# Predicting fish movement and migration in response to a changing climate

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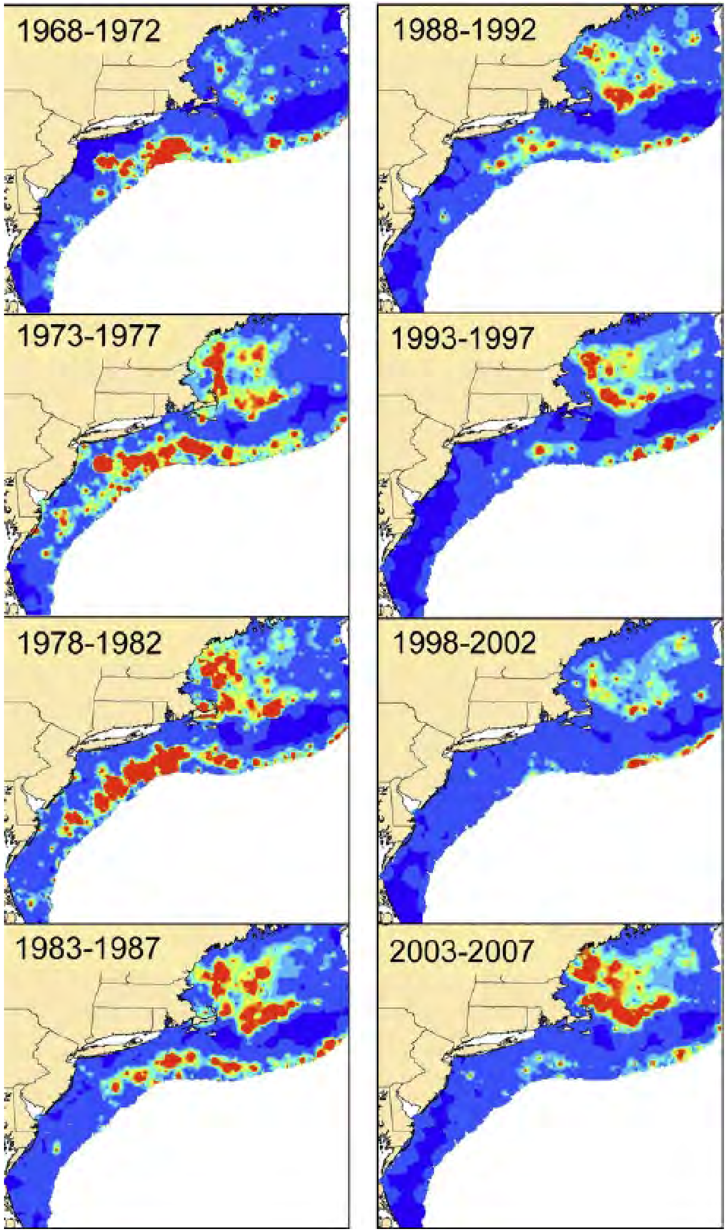
# Today

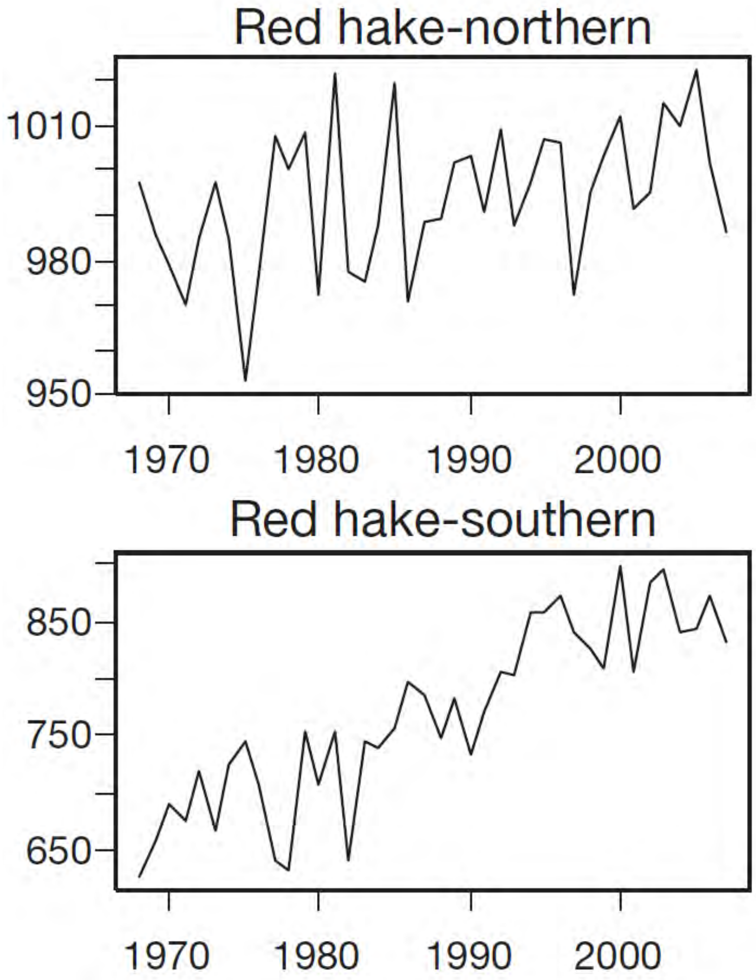
- Organisms will move in response to climate change

- Information informing management is simplified

- Progress on movement
  - Observations
  - Modeling
  - Examples

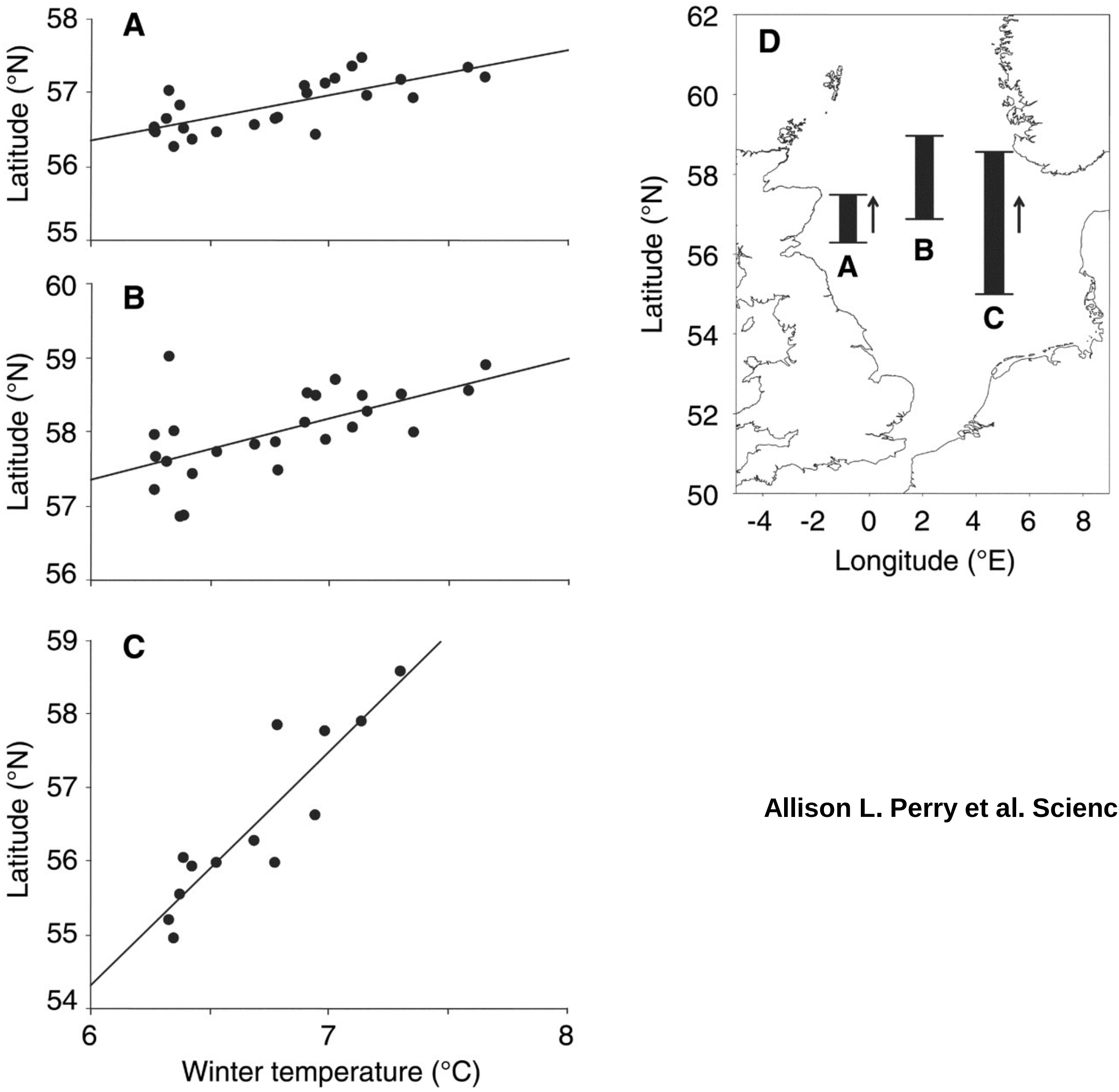
- Needs and opportunities





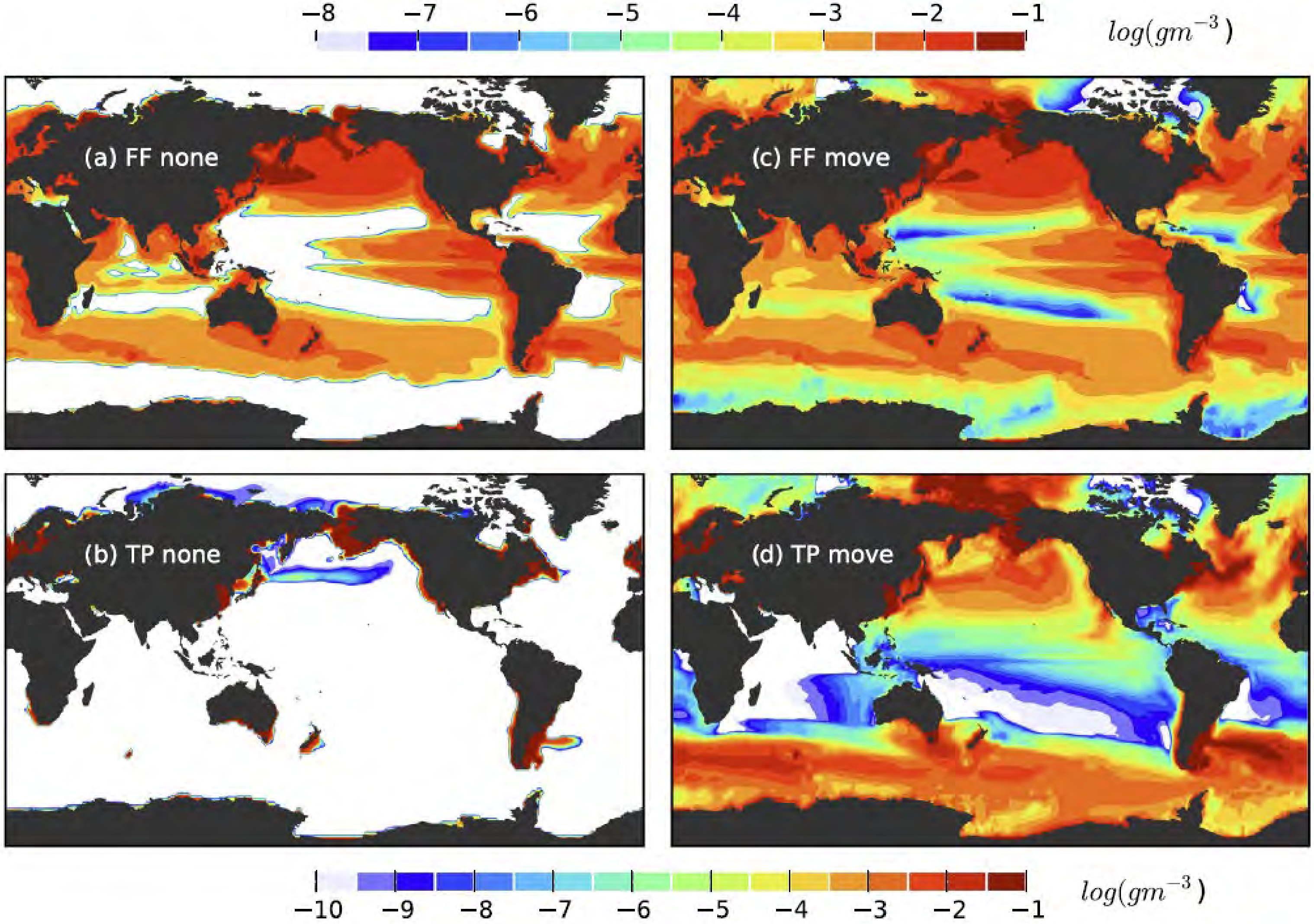
Nye et al. 2009. Marine Ecology Progress Series 393: 111-129.

