Spatial Patterning of Fish Habitat Quality

Fish Habitat Quality

Affects survival, reproductive success, growth and production

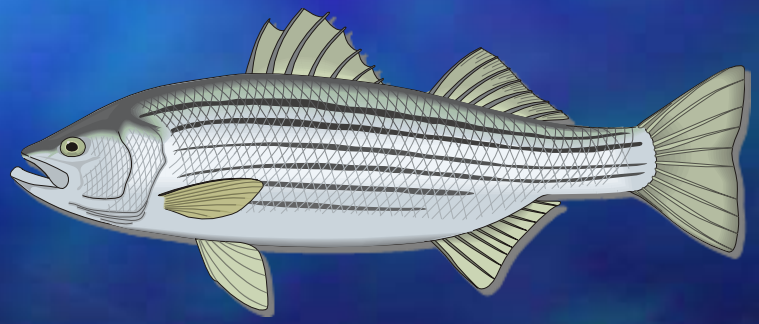
What is good habitat for a pelagic fish?

How do we define it, measure it, and compare it

- Among species? Among Ecosystems?
- Across physical and biological gradients?
- Across time and space?
- In response to environmental stressors?

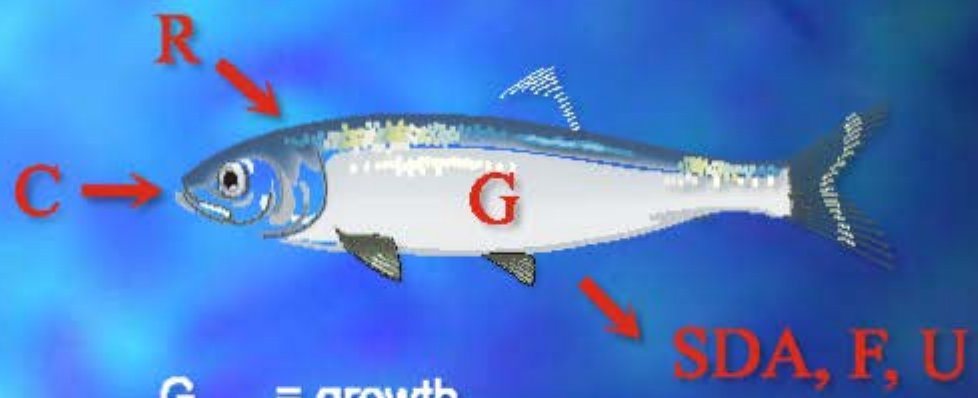
Habitat Quality = Growth Rate Potential

Expected daily growth rate of a fish if placed in a volume of water with known conditions such as prey type, prey size, prey density, temperature, salinity, oxygen and light



Why Fish Growth Rate?

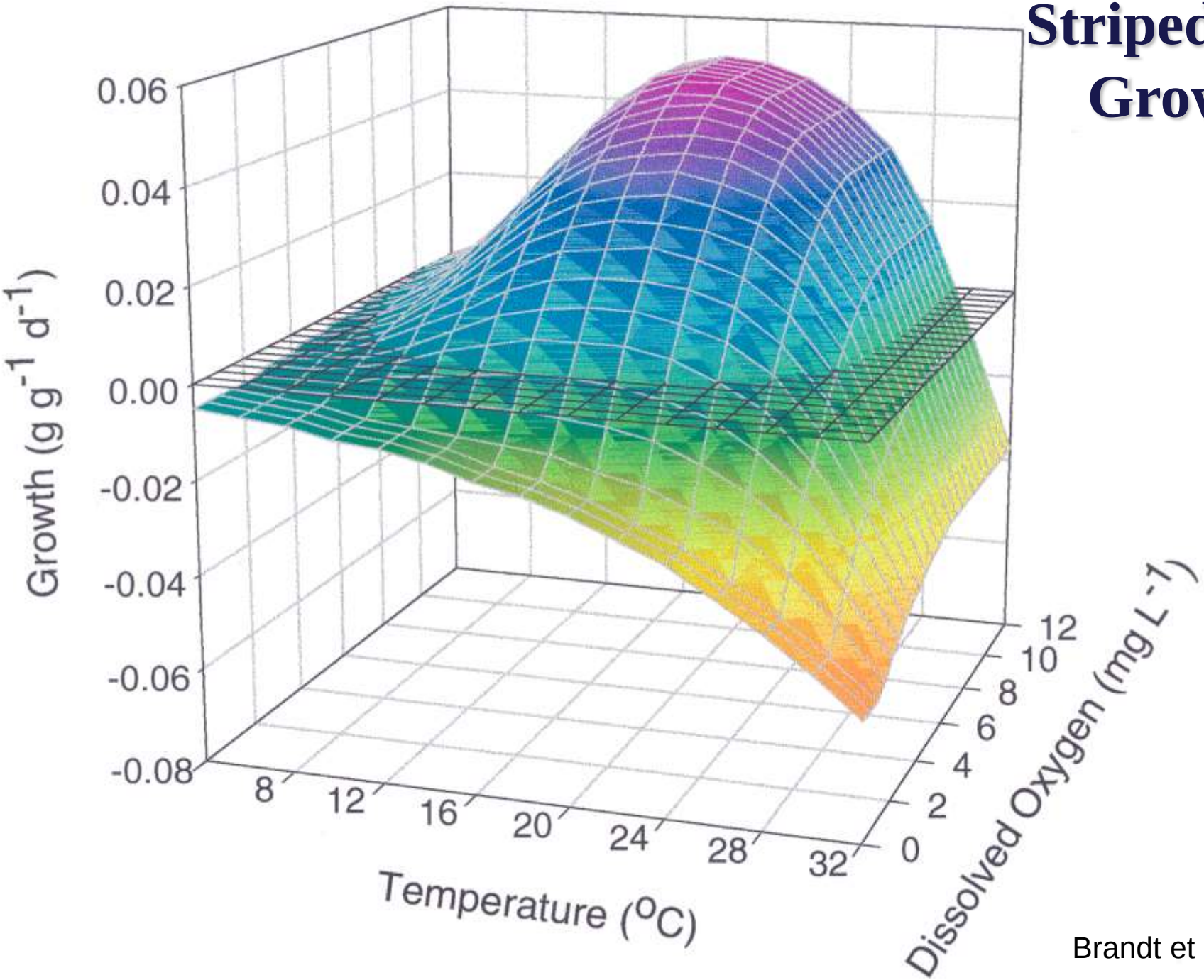
- Integrative Response of fish performance – related to survival rates and reproductive capacity
- Based on fish's requirements and prevailing environmental conditions
- Differs among species and life stages
- Varies in time and space
- Nonlinear response



G = growth
C = consumption
R = respiration
SDA = standard dynamic action
F = egestion
U = excretion

Consumption = Growth + Respiration + Wastes

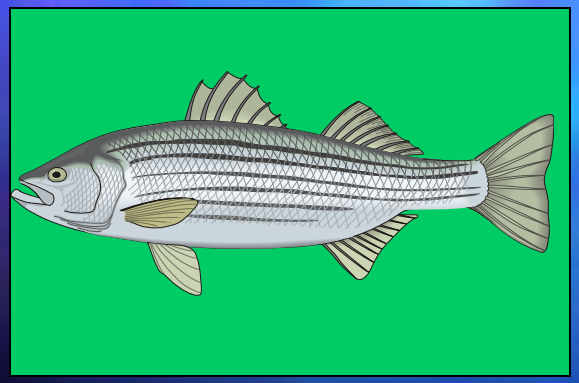
Striped Bass Growth



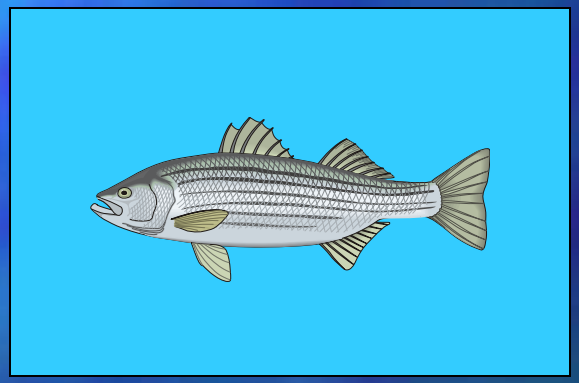
Brandt et al. 2009

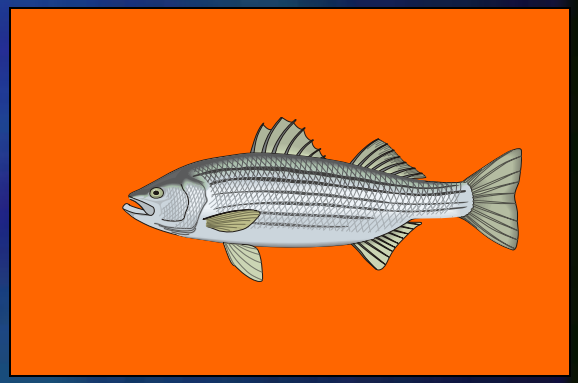
Example: Striped Bass Growth

Growth (T_{20}) $\neq$ Growth (T_{18}), Growth (T_{22})

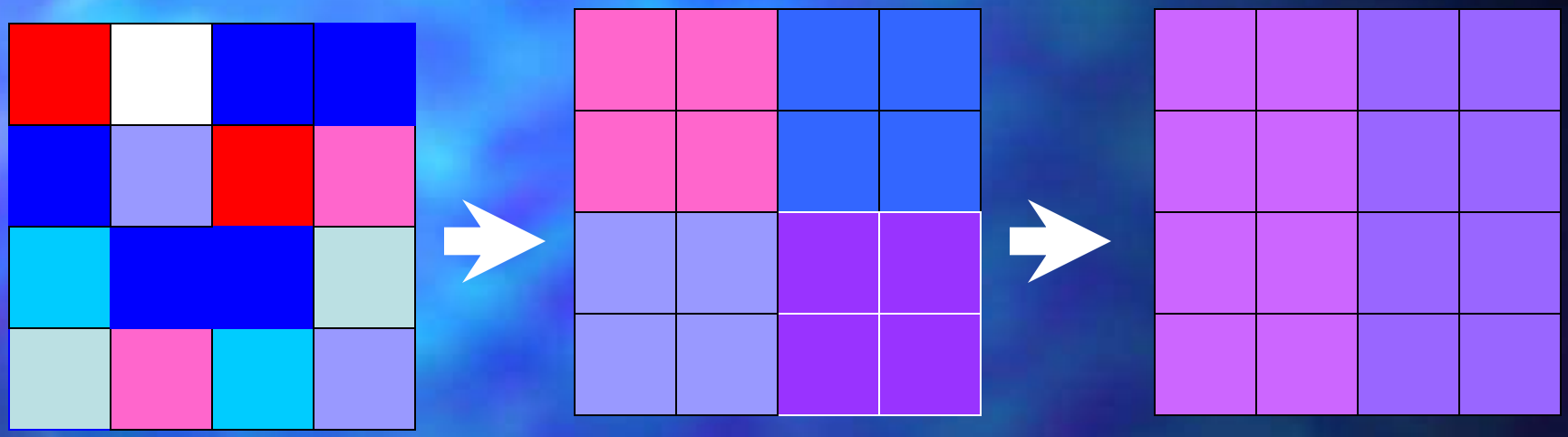


$\neq$



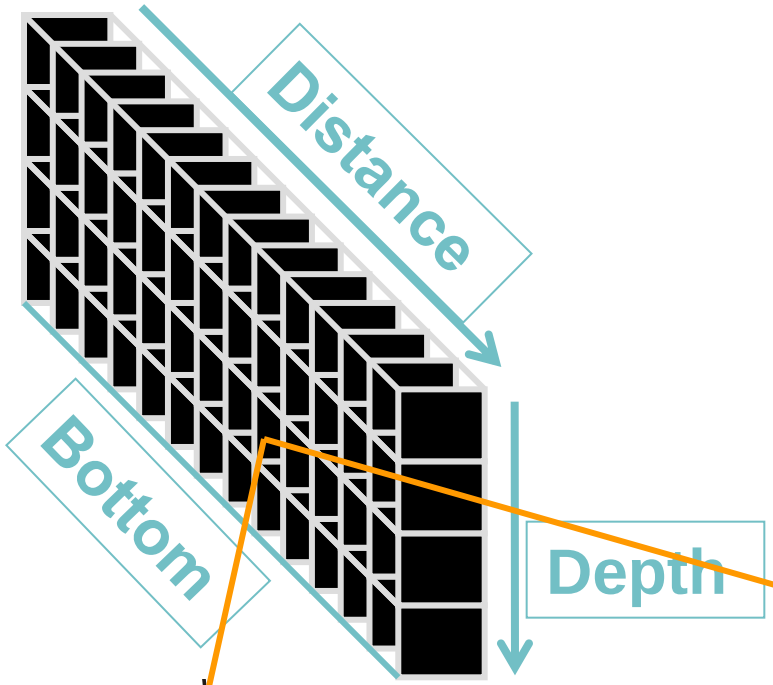


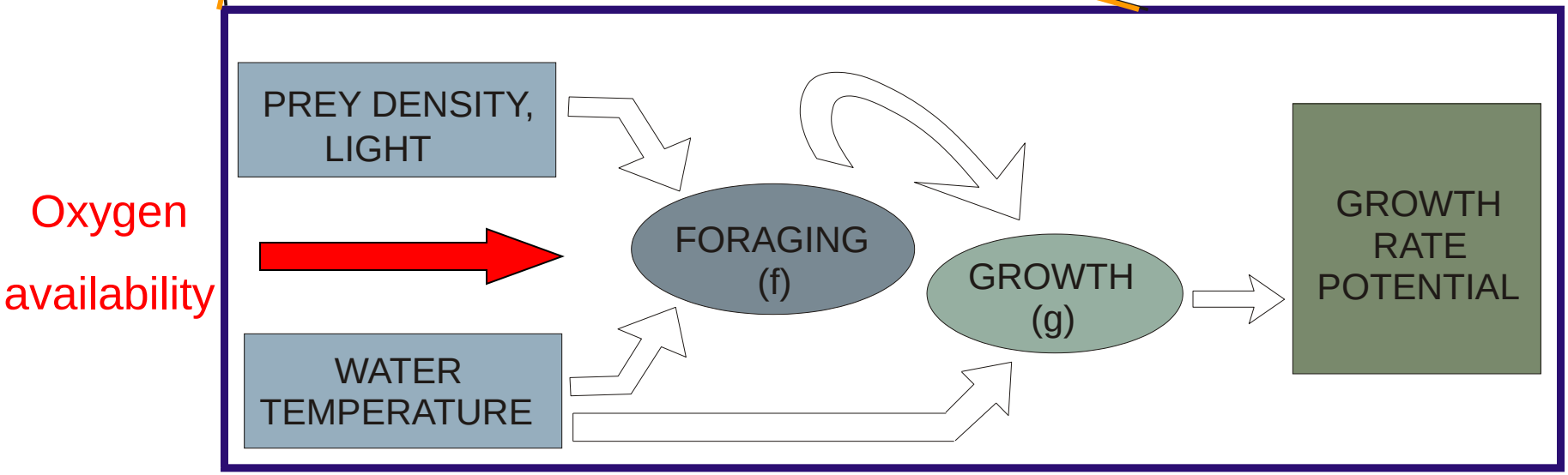
Spatial Averaging



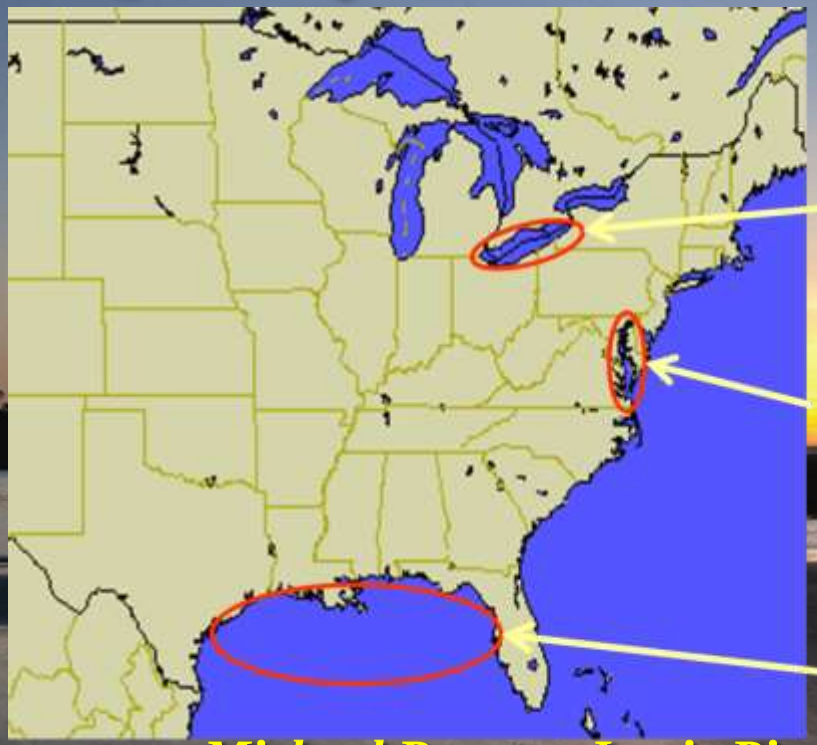
Result: Reduces extreme high and low values

Growth Rate Potential





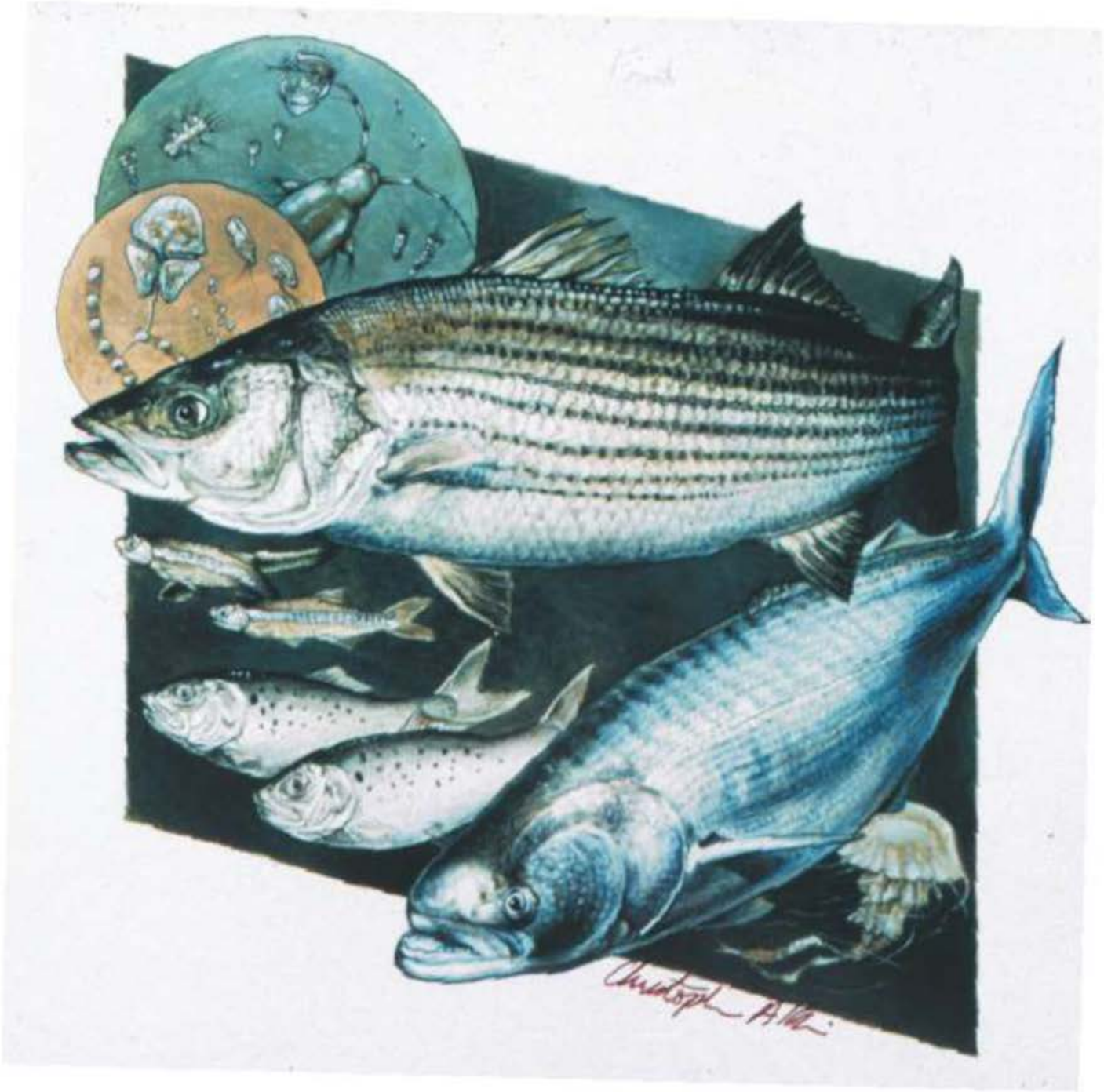
How Does Hypoxia Affect Fish Habitat Quality and food webs?



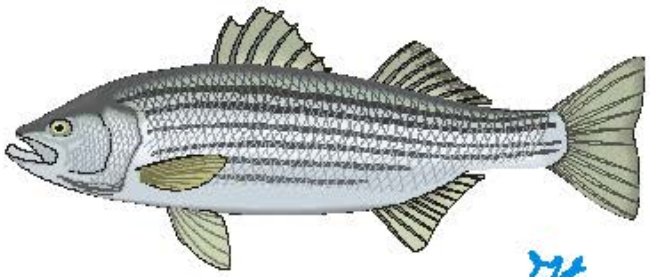
Michael Roman, Jamie Pierson
Cynthia Sellinger, Sarah Kolesar, Doran Mason, William Boicourt, David Kimmel, Adam Adamack, Hongyan Zhang

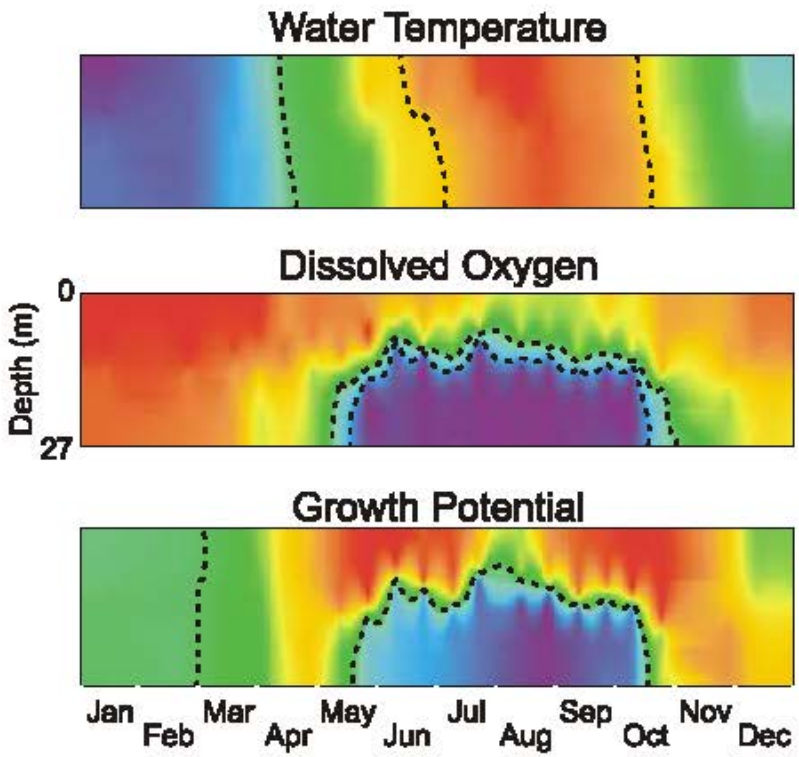
Oregon State University OSU

University of Maryland Center for Environmental Science
HORN POINT LABORATORY



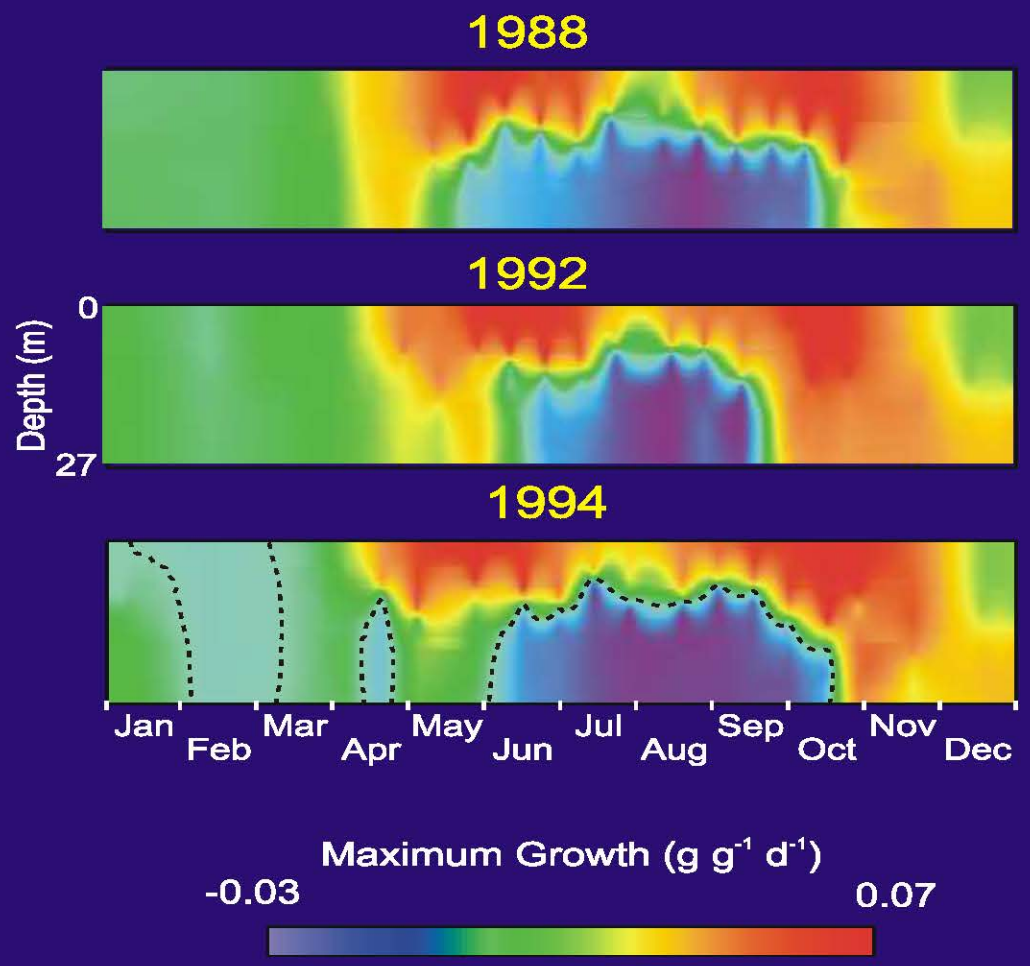
Striped Bass Growth Potential
Mid-Chesapeake Bay



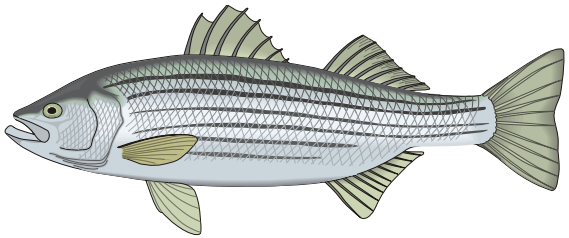


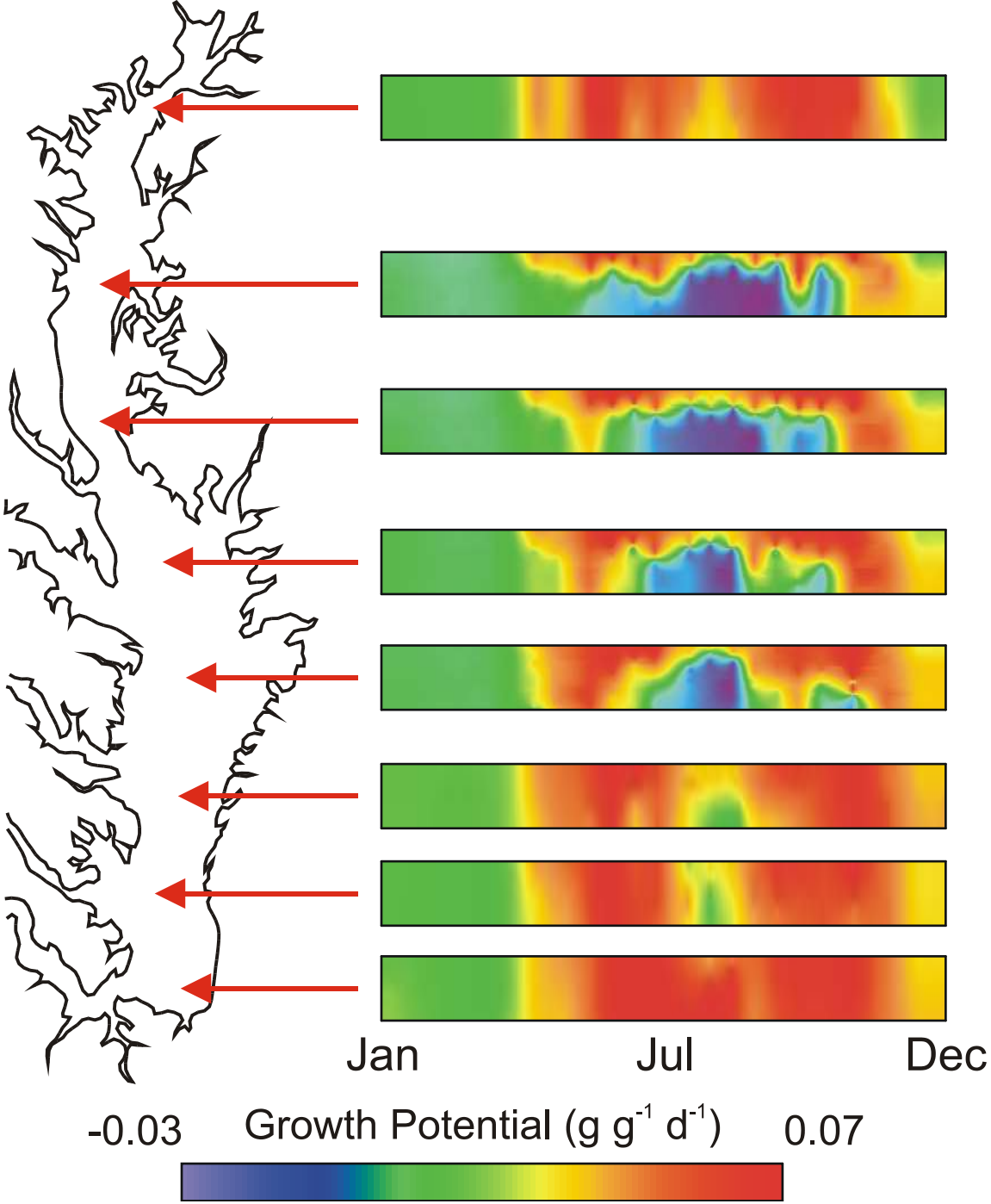
2	Temperature (°C)	26
0	Dissolved Oxygen (mg L^{-1})	12
-0.03	Maximum Growth (g g^{-1} d^{-1})	0.07

