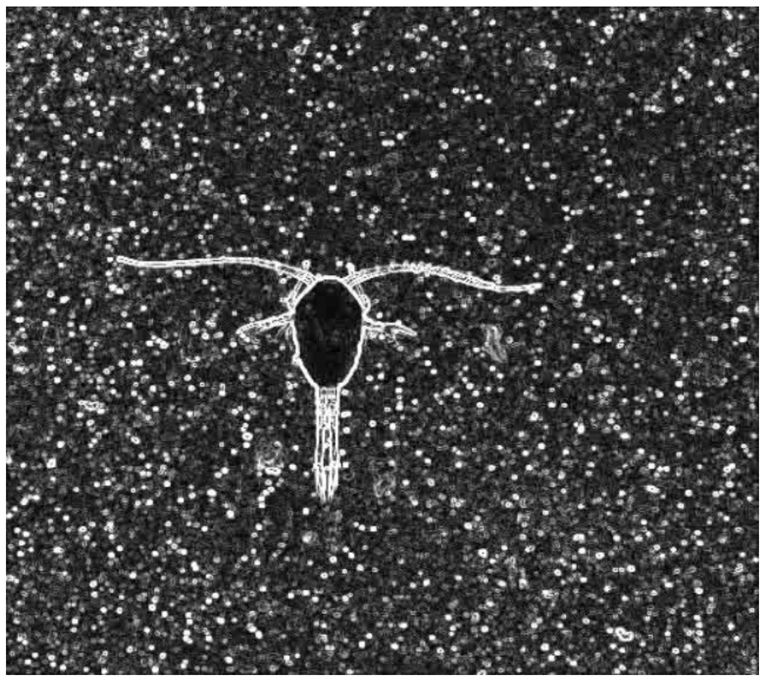
Ocean Life
Centre for Ocean Life
VKR Centre of Excellence

The functional response in suspension feeding copepods

Mechanistic underpinning and implications



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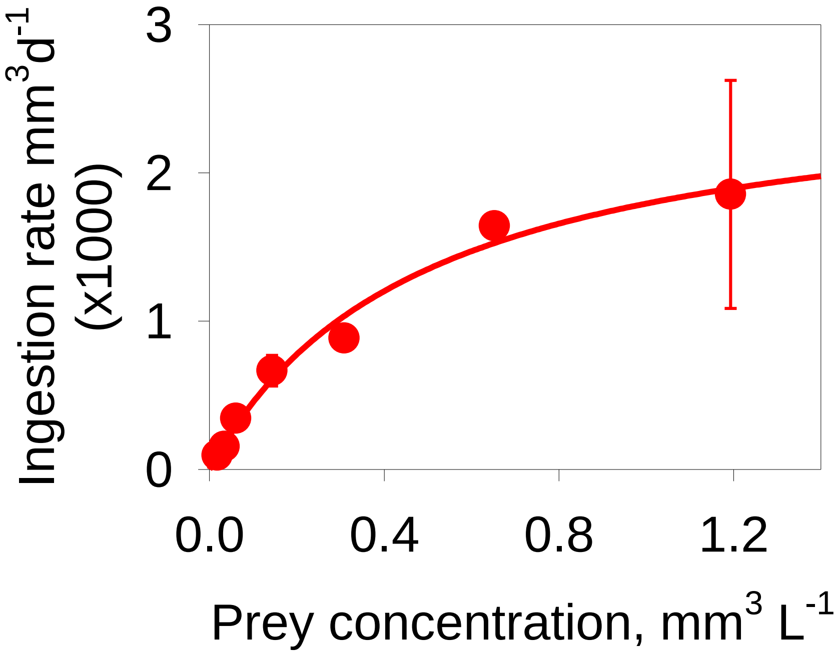
Centre for Ocean Life, DTU Aqua

What is the functional response?

The change in feeding rate with prey concentration

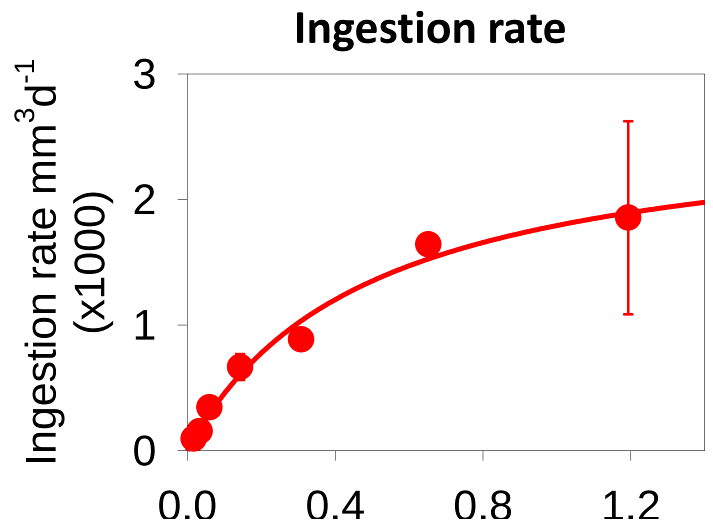


Oithona davisae

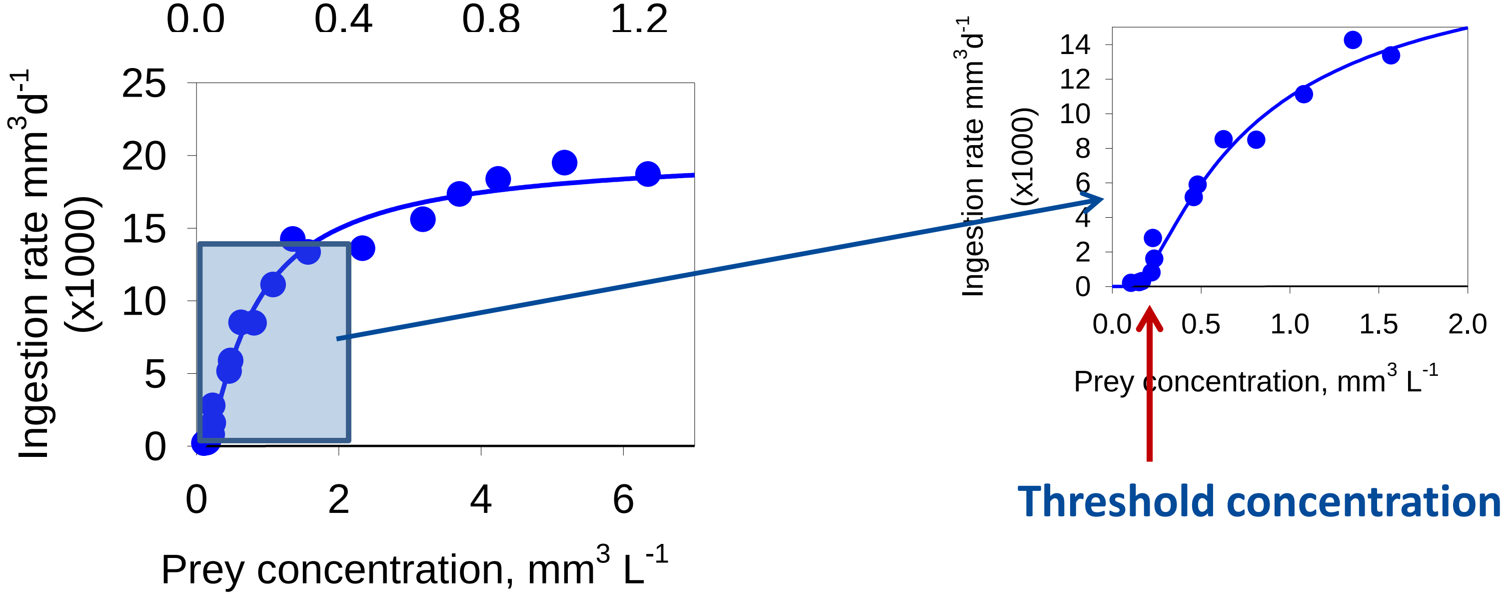
The functional response

Two types of responses

Type II



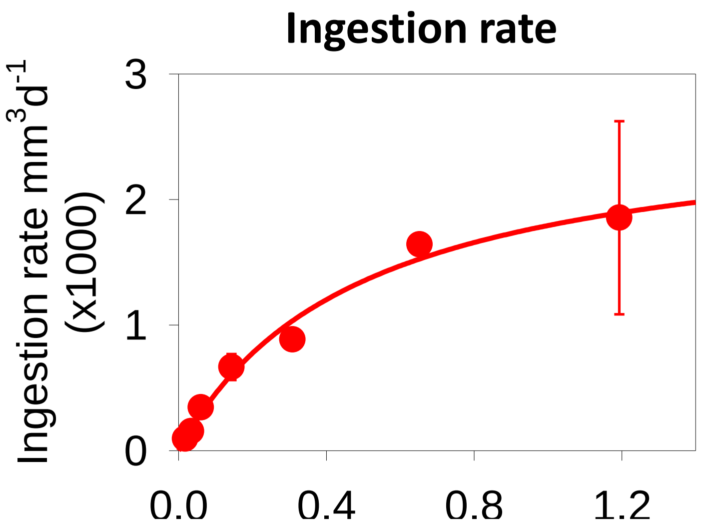
Type III



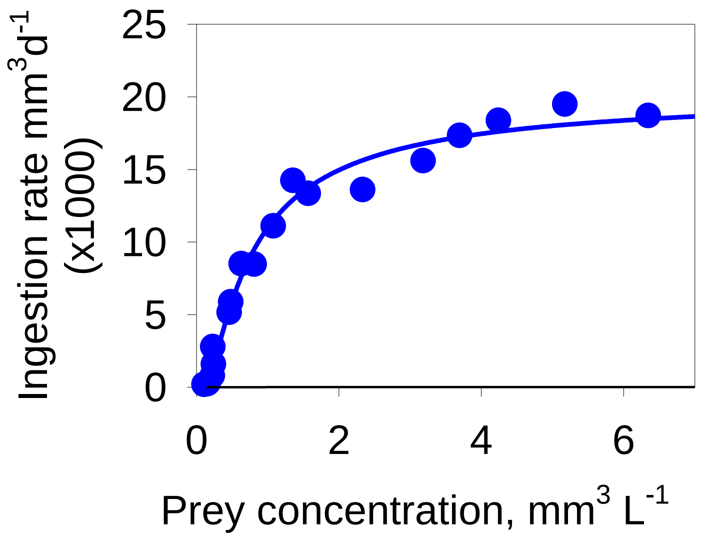
The functional response

Two types of responses

Type II



Type III



The functional response

Two types of responses

- Both types are found in pelagic copepods
  - Literature review: Type II: 88; Type III: 30

→

- Why different and what are the underlying mechanisms?

