Predator prey interactions in the plankton: Linking microscopic behaviors to population dynamics

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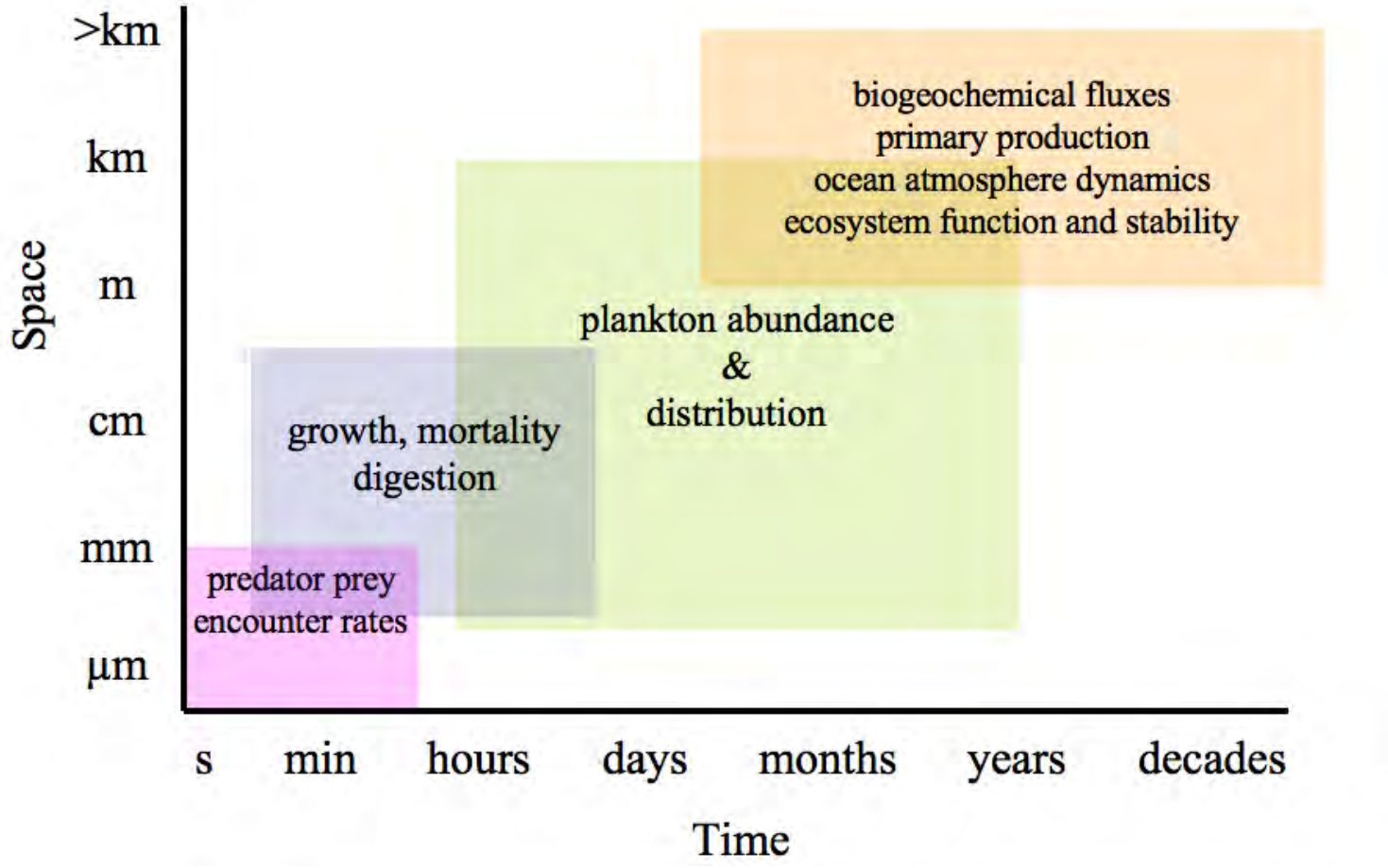
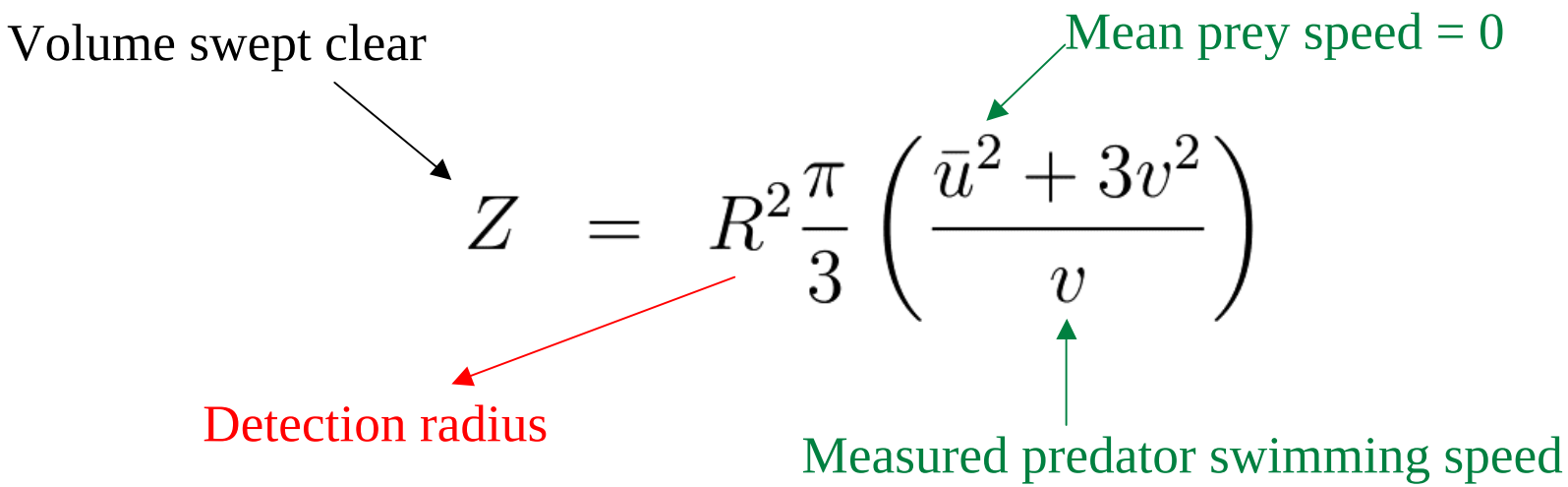
Deciphering small scale interactions to predict large scale ramifications



Predicting predator-prey encounter rates

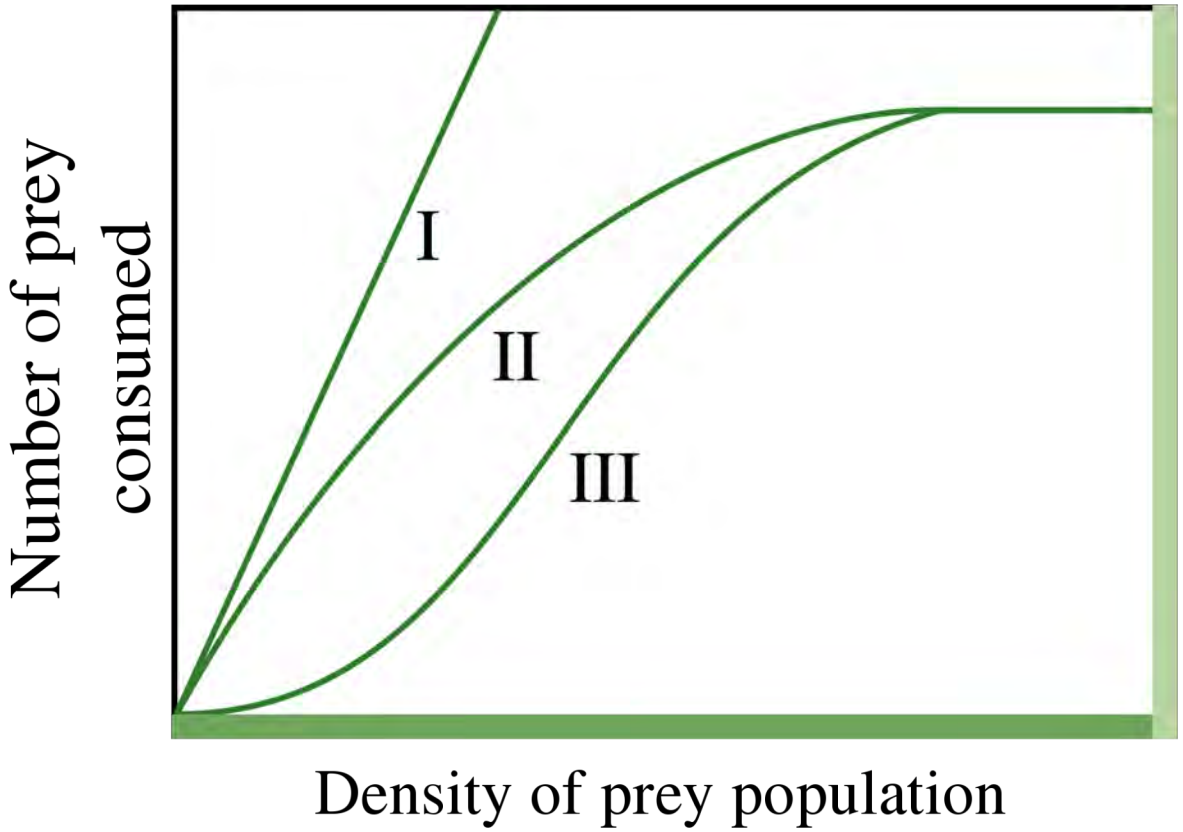
Gerritsen & Strickler 1977

> 500 citations, yet R has only been estimated once (Buskey, 1997)



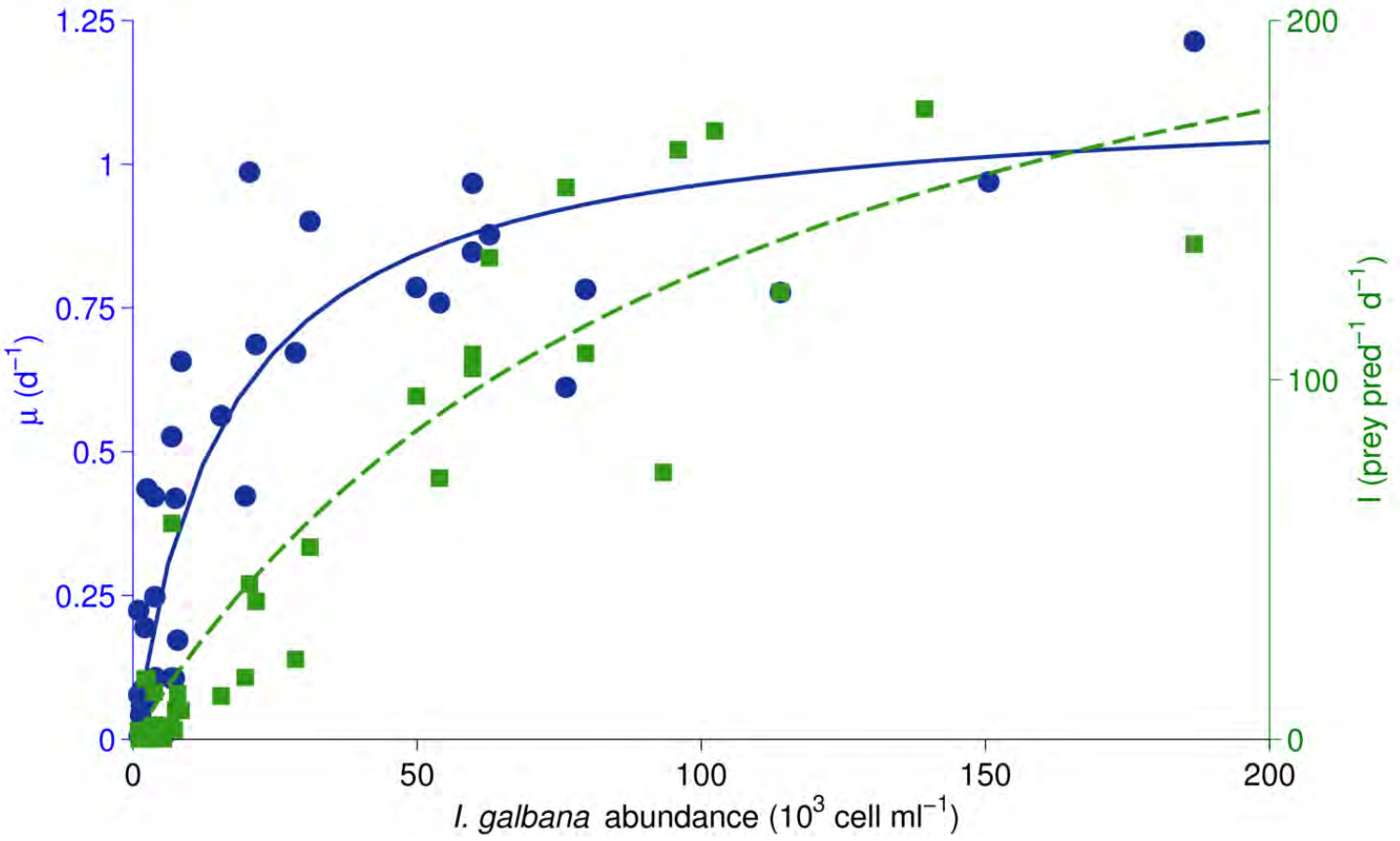
Consumer growth and grazing rate depend on resource concentration

