Selecting appropriate models of fish movement for End-to-End models of marine ecosystems.

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Ecology of Animal Movement

End-to-End (E2E) models hold great promise as tools for studying the dynamics of marine ecosystems.

Incorporating movement behavior of fish in these models is essential to predict ecological impacts of exogenous change on fish populations.

Main Points

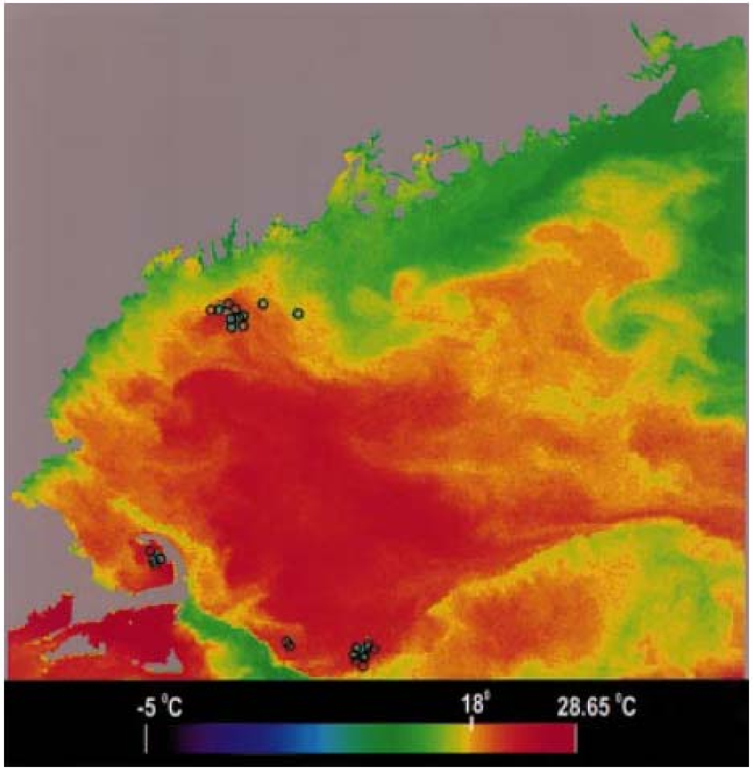
Behavioral mechanisms determine 'pathways' of fish movement, and these pathways are highly influential.

Exact mechanisms are unknown and must be approximated; careful selection will balance:

- Modeling goals
- Simulation structure
- Known biology

Origins

Distribution of large pelagic species strongly associated with thermal fronts*



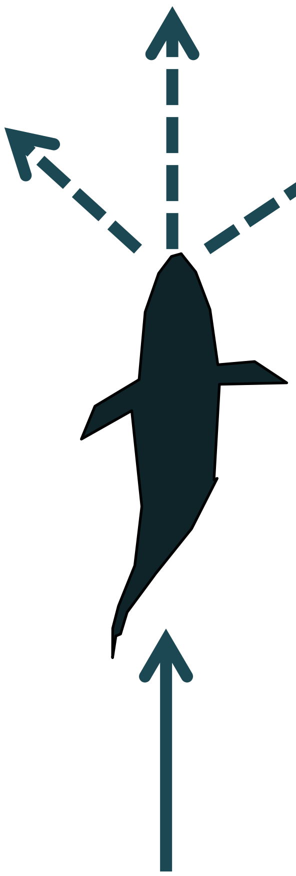
Though behavioral motivation not likely temperature alone, SST could be used as a ‘proxy’ cue for navigation.

