# Modeling movement of fish over spatial and temporal scales:

## *if fish were dumber and people were smarter*


Kenneth Rose
Louisiana State University
Baton Rouge, LA USA

Katherine Shepard, Haosheng Huang, Sean Creekmore, and Dubravko Justic
Department of Oceanography and Coastal Sciences
Louisiana State University
Baton Rouge LA 70803 U.S.A.

Jerome Fiechter
Institute of Marine Sciences
University of California
Santa Cruz, CA 95064 U.S.A.

Enrique N. Curchister
Institute of Marine and Coastal Sciences
Rutgers University
New Brunswick, NJ 08901 U.S.A.

Kate Hedstrom
Arctic Region Supercomputing Center
Fairbanks AK 99775 U.S.A.

Paul Venturelli
Department of Fisheries, Wildlife,
and Conservation Biology
University of Minnesota
St Paul, MN 55108 U.S.A

Matthew Campbell
NOAA-NMFS
Mississippi Laboratories
Pascagoula, MS, 39567 U.S.A.

# Introduction

- Increasing use of spatially-explicit models
- End-to-end are one type
- Wide range of temporal and spatial scales

# Why Now?

- Traditional methods perceived as unsuccessful
- Many management issues involve space
- Climate change
- Data collection is spatially-detailed
- Computing power continues to increase
- Advances in hydrodynamics and upper trophic level modeling

# Movement

- A major challenge is modeling movement
  - Eggs and larvae maybe reasonably simulated with particle-tracking
  - Juveniles and adults require behavioral approaches

- Wide range of temporal and spatial scales
  - Often scales determined by other submodels
  - Compatibility issues

# Movement

- Many approaches have been proposed
  - X(t+1) = X(t) + Vx(t)
  - Y(t+1) = Y(t) + Vy(t)
  - Z(t+1) = Z(t) + Vz(t)
  - Determine the cell

- Quite confusing because of non-standard descriptions and terminology for $V_x$, $V_y$, and $V_z$
  - Random walk
  - Levy flight
  - Event-based
  - Fitness-based
  - Kinesis
  - ANN

| Taxa | Domain | Dimension | Cell size | Timestep | Duration | Methods |
|---|---|---|---|---|---|---|
| Croaker | Gulf of Mexico | 2-D | 1 km | hourly | 100 yrs | Kinesis |
| Salinity sensitive fish | Brenton Sound | 3-D | 10 to 100's m | 7-15 sec | 4 mo | Advection and event-based |
| Sardine, anchovy, albacore | California Current | 3-D | 10 km | 15 mins | 50 yrs | Kinesis and neighborhood search |
| 5 species | marsh | 2-D water levels | 2 m | Hourly, variable | 10 yrs | Neighborhood search |
| Shrimp | marsh | 2-D | 1 m | Hourly | 1 yr | Neighborhood search |
| Bay anchovy | Chesapeake Bay | 3-D | 10 m | 30 min | 20 yrs | Neighborhood search |
| Delta smelt | San Francisco Estuary | 1-D, implicit 3-D for particles | 10's m | hourly | 20 yrs | Particle, smart particle, kinesis |
| Spot | Neuse River | 2-D | 100 m | hourly | 1 yr | Random walk |

# Issues

- Fixed parameters preventing adaptive and phenotypic variation in behavior
- Edge effects on finite grids
- Stranding and oscillatory movements
- Weakly convergent parameter values
- Non-unique pattern matching

# Issues

- Renegade individuals
- Bifurcated movement patterns
- Short-cut solutions that use geography
- Compromise behaviors from multiple cues
- ***Calibration and validation***

# Major Issue

- If we are to use spatially-explicit models, then the methods must capture the response to cue(s)
- Little investigation of performance of any of these approaches under novel conditions
- We will explore this issue in more detail

# Calibration and Validation

- Challenge: Calibration data are rarely available at the necessary scale
- Genetic algorithms calibrate without data by evolving a population with parameters that produce fit movement
- GAs assume fish inherit movement instincts that maximized fitness in previous generations
- Examples: ANNs (Huse and Giske 1998; Huse and Ellingsen 2008; Mueller et al. 2010), neighborhood search (Giske et al. 2003), rule-based (Huse 2001)

# Calibration and Validation

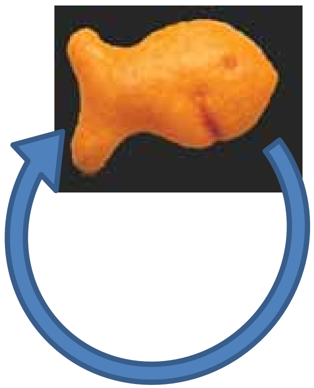
- Calibrate 3 movement models (neighborhood search, kinesis, and event-based) with a GA in four hypothetical 2-D environments

