The energy budget of egg production in *Calanus glacialis* during spring and summer in the Beaufort-Chukchi Seas

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Introduction

- ***Calanus glacialis*** **is an important component of the zooplankton community in the Arctic Ocean and its adjacent seas**

- **Evidence for a mixed reproductive strategy with food-independent and food-dependent egg production (Hirche & Bohrer 1987, Hirche 1989, Smith 1990, Kosokobova & Hirche 2001, Madsen et al. 2008)**

- **Our view of the feeding biology of *C. glacialis* has been challenged: herbivory vs. 'carnivory' on microzooplankton (i.e. Campbell et al. 2009)**

- **The capacity of filter feeding *Calanus* species to eat their own eggs and nauplii has been demonstrated in the laboratory (Landry 1981, Bonnet et al. 2004, Basedow & Tande 2007)**

- **Egg production and feeding on microplankton of *C. glacialis/marshallae* was studied in the Chukchi and Beaufort seas during the Shelf-Basin Interactions program (Plourde et al. 2006, Campbell et al. 2009)**

- **Genetic work has confirmed that *C. marshallae* is seldom observed in these regions (Nelson et al. 2009, Campbell et al. unpublished)**

- **These data provide a great opportunity to study the energy budget of egg production in *C. glacialis***

General objective

To build a carbon-based energy budget of egg production in *C. glacialis* in the Chukchi and Beaufort seas in Spring and Summer of 2002 and 2004 considering all potential food/energy sources

Specific objectives

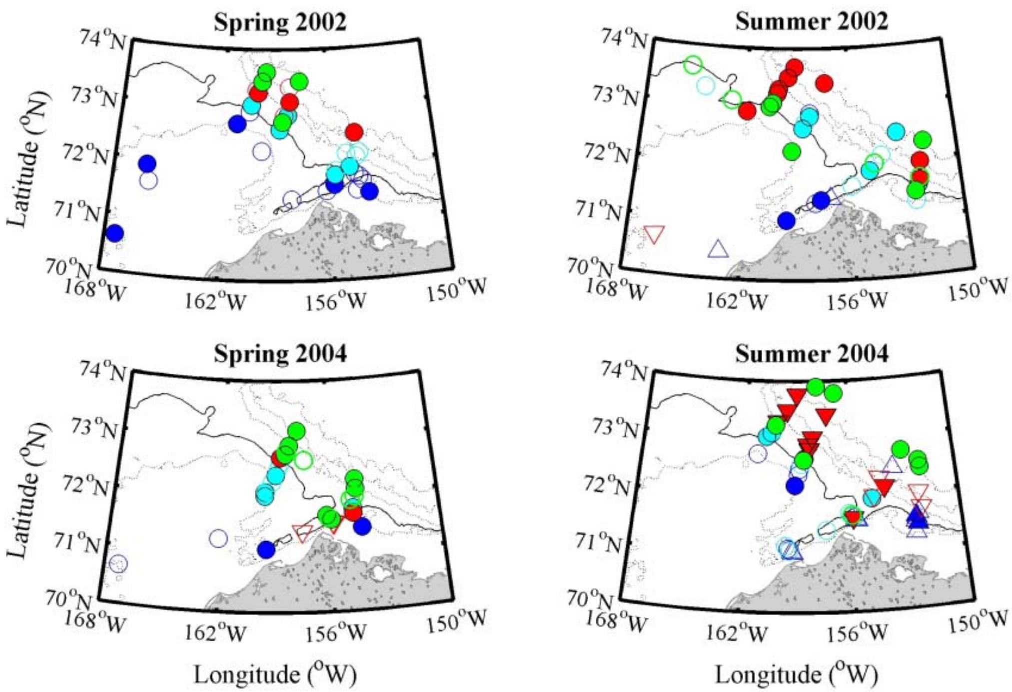
- **To compare chl *a* and microzooplankton daily ingestion with daily energy costs (egg production + respiration+excretion)**

- **To evaluate the potential contribution of ice algae**

- **To evaluate the potential contribution of a food-independent reproductive strategy (body reserves)**