Striped Bass Growth Potential
Mid-Chesapeake Bay



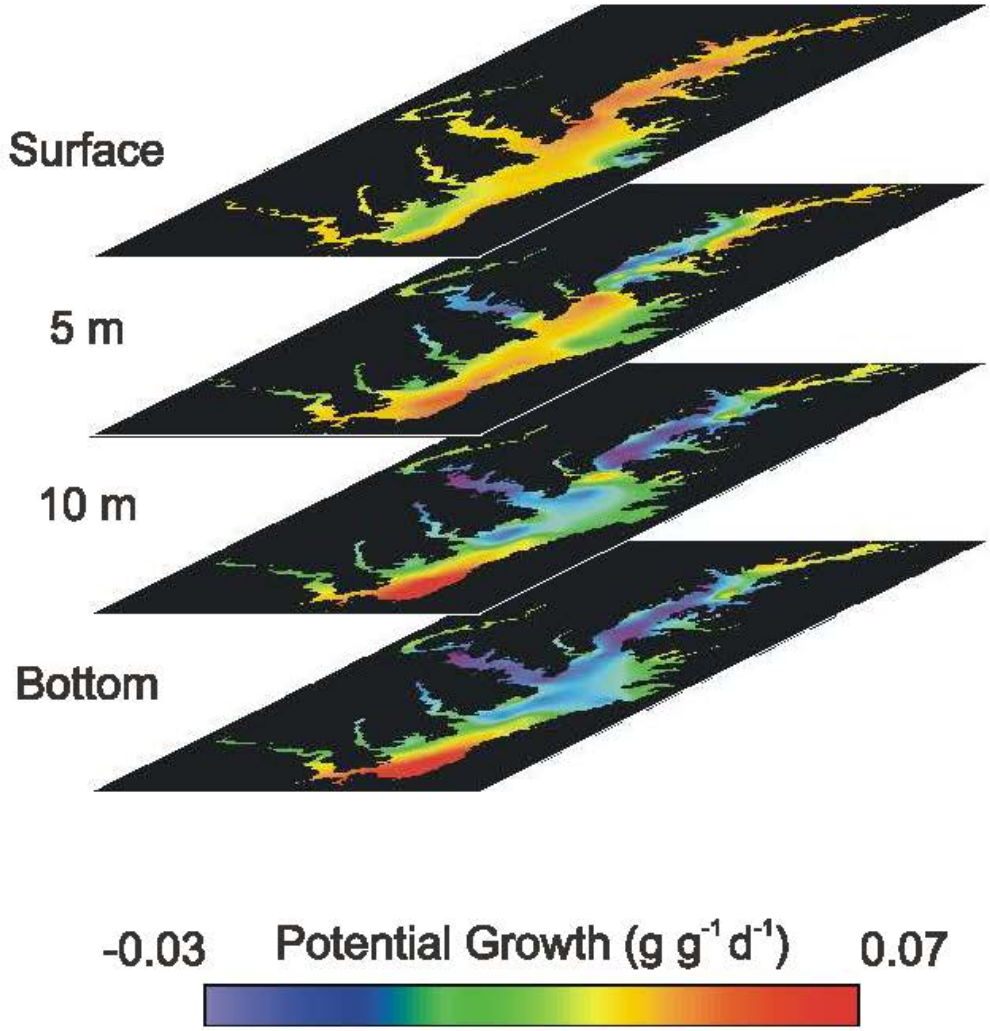
Striped Bass Annual Growth Pattern



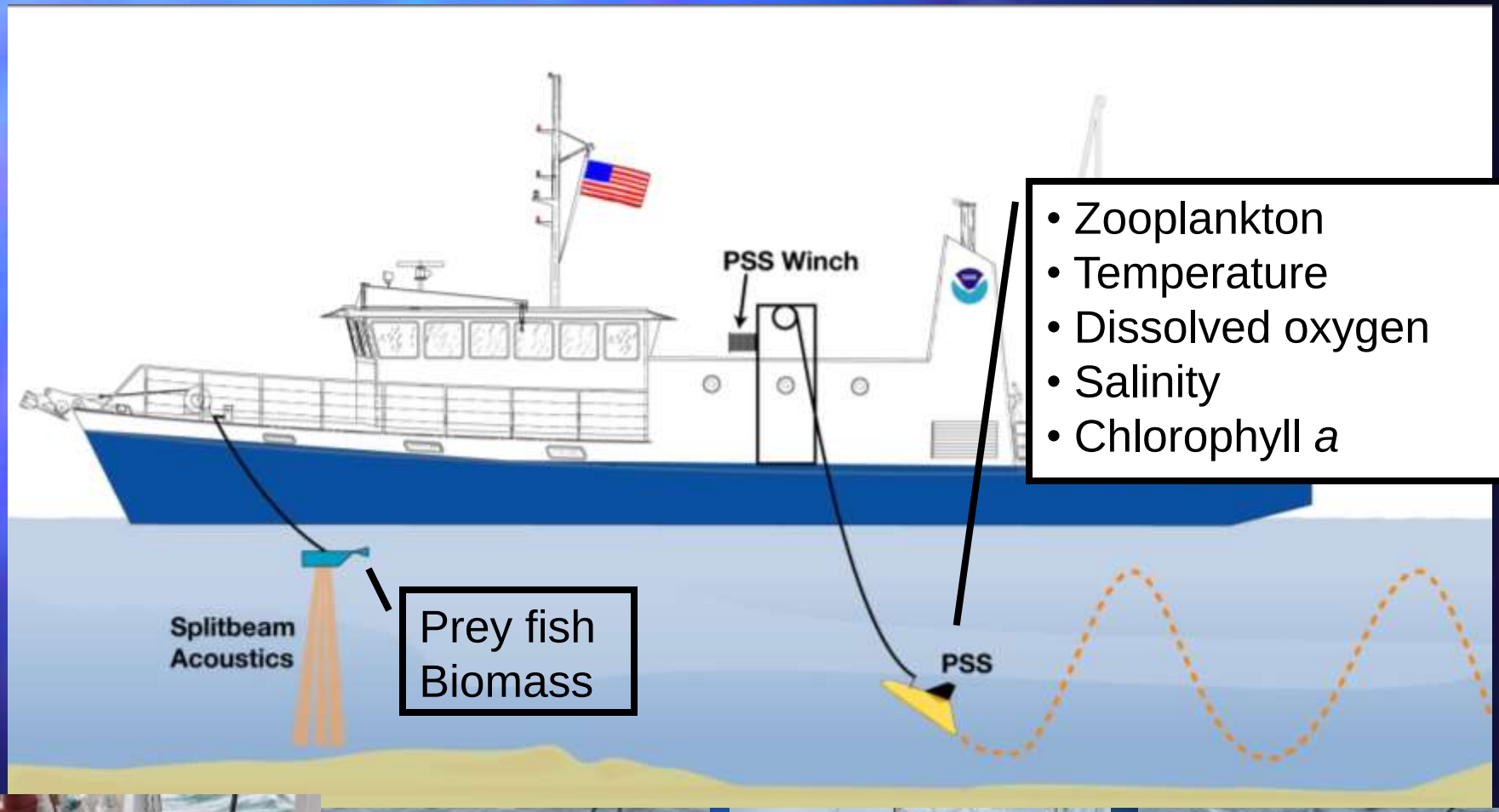


Striped Bass Potential Growth

Chesapeake Bay



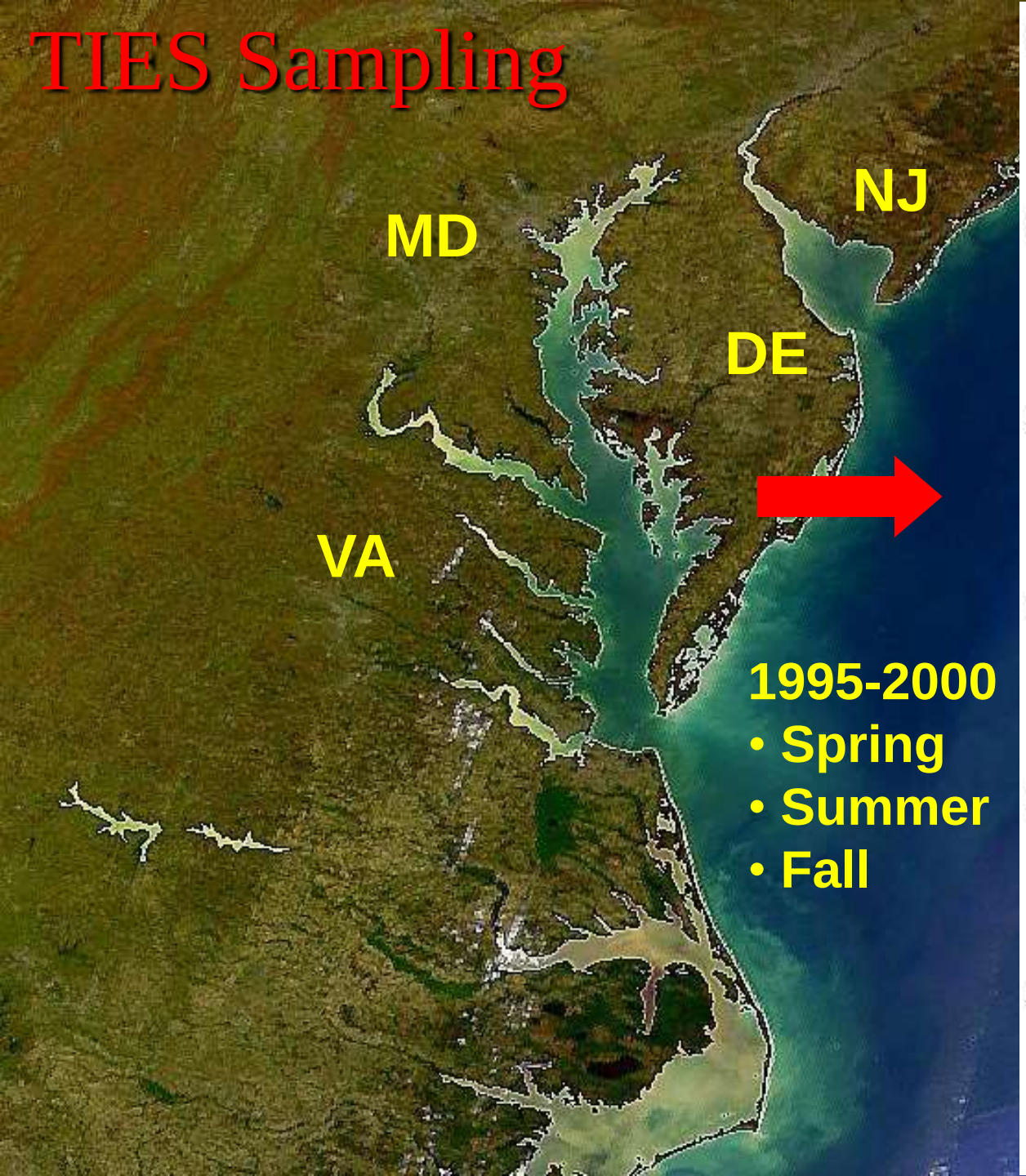
Baseline Field Sampling



- Zooplankton
- Temperature
- Dissolved oxygen
- Salinity
- Chlorophyll *a*

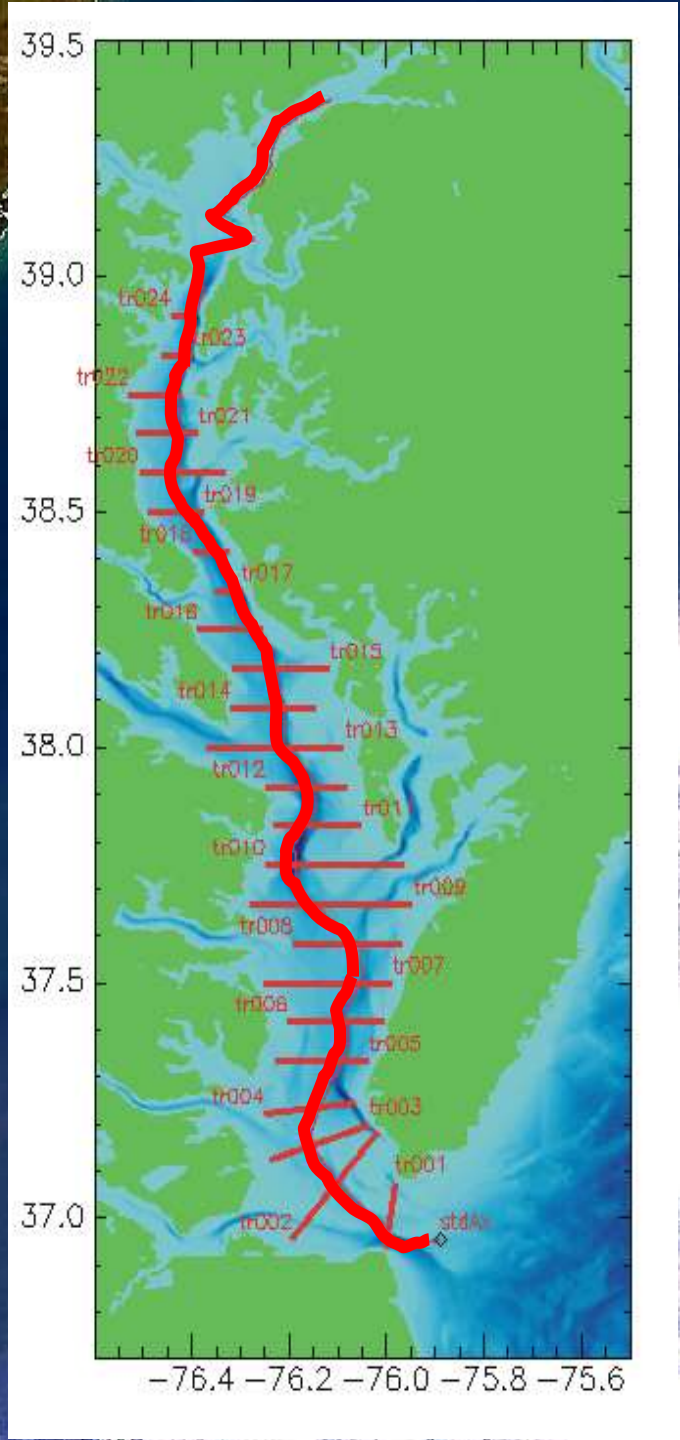
Prey fish Biomass

TIES Sampling

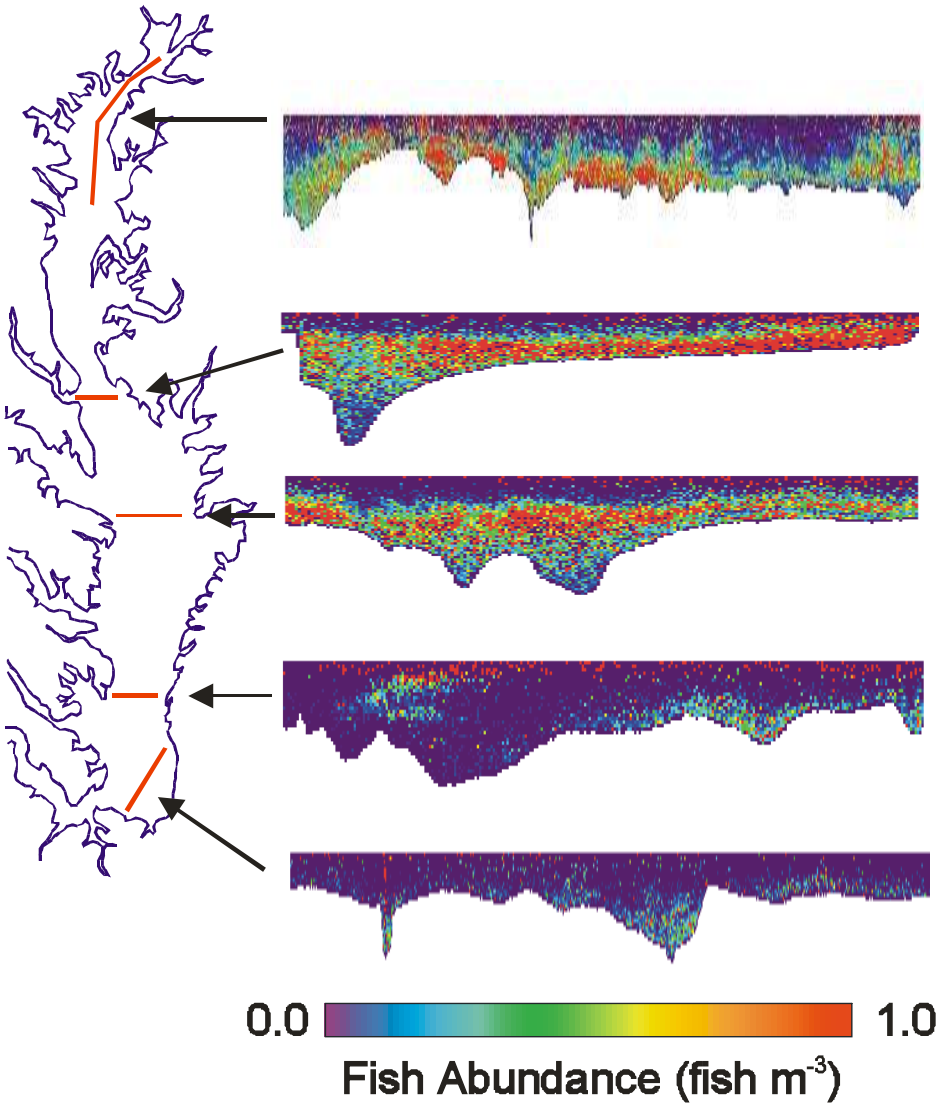


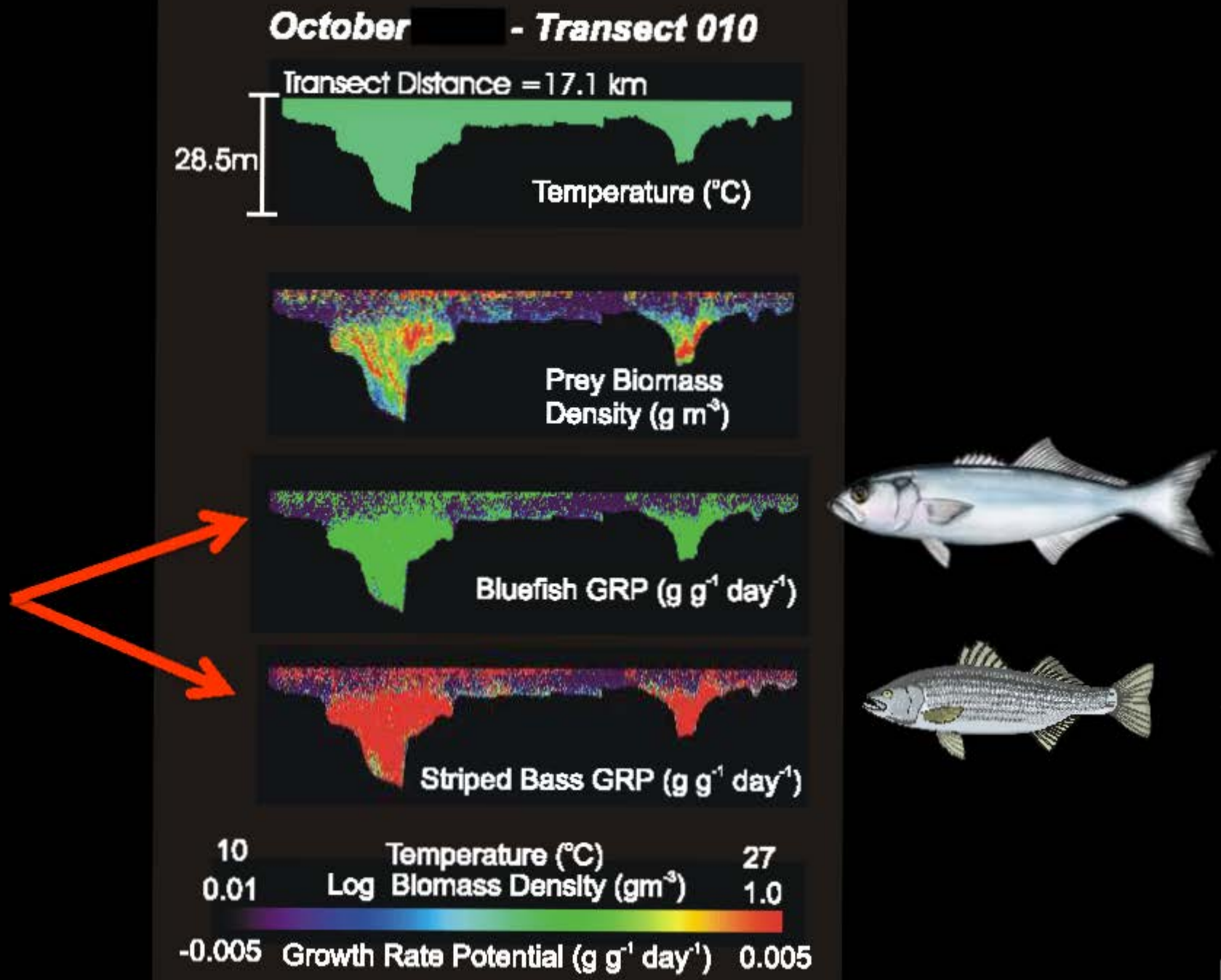
1995-2000

- **Spring**
- **Summer**
- **Fall**



Acoustic Estimates of Fish Abundance from Selected Transects: October

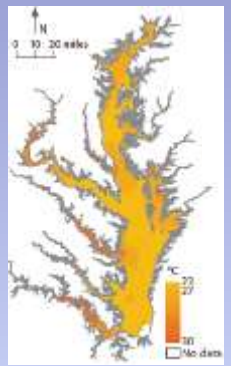


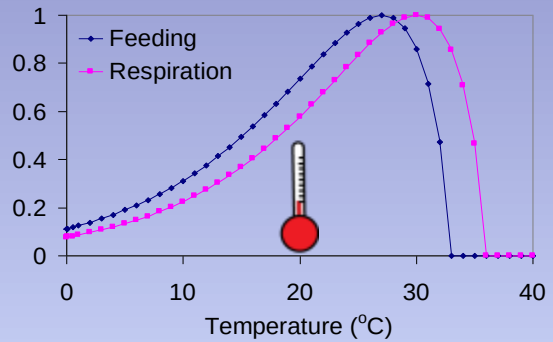

October [redacted] - Transect 010
Transect Distance =17.1 km
28.5m
Temperature (°C)
Prey Biomass Density (g m-3)
Bluefish GRP (g g-1 day-1)
Striped Bass GRP (g g-1 day-1)
10
Temperature (°C)
27
0.01
Log Biomass Density (gm-3)
1.0
-0.005
Growth Rate Potential (g g-1 day-1)
0.005

Bay Anchovy growth rate potential

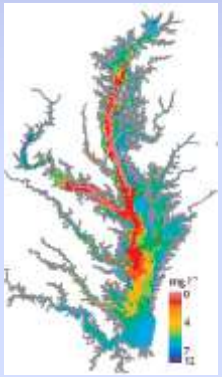
Monitoring Data | Response Scale Functions | Growth Rate Potential

