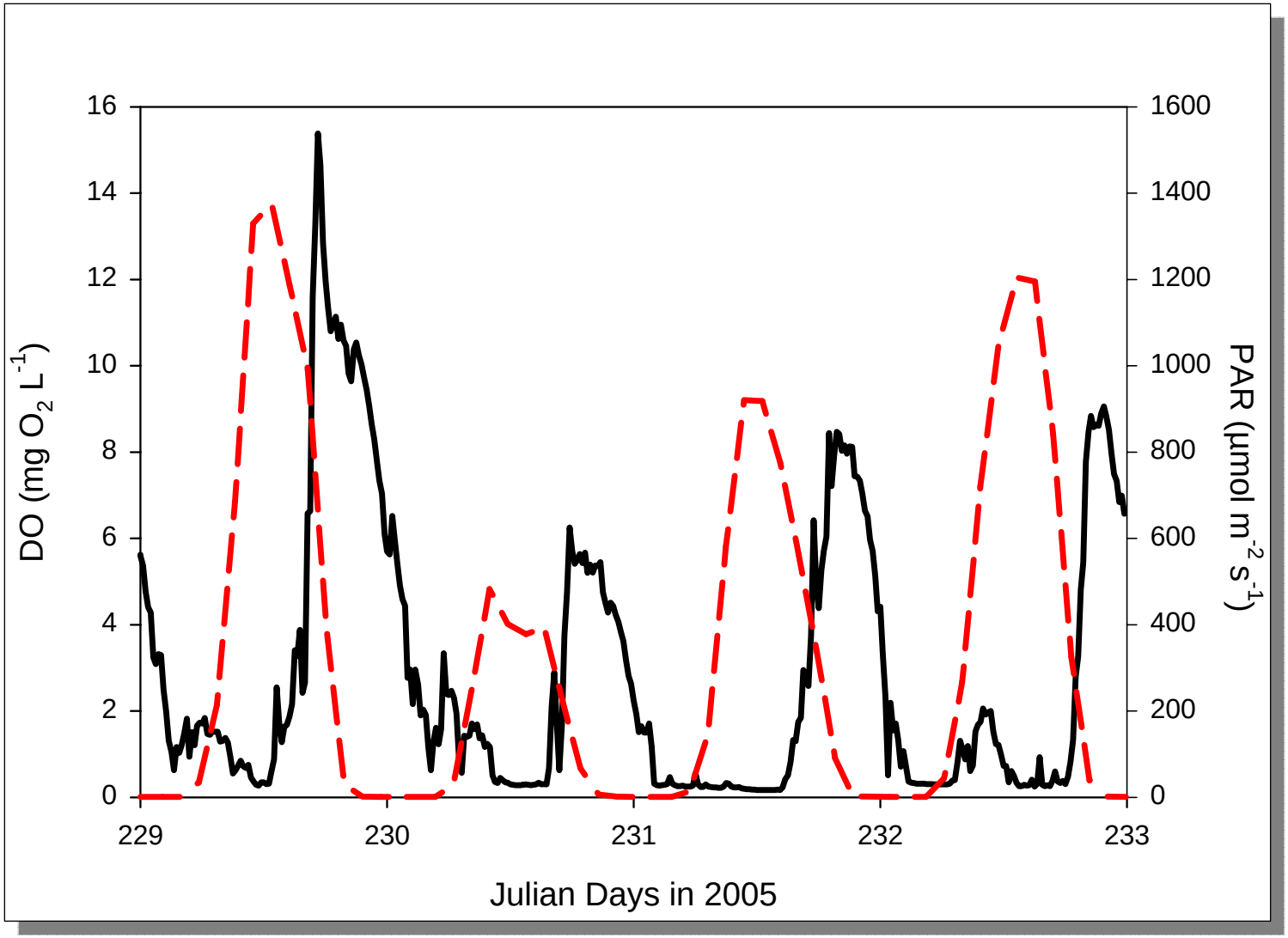


Mix it Together and What Do You Get?