- **To quantify the potential role of carnivory (cannibalism, predation) in supporting egg production and metabolism by using published or unpublished clearance rates of *C. finmarchicus* and *C. glacialis* on their eggs and nauplii in conjunction with density of copepod eggs and nauplii**

Regions Based on Physical-Chemical Characteristics

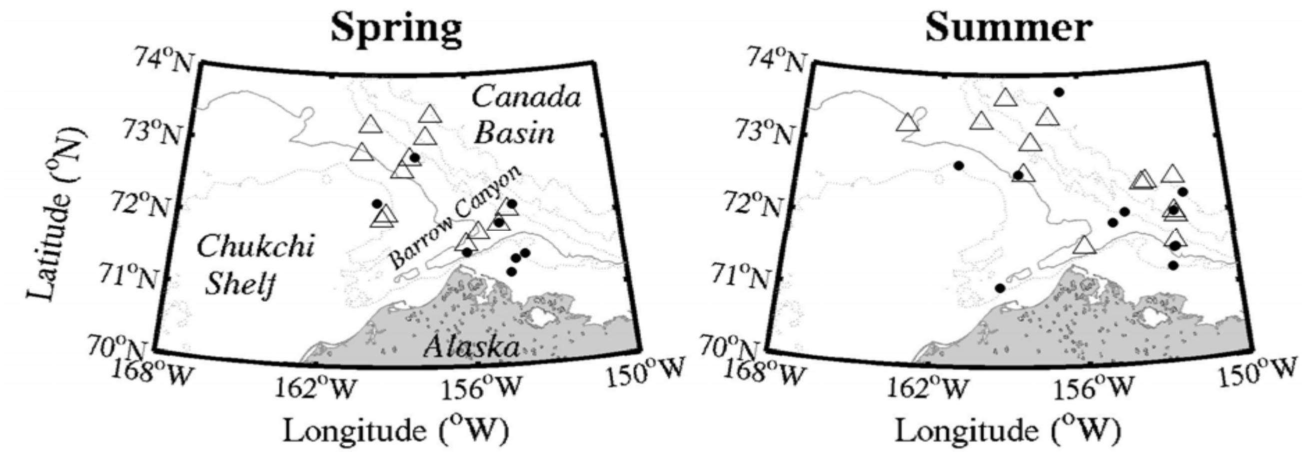


- **Regions 1 (●) and 2 (●) : saline + nutrient-rich water on the shelf (depth: region 1 = 70 m, region 2 = 375 m)**
- **Regions 3 (●) and 4 (●): water with lower salinity and nutrients on the slope/basin (depth: region 3 = 940 m, region 4 = 1425 m)**
- **Region 1a (▲) in Summer 2004: located to the south and east (mean depth = 225 m)**
- **Region 3a (▼) in Summer 2004: located on the slope/basin (mean depth = 1170 m)**
- **Regions 1a-3a: much warmer water**

- **EPR measured at locations indicated by the filled symbols**
- **Open symbols: EPR was predicted from the relationship: EPR= 69.7*GS4% + 6.5, r^2= 0.45 (Niehoff et al. 2003)**
- **Total: 70**

(Plourde et al. 2005, 2006)

Ingestion Rates on Phytoplankton and Microzooplankton Measured in 2002 and 2004



- **(△): Ingestion rate on chlorophyll *a* only (Ingest$_{Chla}$)**
- **(●): Ingestion rate on chlorophyll *a* and microzooplankton (Ingest$_{\mu zoo}$)**
- **Ingestion rate on microzooplankton at stations (△) predicted from the chlorophyll standing stock and chlorophyll ingestion:**

  Ingest$_{\mu zoo}$/Ingest$_{Chla}$= 1.6 at chl *a* < 1 mg m^{-3}

  Ingest$_{\mu zoo}$/Ingest$_{Chla}$= 0.1 at chl *a* > 1 mg m^{-3}
- **Total: 30 ingestion estimates**
- **Body C and N measured on all individuals**

(Campbell et al. 2009, Sherr et al. 2009)

Carbon-Based Energy Budget of EPR

-EPR converted to a rate as μg C fem^{-1} d^{-1} using egg weight of 0.38 μg C (Campbell, unpublished data)

- $Ingest_{Chla}$ and $Ingest_{\mu zoo}$: μg C fem^{-1} d^{-1} (Campbell et al. 2009, Sherr et al. 2009)

