A modeling study on processes controlling the biogeographic boundary of *Calanus* copepods in the North Atlantic - Arctic region

Rubao Ji (WHOI)

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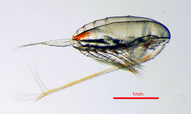
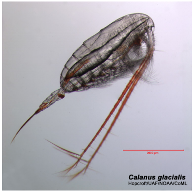
March 22, 2010

Calanus copepods in the north Atlantic - Arctic region

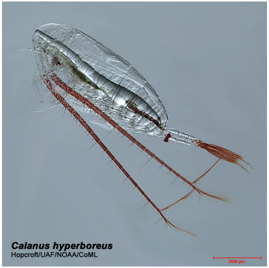
- Play a key role in the north Atlantic and Arctic pelagic ecosystem ("wasp-waist" species)



finmarchicus



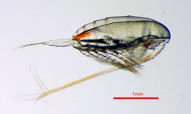
glacialis



hyperboreus

Calanus copepods in the north Atlantic - Arctic region

- Play a key role in the north Atlantic and Arctic pelagic ecosystem ("wasp-waist" species)
- Unique biogeographic boundaries; Warming and decreasing seasonal ice cover might cause the shift of boundaries.



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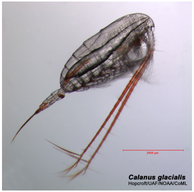

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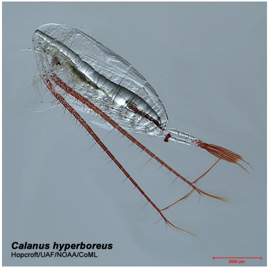

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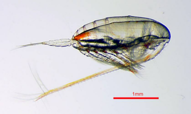
Calanus copepods in the north Atlantic - Arctic region

- Play a key role in the north Atlantic and Arctic pelagic ecosystem ("wasp-waist" species)
- Unique biogeographic boundaries; Warming and decreasing seasonal ice cover might cause the shift of boundaries.
- Critical to understand how the combinations of life hisotry, physical advection, seasonality, and food environment limits their ranges.



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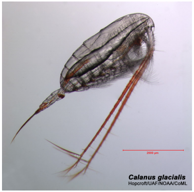

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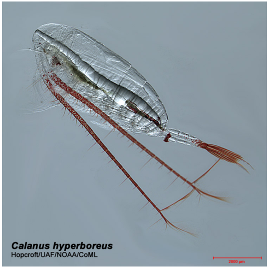


hyperboreus

Background

Estimated boundary of *Calanus finmarchicus*

- Endemic in the NN Atlantic, such as GIN Seas.

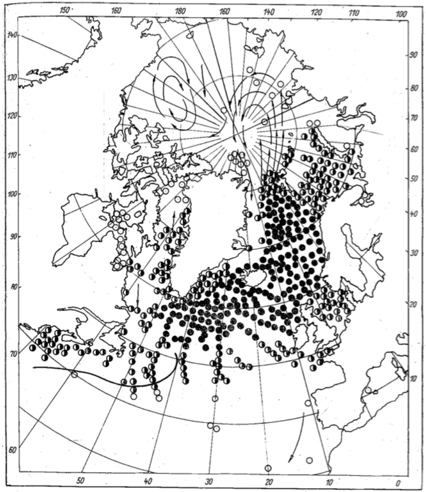
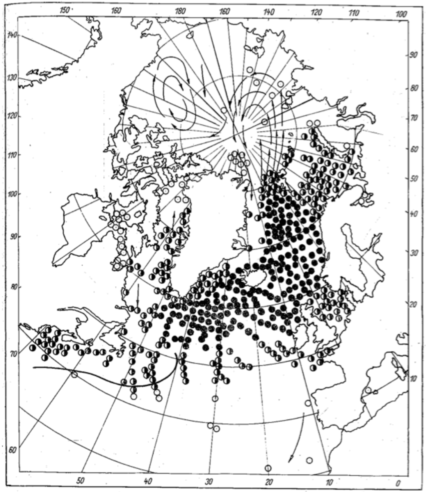


Figure: Jaschnov, 1970

Estimated boundary of *Calanus finmarchicus*

- <u>Endemic</u> in the NN Atlantic, such as GIN Seas.
- <u>Immigration</u> (non-sterile expatriation) to S. Barents Sea, North Sea and NW Atlantic.