# Fig. 1. Examples of North Sea fish distributions that have shifted north with climatic warming.

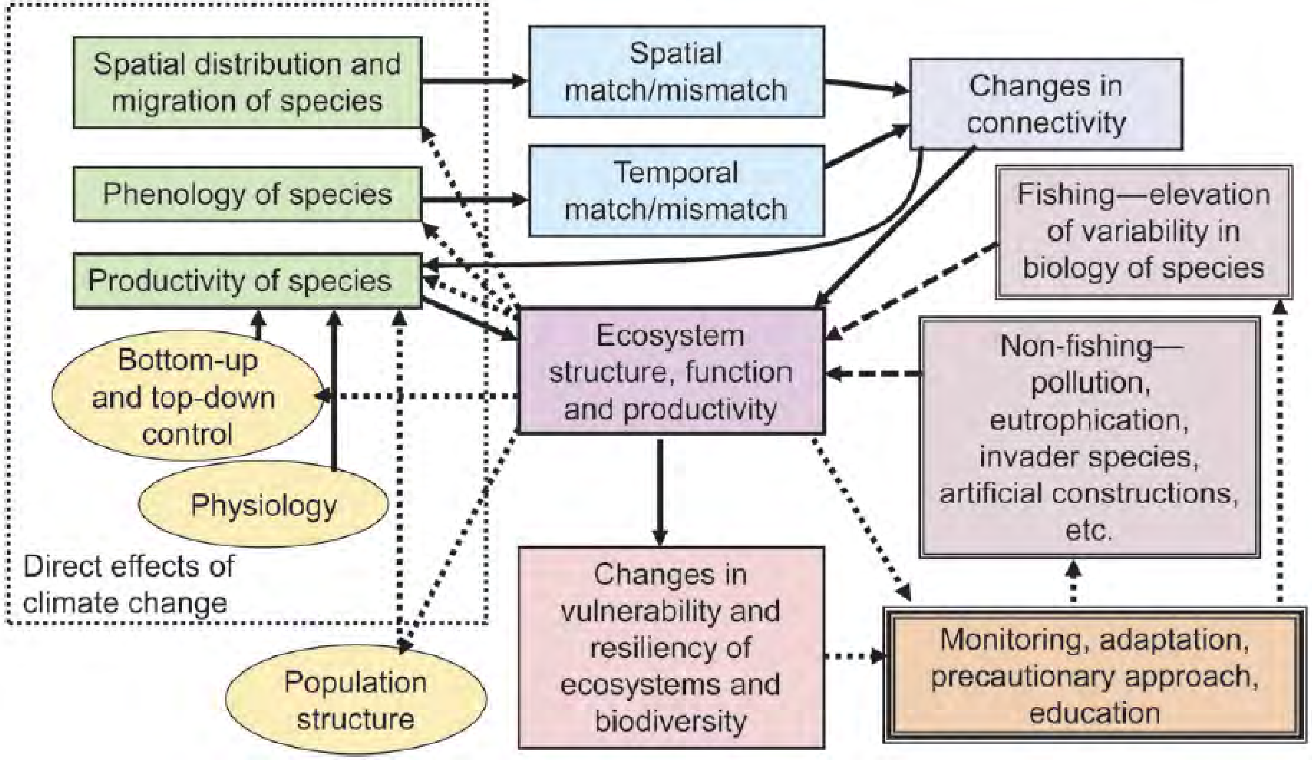


Allison L. Perry et al. Science 2005;308:1912-1915

Science
AAAS

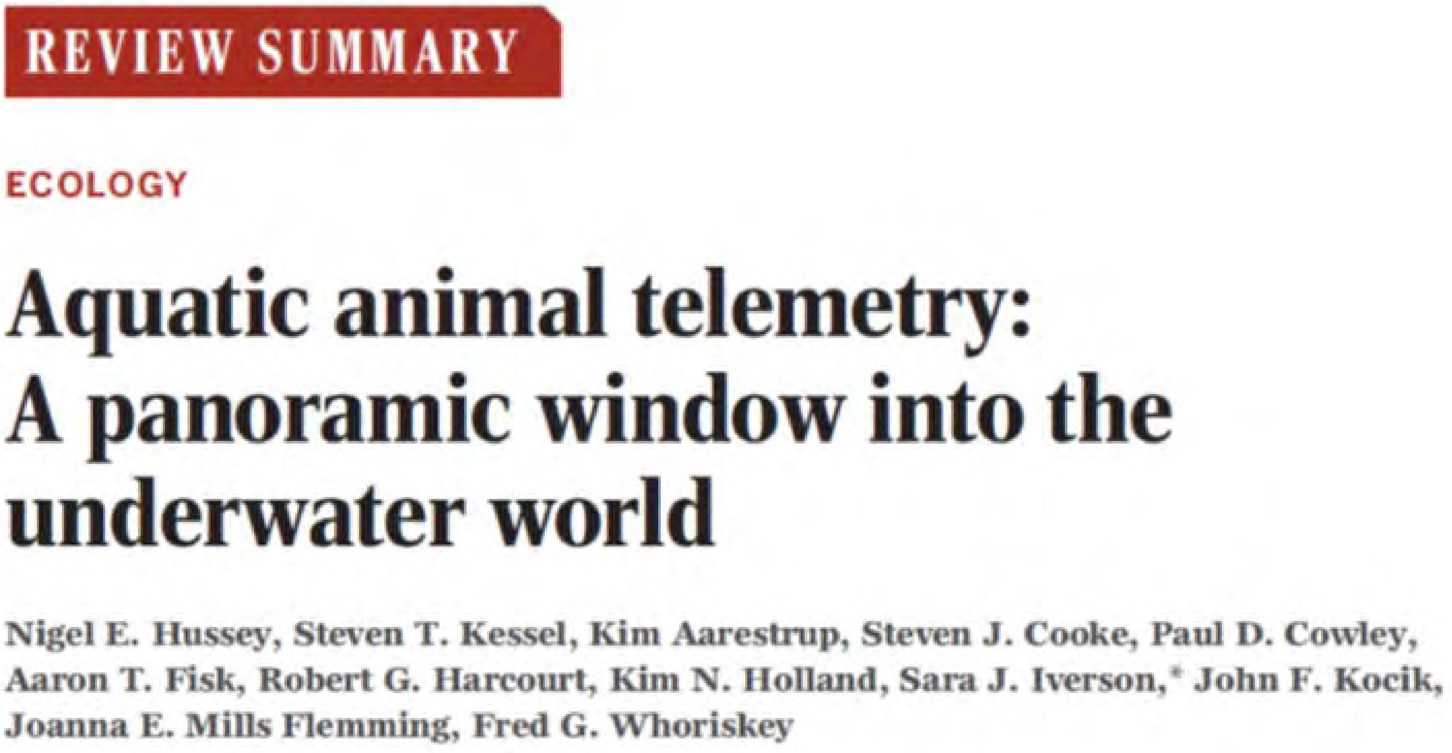


Watson et al. 2015. Progress in Oceanography 138: 521-532.



Hollowed et al. 2013. ICES Journal of Marine Science 70: 1023-1037.

# Progress: Movement Data



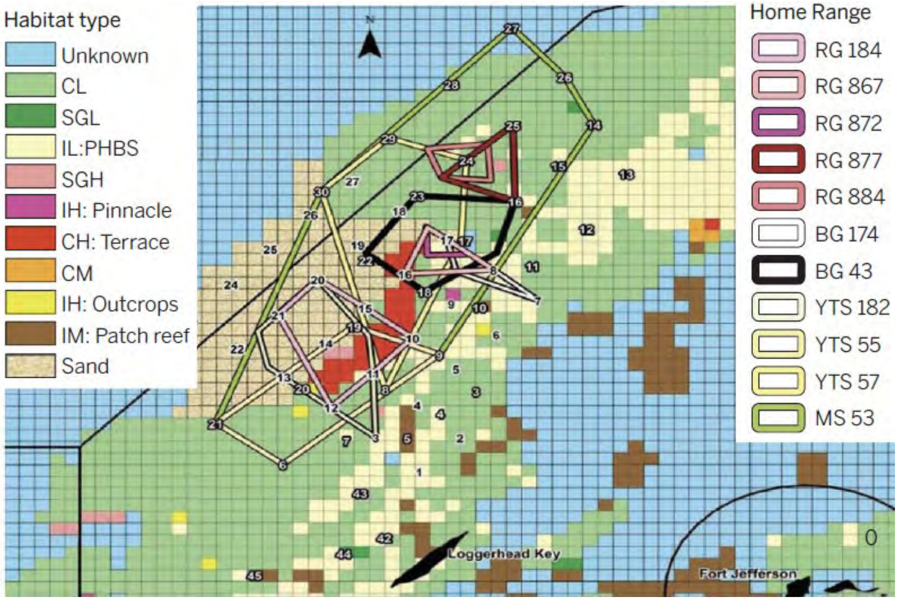
REVIEW SUMMARY

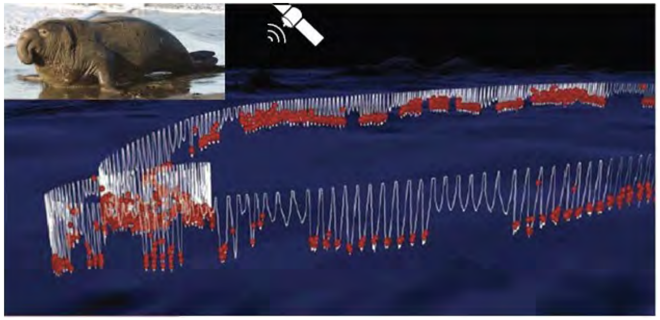
ECOLOGY

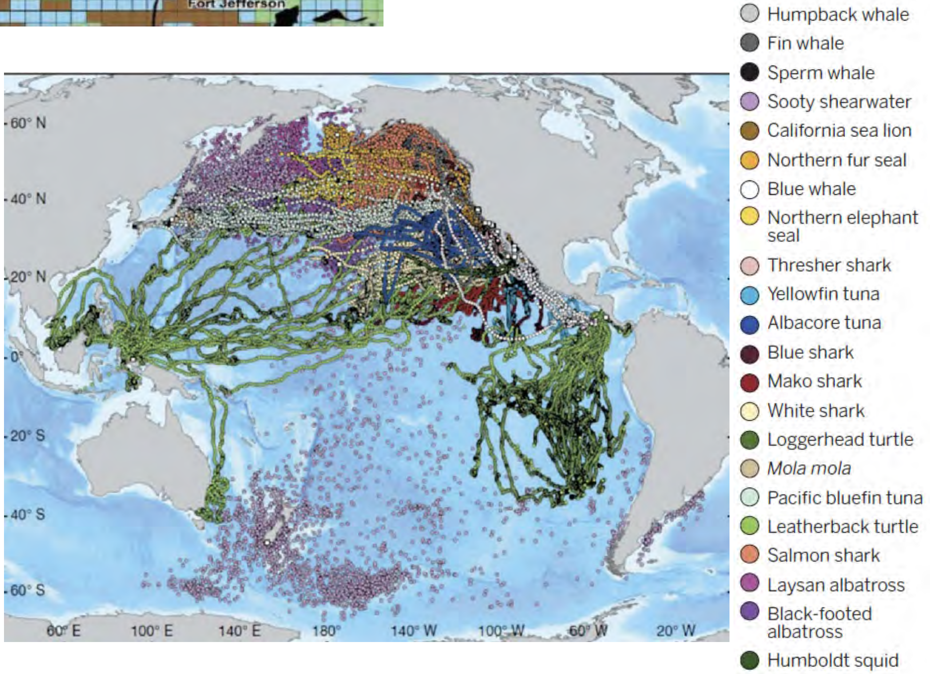
## Aquatic animal telemetry: A panoramic window into the underwater world

Nigel E. Hussey, Steven T. Kessel, Kim Aarestrup, Steven J. Cooke, Paul D. Cowley, Aaron T. Fisk, Robert G. Harcourt, Kim N. Holland, Sara J. Iverson,* John F. Kocik, Joanna E. Mills Flemming, Fred G. Whoriskey

