Outline

1. Motivations: Large-scale models vs. small-scale heterogeneity

2. Observations: Statistics of movement at the individual level

3. Derivations: Spatially-explicit models of populations

4. Approximations: Large-scale effects of unresolved heterogeneity

Quantifying organism movement: gps data logger

Charlotte Boyd

Peruvian Boobies (*Sula variegata*)

Photo: S. Bertrand, IRD

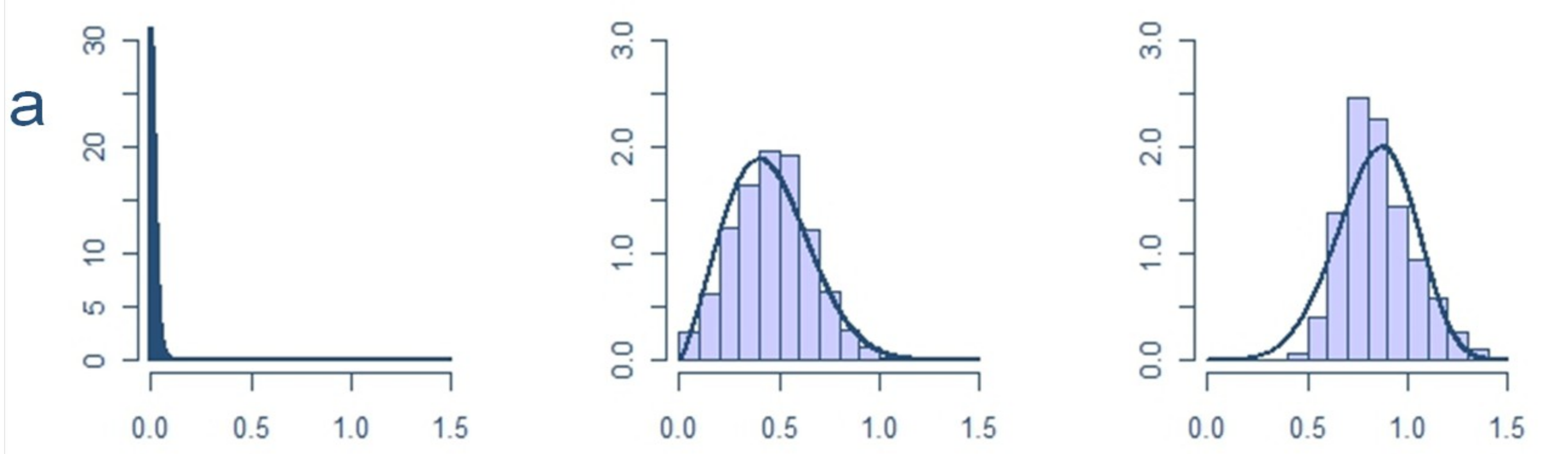
Quantifying organism movement: gps data logger

Charlotte Boyd

Hidden Markov Model / Maximum Likelihood Estimation

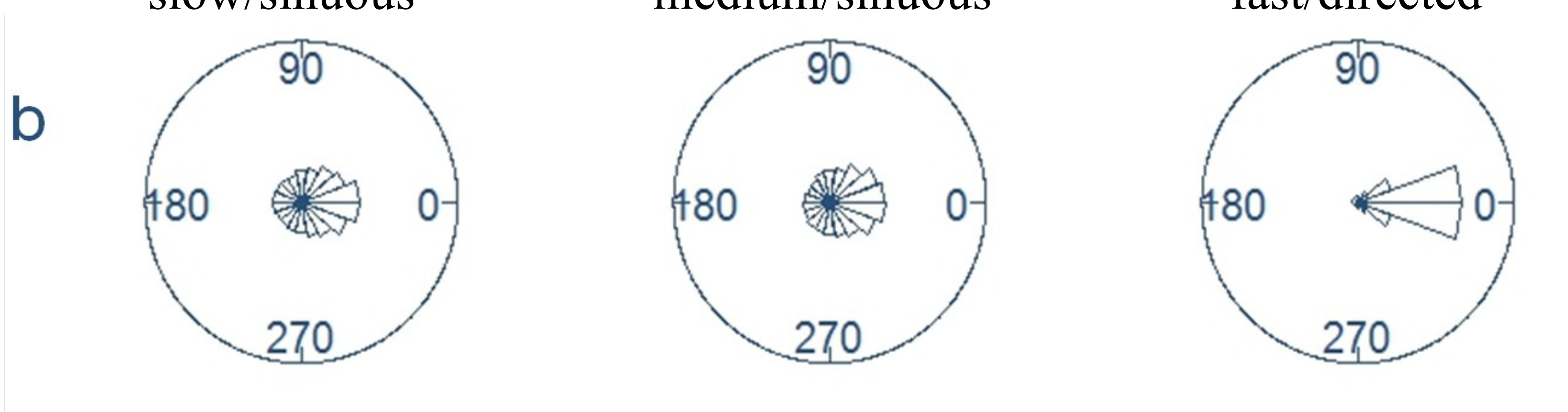
Observed distances (km over 1 minute intervals) assigned by maximum likelihood

“slow/sinuous” “medium/sinuous” “fast/directed”



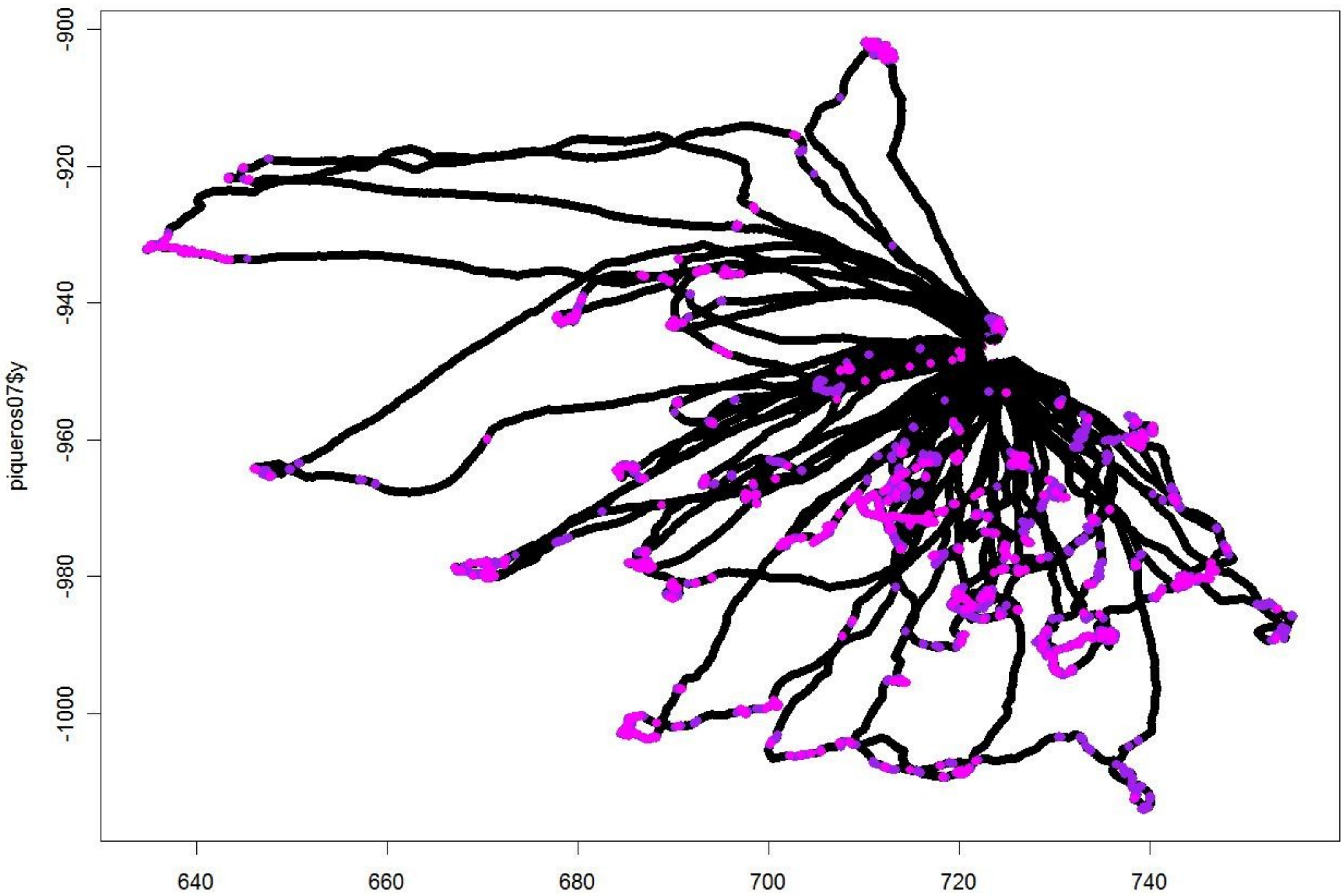
Observed turning angles assigned by maximum likelihood

“slow/sinuous” “medium/sinuous” “fast/directed”



Quantifying organism movement: gps data logger

Charlotte Boyd



Central-place foraging near breeding colonies: slow/sinuous modes indicative of fine-scale search or foraging in magenta