- What are the implications?

Theoretical model

Feeding induced predation risk and metabolic costs reduces foraging effort

Theoretical model

Feeding induced predation risk and metabolic costs reduces foraging effort

Feeding rate (Holling II): $$F = F_{max}\frac{\beta R}{\beta R + F_{max}}$$

Foraging effort, *p* $$F(p) = F_{max}\frac{p\beta R}{p\beta R + F_{max}}$$

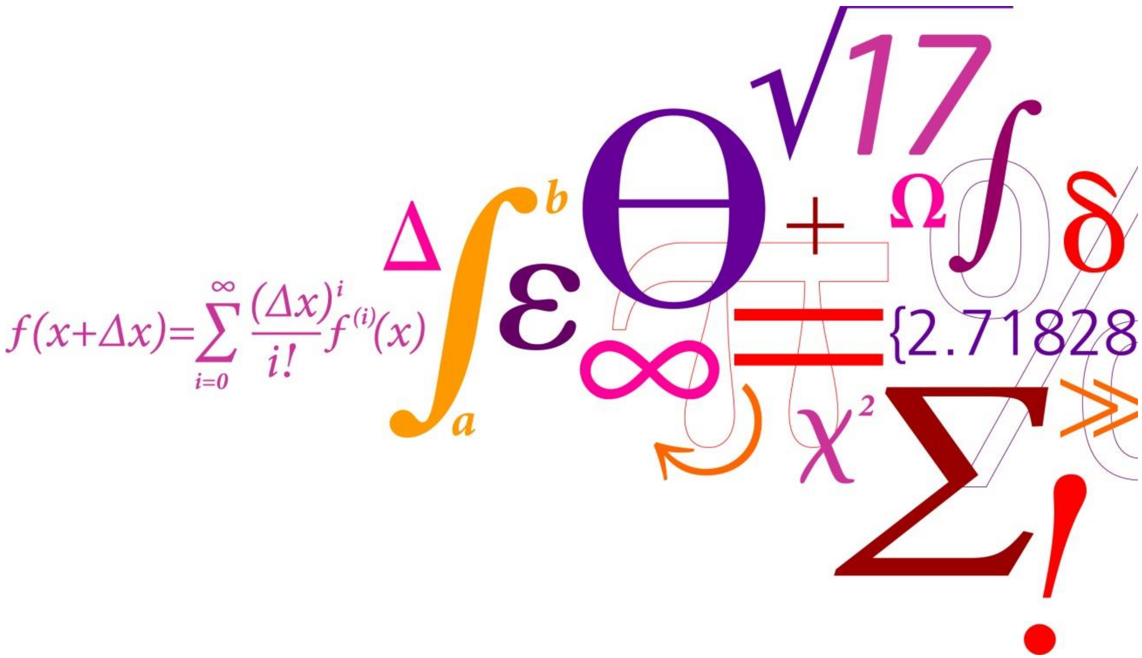
What foraging effort (*p*) optimizes the net energy gain?

Metabolism $M = m_0 + pm_f$ ← **Metabolic cost of feeding**

Mortality $\mu = \mu_0 + p\mu_f$ ← **Predation risk of feeding**

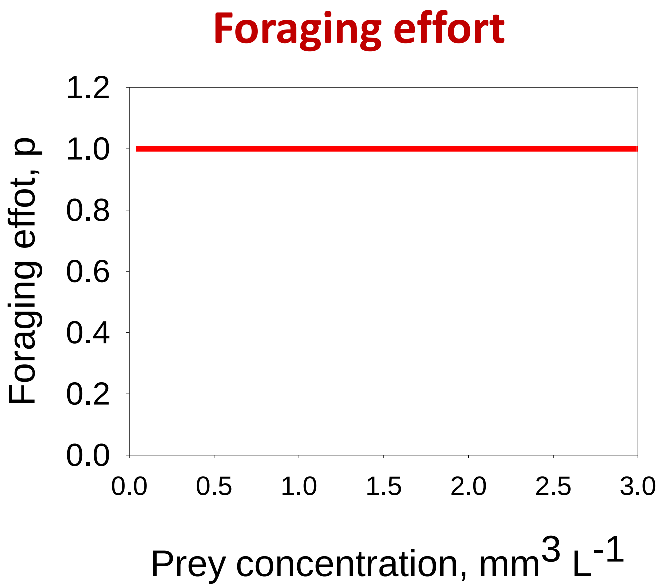
Theoretical model

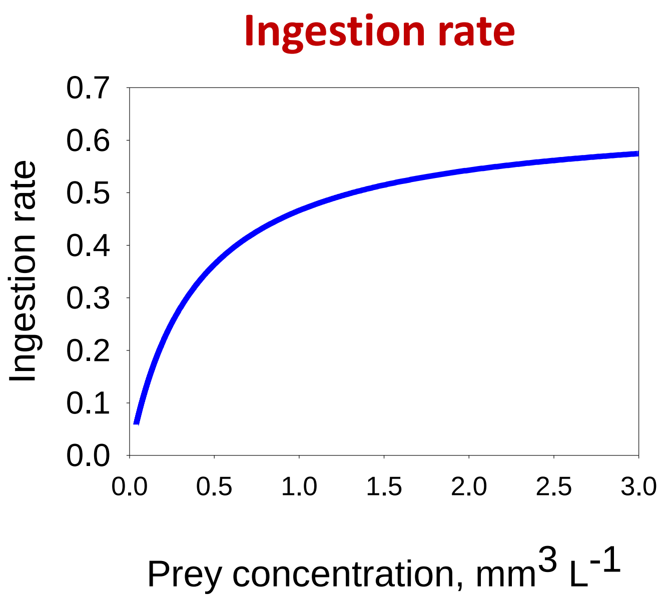
Solve the optimization (or have someone do it):



