Calanus copepods along the Eurasian Arctic inflow corridor: The future is already here

maybe

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Calanus copepods are a crucial link from phytoplankton and ice algae to higher trophic levels in northern oceans. But subarctic *C. finmarchicus* are smaller and less energy-rich than Arctic *C. glacialis* and *C. hyperboreus*, raising concerns about **how and when *C. finmarchicus* will expand into an Atlantifying Arctic**, and the ecosystem consequences if it does.

I'm mainly concerned about the Me consequences

Renaud et al., "Pelagic food-webs in a changing Arctic: a trait-based perspective suggests a mode of resilience", *ICES JMS*, 2018

An early, idealised experiment using the trait-based life-history model **Coltrane** found that energy transfer to predators via *Calanus* might actually be *more* efficient under sea-ice loss, with shorter generation length and faster turnover compensating for smaller individual size.

This is such good news

But does this prediction of resilience hold up in a more realistic model experiment?

Oh great, here it comes

v2.0: Bourreau et al, in prep.

We ran Coltrane v2.0 along the Eurasian Arctic inflow corridor, in an ensemble experiment spanning the uncertainty in several crucial model parameters.

v1.0: Banas et al., Copepod life strategy and population viability in response to prey timing and temperature: Testing a new model across latitude, time, and the size spectrum", *Front Mar Res*, 2016

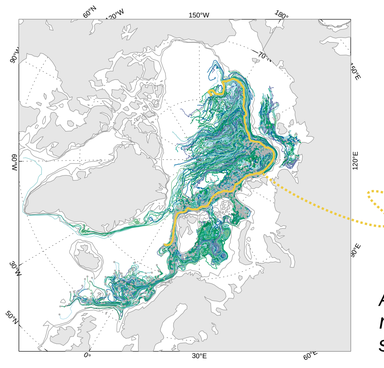
Coltrane is an individual-based model that takes time series of surface temperature, deep temperature, and prey as input, and predicts the optimal and viable range of *Calanus* traits (body size, lipid/energy content, seasonal timing, life cycle).

Vernet et al., *Front Mar Res*, 2019

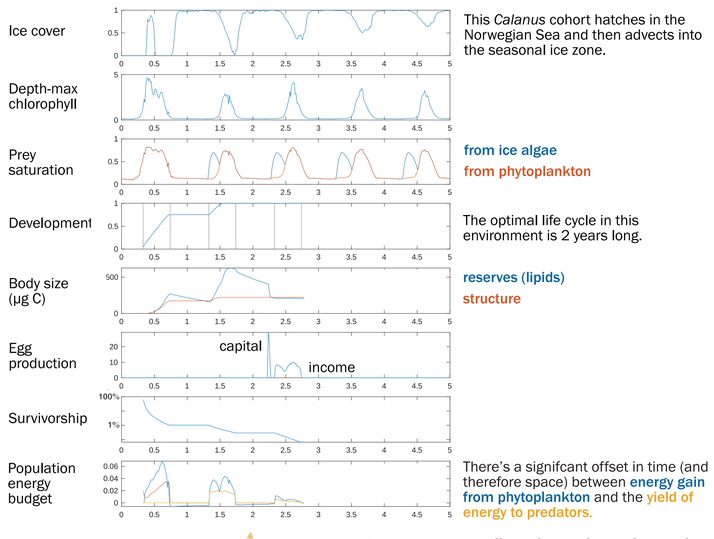
Each experiment consisted of 1000 five-year transport pathways extracted from the **SINMOD** ice-ocean model, start dates 2004 to 2012.

Prey is determined by phytoplankton concentration and ice cover from SINMOD. Ice algae availability is estimated from ice cover, latitude, and yearday based on mean patterns from **MITgcm + SIMBA**.

Castellani et al., *J Geophys Res*, 2017



An example model solution



This *Calanus* cohort hatches in the Norwegian Sea and then advects into the seasonal ice zone.

from ice algae
from phytoplankton

The optimal life cycle in this environment is 2 years long.