Hollings functional response curves



Functional and numeric response curves of a het. protist feeding on single celled algae

Oxyrrhis marina (predator), *Isochrysis galbana* (prey)



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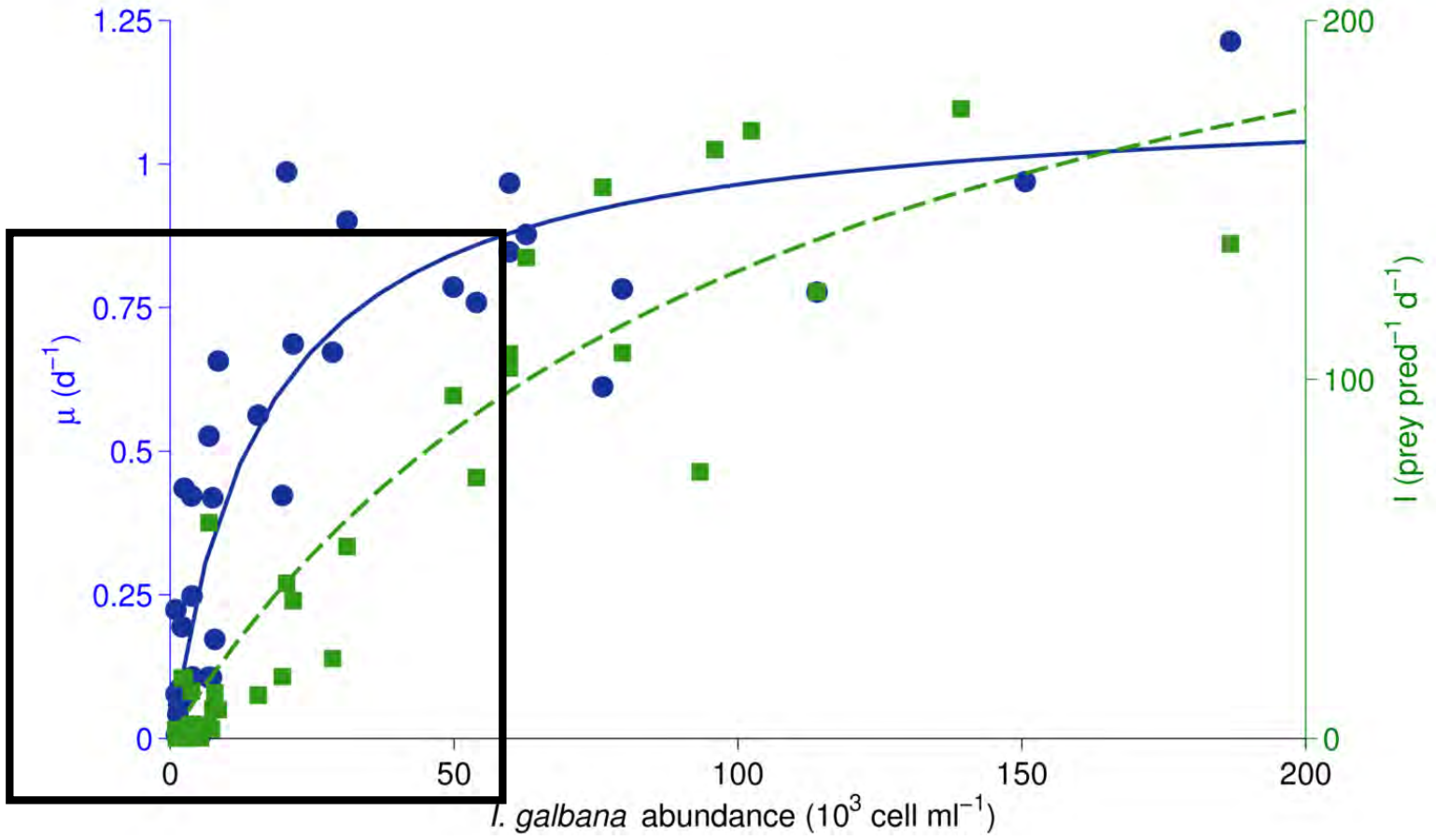
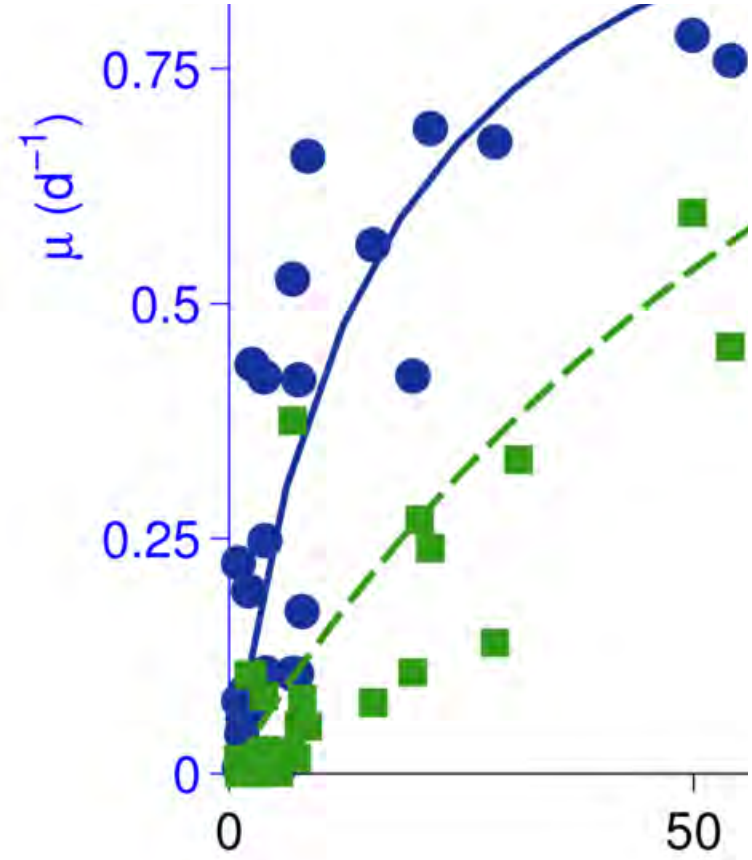


Small increases in resource encounter rate (= prey concentration) result in significant increases in consumer growth and grazing rates



Microscopic protists considered interception feeders

Direct interception radius is prey radius (Kiorboe 2008)

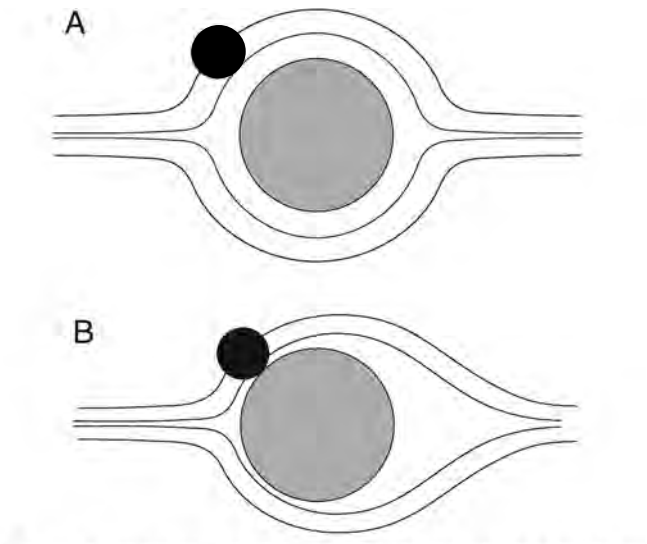
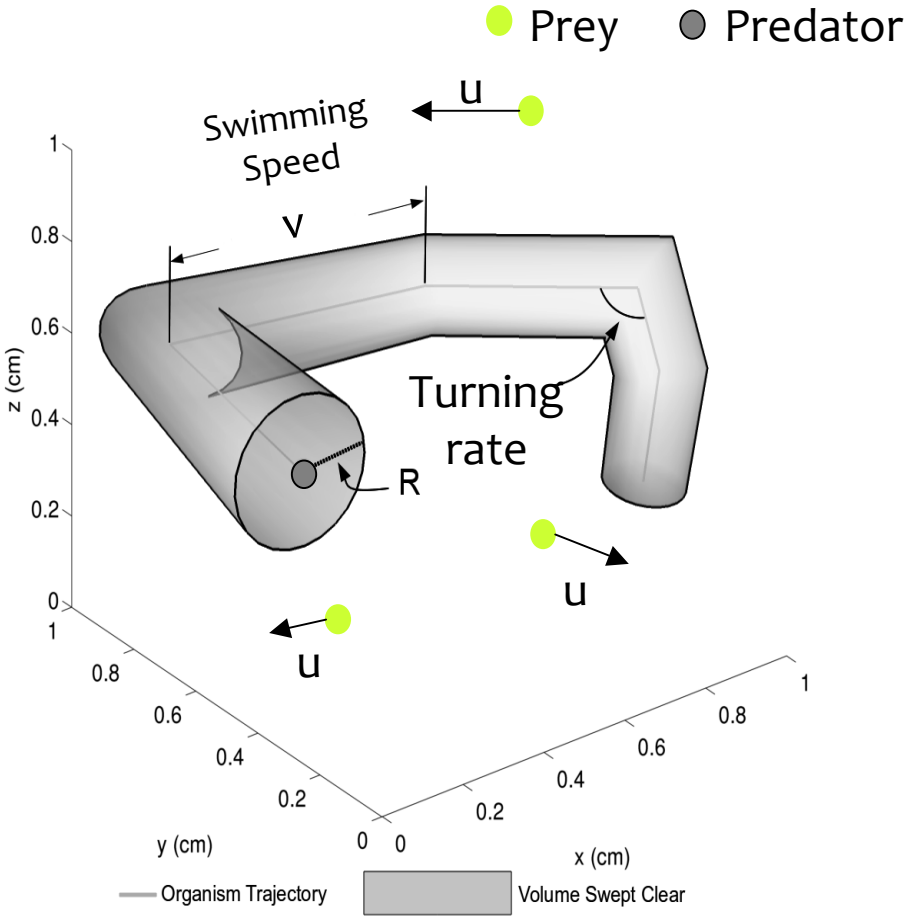