Theoretical model: predictions

No risk, no cost

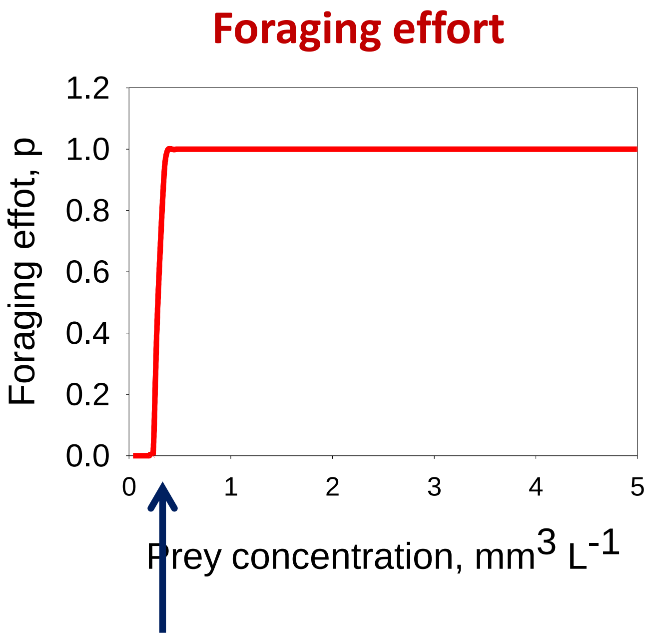




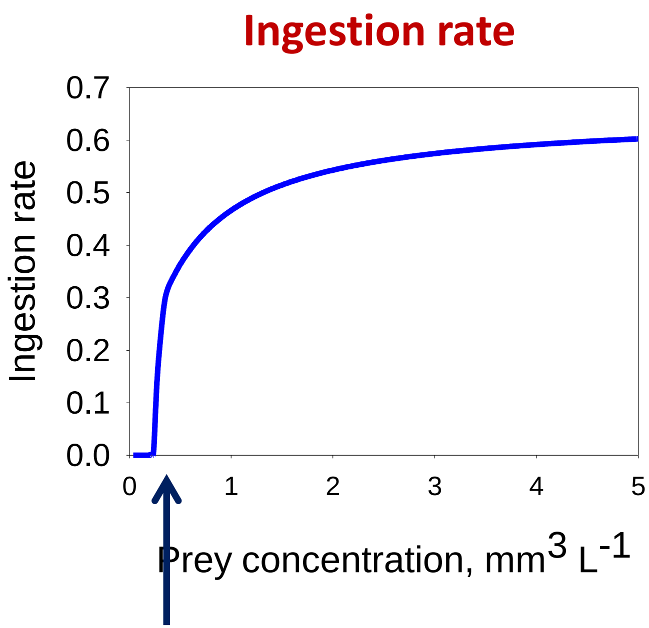
Type II response

Theoretical model: predictions

Metabolic cost



Feeding threshold



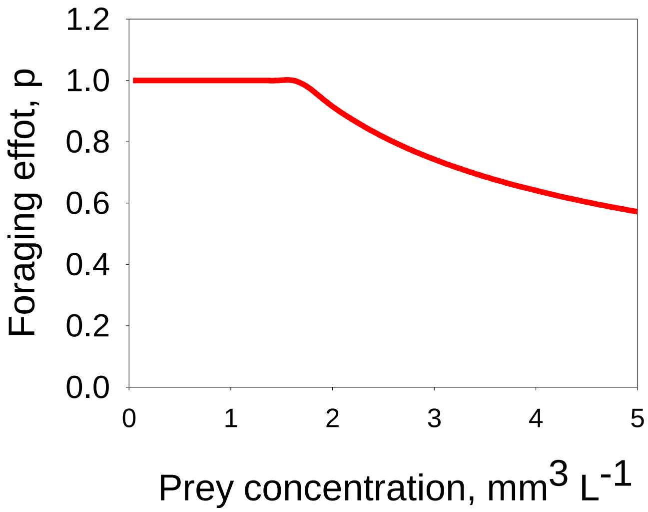
Feeding threshold

Type III response

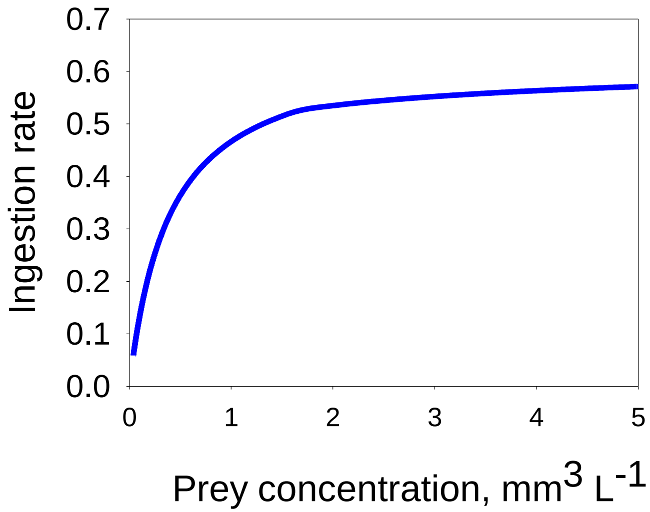
Theoretical model: predictions

Predation risk

Foraging effort



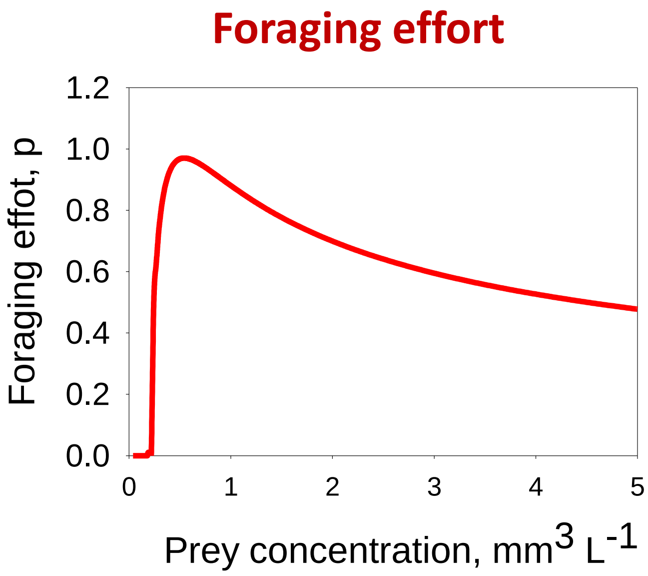
Ingestion rate

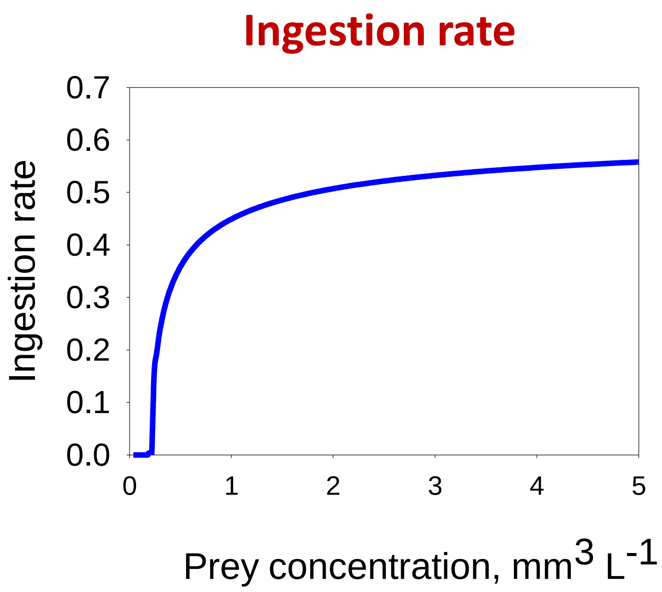


Type II response

Theoretical model: predictions

Predation risk + metabolic cost





Type III response

Theoretical model: summary of predictions

Feeding induced predation risk and metabolic costs reduces foraging effort

- Metabolic cost of feeding leads to feeding threshold and type III
- Predation risk leads to reduced foraging effort at high prey availibility, but still a type II response
- **Question:** Are there differences in risk and cost between copepod species?

Two feeding modes

feeding current feeders

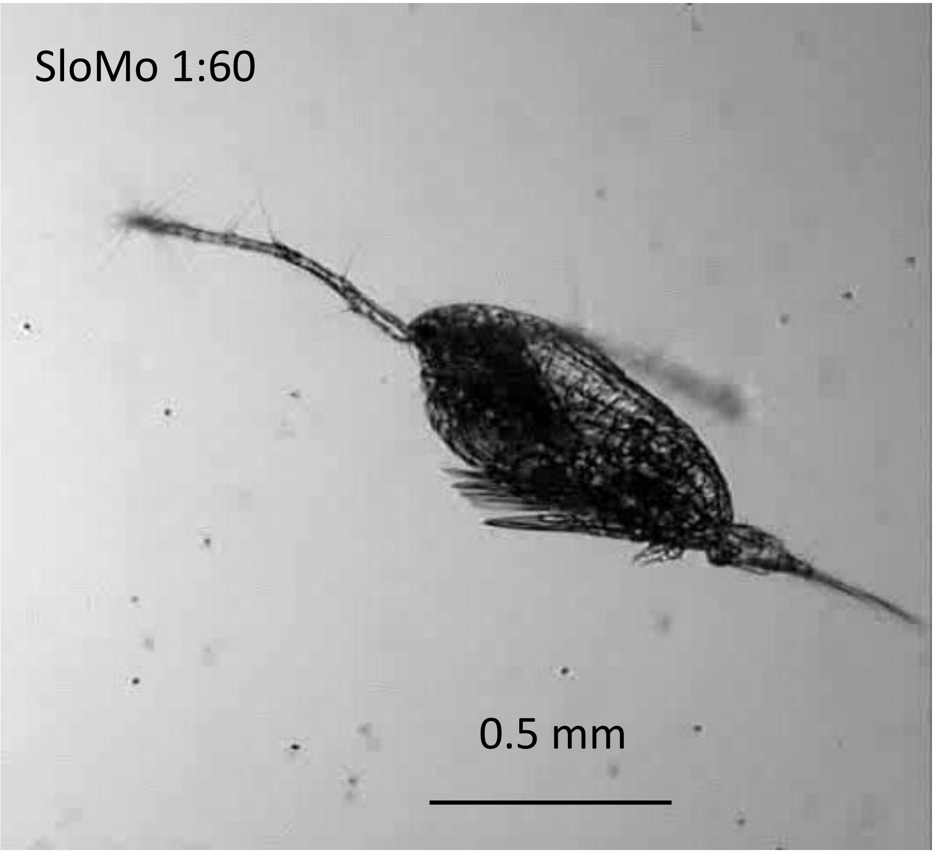
or

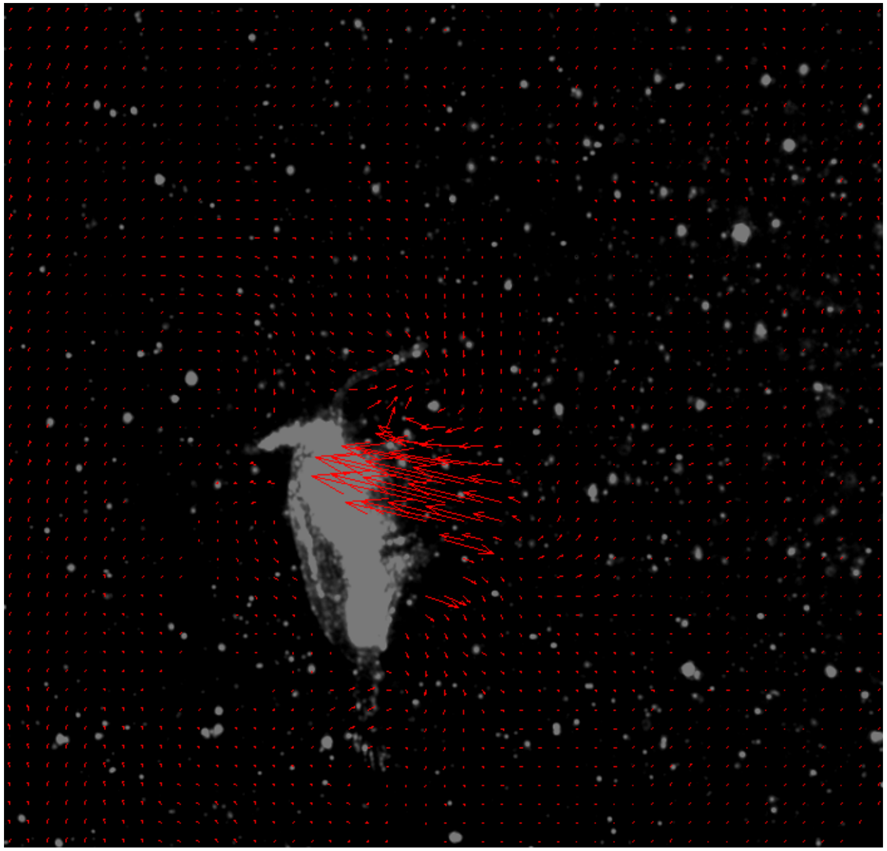
ambush feeders.

or both.