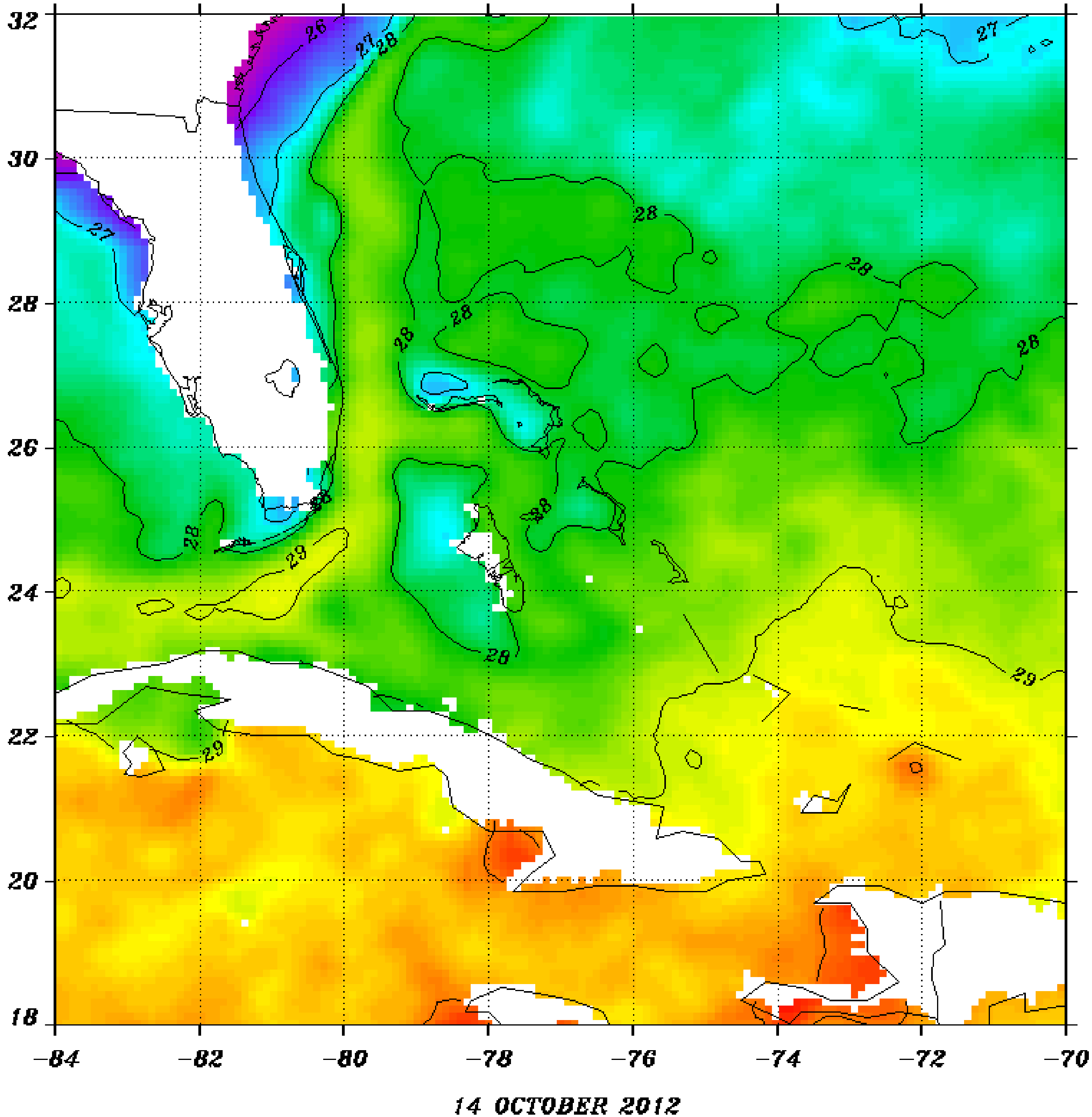
* e.g. Podesta et al. 1993

Directional orientation of movement:
How do fish navigate?

- Random walk, correlated random walk
- Kinesis
- Taxis
- Area-search

Gradient-response





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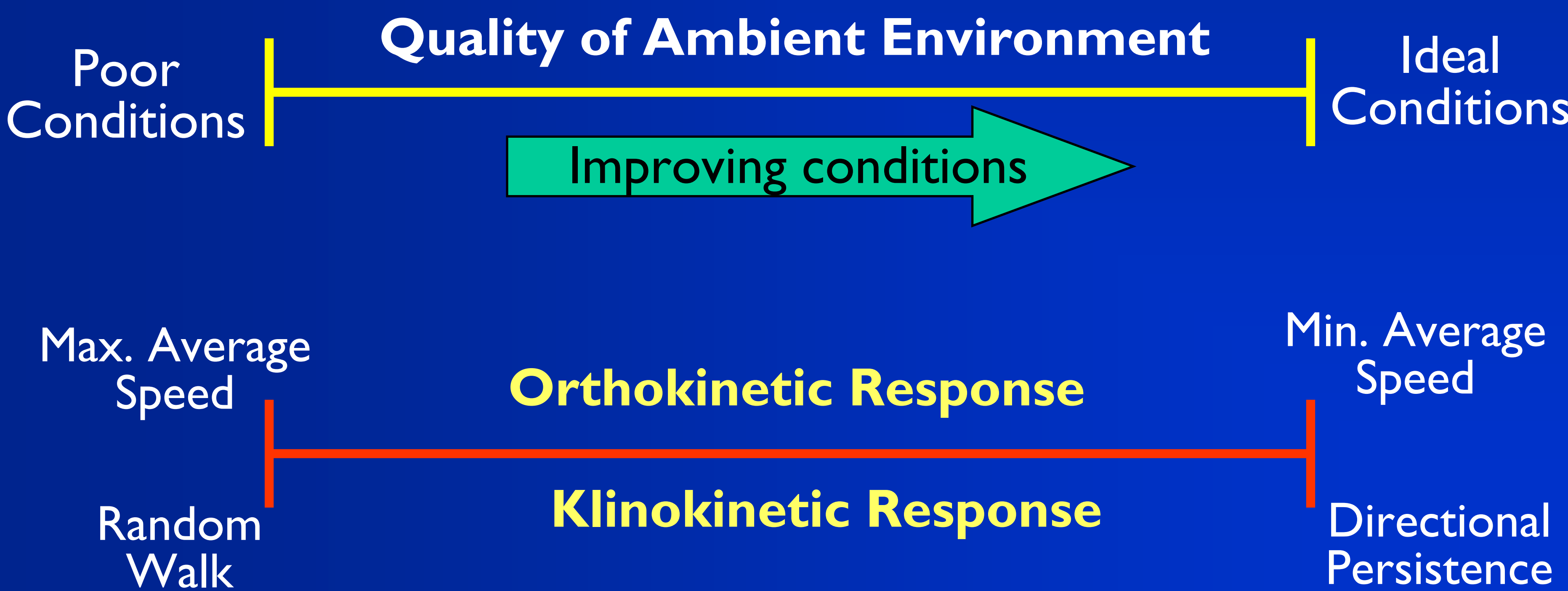
Kinesis Approach

Non-directional, change nature of movement according to conditions and preference.