Figure from Humphries (2009) demonstrating streamlines around cell at low Reynolds numbers

Volume swept clear = swimming behaviors + range of detection radius



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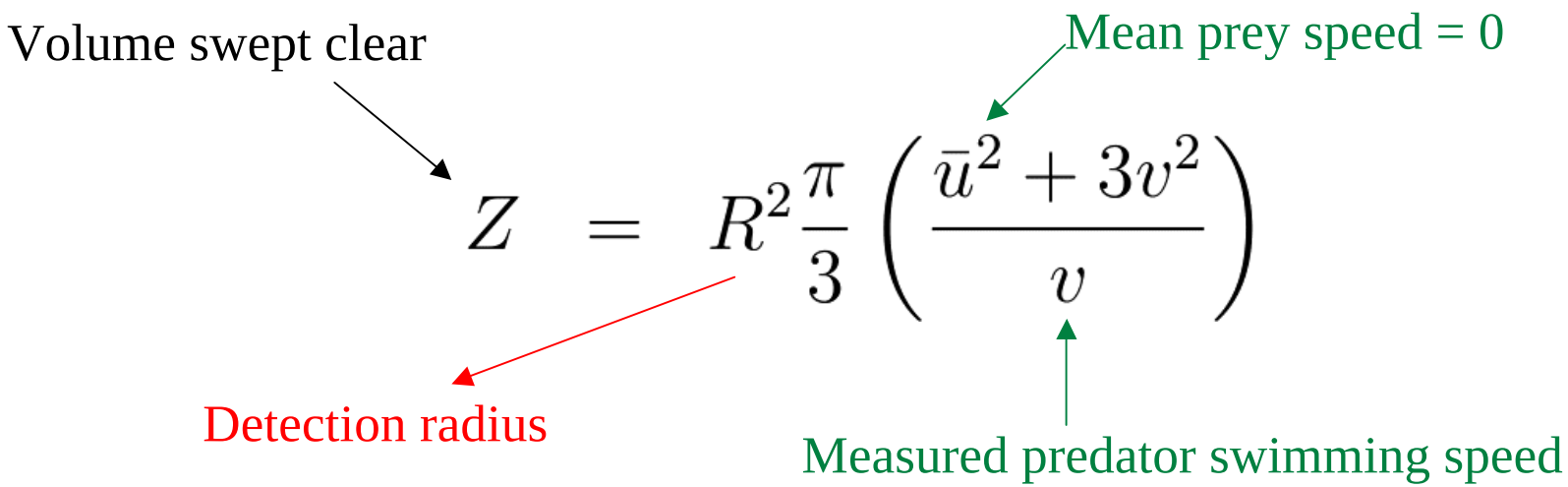

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Volume swept clear

Mean prey speed = 0

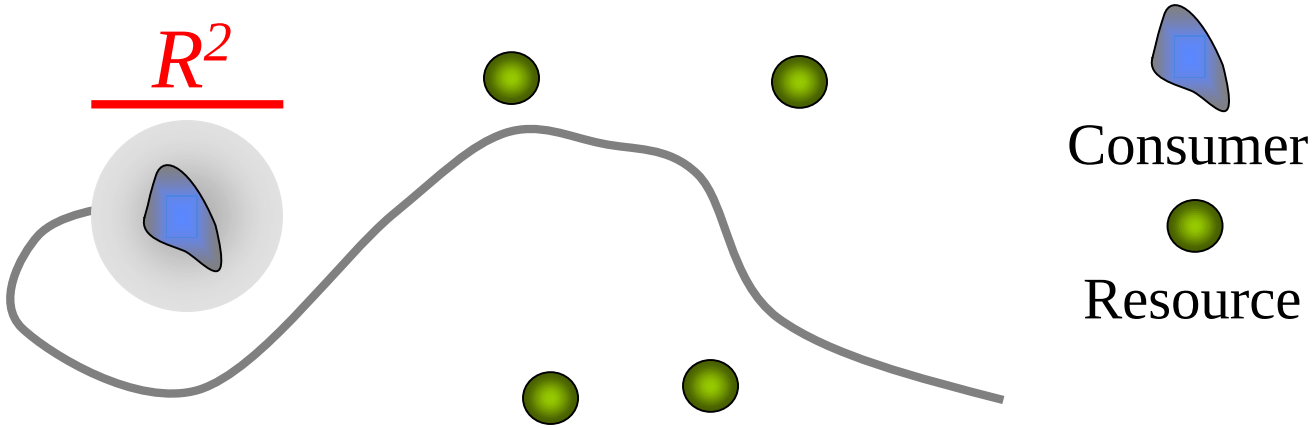
$$Z = R^2 \frac{\pi}{3} \left(\frac{\bar{u}^2 + 3v^2}{v} \right)$$

Detection radius

Measured predator swimming speed

Given swimming behaviors and ingestion rates,
the only free parameter is the detection radius R

Increased detection radius results in squared increase in predicted encounter rate



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Solve for R

Measured predator swimming speed

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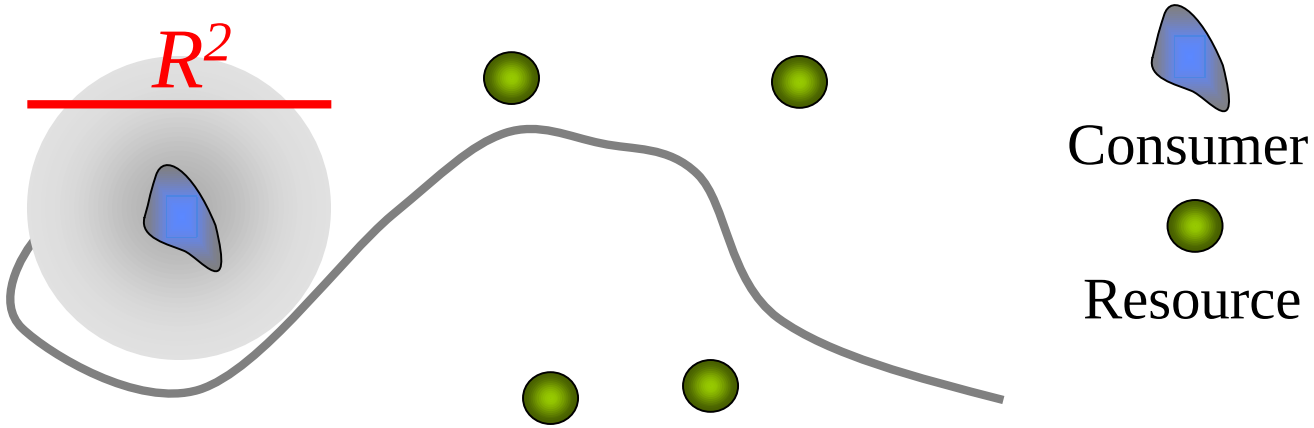

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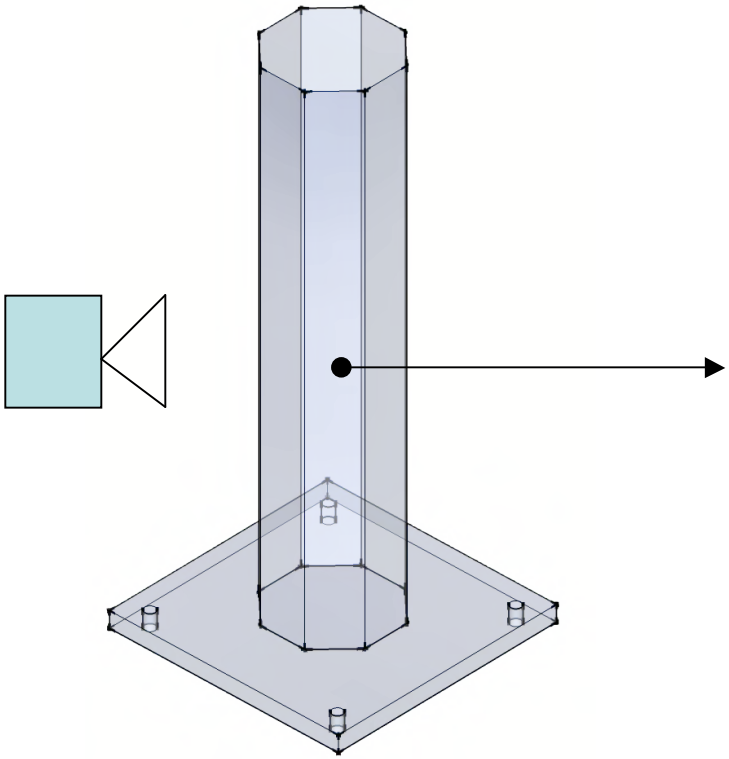
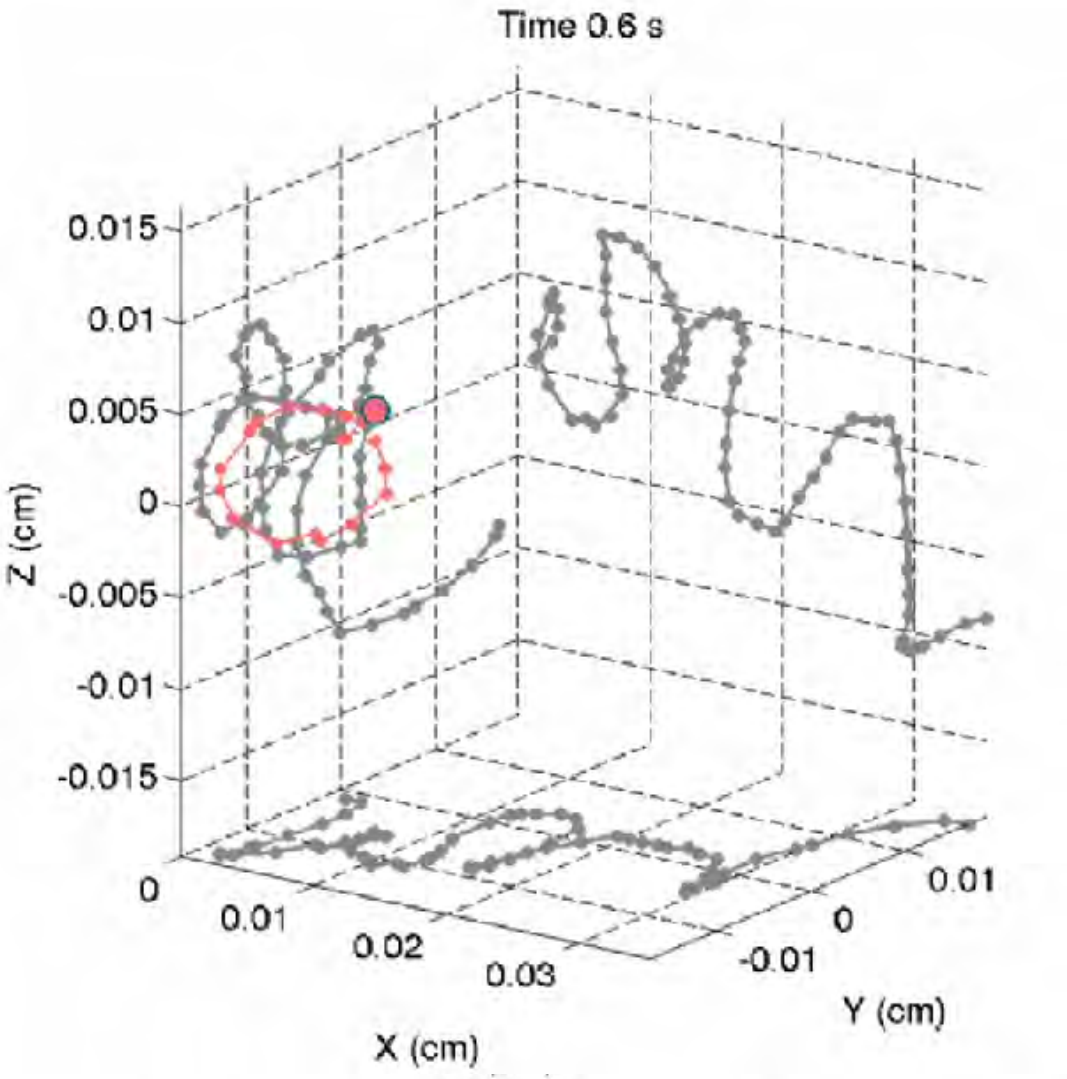
Solve for R