Feeding current feeding

Metabolic cost of beating appendages; fluid signal = predation risk.





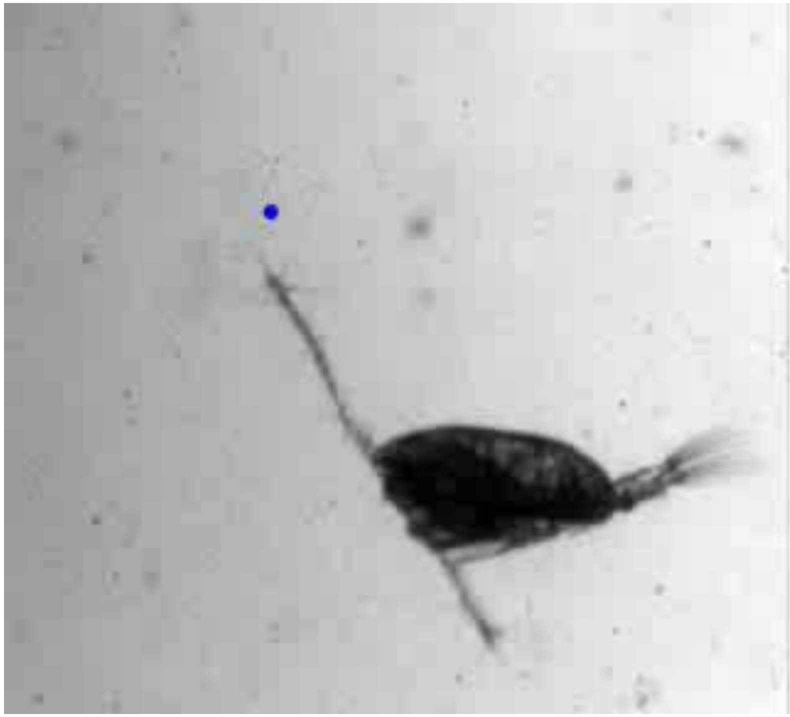
Acartia tonsa beating its feeding appendags to generate a feeding current

SloMo 1:40

Ambush feeding

Sit-wait-and attack: no foraging effort; no feeding-induce risk

Real time



SloMo 1:270

Hypotheses

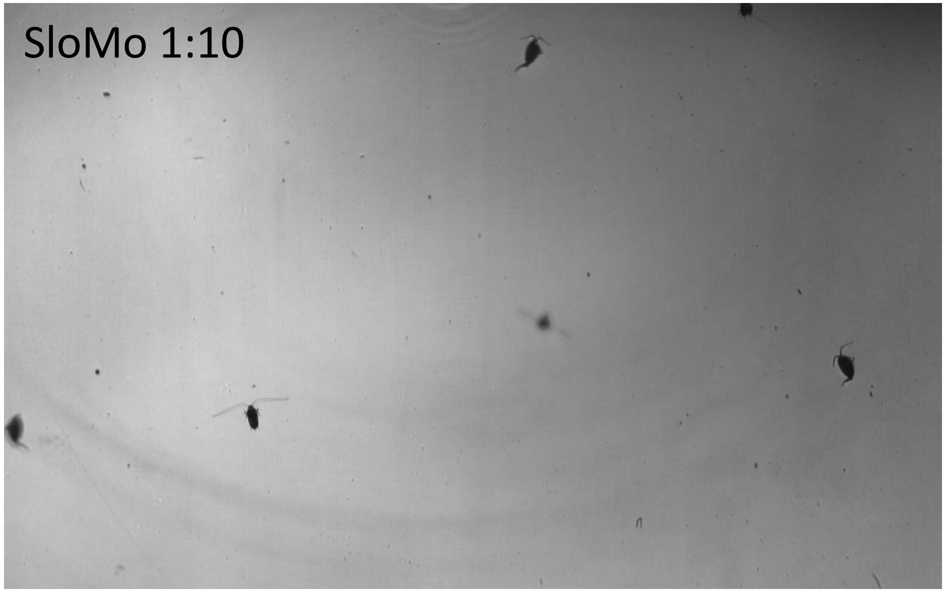
- **Feeding current feeders**:
  - Reduce foraging at low prey concentration; type III response
  - Reduced foraging effort in the presence of predator (cue)

- **Ambush feeders**:
  - Type II response
  - No effect of predator (cue)

Experiments

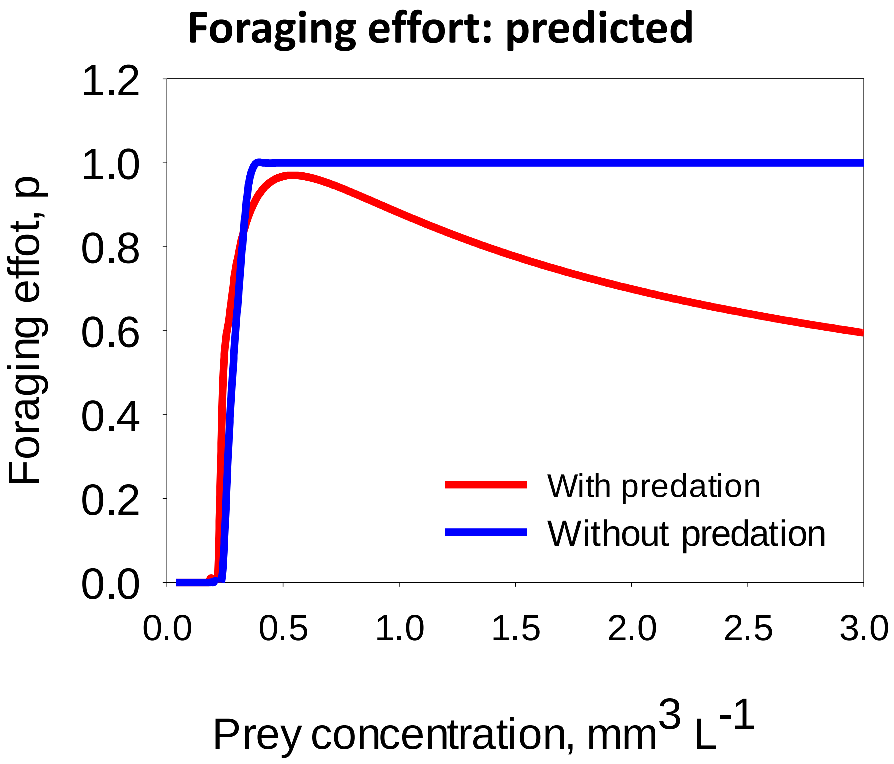
- **Observe behavior of free-swimming copepods**
    - Quantify foraging effort (appendage beating)
    - At different prey concentrations
    - In absence and presence of predator cue (fish smell)
    - For ambush and feeding current feeders

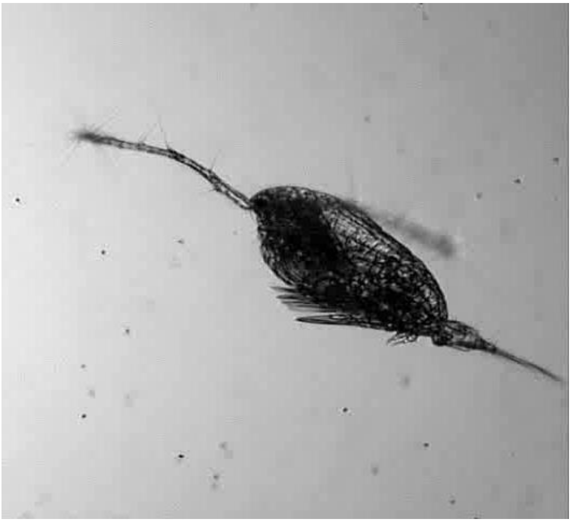
- **Measure functional response** (incubation experiments)