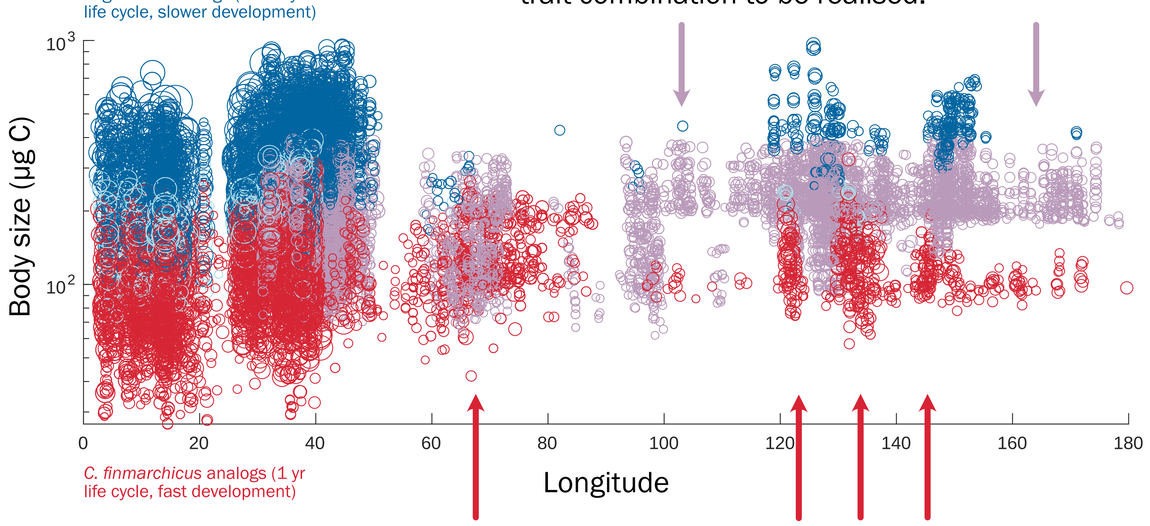
reserves (lipids)
structure

There's a signifcant offset in time (and therefore space) between **energy gain from phytoplankton** and the yield of energy to predators.

Especially predators who wisely specialise in delicious oily late life stages

Centroid of egg production for each viable trait combination

A model population with intermediate characteristics (interpretable either as *C. glacialis* adopting a fast-development, small-body-size strategy, or *C. finmarchicus* adopting a slower, multi-year life history) is optimally suited to much of the seasonal ice zone—to the extent that evolution and plasticity allow this trait combination to be realised.



Results suggest that **pockets of good habitat for *C. finmarchicus*—often described as a potential *future* for the high Arctic—may *already* exist in a patchy pattern throughout the Eurasian Arctic seas**, although connectivity might limit the ability of Atlantic *C. finmarchicus* to expand into them.

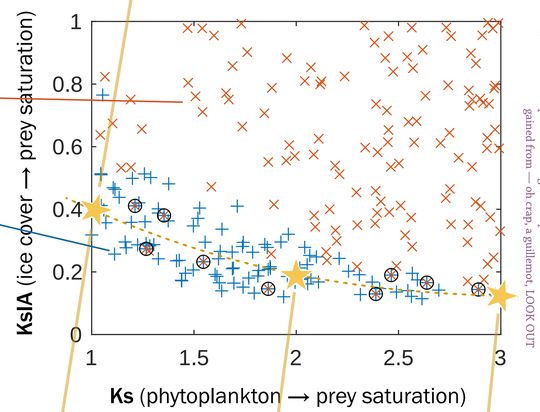
I can wait

Two large-scale empirical patterns were used to select among random parameter combinations:

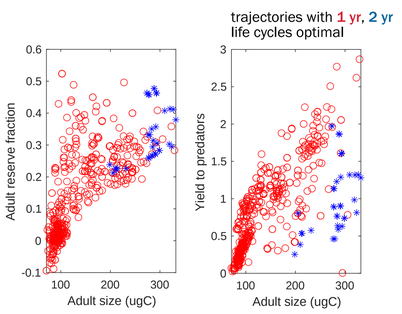
1) Adult size vs. temperature-corrected development rate

2) Viability of 2-year life cycles in the iciest conditions

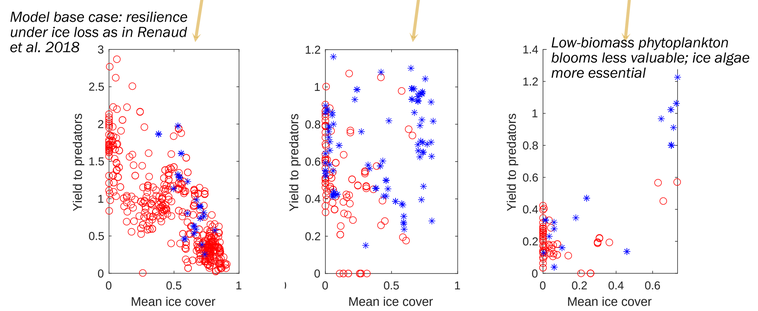
The **ensemble of possible models** that pass these filters suggest a variety of relative contributions of phytoplankton and ice algae to the *Calanus* diet—especially when phytoplankton biomass is medium–low.



This looks a lot like Approximate Bayesian Computation. In that it uses a rejection algorithm to estimate the posterior distribution of the model parameters without explicit calculation of likelihoods, thereby integrating prior knowledge of the parameters with the information gained from — oh crap, a guillemot. LOOK OUT



In all model versions, larger *Calanus* have higher lipid/energy content and produce a greater energetic yield to predators—all else equal.



Whether icier conditions mean higher or lower energetic yield to predators depends on uncertain model assumptions about the value of ice algae and phytoplankton as prey.

We are looking for partnerships in which to use these Coltrane ensemble methods to link potential biological process studies to uncertainty reduction in large-scale ecosystem projections—possibly as part of the planning phase of IPY5.

Please figure this out. I will give you an amphipod