Measured predator swimming speed

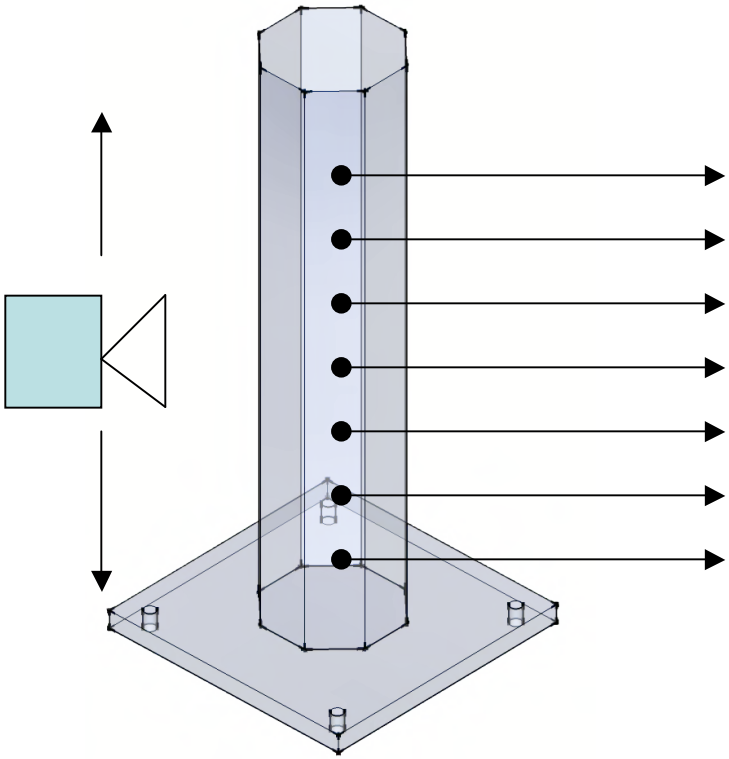
Simultaneously quantifying *microscopic movement* behaviors and macroscopic population distributions

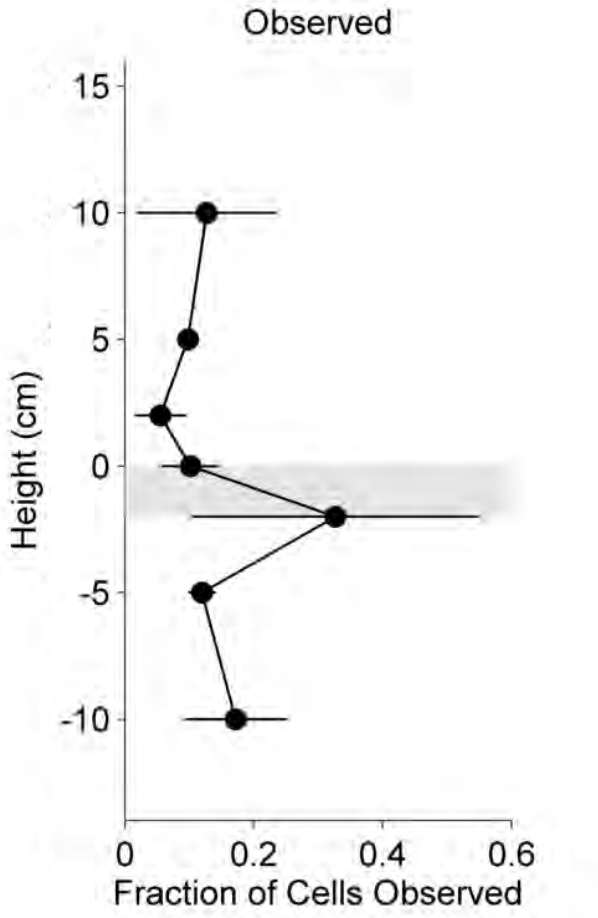




Menden-Deuer & Grünbaum, 2006

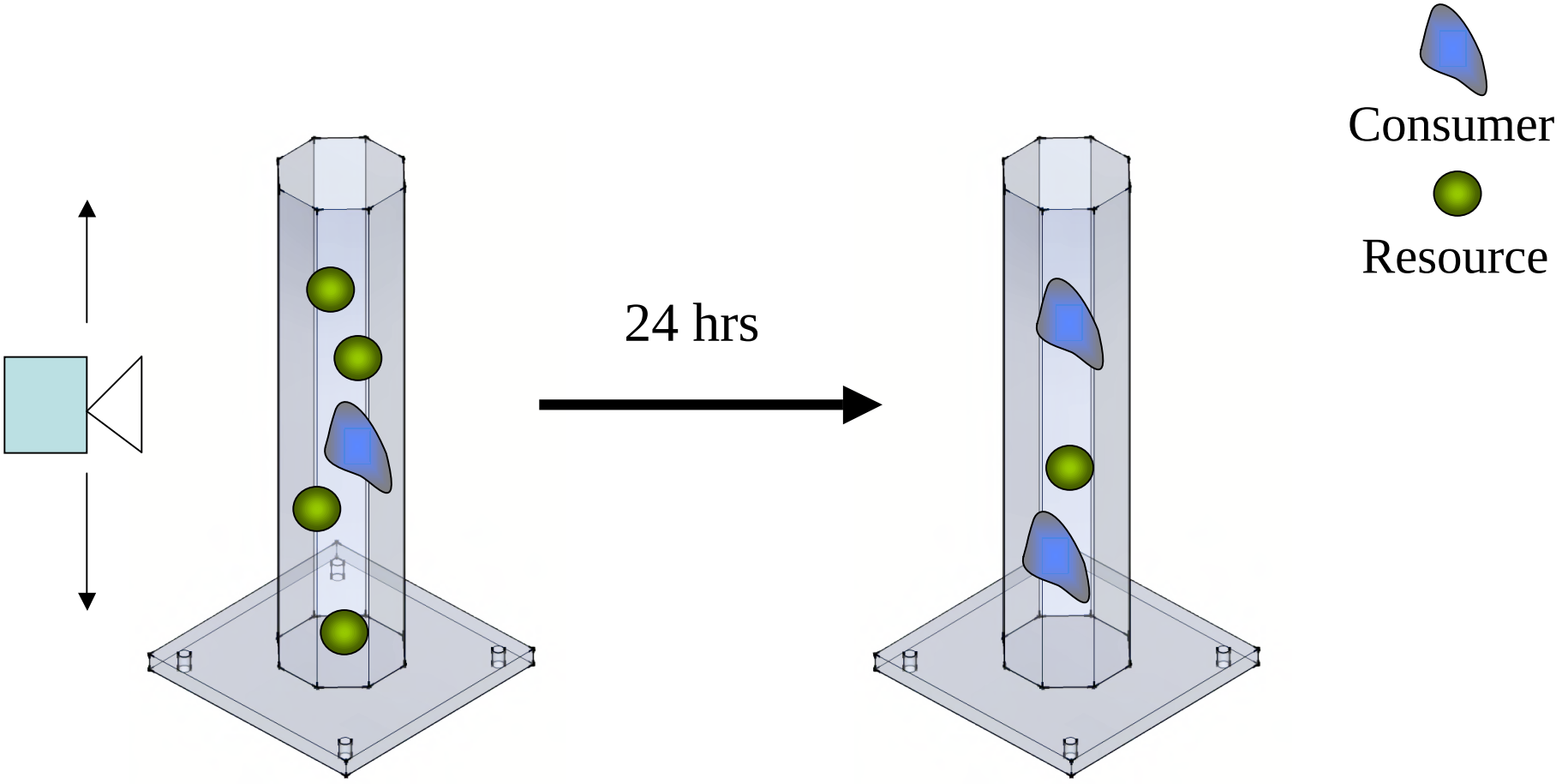
Simultaneously quantifying microscopic movement behaviors and macroscopic *population distributions*





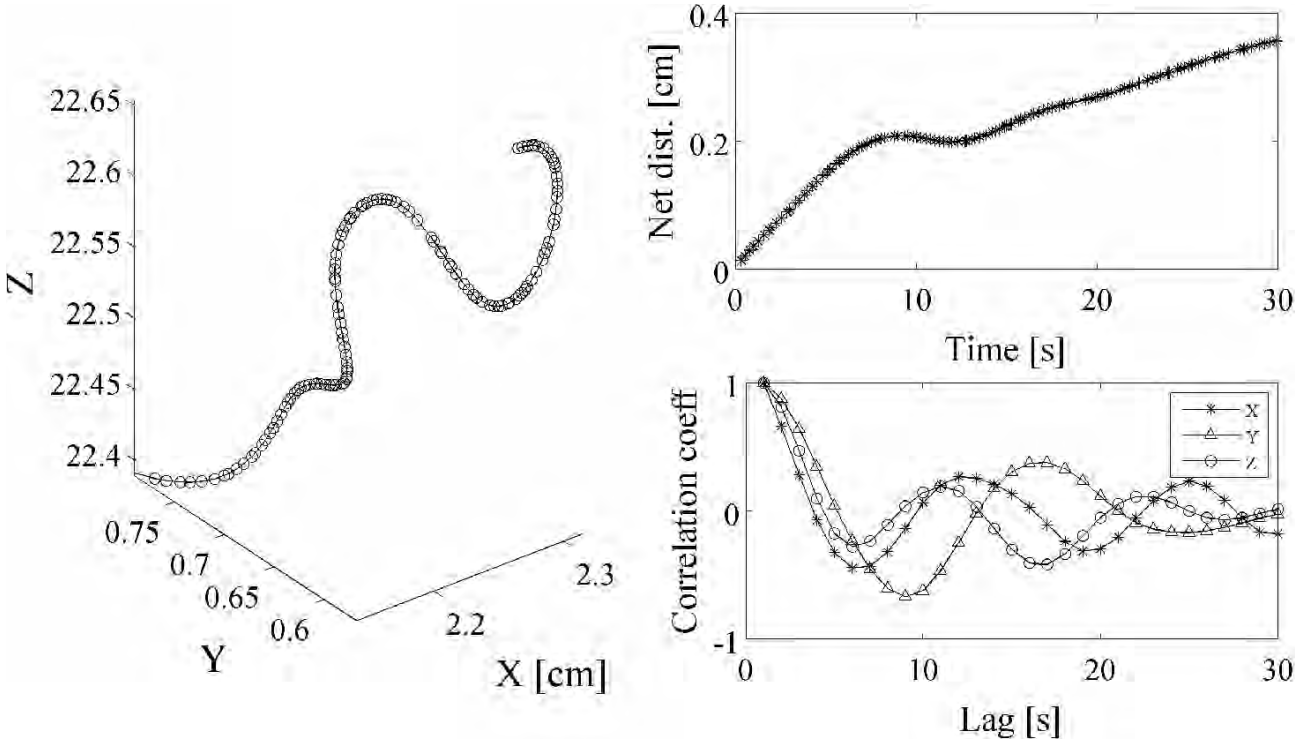
Menden-Deuer & Grünbaum, 2006

Simultaneously quantifying microscopic movements behaviors and macroscopic population distributions and *ingestion rate*