Science 348: 1255642, 2015

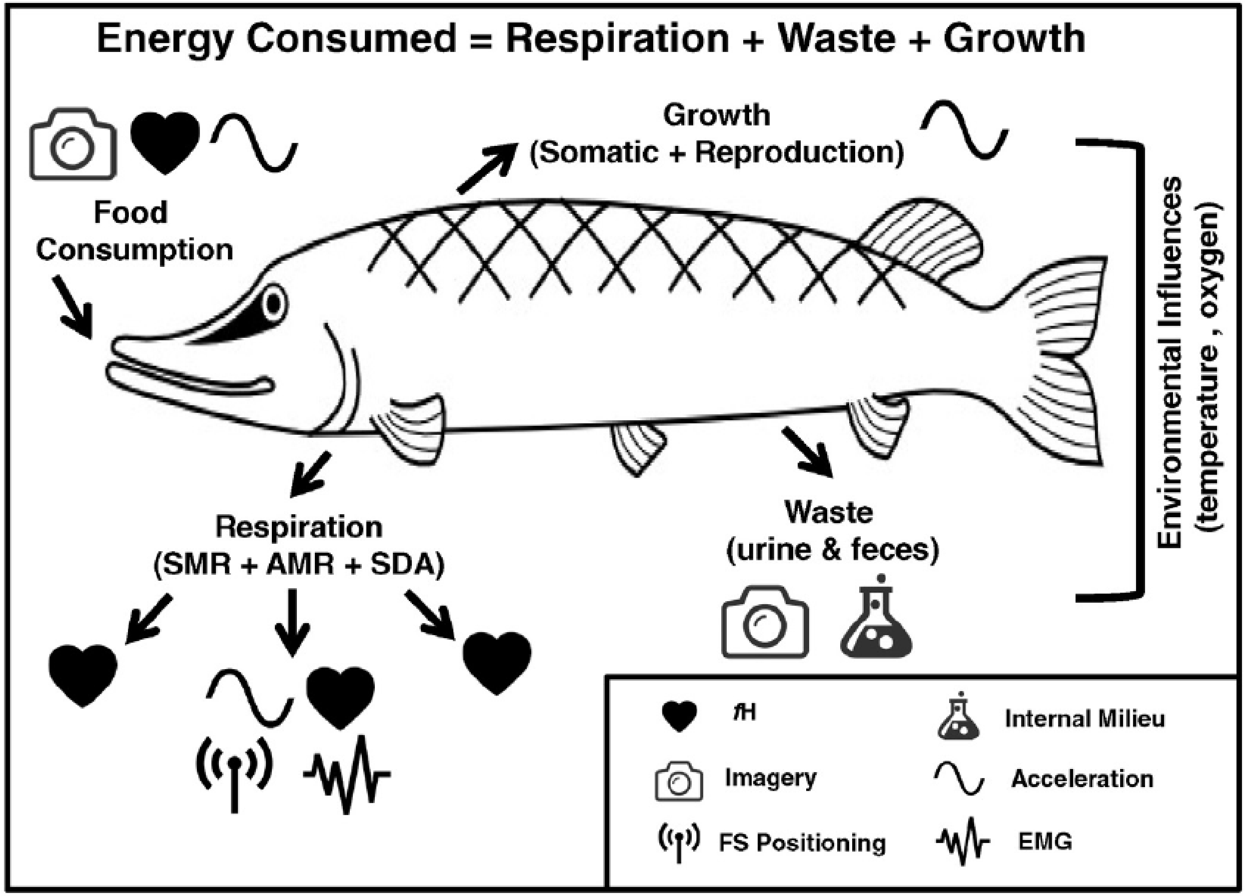






**Nigel E. Hussey et al. Science 2015;348:1255642**

Published by AAAS




Contents lists available at ScienceDirect

Comparative Biochemistry and Physiology, Part A

journal homepage: www.elsevier.com/locate/cbpa

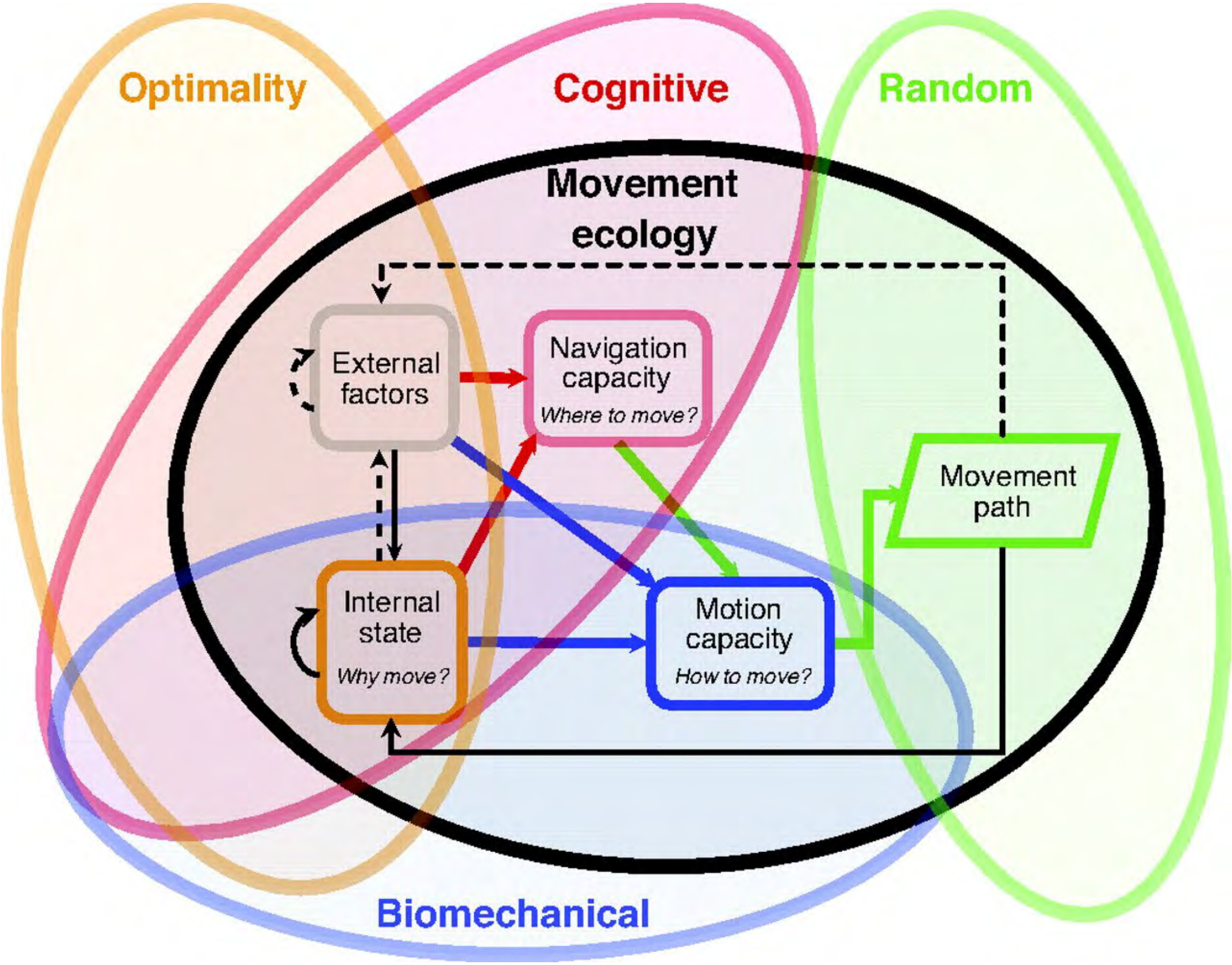
Remote bioenergetics measurements in wild fish: Opportunities and challenges☆

Steven J. Cooke[a,*], Jacob W. Brownscombe[a], Graham D. Raby[b], Franziska Broell[c], Scott G. Hinch[d], Timothy D. Clark[e], Jayson M. Semmens[f]

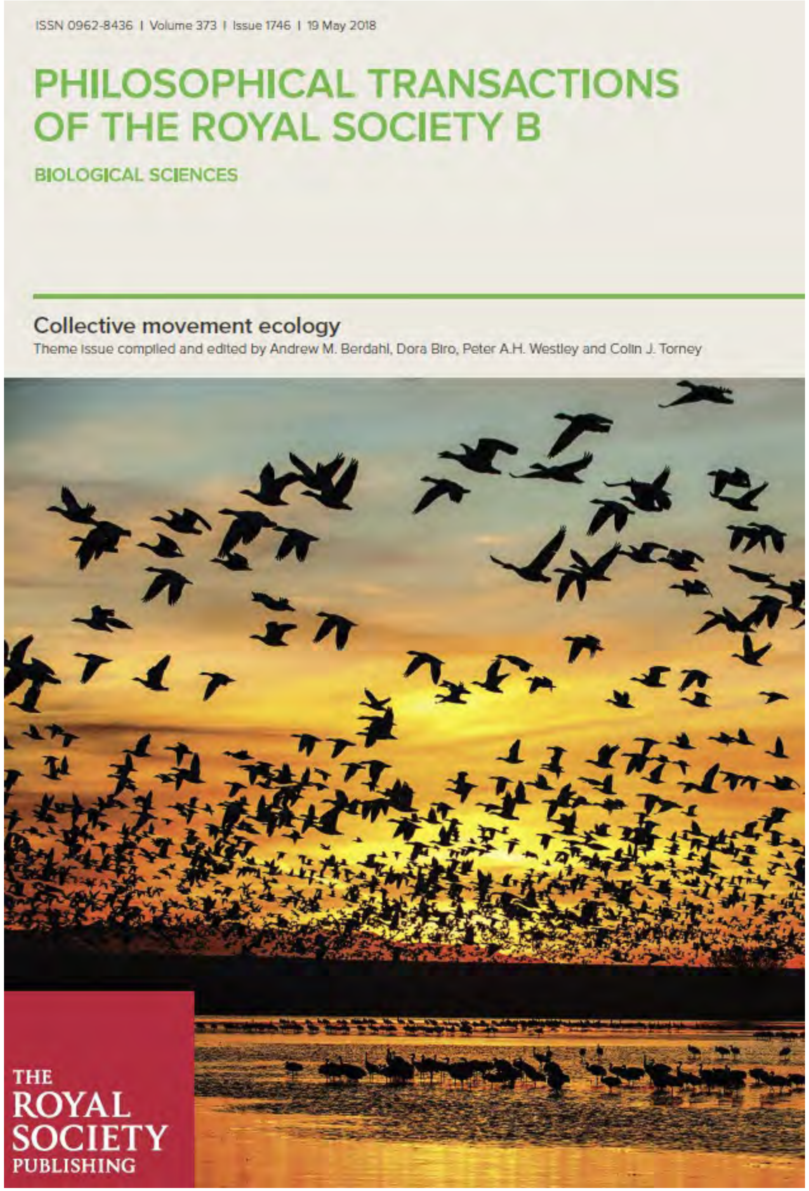
# Progress: Movement Modeling

- Many approaches have been proposed
  - $X(t+1) = X(t) + V_x(t)$
  - $Y(t+1) = Y(t) + V_y(t)$
  - $Z(t+1) = Z(t) + V_z(t)$
  - Determine the cell

- Quite confusing because of non-standard descriptions and terminology for $V_x$, $V_y$, and $V_z$
  - Random walk
  - Run and tumble
  - Event-based
  - Restricted-area
  - Kinesis
  - ANN



Ran Nathan et al. J Exp Biol 2012;215:986-996



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PHILOSOPHICAL TRANSACTIONS
OF THE ROYAL SOCIETY B

BIOLOGICAL SCIENCES

Collective movement ecology
Theme issue compiled and edited by Andrew M. Berdahl, Dora Biro, Peter A.H. Westley and Colin J. Torney

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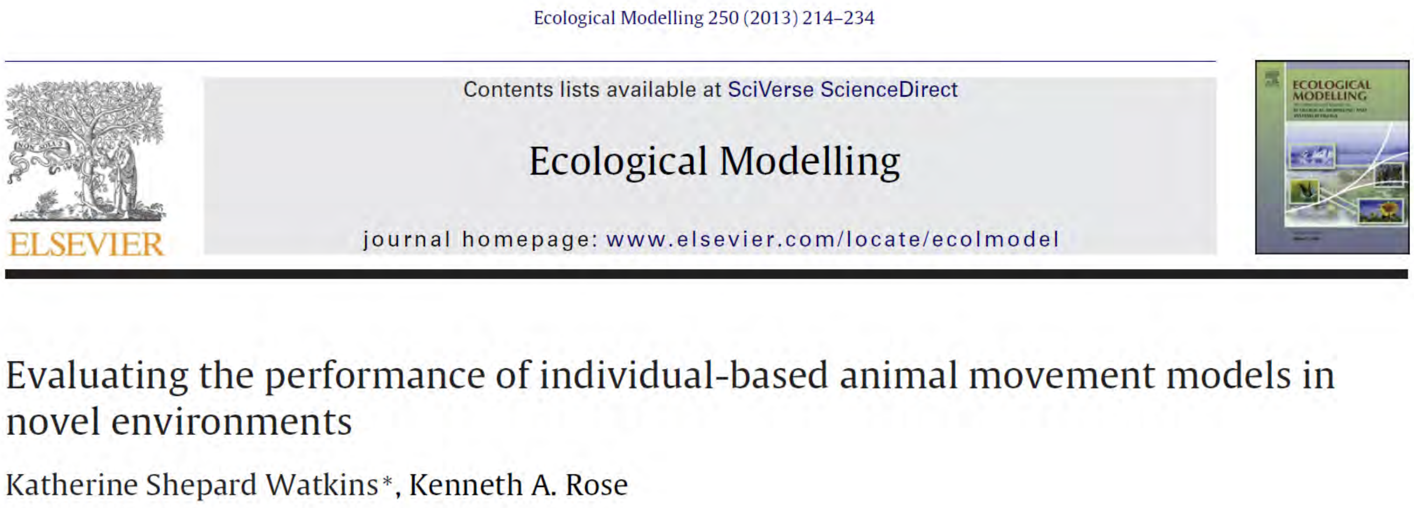
**biomove symposium 2018**
Integrating Biodiversity Research with Movement Ecology

GRC

**Movement Ecology of Animals**
*Gordon Research Conference*

# Major Issue

- If we are to use these methods to simulate management actions and climate change, then the methods must predict responses to changes in cue(s)



Ecological Modelling 250 (2013) 214–234

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

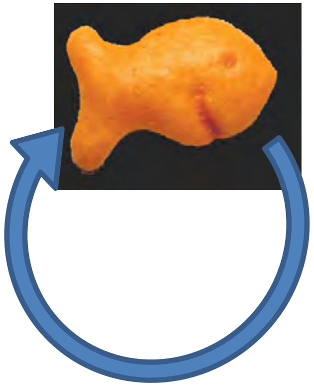
ELSEVIER

Evaluating the performance of individual-based animal movement models in novel environments