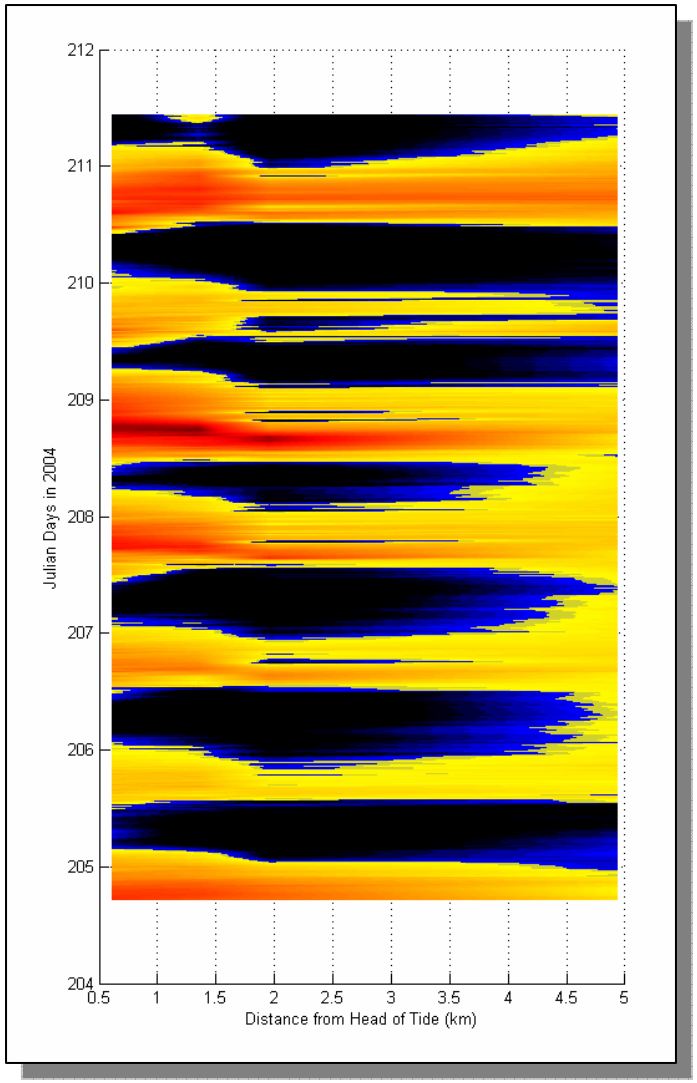


Less than 2 mg/L throughout the creek

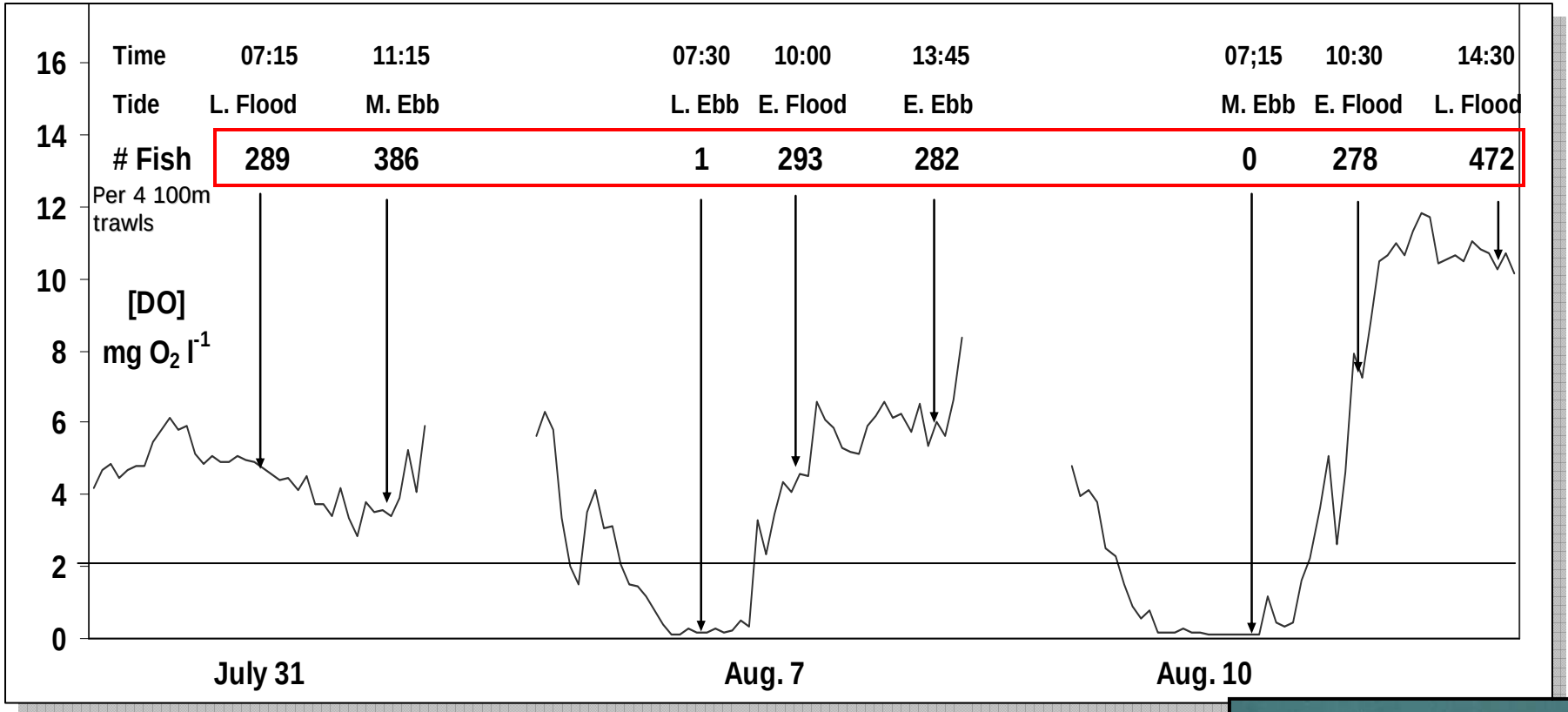
Sunlight


16
14
12
10
8
6
4
2
0
DO (mg O_2 L^{-1})
1600
1400
1200
1000
800
600
400
200
0
PAR (µmol m^{-2} s^{-1})
229
230
231
232
233
Julian Days in 2005

Love Creek


212
211
210
209
208
207
206
205
204
Julian Days in 2004
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Distance from Head of Tide (km)

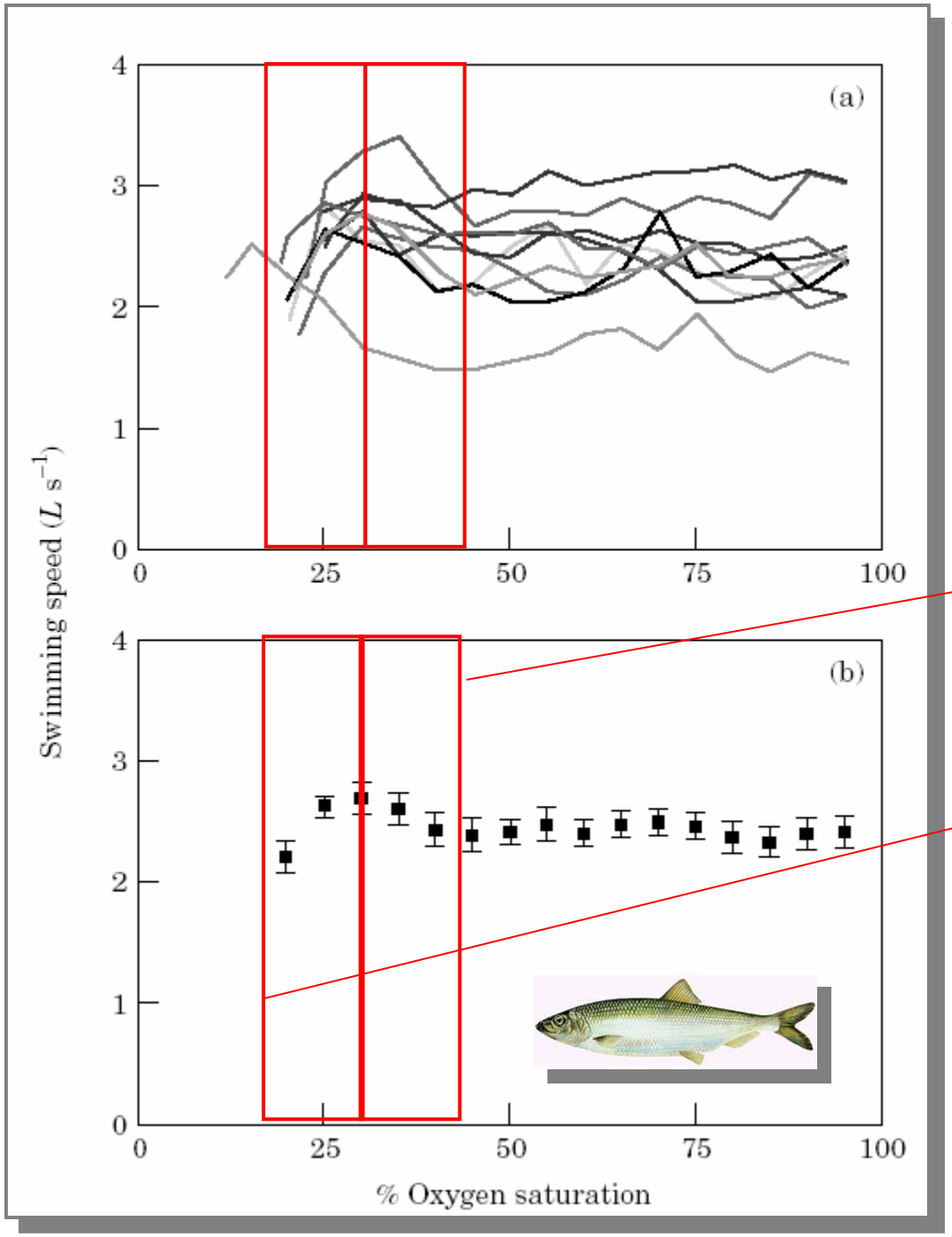
Avoidance in the Field



From R. Tyler (DNREC)

Moving Targets

- If DO varies temporally and spatially and fish are behaviorally mediating their environment . . .
  - How can we link water quality with juvenile fish populations?