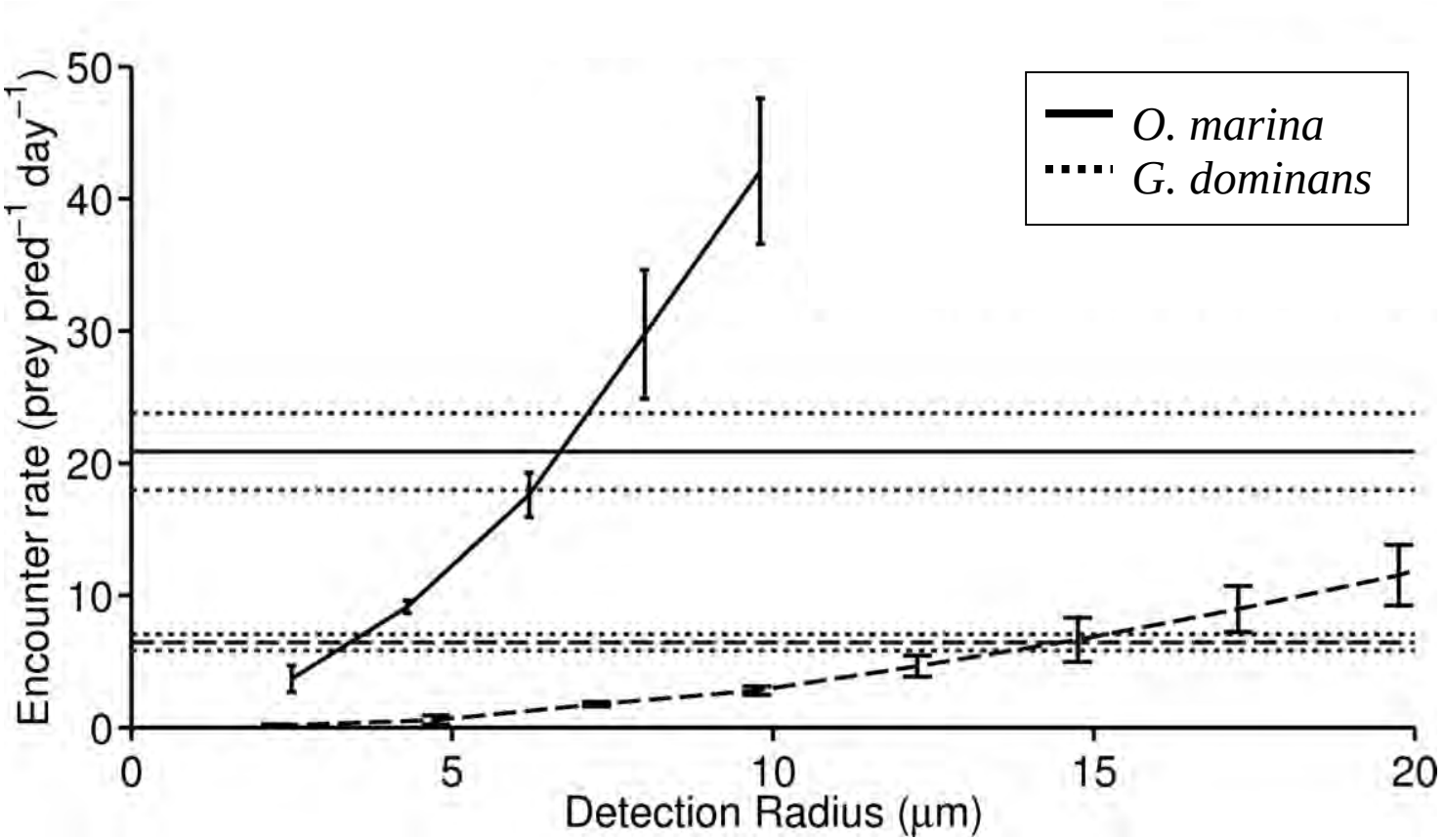


Predict predator-prey encounter rate based on measured swimming behaviors

- individual based
- biased random walk model
- empirical movement statistics of 100s to 1000s of individuals

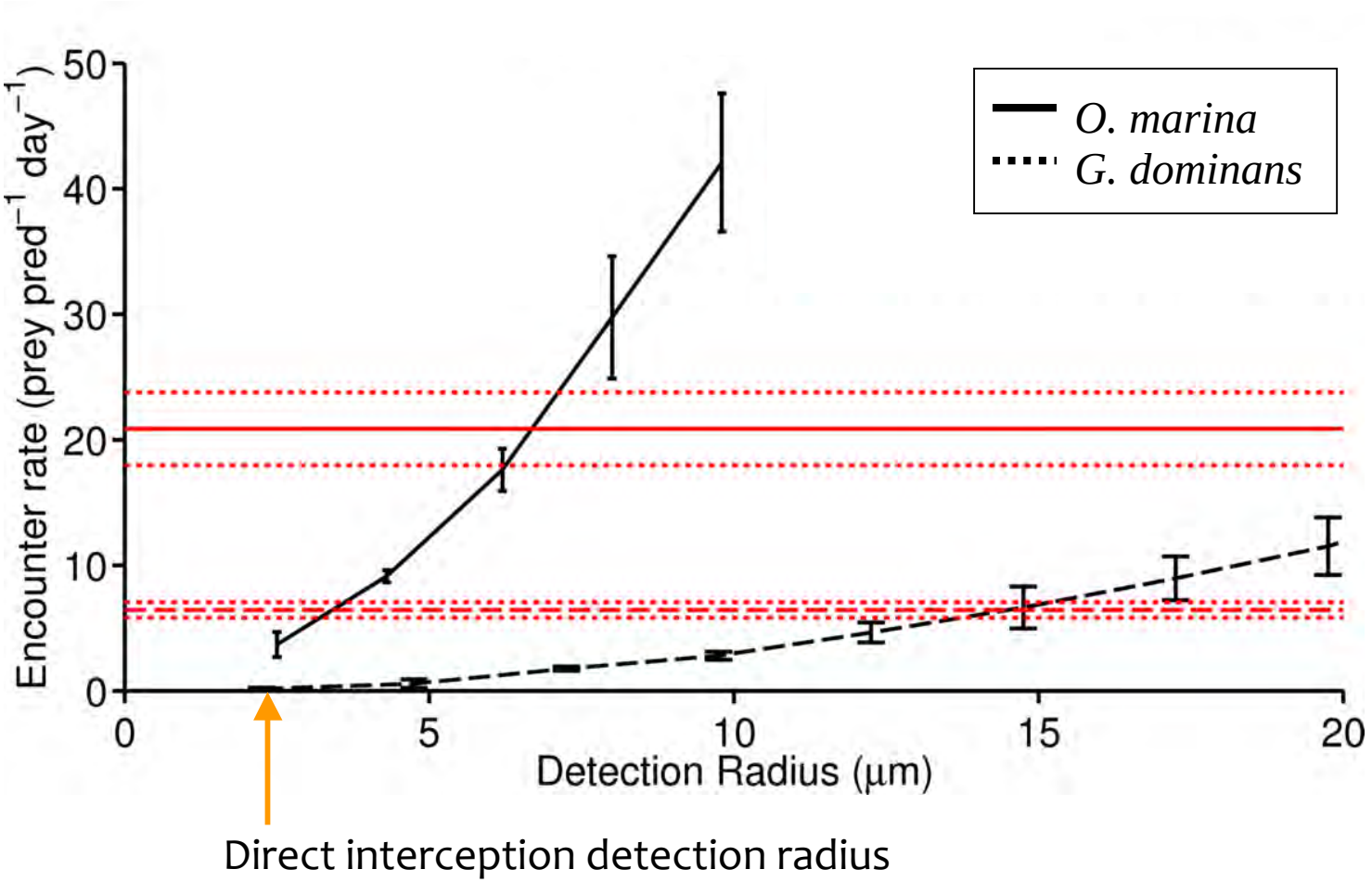


Model encounter rate based on assumed detection radii



Overlay realized ingestion rate = minimum encounter rate

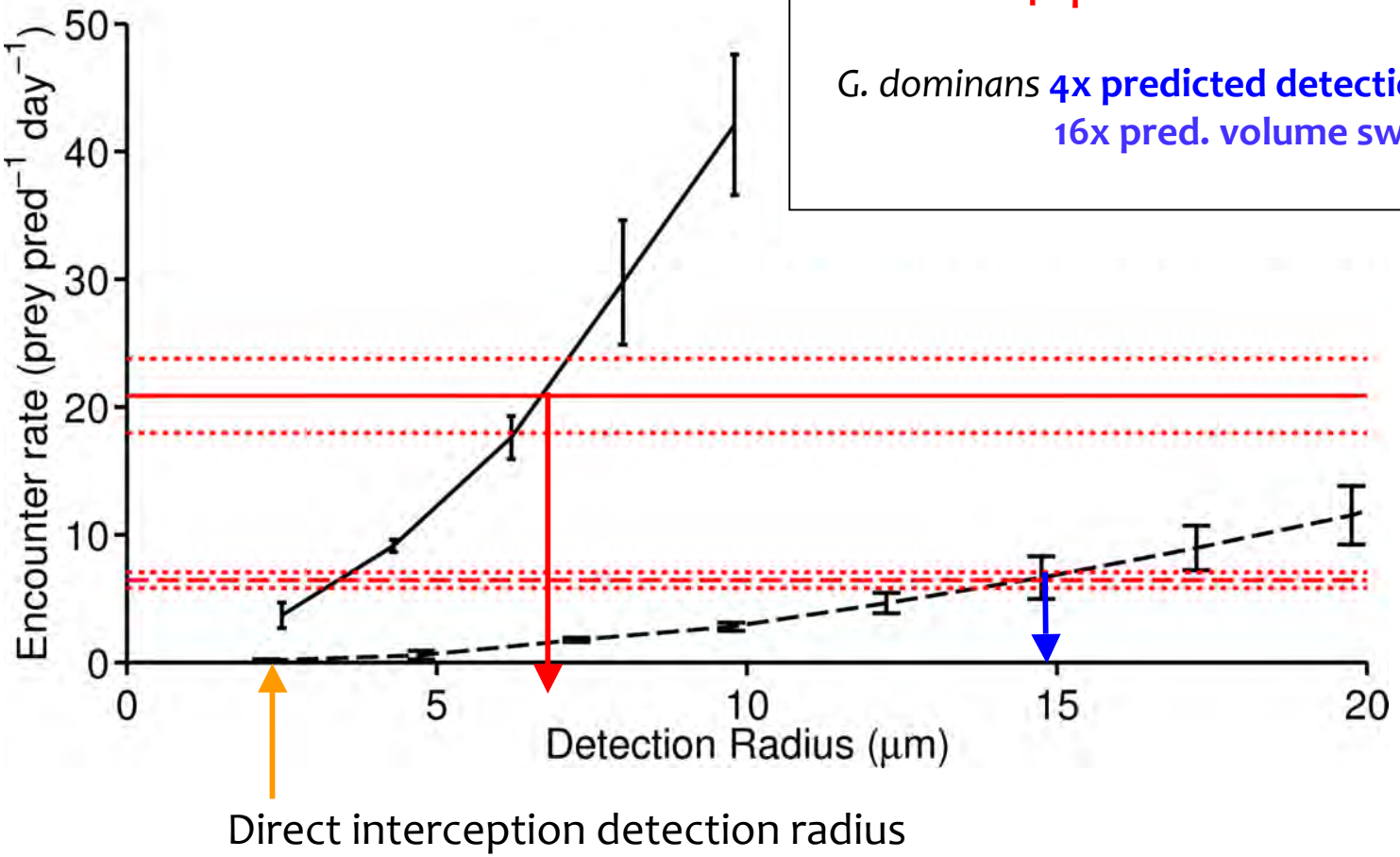
- triplicate, independent measurements of ingestion and movement behaviors