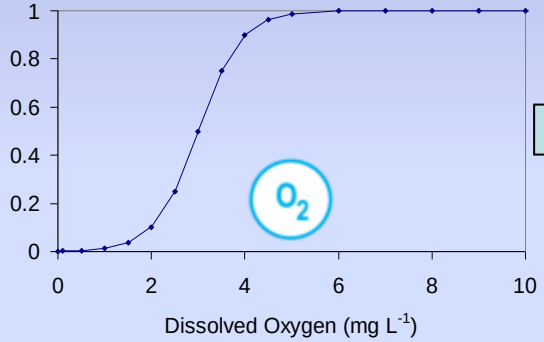
Temperature



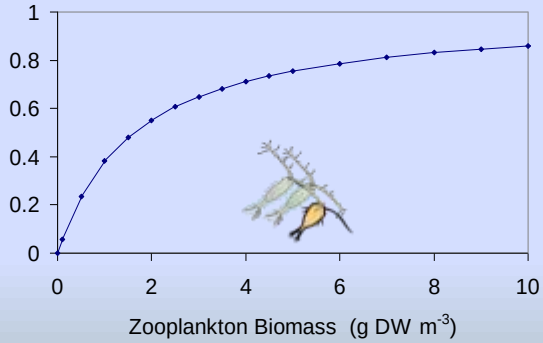


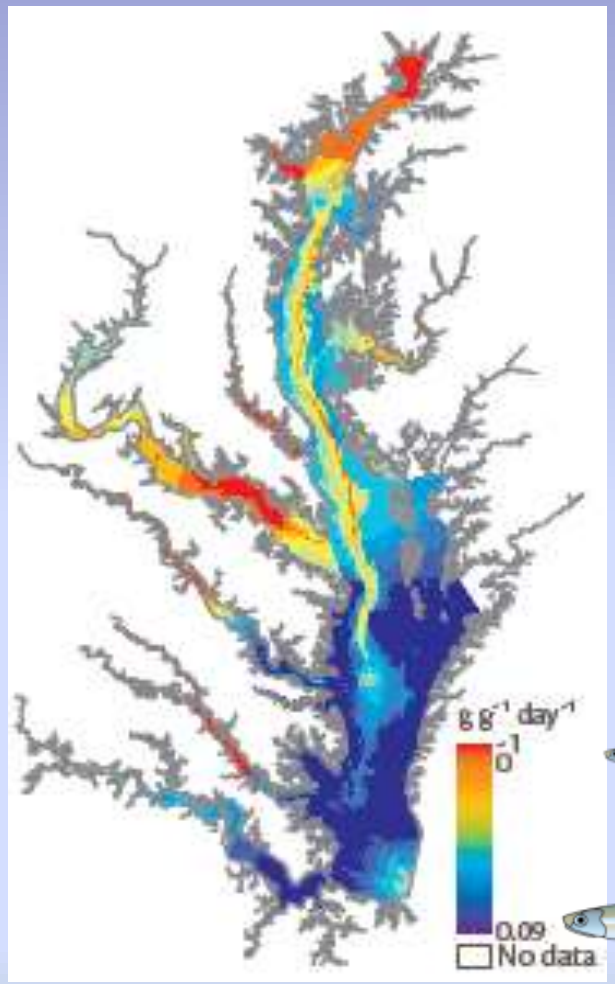
Dissolved Oxygen





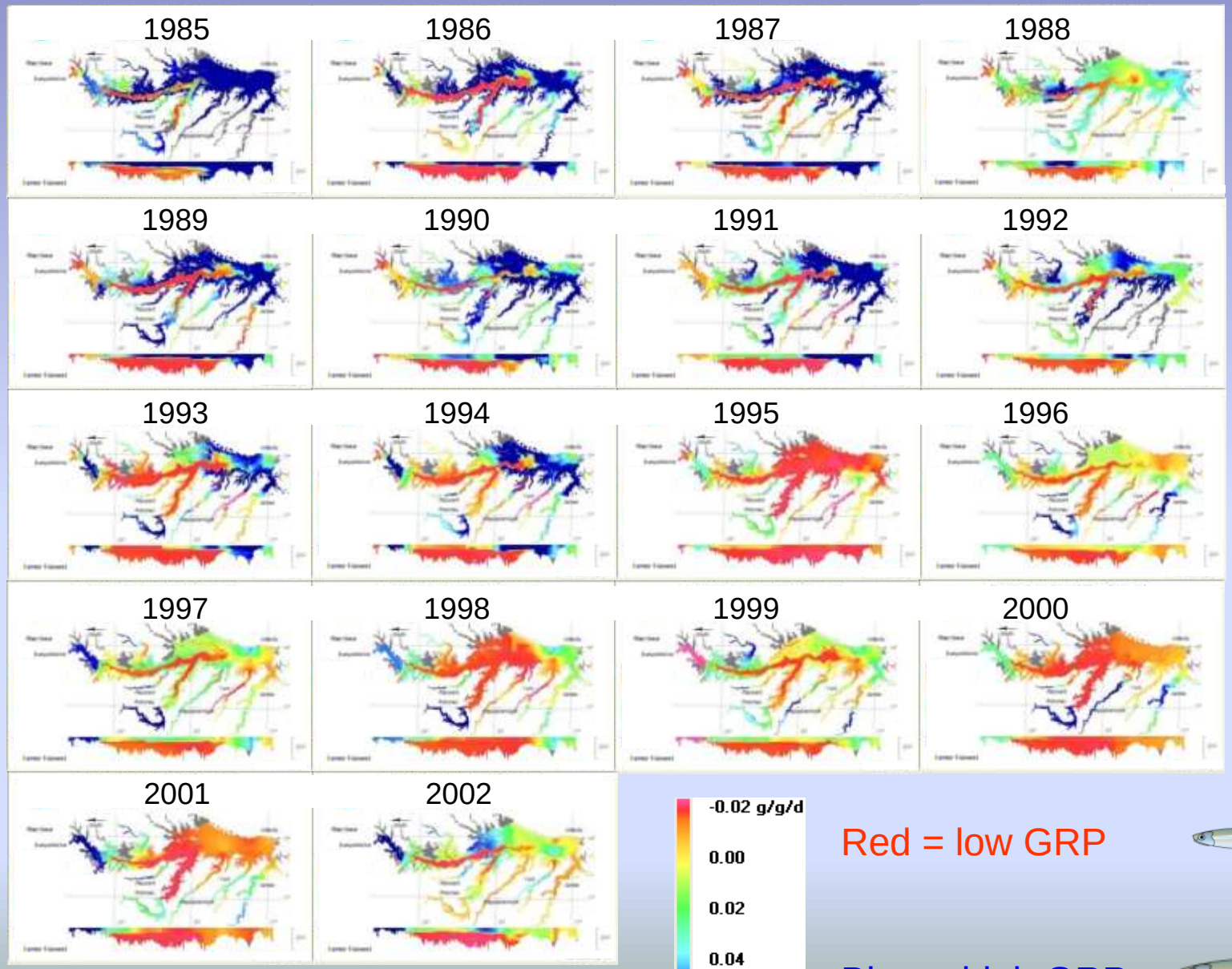
Zooplankton





Response scale functions are based on Brandt et al. 1992; Luo & Brandt 1993

Significant long-term decline in modeled anchovy GRP

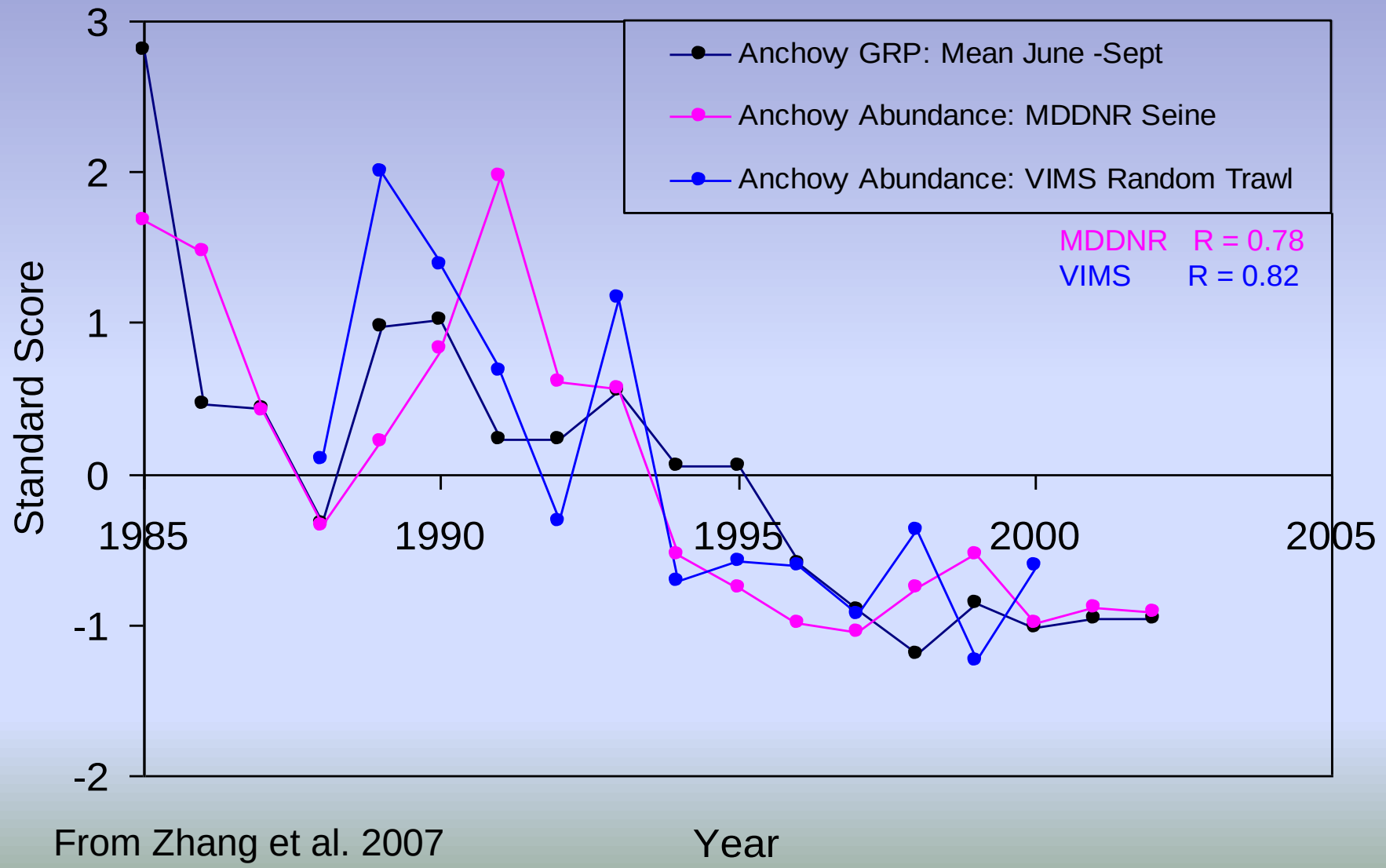


Red = low GRP

Blue = high GRP

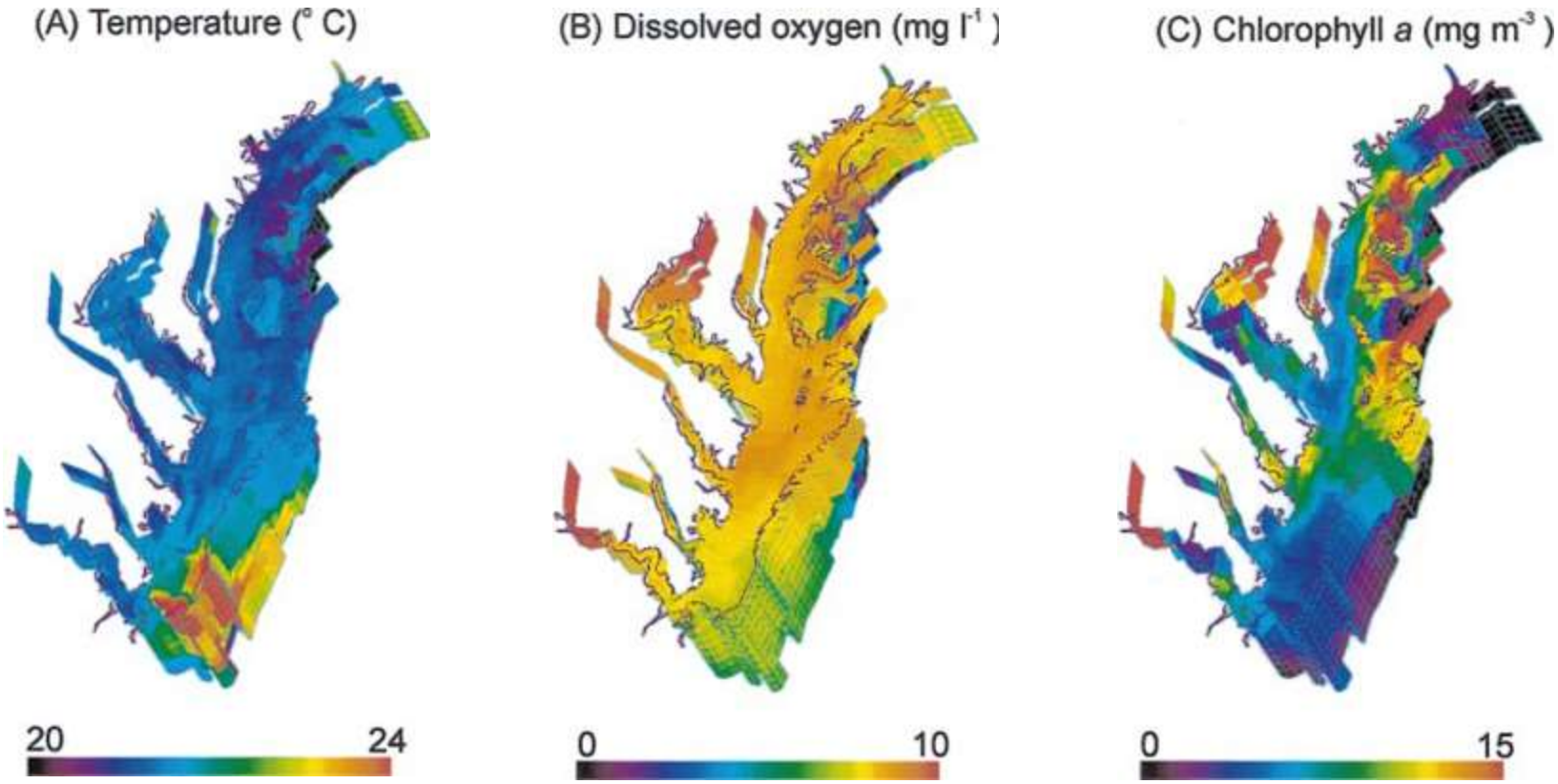
From Zhang et al. 2007

Anchovy growth rate potential is correlated with abundance



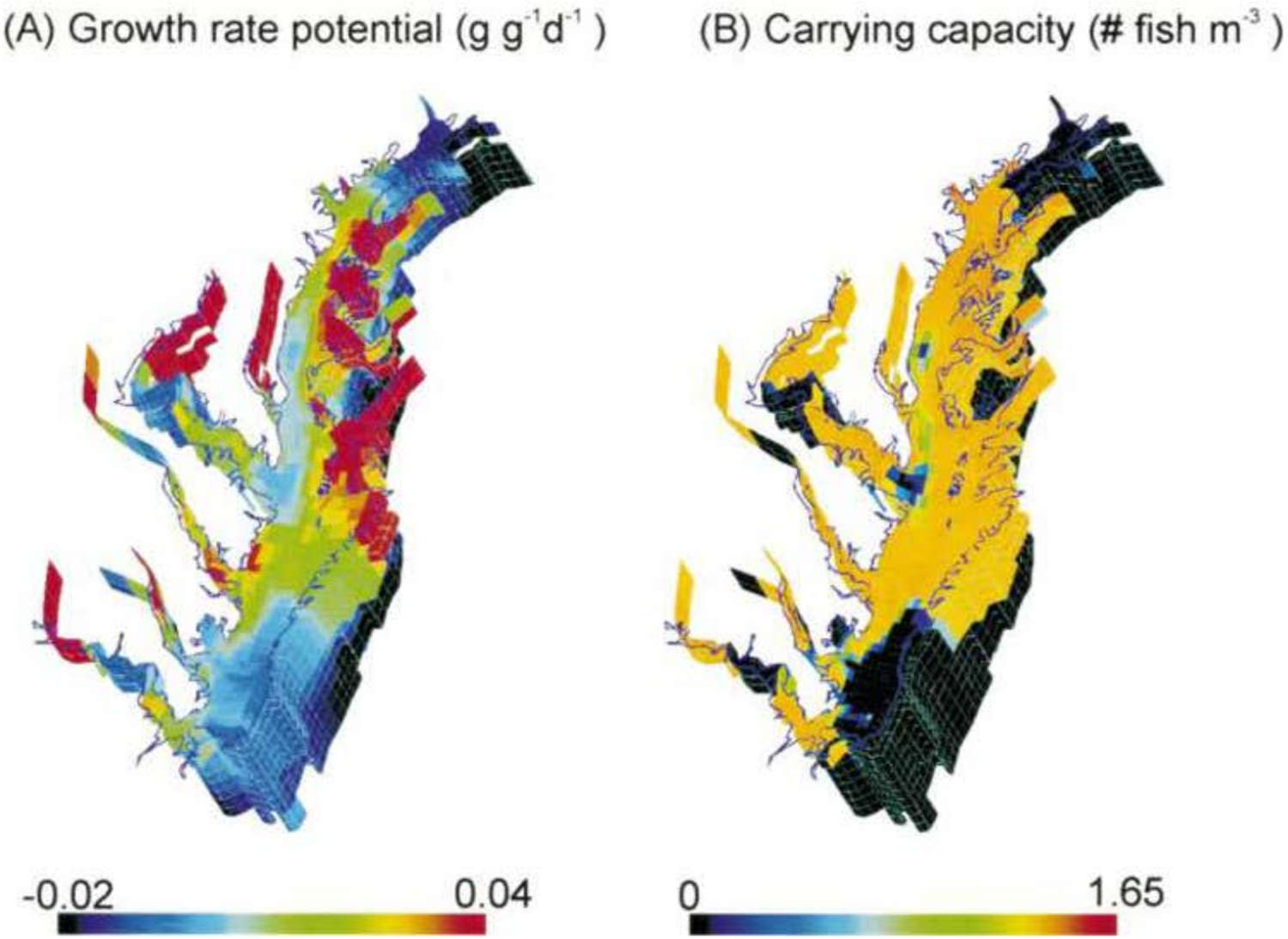
From Zhang et al. 2007

Menhaden Growth Rate Potential predicted from 3-D Water Quality Model of Chesapeake Bay July 1



from Luo et al. 2001

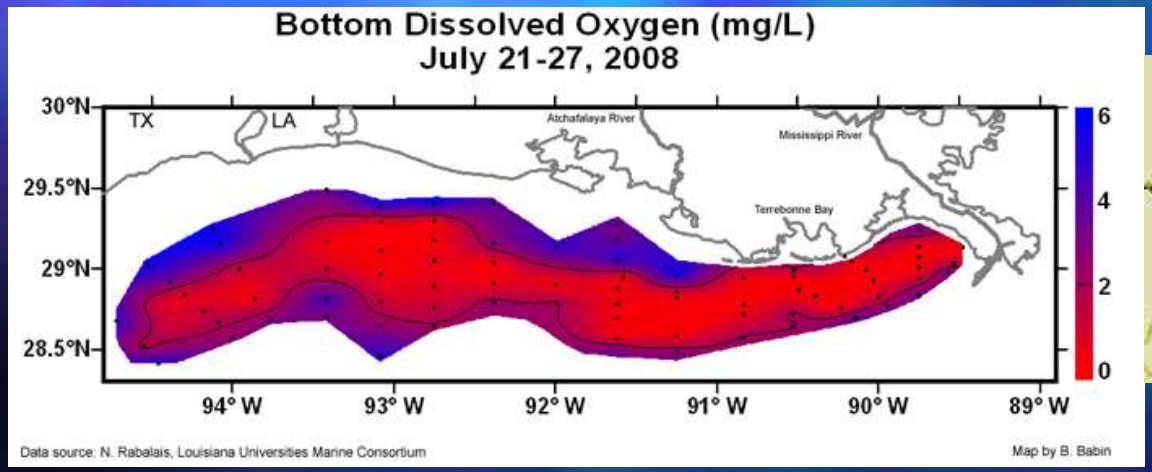
Atlantic Menhaden

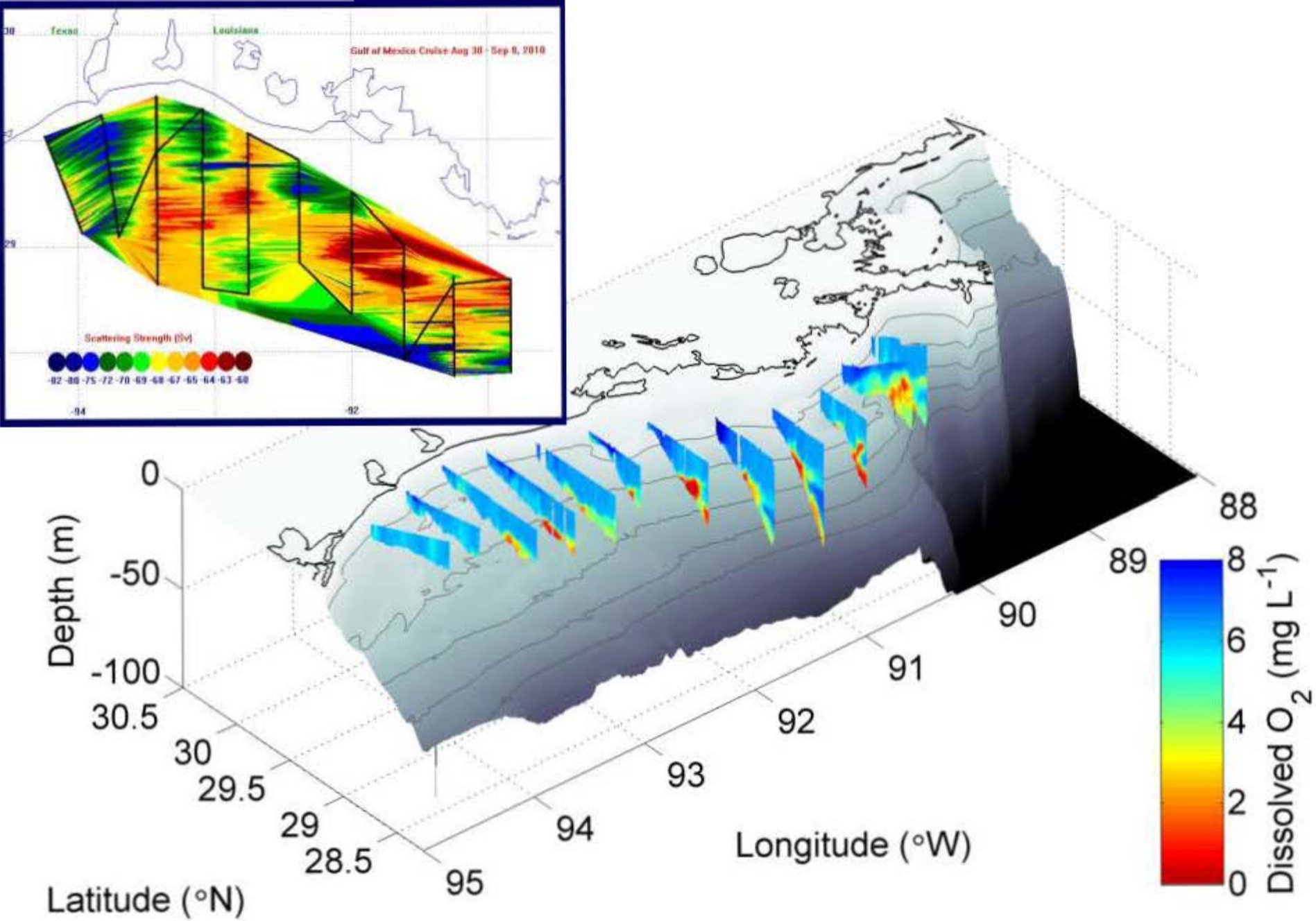


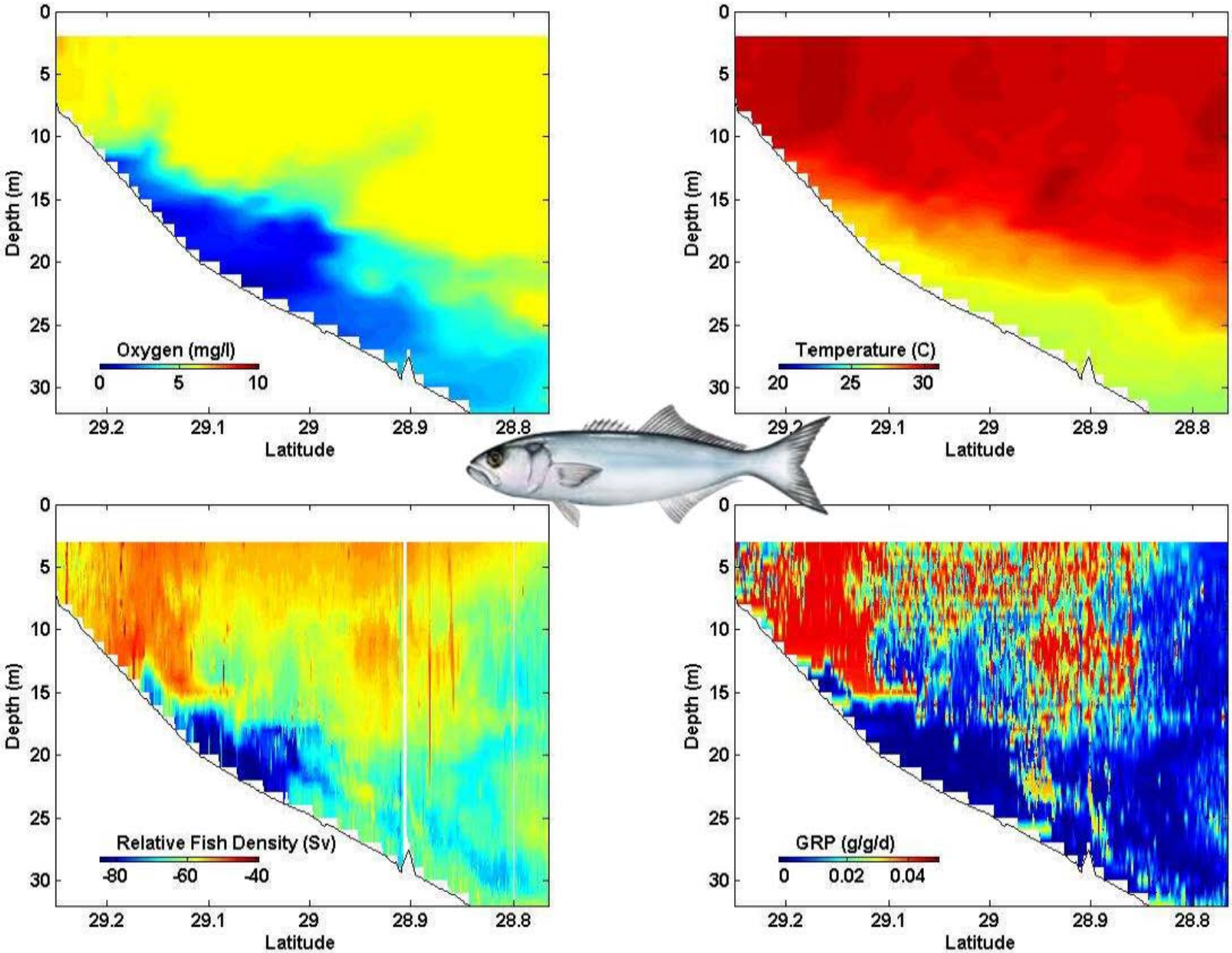
from Luo et al. 2001

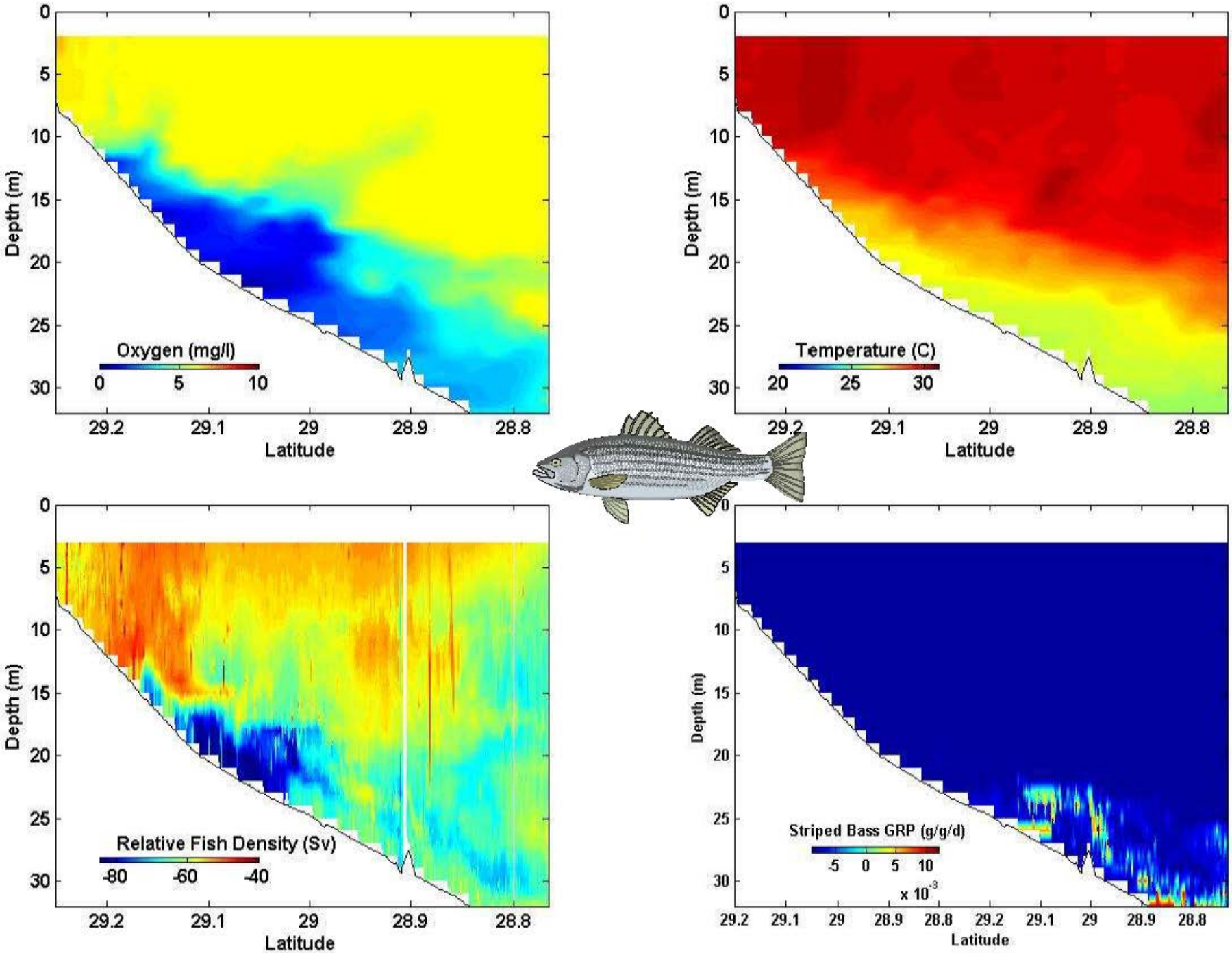
Northern Gulf of Mexico Hypoxia

- Hypoxia occurs annually in the bottom waters of the Northern Gulf of Mexico
- Spatial extent averages ~ 16,000 – 20,000 km^2
- Typically occurs June - September

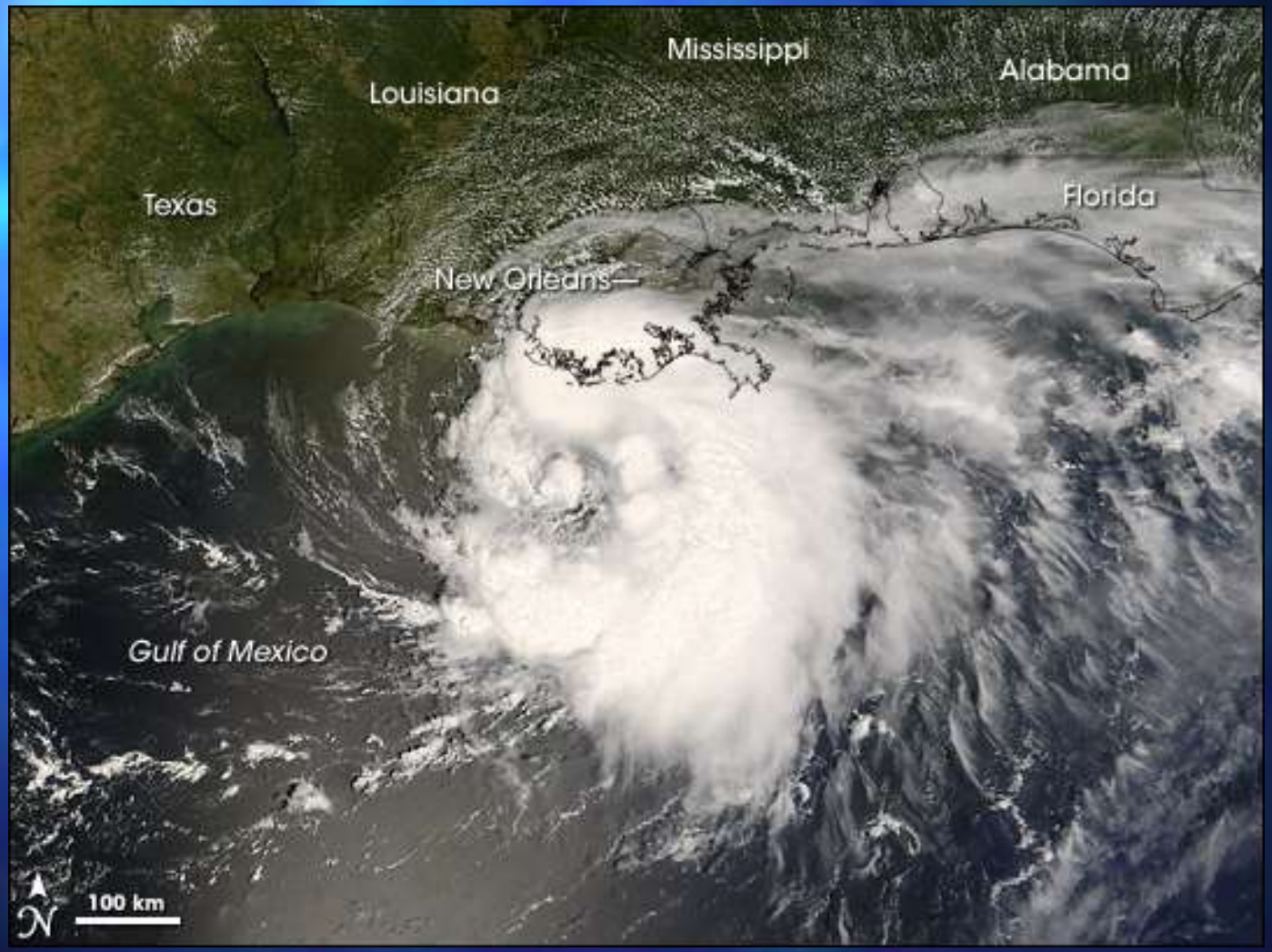



Texas
Louisiana
Gulf of Mexico Cruise Aug 30 - Sep 8, 2010
Scattering Strength (Sv)
-82 -80 -75 -72 -70 -69 -68 -67 -65 -64 -63 -60
-94
-92
Depth (m)
0
-50
-100
30.5
30
29.5
29
28.5
Latitude (°N)
95
94
93
92
91
90
89
88
Longitude (°W)
8
6
4
2
0
Dissolved O_2 (mg L^{-1})