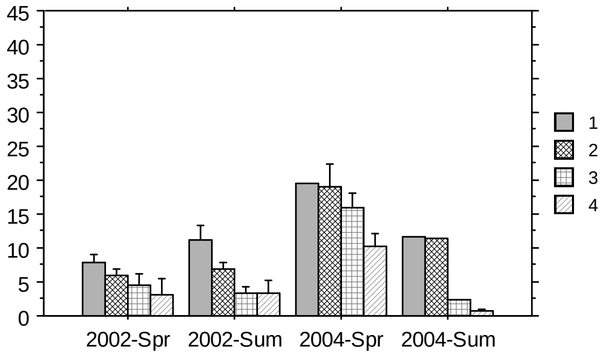
- Respiration and excretion: 1.3% of body carbon d^{-1} at -1 to 0 ºC (Bamstedt & Tande 1986)

- Lipid carbon weight: indirectly estimated from digitized images (Miller et al. 1998, Saumweber & Durbin 2006)

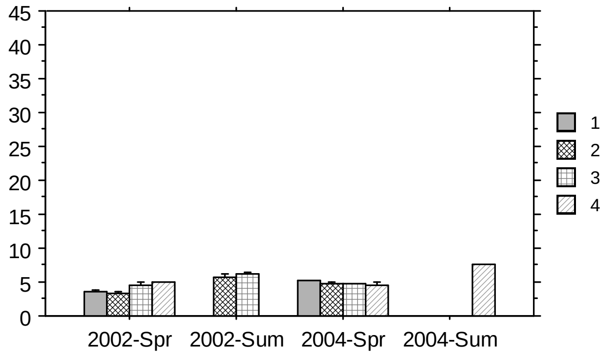
-Contrast the different regions during the different cruises

Carbon-Based Energy Budget: EPR and Respiration+Excretion

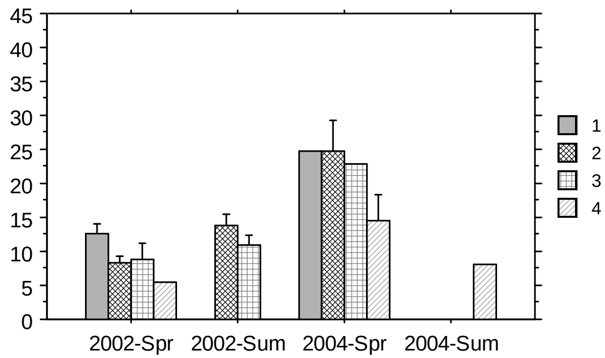
EPR
(µg C/F/d)



R + E
(µg C/F/d)



Total Costs
(µg C/F/d)

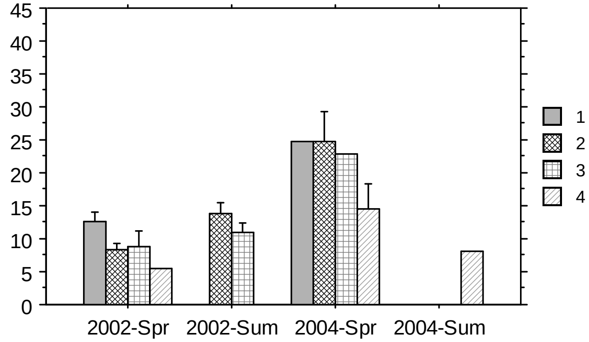


2002 2004

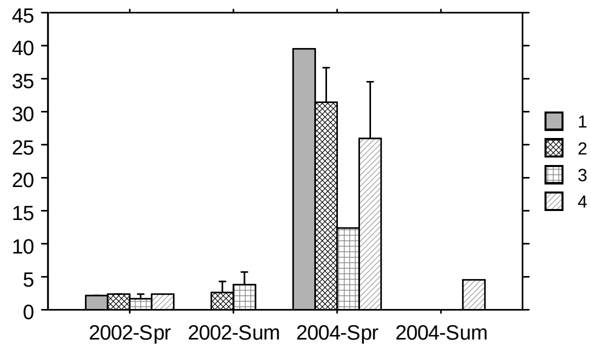
- **EPR: generally greater in Spring 2004 (bloom) than during cruises that were conducted prior (Spring 2002) or after (Summers) the bloom**
- **Generally greater on the shelf and upper slope (Regions 1 and 2)**
- **Respiration and excretion (costs): small variations determined by variations in body C weight (3.5-7.5 µg C f^{-1} d^{-1})**
- **Total energy costs (EPR+resp+excretion): similar pattern to EPR**
- **EPR represents 18-76% of total metabolic costs**