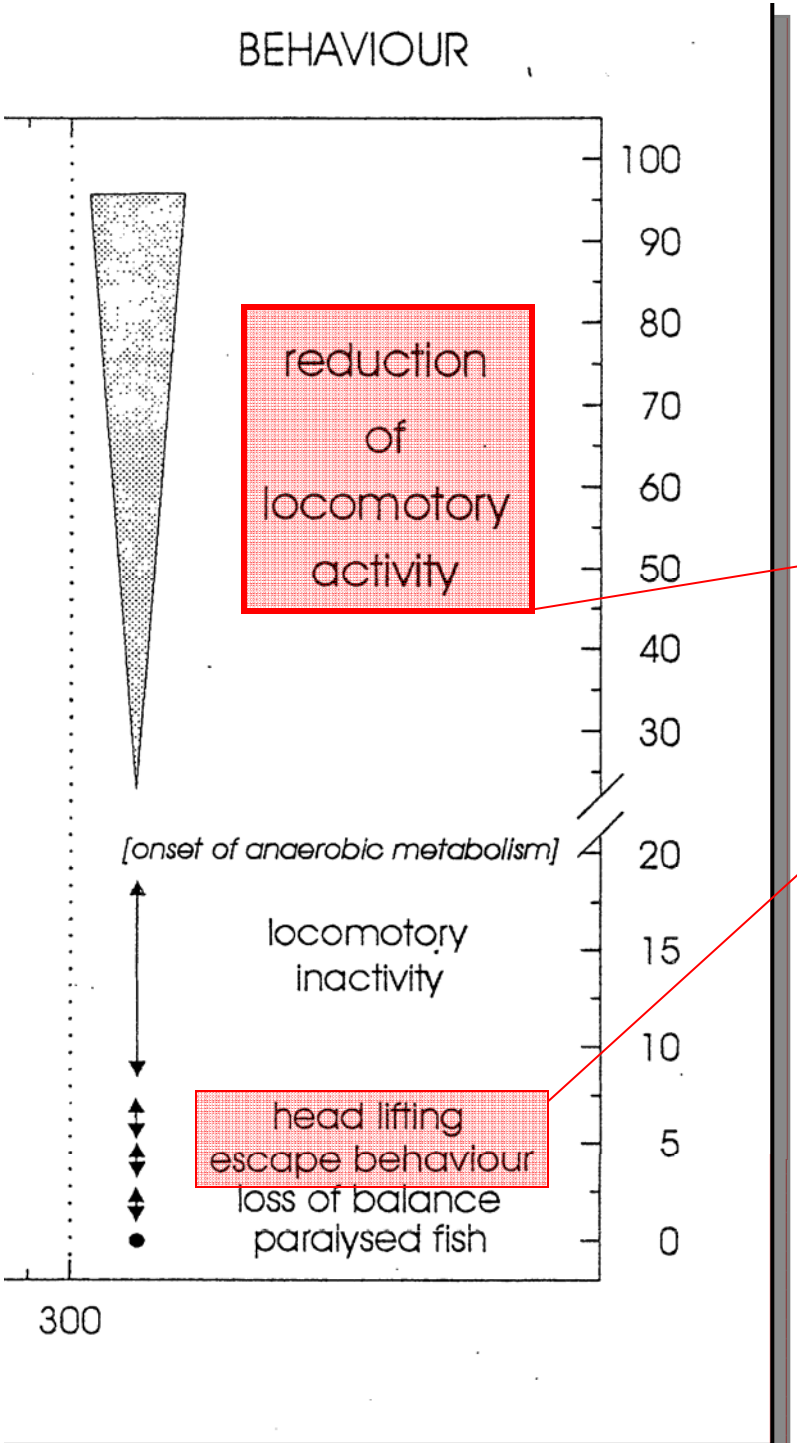


Behavioral response of Atlantic herring to declining DO

Active response

Passive response

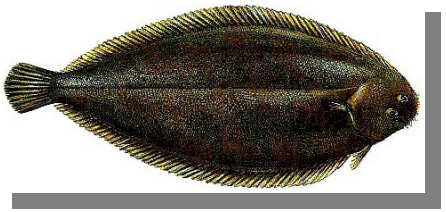
From Domenici *et al.* 2000



Behavioral response of common sole to declining DO

Passive Response

Active Response

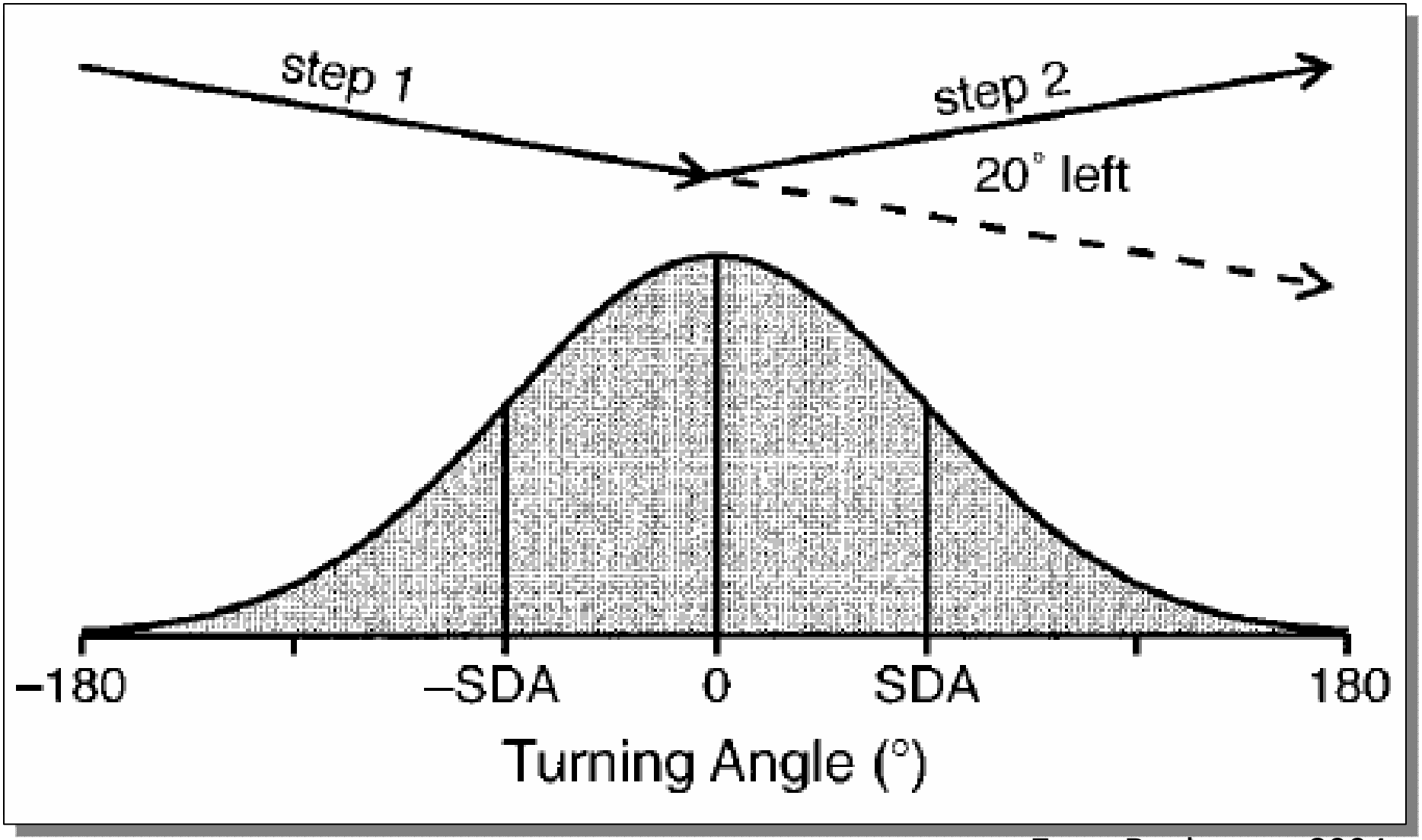


From Dalla Via *et al.* 1998

Search Paths

- The combination of changes in:
  - Velocity &
  - Turning distribution will ultimately determine exposure
  - How fish “use” or explore space is a more important determinant of search success