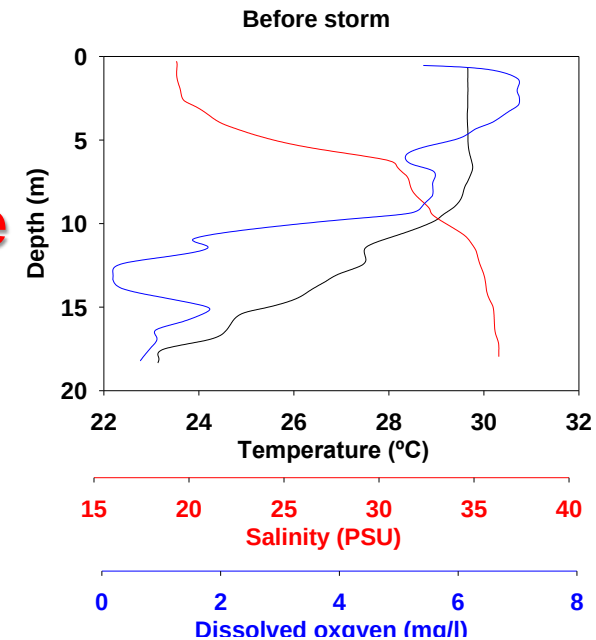

Depth (m)
Latitude
Oxygen (mg/l)
0 5 10
Temperature (C)
20 25 30
Relative Fish Density (Sv)
-80 -60 -40
GRP (g/g/d)
0 0.02 0.04
0 5 10 15 20 25 30
29.2 29.1 29 28.9 28.8

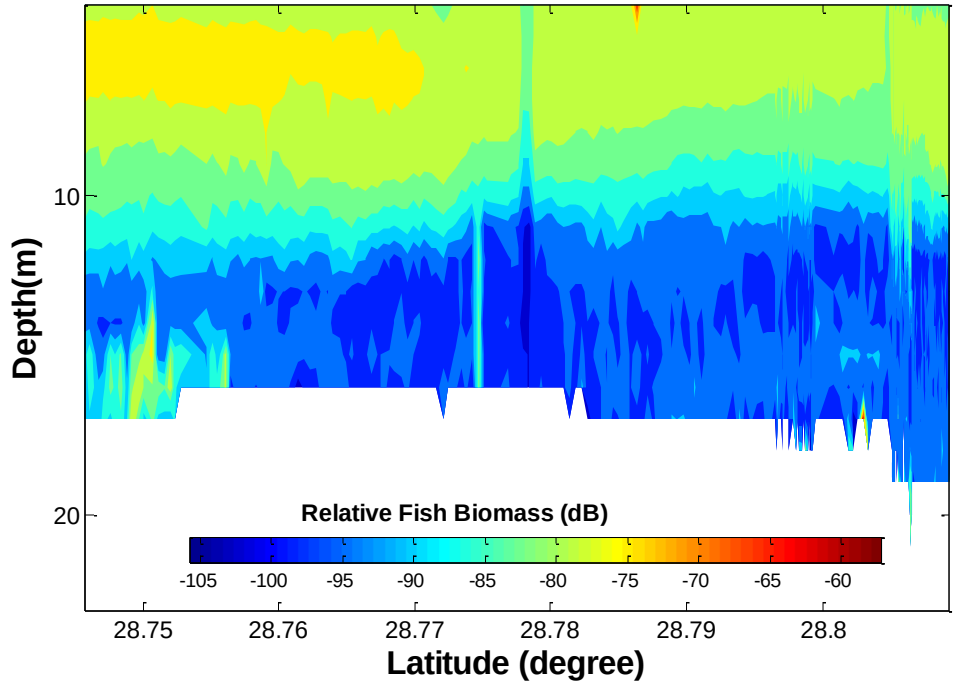

Depth (m)
Oxygen (mg/l)
0 5 10
Latitude
Temperature (C)
20 25 30
Relative Fish Density (Sv)
-80 -60 -40
Striped Bass GRP (g/g/d)
-5 0 5 10
x 10^-3
29.2 29.1 29 28.9 28.8

Tropical Storm Edouard

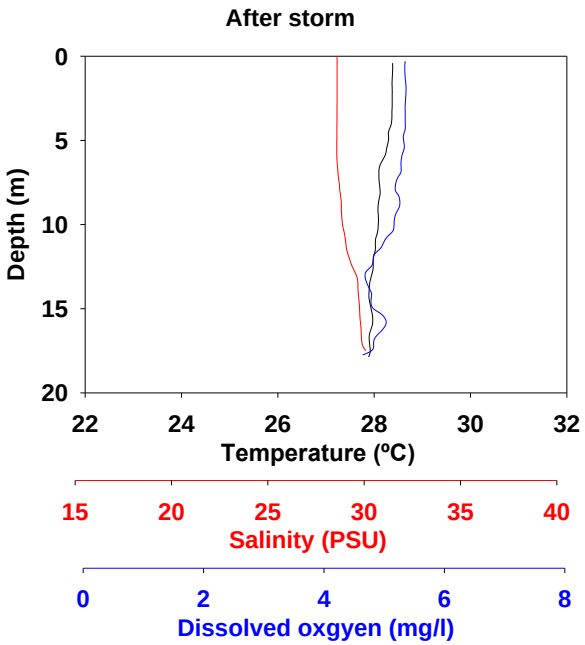


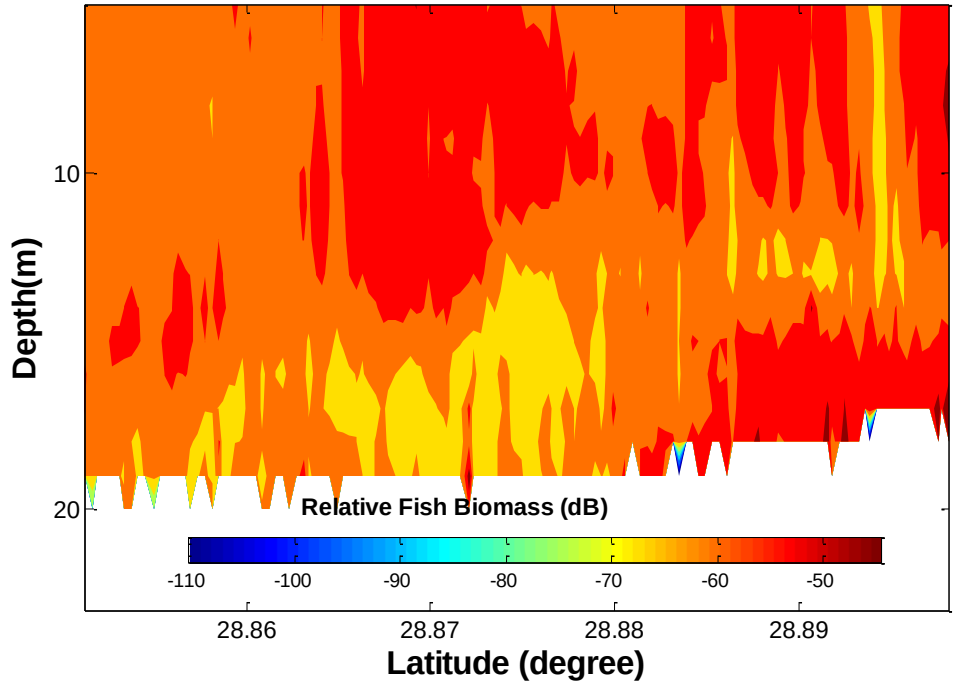
Before Storm





After Storm

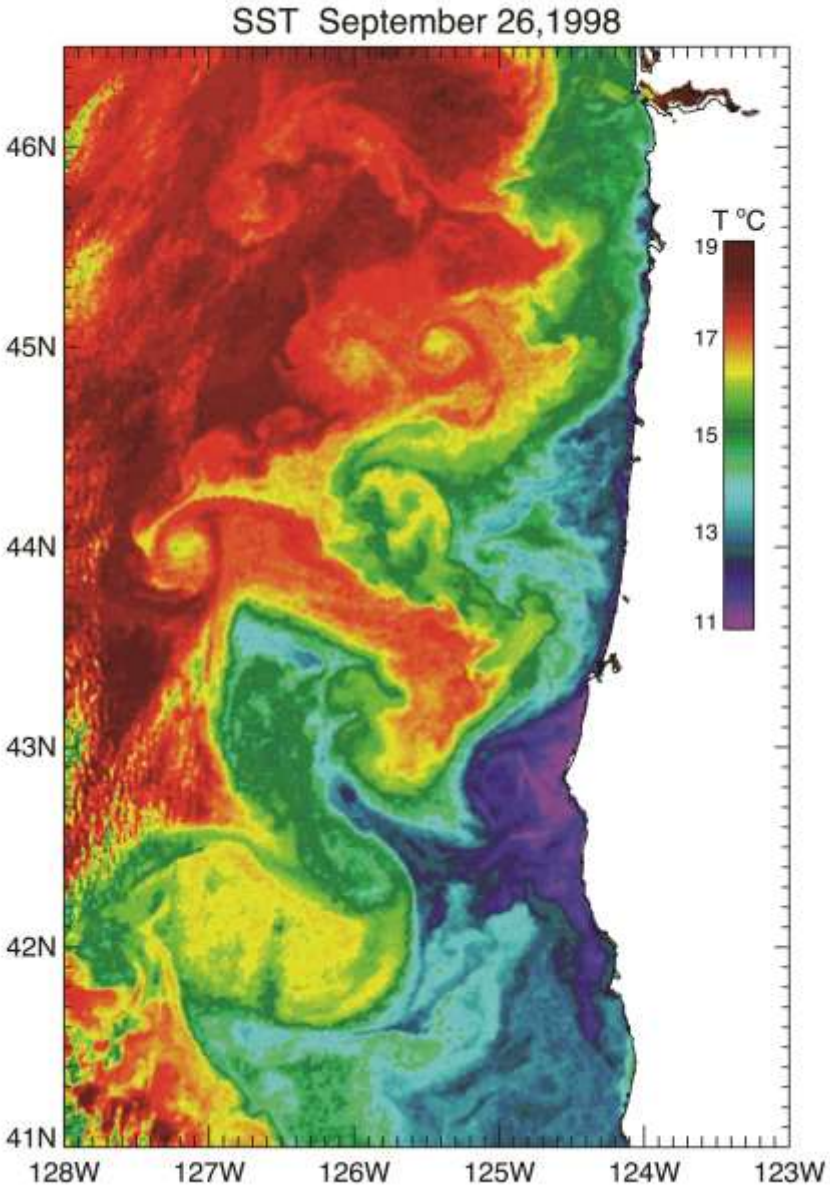




North Pacific Applications?

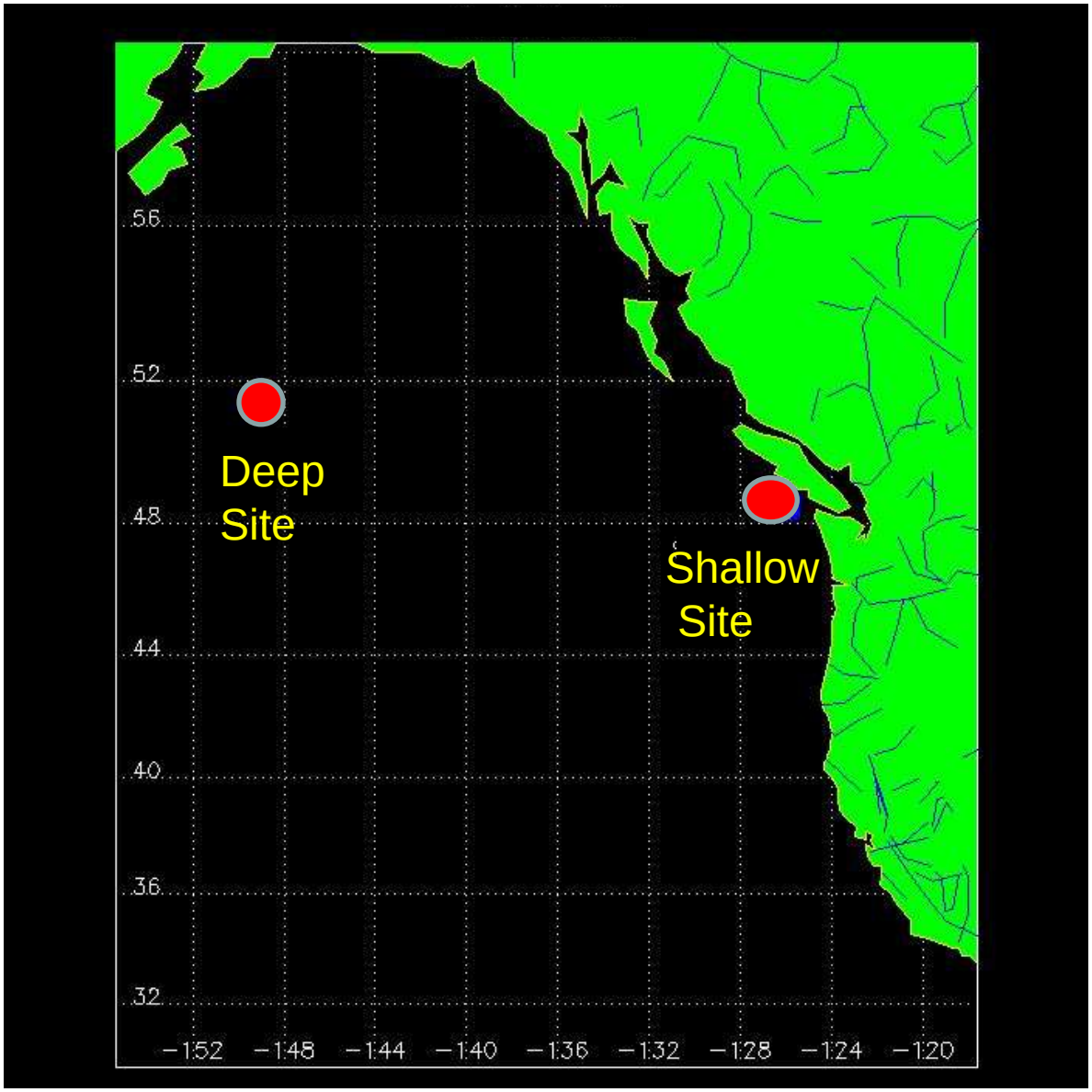
- Use spatially-explicit, foraging, and bioenergetics models to predict habitat quality of key fish species

Temperature
Oxygen
Currents
Prey Density

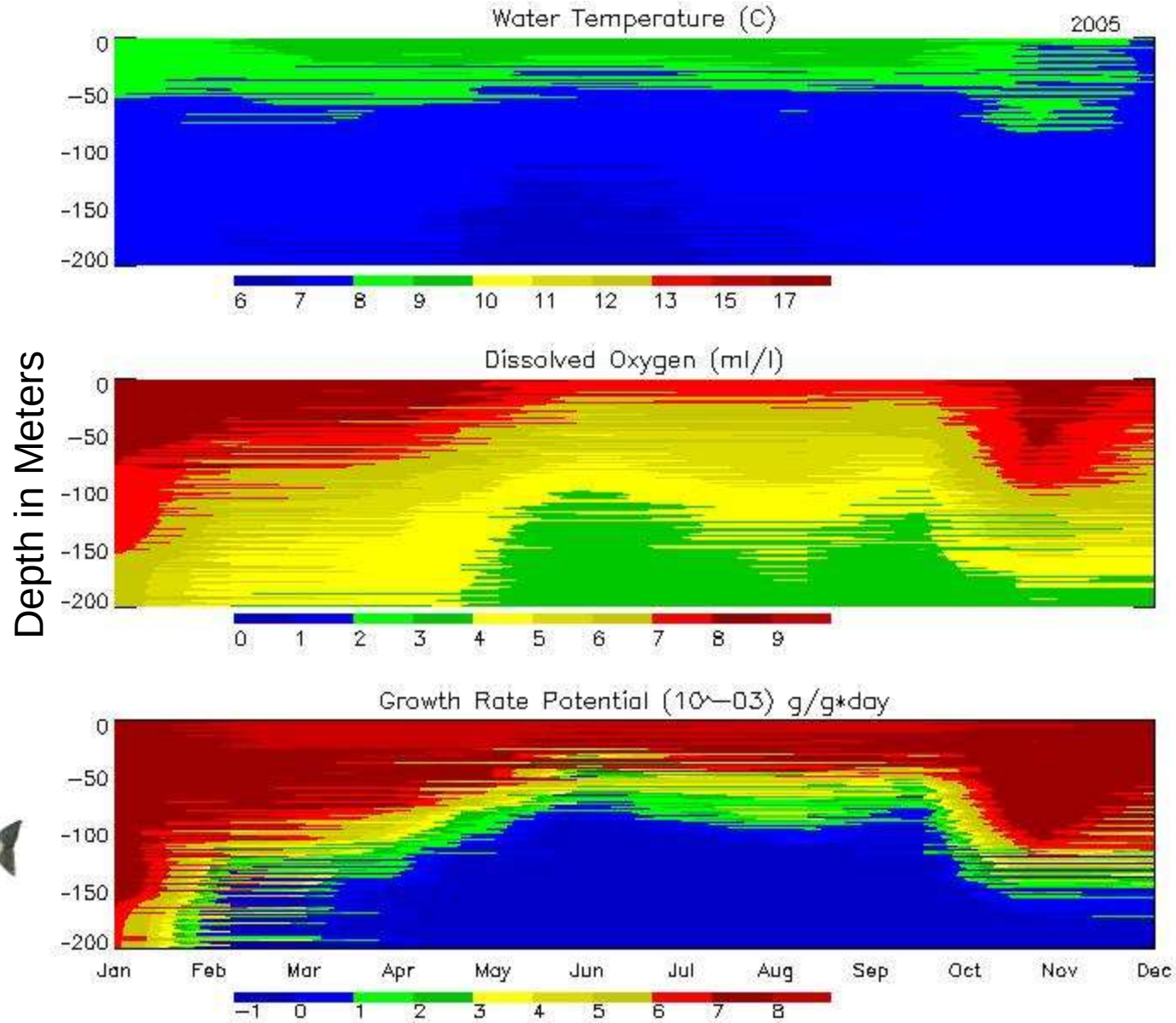


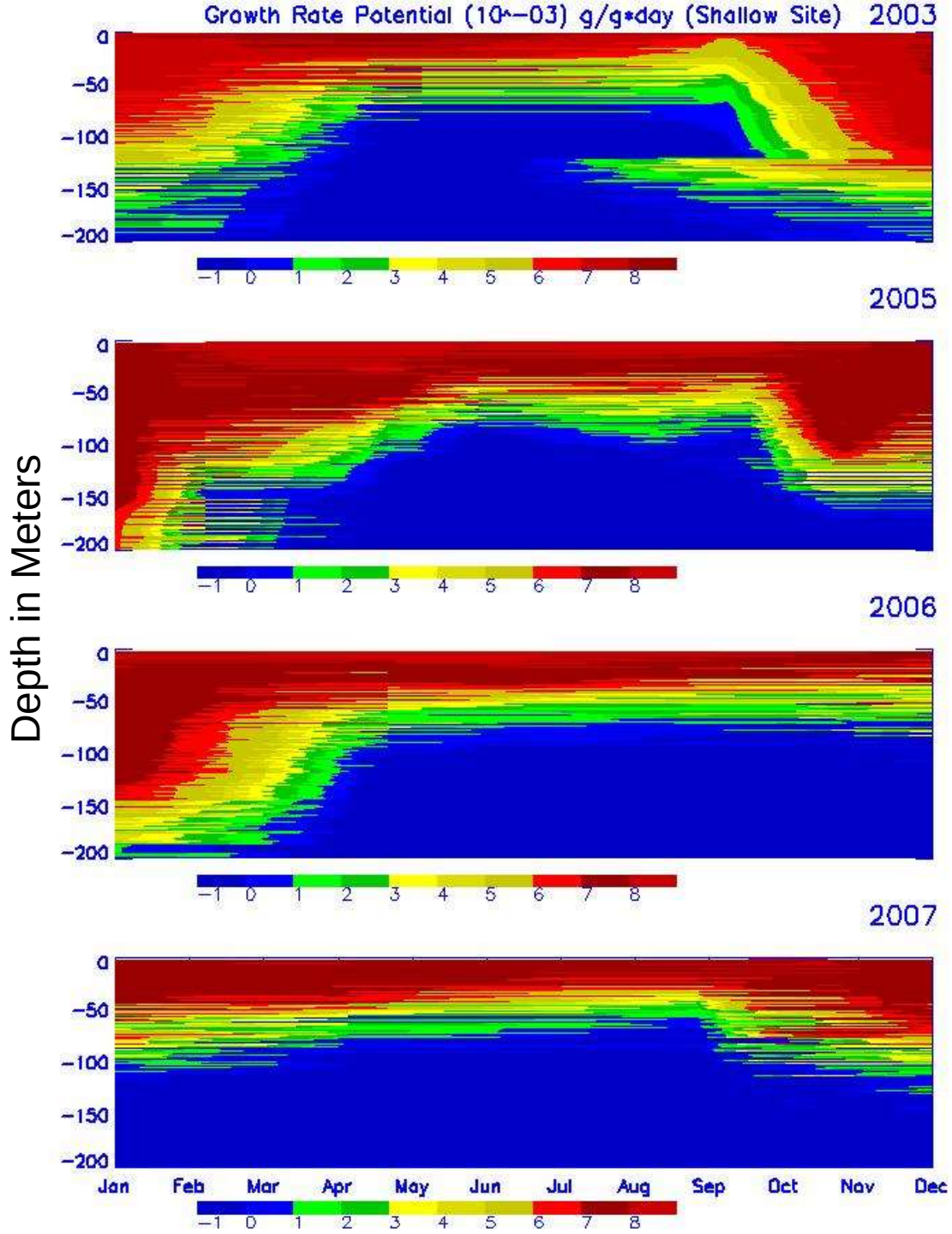
Sea Surface Temperature off NW Coast

North Pacific Study Sites

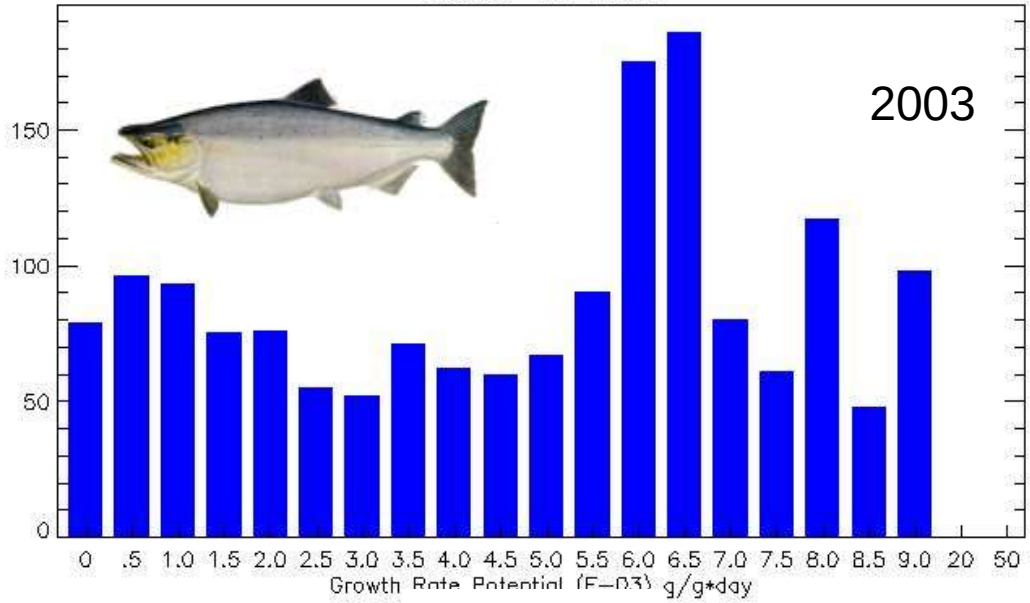


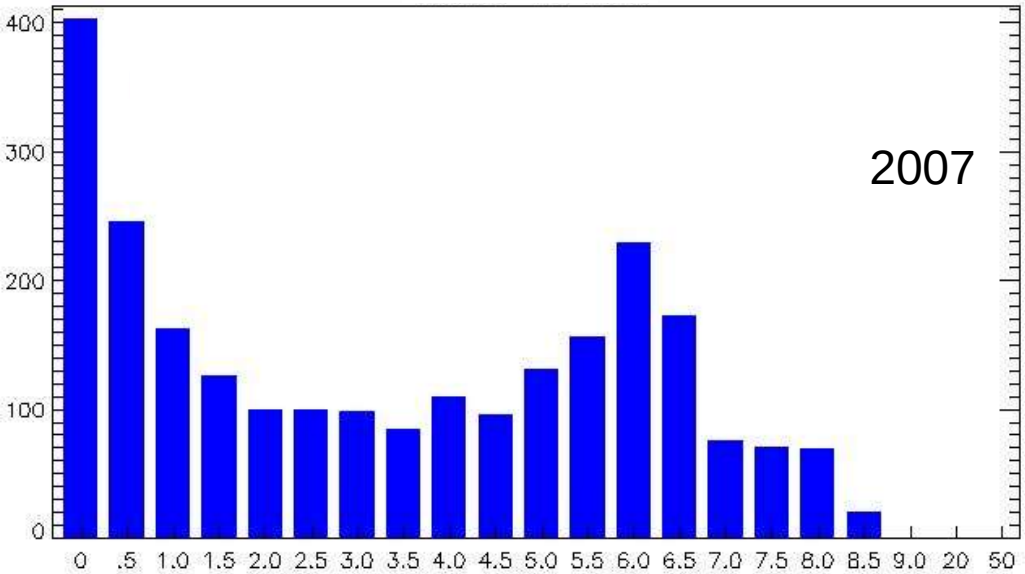
Shallow Site --2005





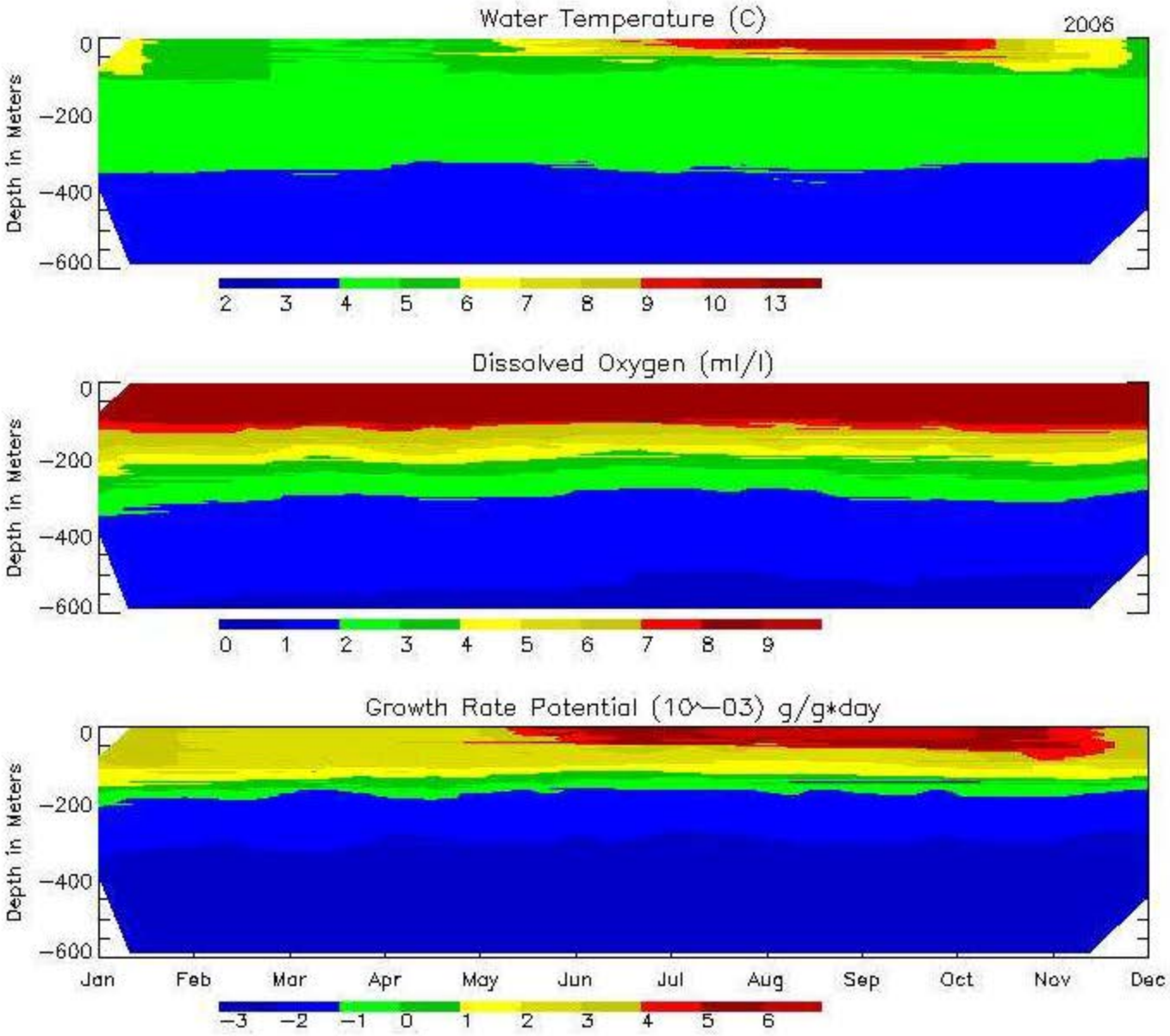
Chinook Salmon Growth Rate Potential Across Different Years