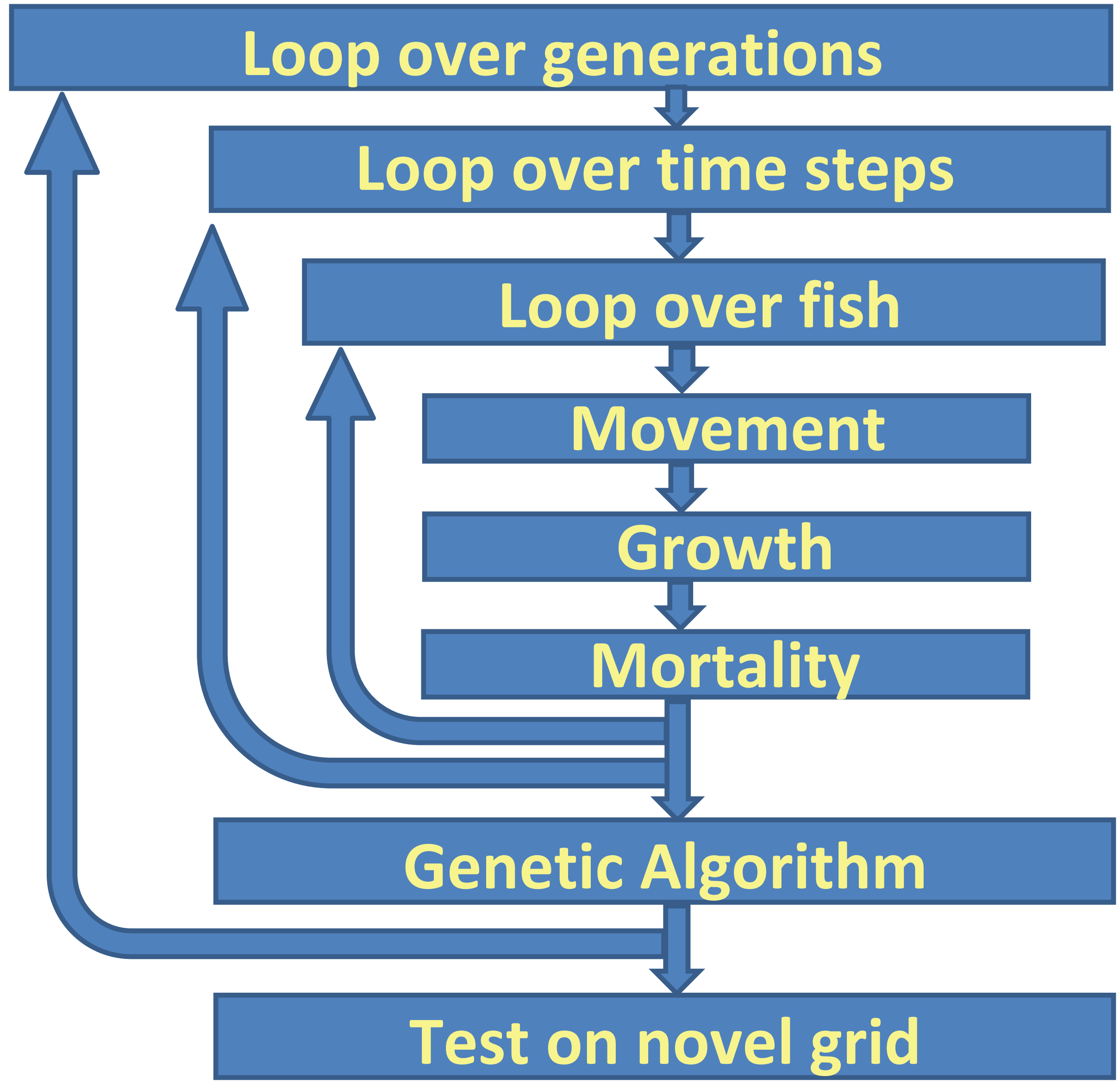
- Evaluate the performance of each calibrated sub-model in novel conditions (i.e., the other three grids)