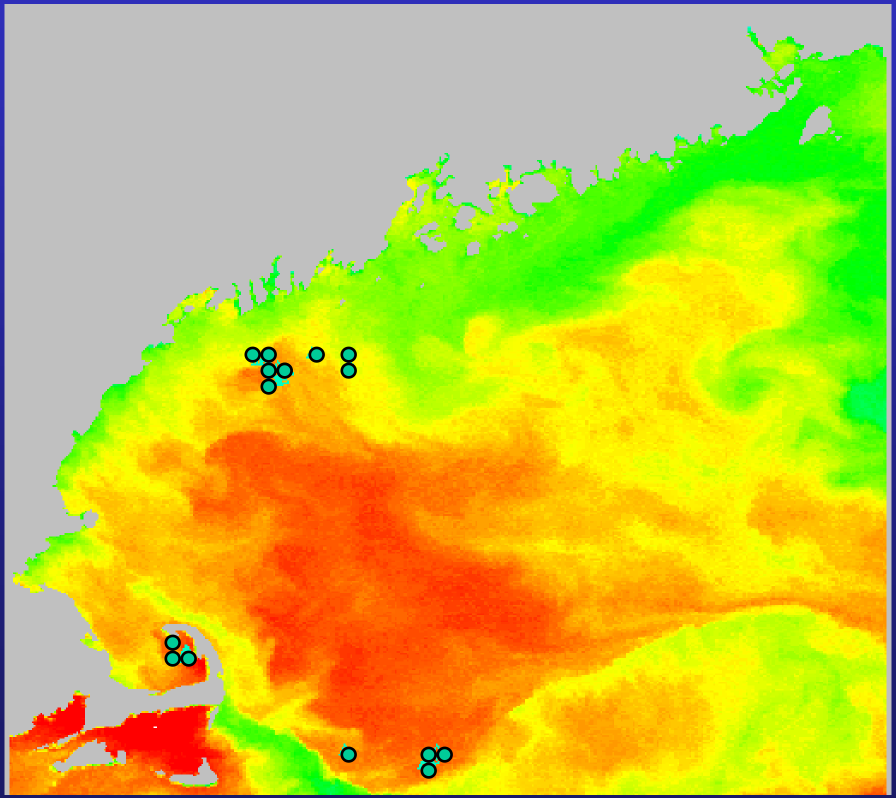
Orthokinesis: Alter speed of movement

Klinokinesis: Alter probability of turning

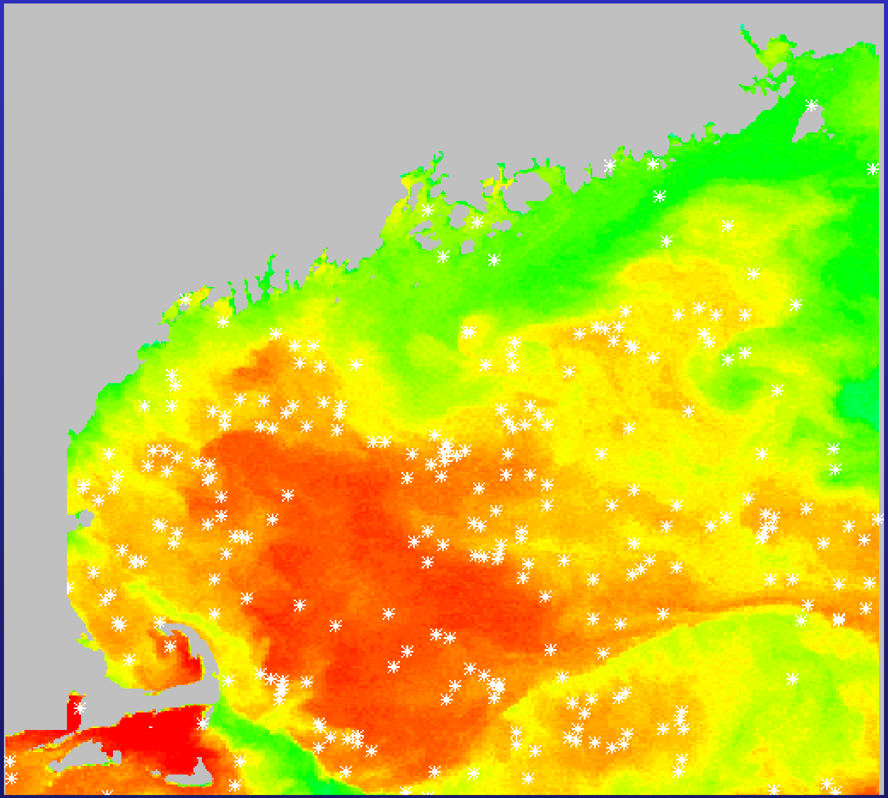


Assessing Model:
Comparing Model and Observed Patterns

School positions from aerial survey: August 16, 1994



Results of model run with 8/16/94 SST data.