Katherine Shepard Watkins*, Kenneth A. Rose

# Model Structure

**Simplified Hypothetical Species**



**Scale**

Grid: 540 x 540 cells

Cells: 5 $m^2$

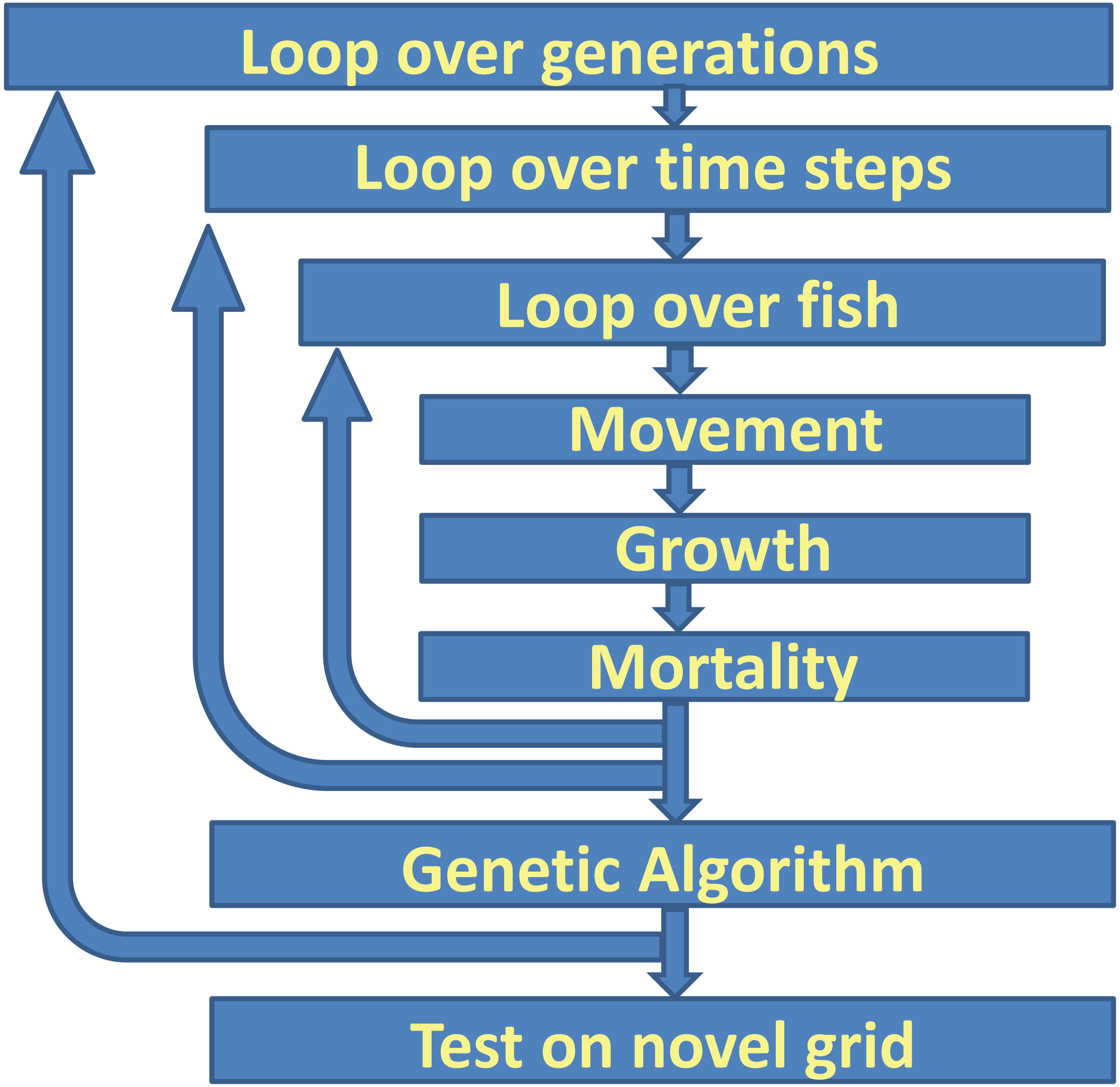
Time step: 5 minute

Generation: 30 days

Initial size = 73.3 mm

Initial worth = 100 fish

3000 super-individuals



Loop over generations

Loop over time steps

Loop over fish

Movement

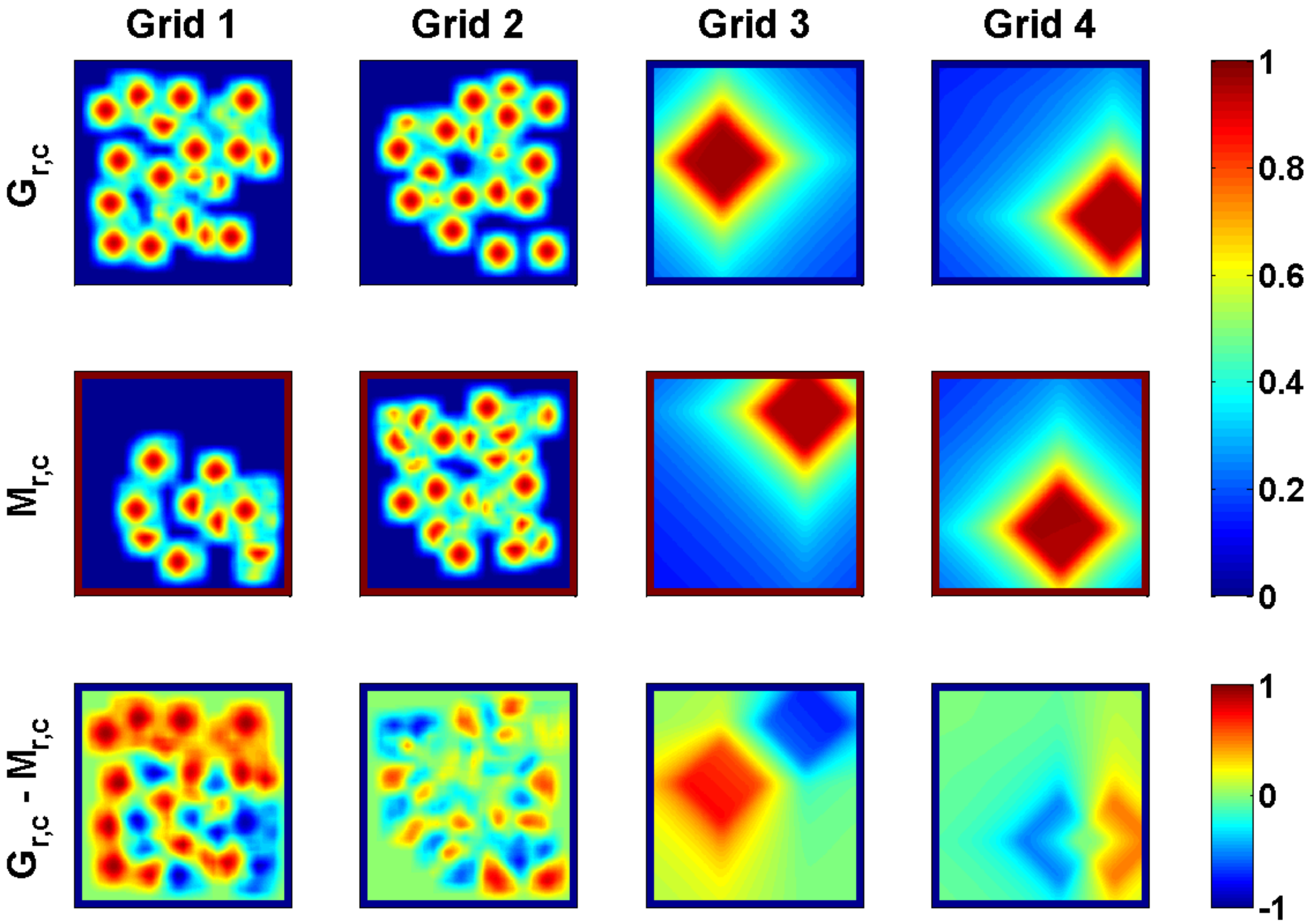
Growth

Mortality

Genetic Algorithm

Test on novel grid

# Environmental Gradients



**Patchy**
**No trade-offs**

**Patchy**
**Trade-offs**

**Smooth**
**No Trade-offs**

**Smooth**
**Trade-offs**

# Model Processes

## Growth (mm 5-min$^{-1}$)

$G = G_{max} * G_{r,c}$

$L(t+1) = L(t) + G$

$W(t+1) = a * L(t+1)^{b}$

## Mortality (5-min)$^{-1}$

$M = M_{max} * M_{r,c} * M_{L}$

$S(t+1) = S(t) * e^{-M}$

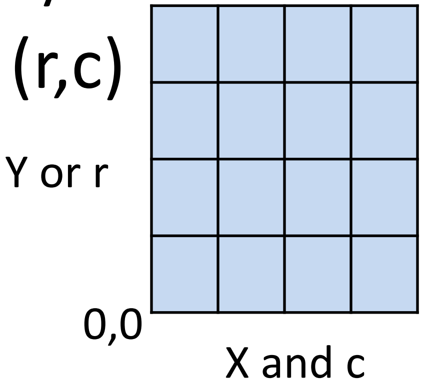
$$M_L = 1 - \frac{L_i - 73.3}{L_{max} - 73.3}$$

## Movement

$\mathbf{X(t+1) = X(t) + V_x(t)}$

$\mathbf{Y(t+1) = Y(t) + V_y(t)}$

cell location (r,c)



## Reproduction

$E = 55 \cdot S(30) \cdot (421.84 \cdot W(30) + 304.79)$

# GA Calibration

- 3000 strategy vectors of parameter values
  - Start with random values for everyone

- Every 30-day generation, select 3000 individuals:
  - P(selection) = $E_i/\Sigma E$
  - Mutate each vector: 6% of parameters, ±0.25

- Use these 1000 vectors for the next generation

- Continue until egg production levels off

- Parameter values should have converged

# Restricted Area Search

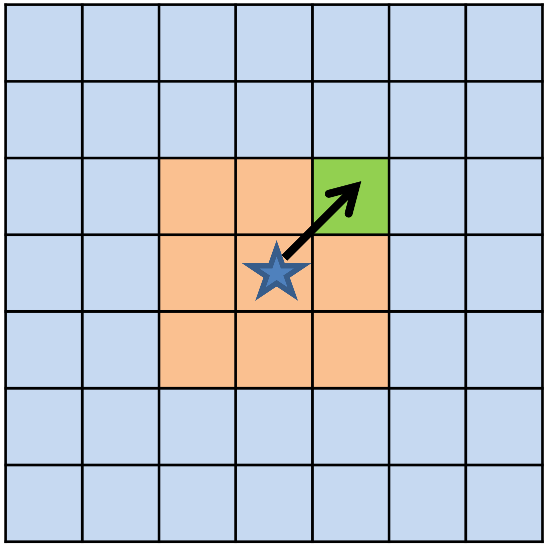
- Rank cells in a $D_{hood}$ cell radius by habitat quality ($Q_{c,r}$)

$$Q_{c,r} = (1-\delta)*(G_{c,r} + n) - \delta*(M_{c,r}*M_L + n)$$

- $n = \left(1 - \frac{1.42}{\sqrt{(c-xcell)^2 + (r-ycell)^2}}\right)$

- Compute Θ = toward the cell with the highest $Q_{c,r}$

$$V_x(t) = (SS + RV_1 \cdot R_{dist}) \cdot \cos(\theta + RV_2 \cdot R_\theta)$$
$$V_y(t) = (SS + RV_1 \cdot R_{dist}) \cdot \sin(\theta + RV_2 \cdot R_\theta)$$



- GA evolves: $\delta$, $R_\theta$, $R_{dist}$, $D_{hood}$

# Kinesis

- Velocities are the sum of inertial (f) and random (g)
- Compute random swim speed: $\varepsilon_x = N(\sqrt{1.0/2}, 0.5)$
- Compute habitat quality: $Q_{c,r} = (1-\delta)*G_{c,r} - \delta*M_{c,r}*M_L$
- Compute f and g weighted by how close habitat quality ($Q_{c,r}$) is to the optimal habitat ($Q_{opt}$)

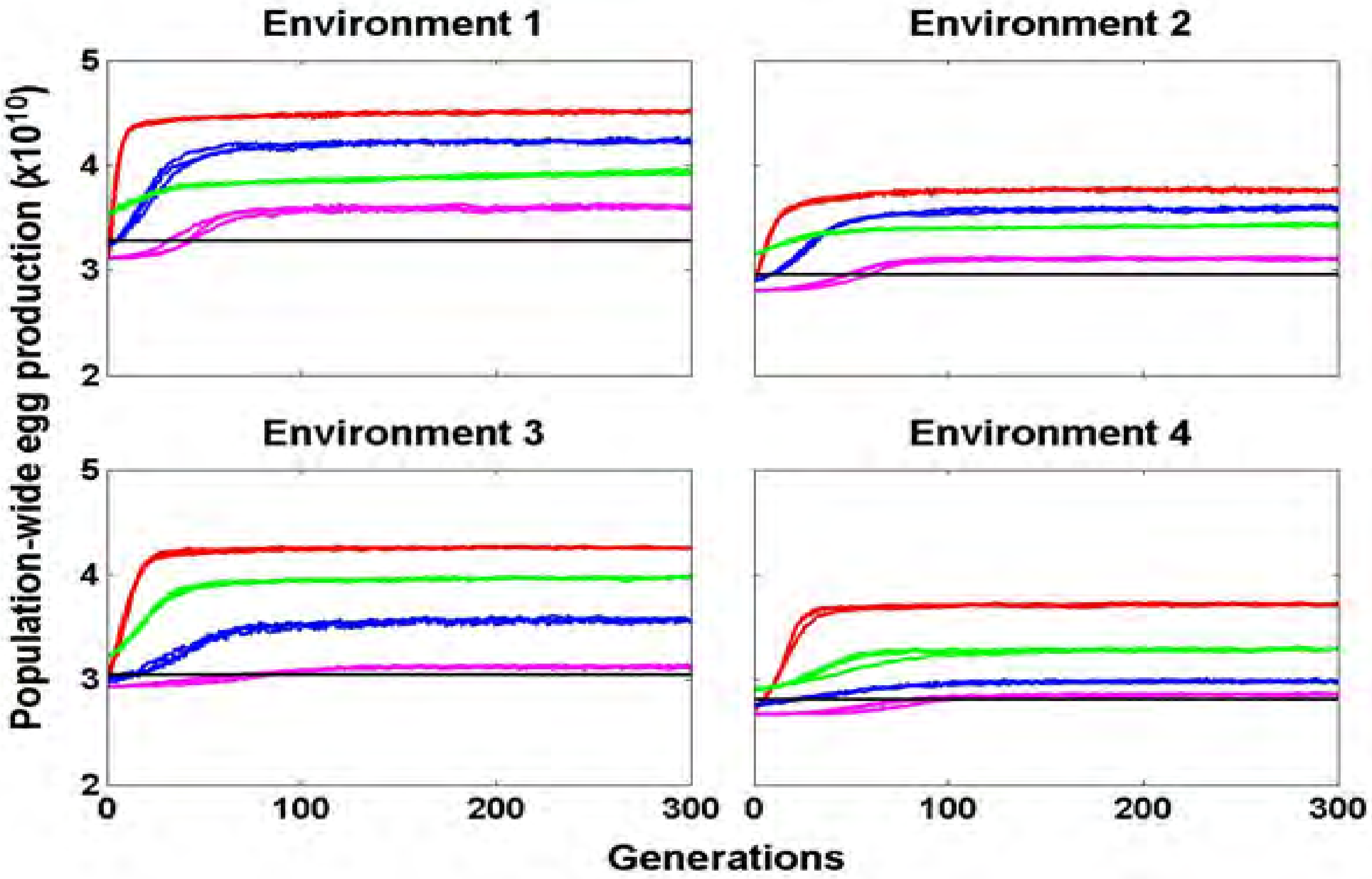
$$f_x = \mathrm{Vel}_x(t-1) \cdot H_1 \cdot e^{-0.5\left(\frac{Q_{c,r}-Q_{opt}}{\sigma_Q}\right)^2}$$

$$g_x = \varepsilon_x \cdot \left(1 - H_2 \cdot e^{-0.5\left(\frac{Q_{c,r}-Q_{opt}}{\sigma_Q}\right)^2}\right)$$

$$\boxed{\begin{aligned} V_x(t) &= f_x + g_x \\ V_y(t) &= f_y + g_y \end{aligned}}$$