Quantifying organism movement: satellite tracking

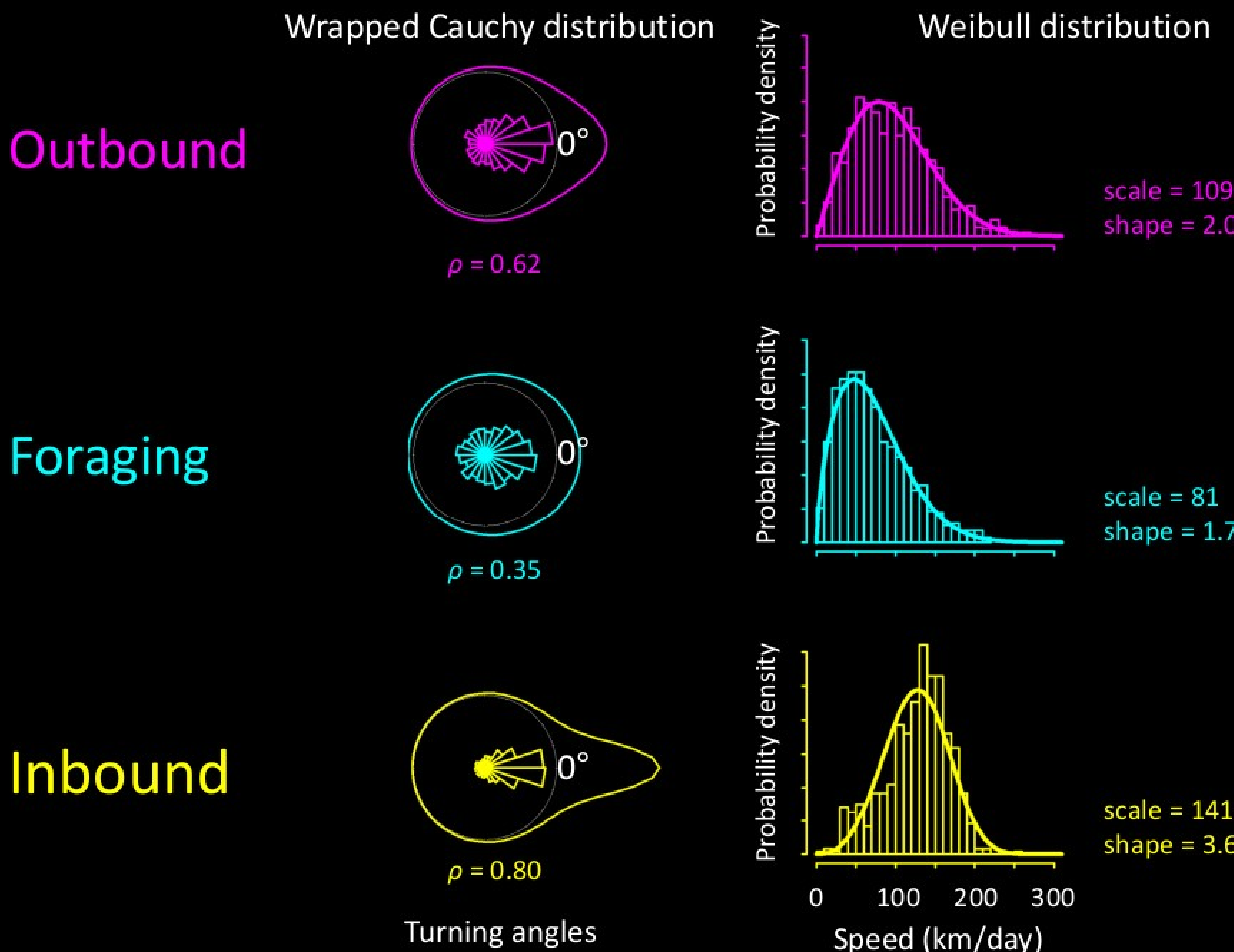
Elizabeth Skewgar

Behavior of Magellanic Penguins at Sea

Quantifying organism movement: satellite tracking

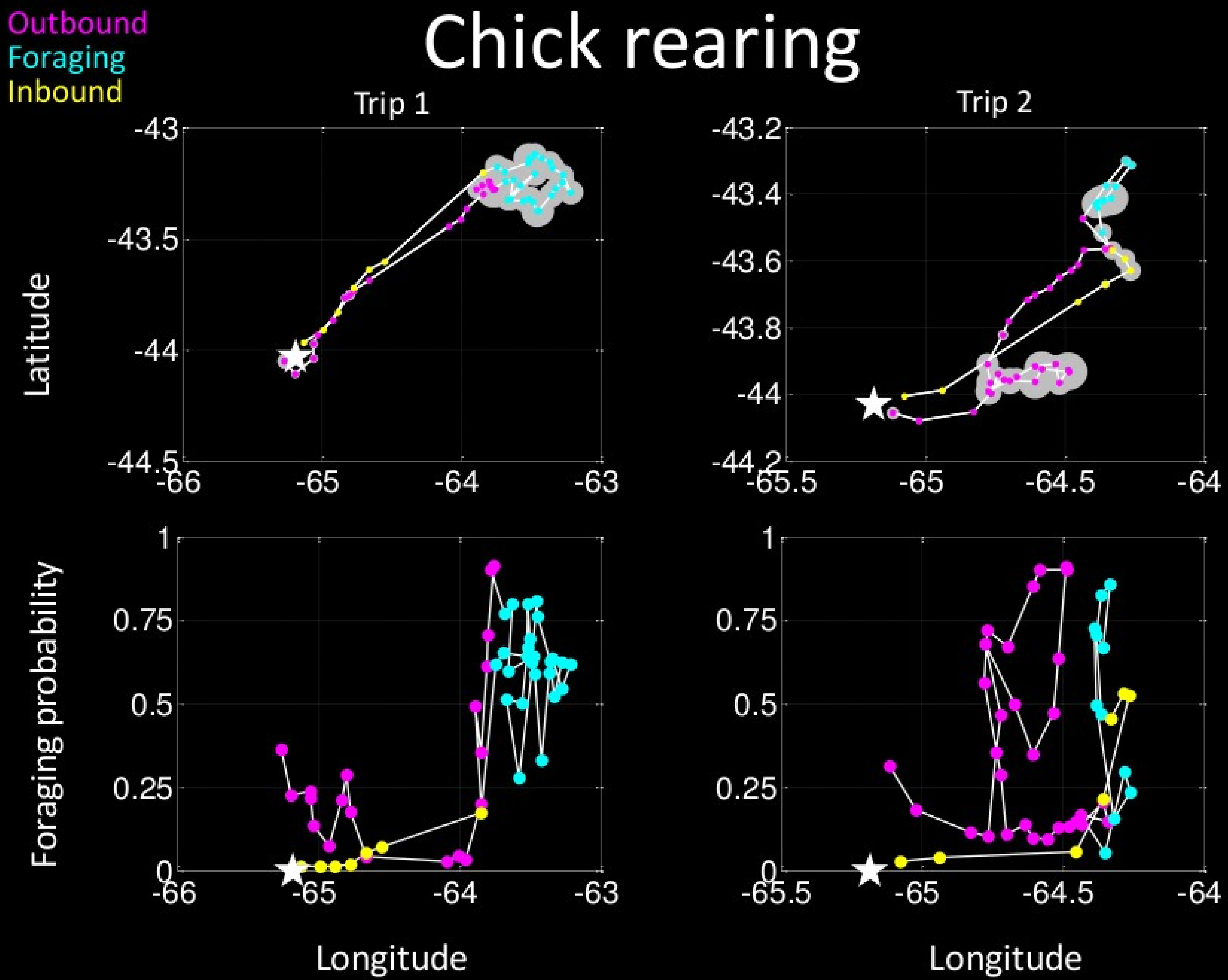
Elizabeth Skewgar

Hidden Markov Model / Maximum Likelihood Estimation constrained by prior data



Quantifying organism movement: satellite tracking

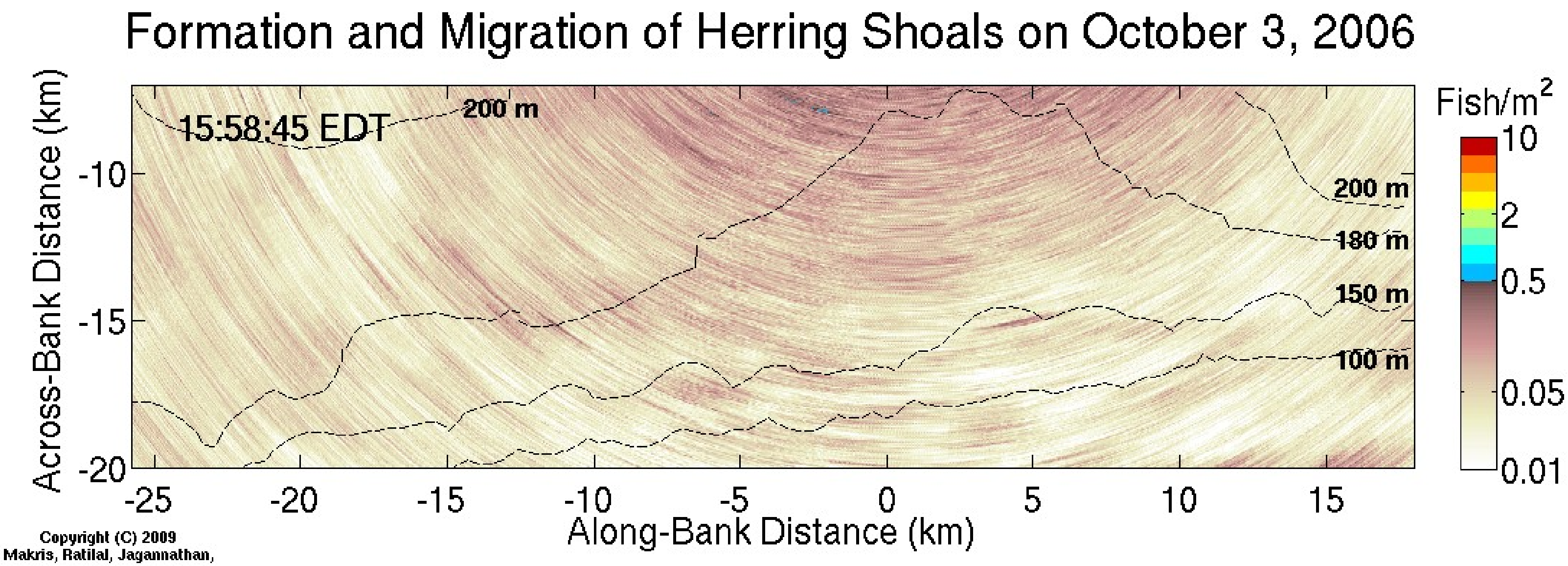
Elizabeth Skewgar



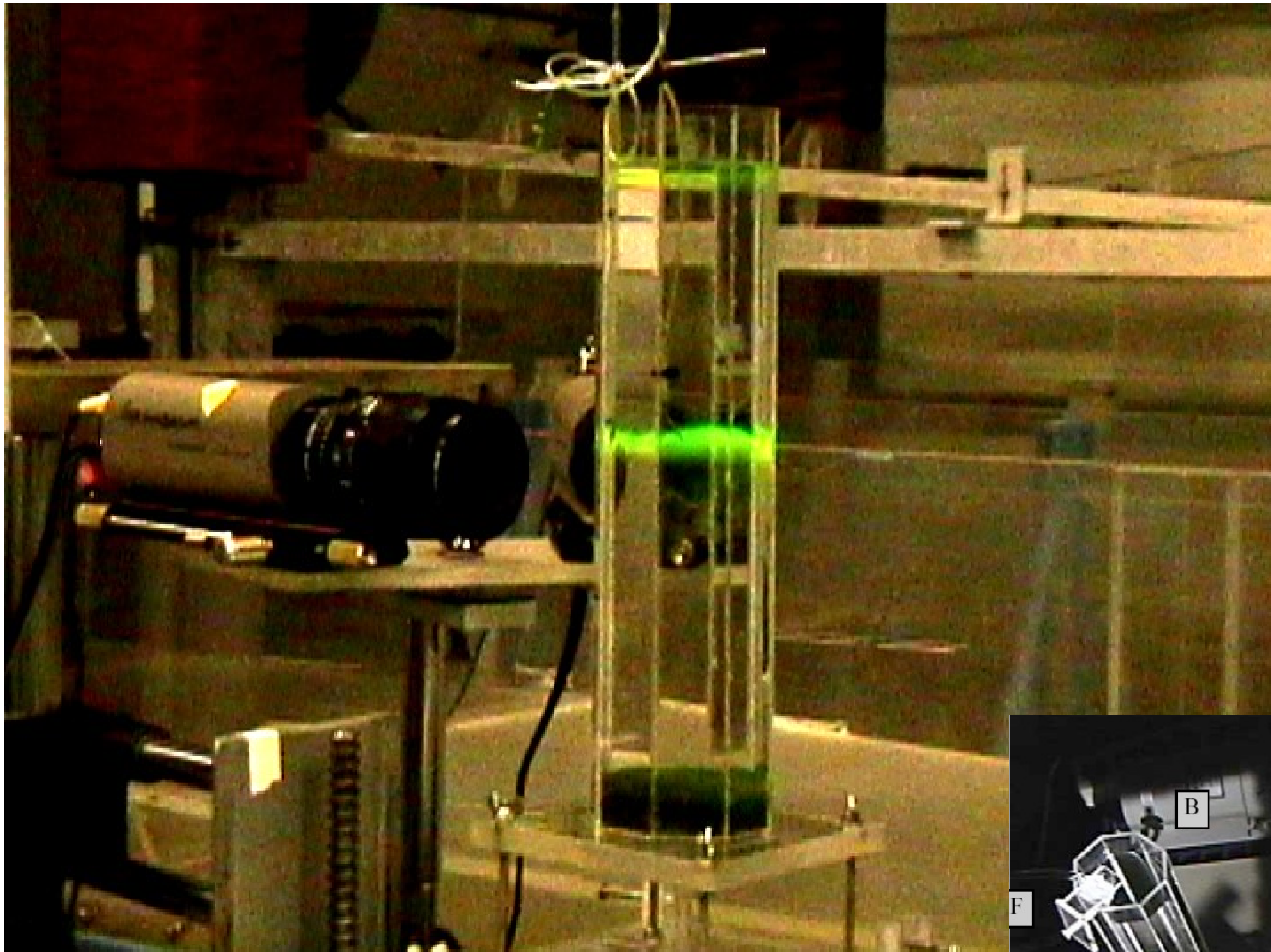
Herring school dynamics from acoustic tracking

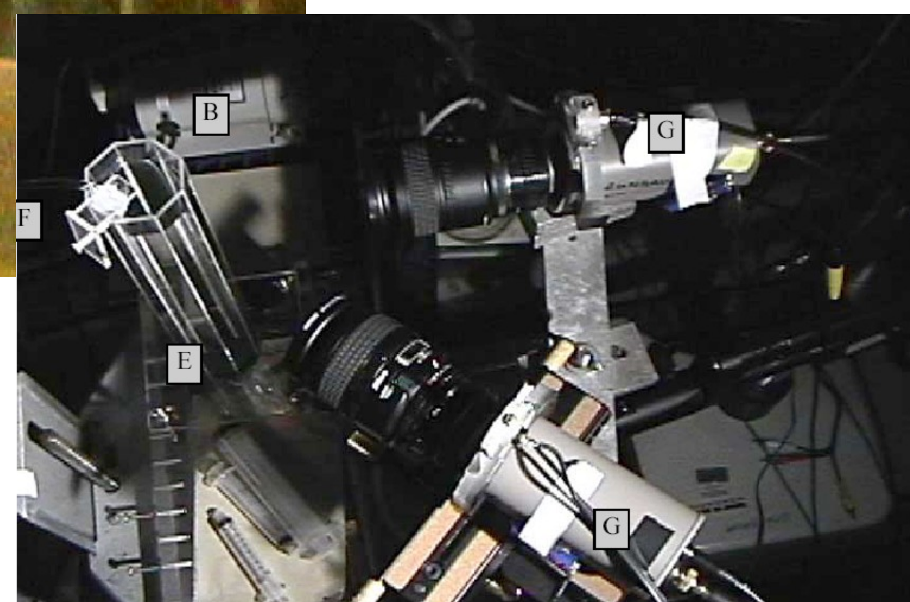
Handegard et al. 2005

Makris et al. 2009



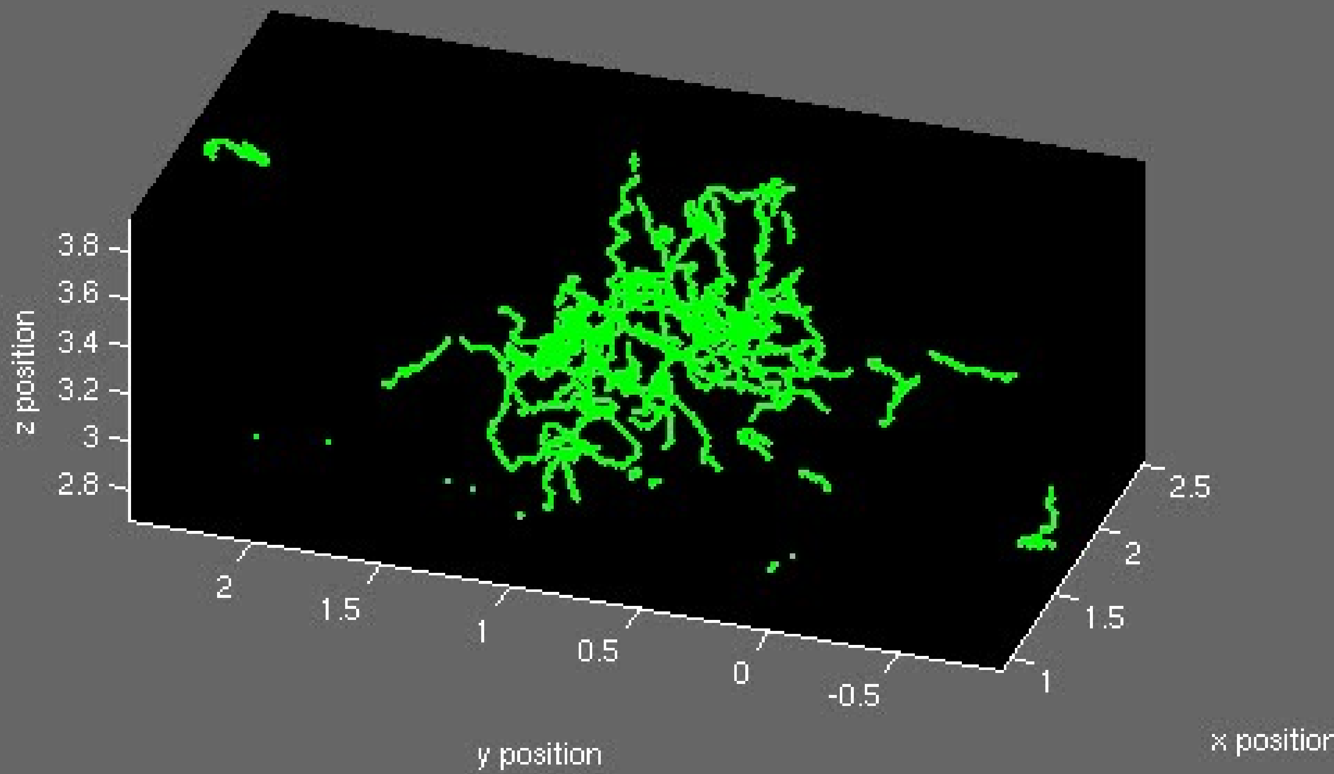
Quantifying organism movement: video tracking





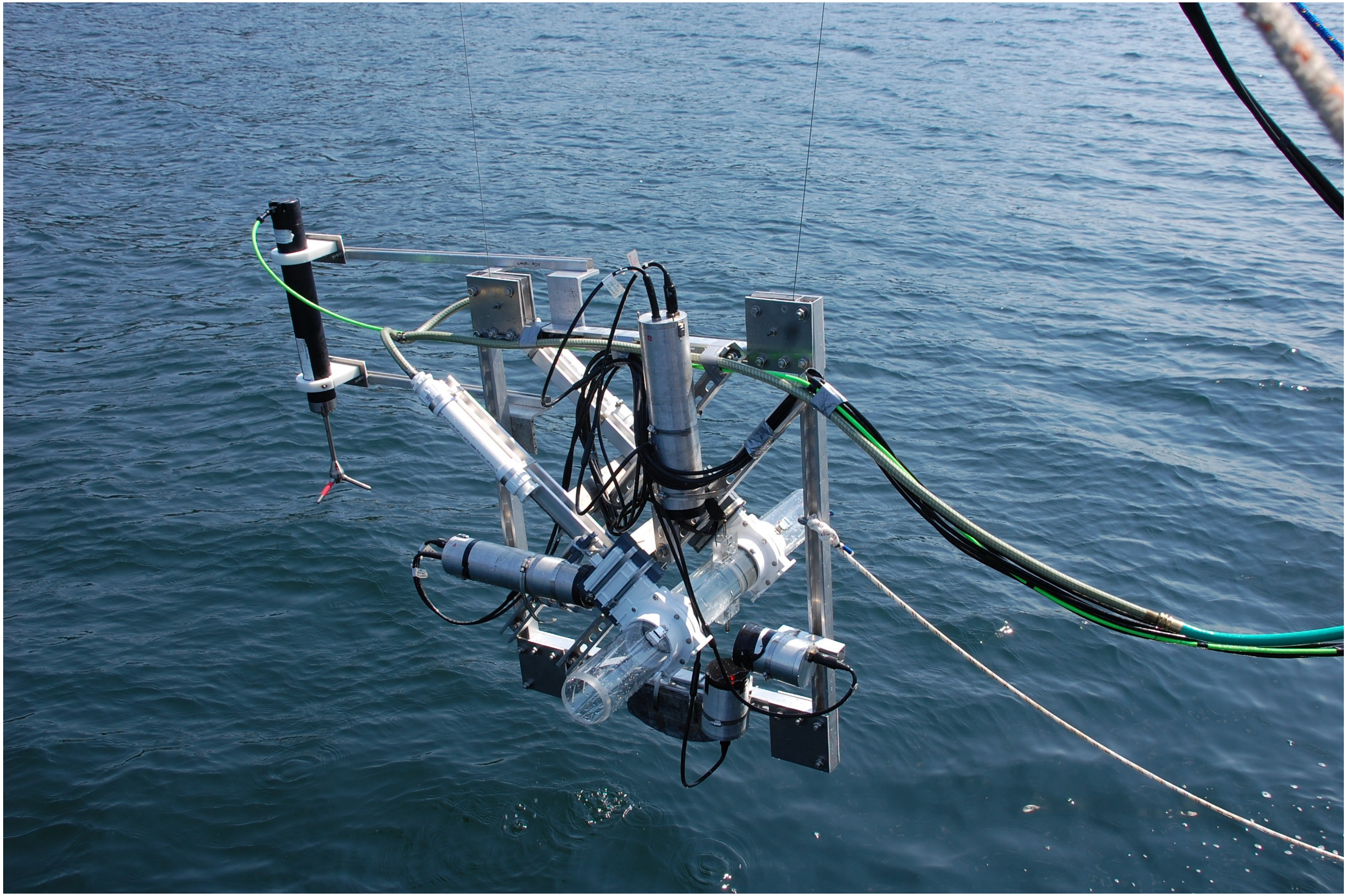
Video tracking for quantifying distributions and movements of plankton