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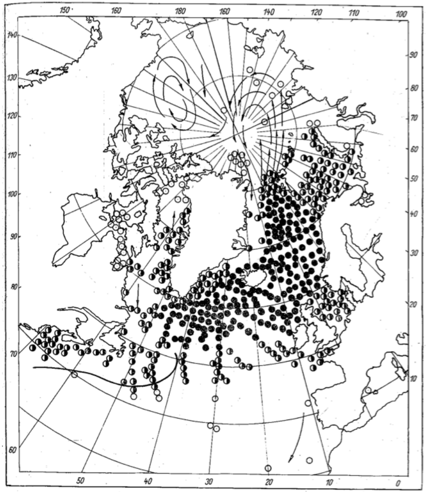
Estimated boundary of *Calanus finmarchicus*

- Endemic in the NN Atlantic, such as GIN Seas.
- Immigration (non-sterile expatriation) to S. Barents Sea, North Sea and NW Atlantic.
- Expatriation to the Polar Basin (fail to reproduce due to low T).



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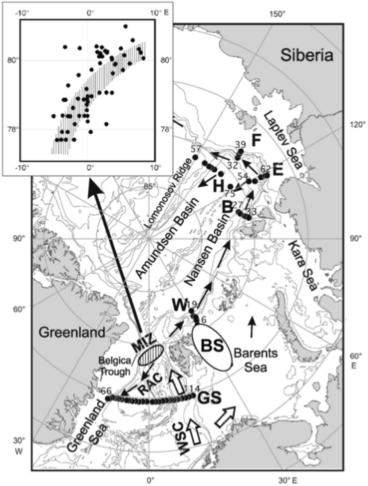
Recent observation on *Calanus finmarchicus*

- Detailed study in the Arctic Ocean and marginal seas by Hirche and Kosobokova (2007) and Kosobokova and Hirche (2009).



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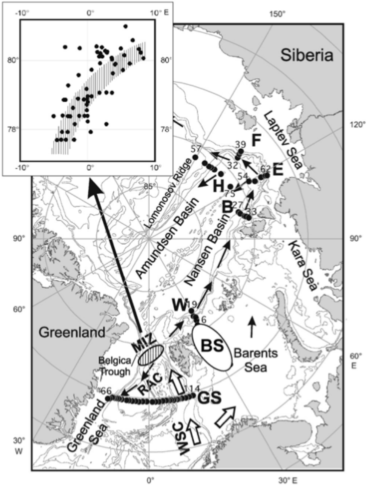

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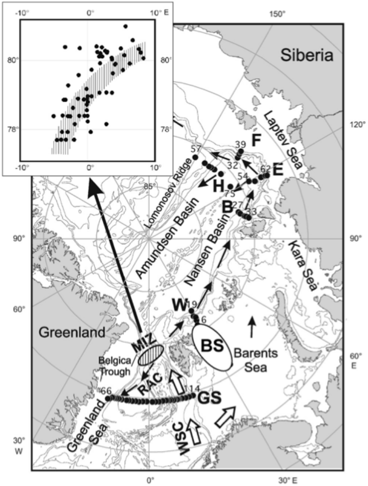
- Temperature alone is not the cause of reproductive failure in the Arctic.
- Low and/or later availability of food limits reproductive success.



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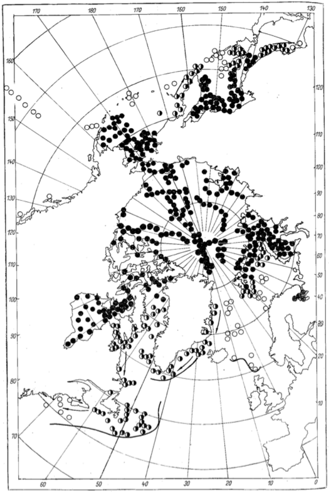
Estimated boundary of *Calanus glacialis*

- One of the most common and widespread copepods in the Arctic Ocean and marginal seas.