Detection radii >> cell radius - suggests remote chemo- or mechanical detection

O. marina **2x predicted detection radius**
4x predicted volume swept clear

G. dominans **4x predicted detection radius**
16x pred. volume swept clear

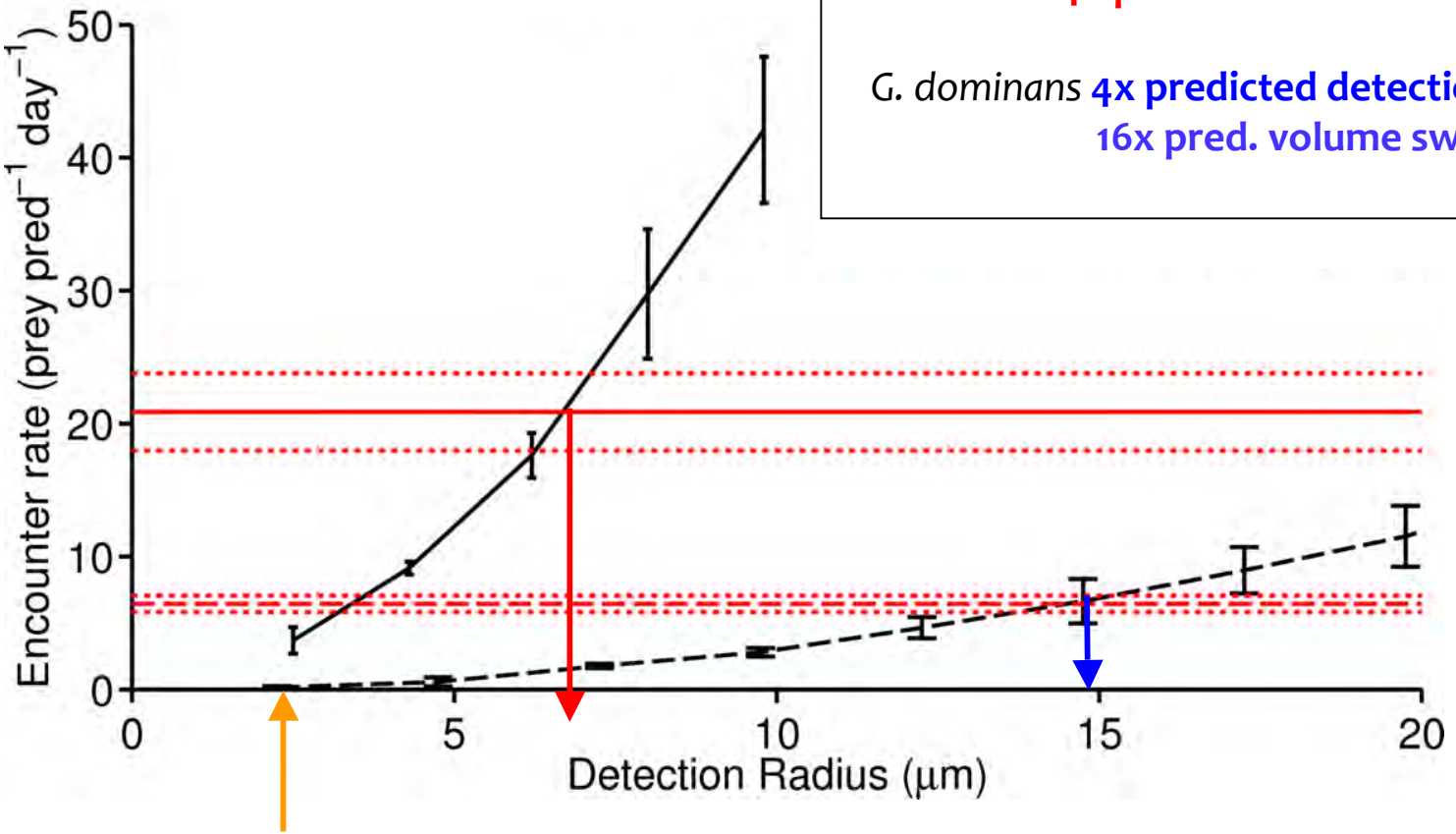


Predators encounter vastly more cells than expected

- estimate is minimum, assumes all cells encountered eaten

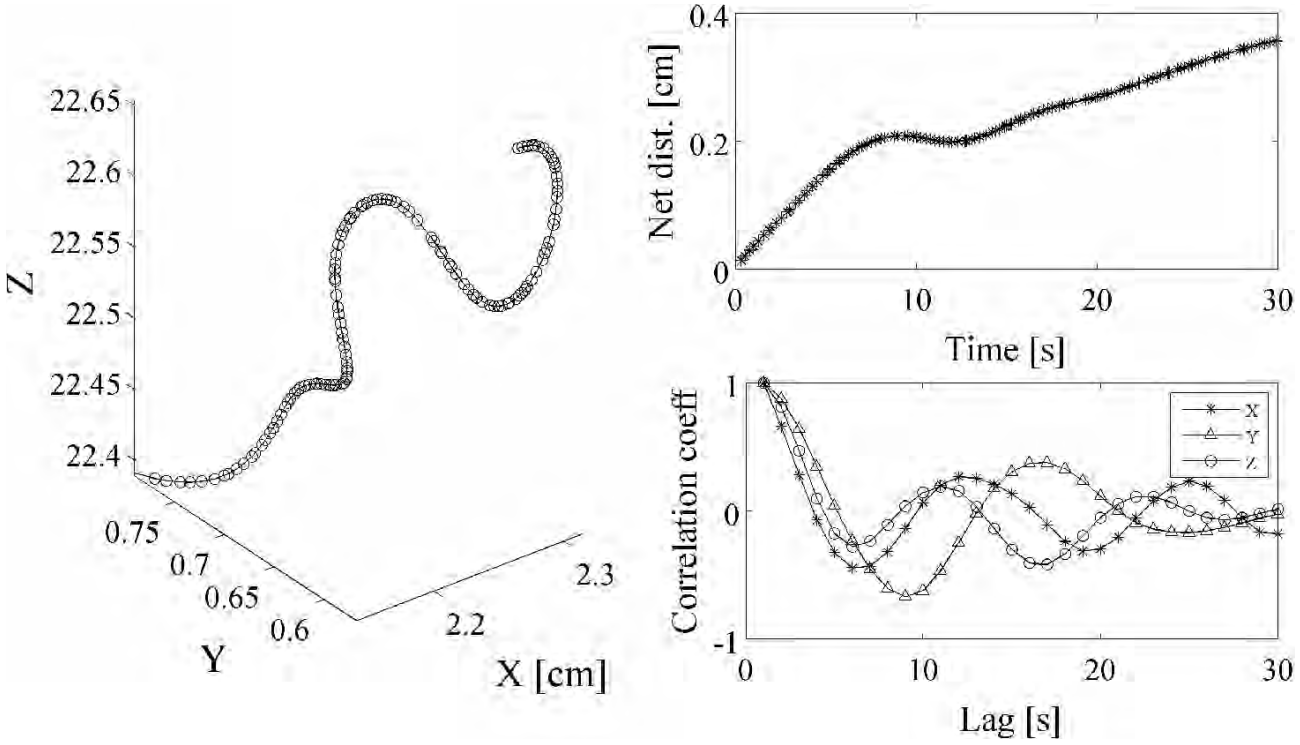
O. marina **2x predicted detection radius**
4x predicted volume swept clear

G. dominans **4x predicted detection radius**
16x pred. volume swept clear



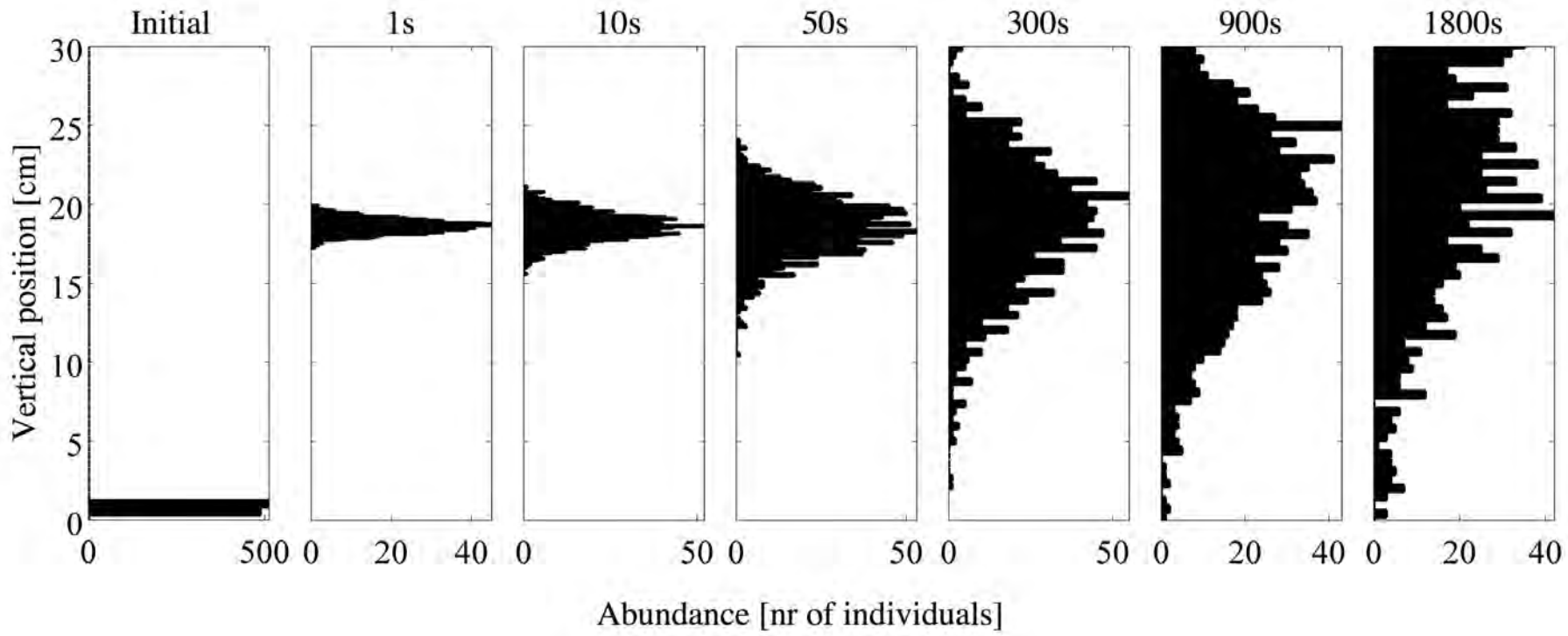
Predict predator vertical distributions based on measured swimming behaviors

- individual based
- biased random walk model
- empirical movement statistics of 100s to 1000s of individuals