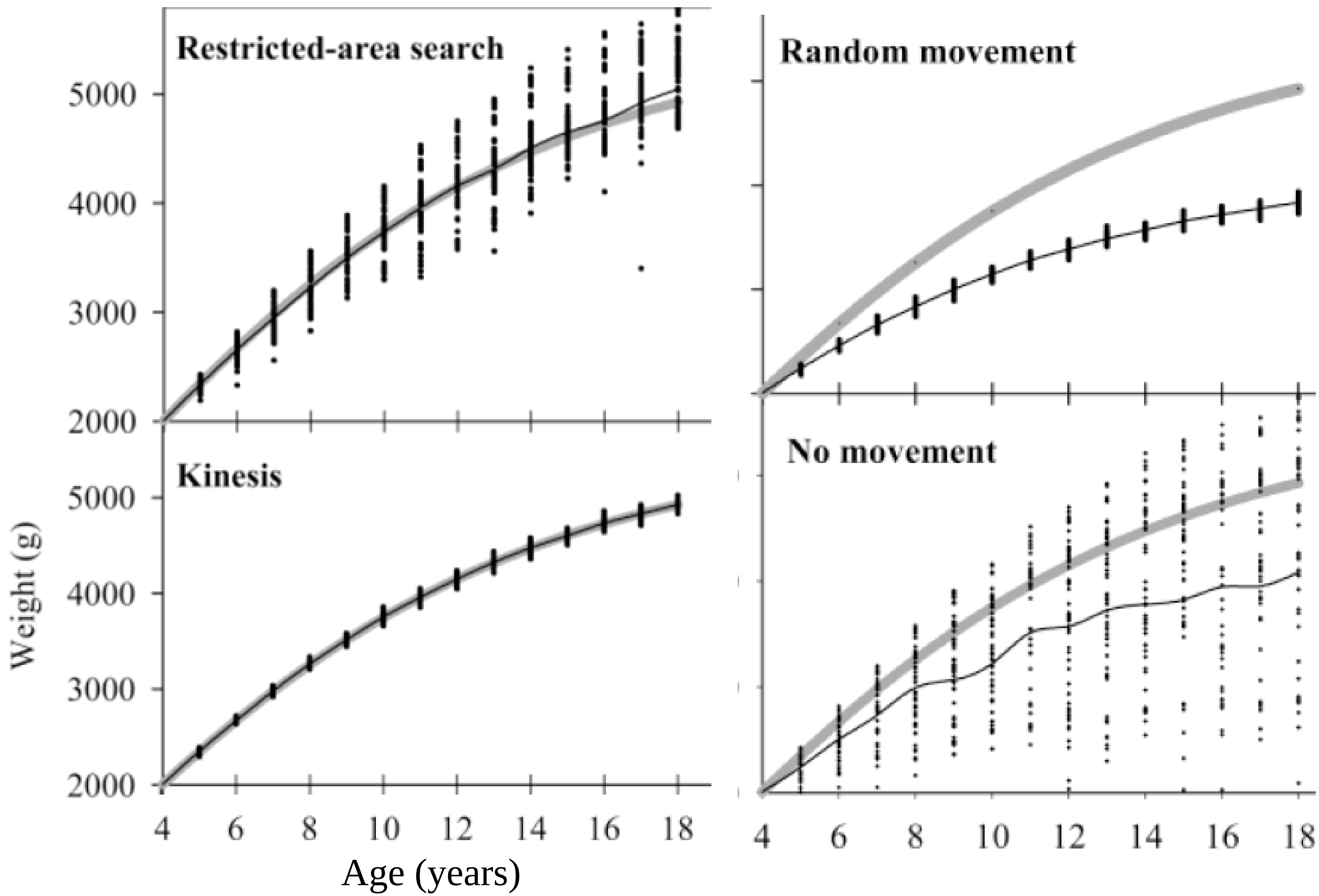
Humston, Ault, Lutcavage, Olson (2000) *Fish. Oceanog.* **9**:136-146