From dissertation research of Kate Shepard

# Model Structure

**Simplified Hypothetical Species**

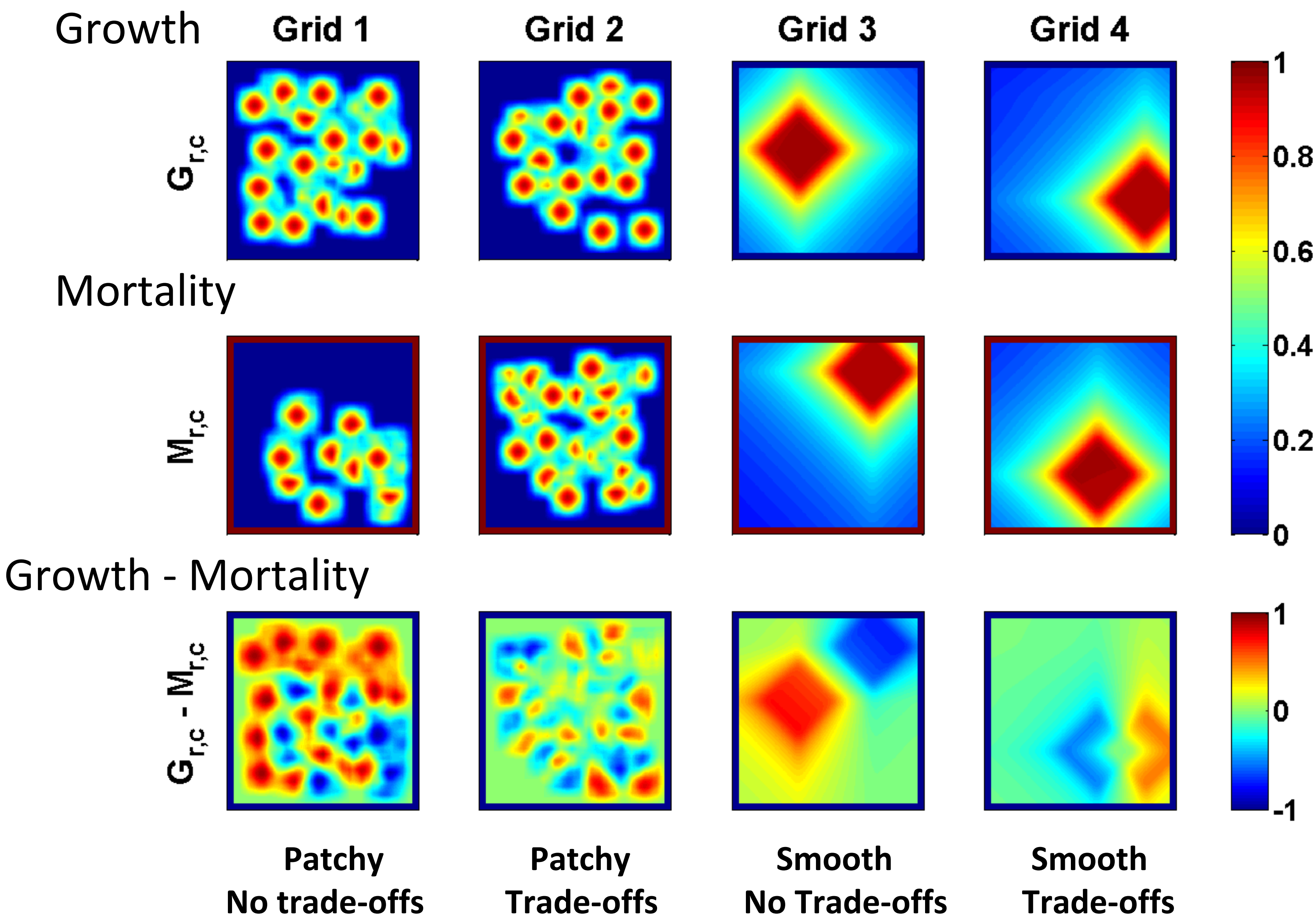





**<u>Scale</u>**

**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**

# Environmental Gradients



# 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)$^{-1}$

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

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

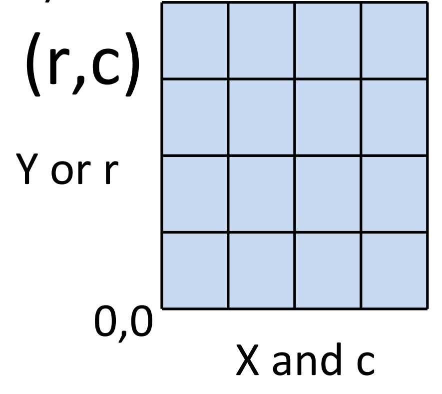
$$M_L = 1 - \frac{L_i - 73.3}{L_{max} - 73.3}$$

## Movement

$$X(t+1) = X(t) + V_x(t)$$

$$Y(t+1) = Y(t) + V_y(t)$$

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 3000 vectors for the next generation
- Continue until egg production levels off
- Parameter values should have converged

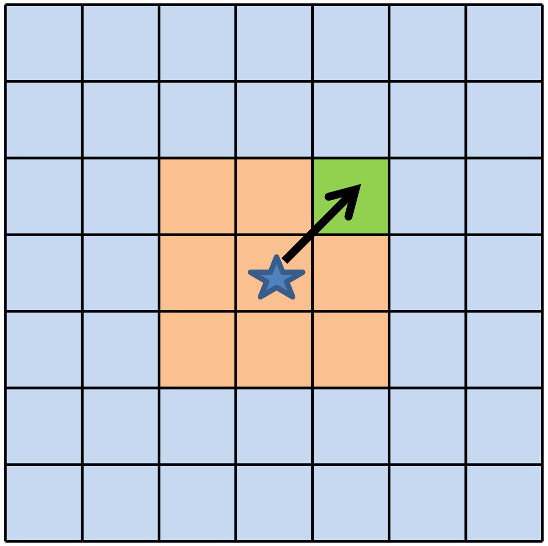
# Neighborhood Search

- Rank cells in Dhood by habitat quality

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

- n is noise that increases with distance

- Compute Θ as angle from cell to center of best cell



# Neighborhood Search

- Use Θ and swim speed to determine $V_x$ and $V_y$

- GA evolves:
  - Dhood: size of neighborhood