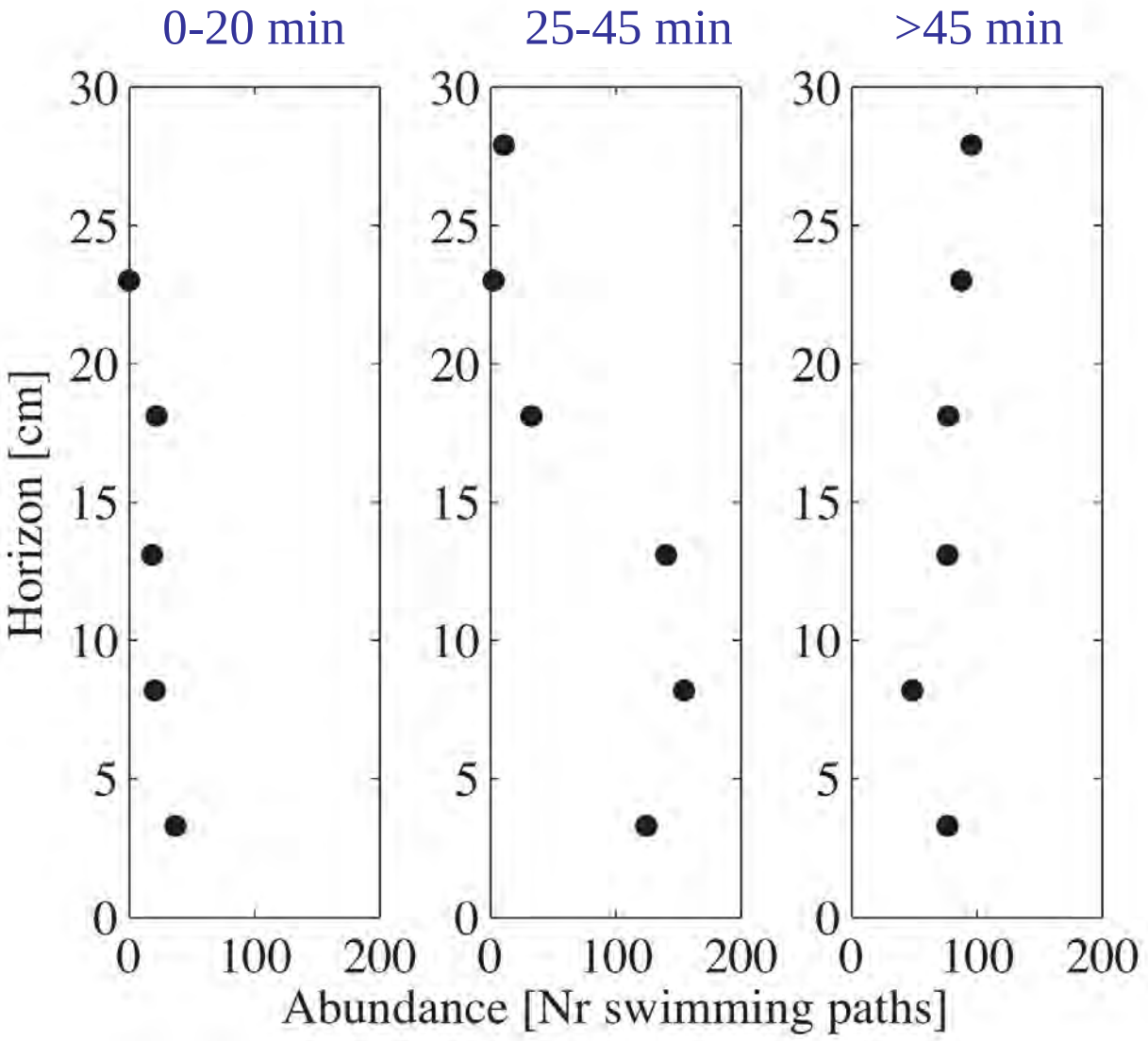
Predicting vertical distributions of predator population using range of assumed correlation times

- modeled assumed correlation time from <1s to 30 min
- predicted vertical distribution after 30 minute model time



Menden-Deuer, 2010

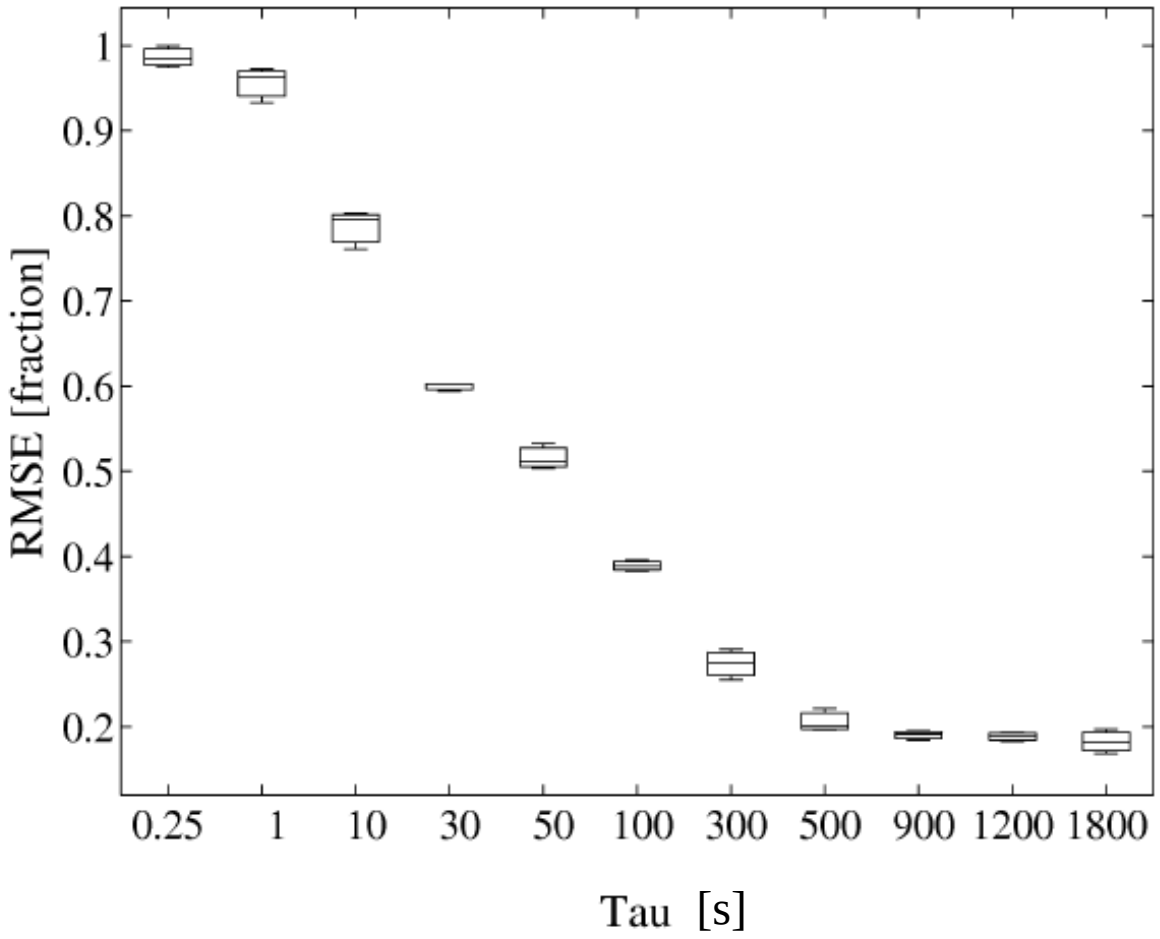
Empirically quantifying shifts in vertical distribution over time



Menden-Deuer, 2010

Correlation time τ estimated >8 minutes!

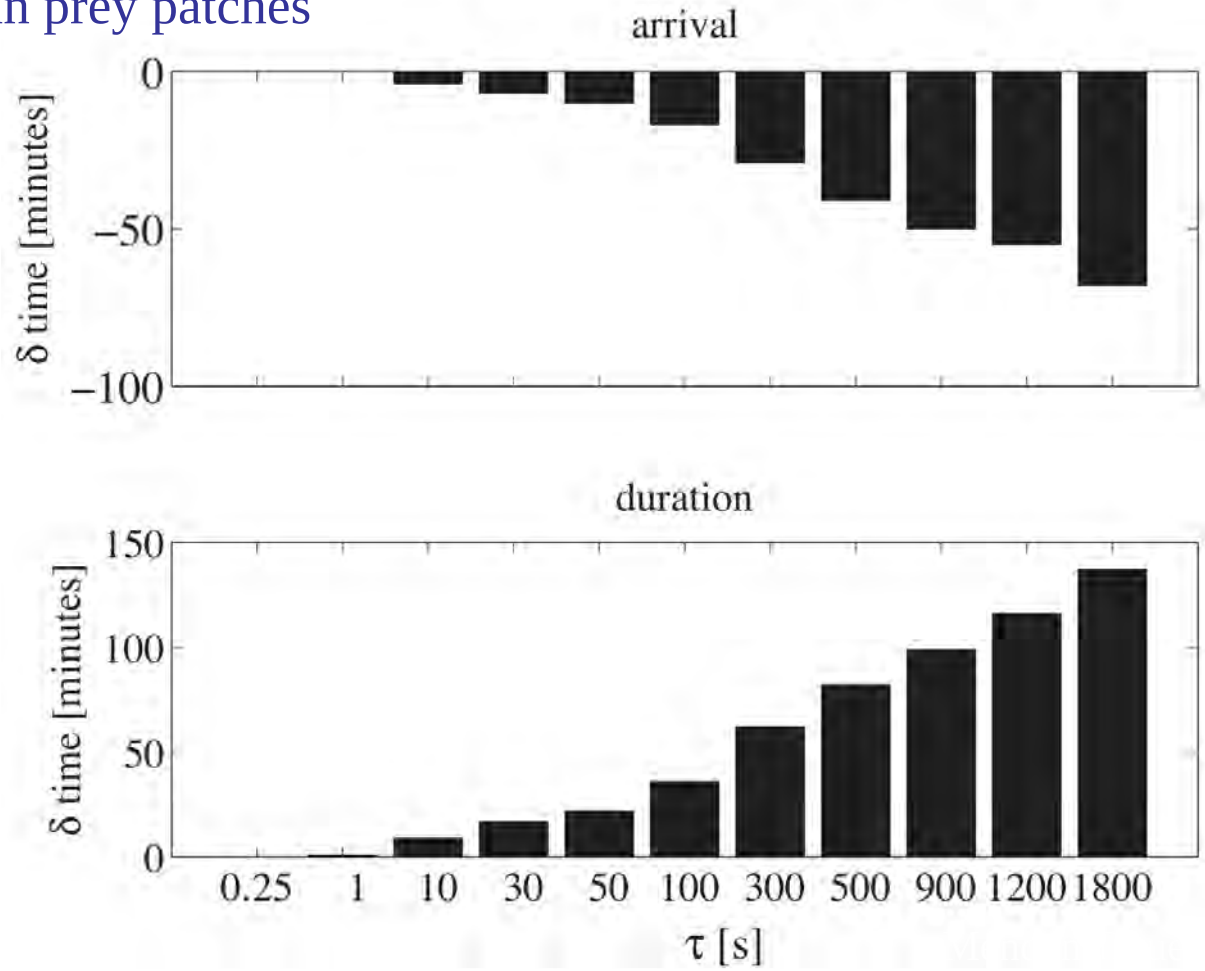
- root mean square error estimates difference in empirical and predicted distributions
- model predictions indistinguishable from empirical data at τ > 500 seconds



Menden-Deuer, 2010

High correlation times suggest high dispersal rates & increase predator range and habitat utilization

-earlier arrival in remote prey patches
-longer residence time in prey patches

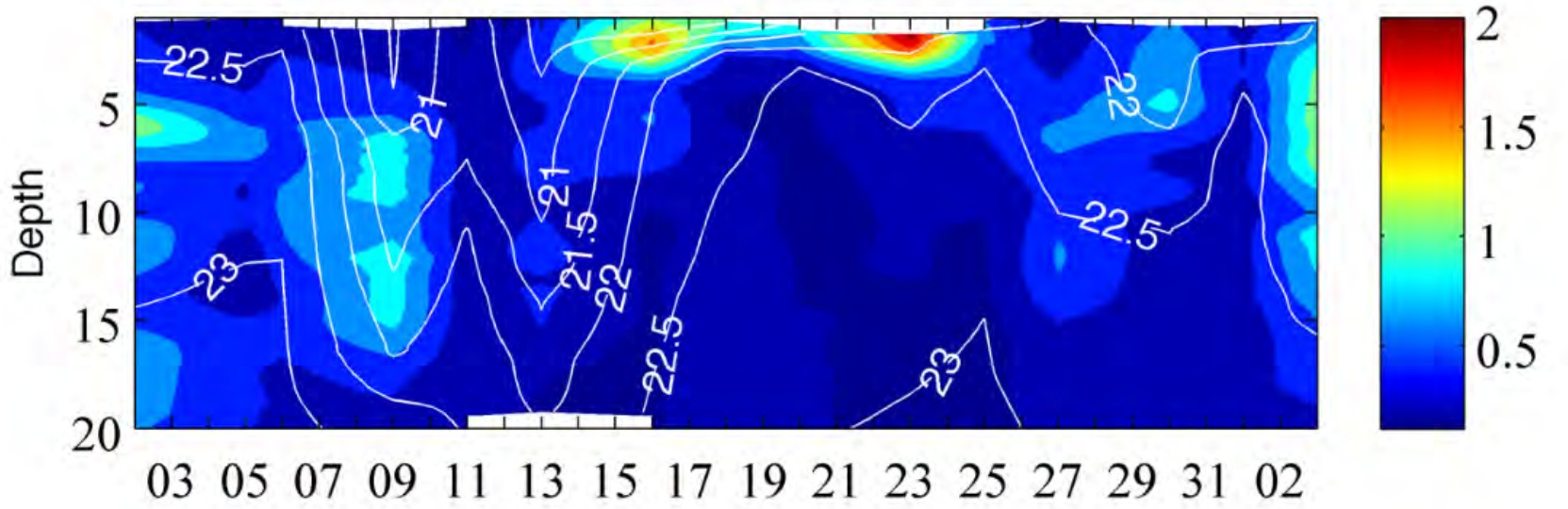


Menden-Deuer, 2010

Predict time and space scales of phytoplankton patch exploitation

- Phytoplankton patches spatially and temporally restricted
- Predators with higher dispersal rates have higher encounter rates with favorable and unfavorable events (e.g. carnivores, prey)