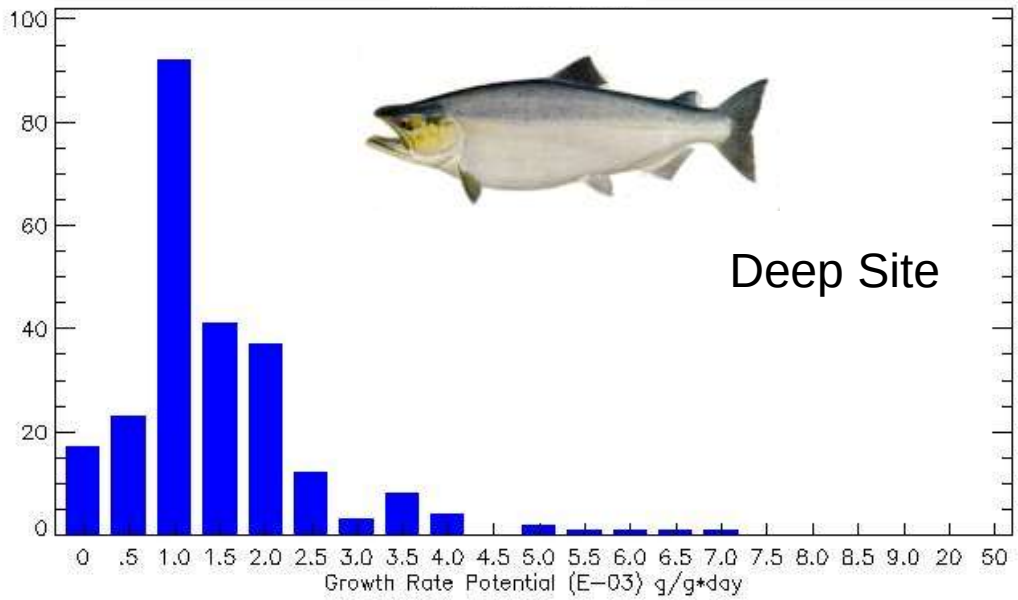


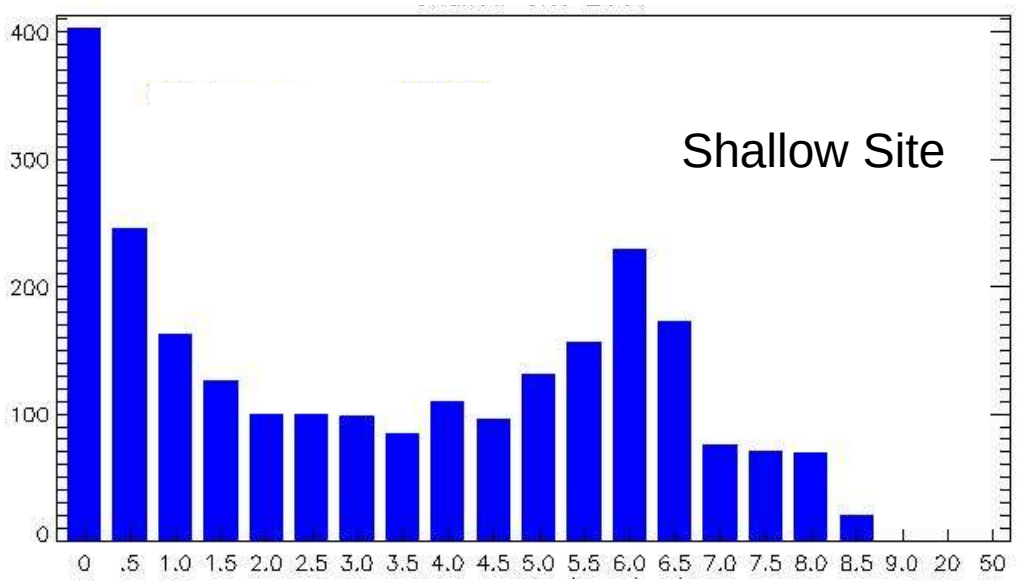
Salmon Growth Rate Potential

Deep Site --2006



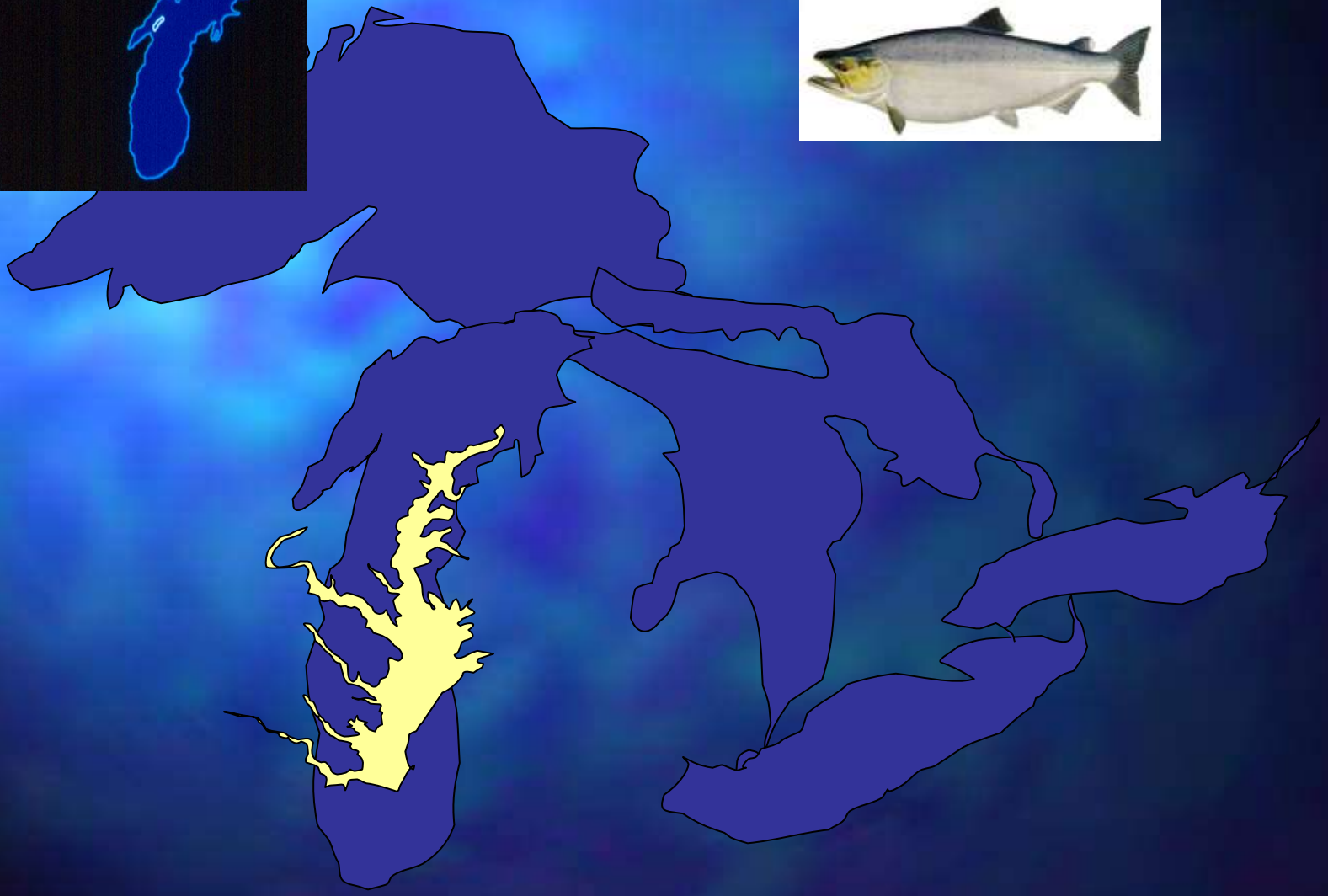
2007



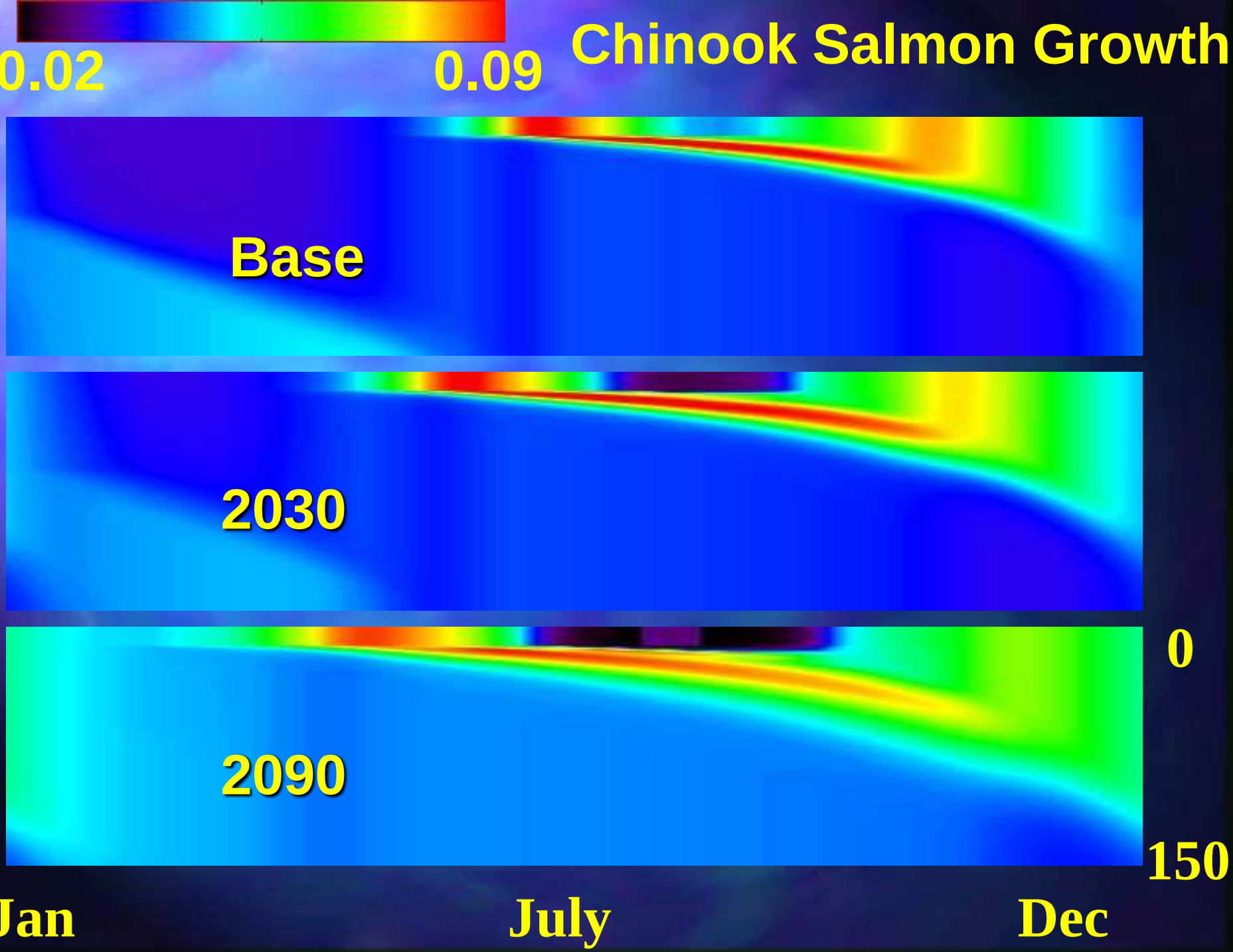


Salmon Growth Rate Potential

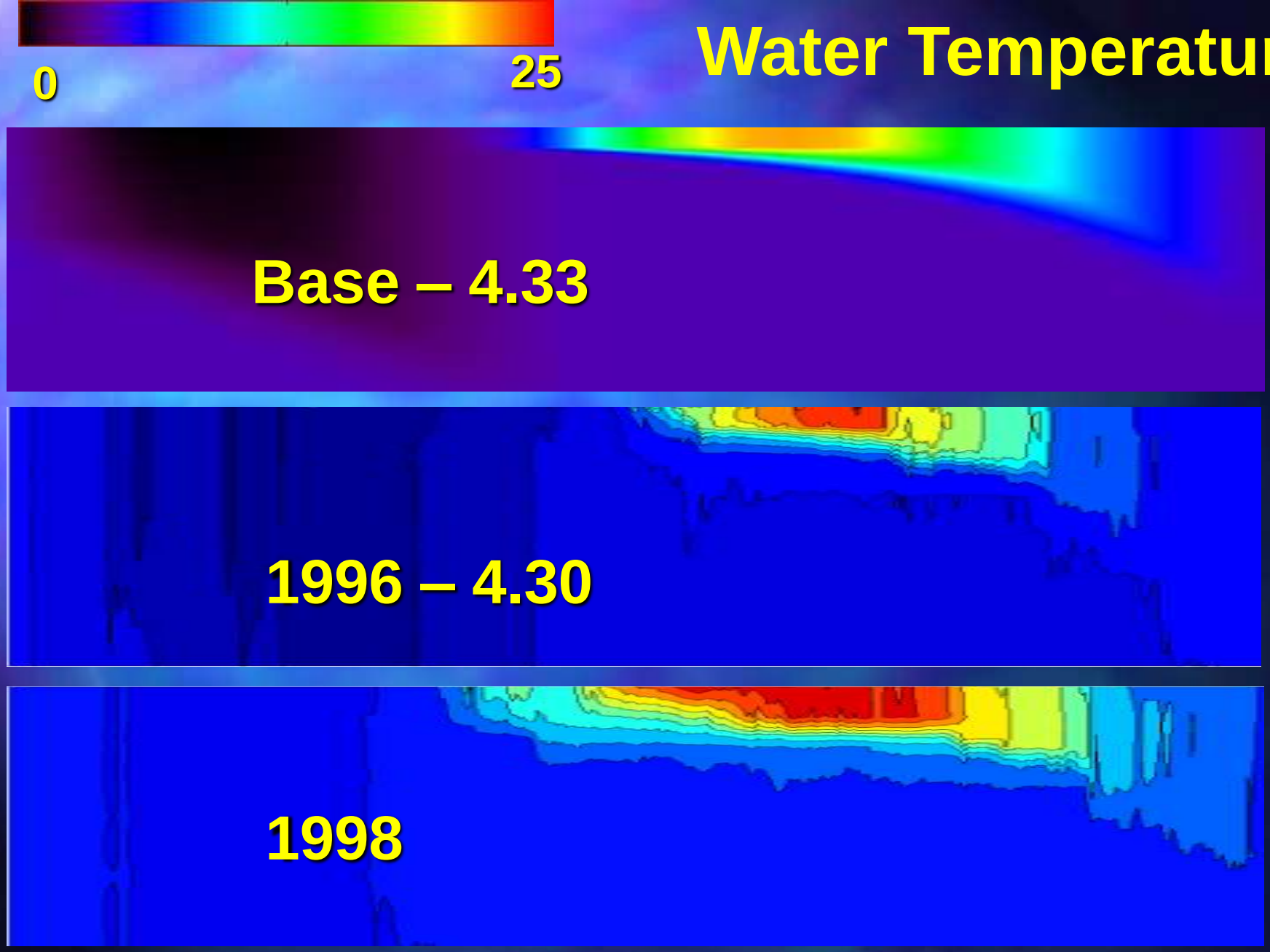
Climate Change Impact on Salmon Growth in The Great Lakes



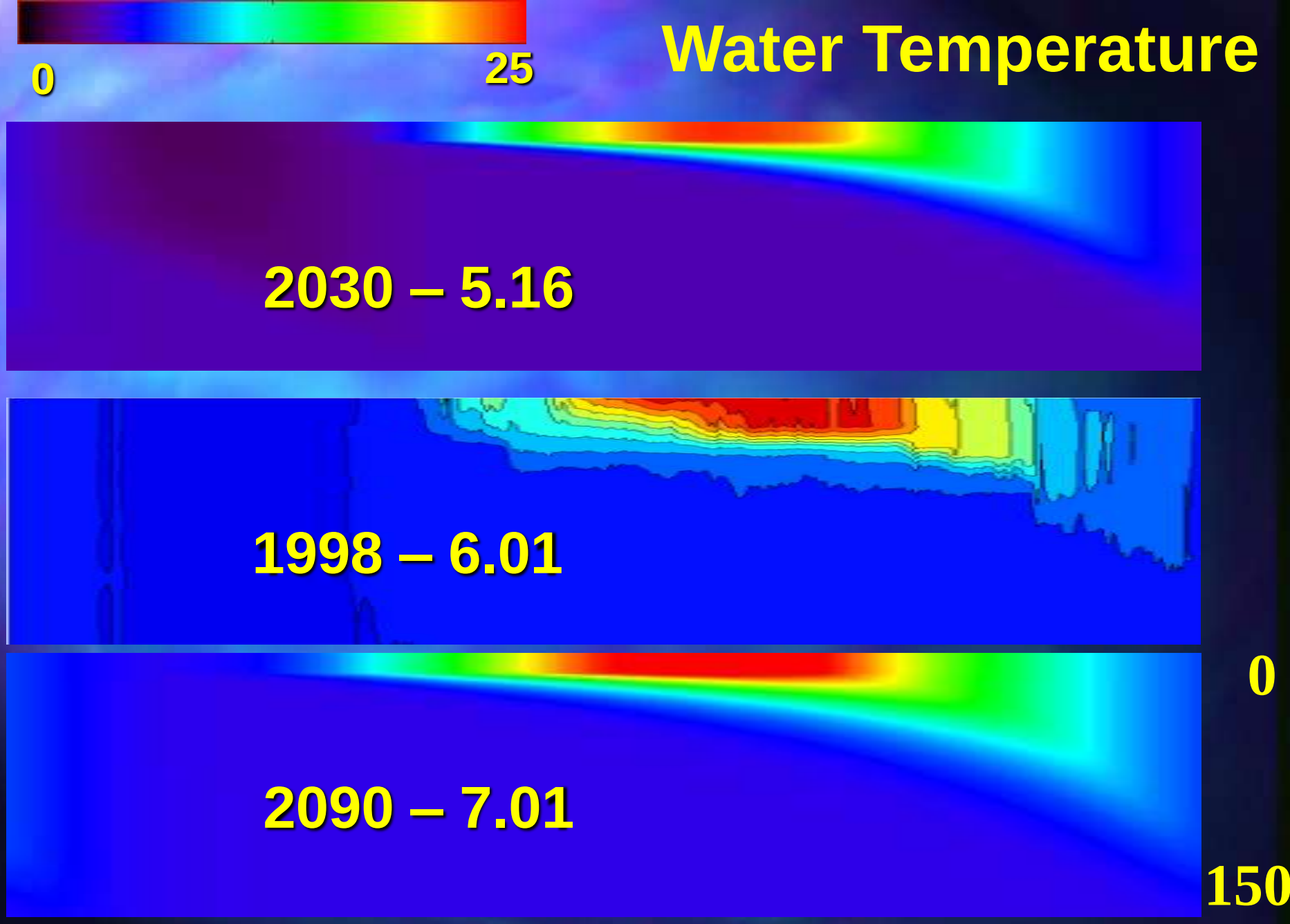
Chinook Salmon Growth

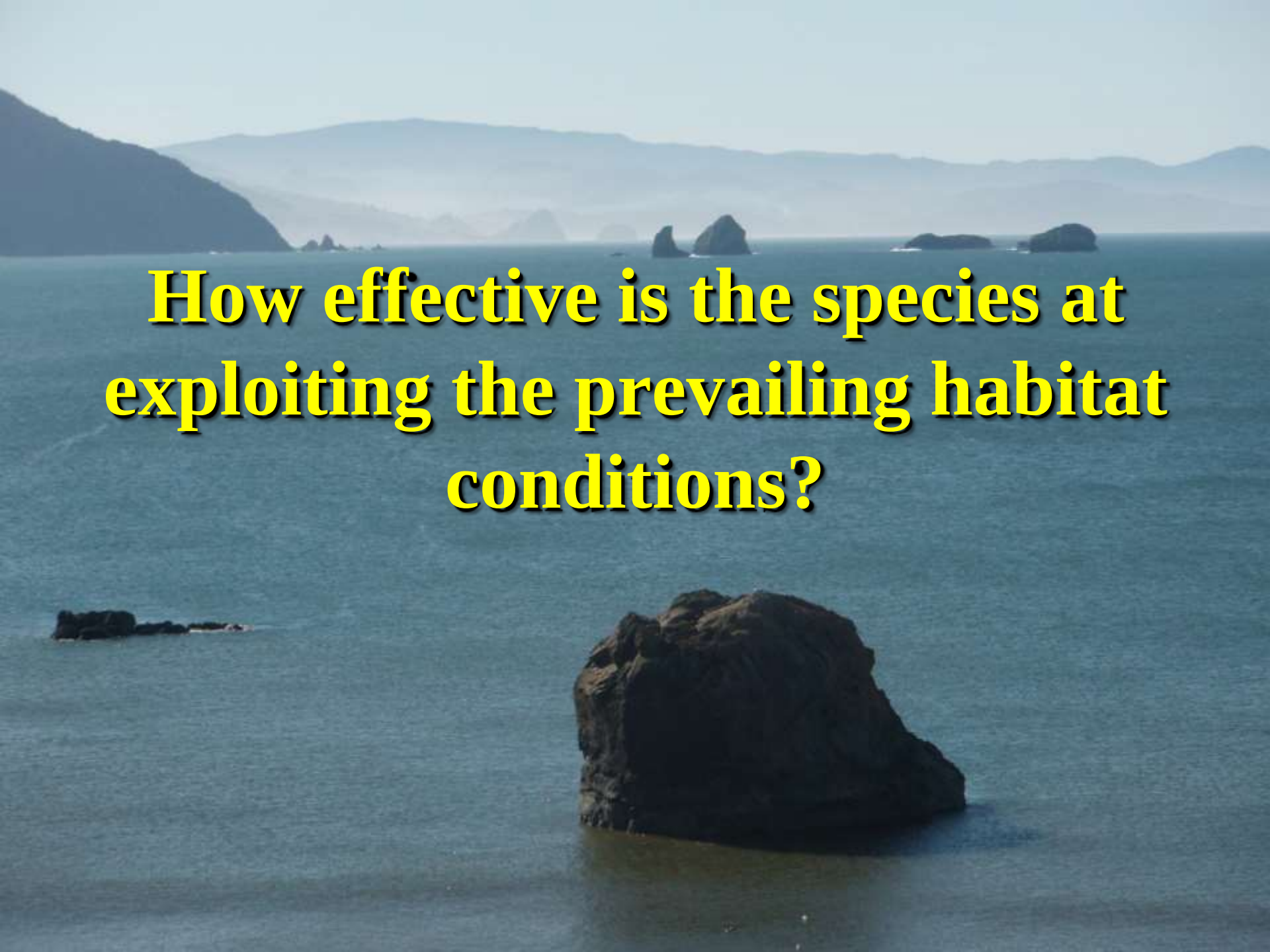


Water Temperature



Water Temperature





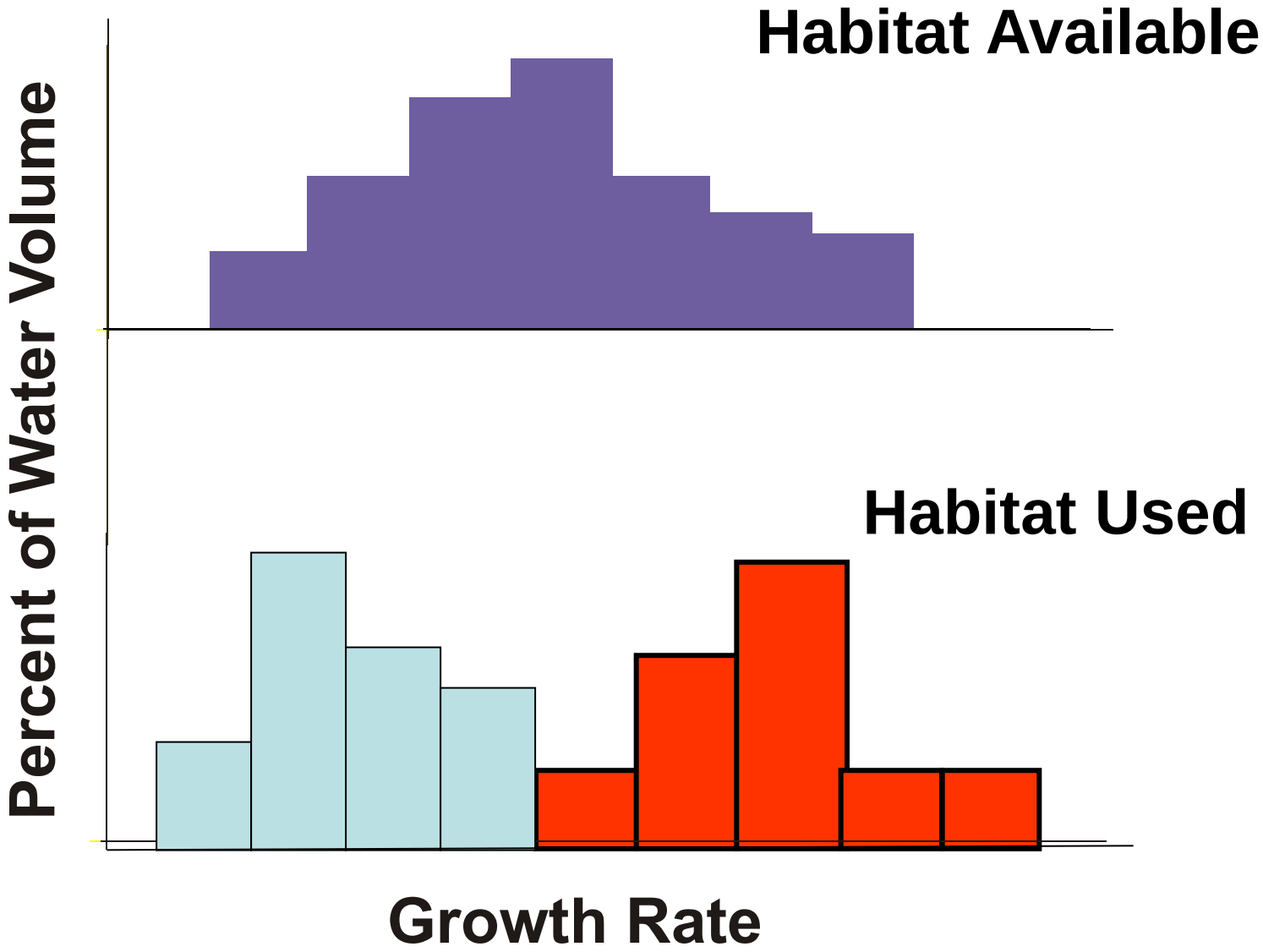
How effective is the species at exploiting the prevailing habitat conditions?