  - δ: mix of growth versus mortality in quality
  - Rθ: randomness on angle
  - Rdist: randomness on swim speed

# Kinesis

- Velocities are the sum of inertial (f) and random (g)
- Compute random swim speed
- Compute habitat quality:

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

# Kinesis

- Compute f and g weighted by how close habitat quality ($Q_{c,r}$) is to the optimal habitat ($Q_{opt}$)

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

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

- $V_x$ and $V_y$ are the sum of their f and g

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

# Event-Based

- Fish respond to either growth (j=1) or mortality (j=2) with tactical (k=0) or strategic (k=1) behaviors

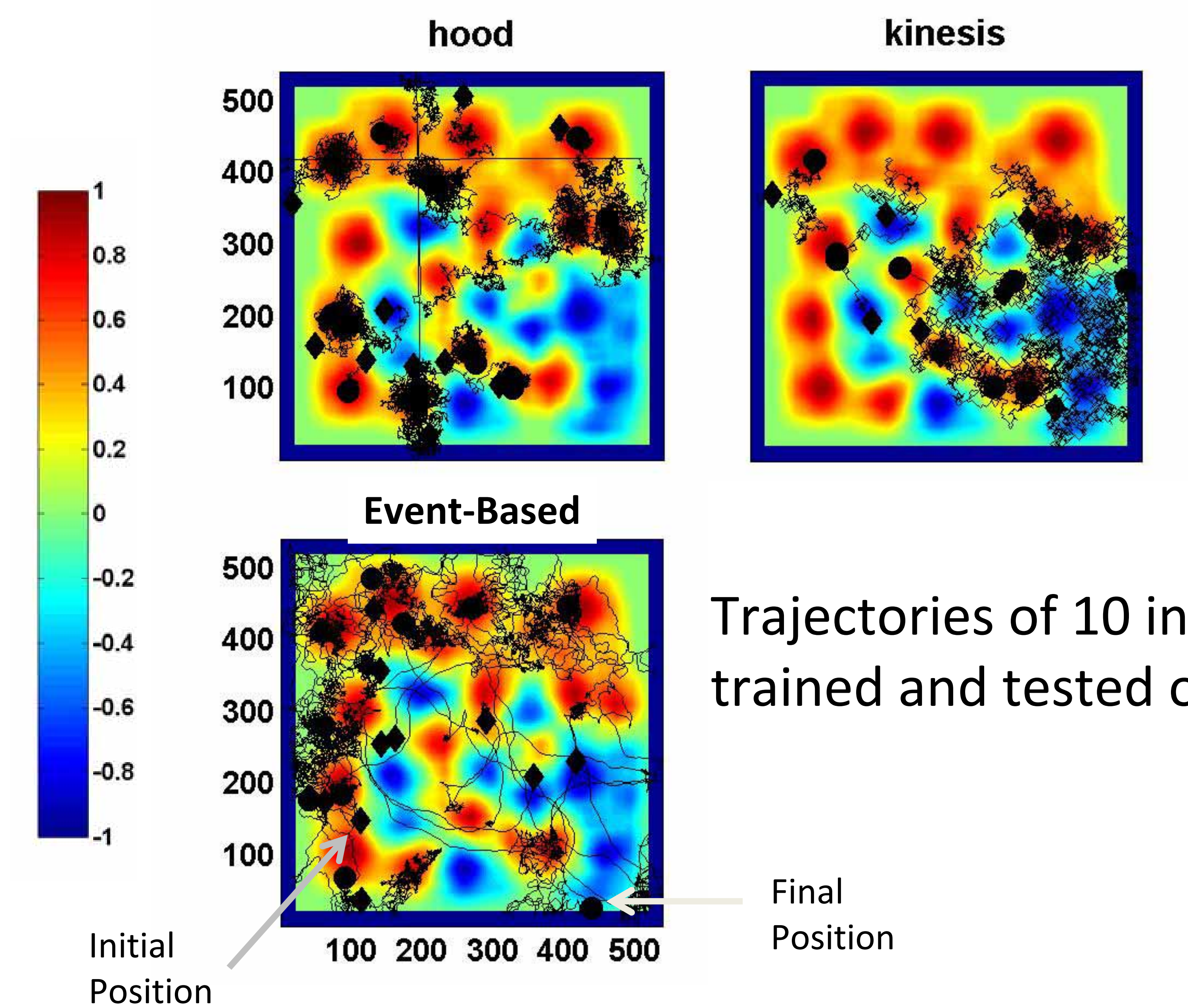
| | **Mortality** | | **Growth** | | **Default** |
|---|---|---|---|---|---|
| | Tactical | Strategic | Tactical | Strategic | |
| **Change in swimming angle (radians)** | π | 0 | 0 | 0 | 0 |
| **Magnitude of randomness (radians)** | 0.1π | 0.25π | π | 0.5π | 2π |
| **Swimming speed (BL/sec)** | 1 | 0.5 | 0.25 | 0.33 | 0.5 |