Sinuosity

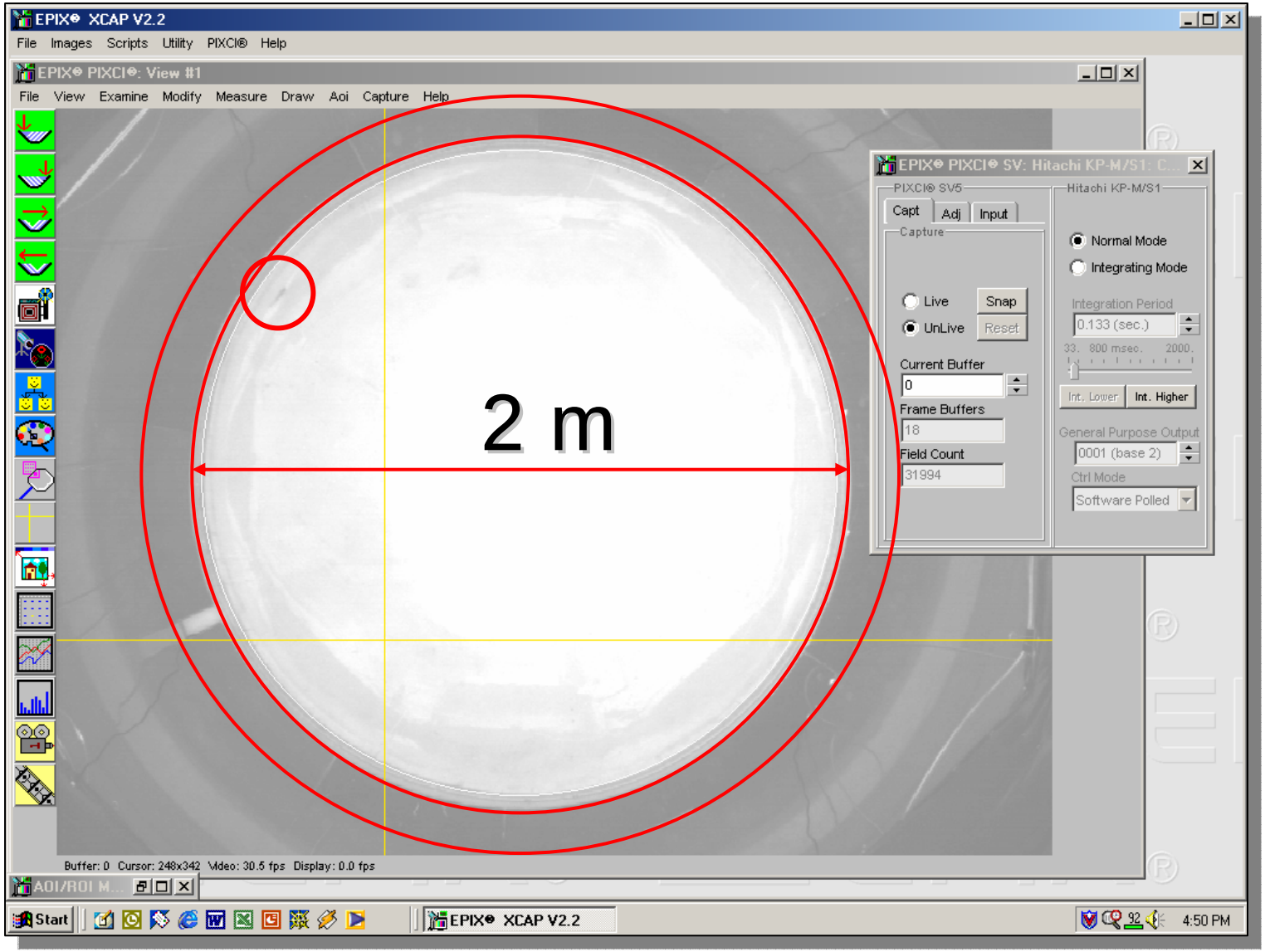


From Benhamou 2004

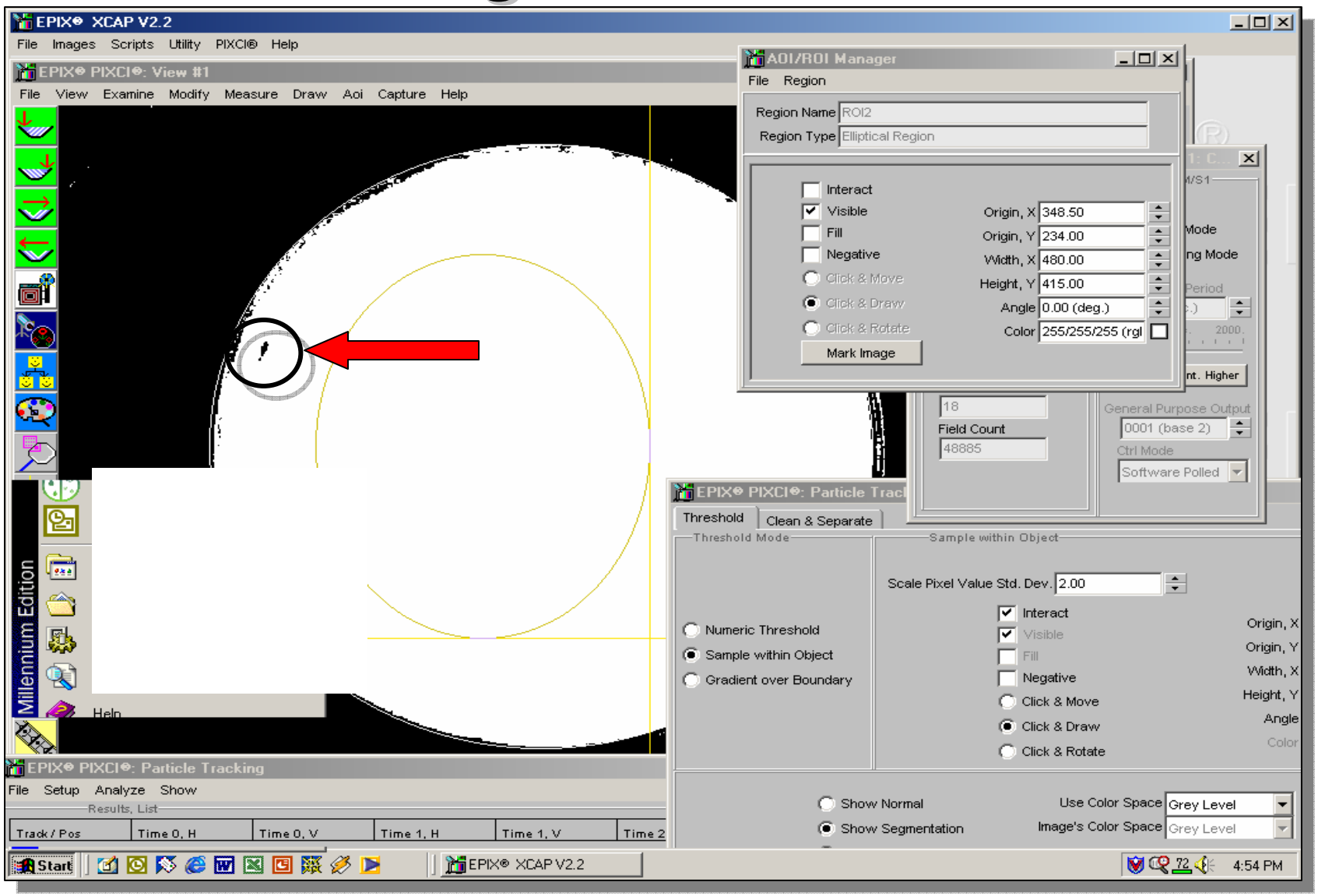
Mesocosm Experiments - Objectives

- Characterize the behavioral mechanisms used to navigate hypoxia impacted systems
  - Thresholds that induce behavioral responses
  - Acclimation
  - Sinuosity
  - Finally, how do changes in sinuosity and velocity interact to affect dispersal?