Swimming trajectories, *Strombidinopsis* sp., Susanne Menden-Deuer

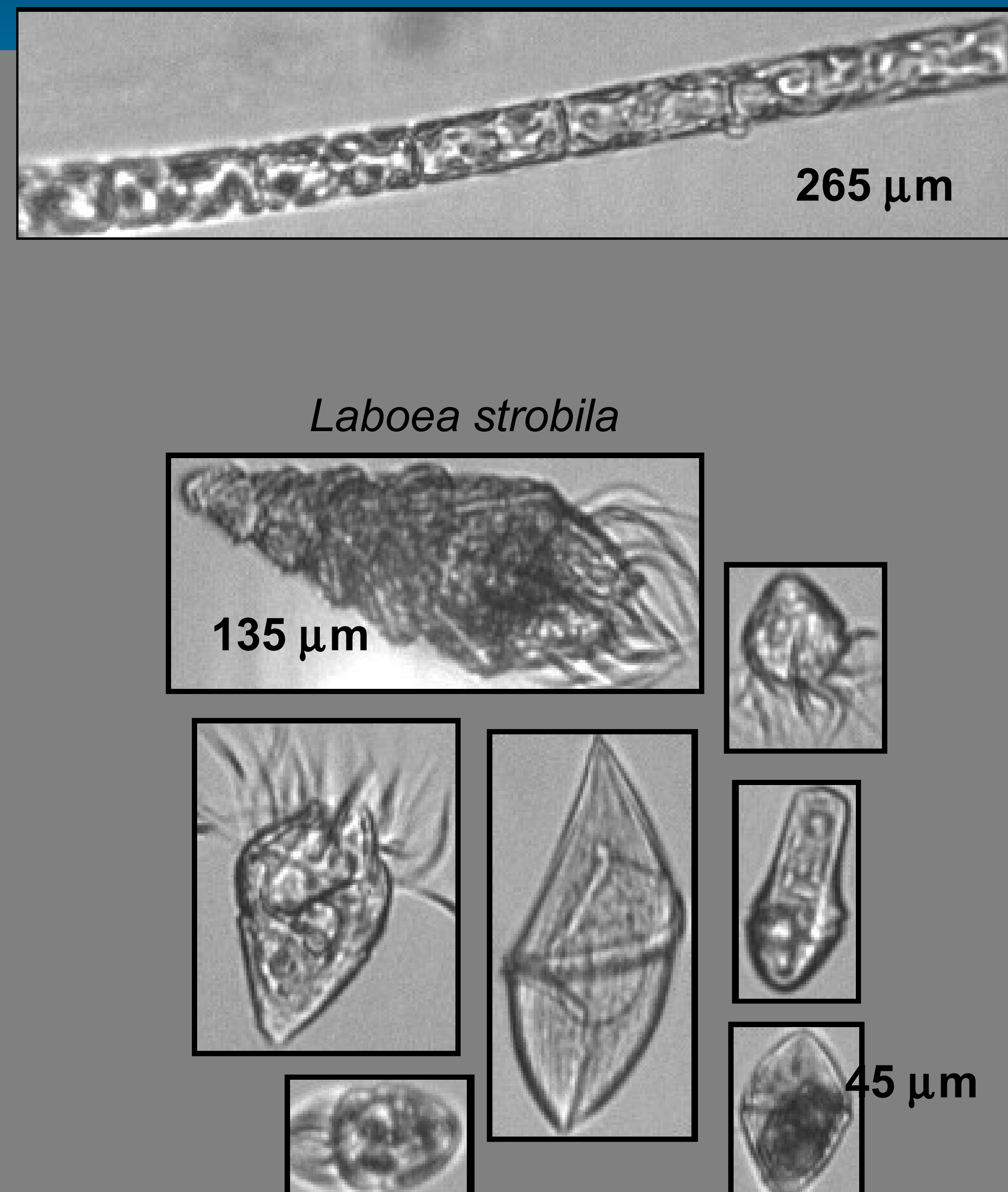


Menden-Deuer & Grünbaum 2006

Low cost, field-deployable *in situ* sampler



3D Footage of Natural Communities



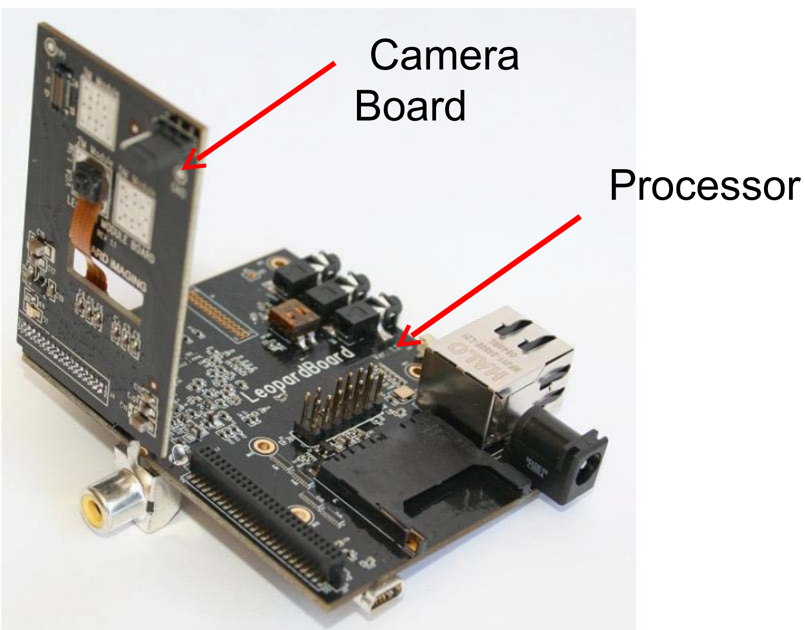
Heterosigma akashiwo Harmful Algal Blooms

Heterosigma cell. Photo: M. Black

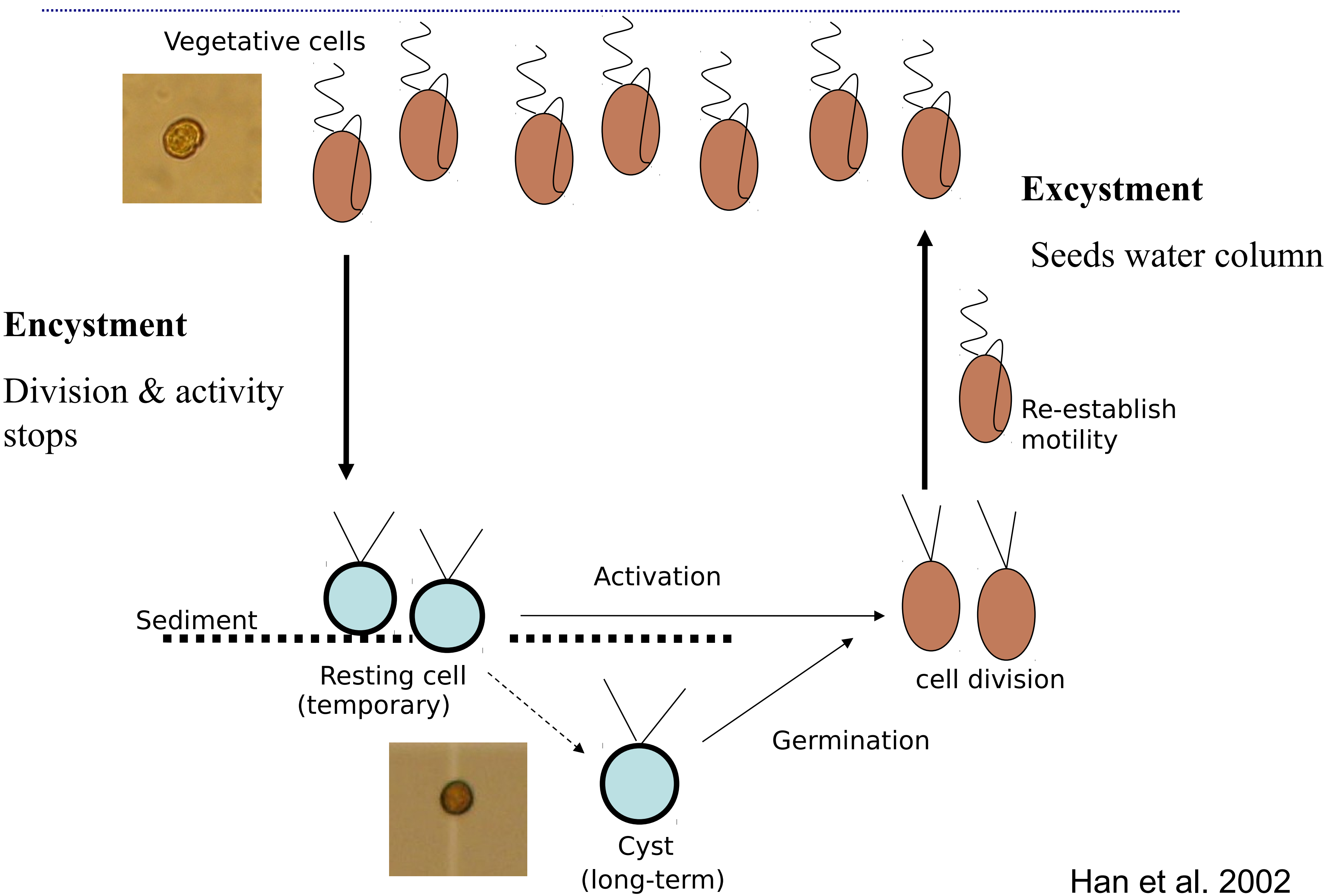
Heterosigma Harmful Algal Bloom. Photo: K. Fredrickson