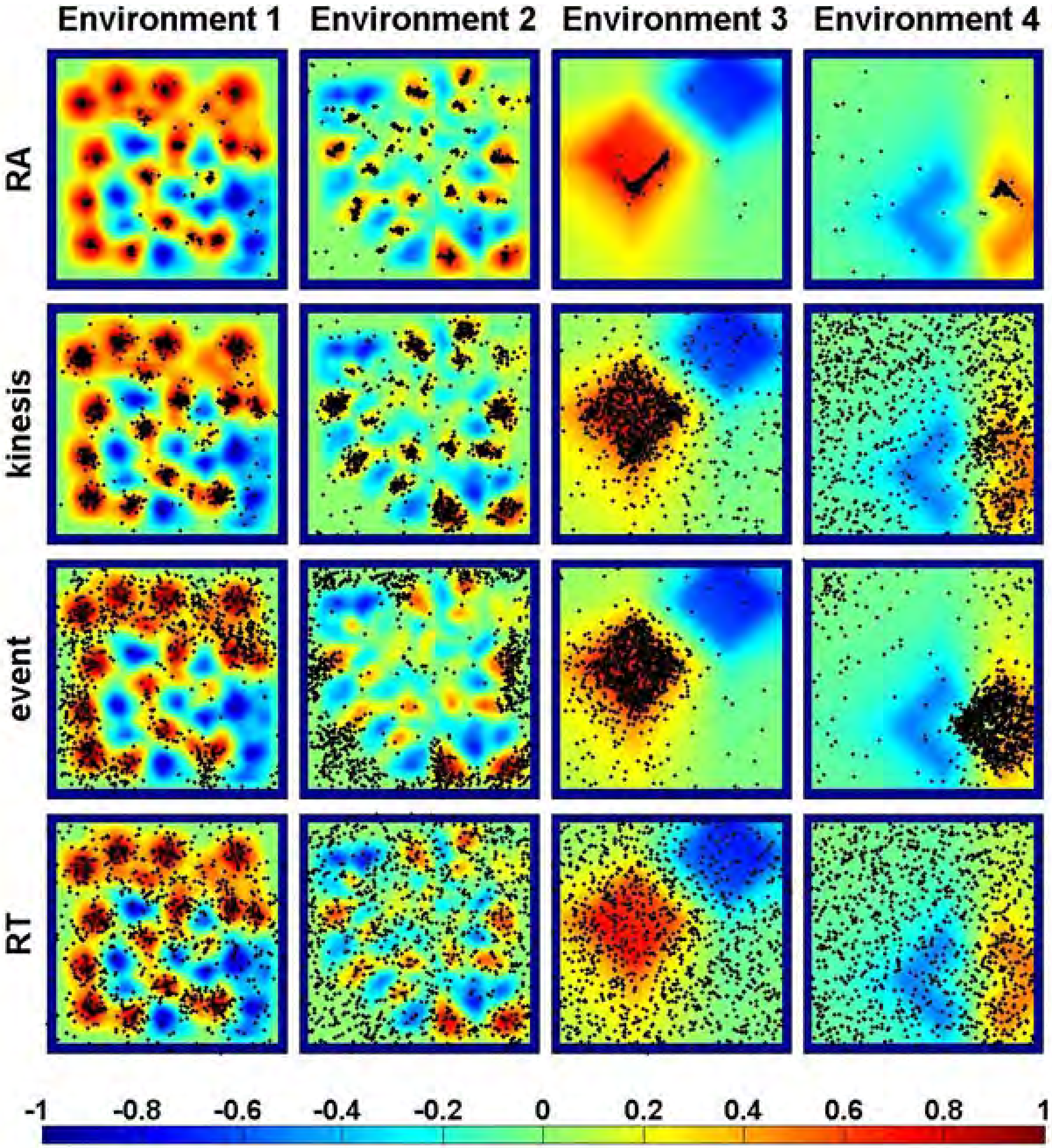
- GA evolves $Q_{opt}$, σ, $H_1$, $H_2$, δ