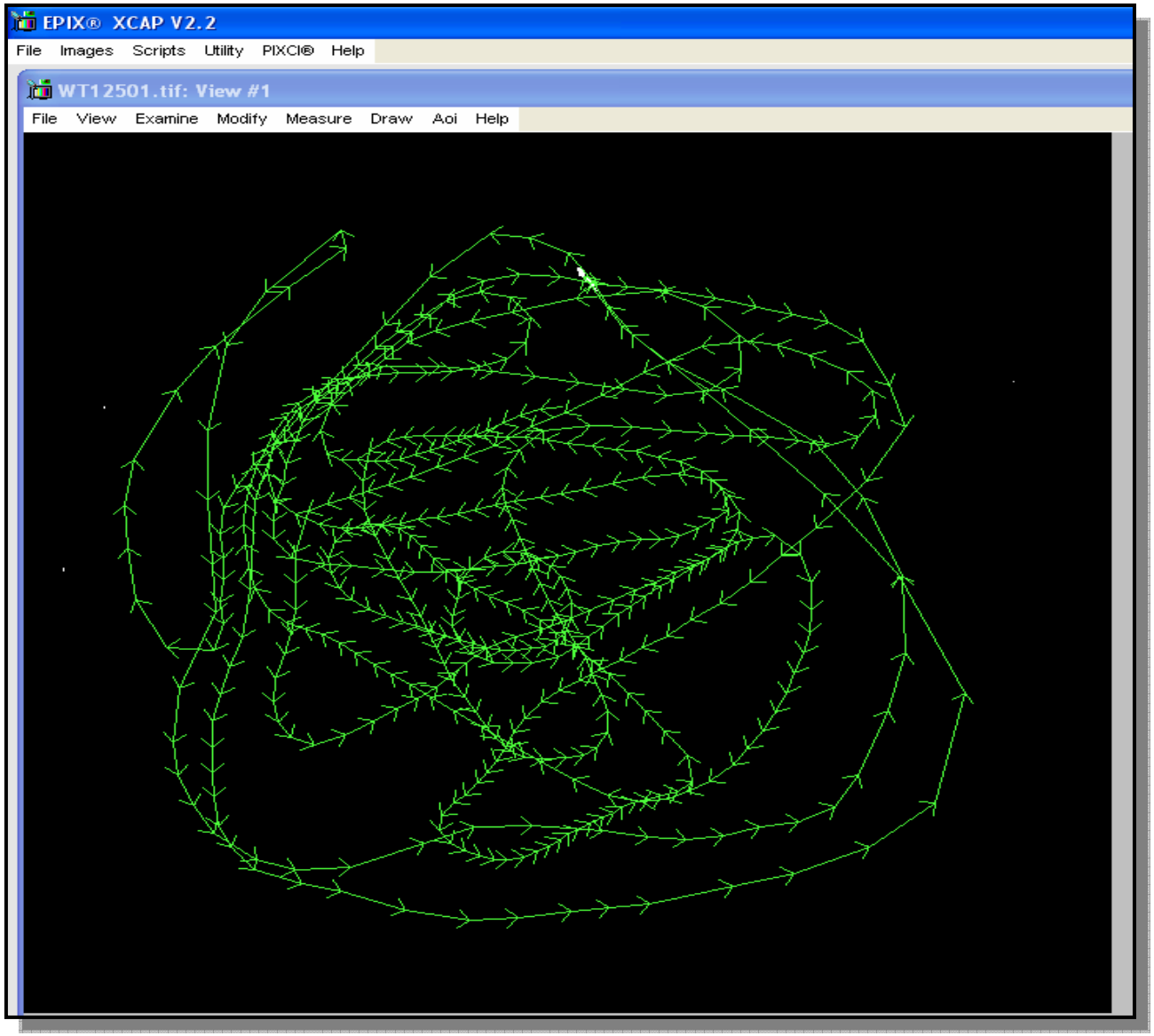
Mesocosm


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: C...
PIXCI® SV5
Capt Adj Input
Capture
Live Snap
UnLive Reset
Current Buffer
0
Frame Buffers
18
Field Count
31994
Hitachi KP-M/S1
Normal Mode
Integrating Mode
Integration Period
0.133 (sec.)
33. 800 msec. 2000.
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
AOI/ROI M...
Start
EPIX® XCAP V2.2
4:50 PM