Lower cost, field-deployable *in situ* sampler

"LeopardBoard":
ARM computer-based
high-definition imager

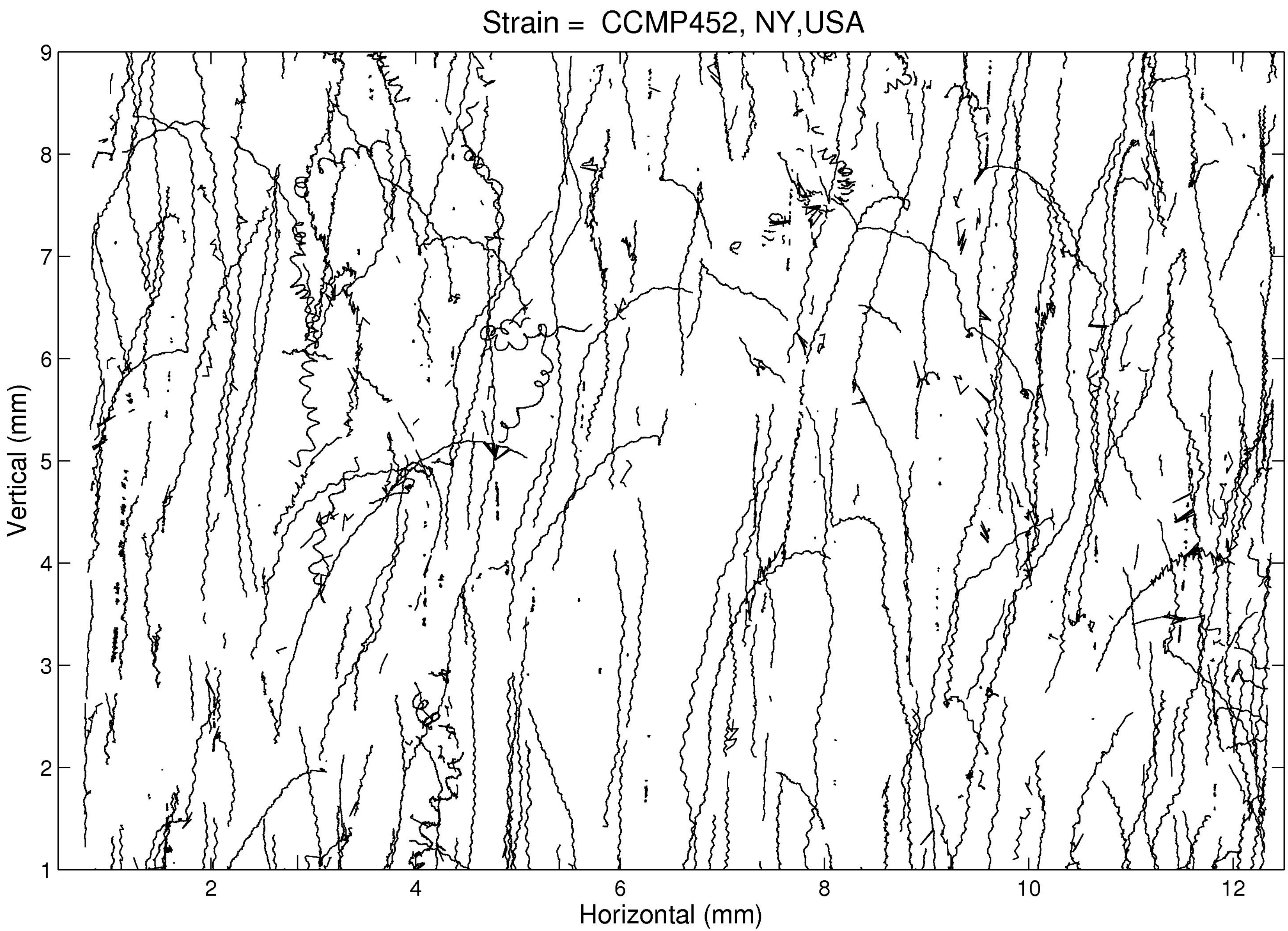


Generalized Lifecycle of *Heterosigma*



Han et al. 2002

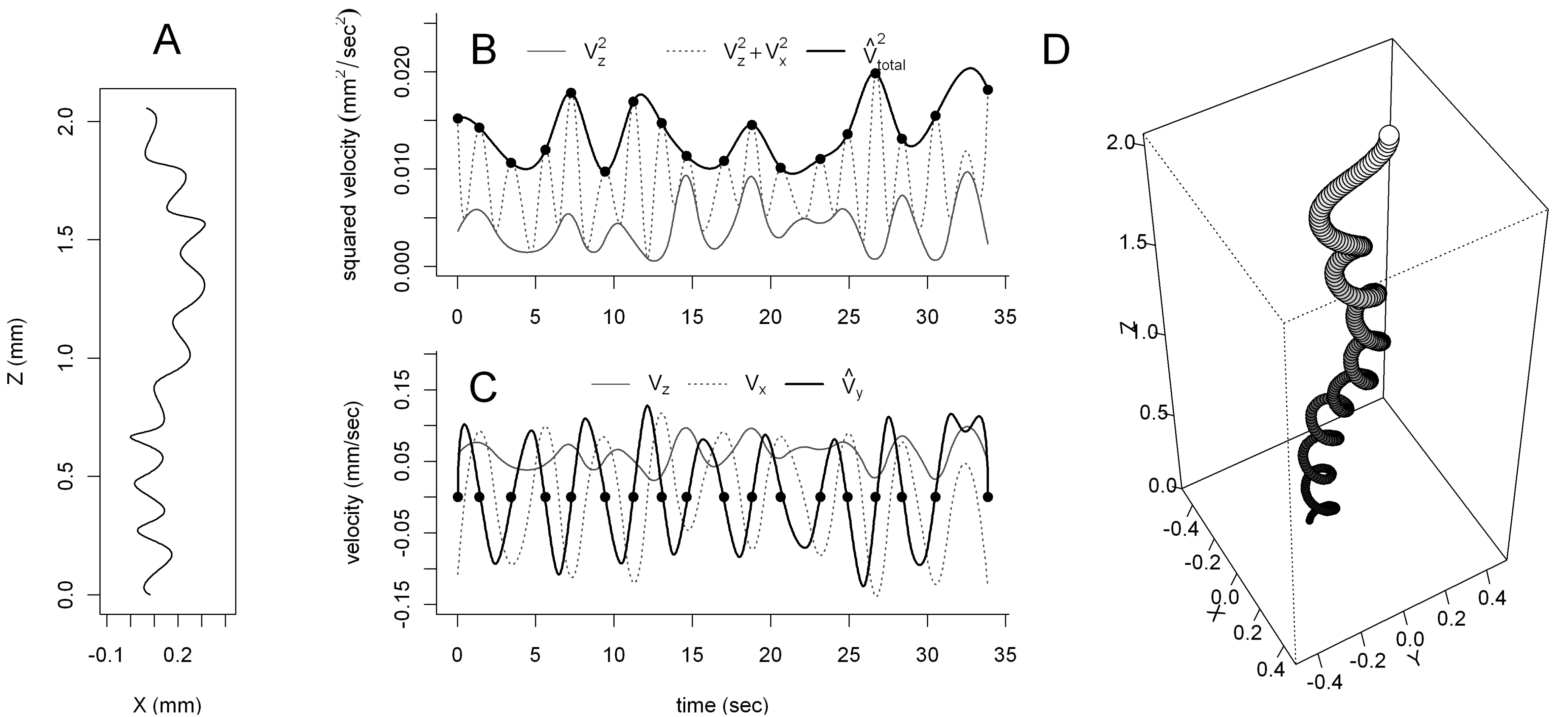
Vegetative *Heterosigma* cell swimming



M. T. Nishizaki

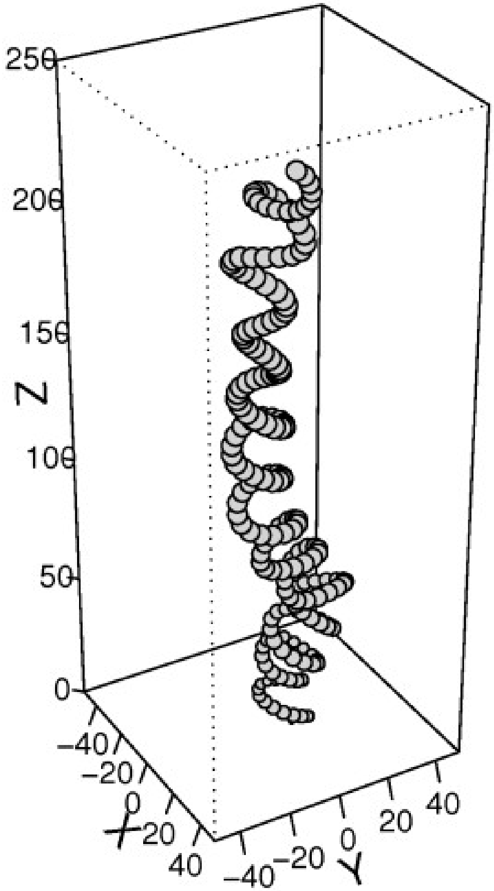
Estimating 3D helical trajectories from 2D data

Gurarie et al. 2010



Helical characteristics are diagnostic of strain (putative genotype)

Gurarie et al. 2010

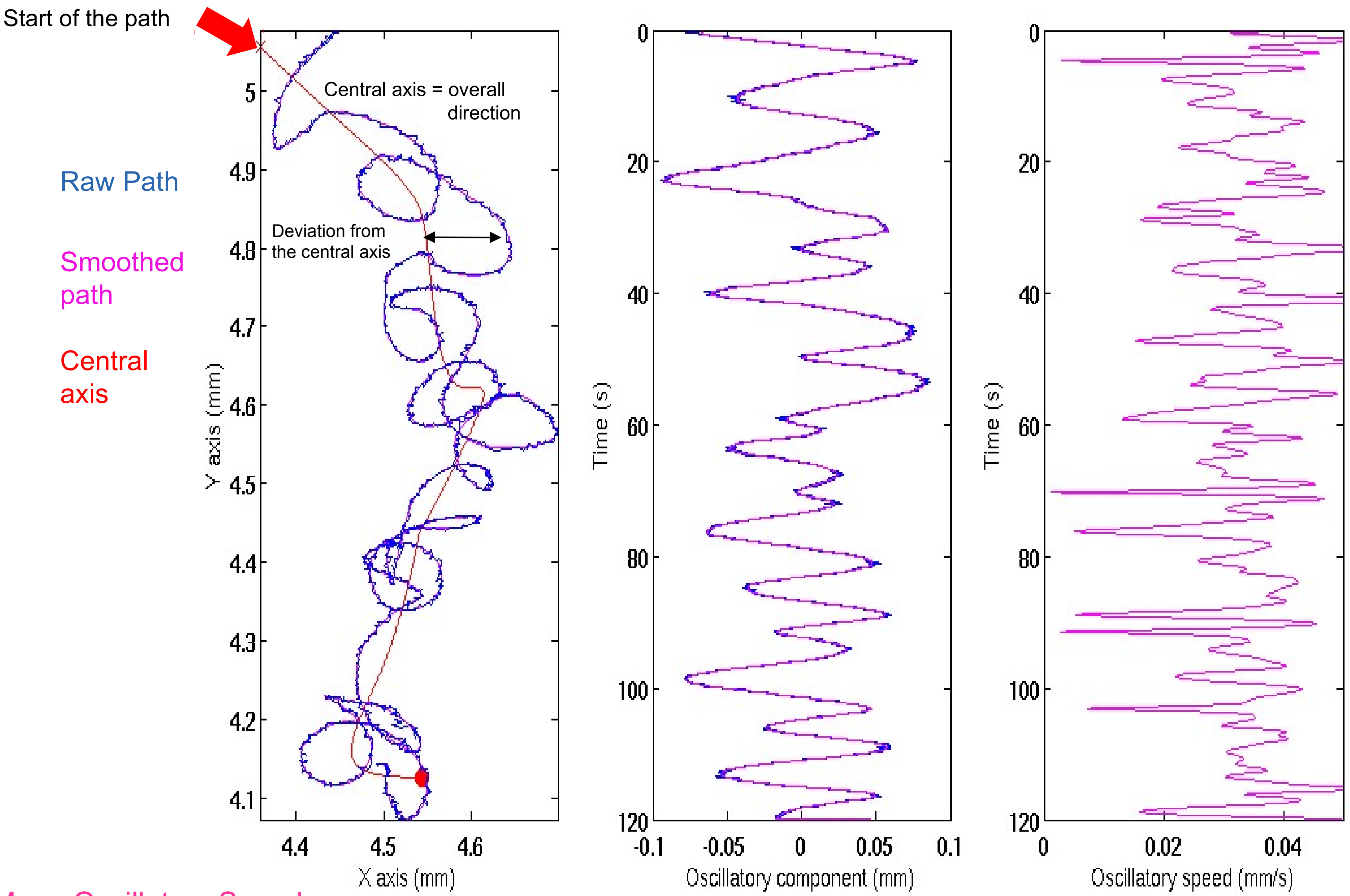


Parameters		
μ_a		mean vertical velocity of $\mathbf{V}^a$
τ_a		characteristic time scale of $\mathbf{V}^a$
σ_a		magnitude of stochasticity for $\mathbf{V}^a$
ω_o		characteristic angular velocity of $\mathbf{V}^o$
P_o	$1/\omega_o$	characteristic period of rotation of $\mathbf{V}^o$
τ_o		characteristic time scale of $\mathbf{V}^o$
σ_o		magnitude of stochasticity for $\mathbf{V}^o$
$\bar{V}_t$		mean tangential velocity
Θ	$\sin^{-1}(\mu_a/\bar{V}_t)$	mean tangential angle

A) Strains					
Location	Narraganset Bay, RI	Long Island Sound, NY	Puget Sound, WA	Puget Sound, WA	Onagawa Bay, Sea of Japan
Year	1991	1952	2002	2007	1984
N	55	131	31	54	33
B) Parameters					
μ_a (mm s^{-1})	0.069 (0.022-0.175)	0.036 (0.005-0.129)	0.047 (0.007-0.088)	0.049 (0.021-0.118)	0.043 (0.013-0.094)
$\bar{V}_t$ (mm s^{-1})	0.141 (0.085-0.383)	0.114 (0.05-0.155)	0.055 (0.022-0.103)	0.097 (0.053-0.12)	0.101 (0.061-0.153)