# Event-Based

- Compute growth and mortality cues based on cell growth and mortality values
- Determine detection of growth or mortality
- Calculate each of the four utility functions, which are running sums that use detection (0 or 1)

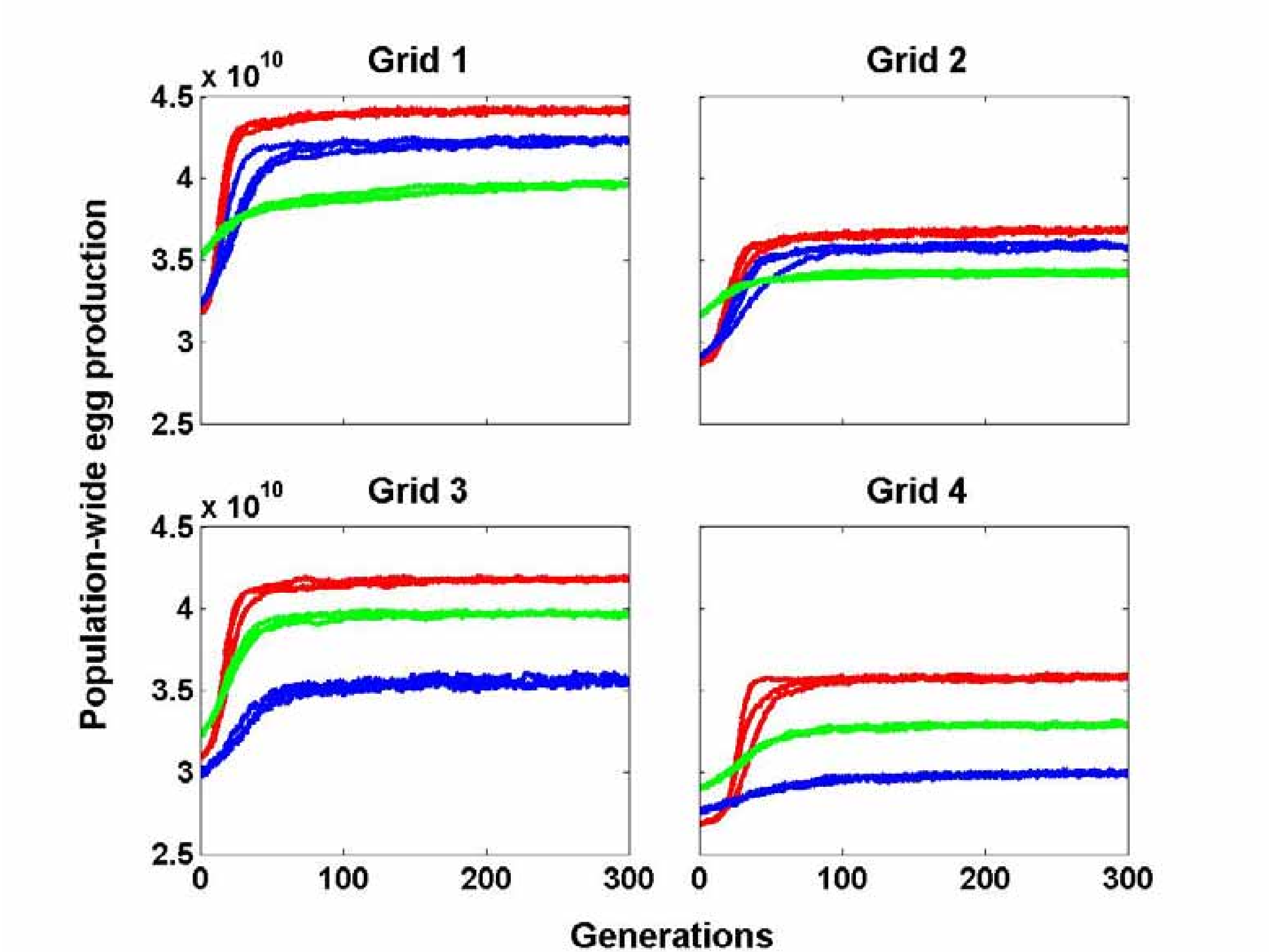
# Event-Based

- Implement behavior with highest utility from table, which determines $V_x$ and $V_y$
- GA evolves:
  - u1, u2: intrinsic utilities of growth and mortality
  - r1, r2: thresholds of detection for growth and mortality
  - m0,m1: tactical and strategic memory coefficients