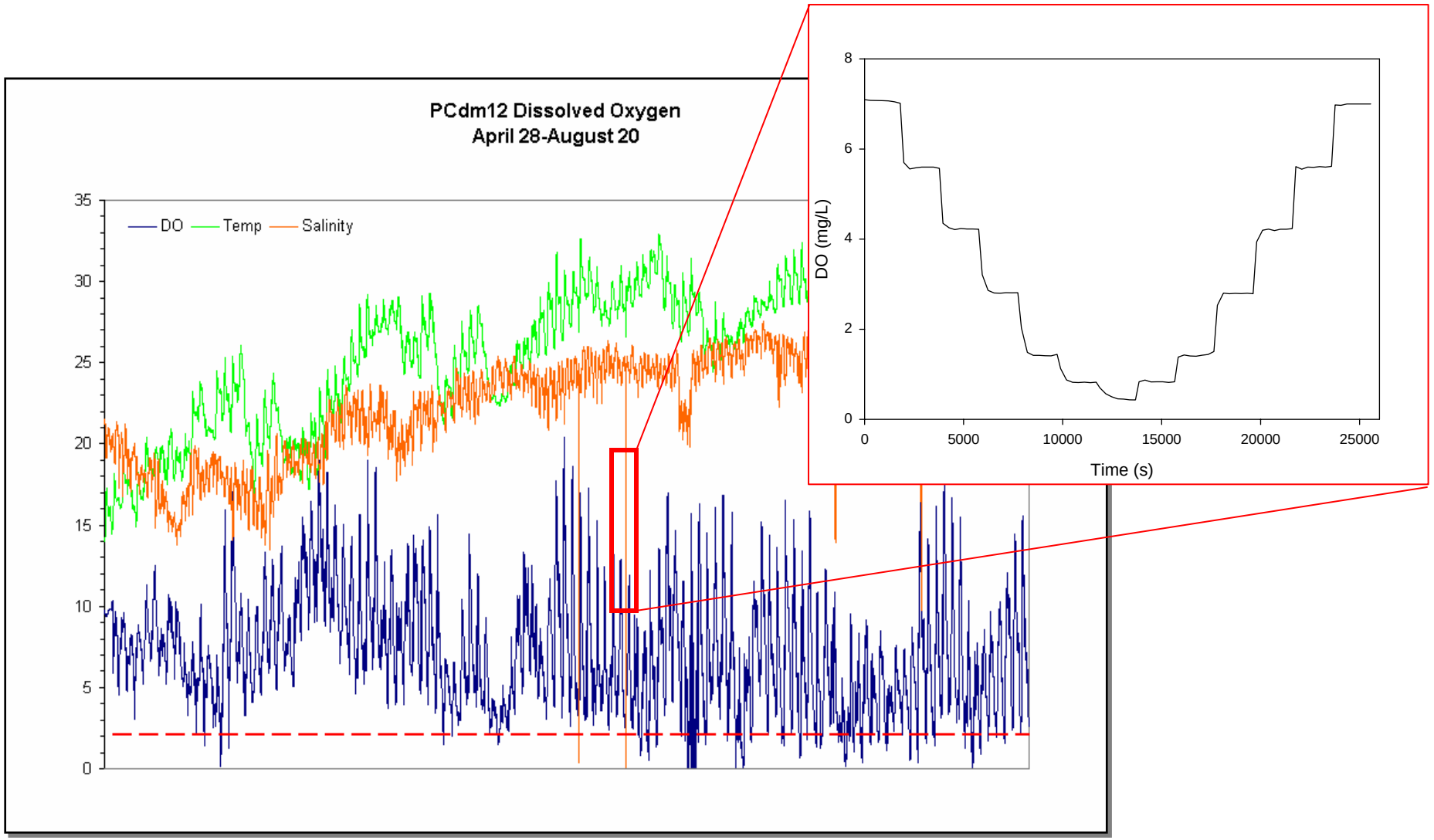
Segmentation



Tracking

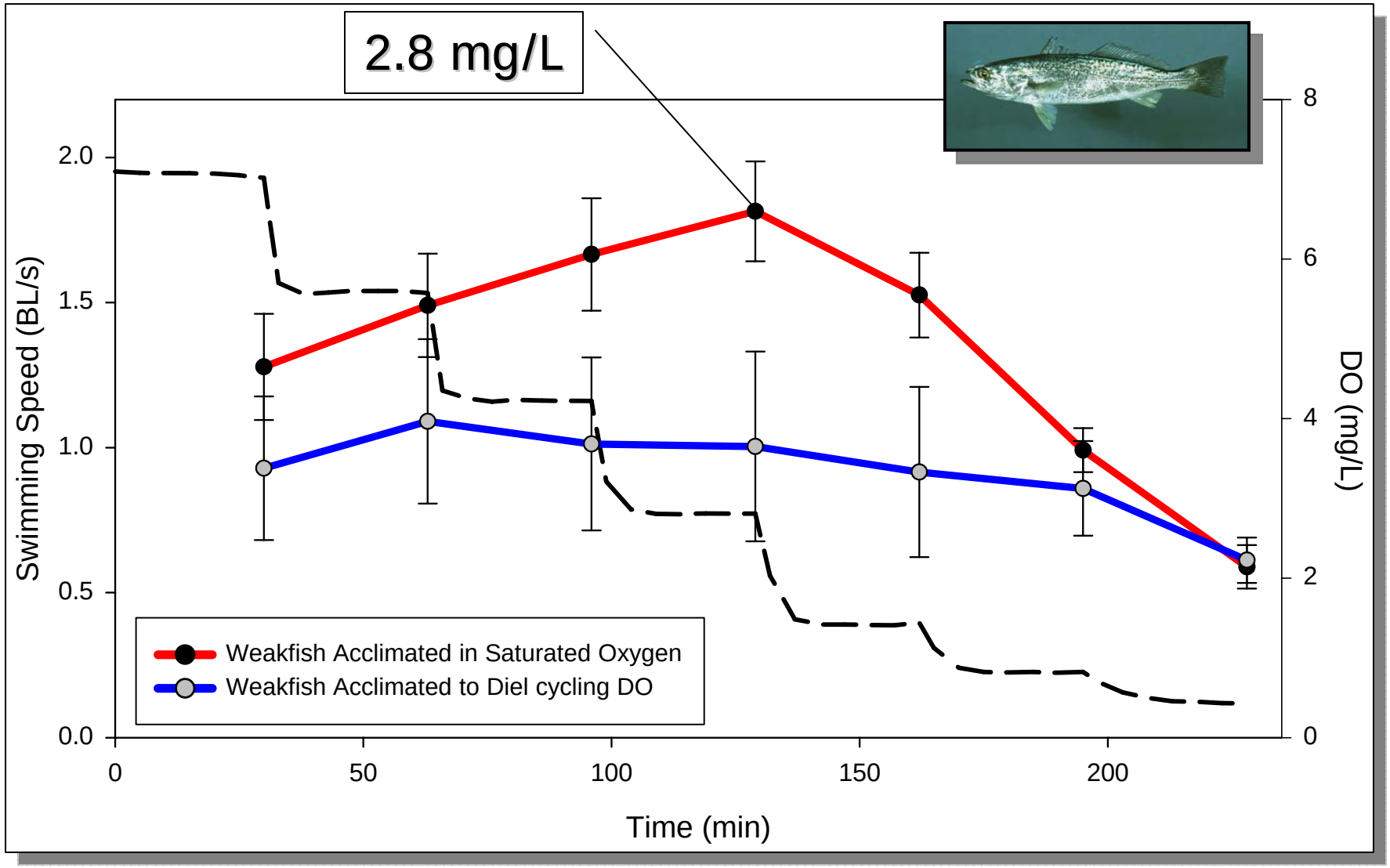

EPIX® XCAP V2.2
File Images Scripts Utility PIXCI® Help
WT12501.tif: View #1
File View Examine Modify Measure Draw Aoi Help