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Estimated boundary of *Calanus glacialis*

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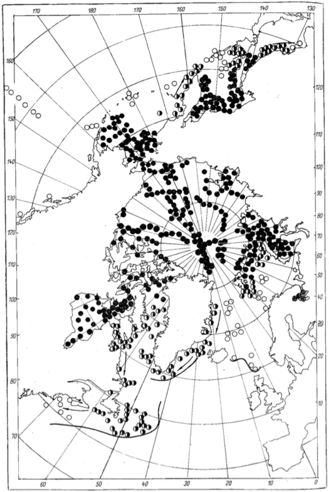

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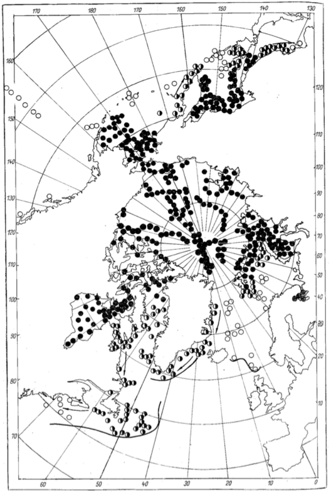
Estimated boundary of *Calanus glacialis*

- One of the most common and widespread copepods in the Arctic Ocean and marginal seas.
- Expatriate in the GIN Seas and S. Barents Sea.
- Warm temperature (>5 ^{o}C) impede spawning (Hirche and Kosobokova, 2007).



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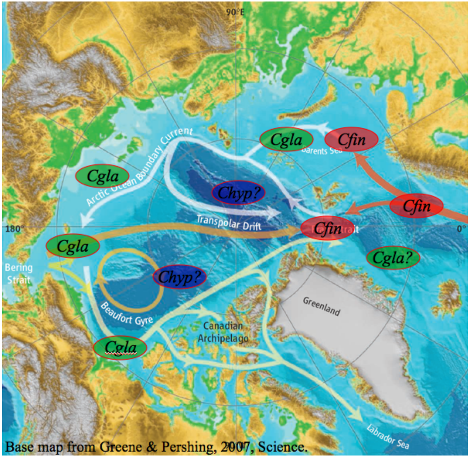
Conceptual view

- C. finmarchicus: adapted to warm Atlantic water; expatriate to the Arctic; low T and food limit reproduction in the Arctic.



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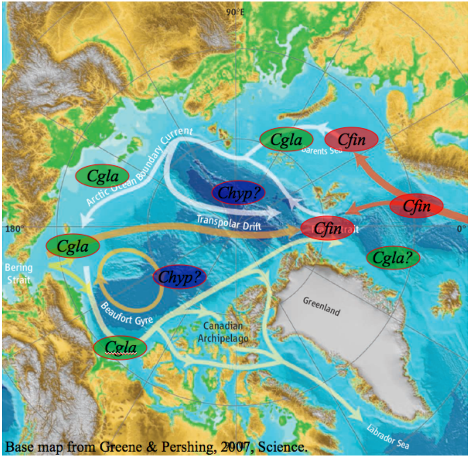
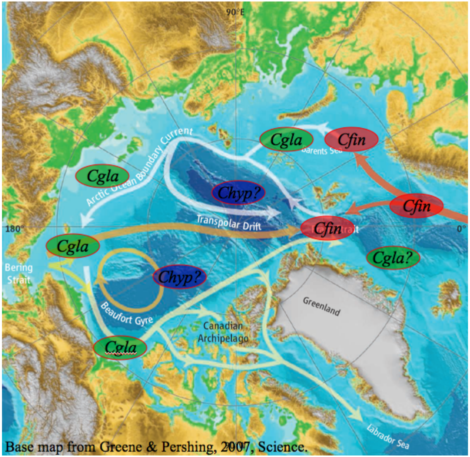


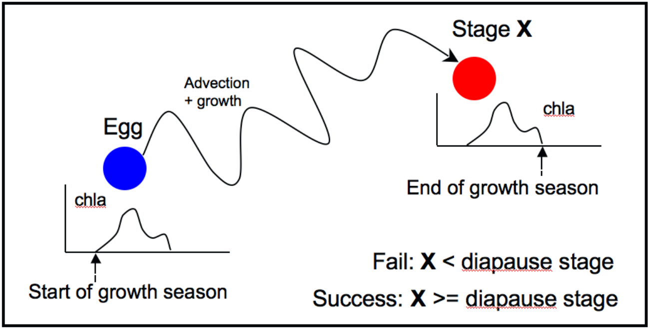
Conceptual view

- C. finmarchicus: adapted to warm Atlantic water; expatriate to the Arctic; low T and food limit reproduction in the Arctic.
- C. glacialis: adapted to cold Arctic water; most dorminant on the Arctic shelves.
- C. hyperboreus: also adapted to cold Arctic water; population center in the central Arctic Basin; expatriate on the Arctic shelves and in subarctic region.