Swimming Statistics of Individual Transitional Cells

Elizabeth Tobin



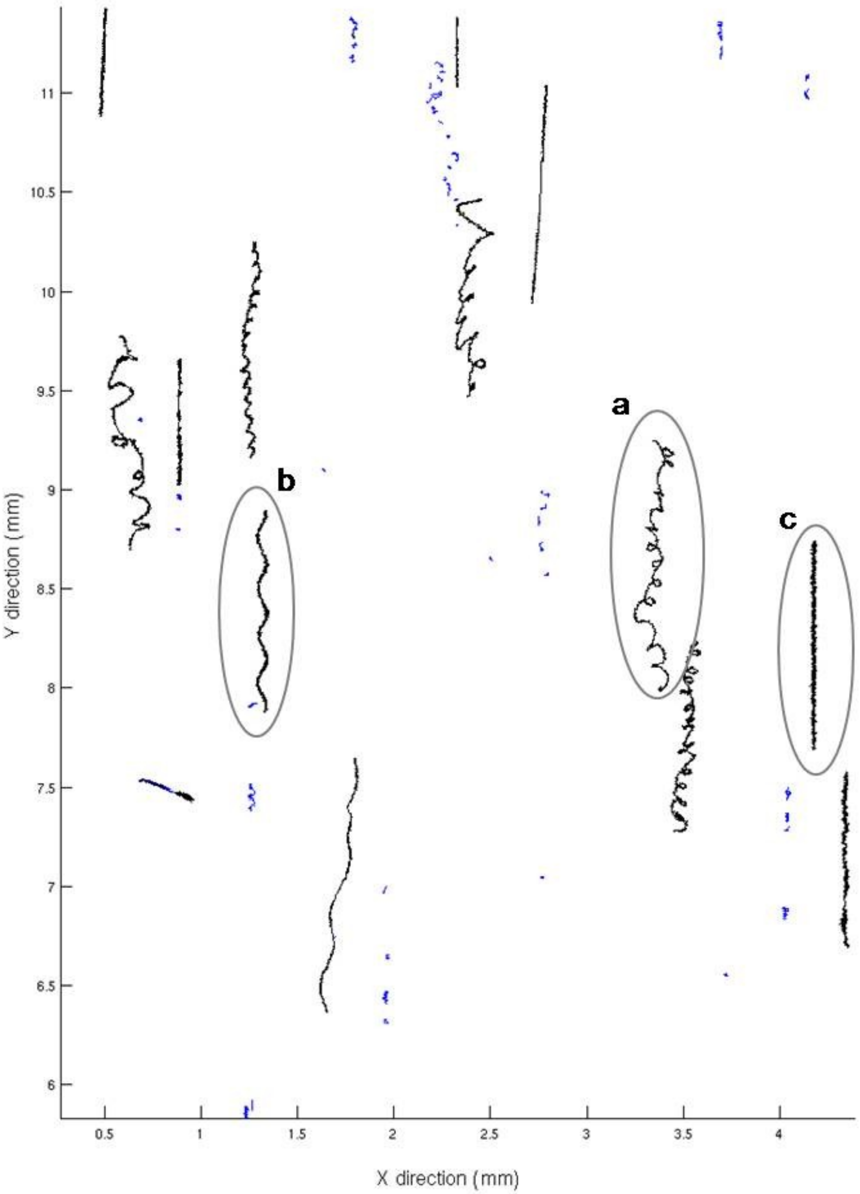
Mean Oscillatory Speed

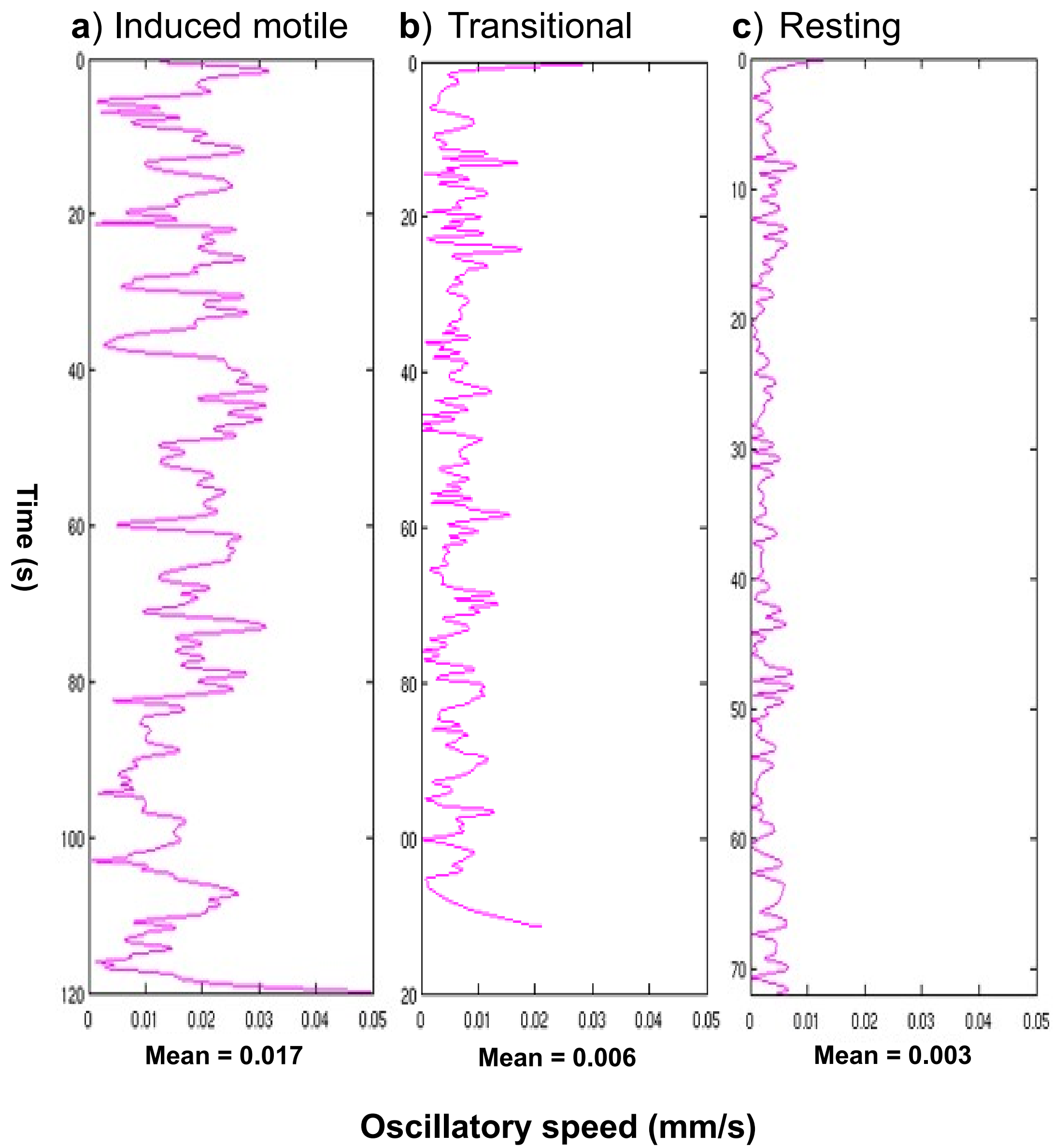
Mean Gross Speed

Mean Vertical and Horizontal Velocity

Helical characteristics are characteristic of cell state

Elizabeth Tobin

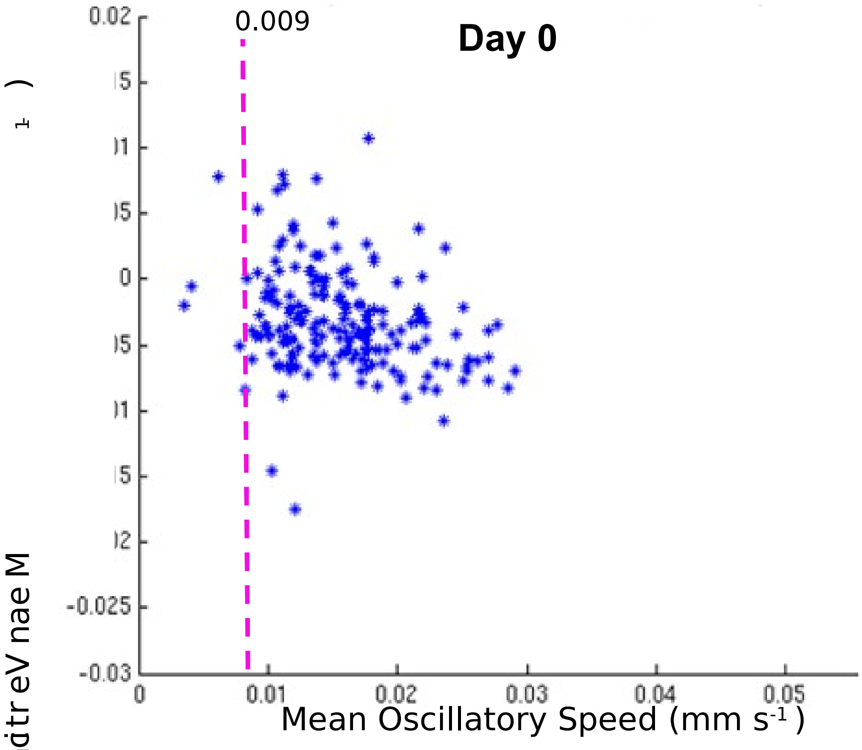


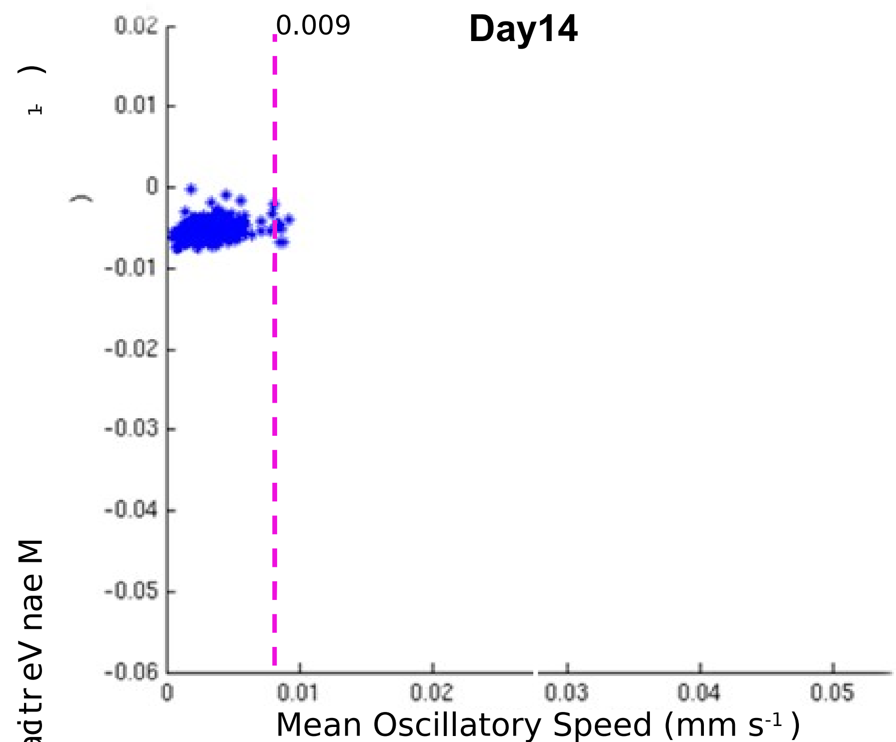


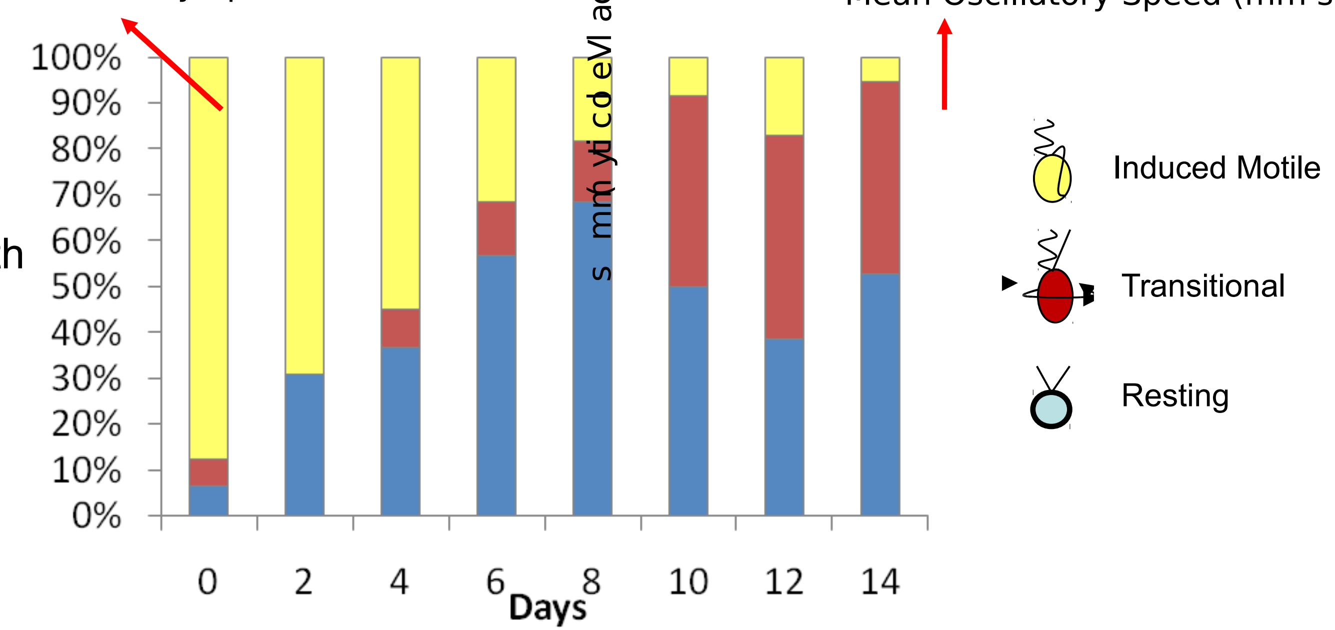
- Mostly type **a** on Days 0 and 2
- Mostly types **b/c** on Days 10 -14

Establishing Motion-based Criteria to Classify Cell State

Elizabeth Tobin







Video assay, verified with microscope counts

Identifying Net Movement for Each Cell State

	Induced motile	Transitional	Resting	Vegetative motile	Settling velocity
Mean Oscillatory Speed ($\mu m\ s^{-1}$)	13.90 ± 6.1	6.79 ± 2.1	3.77 ± 0.9		
Mean Gross Speed ($\mu m\ s^{-1}$)	9.30 ± 4.8	5.87 ± 2.0	4.83 ± 1.7	49 – 66	
Mean Vertical Velocity ($\mu m\ s^{-1}$)	**- 4.25 ± 3.5**	**- 4.16 ± 2.2**	**- 4.47 ± 1.8**	**35 - 60**	**≈ 4 $\mu m\ s^{-1}$**
Mean Horizontal Velocity ($\mu m\ s^{-1}$)	5.45 ± 4.1	2.46 ± 1.7	0.80 ± 0.6	(Bearon et al. 2004)	(Stokes' flow)
N	5712	5161	8434		

Stokes flow (Low Renoylds number)

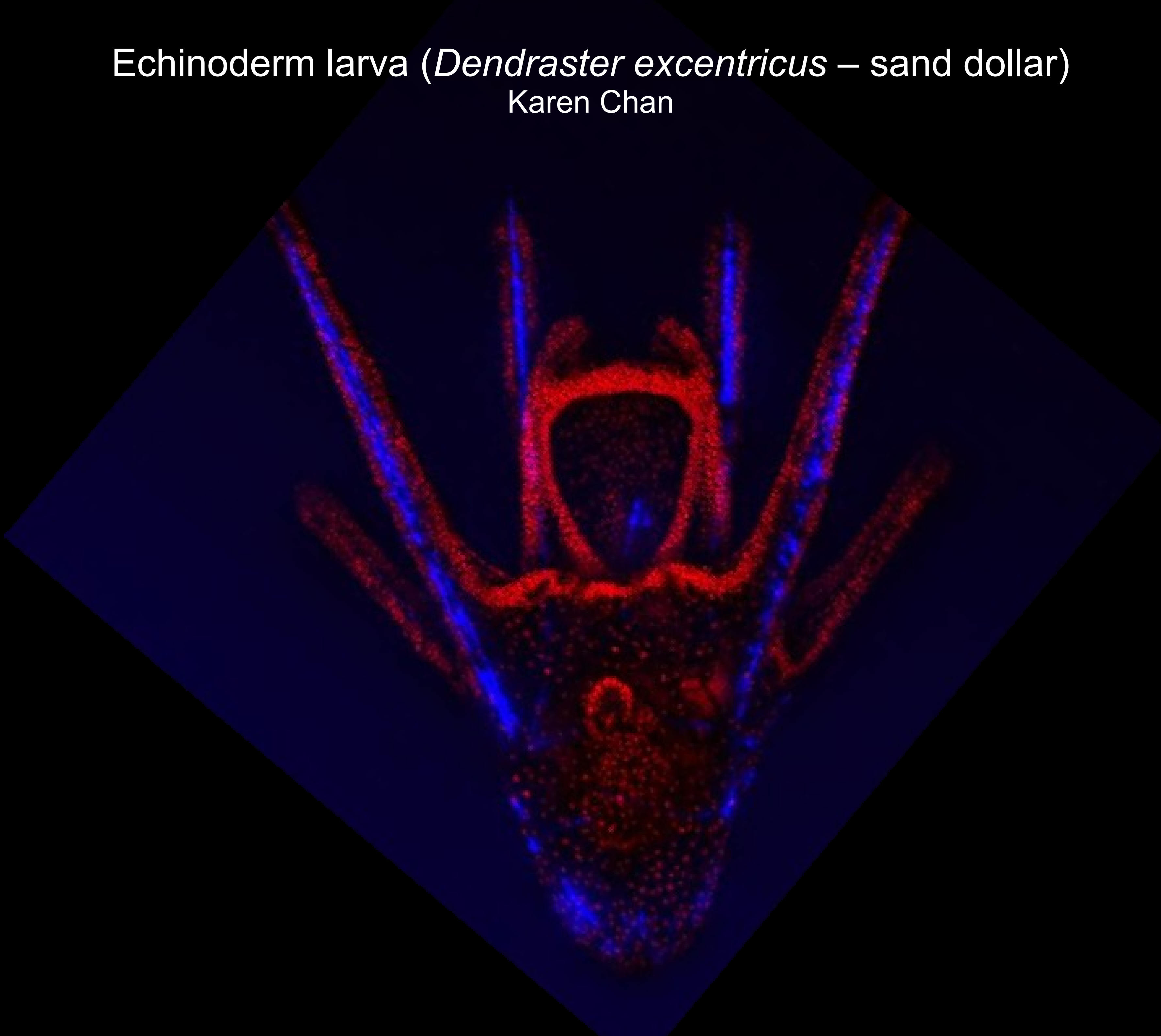
ρ_p = 1.105 g cm^{-3} (Wada et al. 1985)
ρ_f = 1.025 g cm^{-3} (28 psu)
R = 5 μm
μ = 1.376 x 10^{-3} (28 psu, 10°C)

$$V_s = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} g R^2$$

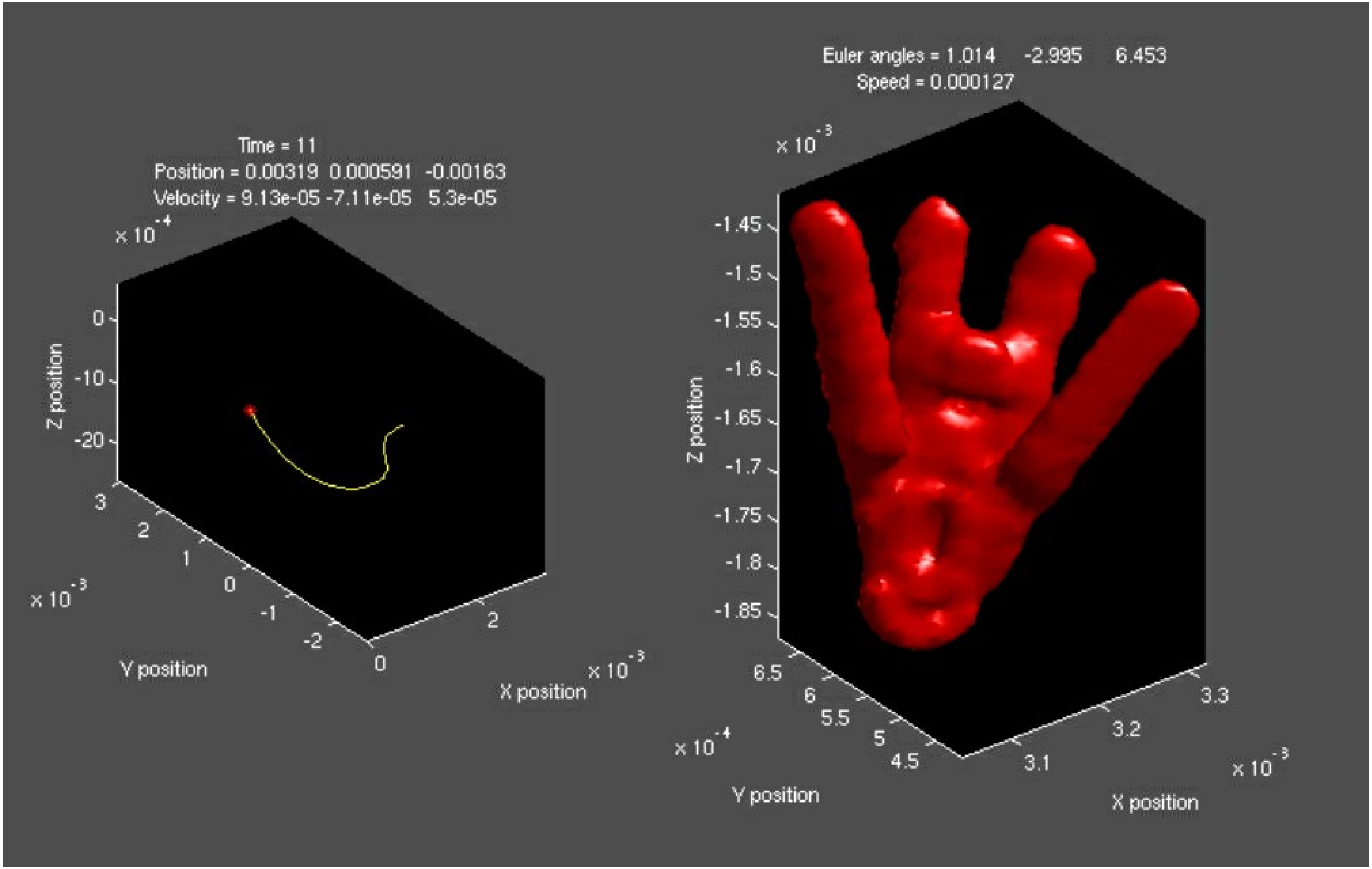
★ *Heterosigma* cells under going life-stage transition have net downward movement comparable to passive sinking.