Pattern and Process

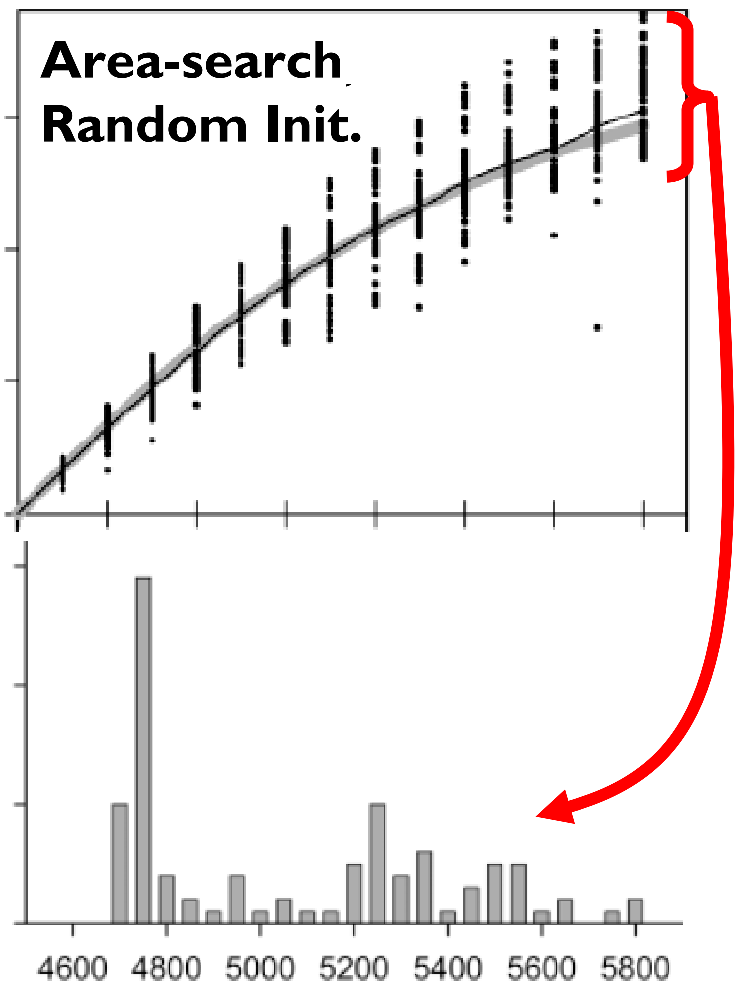
- Matching patterns gives little inference on underlying process
  - But see Grimm et al. *Science* 2005

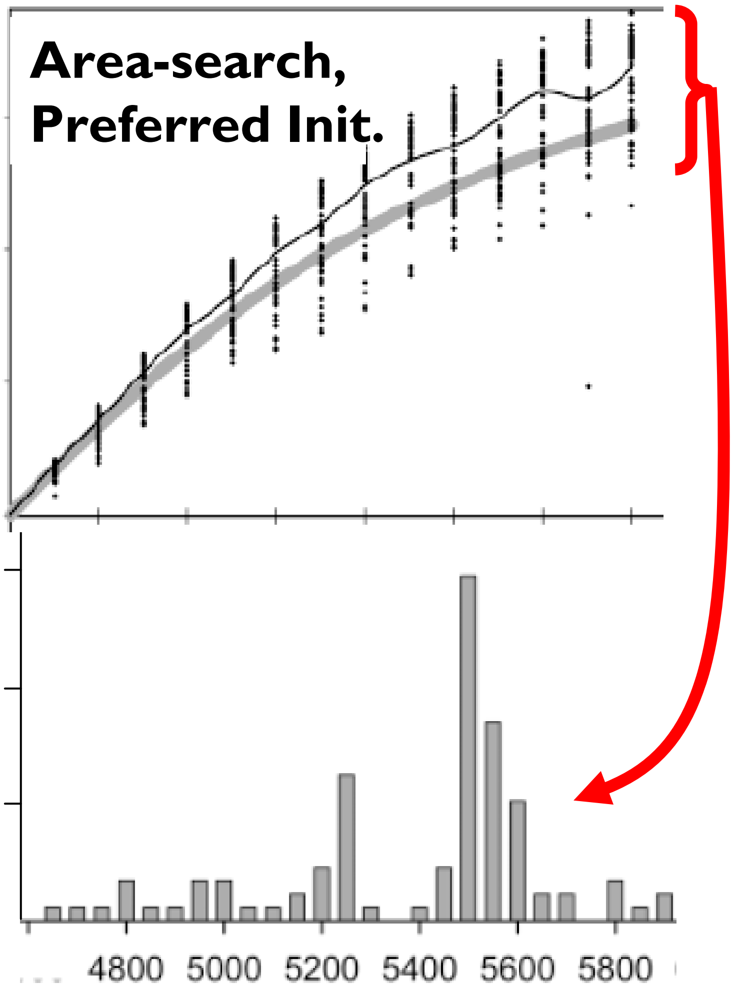
- By comparison to gradient-based mechanisms, kinesis less efficient / precise.
  - How do differences in individual pathways scale up to population differences?