Exposure Protocol

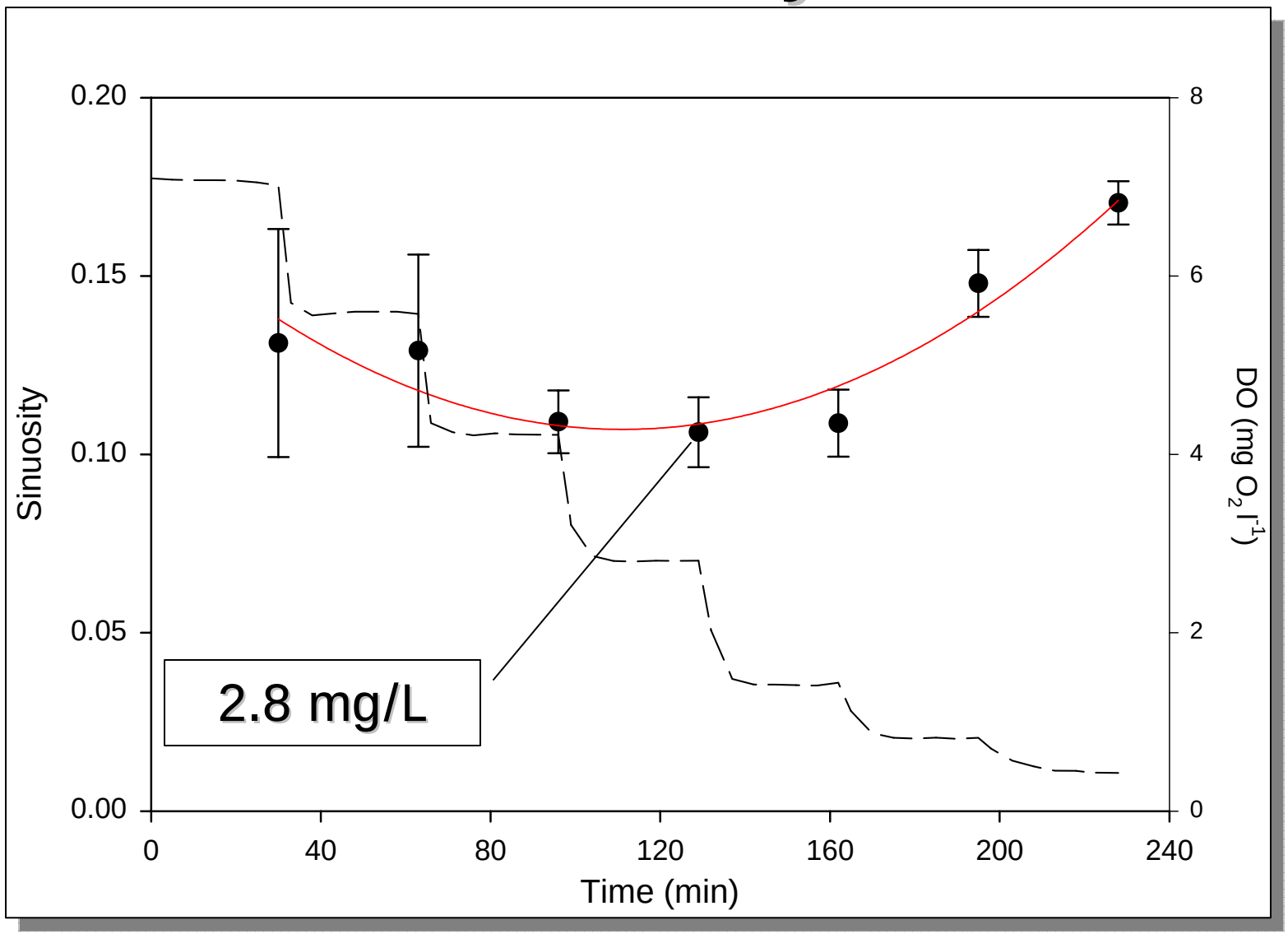


Mesocosm Experiments - Results

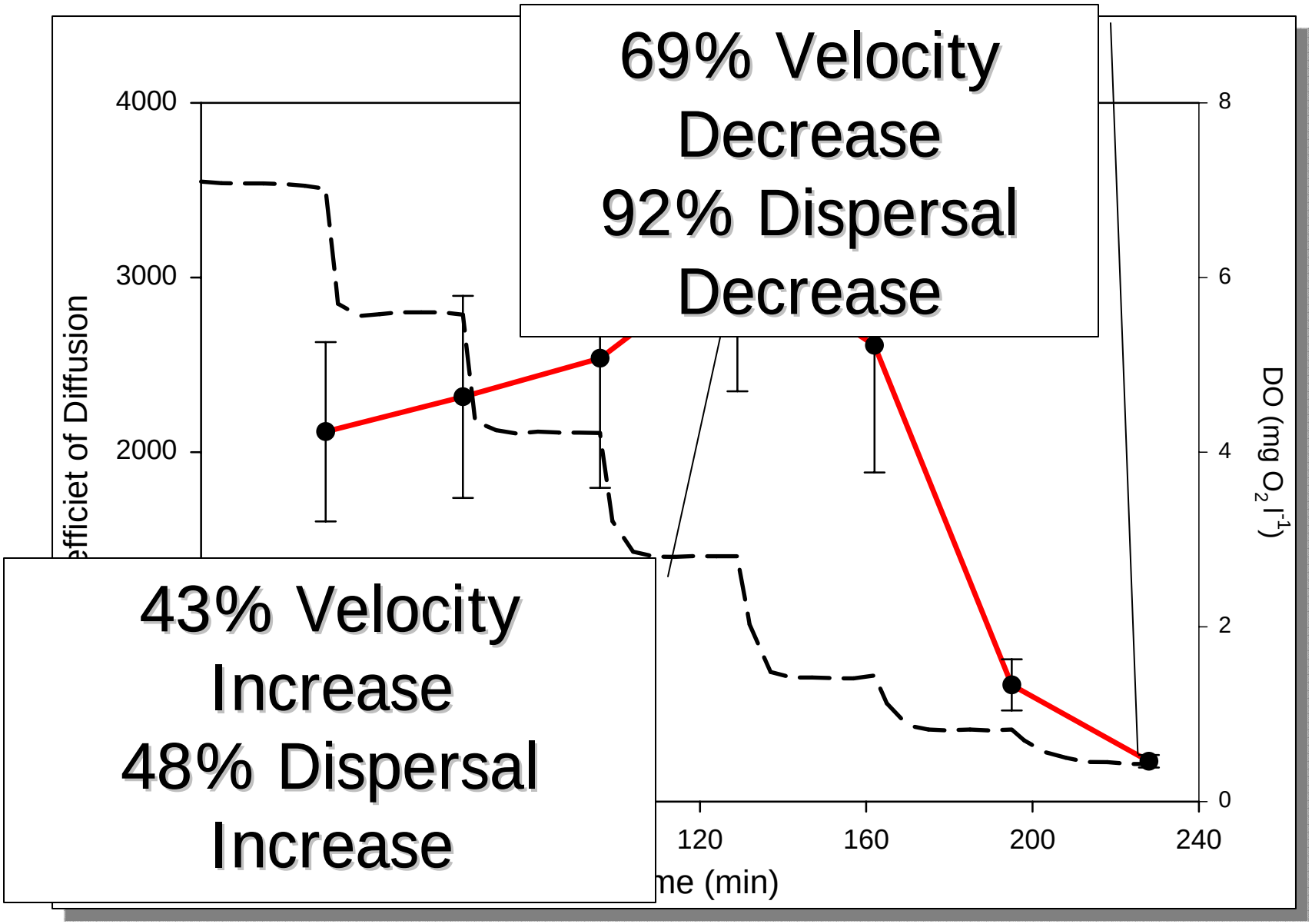
Behavioral response of Weakfish exposed to decreasing DO



Sinuosity


0.20
0.15
0.10
0.05
0.00
Sinuosity
8
6
4
2
0
DO (mg O_2 l^{-1})
0
40
80
120
160
200
240
Time (min)
2.8 mg/L

Diffusion


69% Velocity Decrease
92% Dispersal Decrease
43% Velocity Increase
48% Dispersal Increase
4000
3000
2000
8
6
4
2
0
120
160
200
240
DO (mg O_2 l^{-1})

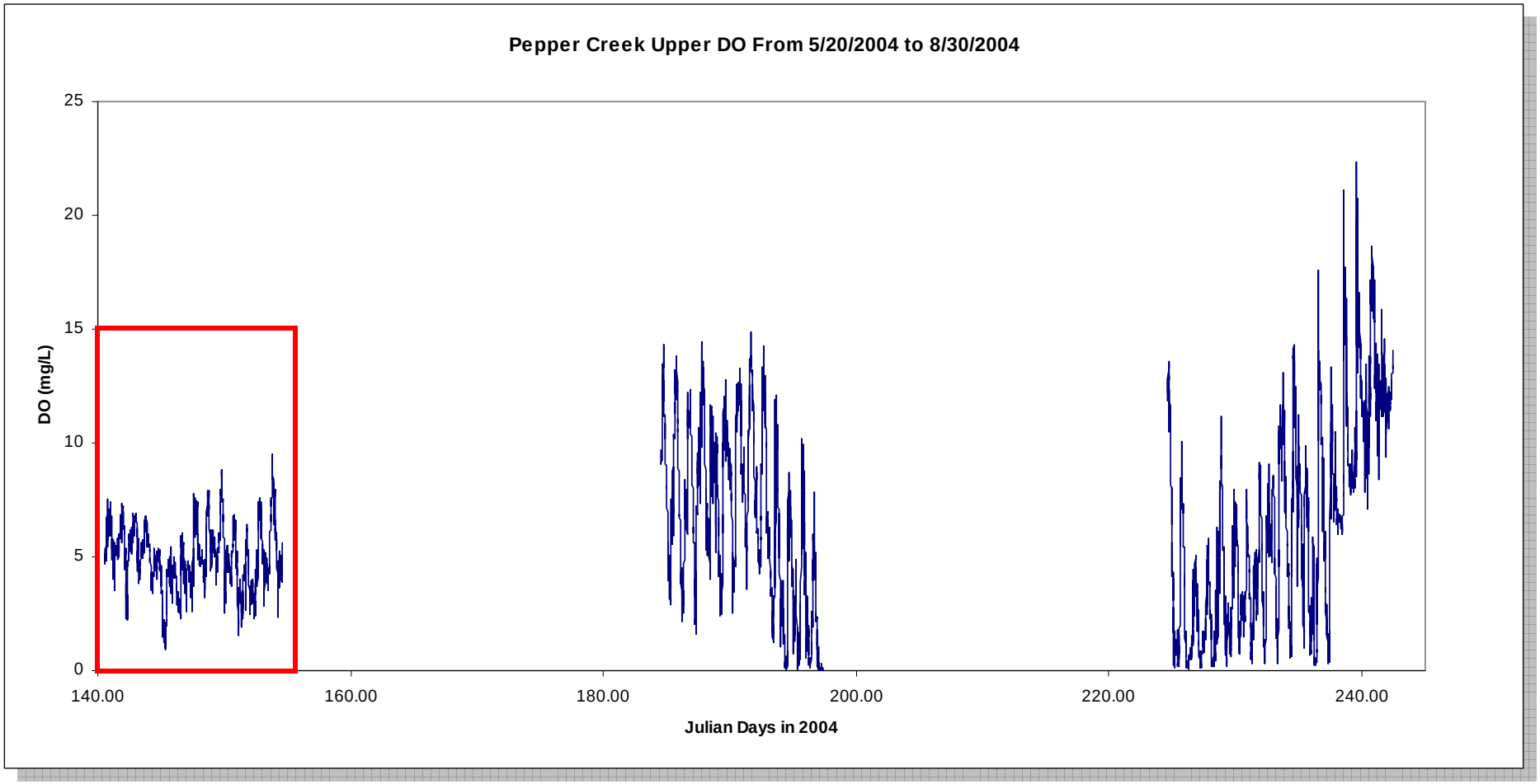
Mesocosm Conclusions

- Short term response
  - Increase in velocity
  - Decrease in sinuosity
  - Interact to significantly increase search radius down to 2.8 mg/L
  - The tradeoff:
    - After this initial burst (e.g. <2.8mg/L), dispersal distance plummets even as fish are still moving
    - Loss of orientation

Mesocosm Conclusions

- Long term response (Acclimation)
  - Increase in survival

Mesocosm Conclusions



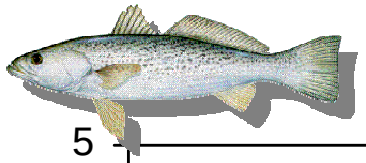
Mesocosm Conclusions

- Long term response
  - Increase in survival
  - Overall decrease in swimming speed
    - Implications
      - Future avoidance and stress responsiveness
      - Feeding

From the Mesocosm to the Field

Preliminary Tagging Results

Listening Array



Distance from Head of Tide (km)

DO (mg $O_2 L^{-1}$)