Growth Rate Potential

- Measure of habitat conditions
- Quality defined by fishes energetic needs and foraging abilities
- Independent of fish distribution

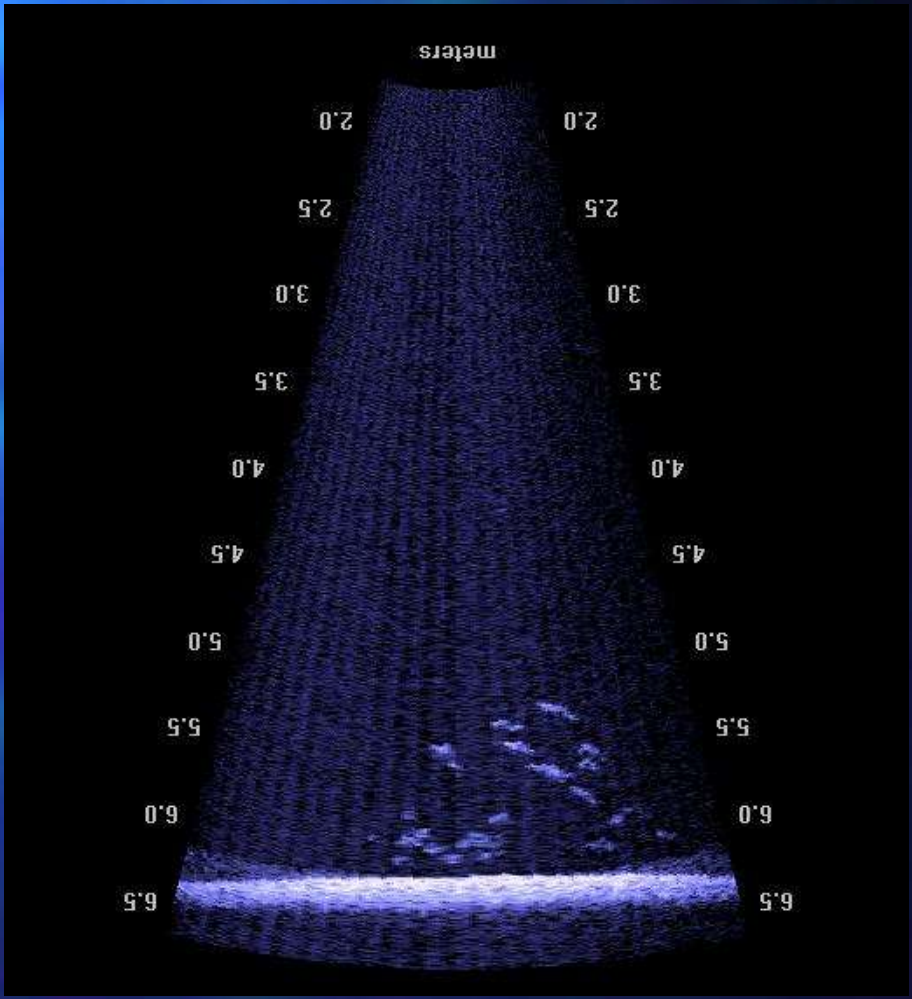
Observed Growth

- Measure of response of fish to habitat conditions
- Depends on fish behavior and distribution (actual or modeled)


Habitat Available
Habitat Used
Percent of Water Volume
Growth Rate

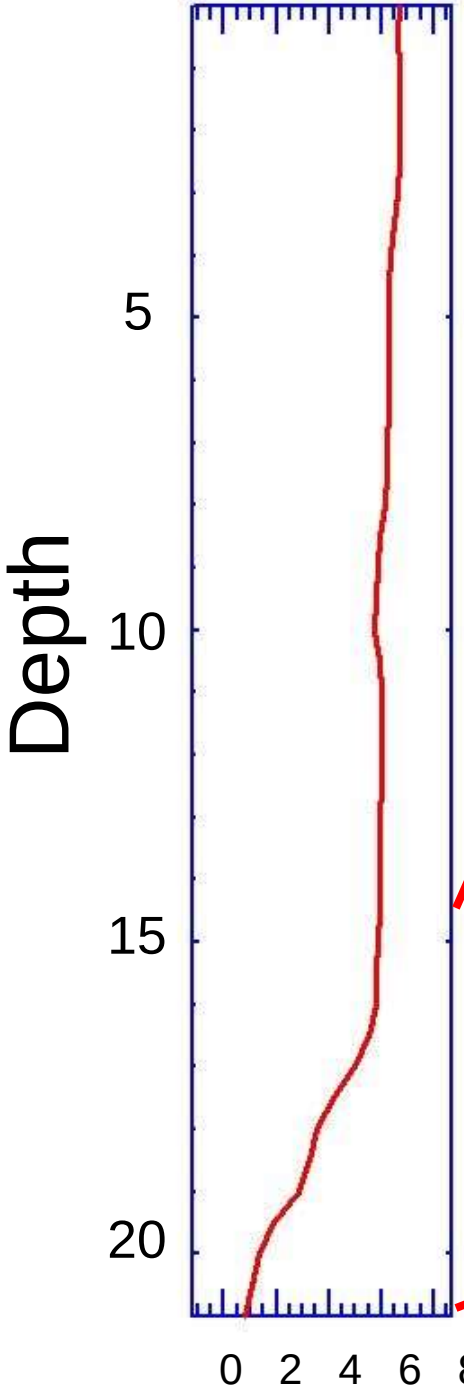
Fish Behavior

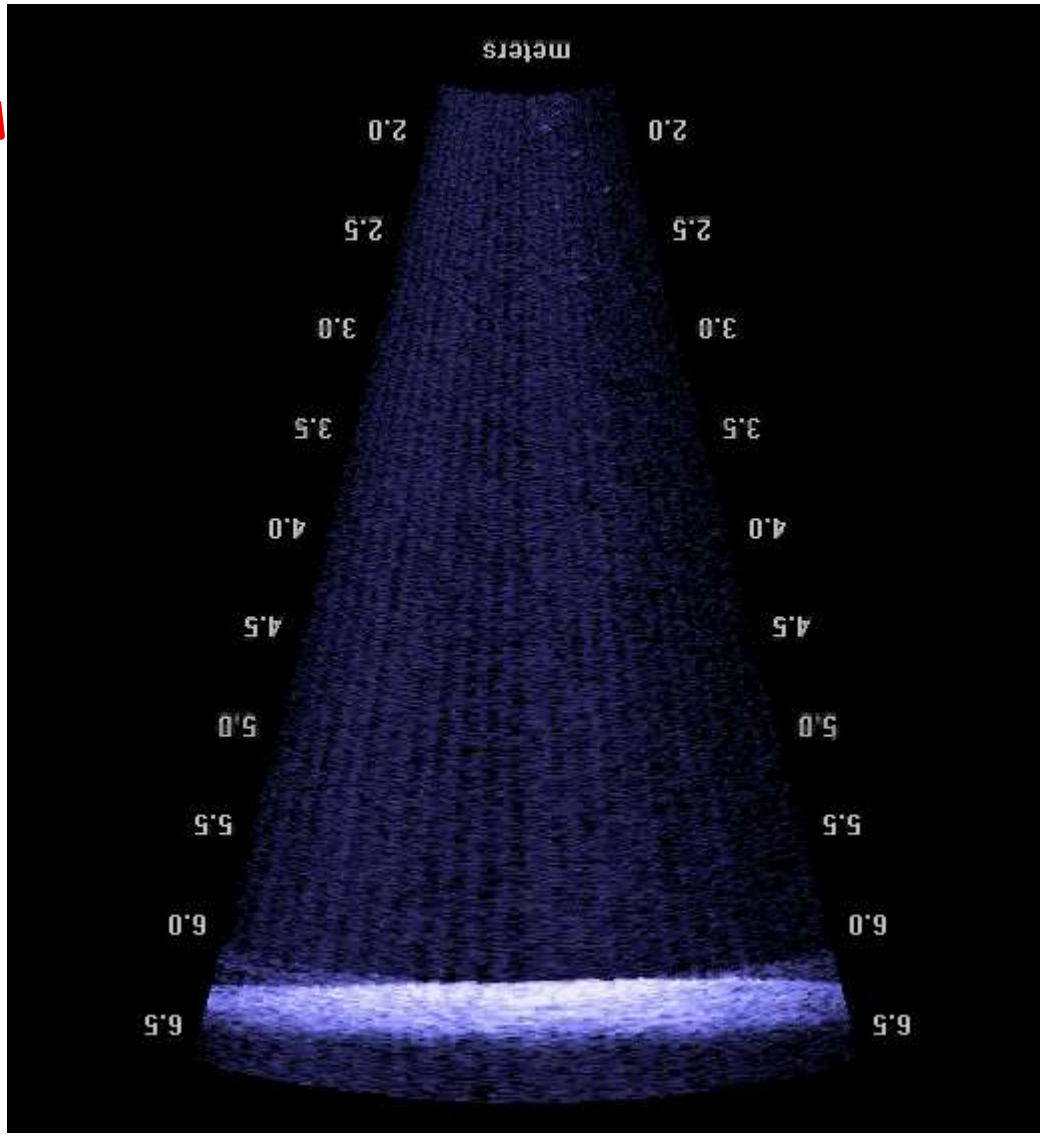
- To investigate the behavior and fine scale vertical distribution of pelagic fish in relation to hypoxia we used a DIDSON system (Dual-frequency Identification SONar)



Data From: Kevin Boswell

Oxygen





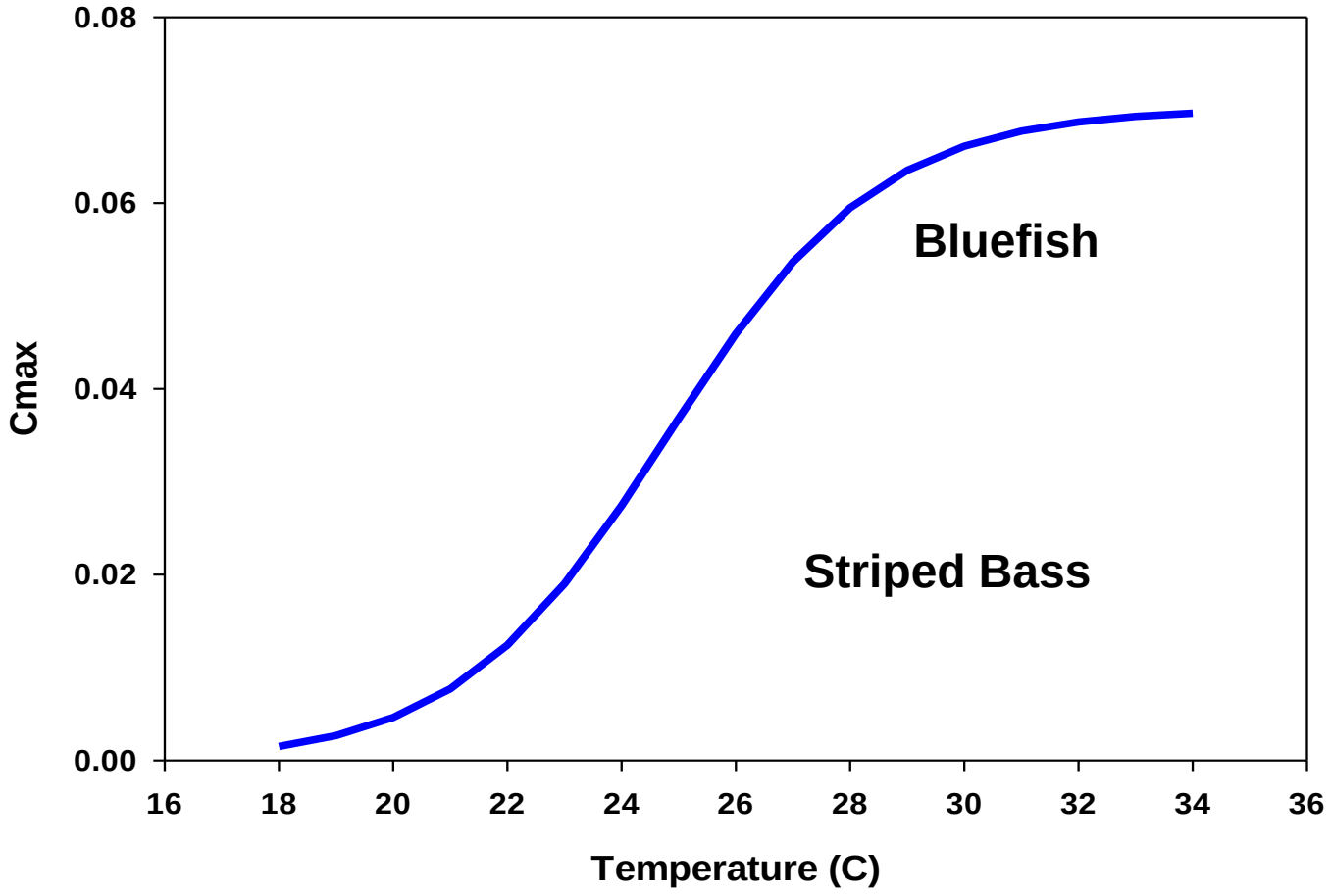
Take-Home Messages

- Nonlinearity – Correlations
- Multiple/Interactive (prevailing biotic and abiotic)
- Spatial Scales – average across habitats
- Time Scales (events – climate)
- Time Duration (seasonal scope for growth)
- Fish physiology and perceptive capabilities (species and life stages)
- Habitat choice options
  (Habitat quality $\neq$ Habitat use)
- Whole system perspective

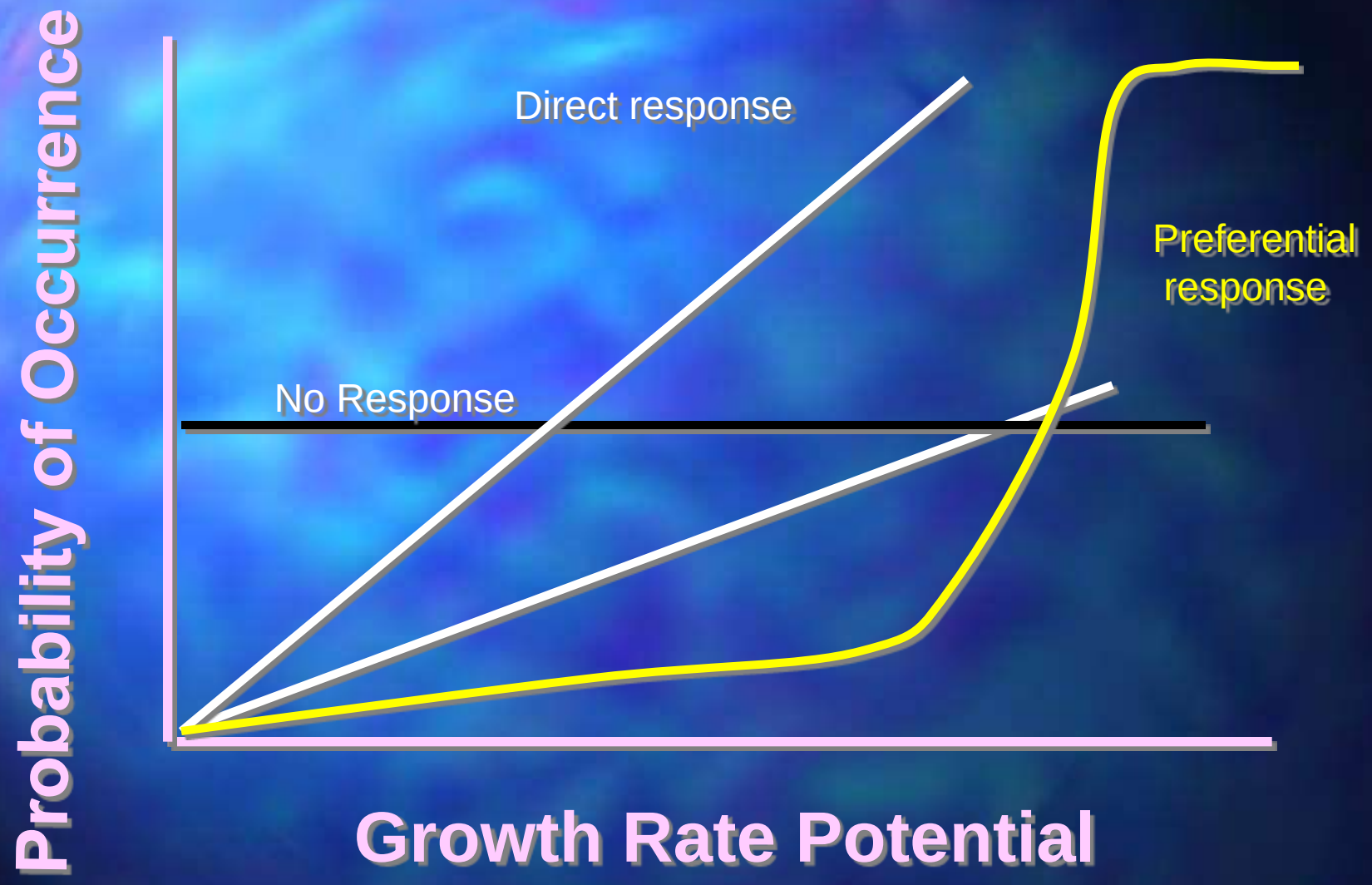
Questions?

Support from NOAA-CSCOR NGOMEX and NSF RAPID RESPONSE

Cmax vs. Temperature



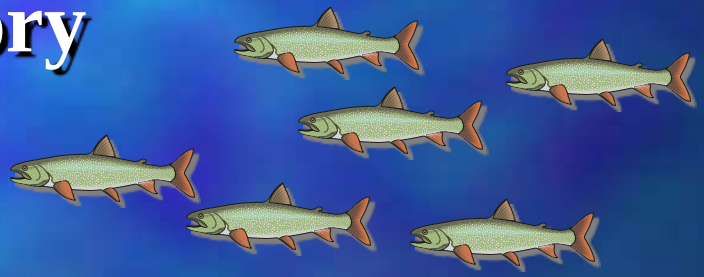
FISH BEHAVIORIAL RESPONSE TO GRP



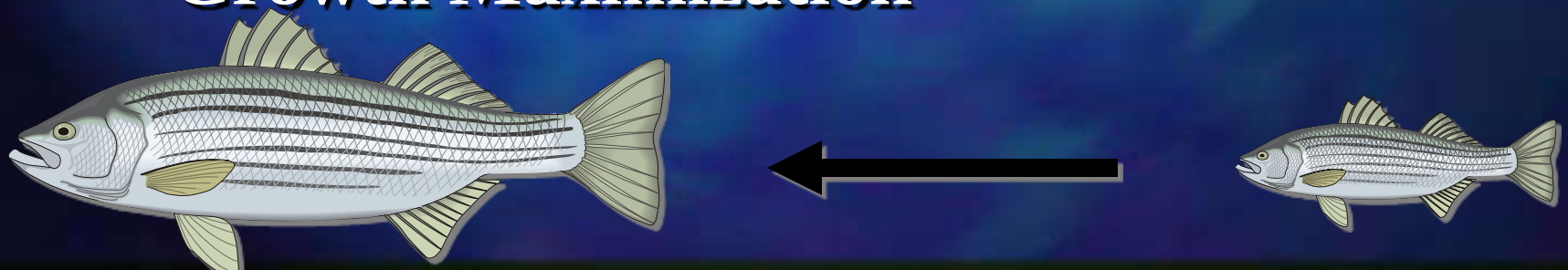
How do Fish Respond to Growth Rate Potential?

Behavioral Thermoregulation

Foraging Theory

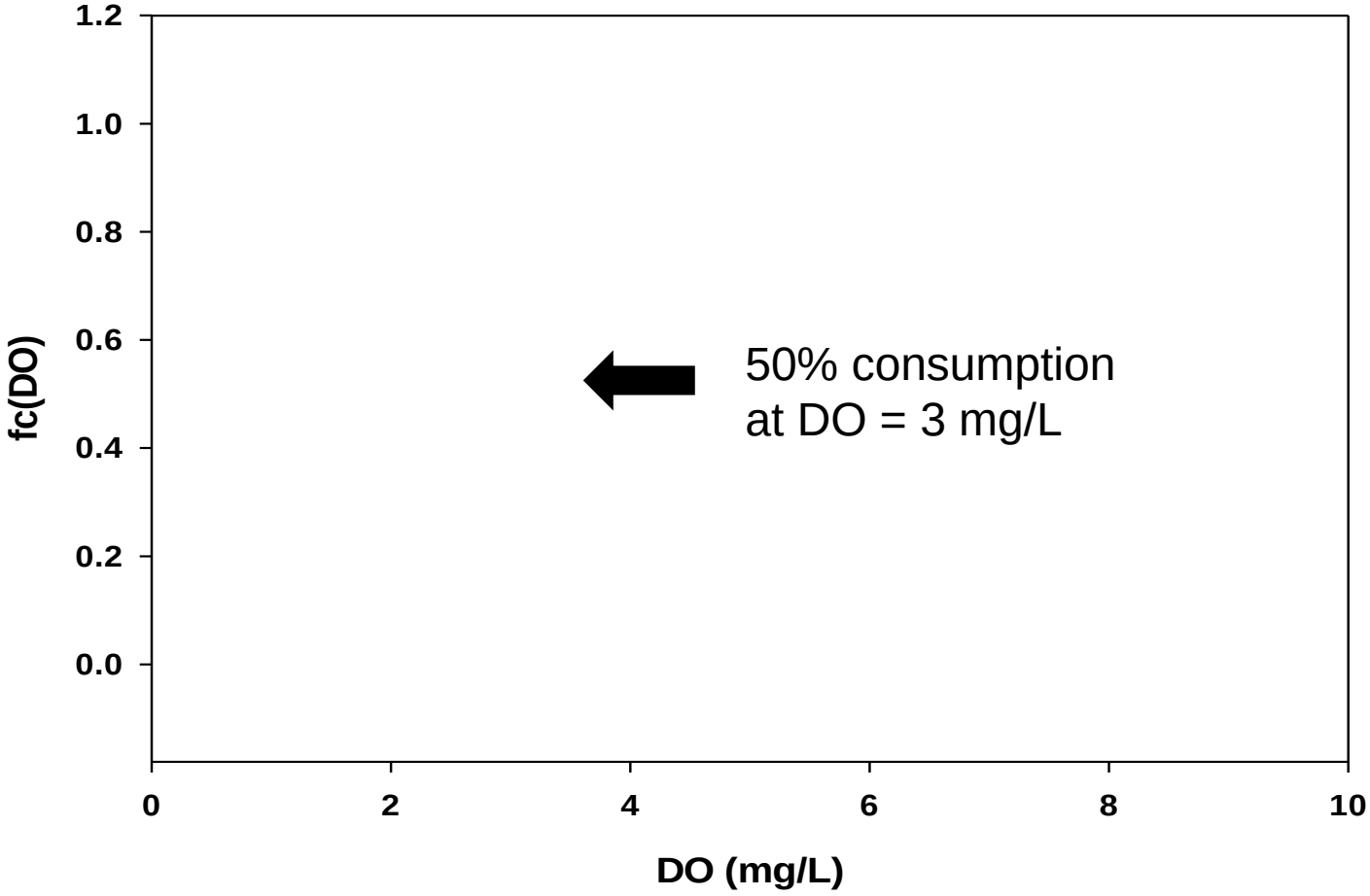


Growth Maximization



Dissolved Oxygen Function

$f_c(DO) = 1 / (1 + EXP(-2.197 * DO + 6.592))$



Brandt and Mason 2003

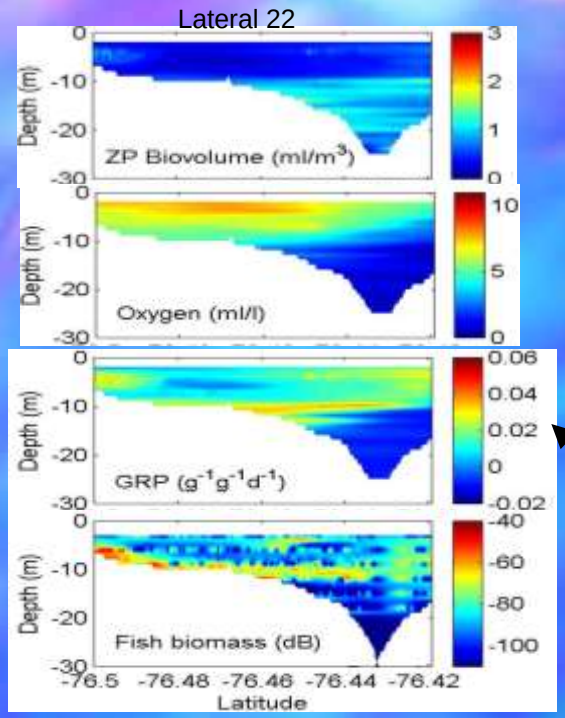
Key Questions:

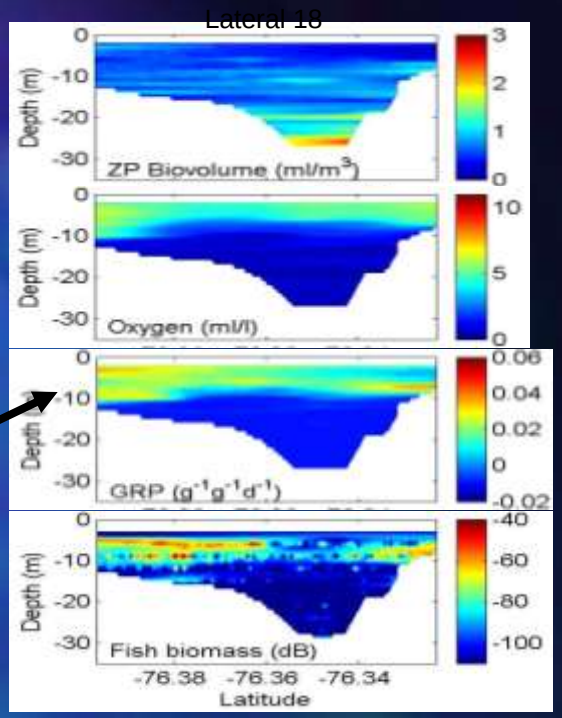
1. How does Growth Rate Potential of key species change
   - Seasonally
   - From year-to-year
   - With events
   - Long-term (Climate change)
   - Environmental stressors

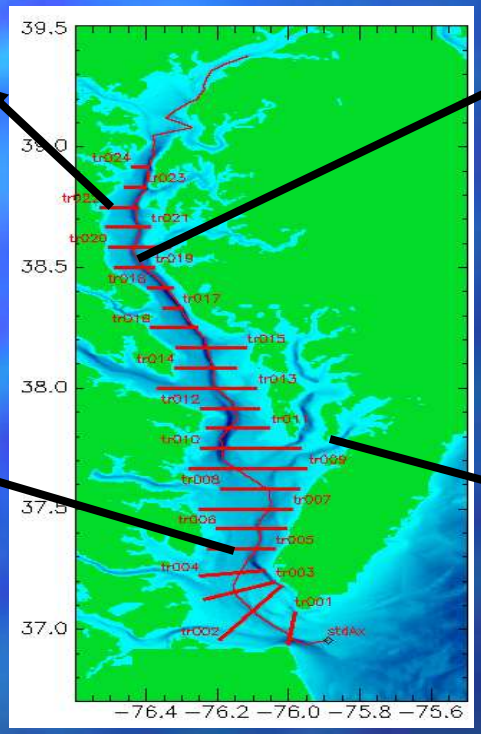
2. How well do patterns in Growth Rate Potential map migrations or production?

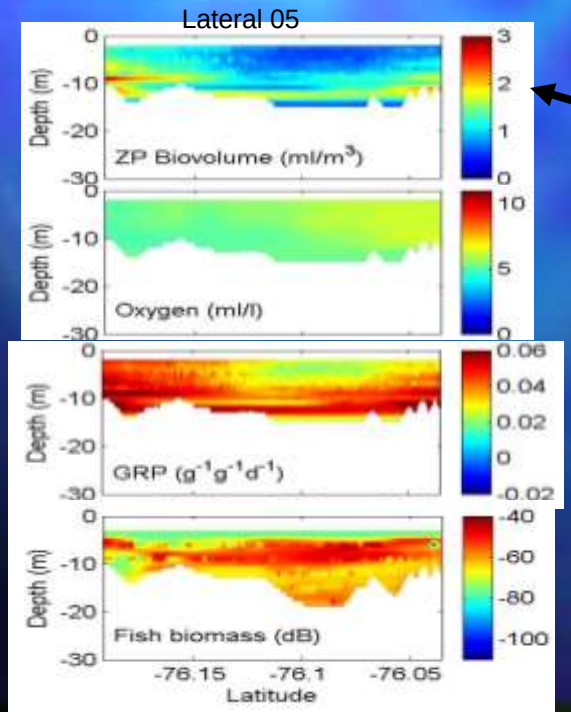
3. What are the relevant Space and Time scales?