Echinoderm larva (*Dendraster excentricus* – sand dollar)

Karen Chan



Confocal-based low-Re model of swimming biomechanics



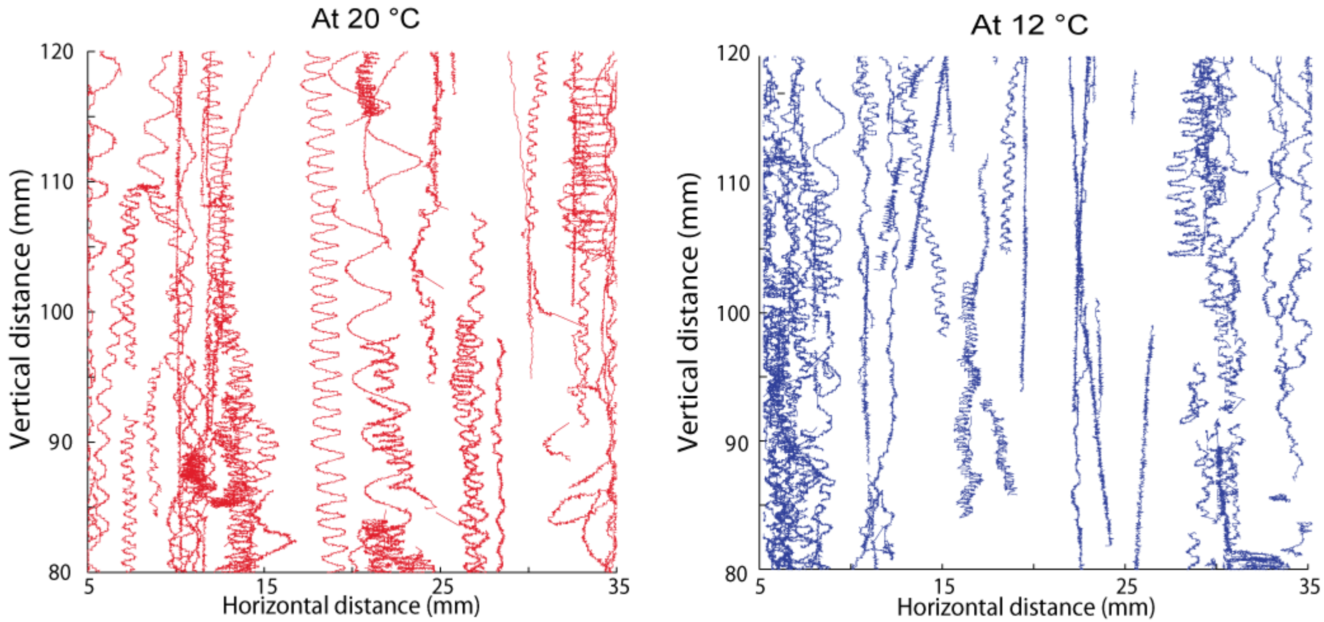
Chan and Grunbaum, in prep.

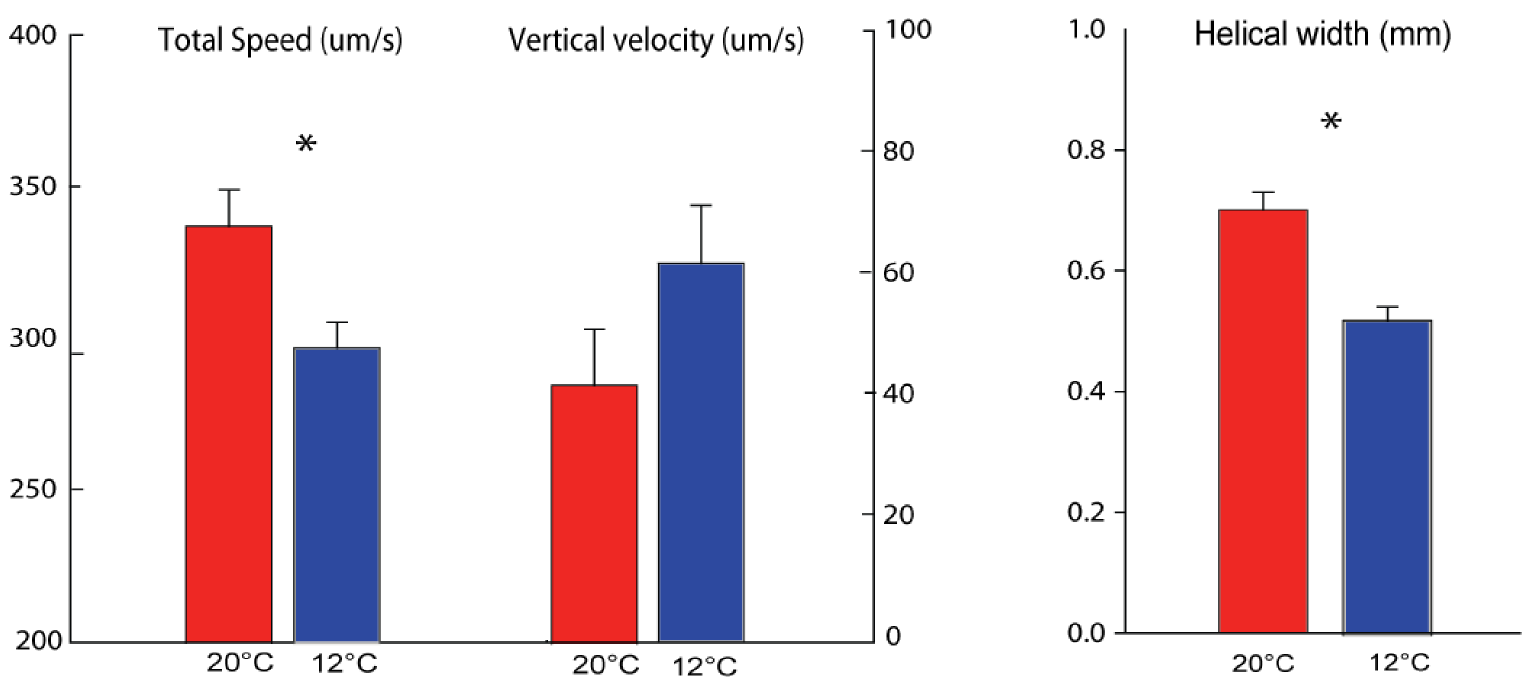
Confocal-based low-Re model of swimming biomechanics

Chan and Grunbaum, in prep.

Sand dollar larvae decrease helical widths to conserve upward speed in colder water

Karen Chan

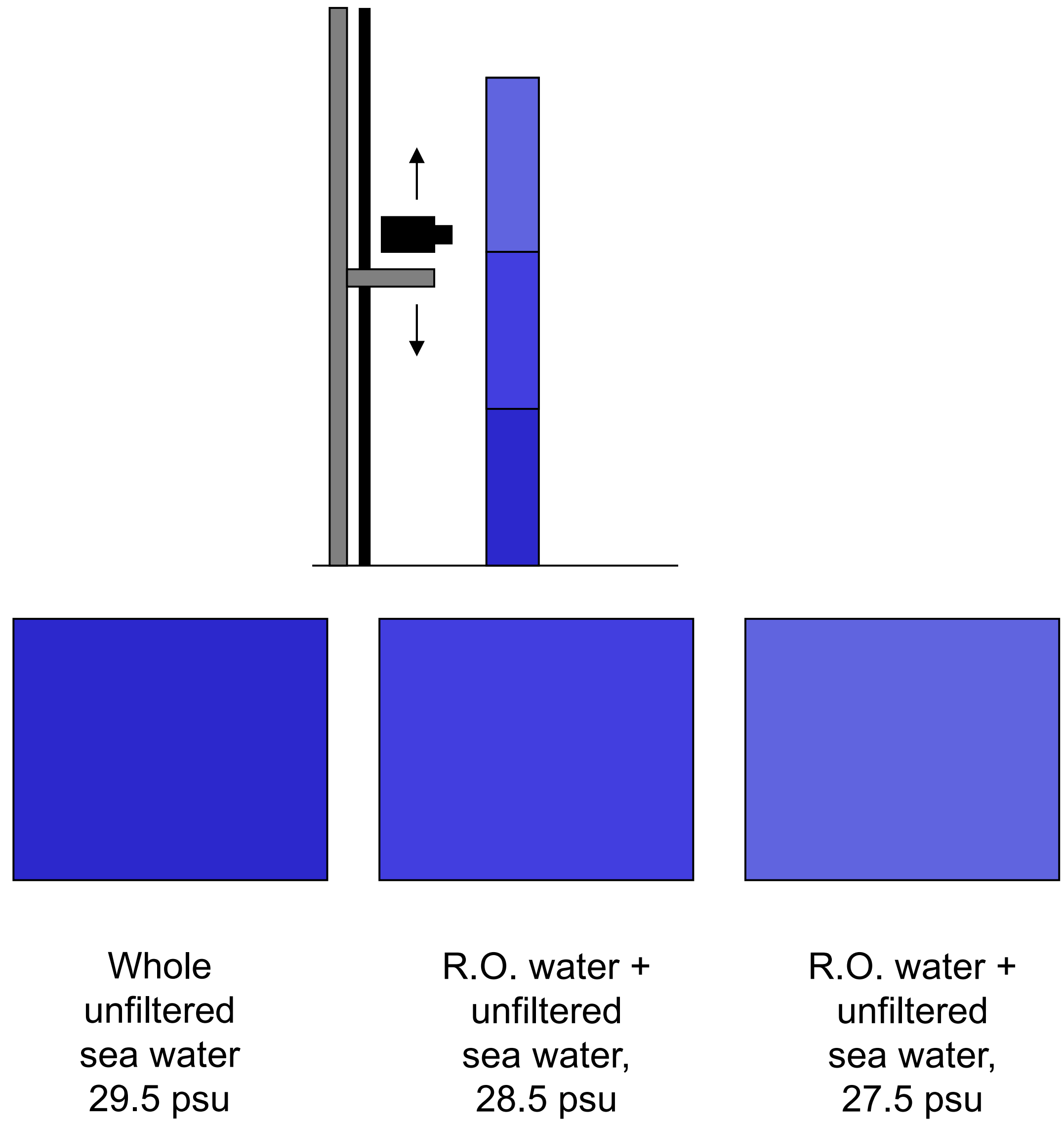




Thin layer formation by natural plankton communities - 2-halocline experiment

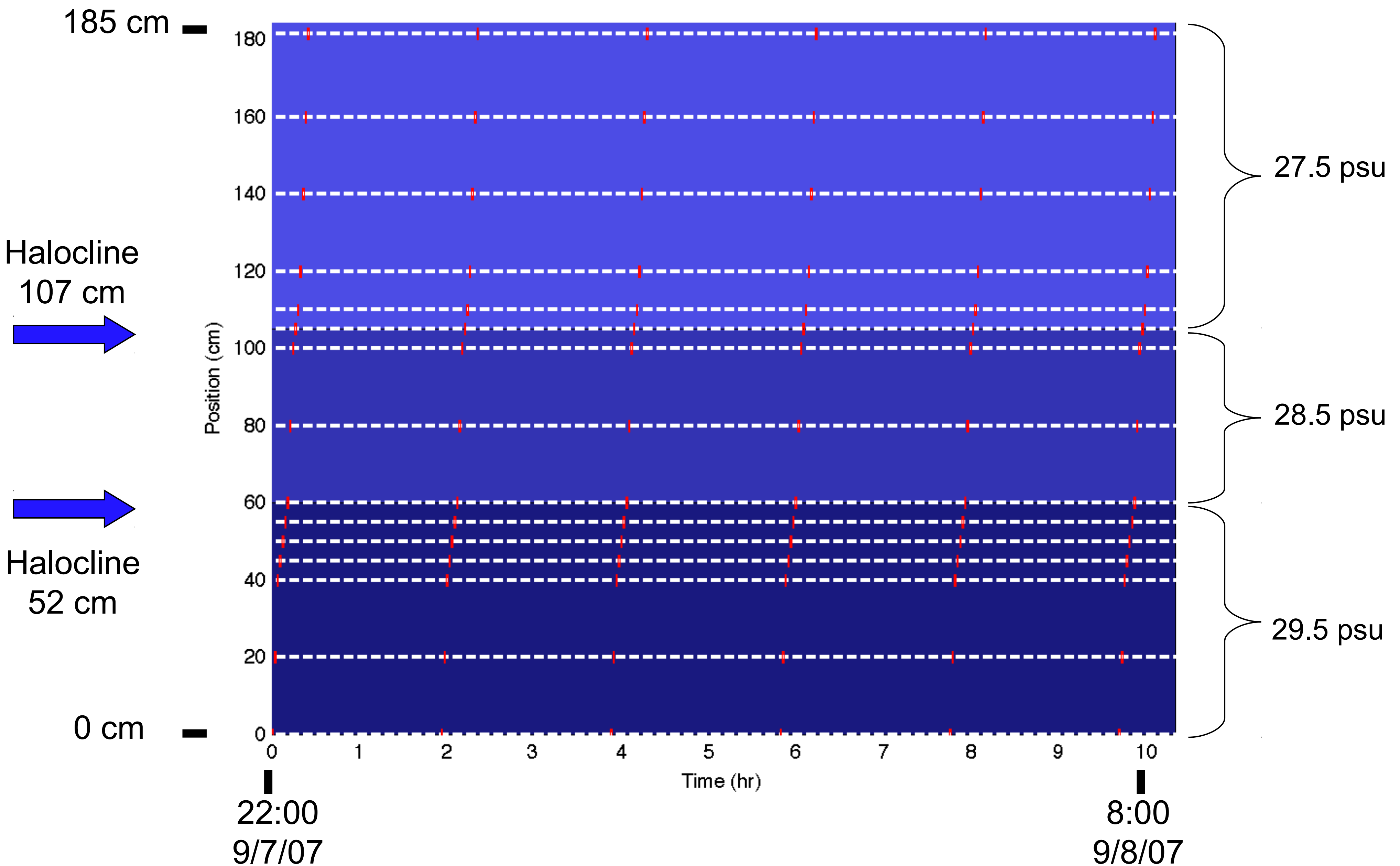
Experimental design:

1. Plankton pump water from 1 m and 4 m (Friday Harbor Laboratories dock)
2. Dilute with R.O. water to create two 1 psu haloclines
3. Sequential vertical profiles with video tracker