Growth Trajectories Differ among Movement Behaviors

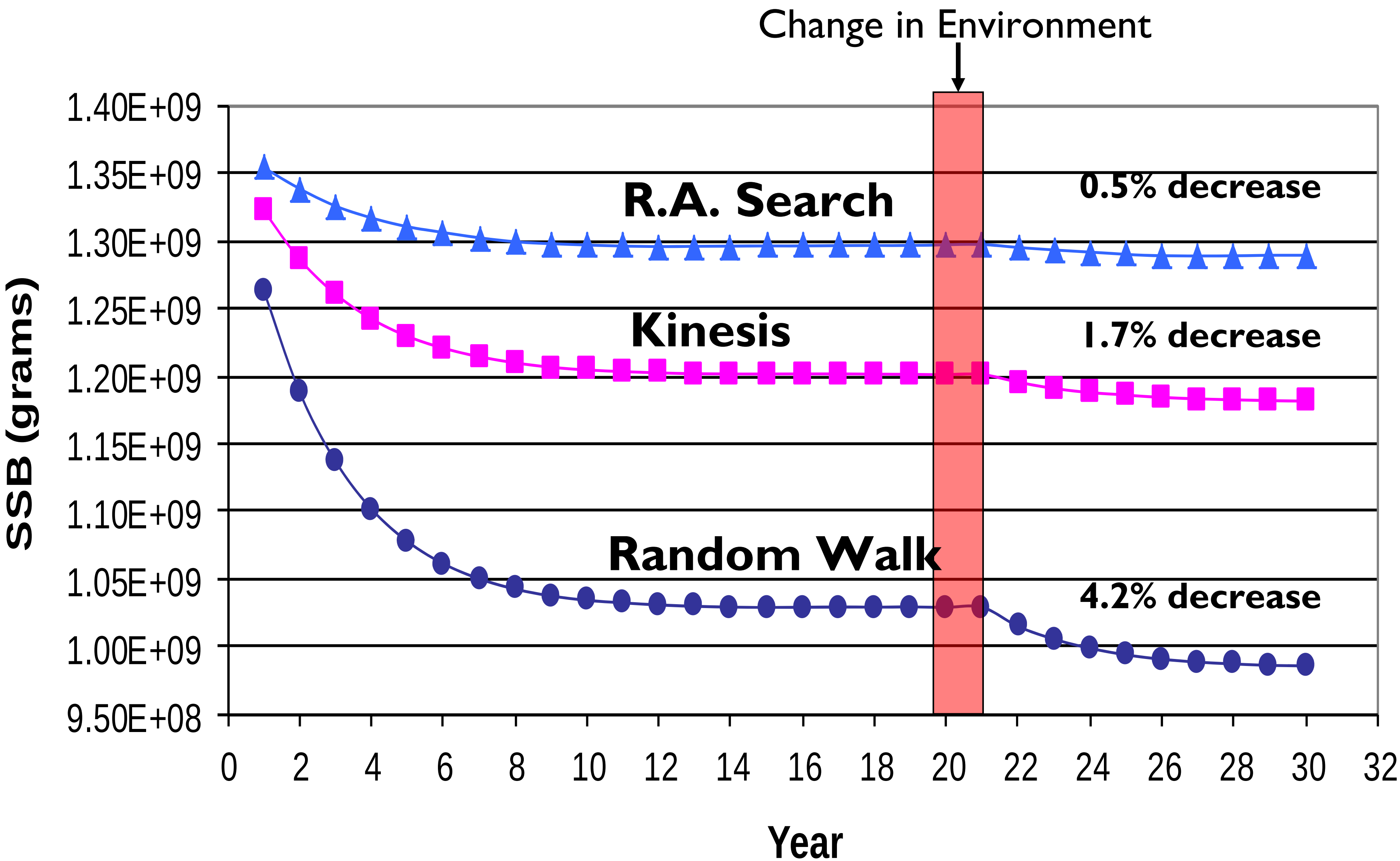


Sensitivity of Gradient-Response to Initial Position / Local Structure





Population Response to Environmental Change



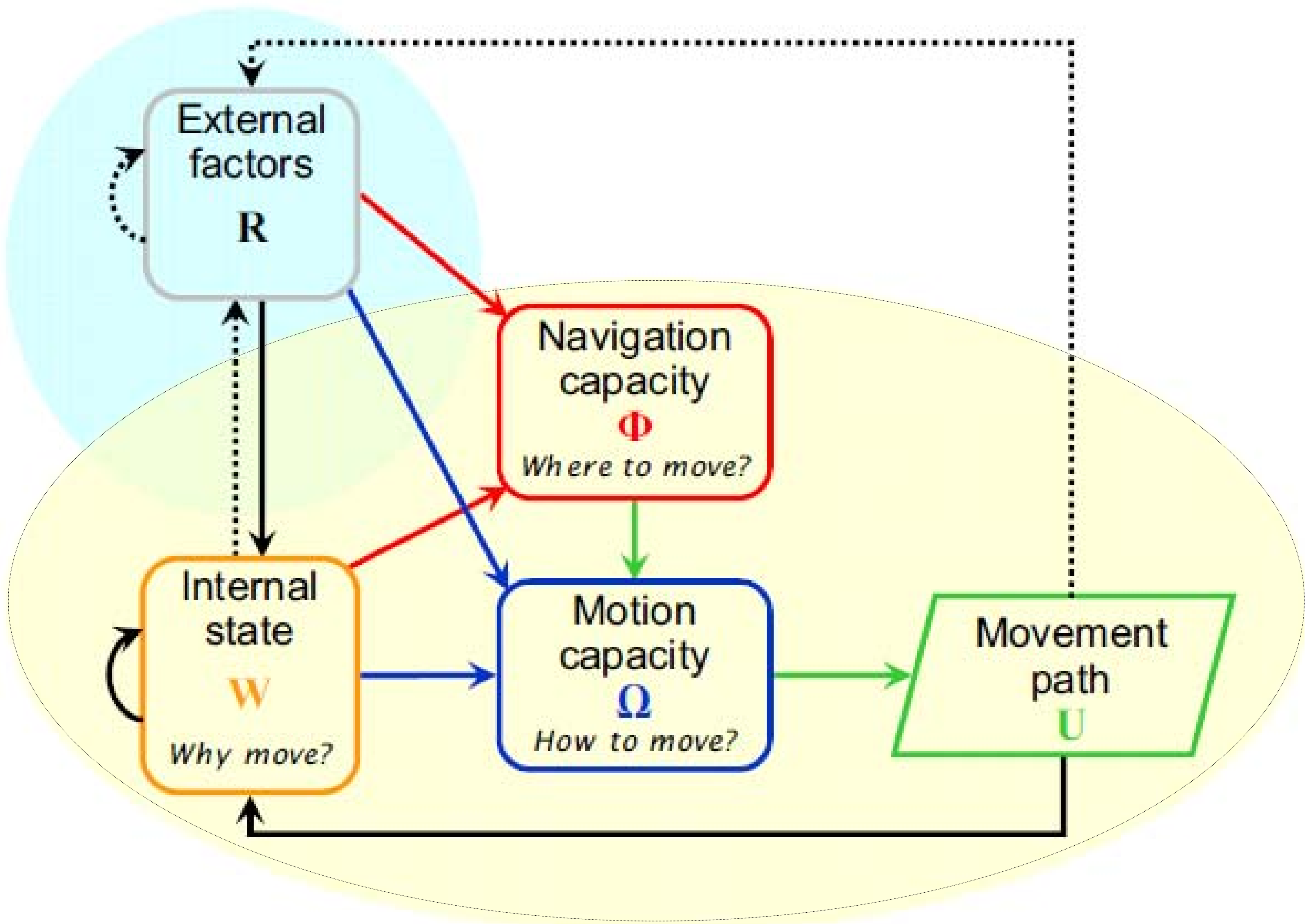
The Importance of Model Selection

Movement behavior determines relative ecological response of population to environmental change.