Observed behavior:feeding current feeder

Acartia feeding on a small (~non-motile) phytoplankton



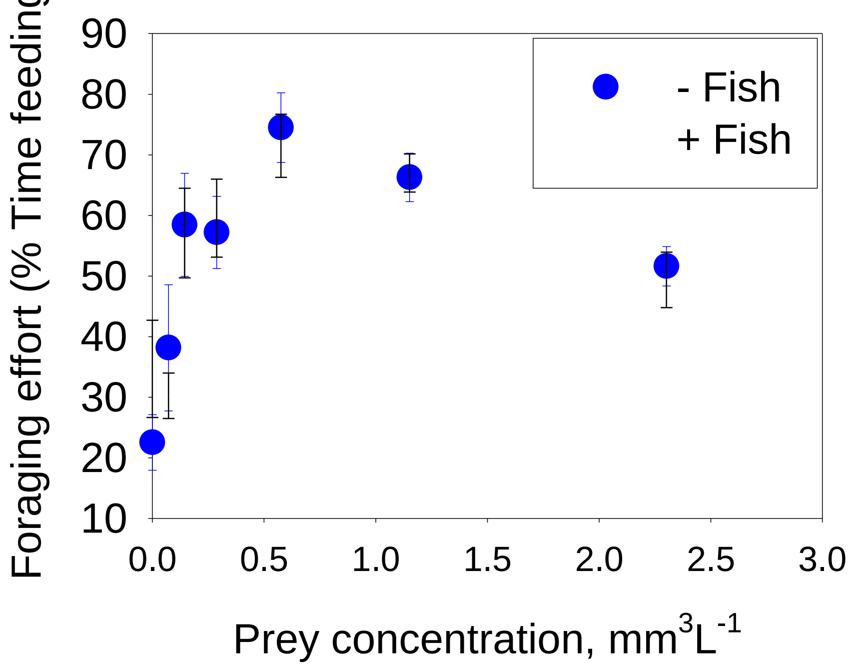


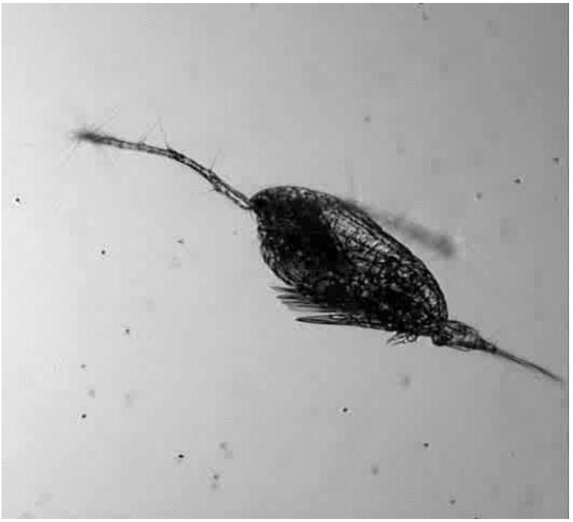
Parameter estimates based on Kiørboe et al. 1985

Observed behavior

Acartia feeding on a small (~non-motile) phytoplankton

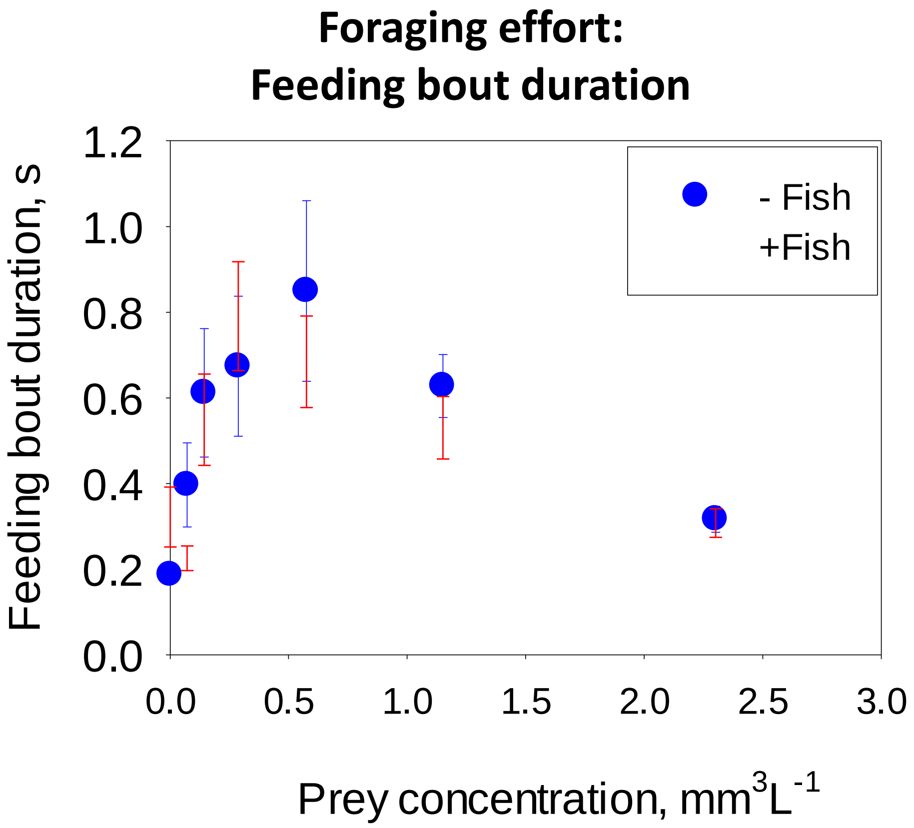
Foraging effort:
Fraction of time beating

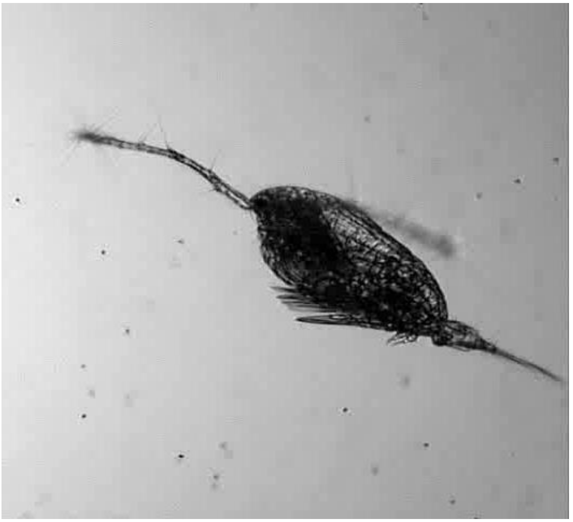




Observed behavior

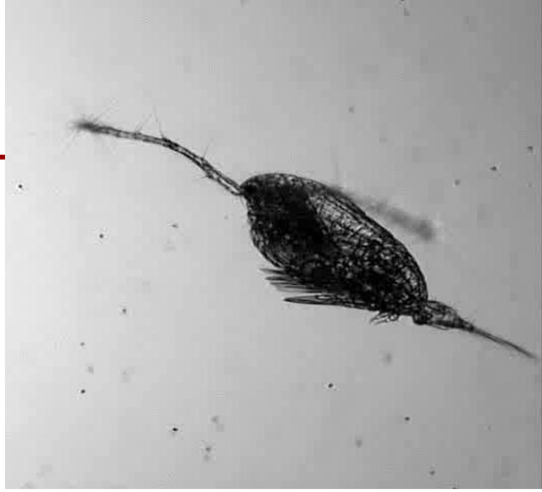
Acartia feeding on a small (~non-motile) phytoplankton