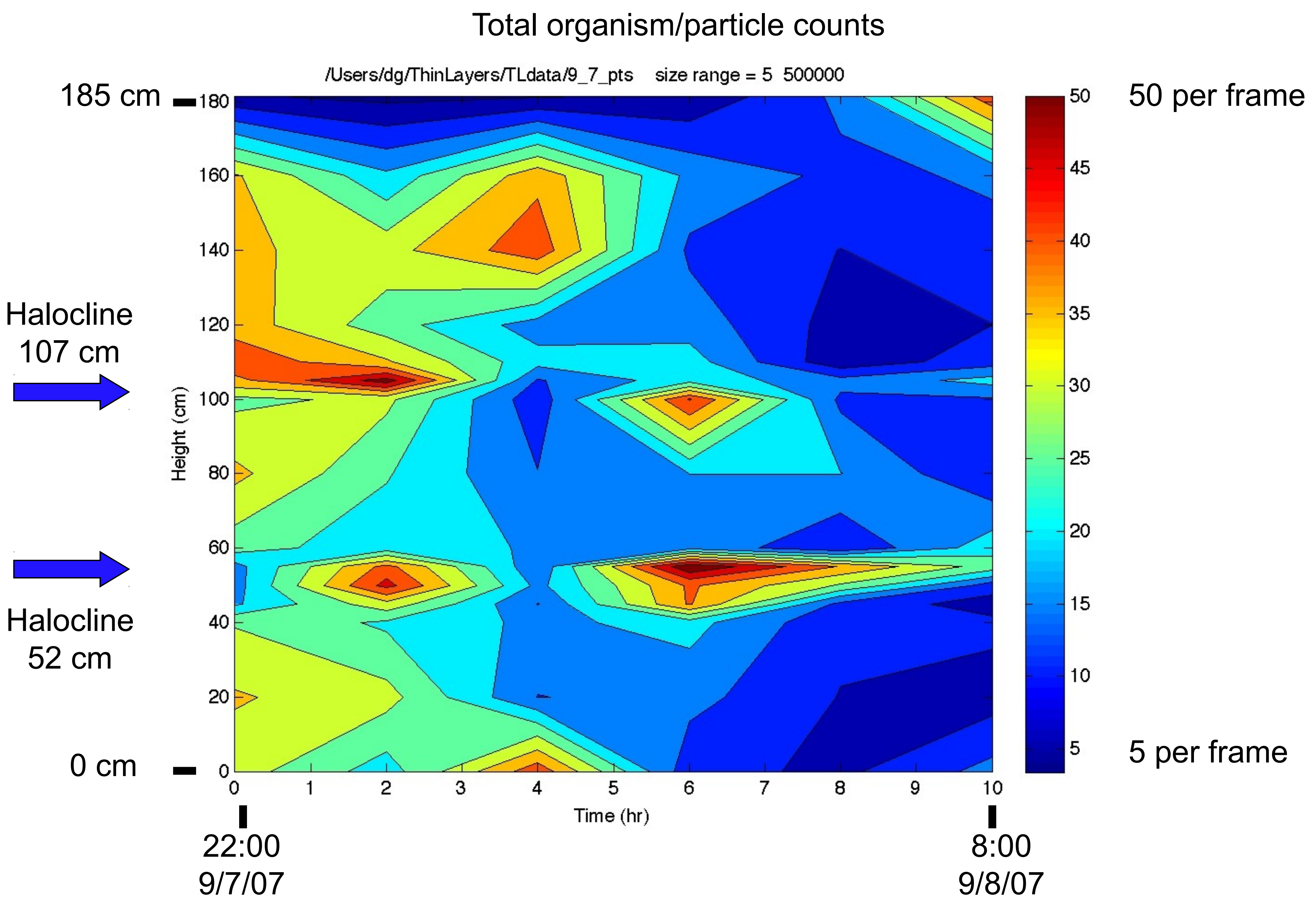


Thin layer formation by natural plankton communities - 2-halocline experiment

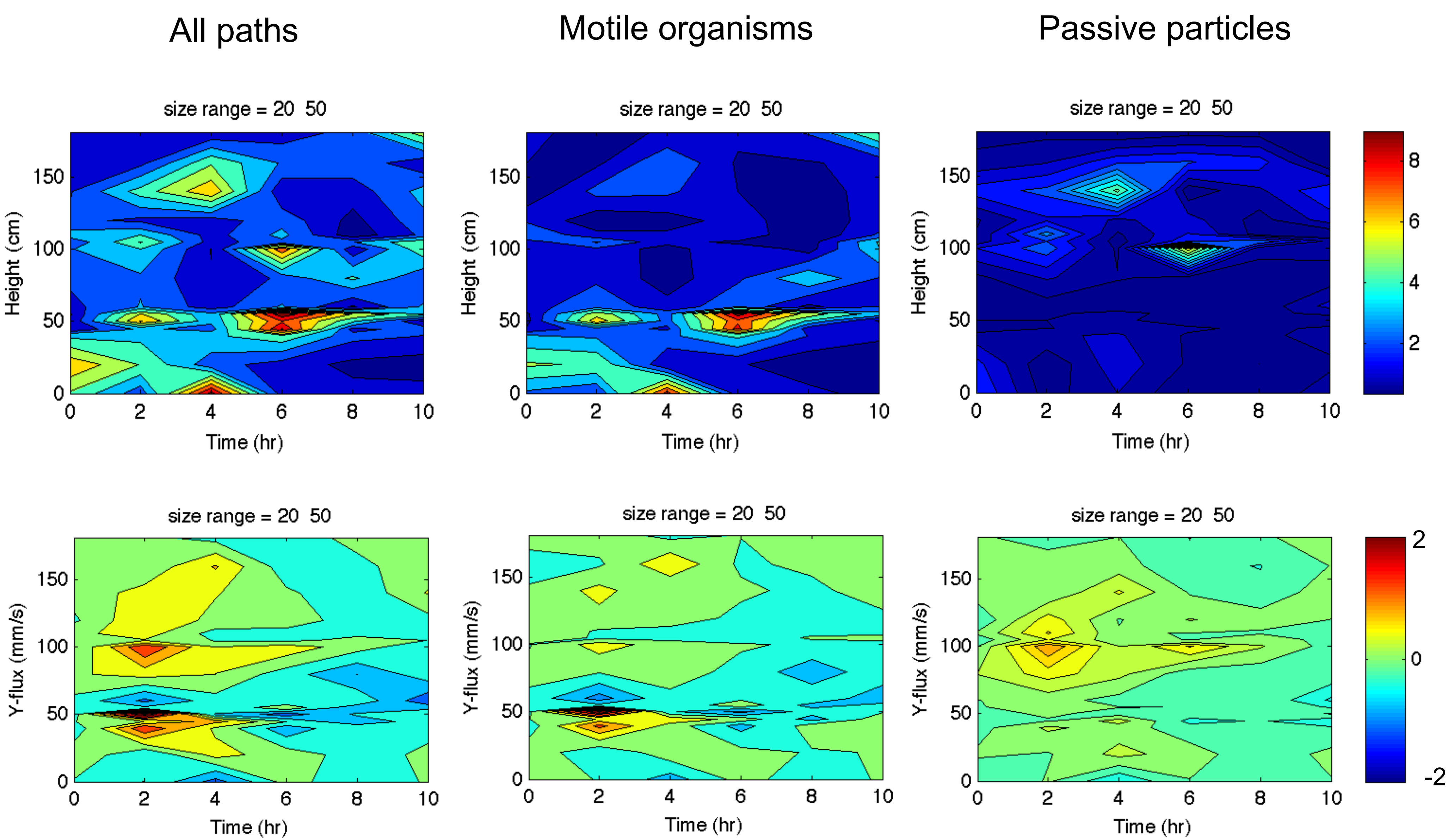
15 vertical stations, 6 profiles, 90 video clips, > 1.8 10^6 particle localizations



Thin layer formation by natural plankton communities - 2-halocline experiment



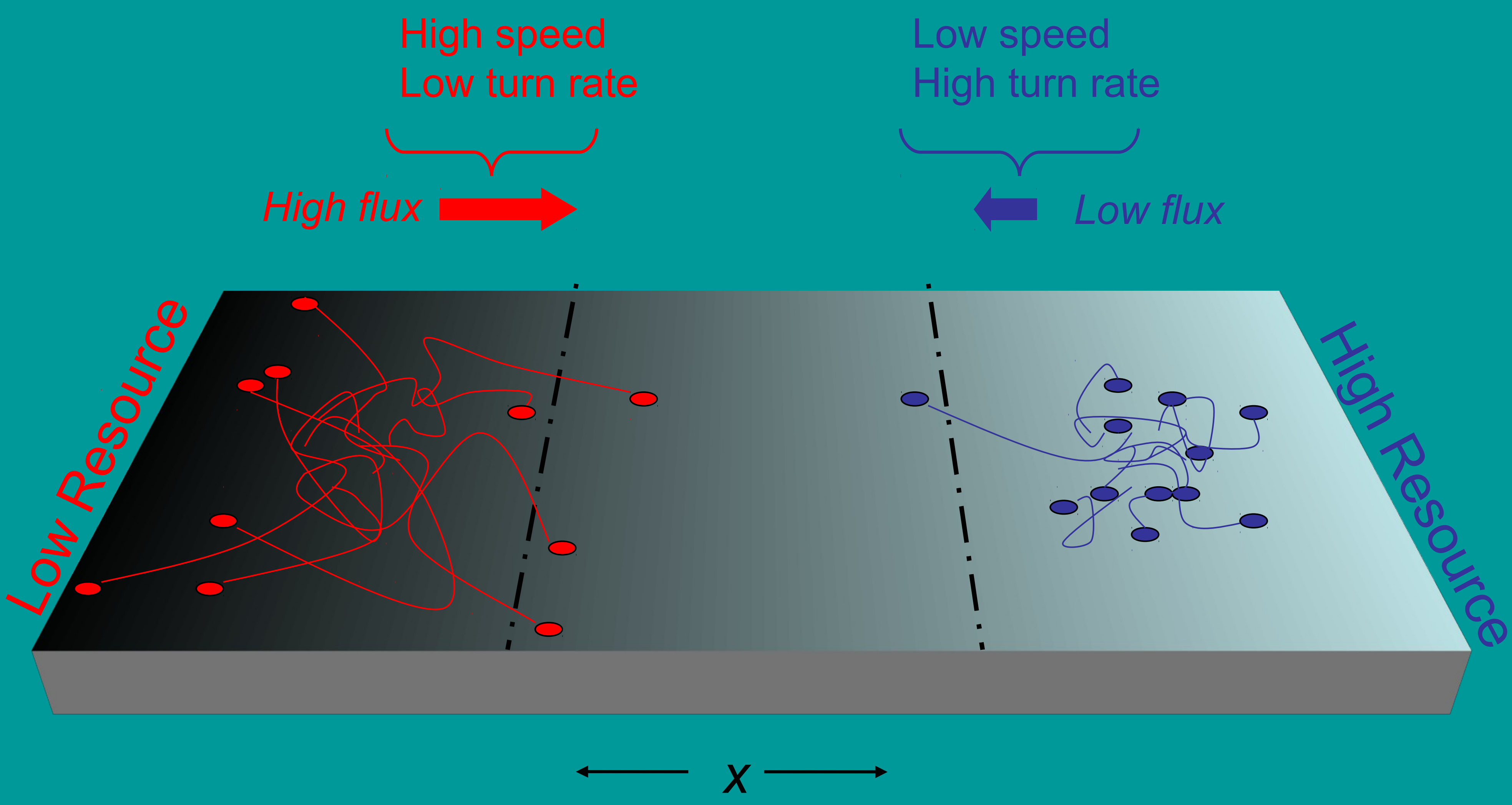
Abundance and vertical flux for motile and passive particles



Upward fluxes (# mm/s)

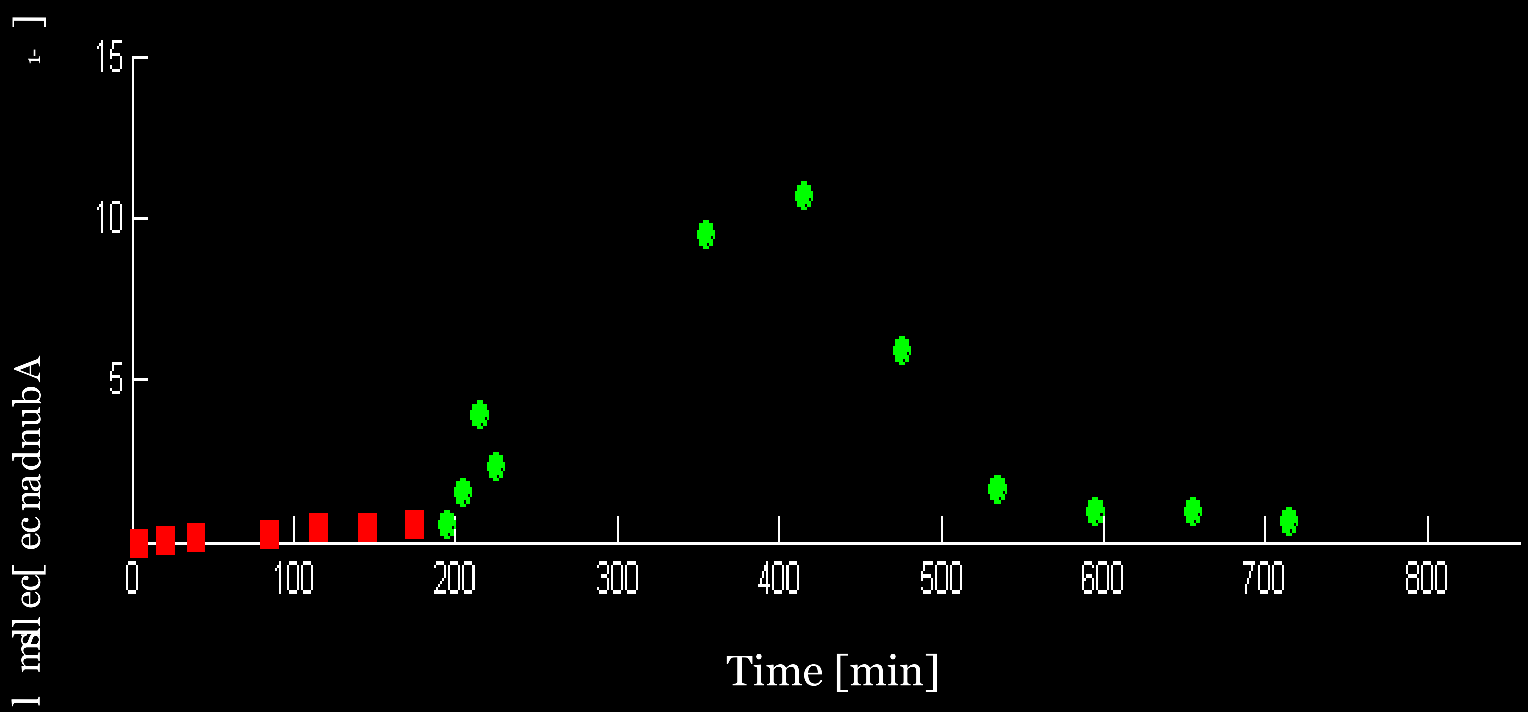
Foraging with sensory constraints

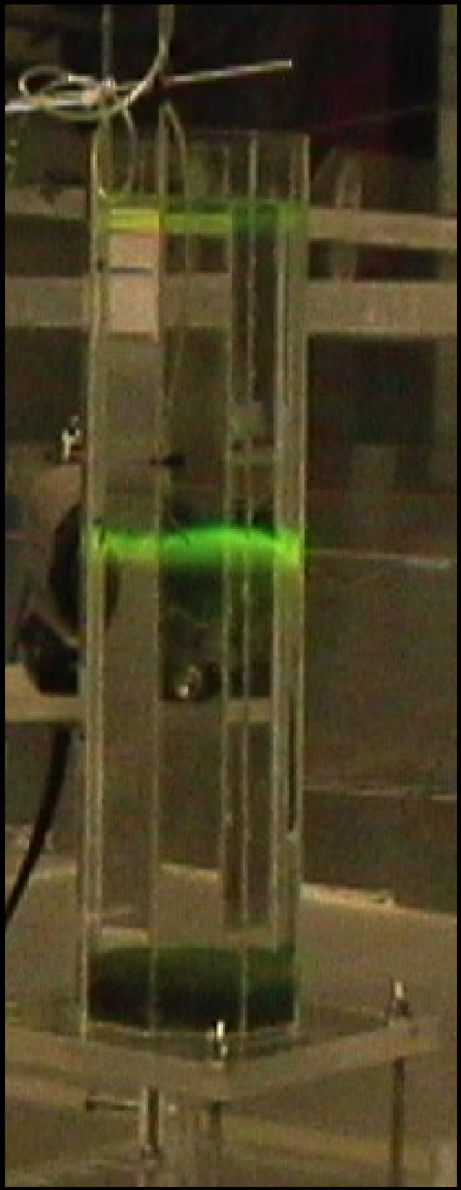
Biased Random Walks Mediated by Internal States