Trajectories of 10 individuals trained and tested on grid 1

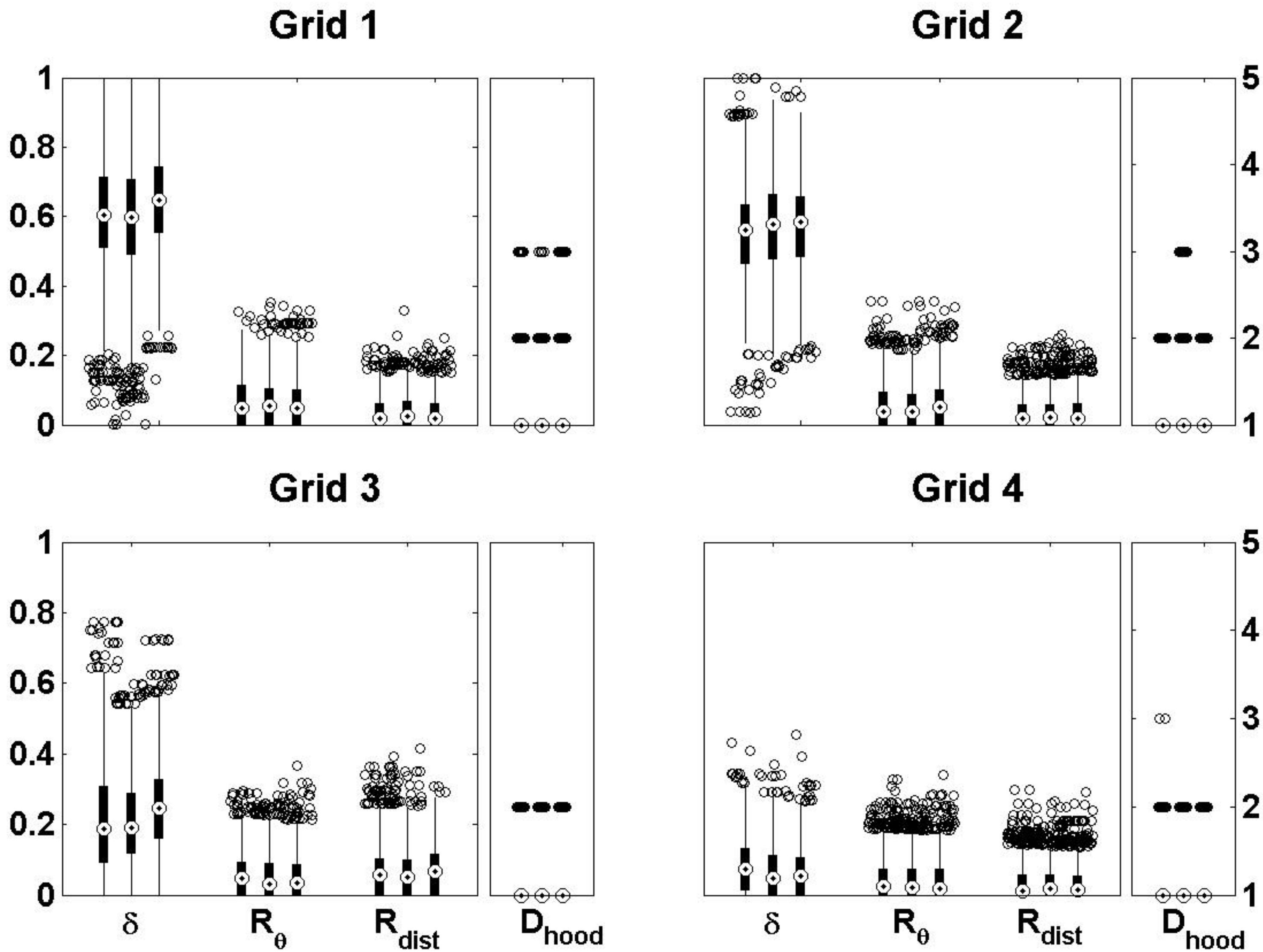
# Training – Fitness Convergence




Neighborhood search, Kinesis , Event-Based

# Parameter Vectors

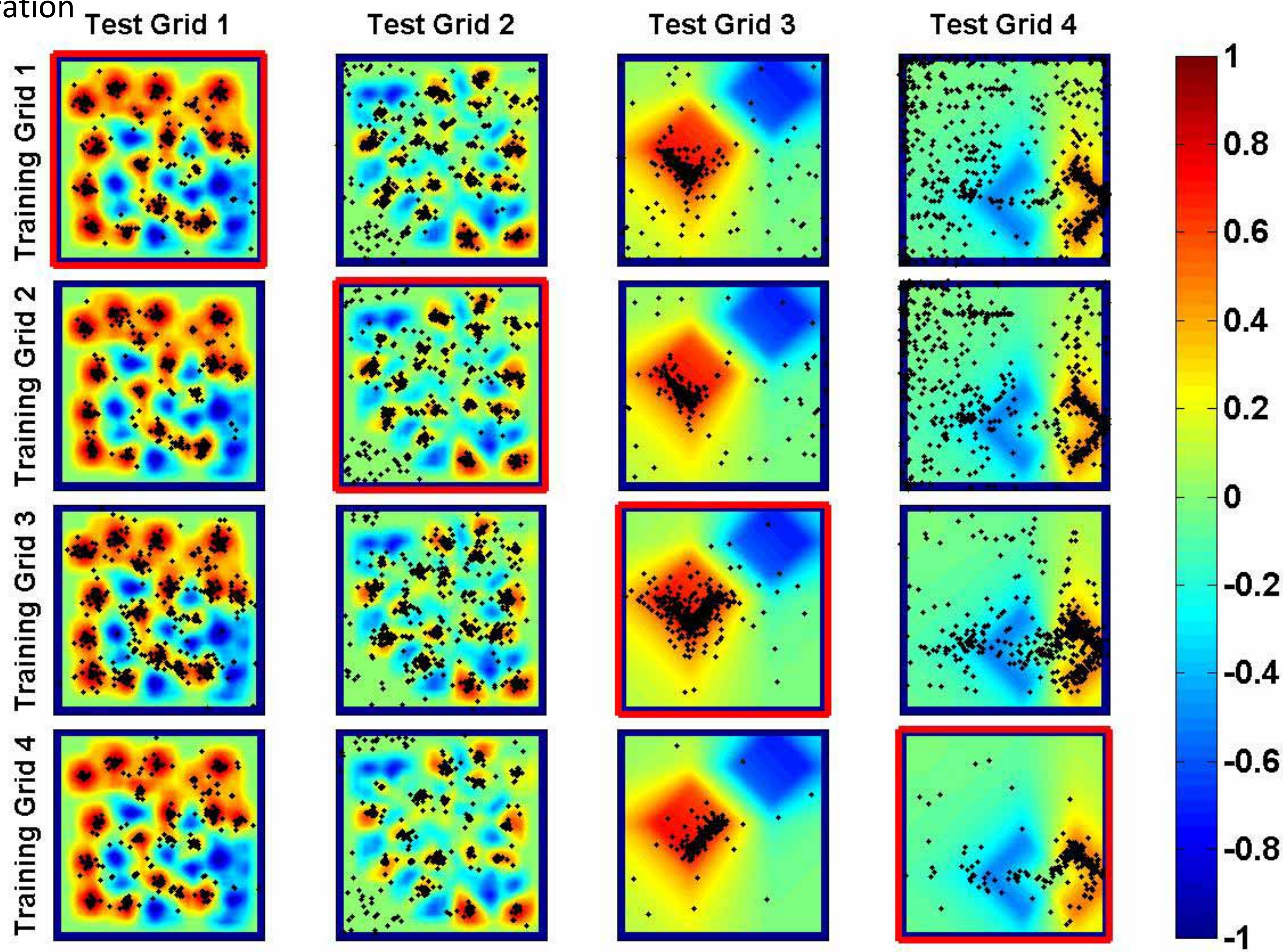