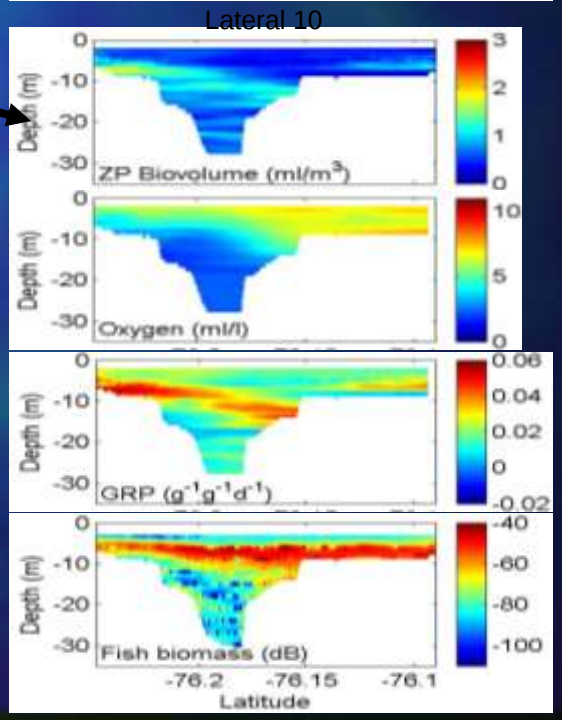
Chesapeake Bay Summer 2000

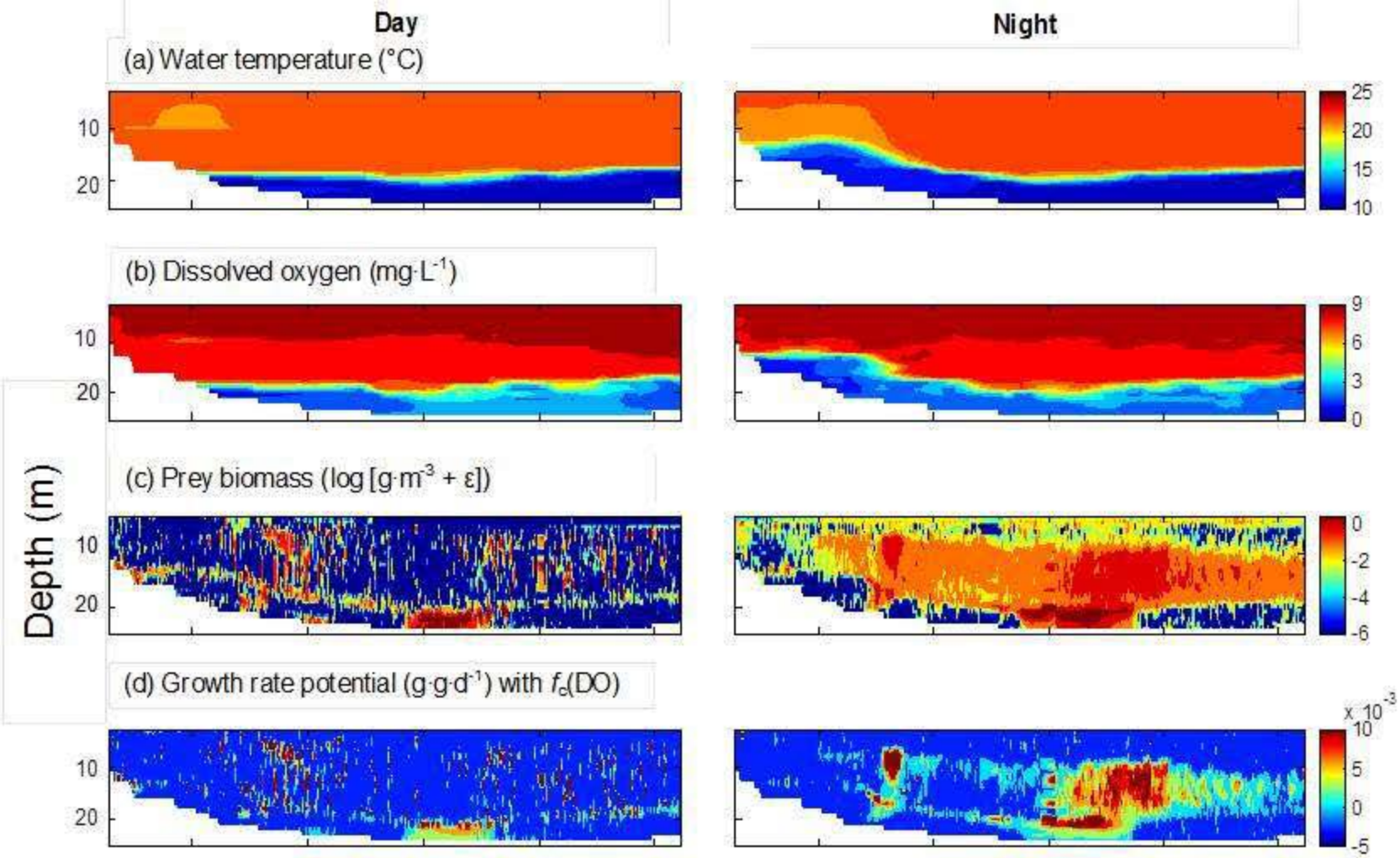








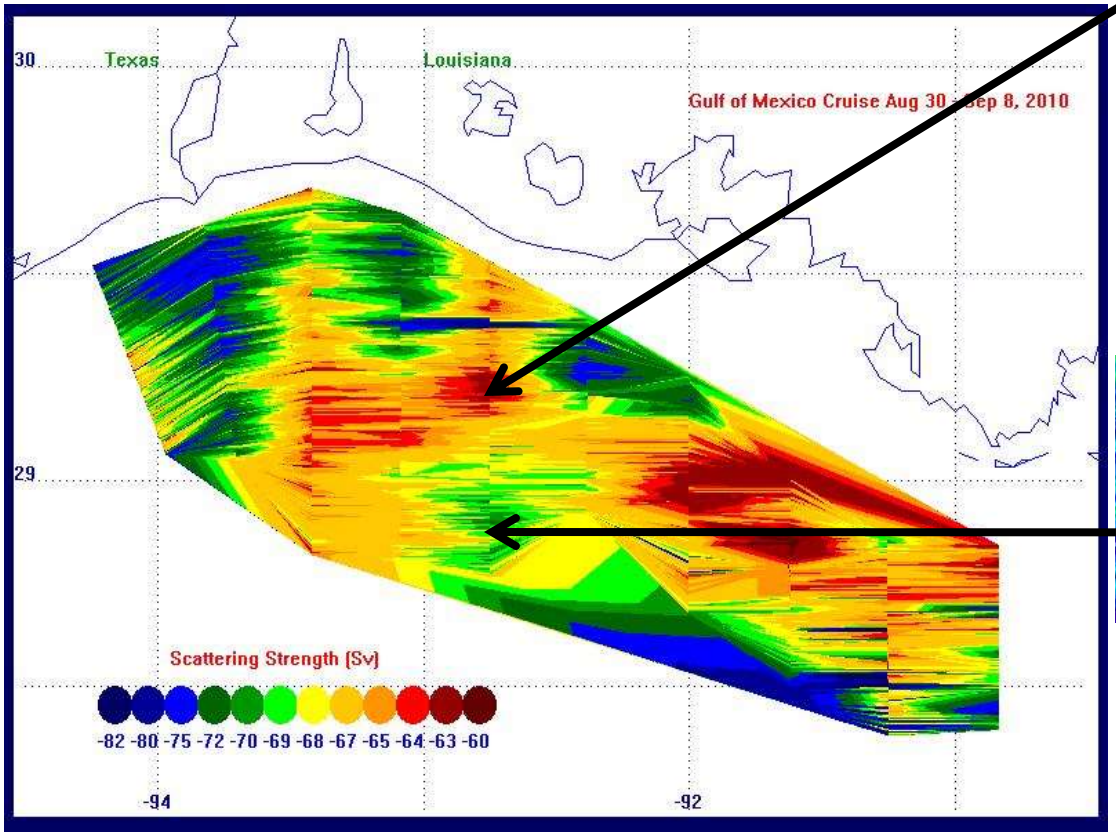


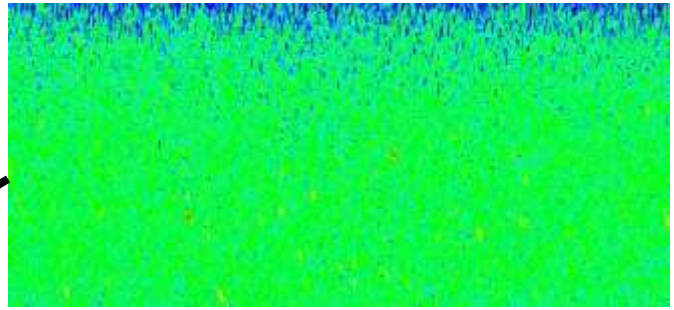


Walleye
Lake Erie

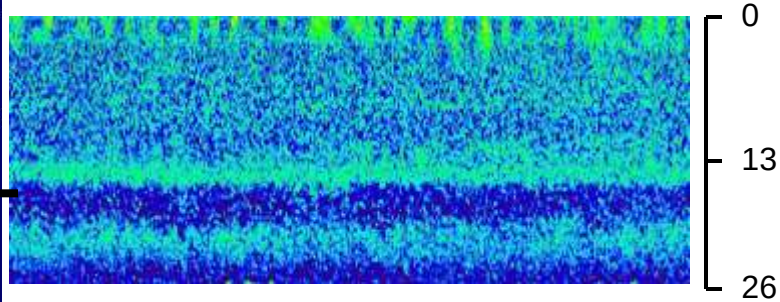
Brandt et al. 2011

Transect I





Targets throughout the water column (Sv = -62)



Targets at the water surface. Double Oxygen Layer (Sv = -69

Spatially-explicit, high resolution mapping and modeling to quantify hypoxia effects on the pelagic living resources of the northern Gulf of Mexico, Chesapeake Bay and Lake Erie

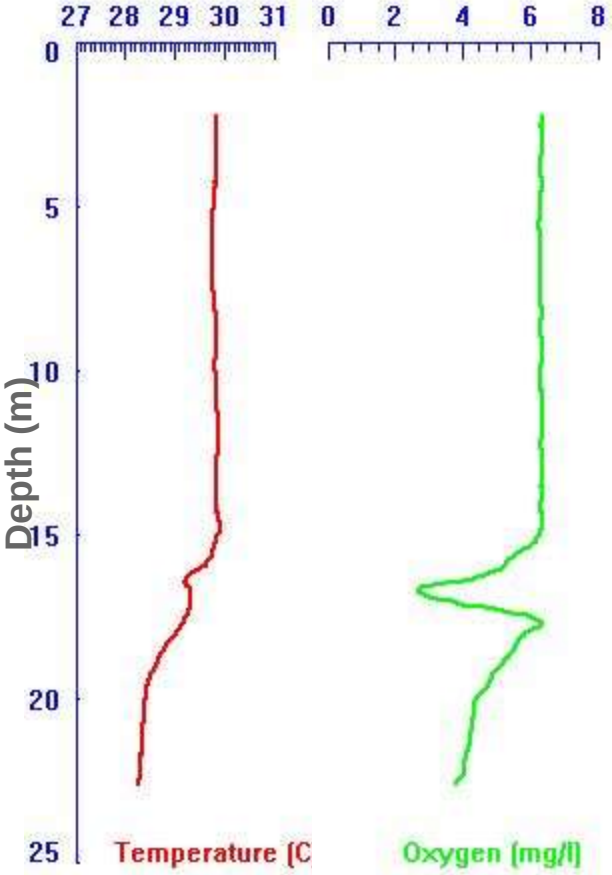
SPACE SCALES:

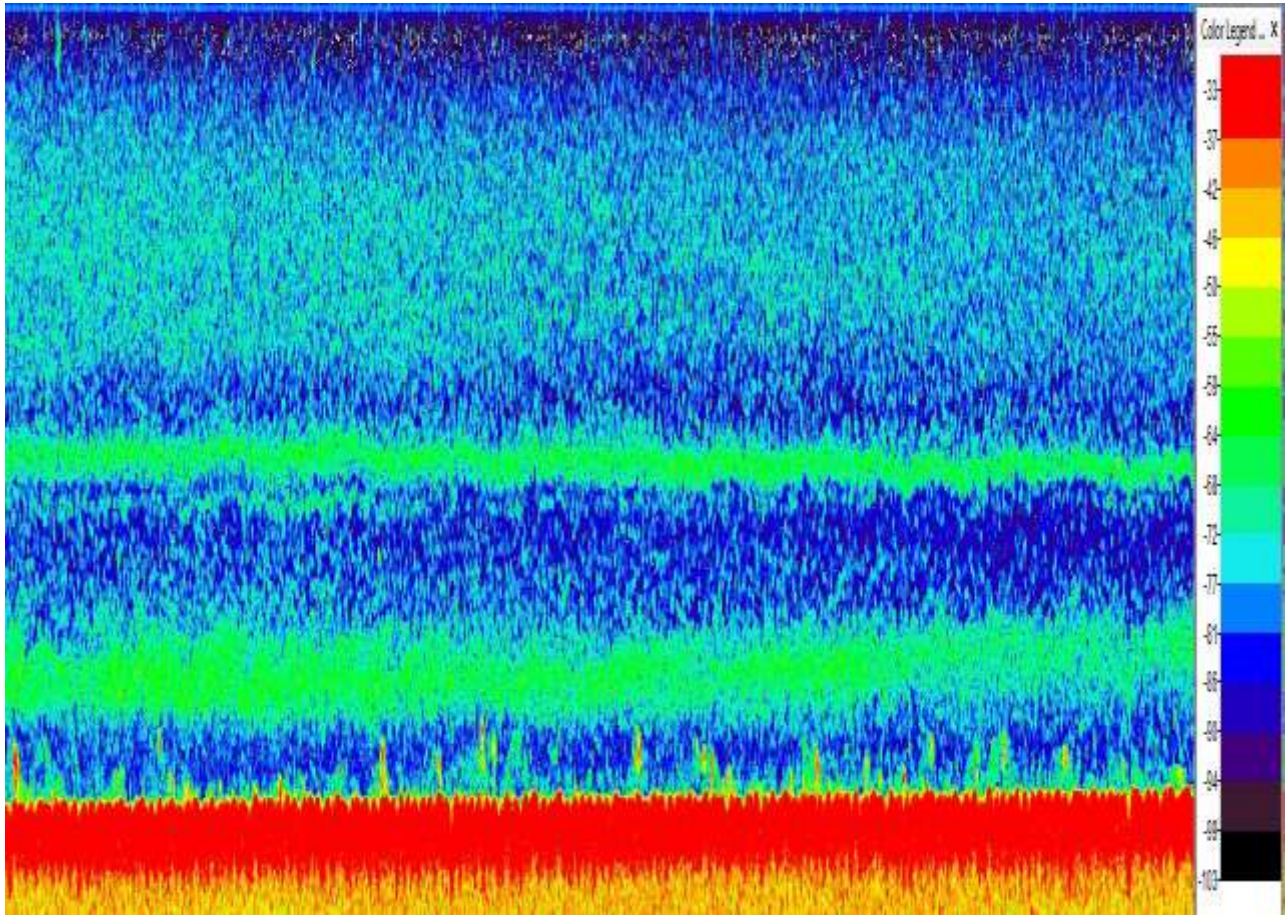
Broad geographic (100 km)
Cross – sections (10 km)
Fine Scale (<1m – 1km)

TIME SCALES:

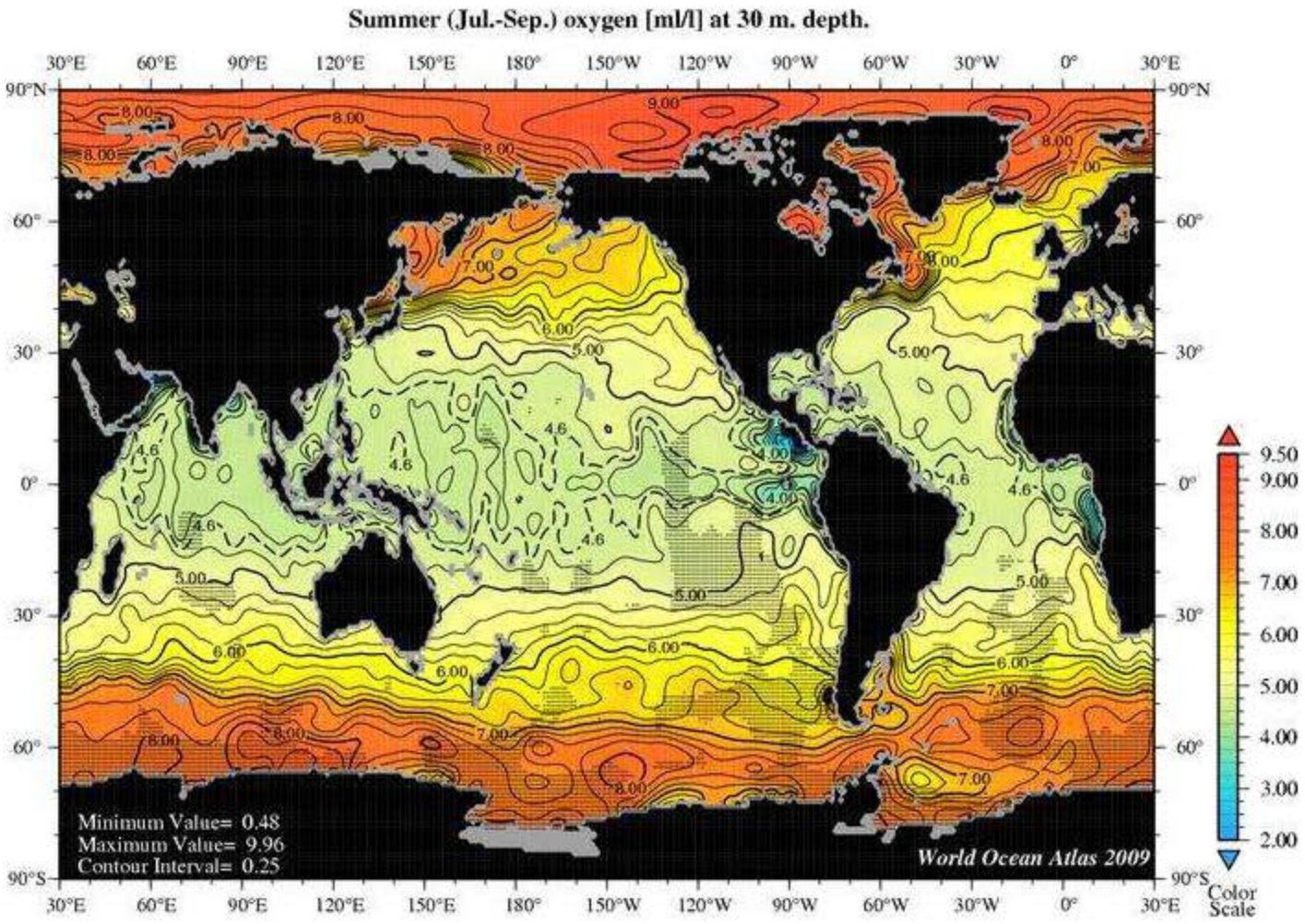
Interannual
Events
Diel
Minutes

Gulf of Mexico—H Transect
Double Hypoxia Layer



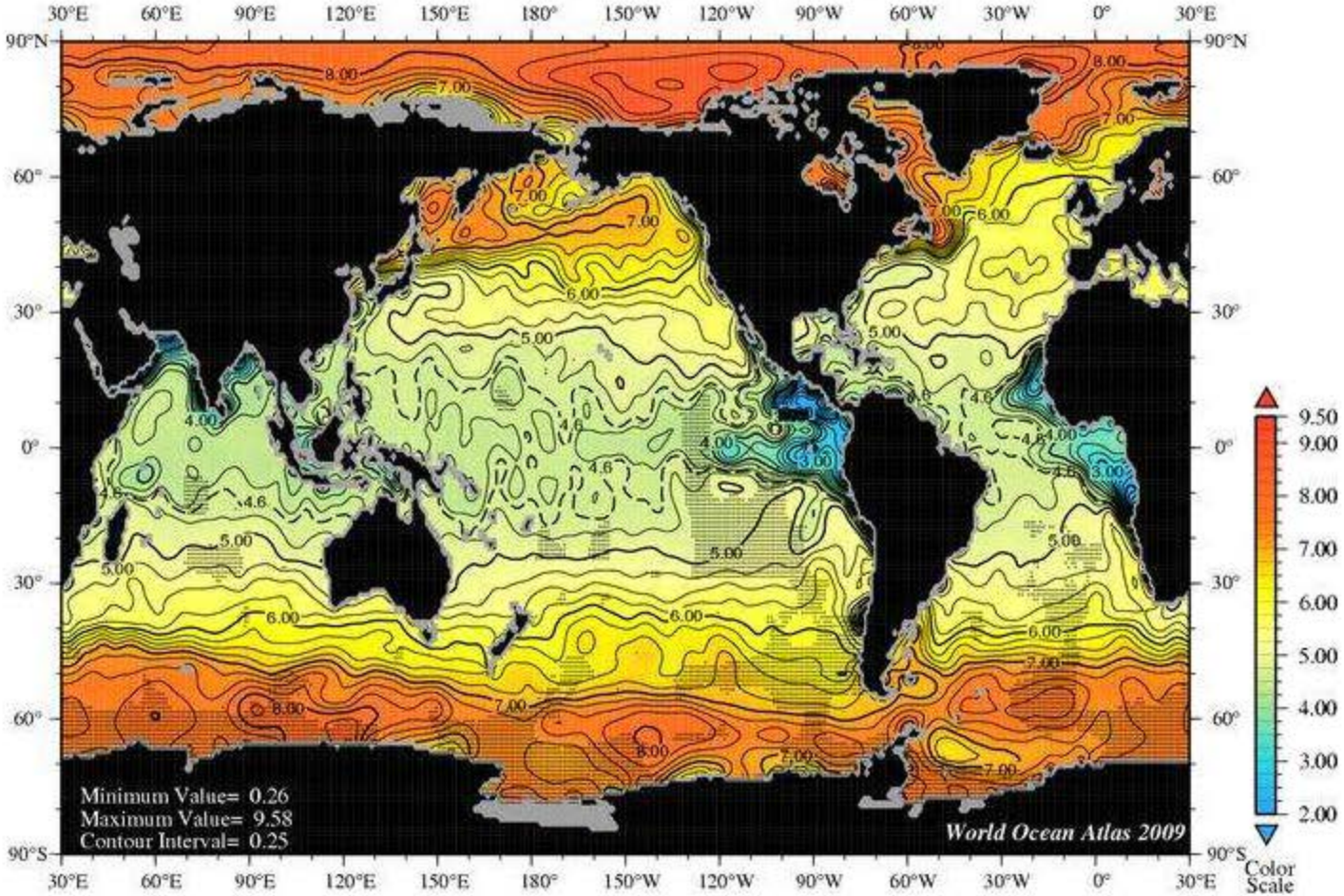


Oxygen 30m

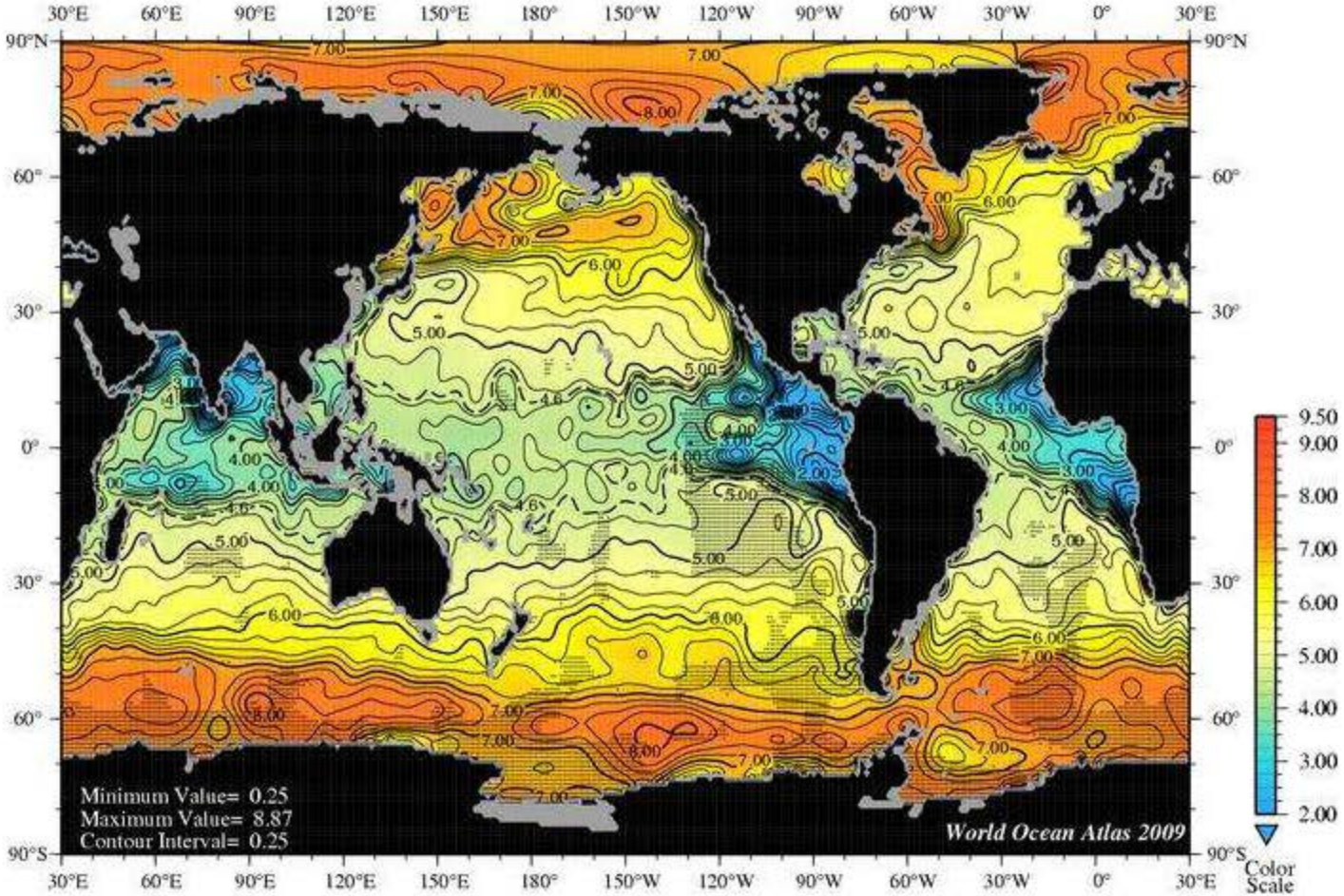


NOAA NODC

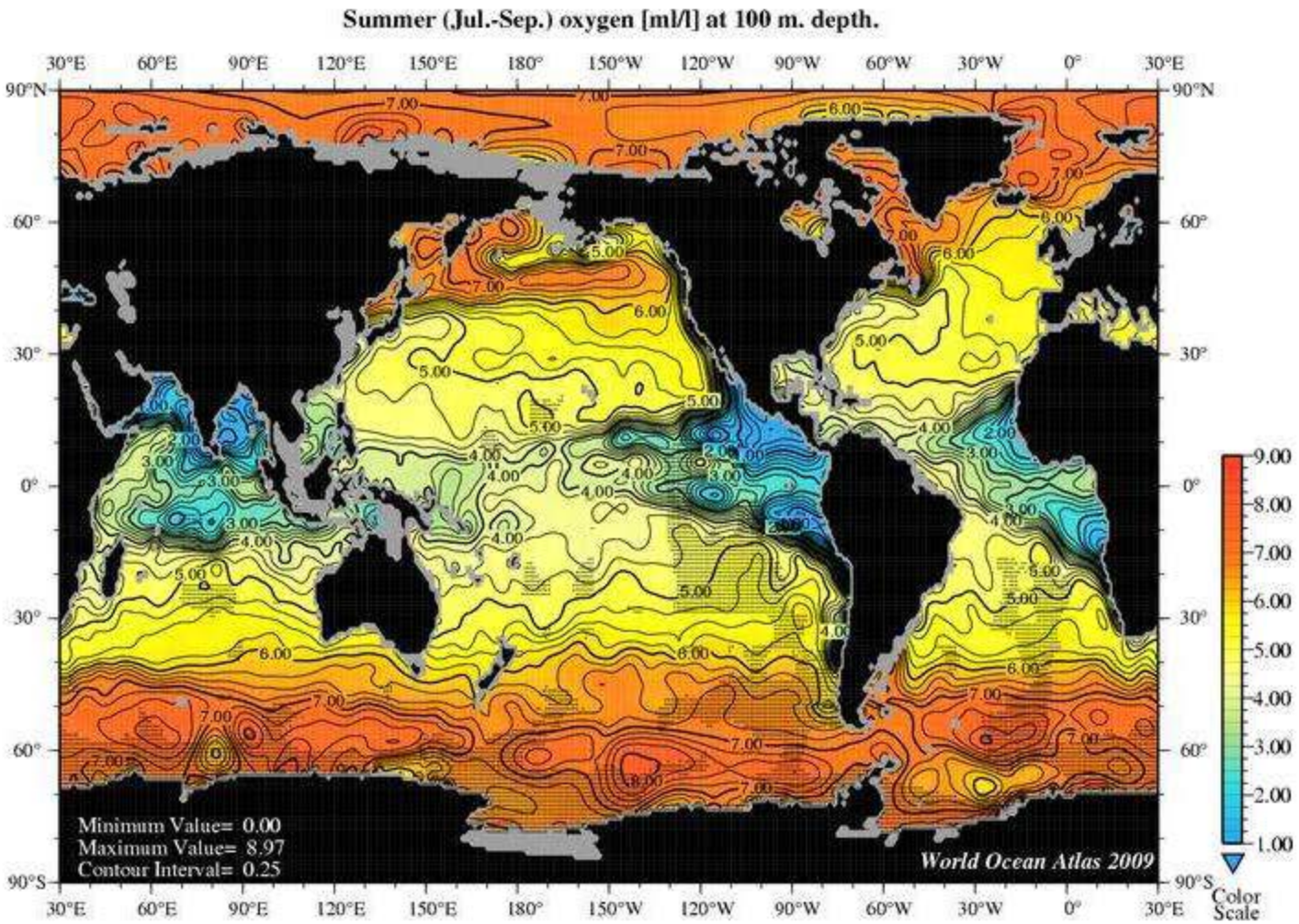
Summer (Jul.-Sep.) oxygen [ml/l] at 50 m. depth.



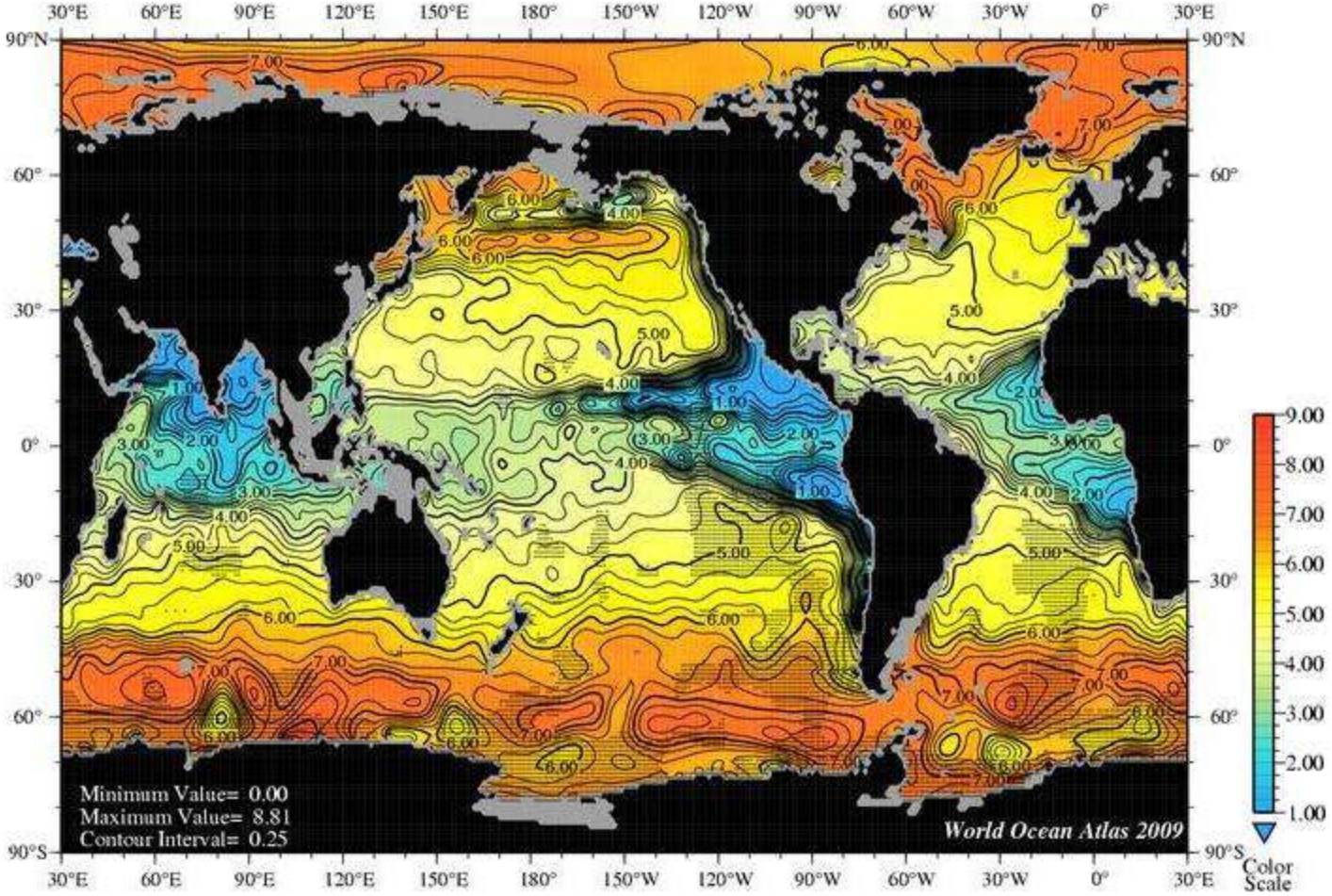
Summer (Jul.-Sep.) oxygen [ml/l] at 75 m. depth.