-Efficiency of population response (e.g. Humston et al. 2004; Wildhaber & Lamberson 2004)

-Ability of populations to find suitable habitat under novel conditions (e.g. Watkins & Rose *in press*)

Nathan et al. (2008) *PNAS* 105(49)



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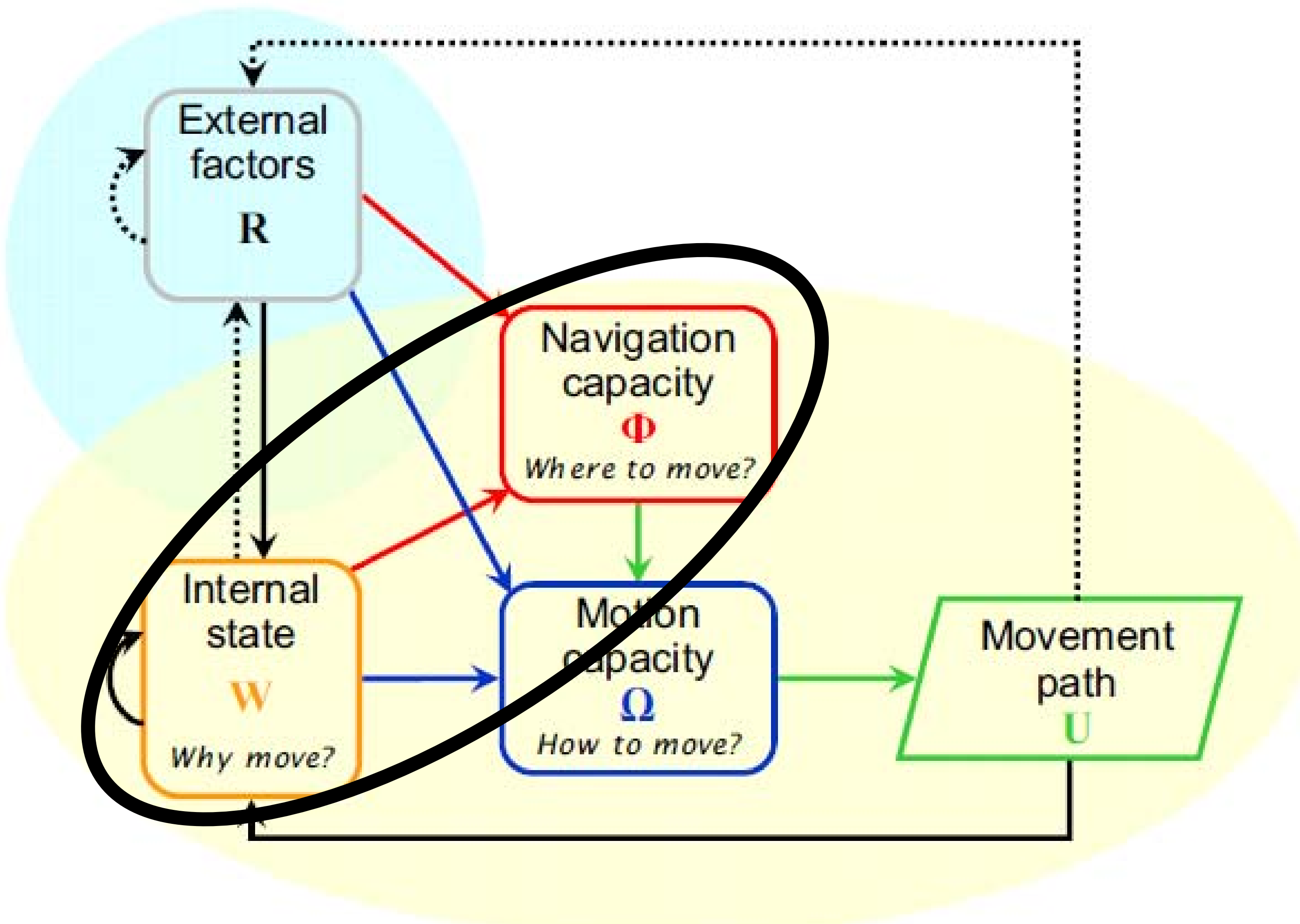

Why move?