Carbon-Based Energy Budget: Ingestion of Microplankton vs. Total Costs

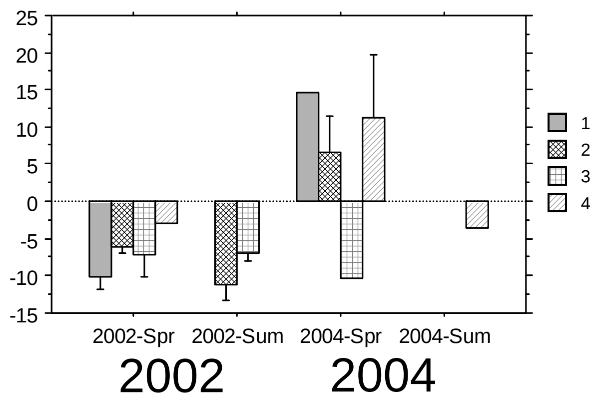
Total Costs
(µg C/F/d)



Microplankt.
Ingestion
(µg C/F/d)



Ingestion-
Metabolic
Cost
(µg C/F/d)



- **Total energy costs (EPR+resp+excretion): similar pattern to EPR**

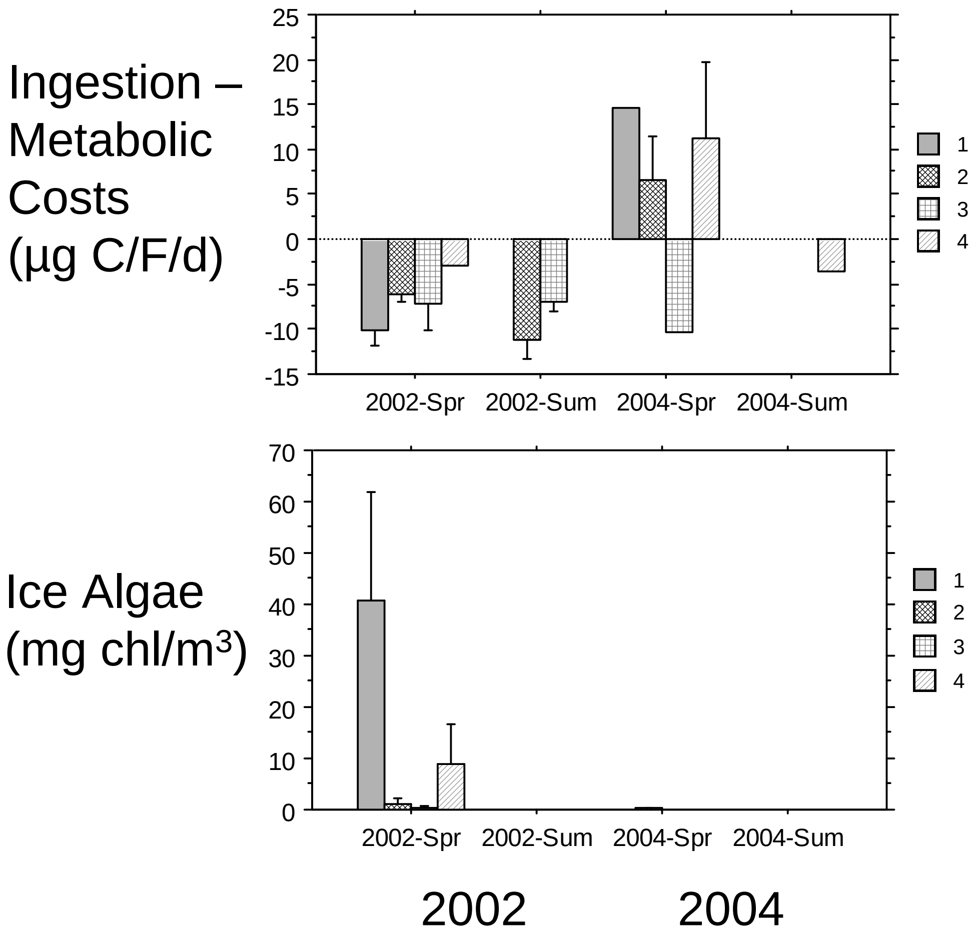
- **Microplankton ingestion (chla+microzoo): very high in Spring 2004 (bloom), much lower during other cruises (prior to or after bloom)**