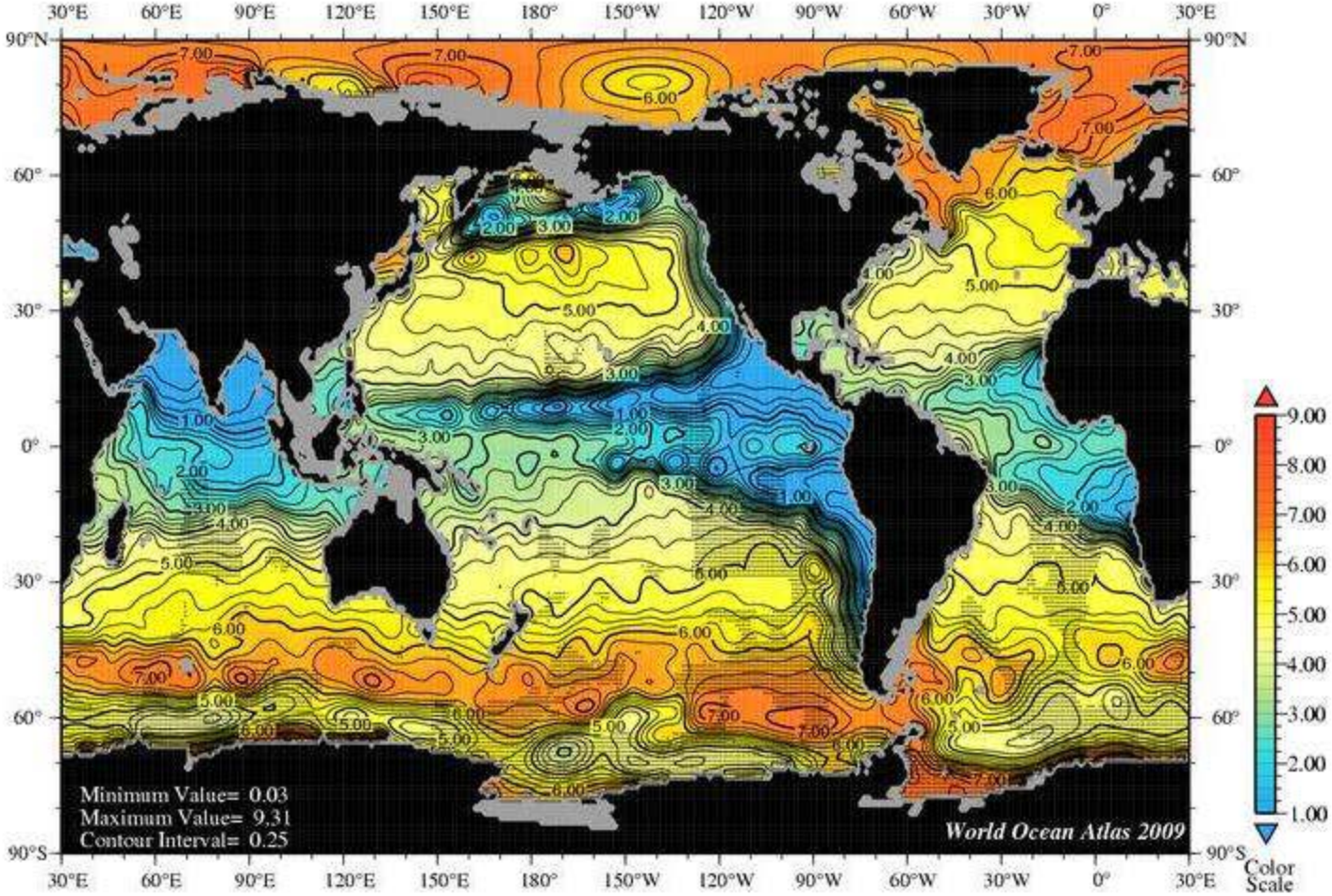
Oxygen 100m


Summer (Jul.-Sep.) oxygen [ml/l] at 100 m. depth.
Minimum Value= 0.00
Maximum Value= 8.97
Contour Interval= 0.25
World Ocean Atlas 2009
Color Scale
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00

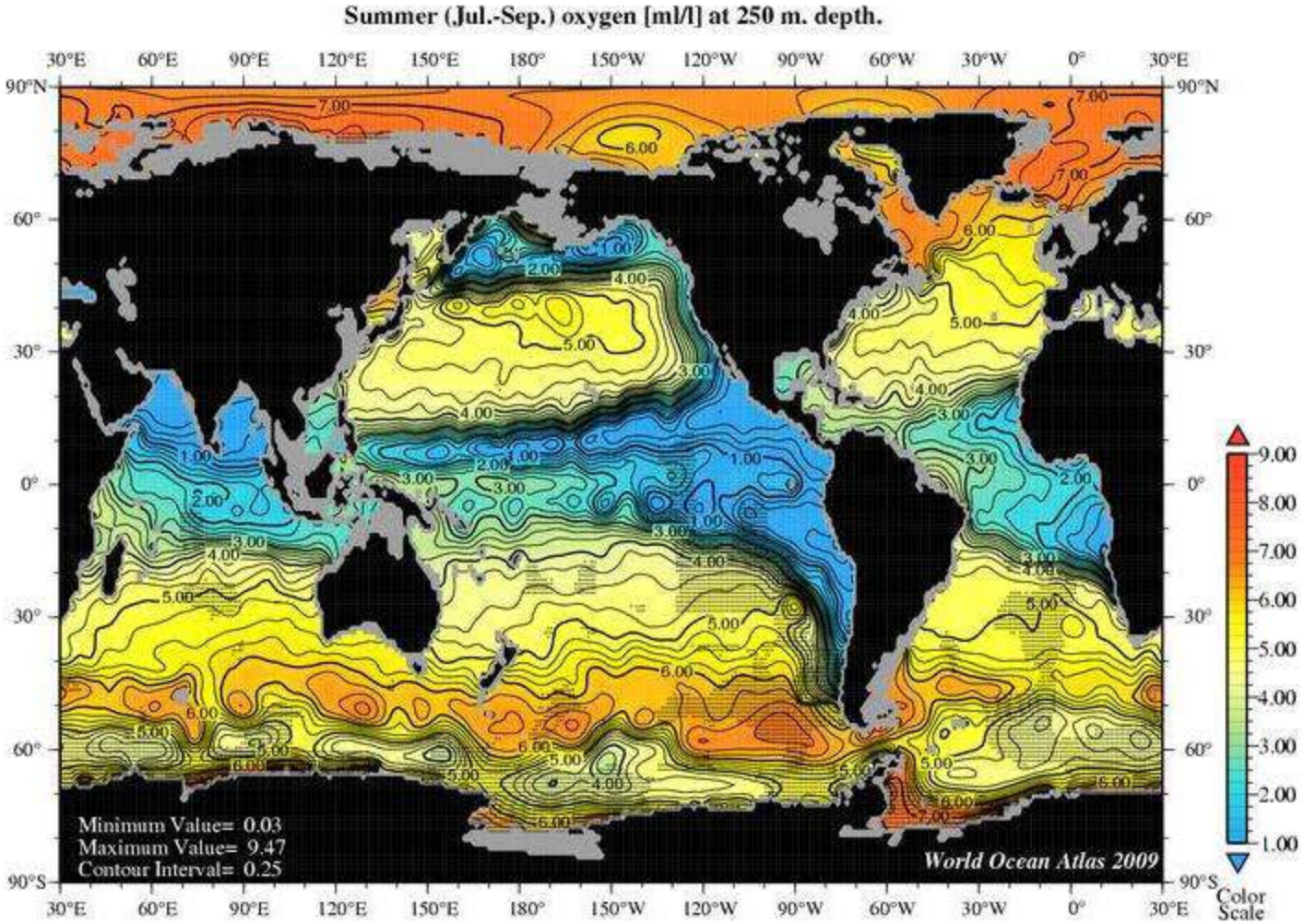
Summer (Jul.-Sep.) oxygen [ml/l] at 125 m. depth.



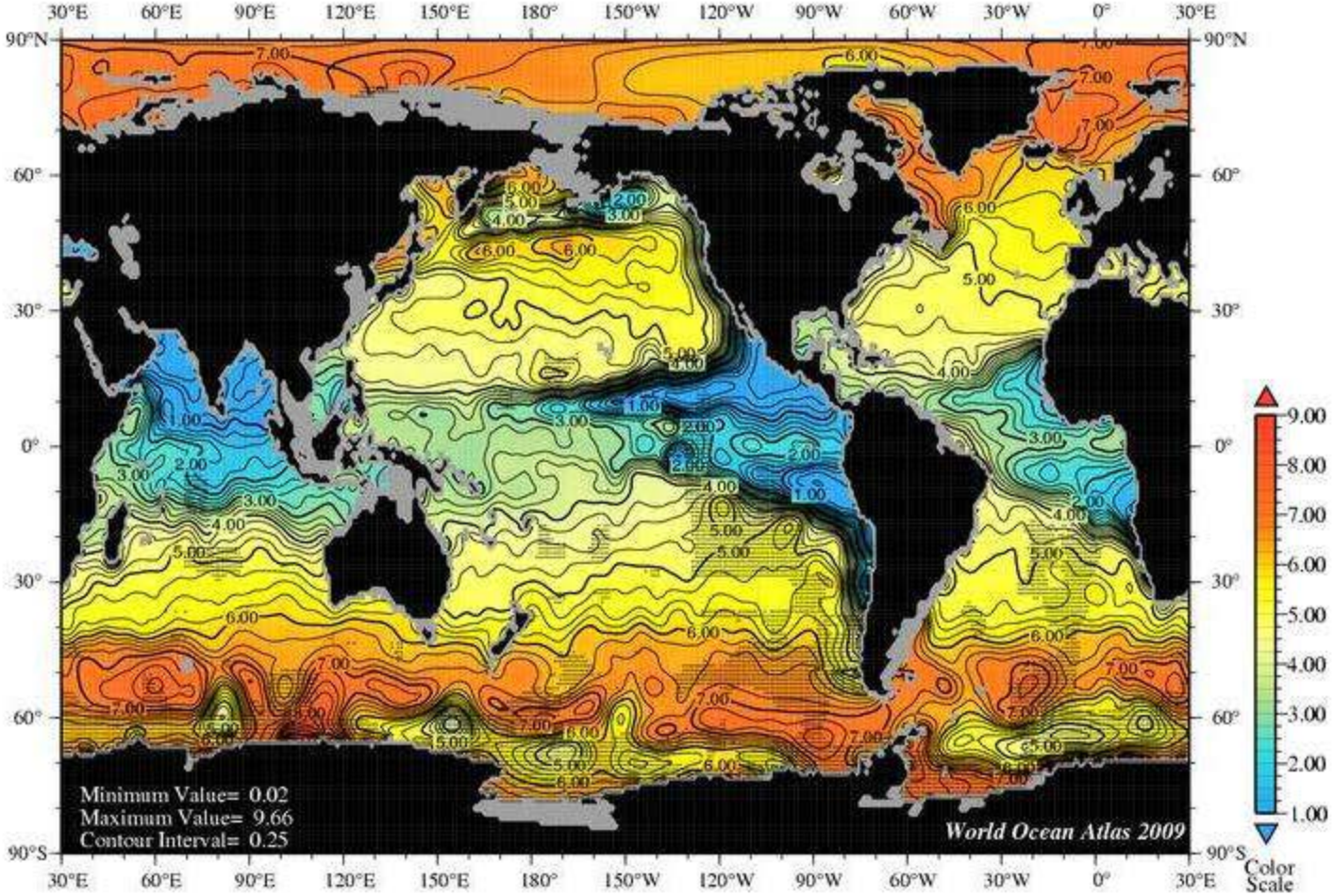
Summer (Jul.-Sep.) oxygen [ml/l] at 200 m. depth.



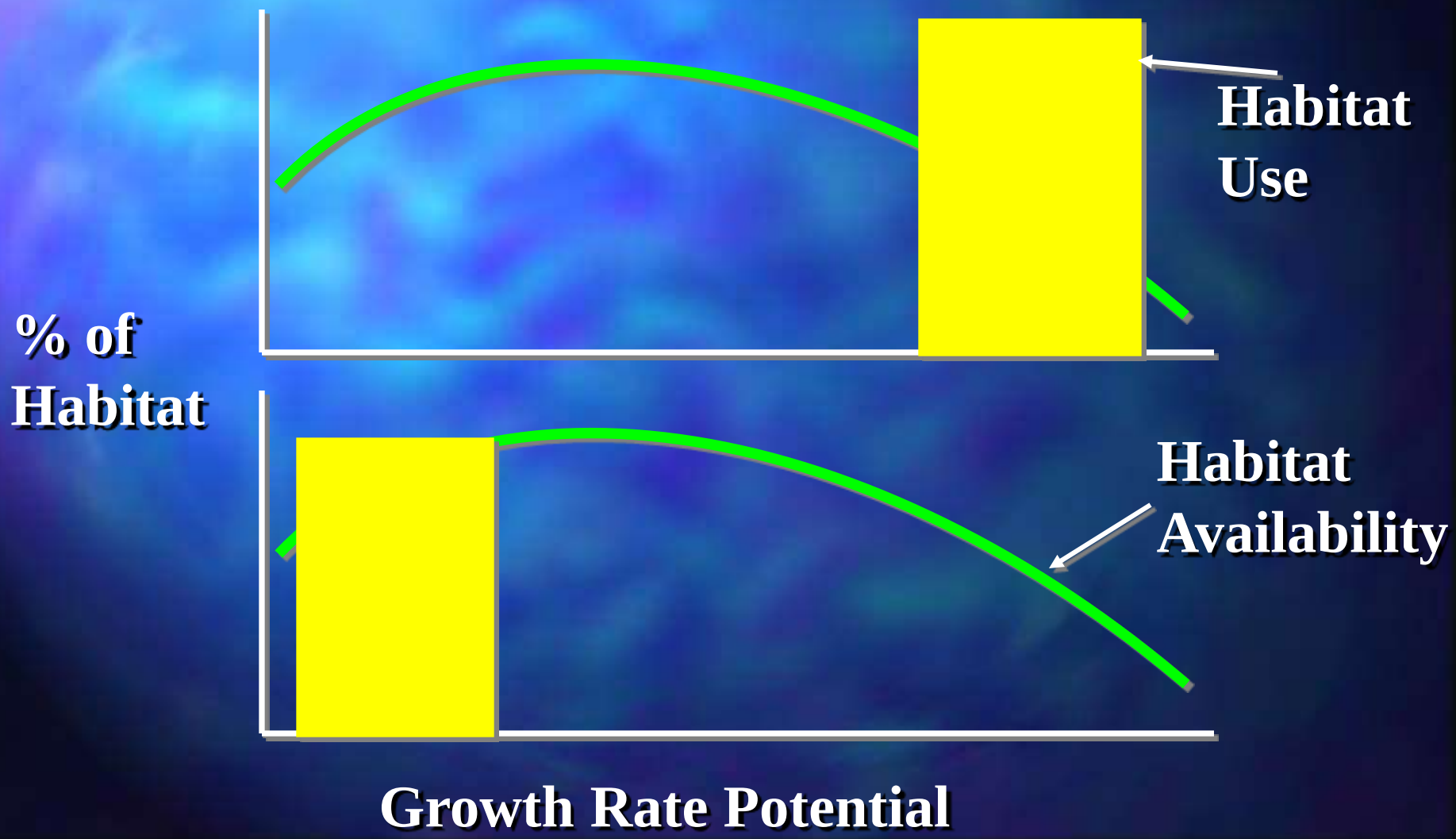
Oxygen 250m


Summer (Jul.-Sep.) oxygen [ml/l] at 250 m. depth.
Minimum Value= 0.03
Maximum Value= 9.47
Contour Interval= 0.25
World Ocean Atlas 2009
Color Scale
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00

Summer (Jul.-Sep.) oxygen [ml/l] at 150 m. depth.



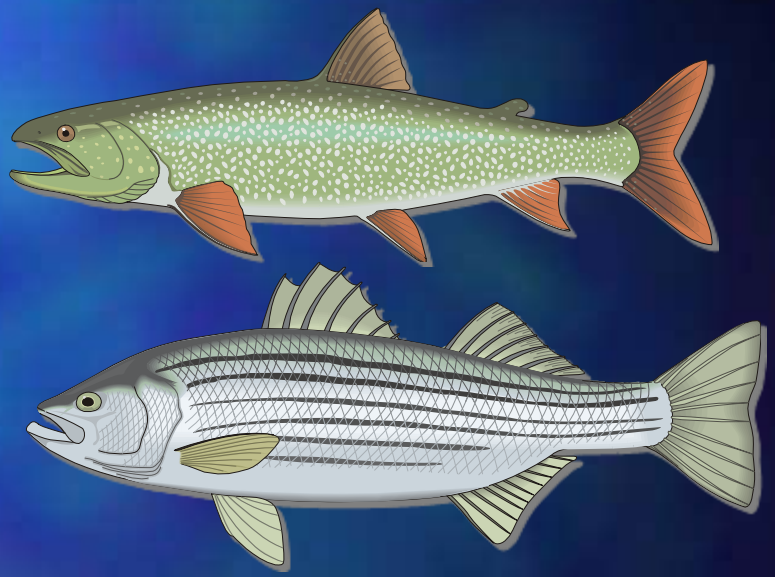
Efficiency


Habitat Use
% of Habitat
Habitat Availability
Growth Rate Potential

Objective

Compare Fish Growth Rate Potential of:

- **Chinook Salmon**
- **Lake Trout**
- **Striped Bass**



between Base (1954-1995) and 2030 and 2090 under predictions made by the Canadian Climate Center Climate Change Model (CGCM1).

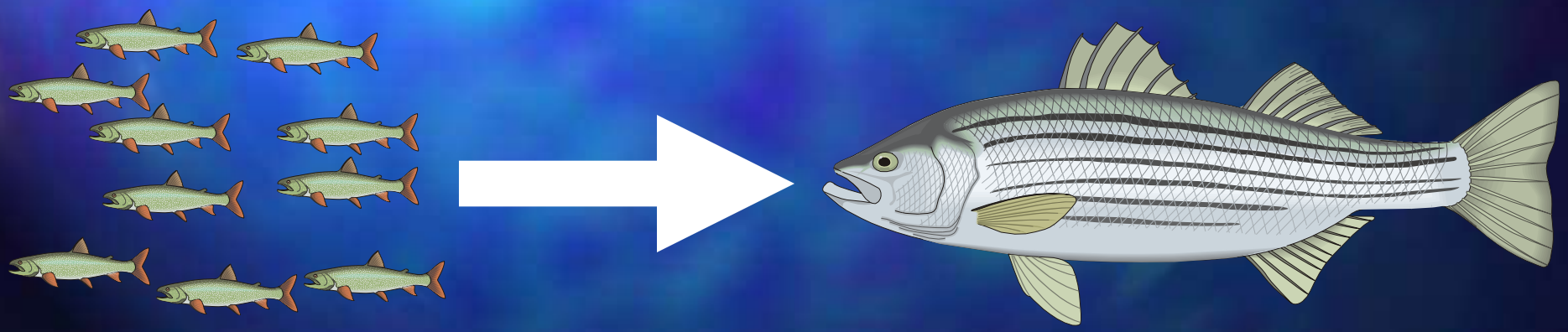
Predation Risk

Function of:

Predator Consumption Rate

- predator size, foraging capabilities, temperature

Predator density



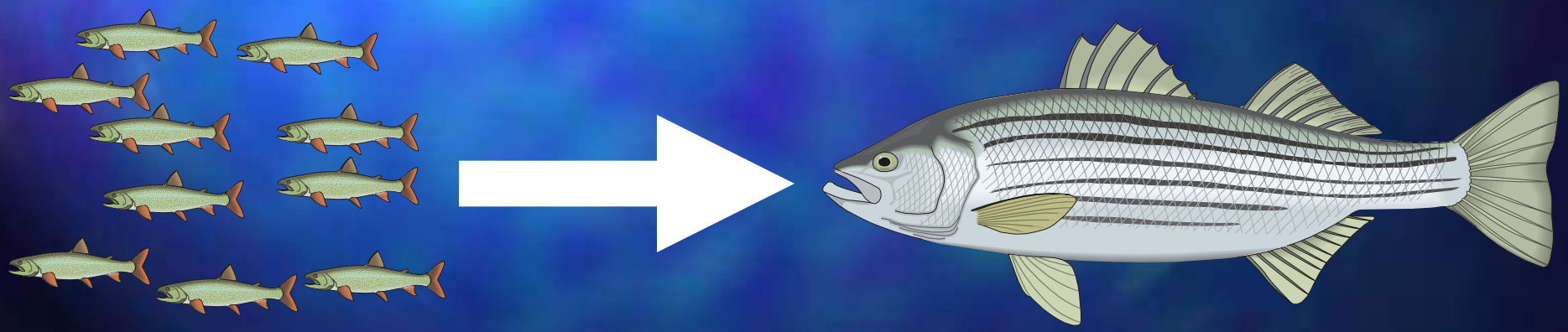
Consumption

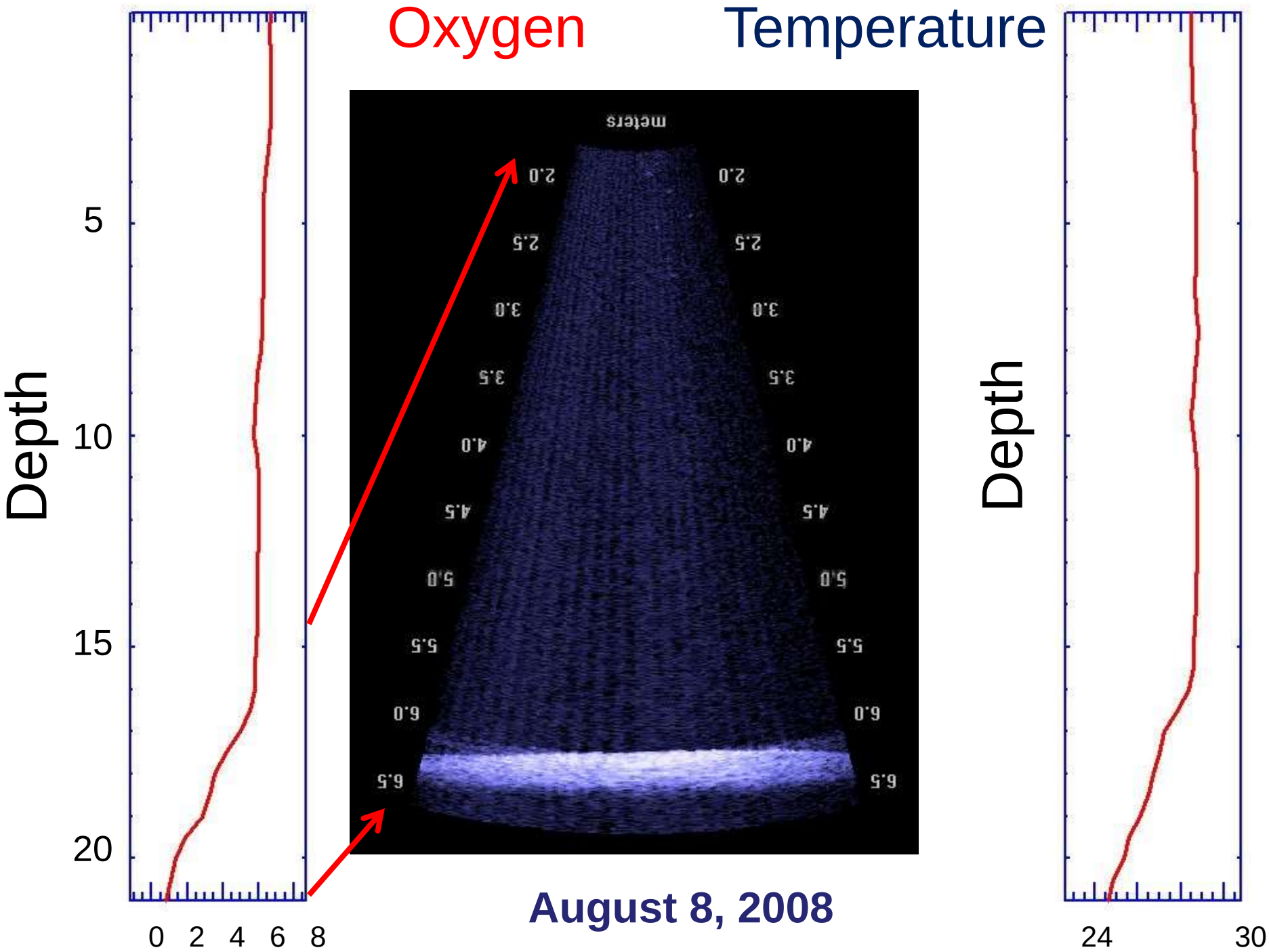
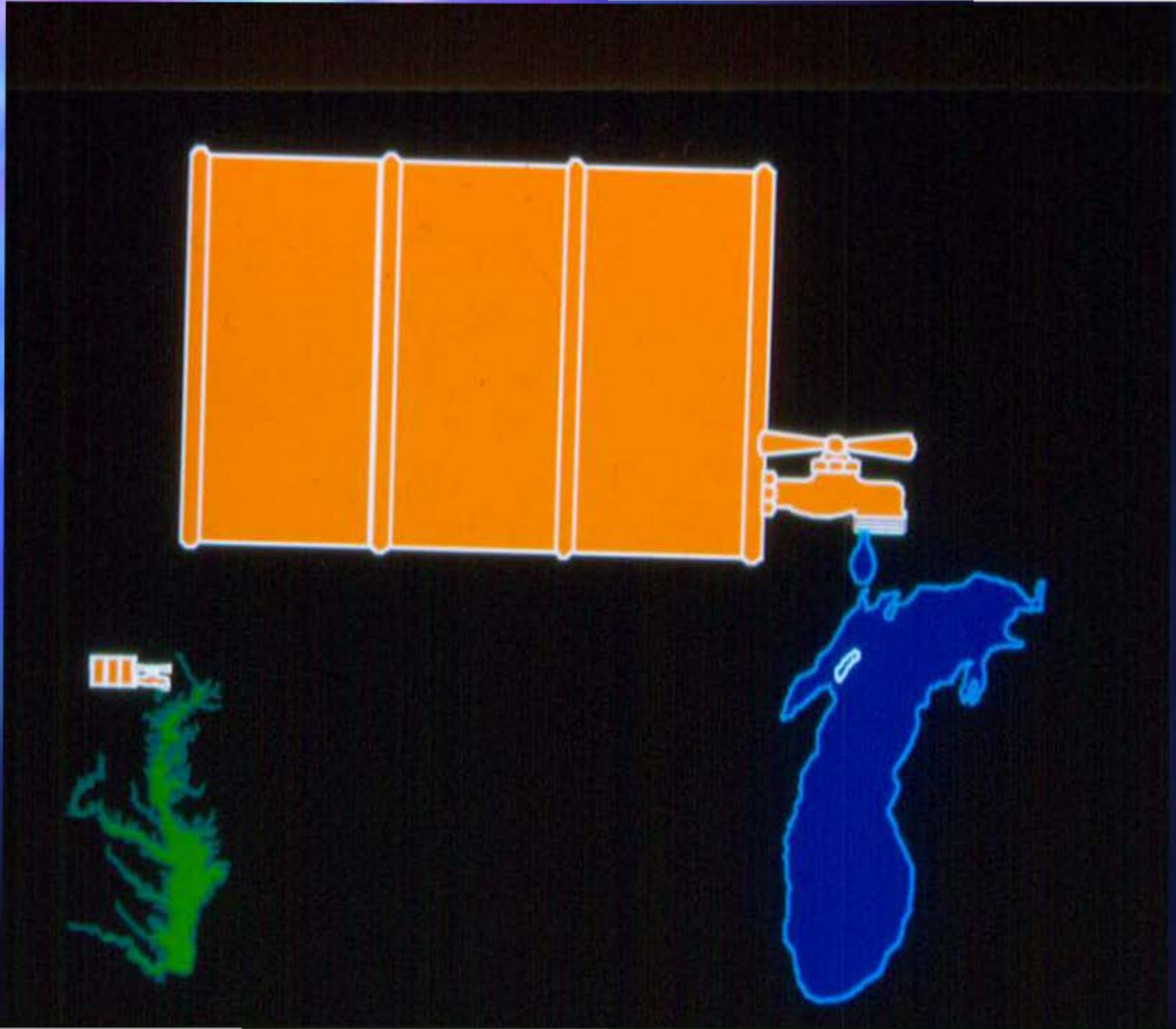
Function of:

Predator Consumption Capabilities

- **predator size, foraging capabilities, temperature, oxygen, light**

Prey density




Oxygen
Temperature
Depth
5
10
15
20
0 2 4 6 8
24 30
Depth
August 8, 2008