Heterotrophic protists aggregate to thin layer of phytoplankton prey cells

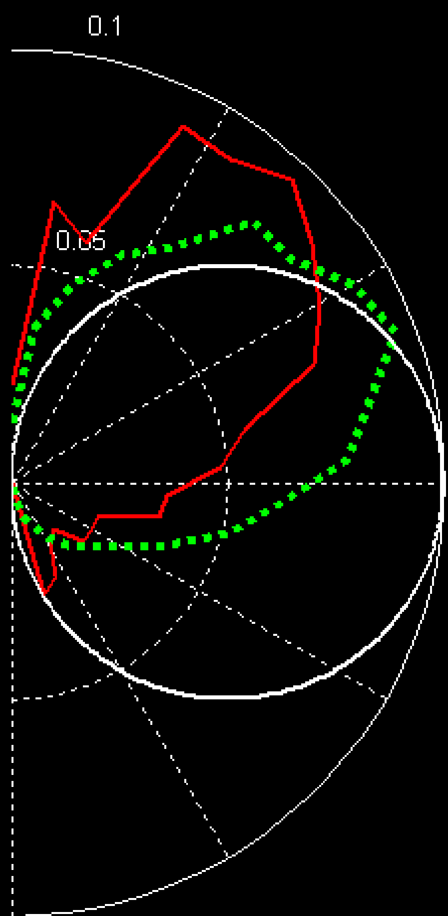
Susanne Menden-Deuer





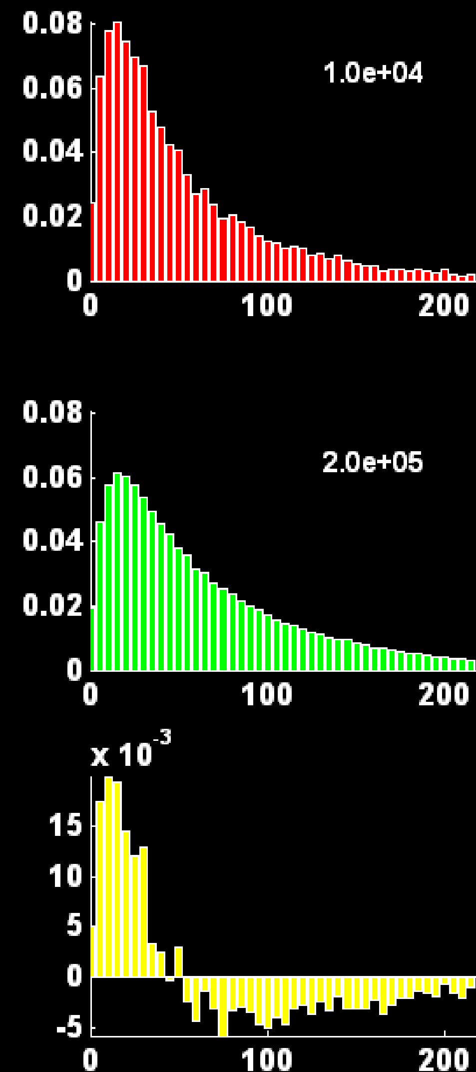
Mechanisms of aggregation: behavioral responses to food

Direction



no prey
prey
random
direction

Turning rate [deg. s^{-1}]

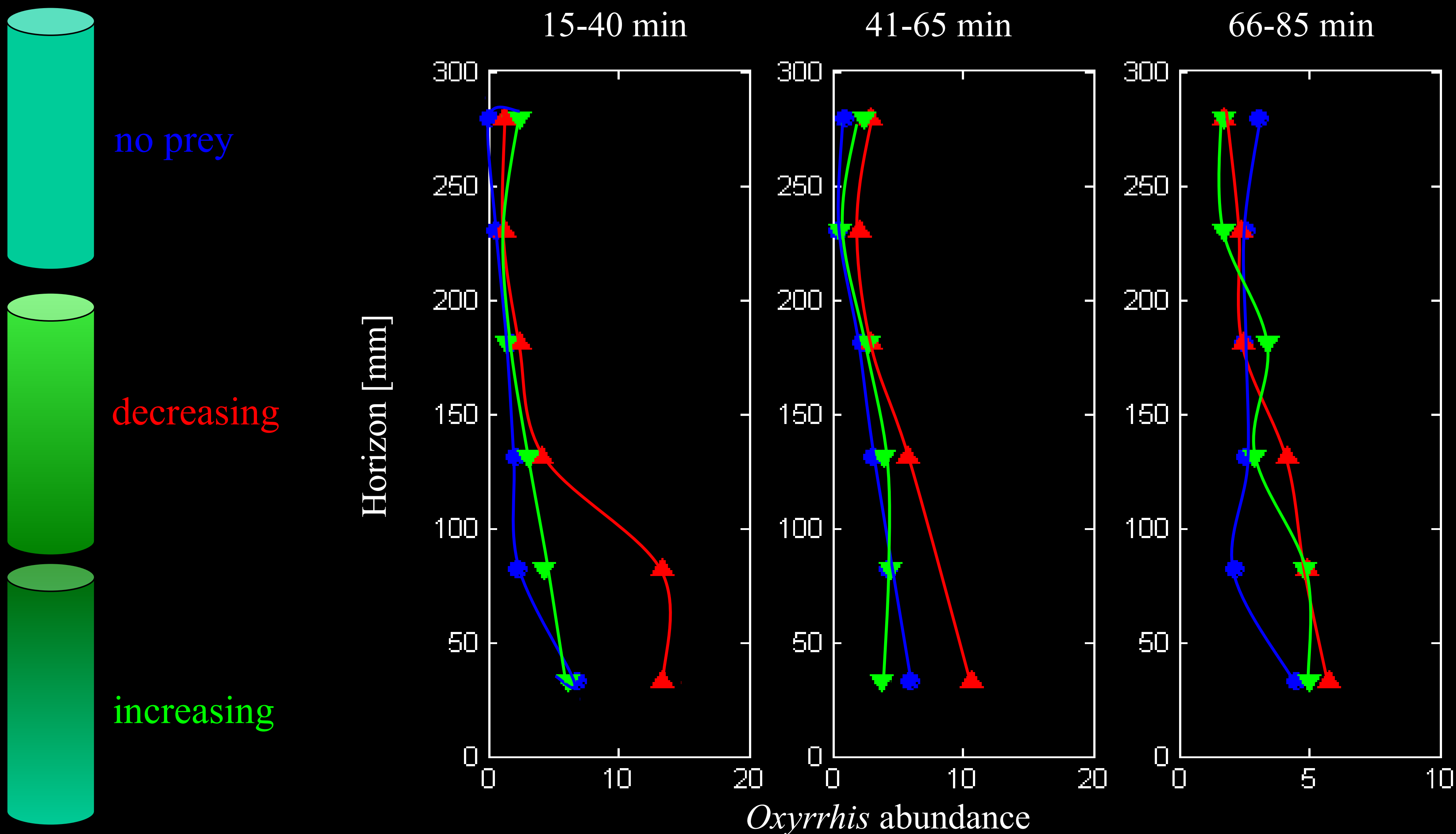


no prey

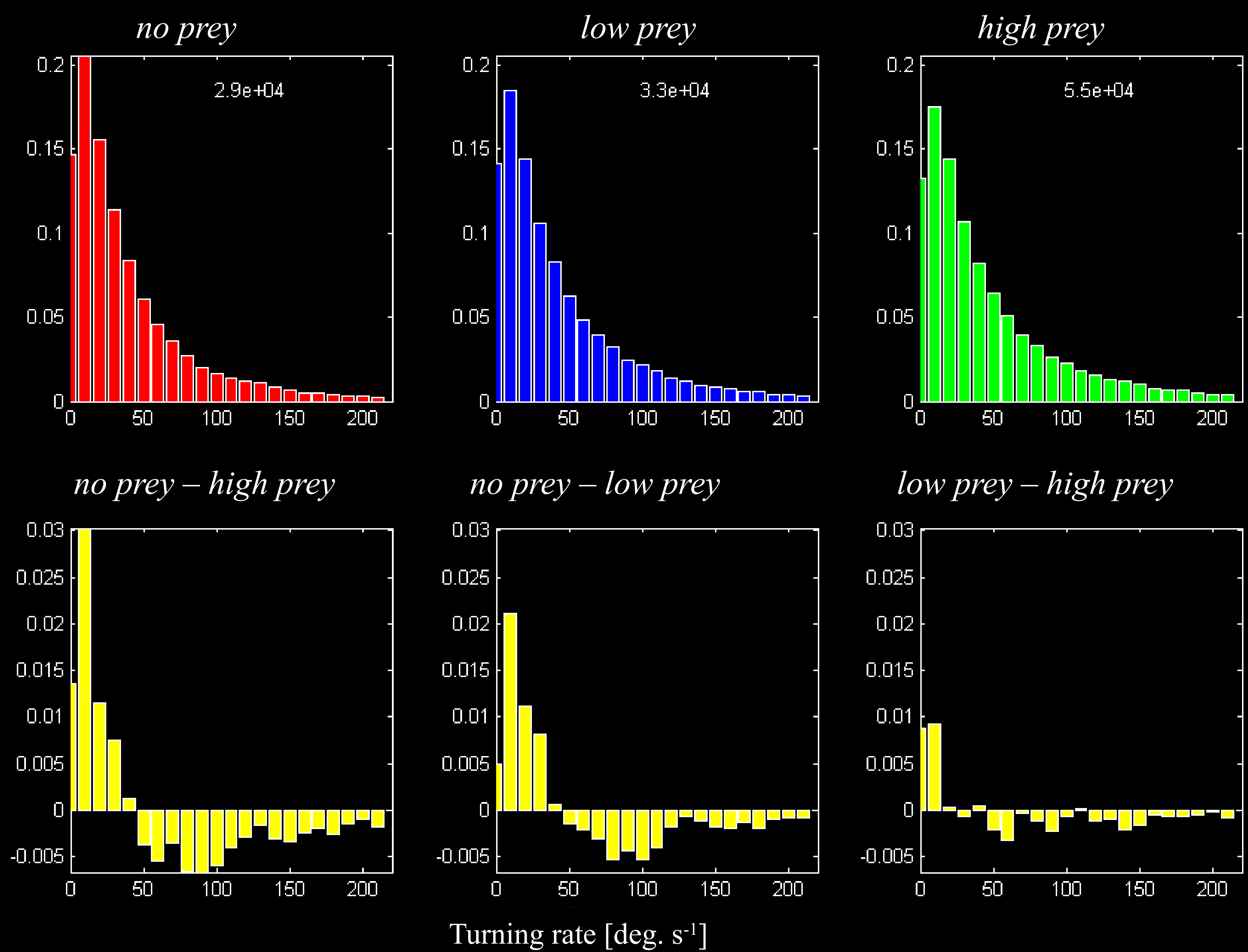
with prey

behavioral response

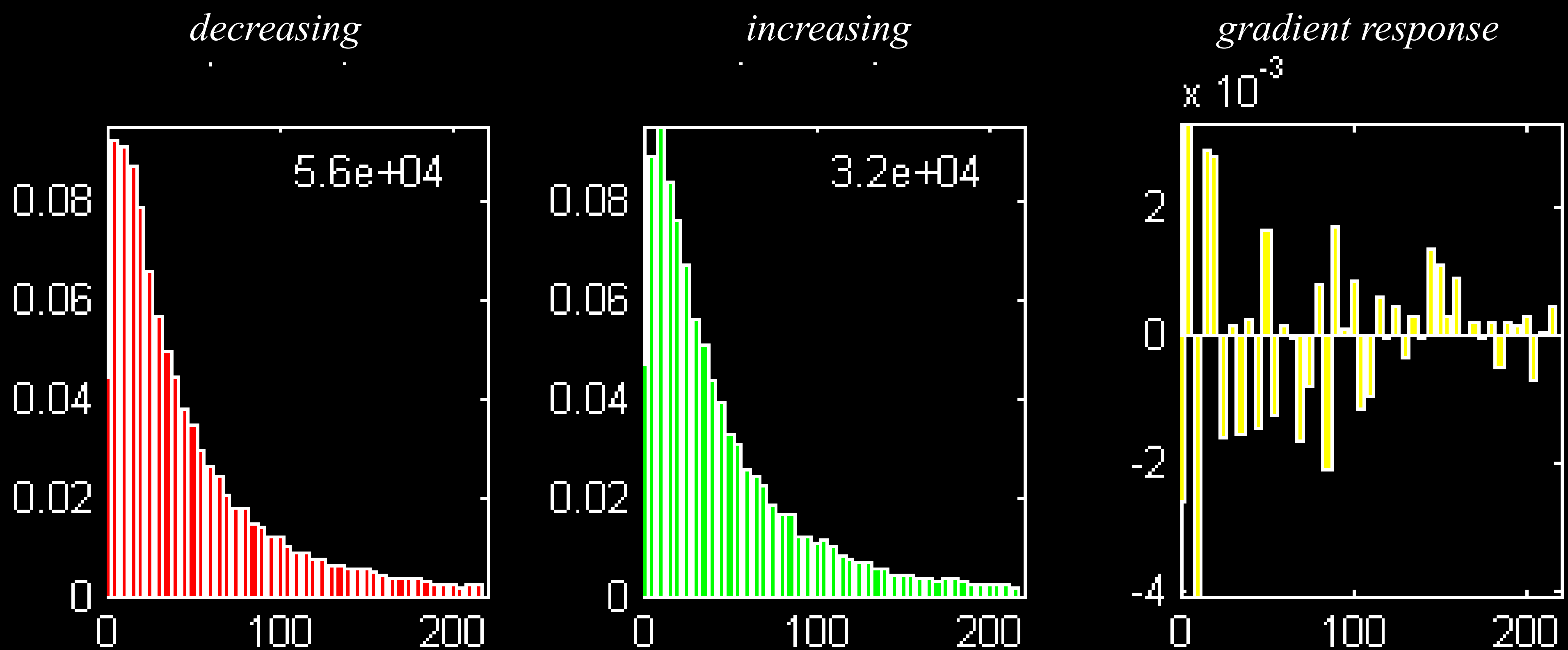
Population redistribution in prey gradients



Frequency of high turning rates increases with ambient prey concentration



Distributions of turning rates do not differ depending on gradient direction



Turning rate [deg. s^{-1}]