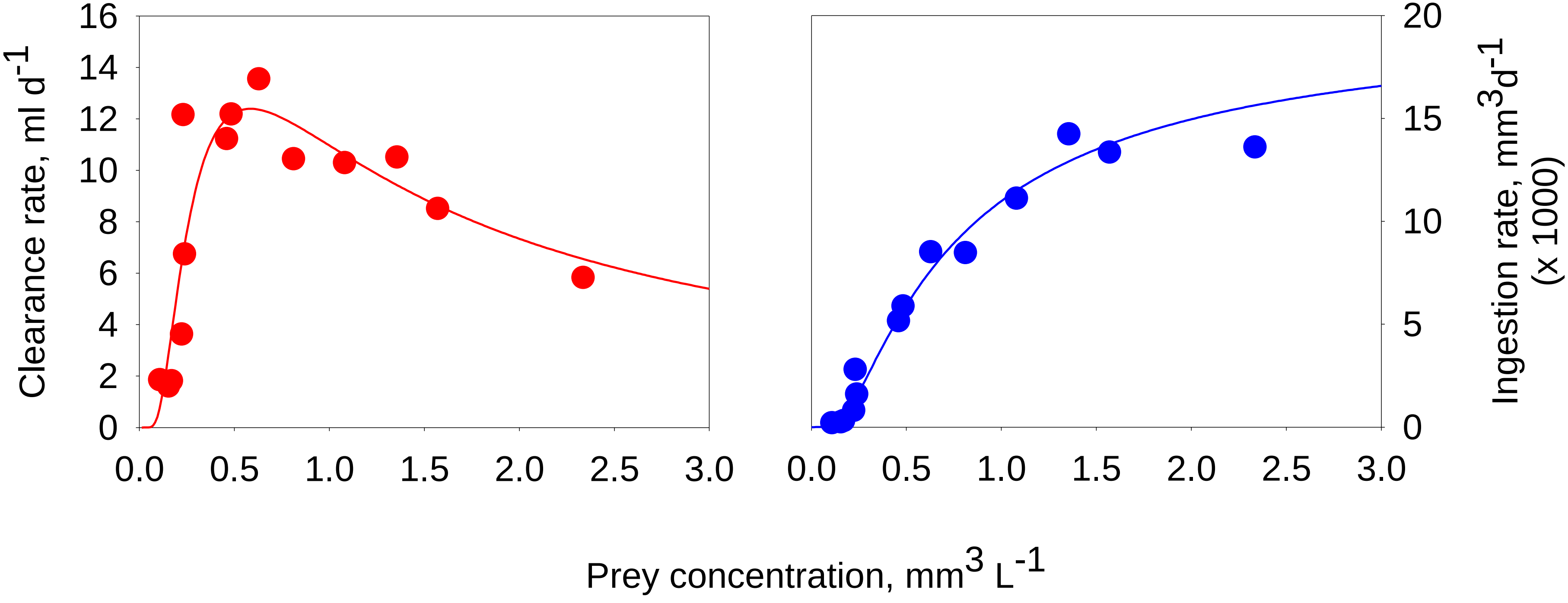




Resulting functional response

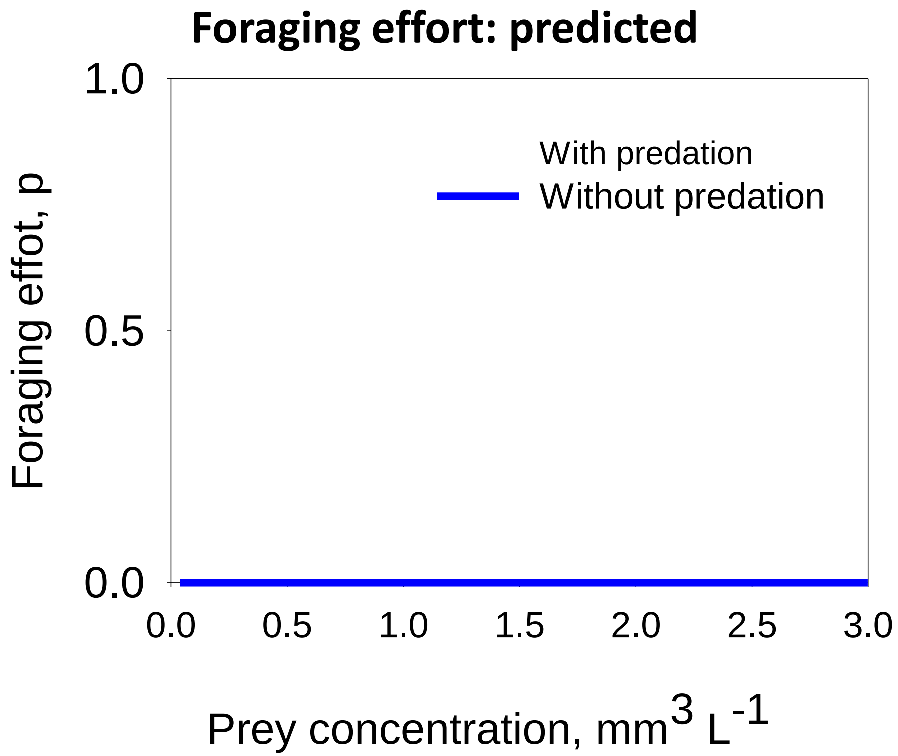
Acartia feeding on a small (~non-motile) phytoplankton





Observed behavior ambush feeder

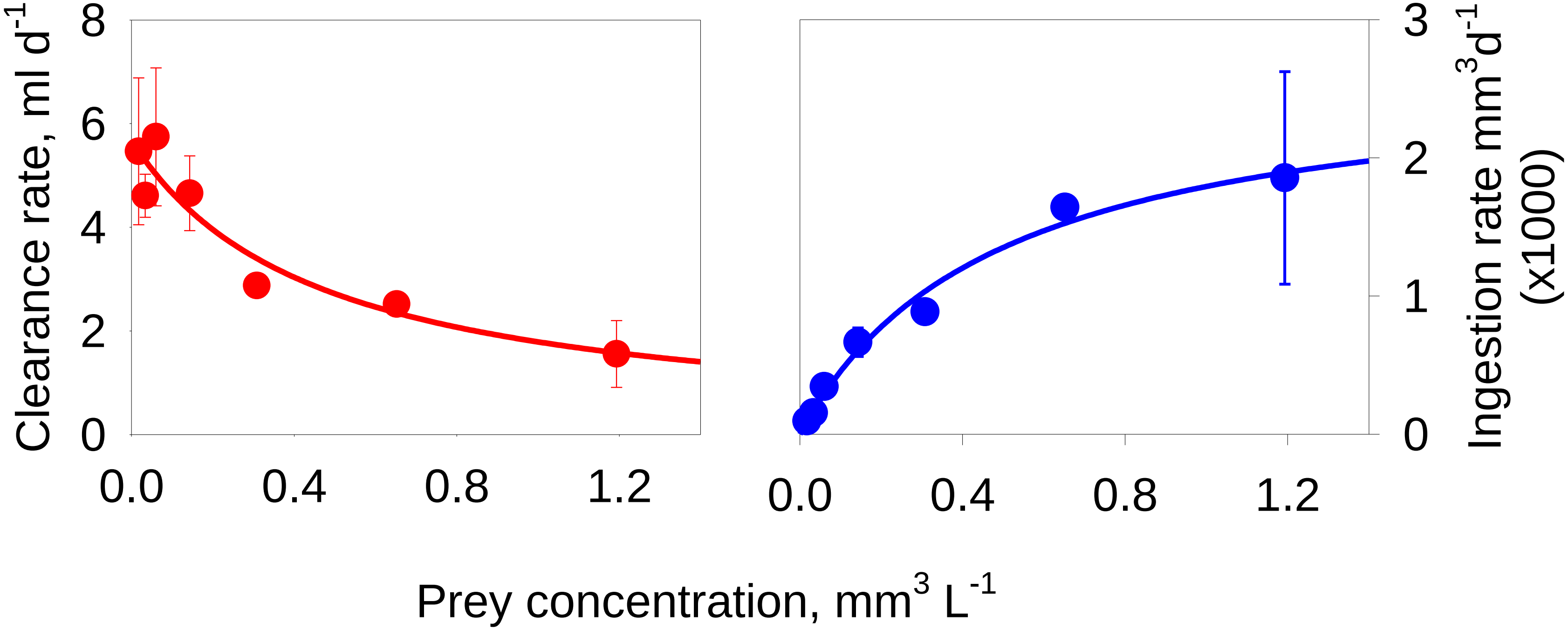
Oithona davisae feeding on Oxyrrhis marina
(No cost, no risk – no effort)