Avoidance

Return

Avoidance

2.8 mg/L

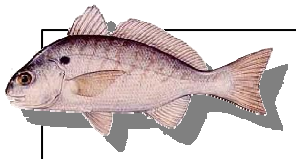
Sat 27

Sun 28

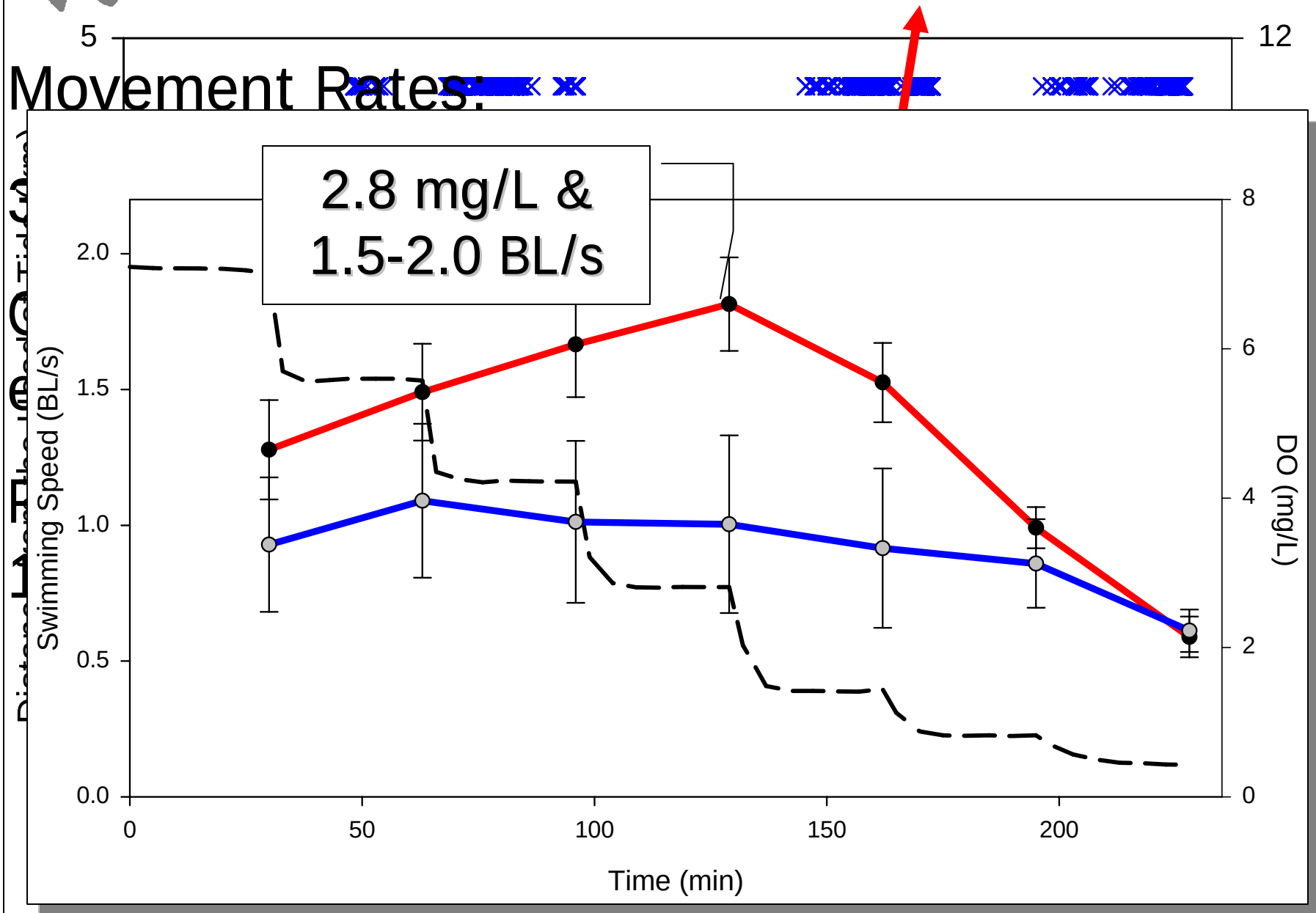
August 2005

Fish Location

DO



Movement Rates:



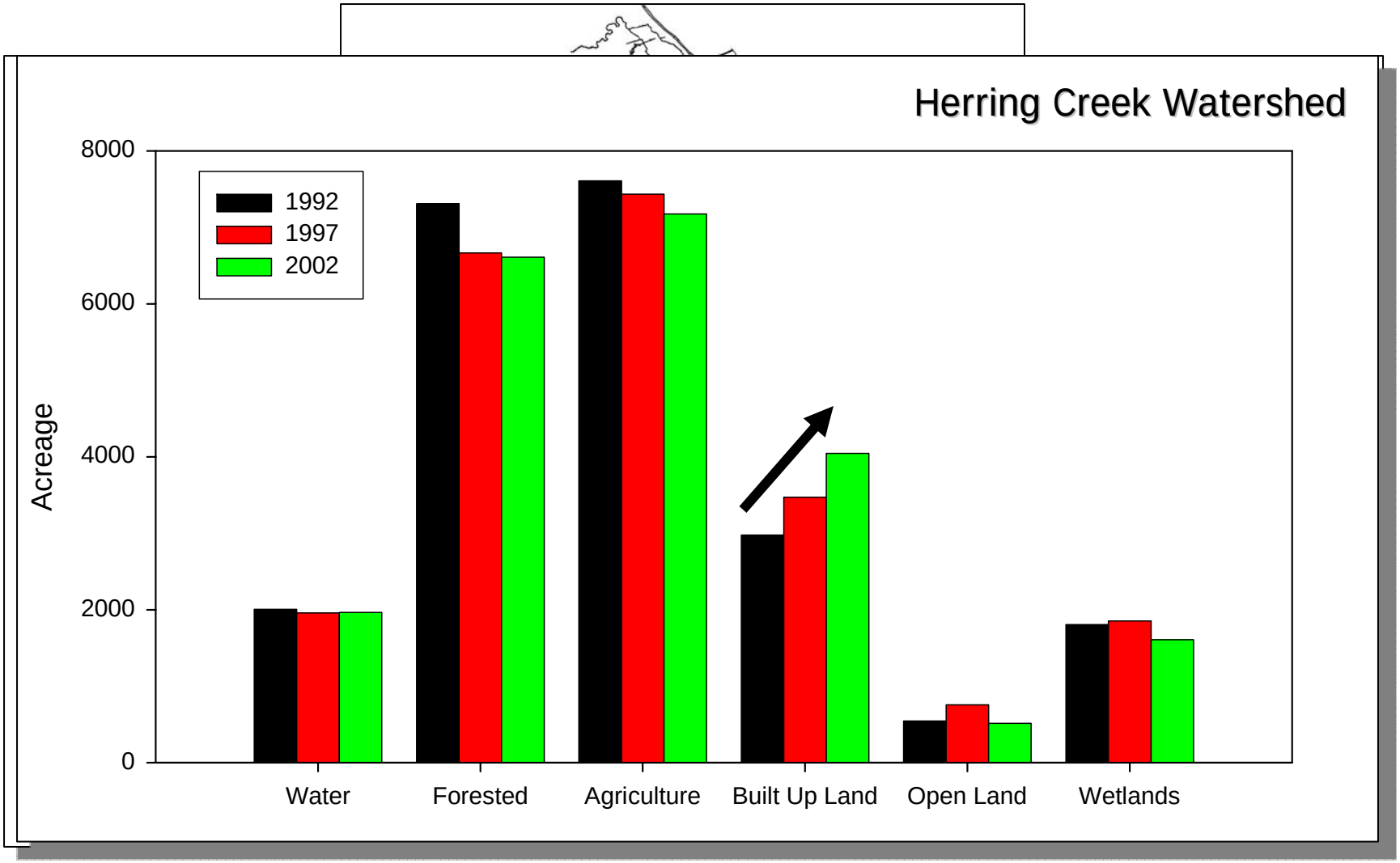
Conclusions and Questions from Mesocosm to Field

- Field results corroborate and strengthen mesocosm results and vice versa
  - Both in determining important thresholds and changes in movement rate
- Avoidance is extremely effective but at what cost?
  - Significant time not feeding
  - Situational circumstance make prediction difficult

Historical and Future Perspective

- How long has the ecosystem been like this?

Watershed Analysis



Historical and Future Perspective

- How long has the ecosystem been like this?
- Can this ecosystem cross a threshold and become uninhabitable?
- The role of acclimation?

Acknowledgements

- Delaware DNREC
- Targett lab (Kevin Stierhoff, Ben Ciotti, Brian Boutin, Robin Tyler, and Mike Rhode)
- Ryan Dale (MatLab)
- Nicole Minni (GIS)