# Calibration – Fitness Convergence

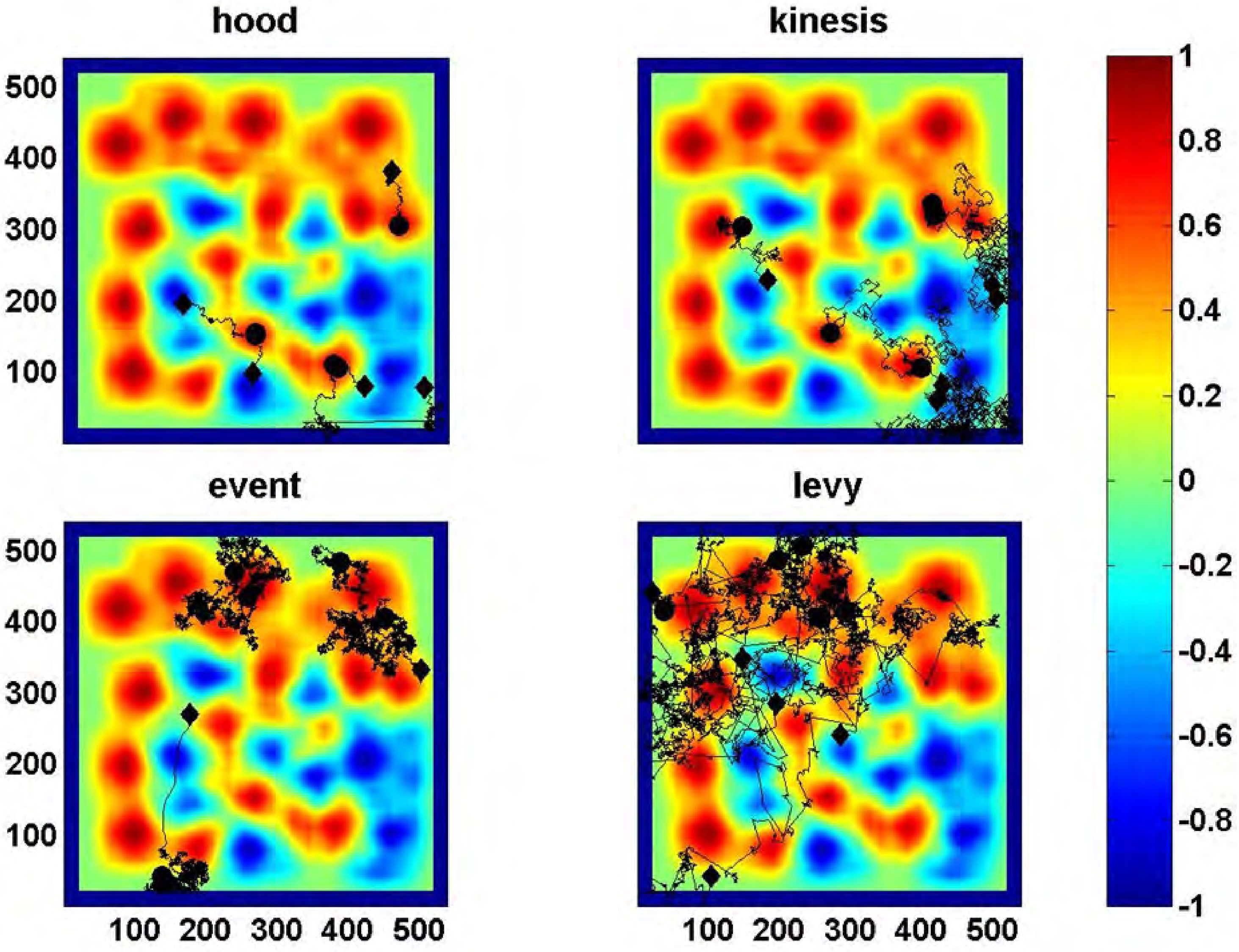


Restricted area, Kinesis , Event-based, Run-tumble

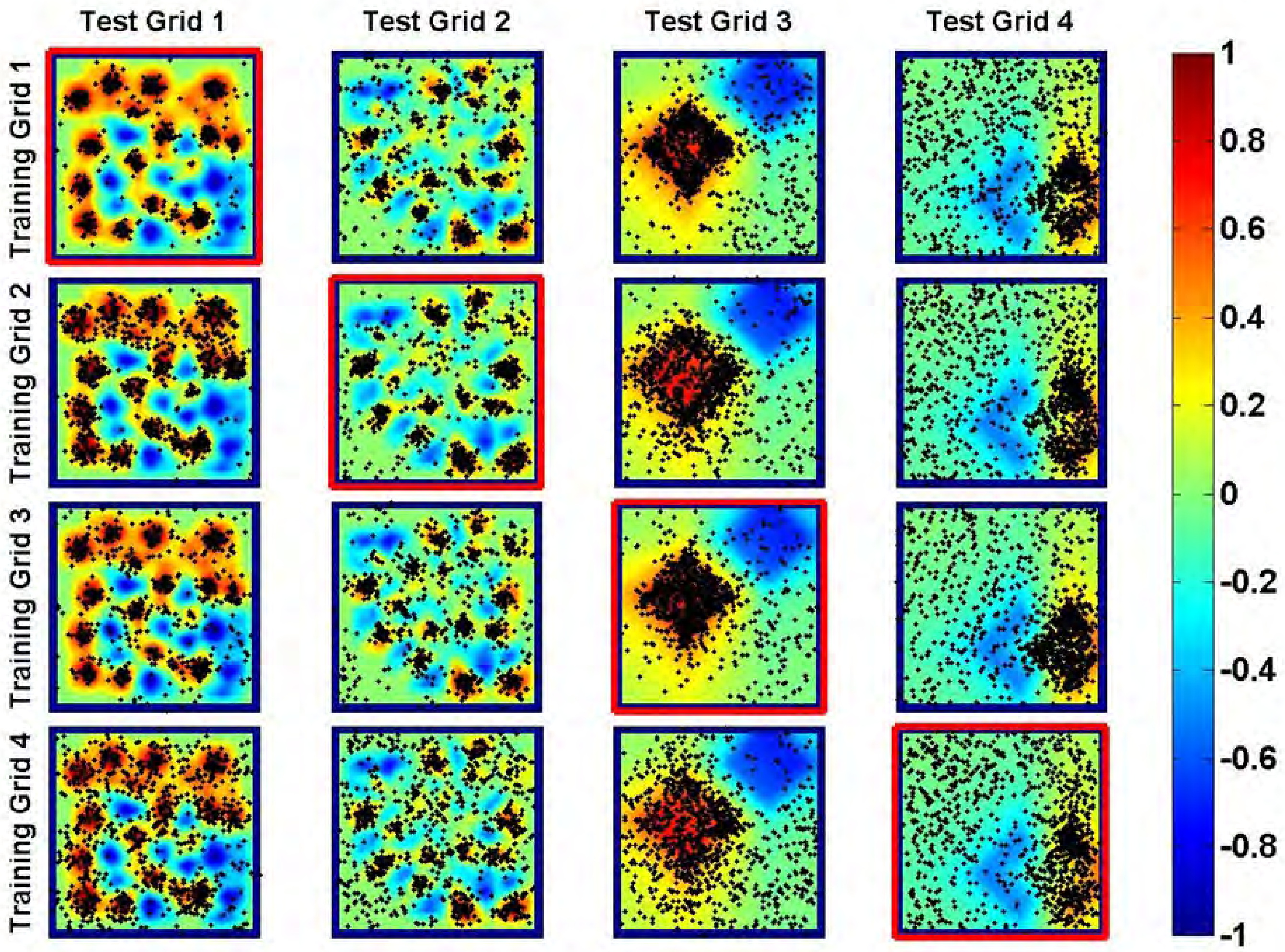
Last day
of 300th
generation



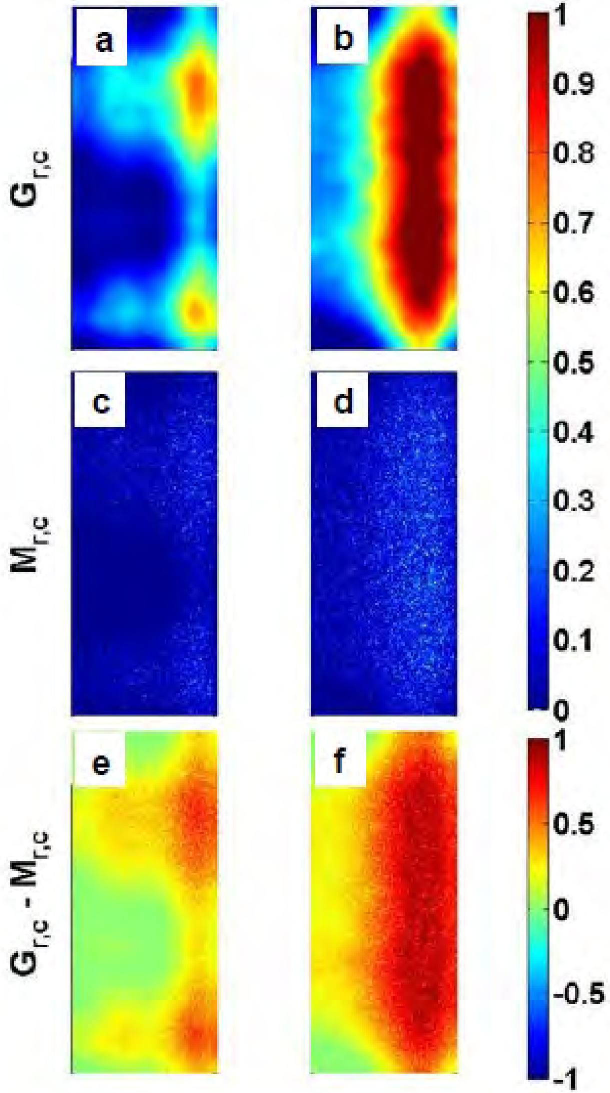
# 10 Individuals

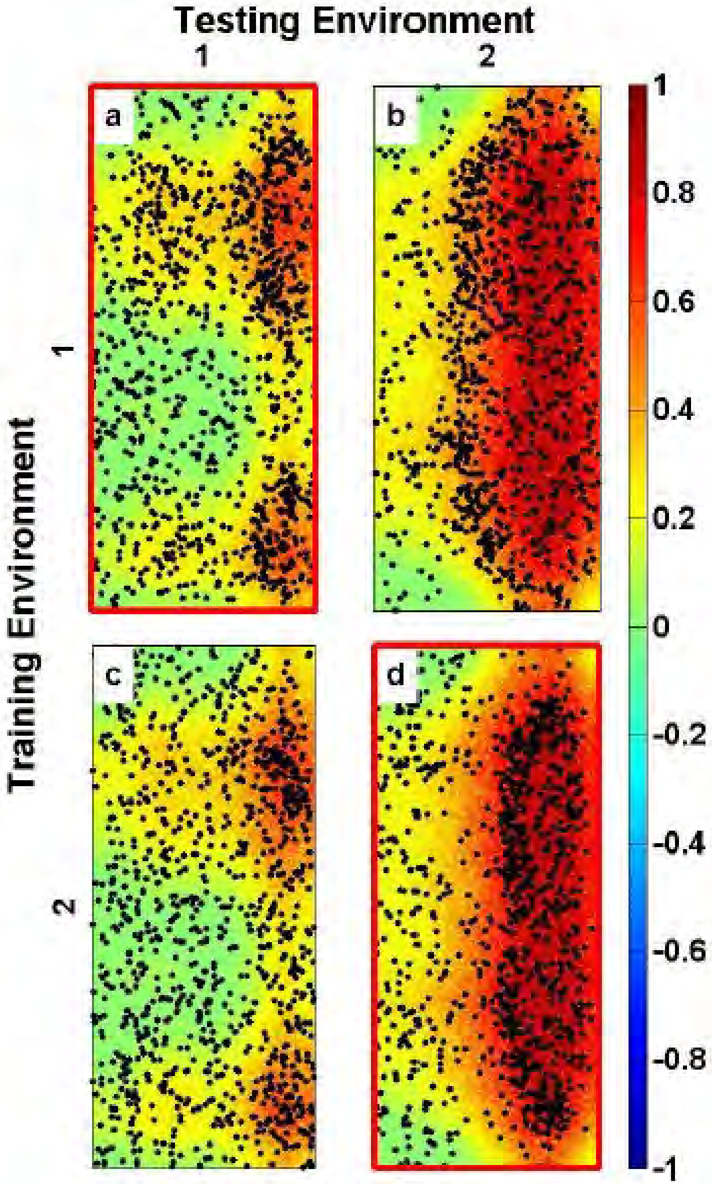


# Kinesis - Testing



# Regional Ocean Grid





Enrique N. Curchitser
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Miguel Bernal
FAO – Rome

Sean Creekmore
Louisiana State University

Alan Haynie
Alaska Fisheries Science Center - NOAA

Shin-ichi Ito
University of Tokyo

Bernard Megrey
Alaska Fisheries Science Center - NOAA

Chris Edwards
University of California – Santa Cruz

Dave Checkley
Scripps Institute of Oceanography

Tony Koslow
Scripps Institute – CALCOFI

Sam McClatchie
Southwest Fisheries Science Center - NOAA

Francisco Werner
Southwest Fisheries Science Center - NOAA

Alec MacCall
Southwest Fisheries Science Center - NOAA

Vera Agostini
Nature Conservancy

Rose et al. 2015. Demonstration of a fully-coupled end-to-end model for small pelagic fish using sardine and anchovy in the California Current. Progress in Oceanography 138: 348-380.

Fiechter et al. 2015. The role of environmental controls in determining sardine and anchovy population cycles in the California Current: Analysis of an end-to-end model. Progress in Oceanography 138: 381-398.


MARINE and
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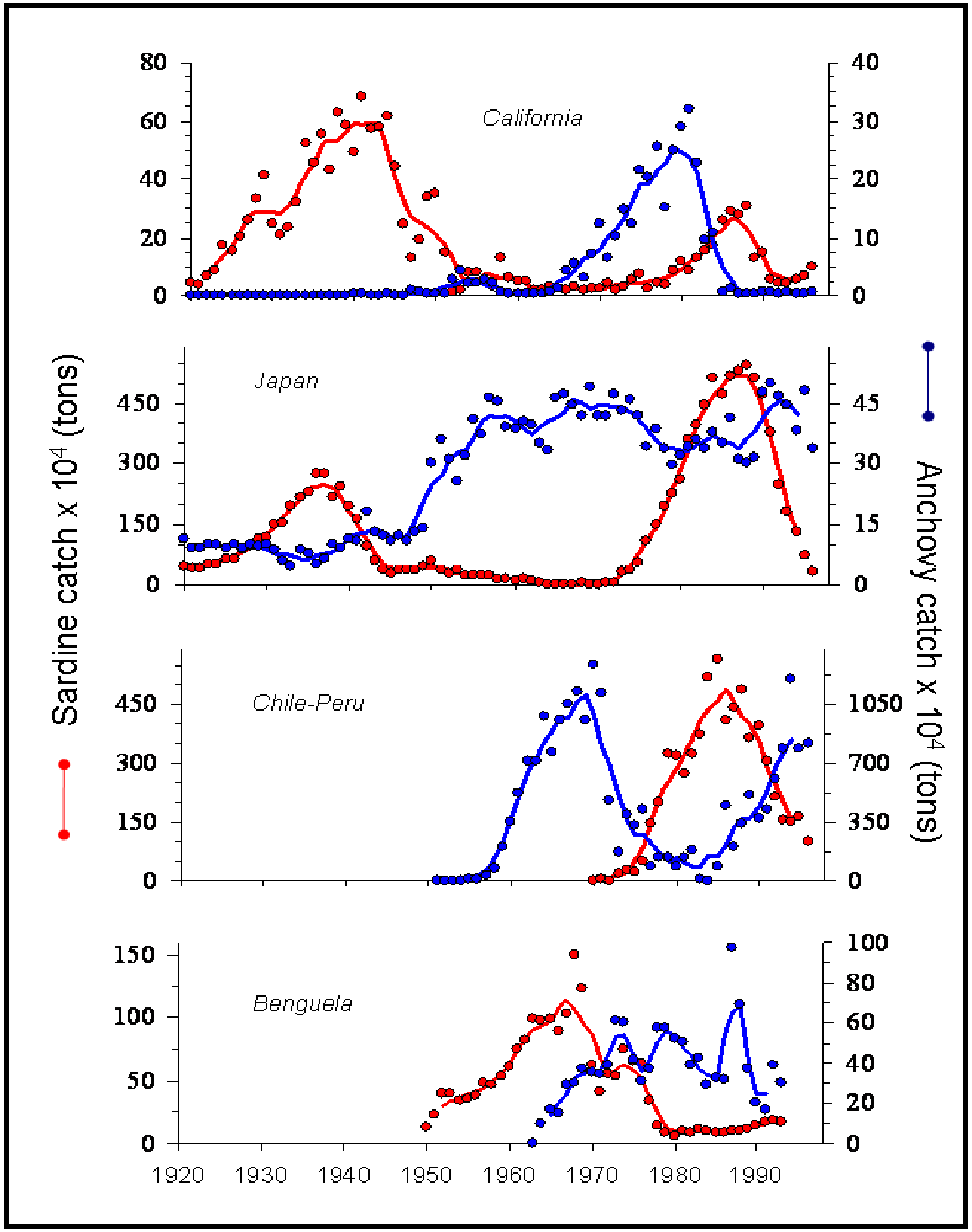
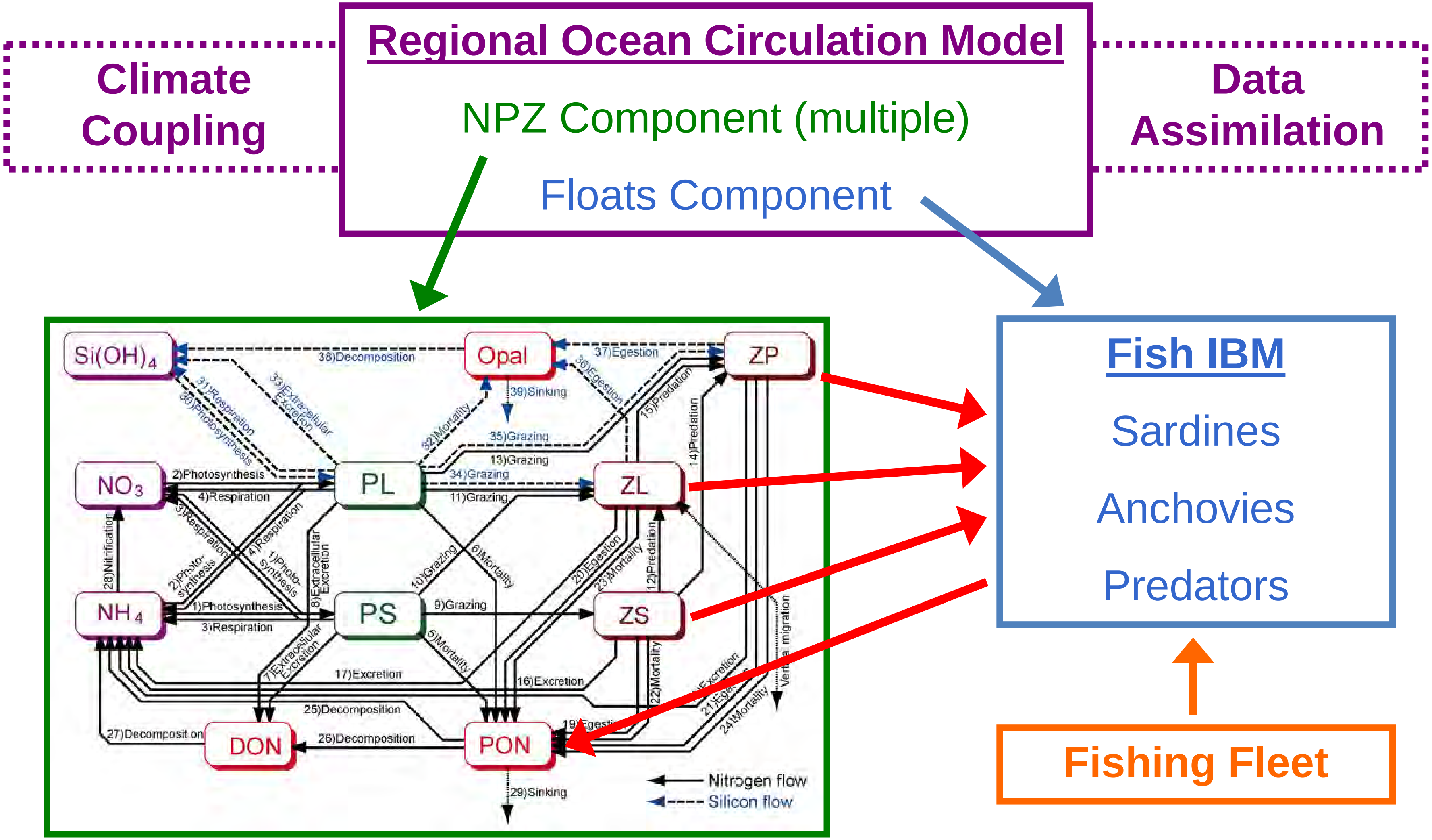