Overall approach

- FVCOM-based IBM approach, including 3-D "offline" Lagrangian tracking and stage-based copepod modules.



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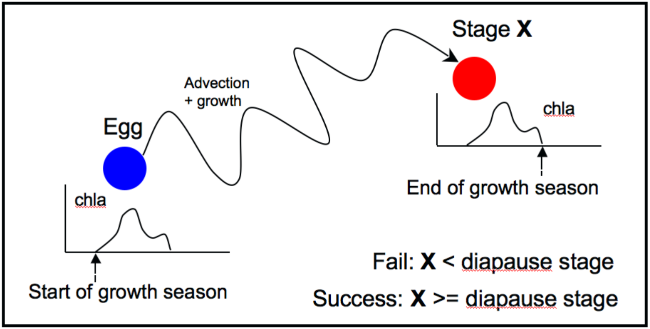
- Eggs (N4 for Chyp) released from model node points at the beginning of the growth season.



Overall approach

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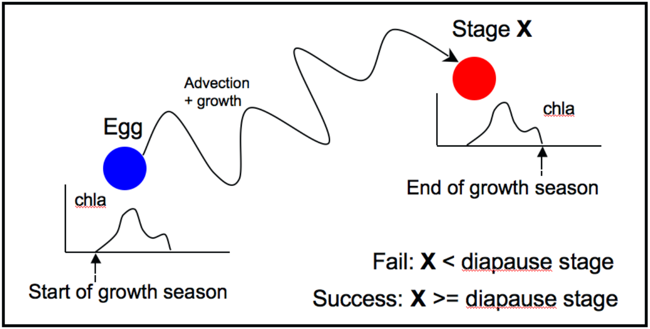
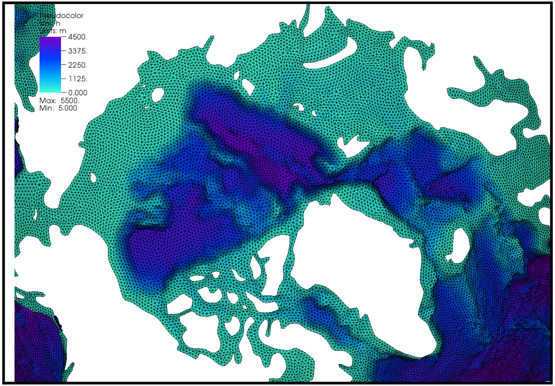
- Eggs (N4 for Chyp) released from model node points at the beginning of the growth season.
- Check whether an individual can reach the diapause stage at the end of growth season.



Offline tracking

- Coarse grid Arctic Ocean FVCOM (part of GLOBAL-FVCOM), including tide and ice dynamics.



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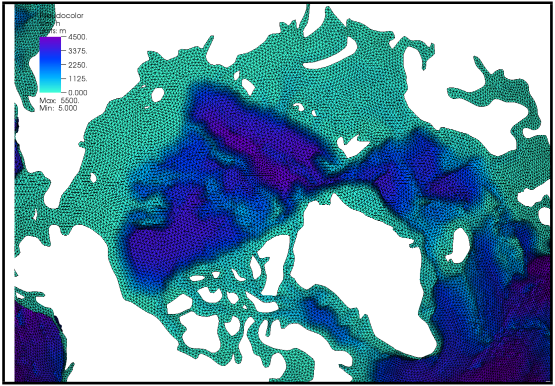
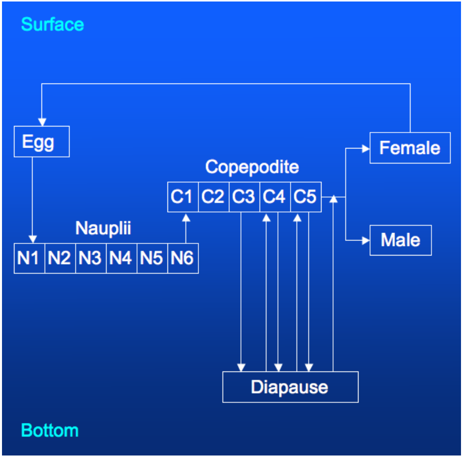
- Driven by hourly-archived FVCOM output (temperature,mixing and current fields).



Calanus model

- Different generation time, varying from 1 to 3 yrs.