- **Energy budget: mostly negative, positive only in regions 1, 2 and 4 in Spring 2004 (bloom)**

- **Microplankt. Ingestion: only 57% of R+E under non-bloom conditions**

C. glacialis **was not obtaining sufficient carbon to meet metabolic needs**

Carbon-Based Energy Budget: Potential Role of Ice Algae



- **Ice algae released in the water column was likely included in our grazing experiments**

- **There is the potential for grazing at the ice-water interface also (e.g., Runge & Ingram 1990)**

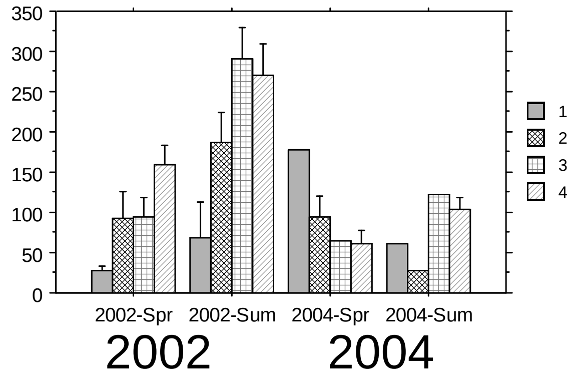
- **Ice algae: (© UCAR, Physical/Chemical/Biological Sea Ice Characteristics in the Chukchi and Beaufort Sea [Gradinger, R.])**

- **High ice algae biomass observed only in Spring 2002 in region 1 (some in region 4)**

- **Therefore, assuming that ice algae was available for grazing by planktonic copepods, it could have contributed to EPR only in region 1 in Spring 2002**

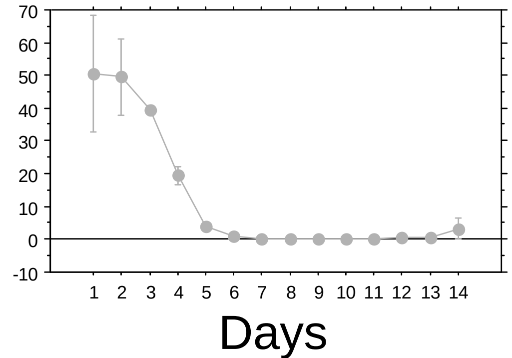
Carbon-Based Energy Budget: Potential of Food-Independent EPR (lipids)

Total Lipid (µg C/F)



- Lipid C weight: varied from 25 µg C lipid ind^{-1} (region 1 in Spring 2002) to 280 µg C lipid ind-1 (region 3 in Summer 2002)

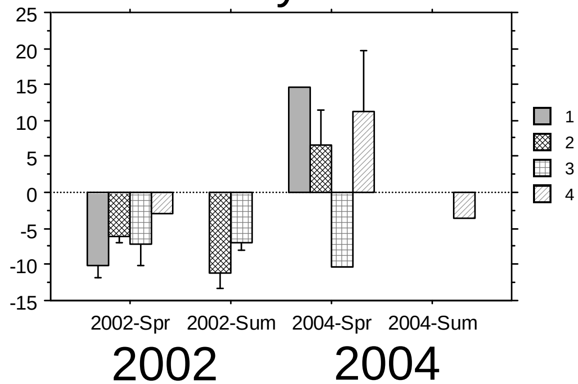
EPR (eggs/F/d)



- Three long-term EPR experiments in FSW were conducted in Spring 2004

-EPR dramatically decreased after 3-4 days, ceased after 5-6 days, indicating the inability of *C. glacialis* F to produce many eggs without food