- Proximate motivation for movement
  - Foraging
  - Habitat selection
  - Predator avoidance (scale dependent)
  - Migration

- Modeling this motivation relates to **cues** available for movement, e.g. comparing ambient vs. preferred conditions.
  - What data are available for input?

Why move?

- Motivation and importance of different cues change with context
  - Huijbers et al. (2012): response to auditory, visual, and olfactory cues changed with ontogeny & presence of conspecifics.

- Which environmental cues drive response, and what associations are indirect?
  - Can indirect cues serve as reliable proxies?

Why move?

- Can "optimality cues" (e.g. fitness, long term survival) be useful?
  - Railsback and Harvey (2002): movement and habitat selection determined by comparing long-term fitness (survival and growth over next 90 days).

- Choice of cues must consider corresponding assumptions of fish cognitive ability.
  - Awareness of internal state
  - Sensitivity to external conditions

Navigation: Where to move?

- Fish are not automatons, but what are they capable of?
  - Detecting differences in habitat
  - Recall of past conditions
  - Construction of spatial 'map'

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Kinesis

Gradient response

Navigation: Where to move?

- Fish are not automatons, but what are they capable of?
  - Detecting differences in habitat *Kinesis*
  - Recall of past conditions
  - Construction of spatial 'map' *Gradient response*

- Ability here is strongly scale-dependent.

Navigation: Critical Questions

Kinesis-type vs. gradient-response behavior

- How large an area can fish effectively search within a timestep?
  - Sample among available habitats
  - Detect habitat differences
  - Construct a spatial map of habitats
  - Correctly determine and orient movement in direction of improving conditions

Navigation: Connecting to Empirical Work

Our understanding of fish orientation and navigation abilities is improving rapidly.

-Research by Victoria Braithwaite, Theresa Burt de Perera

If assumptions can be supported by empirical evidence, then gradient response methods may be justified.

Navigation: The importance of errors

Sensitivity to local conditions can hinder gradient response models

- Low potential for repulsion means less ranging.
- "Mistakes" in navigation can be ecologically important:
  - Locating isolated resources
  - Straying (in migration)

Mistakes are reality

Summary

- Decisions on how motivation and navigation are modeled in movement behavior must consider:
  - Goals of model
  - Simulation structure, including spatiotemporal scales and resolution of data (e.g. Okunishi et al. 2012)
  - Biological understanding
  - Context (life history, environment, etc.)

Summary

- Emphasis on matching patterns may devalue the importance of "outliers" (i.e. anomalous movements)
- Substantial progress can be made by better connecting modeling with empirical research on fish cognition and navigation.
- Conservative assumptions may be warranted in the meantime.

Acknowledgements / Gratitude

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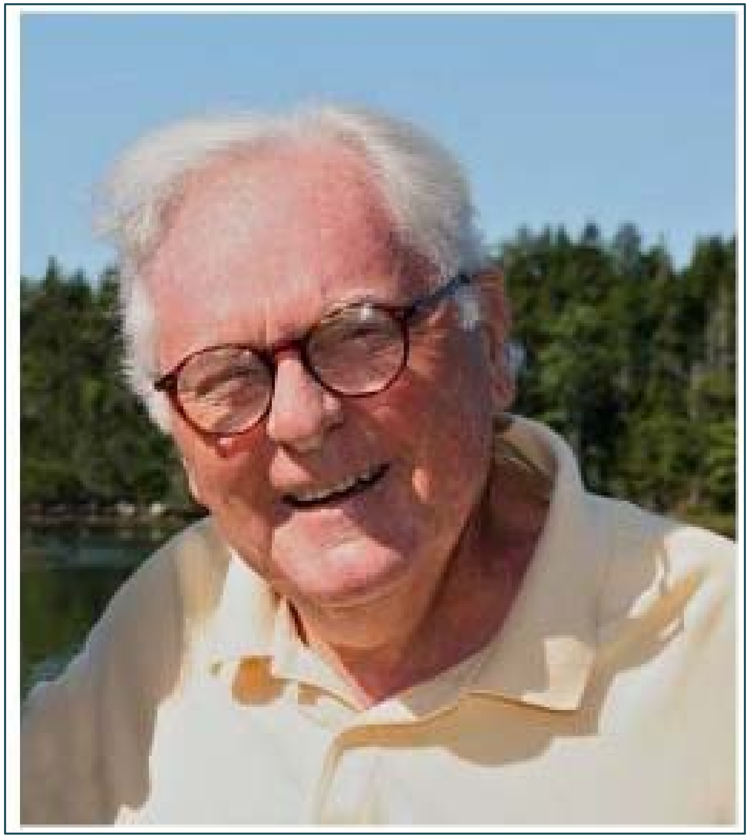

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