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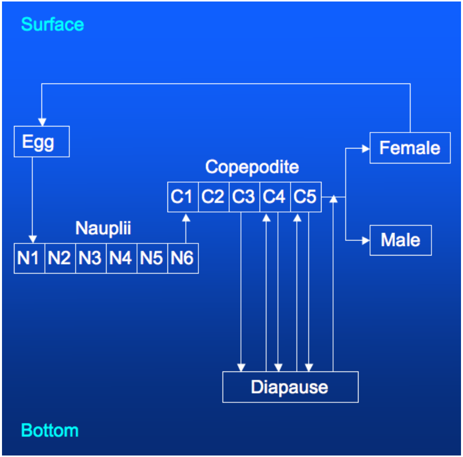

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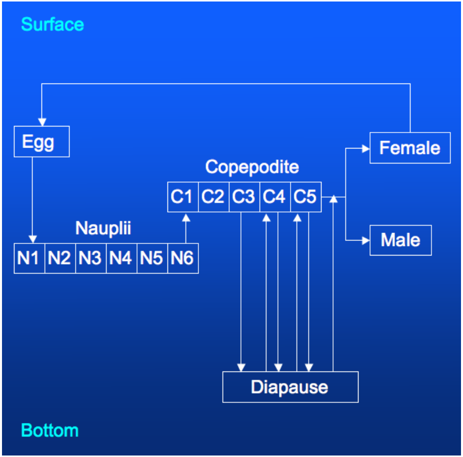

Calanus model

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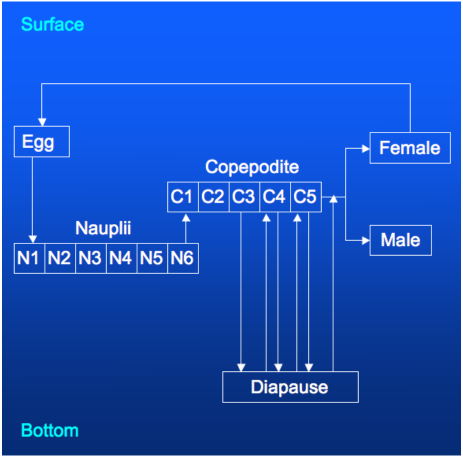
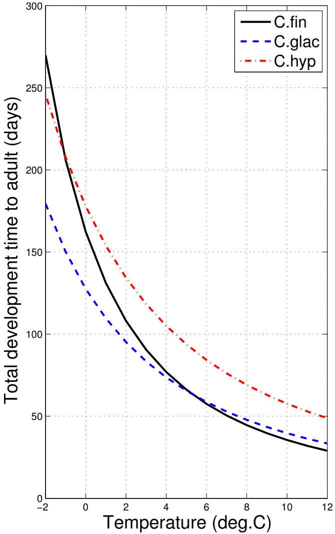
- Temperature and food dependent development. $D = a(T + \alpha)^{\beta}[1 - e^{(-F/K)}]$.



Temperature-dependent development

- *C. finmarchicus* parameter from Campbell et al. (2001).



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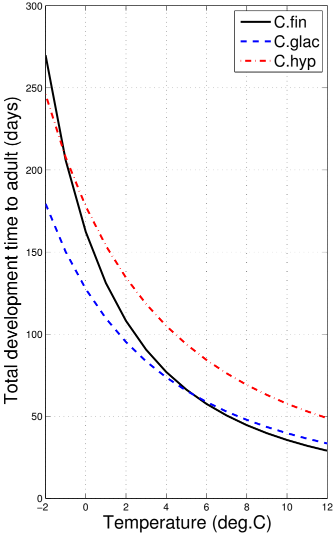

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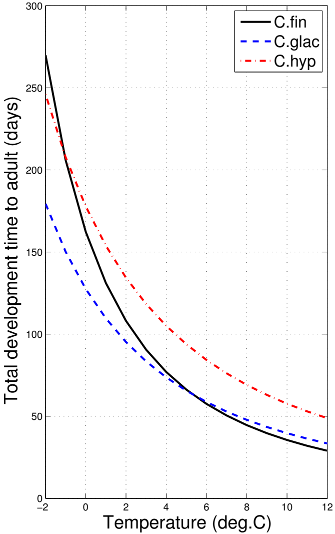
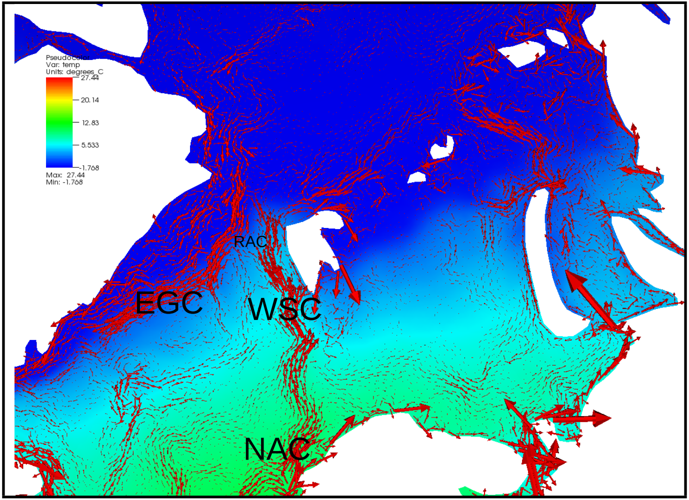
- Verified *C. glacialis* egg hatching time from lab exp. at 0 ^{o}C.