Neighborhood Search



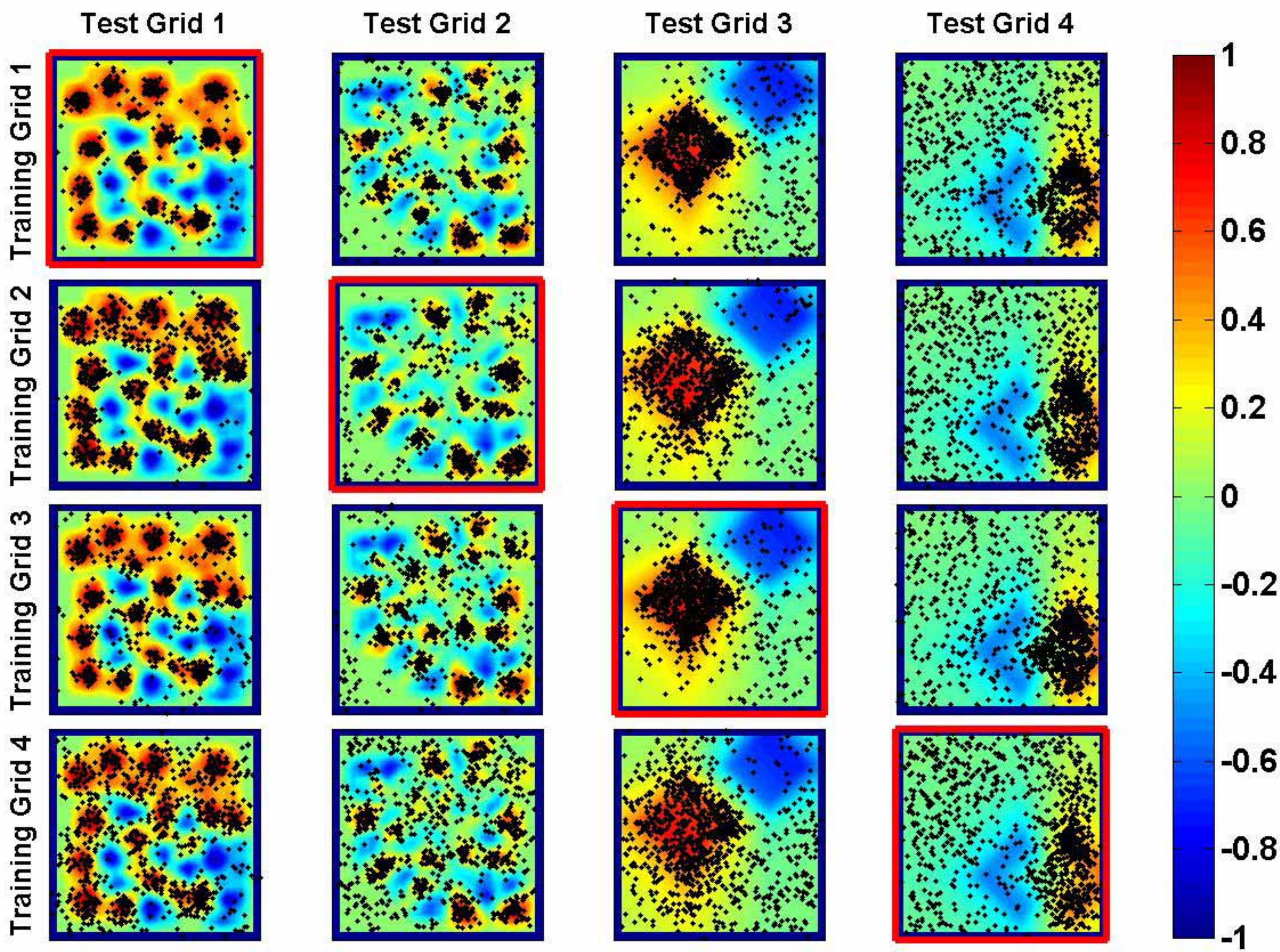
# Neighborhood Search Results

Last day of 300th generation

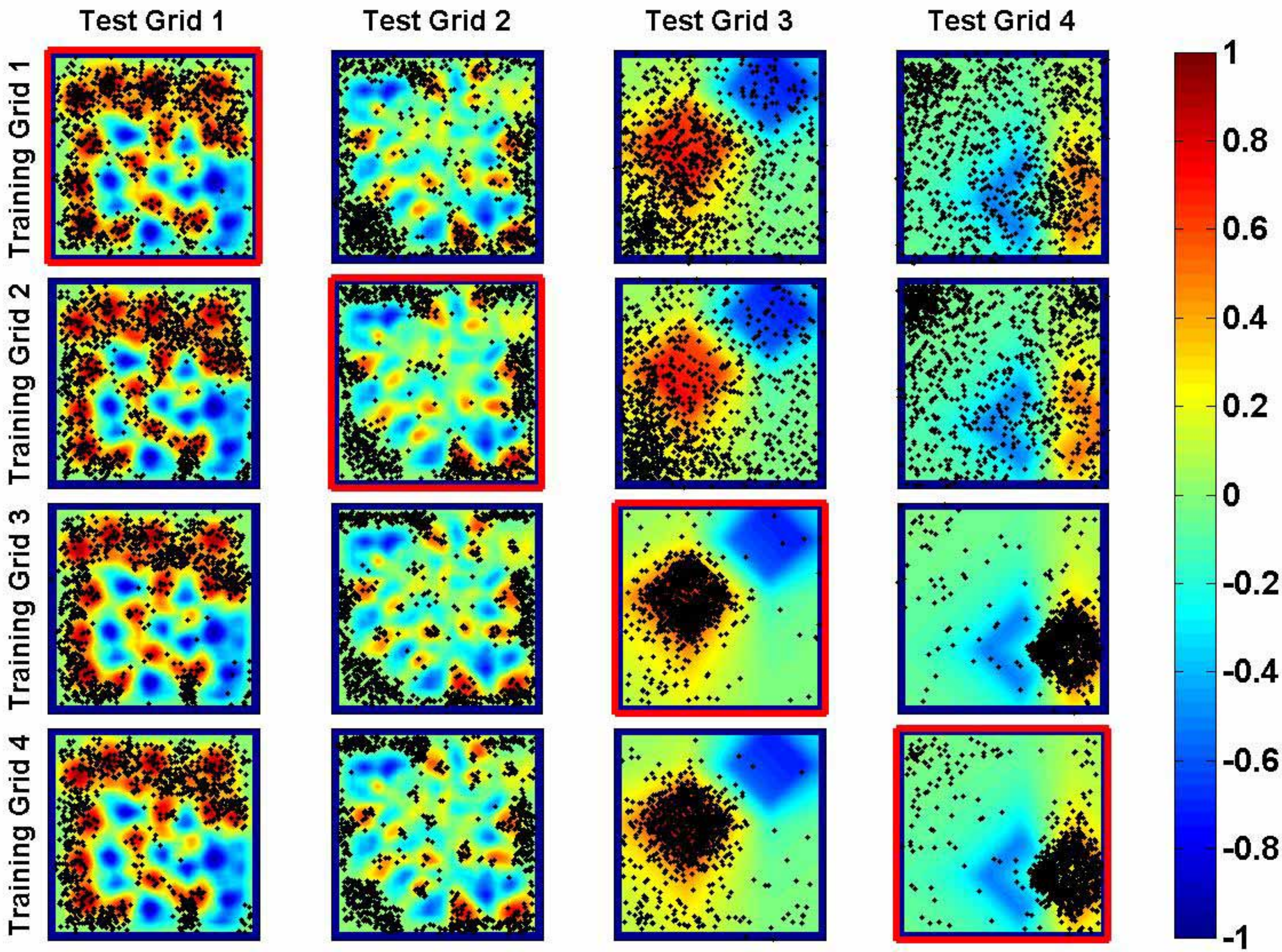
Last day after 1 generation using 3000 vectors from training