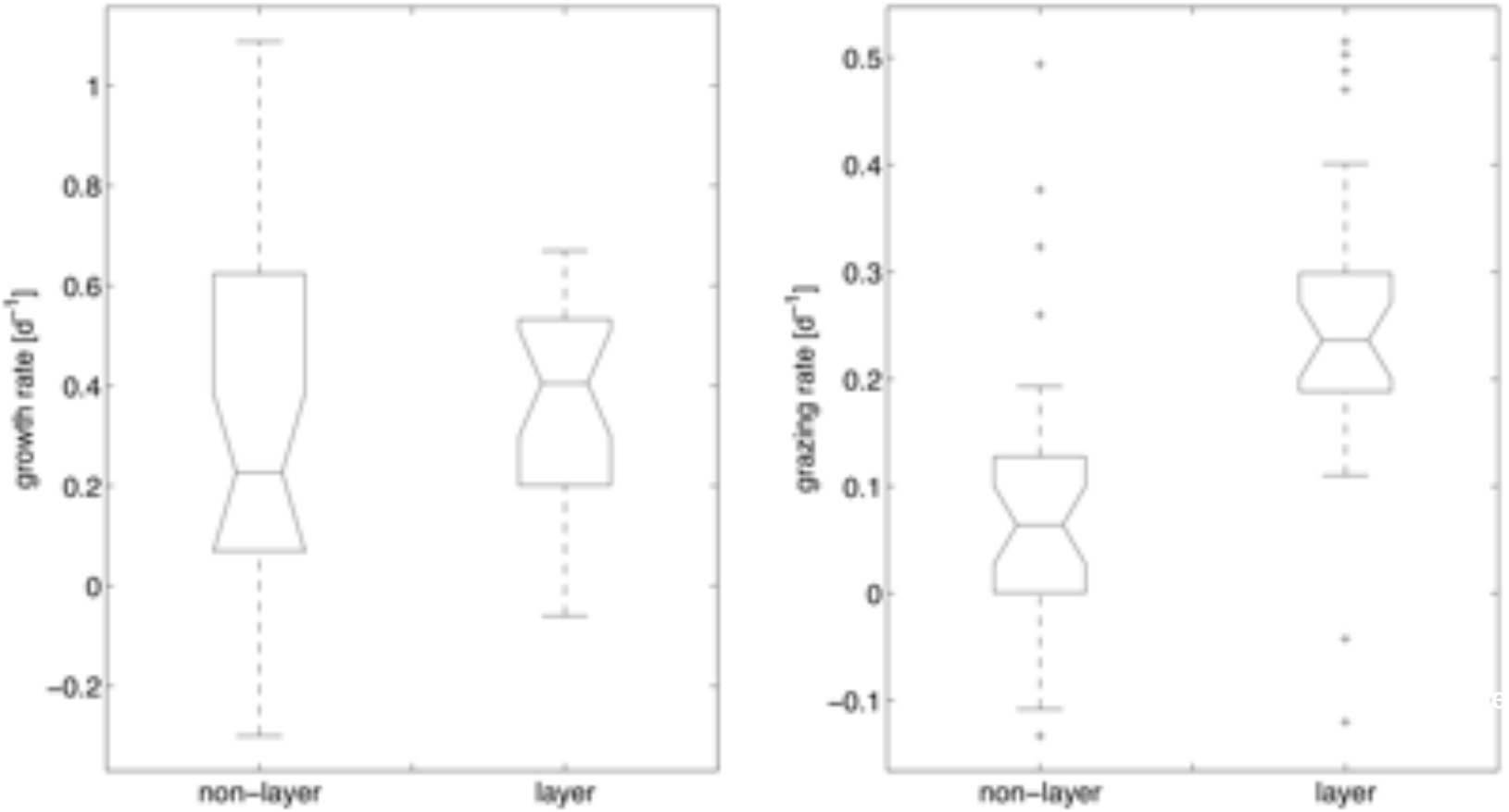
Chl a fluorescence [volts], East Sound, Orcas Island, Washington



Menden-Deuer et al. 2010

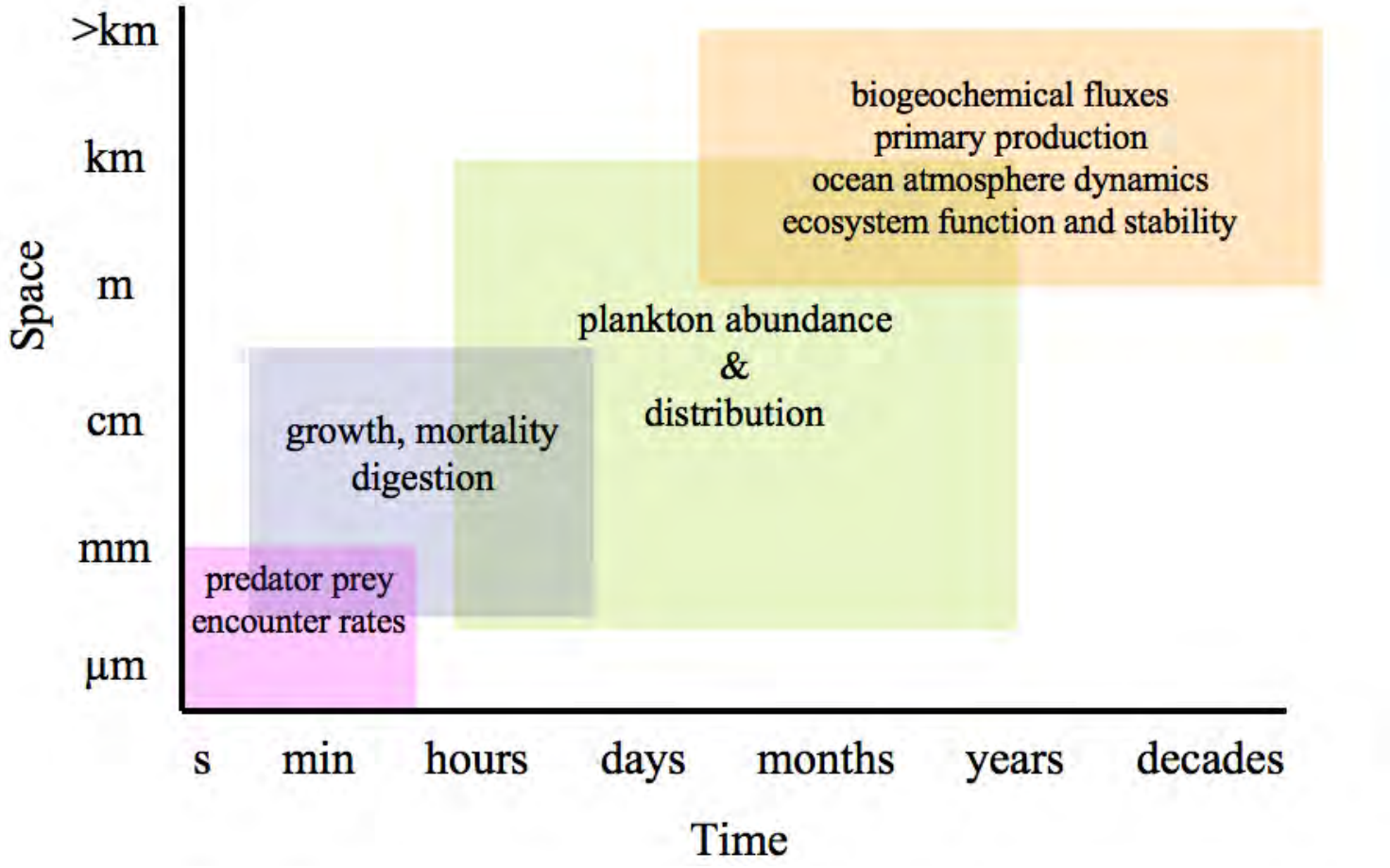
Het. protist grazing rates significantly > within patches

- 11 dilution experiments in- and outside of patches, not paired design
- measured grazing was independent from initial prey concentration



Menden-Deuer & Fredrickson 2010

Conclusions & Implications



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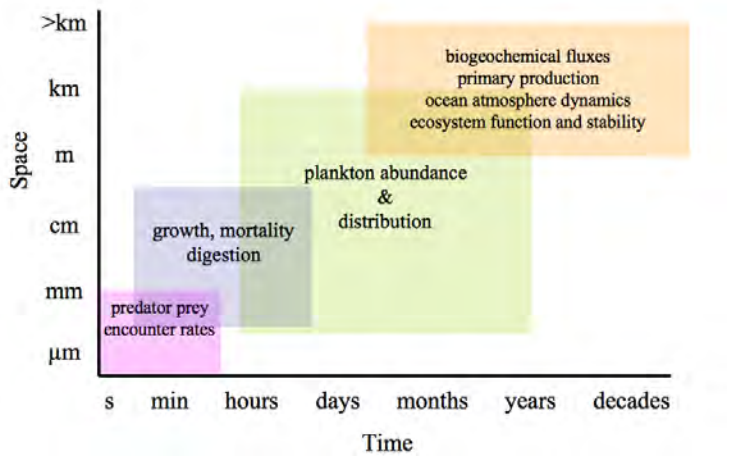


- Individual behaviors quantify cellular responses to complex, biotic and abiotic stimuli
  - – specifying general patterns from 'dose response' relationships
- Detection radius was sign. >> than direct interception
  - – volume swept clear and cells encountered were >> greater than expected
  - – remote detection was necessary to support observed ingestion rates

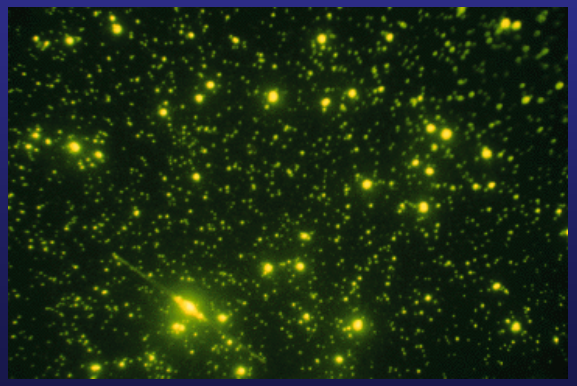
  Chemo- (Buskey 1997; Seymour et al, 2010) & Mechanoreception (Jakobsen 2001)
- Predators encountered many more cells than predicted
  - – implies predators are much more selective
- Predator dispersal rates >> than expected
  - – predators encounter and impact greater portion of their pelagic habitat

Consumers detection radii are important and limited - irrespective of body size

10^{4} m

10^{0} m

10^{-4} m



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Muchas Gracias