Ingestion-Metabolic Costs (µg C/F/d)



However, during other cruises/regions:

- Maximum Epr of *C. glacialis* in FSW during long-term experiments: 5-7 eggs f^{-1} d^{-1} (i.e., Hirche & Bohrer 1987, Kosobokova & Hirche 2001)

- Corresponds to c.a. 1.9-2.2 µg C f^{-1} d^{-1}

Not enough to cover energy deficit in most cruises and regions (representing only 20-33% of the deficit)

Carbon-Based Energy Budget: Potential Role of Predation on Metazoan Prey

Rationale

- *Calanus* spp can eat their own eggs and nauplii (Landry 1981, Bonnet et al. 2004, Basedow & Tande 2006)

- *C. finmarchicus* C6f feeding on nauplii: independent of alternative food, constant clearance rate vs prey concentration (min= 500 ml f^{-1} d^{-1}) (Basedow & Tande 2006)

- Clearance rate of *C. glacialis* C5 on *C. finmarchicus* eggs: constant clearance rate vs prey concentration (c.a. 725 ml f^{-1} d^{-1}) (Plourde, unpublished data)

Approach

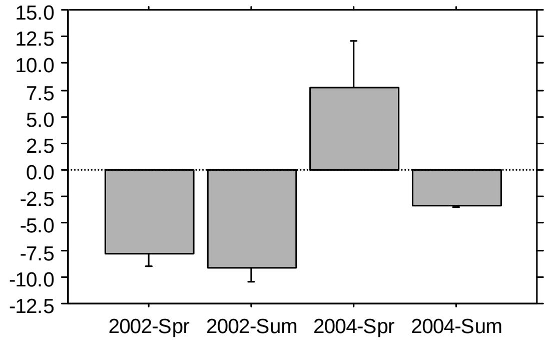
-Average per cruise (limited number of samples for egg-nauplii abundance)

-Ingestion rate: based on total egg or nauplii density (no prey preference) and clearance rate

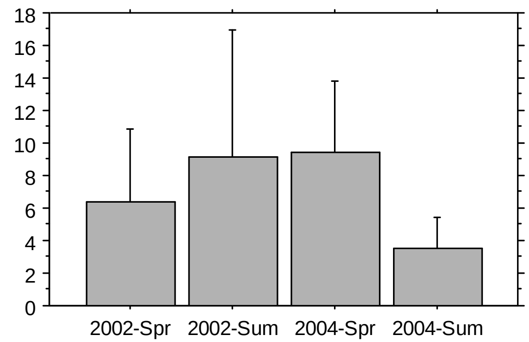
- Converted in µg C f^{-1} d^{-1}: species-specific body C of N3 or eggs (Kiorboe 1985) X relative proportion of different species (nauplii) or size classes (eggs)

Carbon-Based Energy Budget: Potential Role of Predation on Metazoan Prey

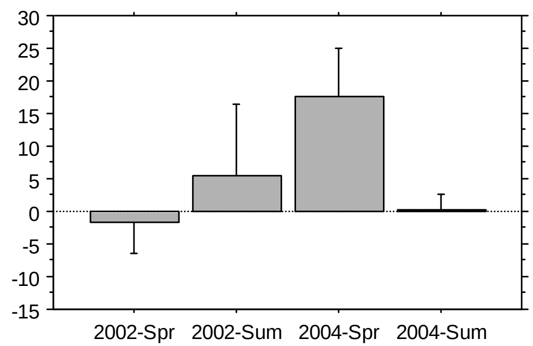
Microplankton Ingestion – Metabolic Cost (µg C/ F/d)



Ingestion of Eggs & Nauplii (µg C/F/d)



Energy Deficit +Metazoan Ingestion (µg C/F/d)