Provided by: Salvador E. Lluch-Cota based on Schwartzlose et al. 1999

# Fully-Coupled Model Within ROMS



**Climate Coupling**

**Regional Ocean Circulation Model**

NPZ Component (multiple)

Floats Component

**Data Assimilation**

**Fish IBM**

Sardines

Anchovies

Predators

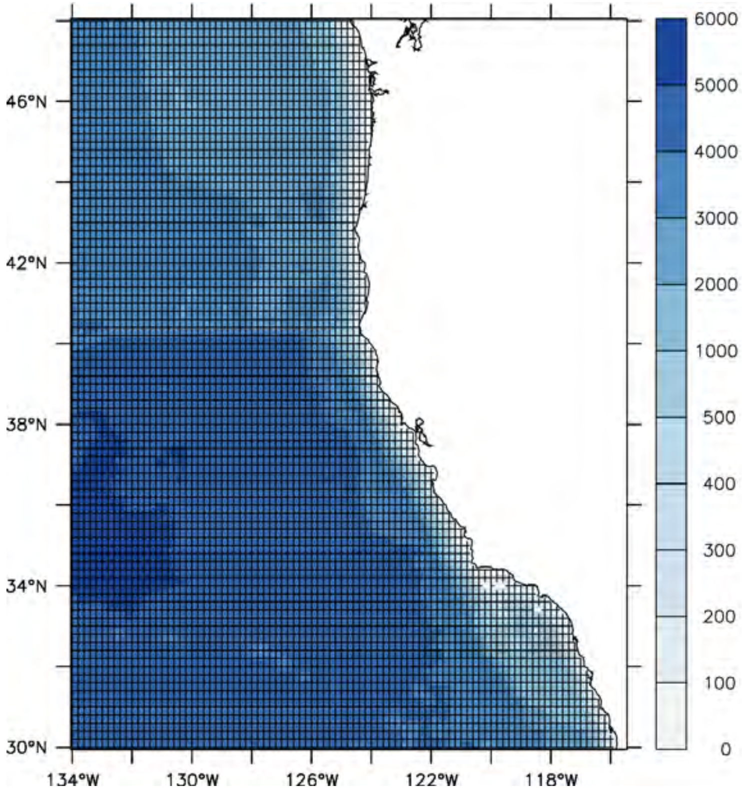
**Fishing Fleet**

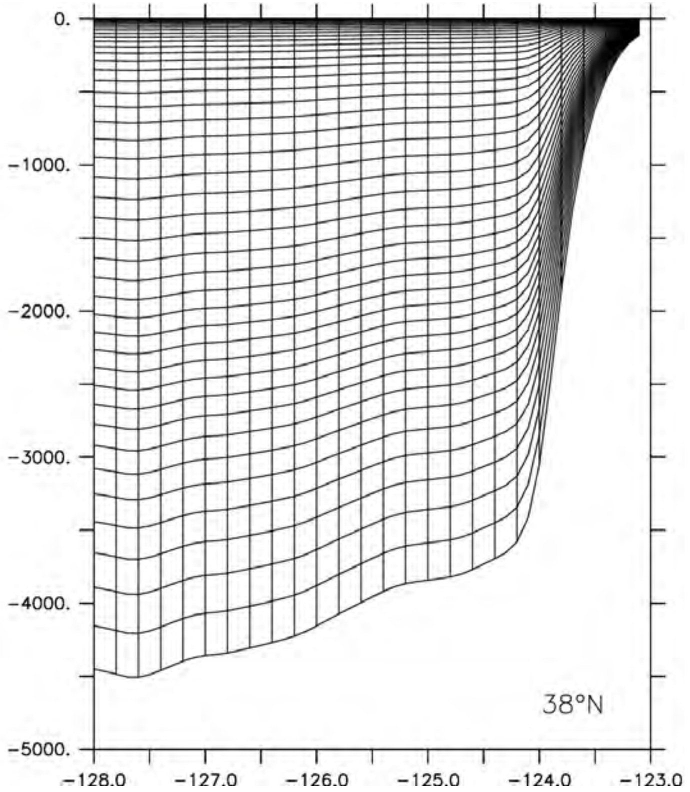
# Model 1: ROMS

- Grid:

10 km

42 levels

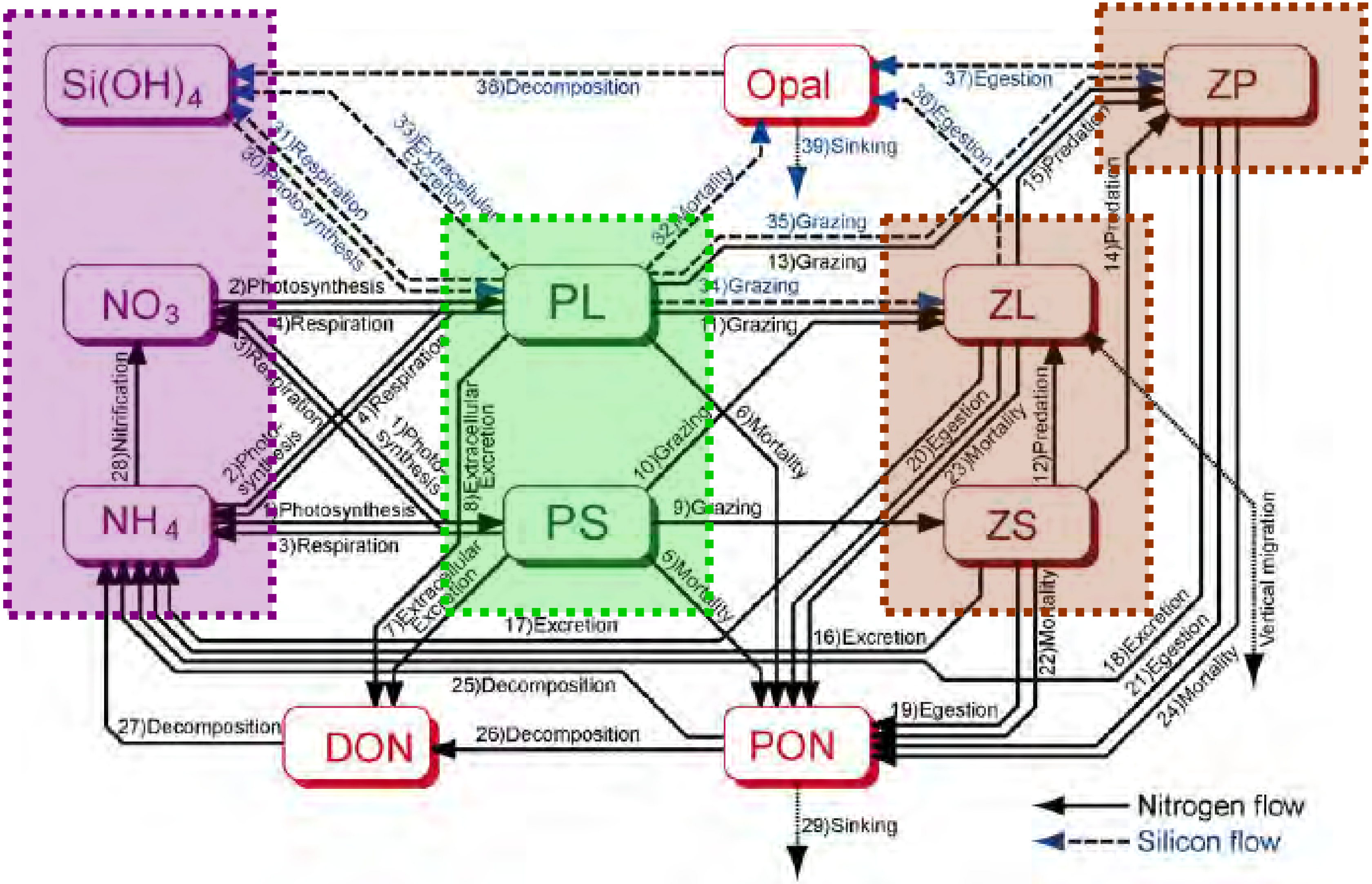




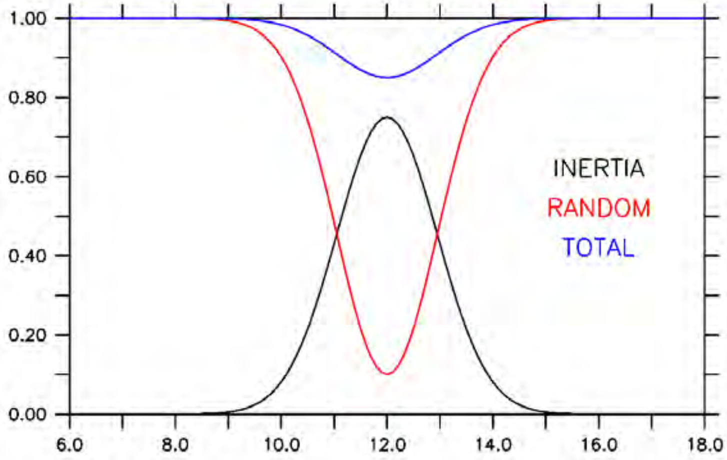
- 900 s

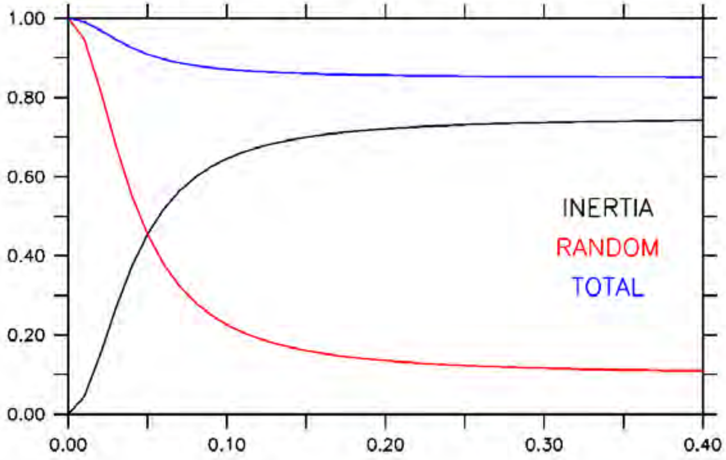
- Run duration: 50 years (1959-2009)

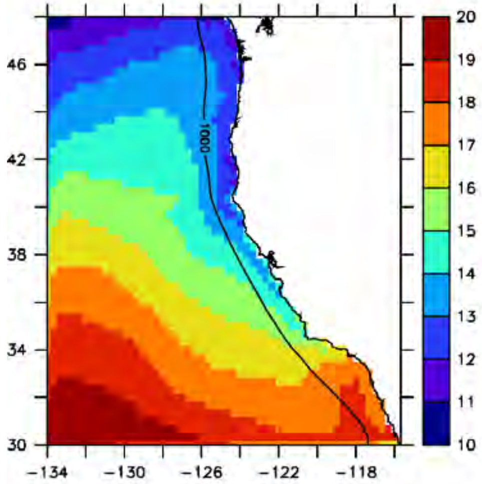
# Model 2: NEMURO



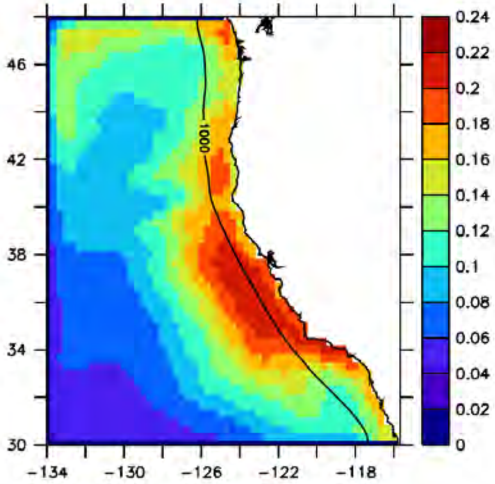
# Environmental Cues for Movement (Kinesis)


Temperature (°C) - Gaussian

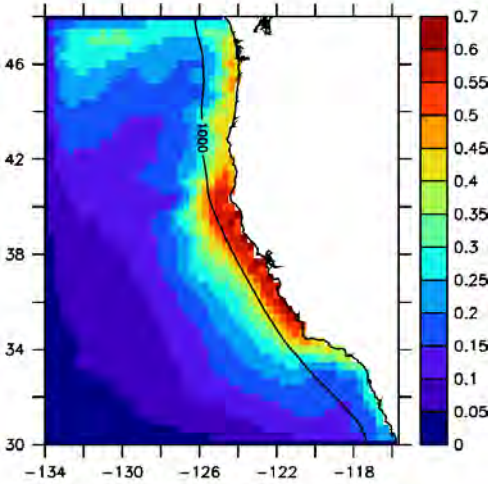

P-Value ($C/C_{max}$) – Holling Type III



Mean SST (1985-2005)