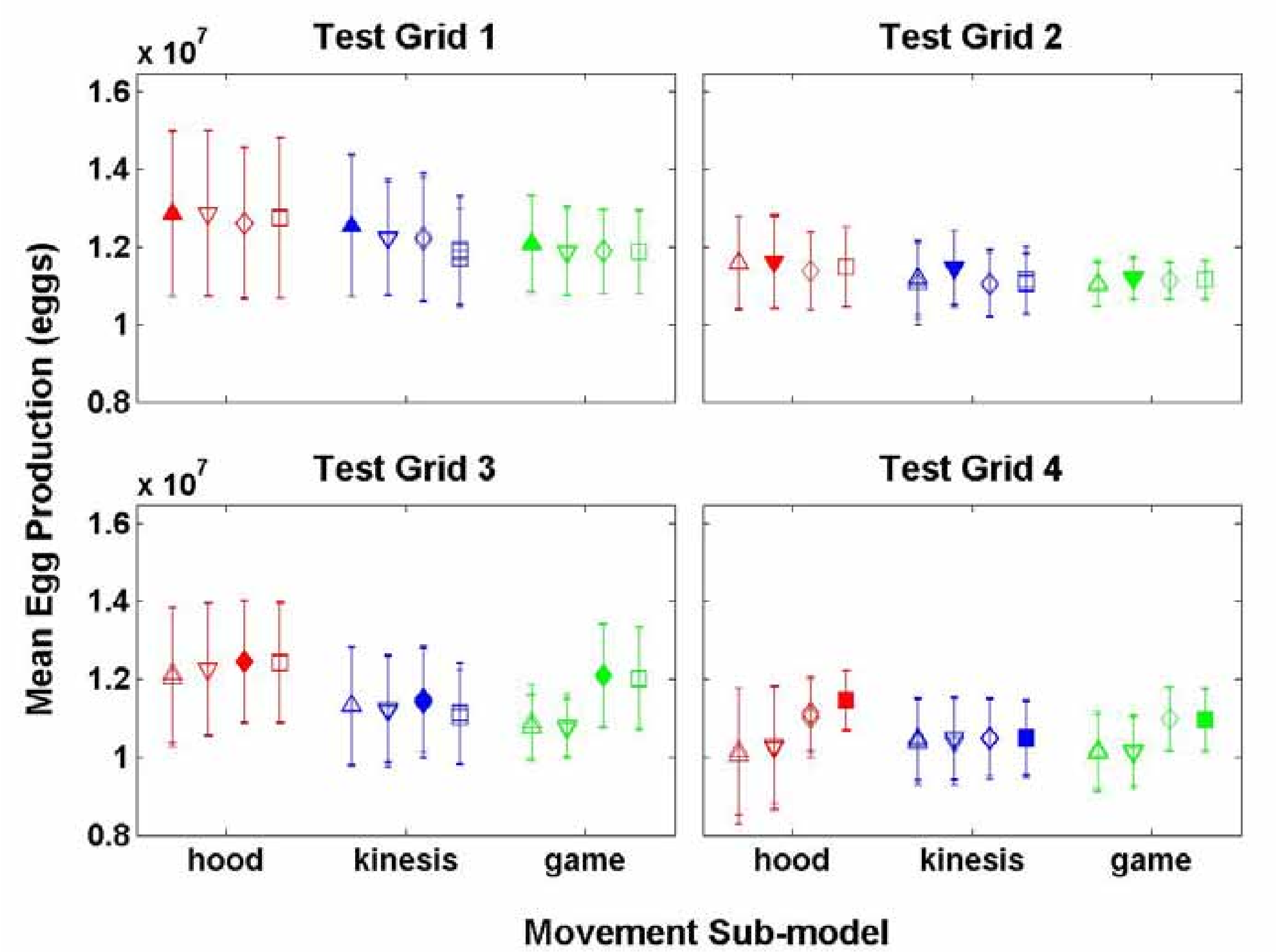
# Kinesis Results



# Event-Based Results



# Mean Total Egg Production




Training Grid: △ = 1 ▽ = 2 □ = 3 ◇ = 4

Neighborhood search, Kinesis , Event-based

# Conclusions

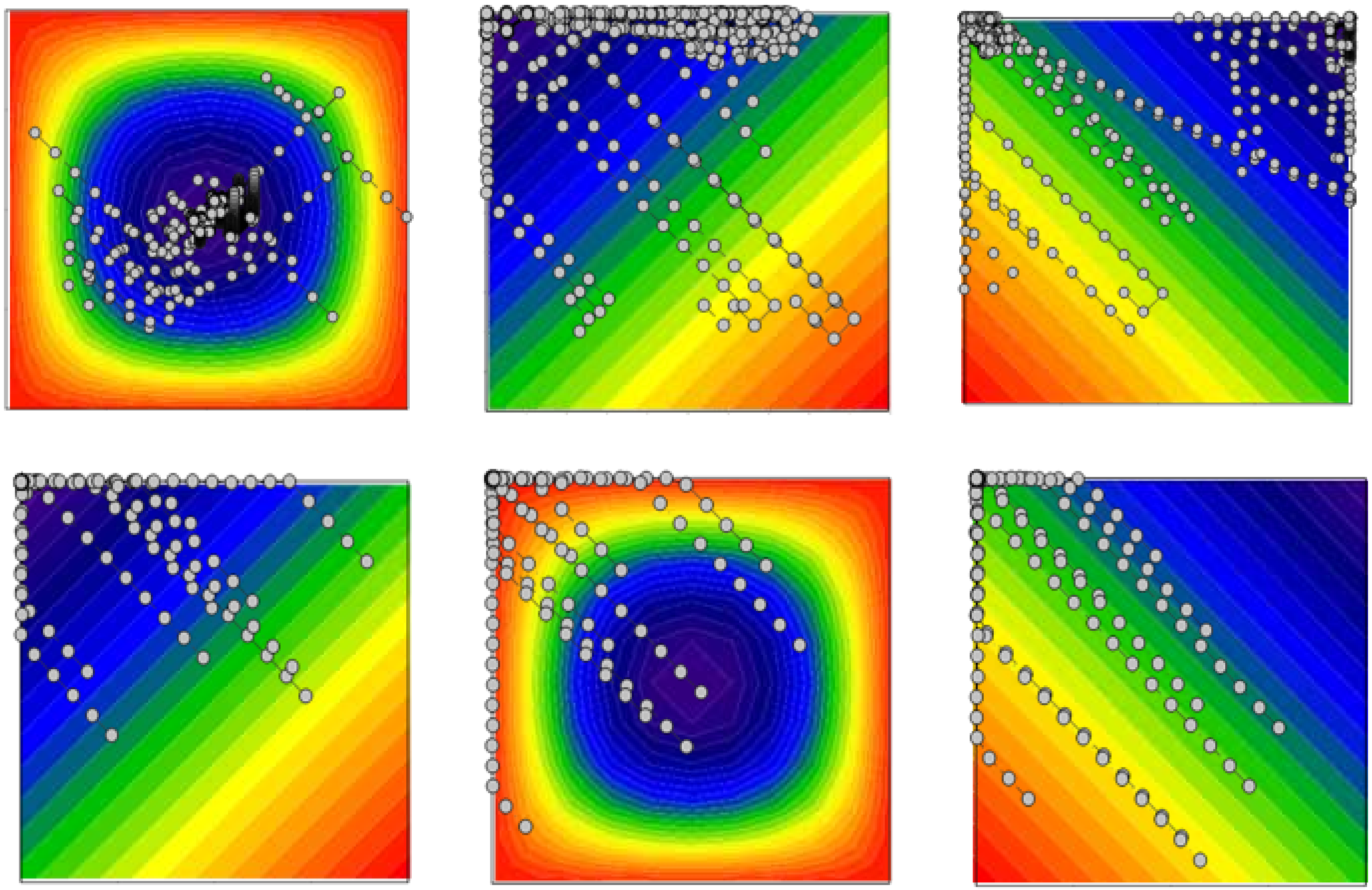
- Behavioral movement is a major uncertainty in spatially-explicit models
- Presently, a variety of approaches that are confounded with scale
- End-to-end models are particularly challenging because scales of physics through fish
- I showed some ongoing analyses to address:
  - Calibration - GA
  - Robustness - testing under novel conditions

# Conclusions

- Results were encouraging
- Three methods successfully trained with the GA and produced realistic movement
- Total egg production fairly constant across methods and grids

# Not All Successes

- ANN with singe cue of mortality



# Next in the Analysis

- Add Levy flight
- Dynamic growth and mortality fields
- Individual prey and predators
- Changing resolution of grid and time step
- Kate finishes her dissertation

# Conclusions

- Critical we get the movement responses to changing and novel conditions realistic
- "If people were smarter or fish were dumber"
- Time is now for
  - Synthesis of approaches
  - Testing
  - Standardization