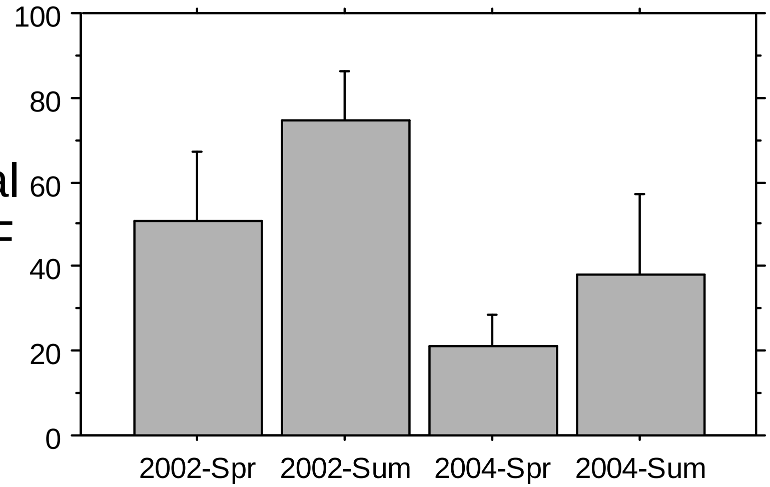


2002 2004

- **Averaged values per cruise**
- **Energy budget recap based on ingestion of phyto- and microzooplankton: negative in Spring-Summer 2002, Summer 2004, positive in Spring 2004**
- **Potential egg-nauplii ingestion= 4 to 9 µg C f^{-1} d^{-1}**
- **Potential egg-nauplii ingestion: enough to 'cover' most of the energy deficit to support EPR**
- **May be necessary to accumulate body reserves**

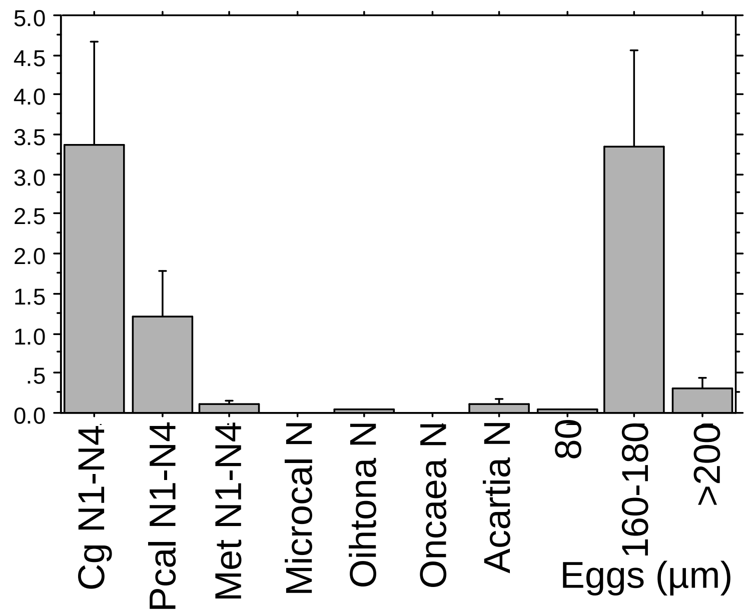
Carbon-Based Energy Budget: Potential Role of Predation on Metazoan Prey

Metazoan Predation as % of Total *C. glacialis* F Ingestion



- **Potential egg-nauplii ingestion: represented between 21% (Spring 2004) and 75% (Summer 2002) of total ingestion**

Ingestion of Different Metazoan Types (µg C/F/d)



- **Contribution of different egg (E) size classes and nauplii (N) species to ingestion (µg C f^{-1} d^{-1}):**
  - **Important contribution of N1-4 of *C. glacialis***
  - **Important contribution of eggs 160-200 µm (dominated by *C. glacialis*)**
  - **Combined effect: density X size**
  - **Cannibalism potentially important**

Conclusions

-***Calanus glacialis*** **cannot meet their metabolic requirements, including the cost of egg production, through ingestion of phytoplankton (chlorophyll *a*) and microzooplankton alone**

- **-Alternative food sources must be available to sustain the animals and to permit reproduction**
- **-Alternatively, conventional grazing methods may be underestimating ingestion**

-**Ingestion of ice algae and utilization of stored lipids may provide more carbon to fuel egg production but this still does not seem to be sufficient at most locations in the study area**

-**Predation on other metazoans, including *C. glacialis* eggs and nauplii, can provide sufficient carbon to sustain metabolic costs in most regions and at most periods during the study**

-**Cannibalism could be a significant and necessary factor contributing to *C. glacialis* recruitment success**

Acknowledgments

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