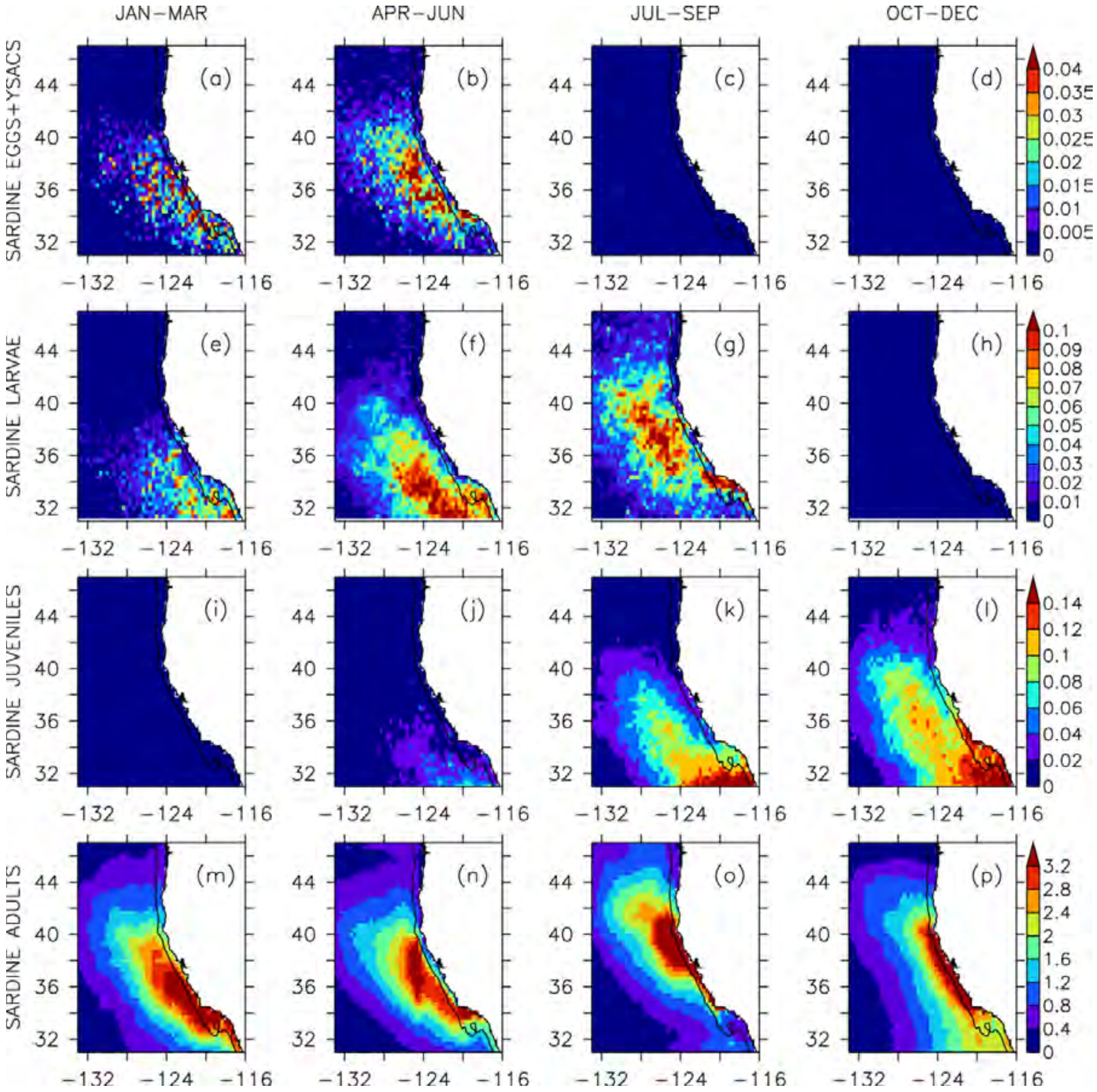
Mean ZS (1985-2005)

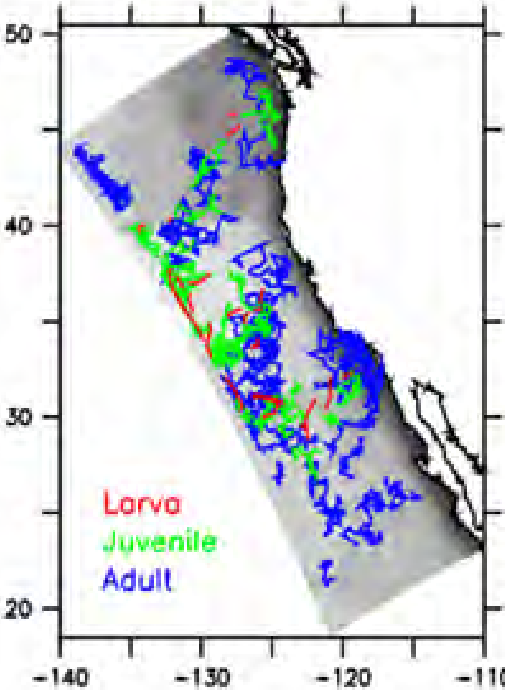


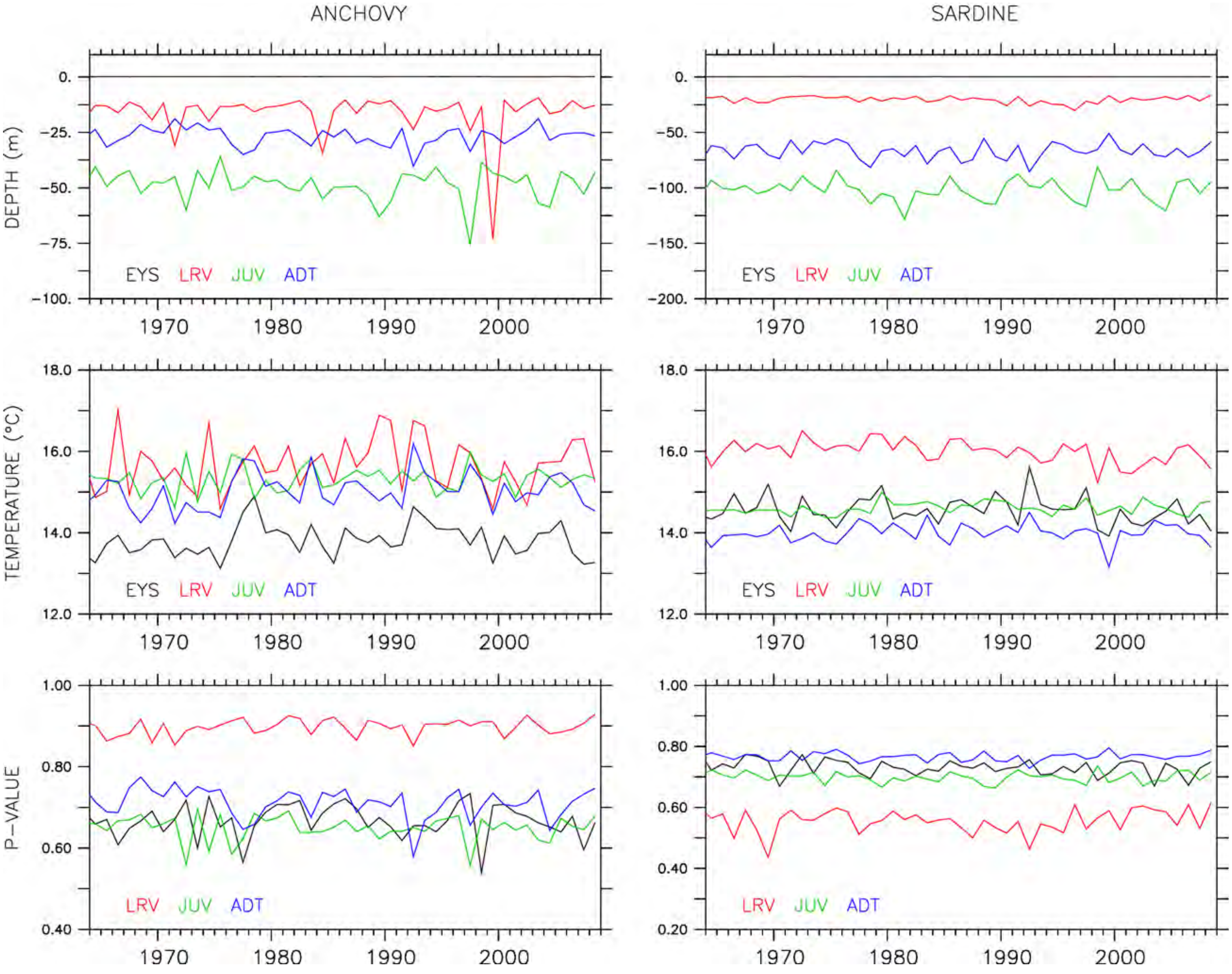
Mean ZL (1985-2005)

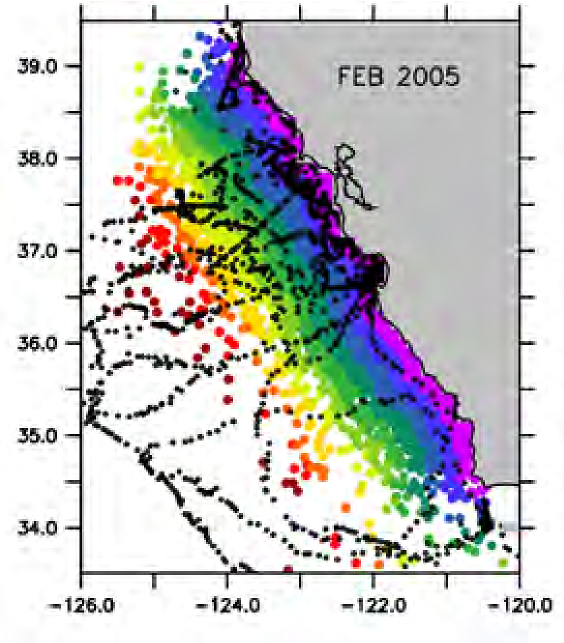
# Sardine Spatial

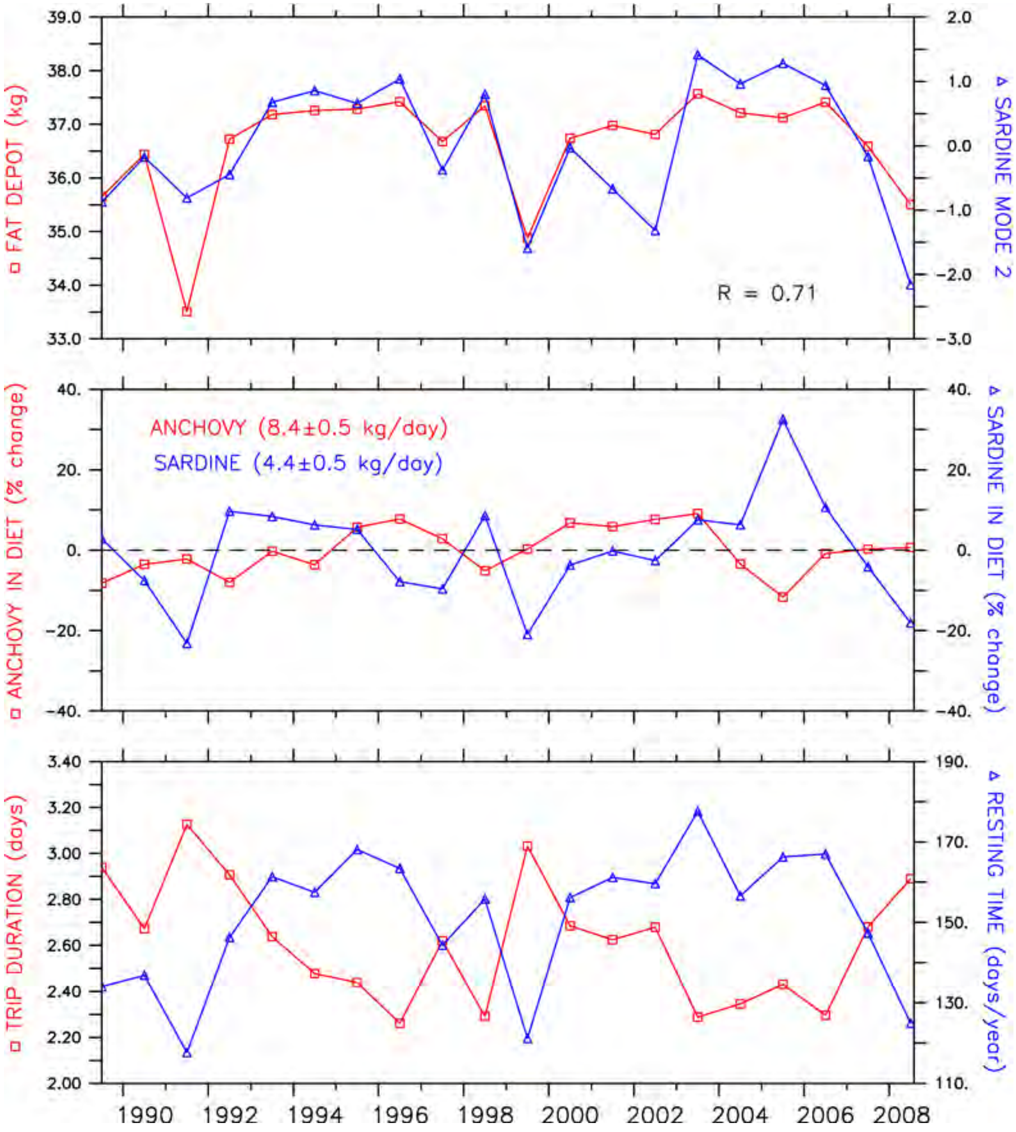
(E&YS – $10^{12}$; 1000 MT)






ANCHOVY
SARDINE
DEPTH (m)
0.
-25.
-50.
-75.
-100.
-50.
-100.
-150.
-200.
TEMPERATURE (°C)
18.0
16.0
14.0
12.0
P-VALUE
1.00
0.80
0.60
0.40
0.20
1970
1980
1990
2000
EYS
LRV
JUV
ADT





Fiechter et al. 2016. Marine Ecology Progress Series 556: 273-285.

# Needs and Opportunities

- Merging of traditional and new data with modeling movement

- Standardization of movement algorithms
  - Description
  - Validation and testing: “out-of-sample”

- Best practices guidance

# Needs and Opportunities

- Confidence in projected and ecological cues
- Two-way link to bioenergetics
- Richness of changes in spatial distributions into fisheries management