Observed:
Fraction of time active: 0

Resulting functional response

Oithona davisae* feeding on *O. marina

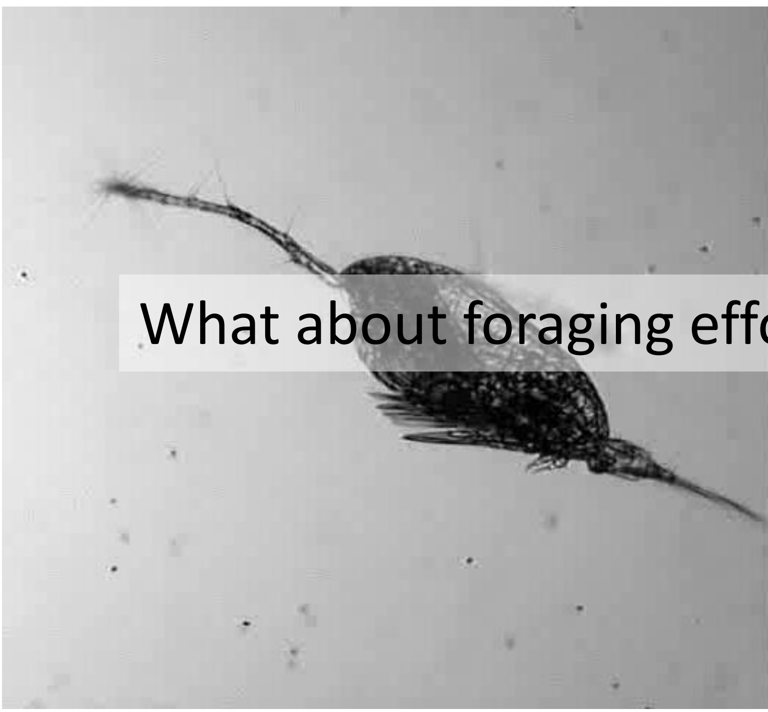


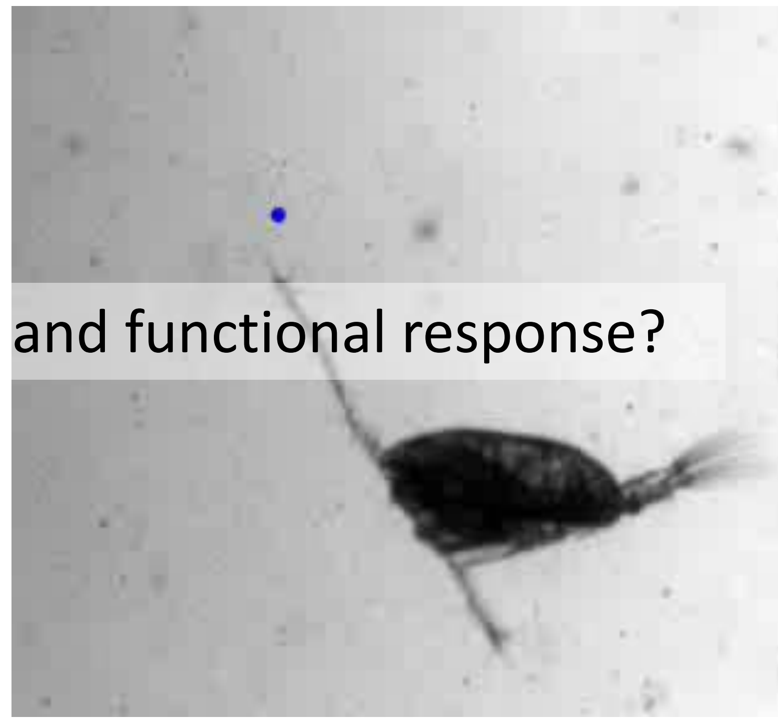
Acartia has two foraging modes

Acatia **can be both a feeding current and an ambush feeder**

Feeding current feeding when offered smal non-motile prey

Ambush feeding when offered large motile prey



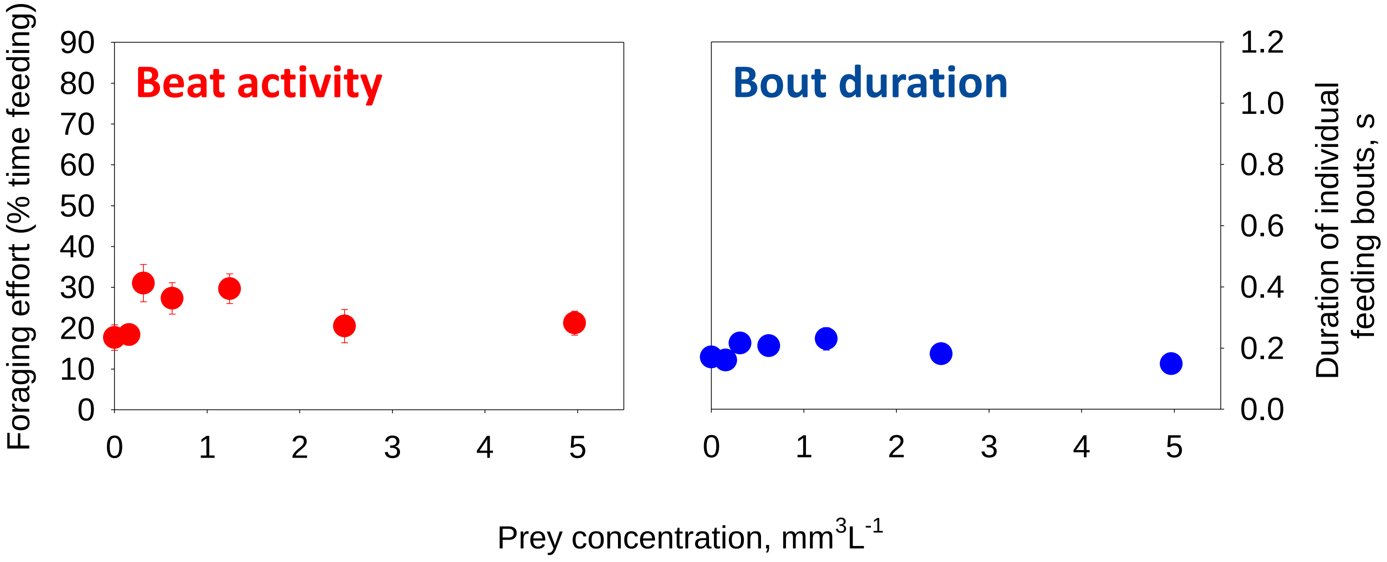


What about foraging effort and functional response?

Acartia as an ambush feeder

Acatia offered large, motile prey

Foraging effort

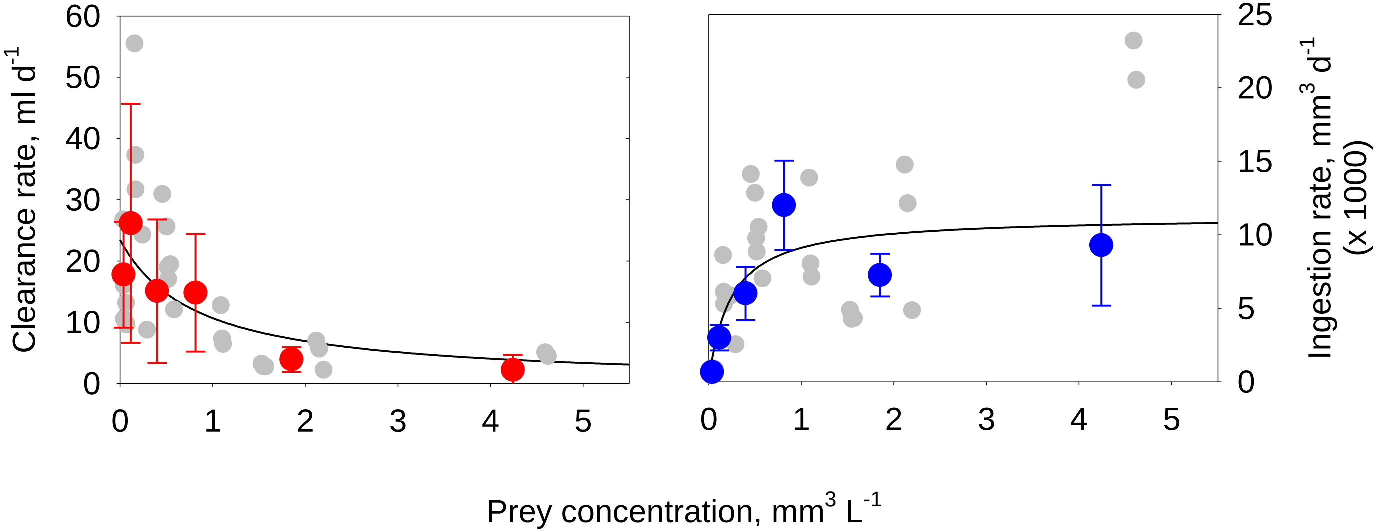


Low, constant foraging effort: Type II

Acartia as an ambush feeder

Acatia offered large, motile prey

Resulting functional response

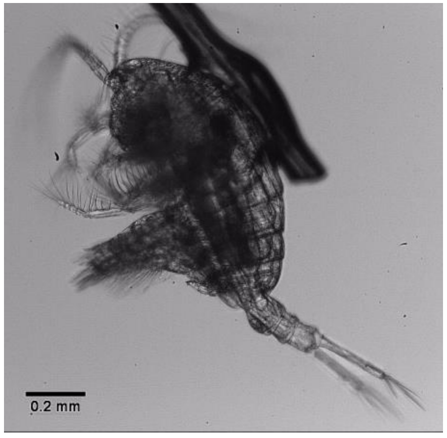


Type II functional response

Unpredicted results

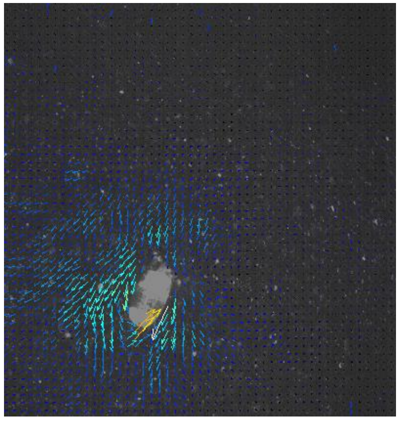
***Temora longicornis* and Centropages *typicus* are active feeders but have type II responses**

Temora



1. ~100 % foraging effort **independent of prey concentration**
2. **Type II response**
3. No effect of **predator cue**

Centropages



1. ~50 % foraging effort **independent of prey concentration**
2. **Type II response**
3. No effect of **predator cue**

Consistency between behavioral observations and resulting functional response

Summary

Conclusions so far

1. **Mechanistic underpinning:** There is consistency between individual behavioural reponses and resulting functional response
2. **Type II and III responses** only partly follow the prediction of the optimization

Literature review # papers	Type II	Type III
Ambush	43	0
Feeding current	30	25 (+20)

3. **Predator responses** (if any) wired into the genes

The functional response

Two types of responses

- Both types are found in pelagic copepods
  - Literature review: Type II: 88; Type III: 30
- What are the underlying mechanisms?
- → What are the implications?

Feeding and maintenance thresholds

The optimization model predicts two thresholds.

The feeding threshold is the prey concentration a which foraging stops (only type III)

(Frequency distribution of thresholds estimated from ~200 functional response experiments)

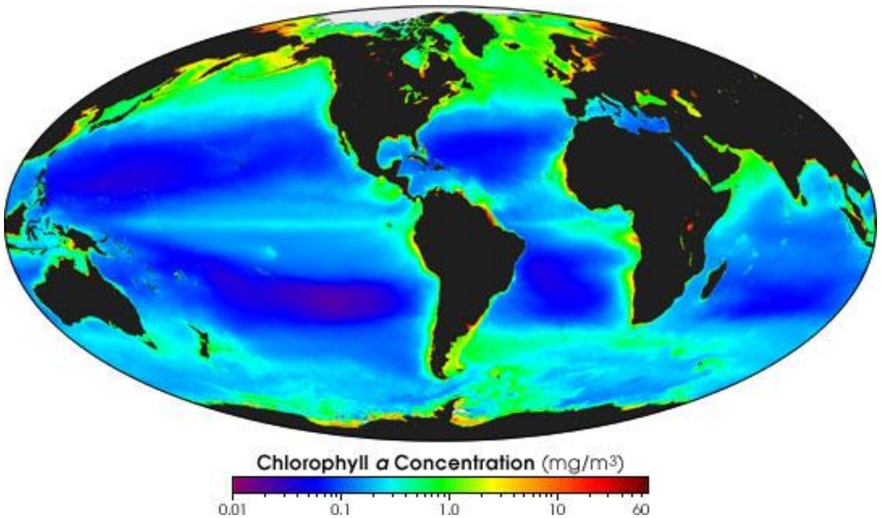
The two thresholds depend on the relative prey size:

The smaller the prey, the higher the concentration needed to maintain a population

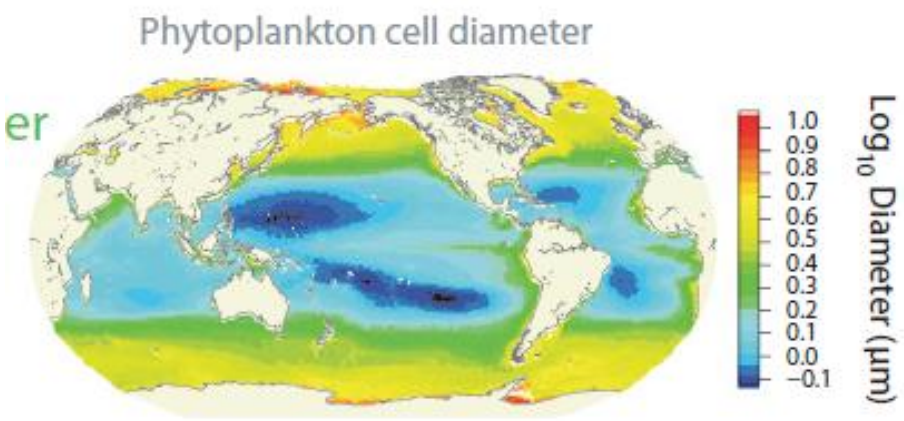
If we know the **biomass** and **size** of phytoplankotn in the ocean, we can estimate the **maximum possible size of the (copepod) grazers**

Global distribution of phytoplankton biomas and size

Biomass and size estimated from sattelite



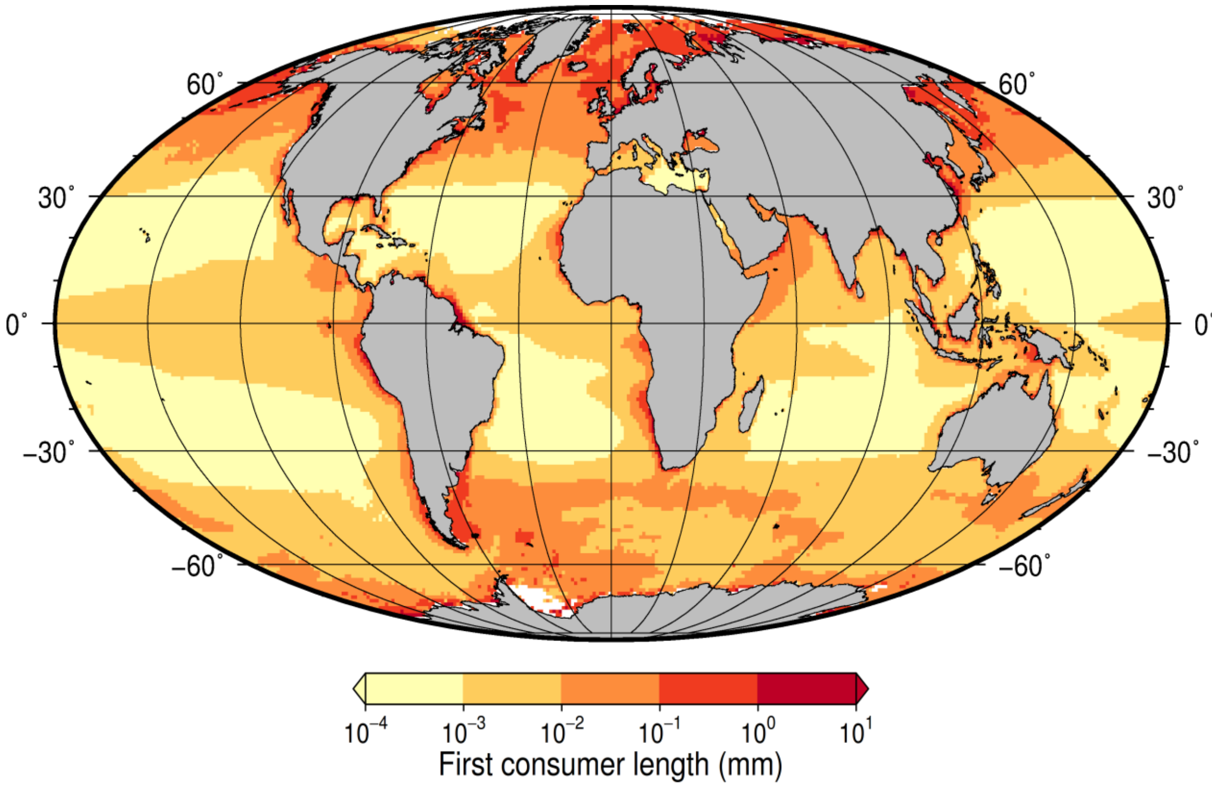
Biomass (NaSA)



Phytoplankton median diameter (based on Barnes et al. 2011)

Copepod trait biogeography: Size

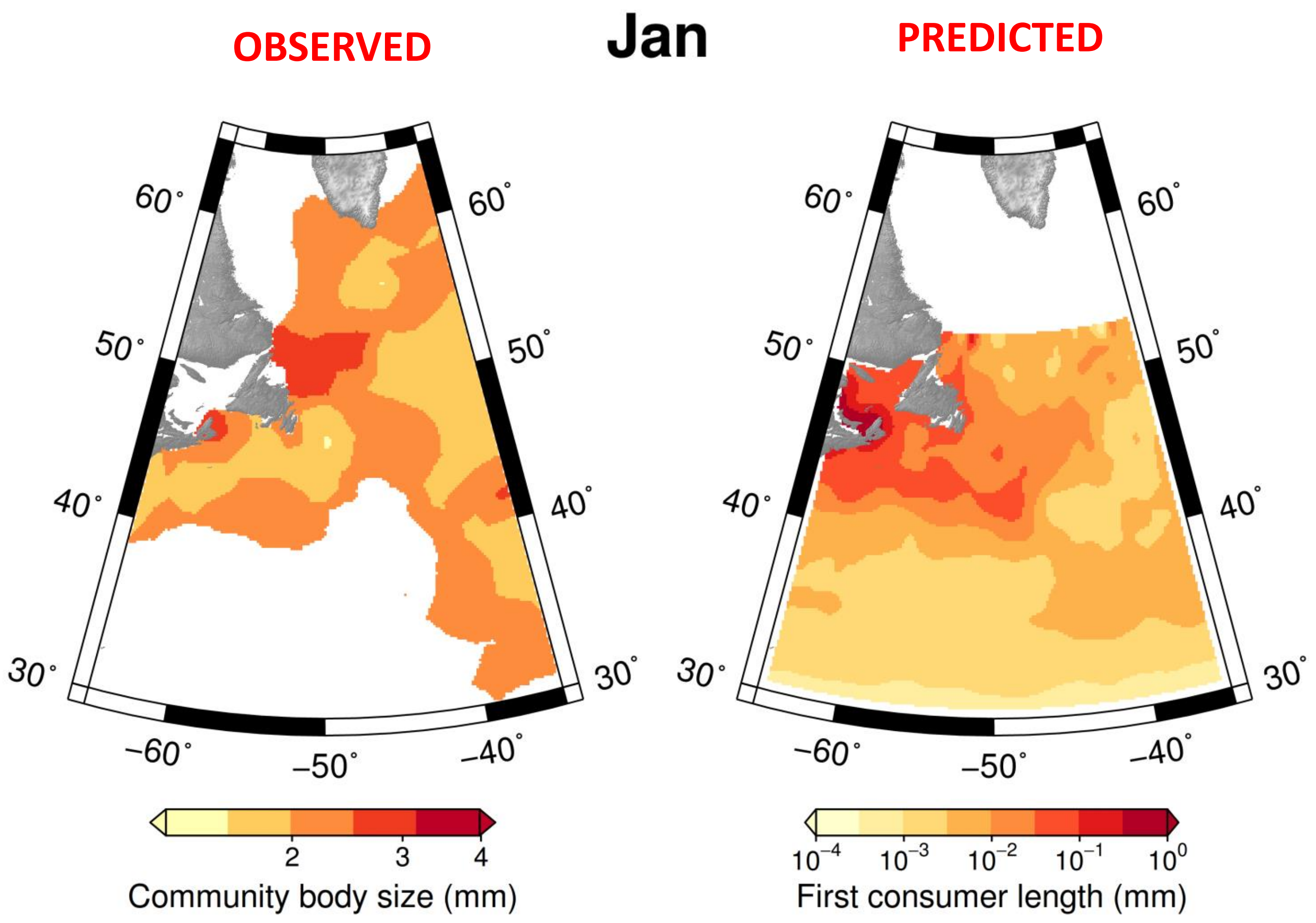
Copepdd (first consumer) maximum size



Is this phantasy?

Copepod trait biogeography: Size

Observed and predicted spatio-temporal pattern in copepod size in NW Atlantic



Conclusions

Conclusions

1. Mechanistic underpinning: There is consistency between individual behavioural reponses and resulting functional response
2. Type II and III responses only partly follow the prediction of the optimization

Literature review	Type II	Type III
Ambush	43	0
Feeding current	30	25 (+20)

3. Predator responses (if any) wired into the genes
4. **The functional response is a fundamental property of a zooplankter that impacts population dynamics, trophic structure and transfer efficiencies, as well as biogeography**