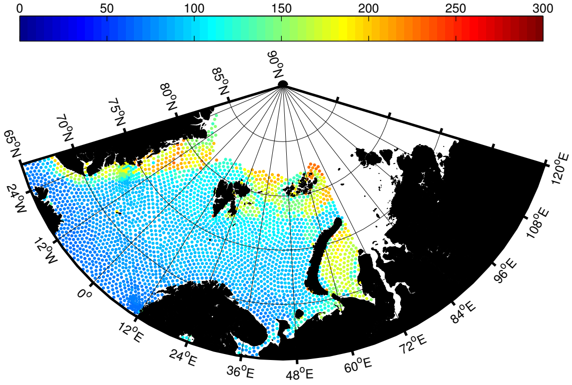


Model-computed currents and temperature
(example: September mean)



Timing and location of initial releasing

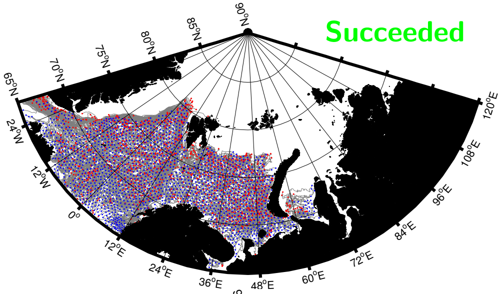
- Timing based on satellite detected Chl-a concentration (for *C.finmarchicus*).
- Each dot represents starting year day (in color) and location.
- Earlier in the E. Greenland Sea and the S. Barents Sea.

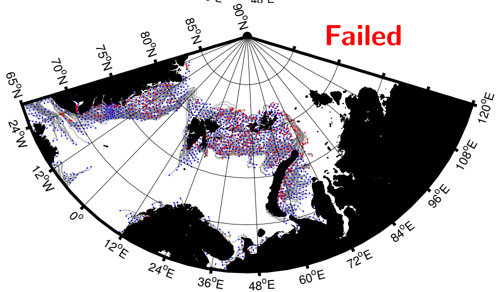


Case 1

Dev=f(T); Surface

- Individuals in the S. GIN Seas and S. Barents Sea successfully reach C5.
- No penetration into the Arctic Basin, possibly due to low T and short GSL.
- Individuals that failed to reach diapause not advected into the Arctic Basin by the end of growth season.

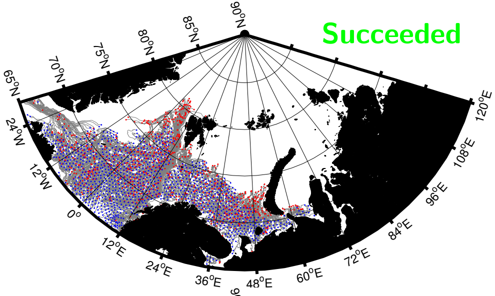


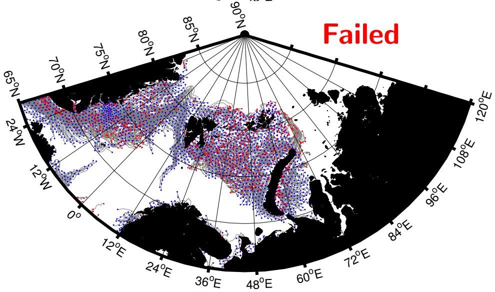


Case 2a

Dev=f(T,food); Surface

- Successful individuals located further south.
- Match with estimated boundaries near the Polar Front and the Arctic Front.
- Food availability plays an important role.



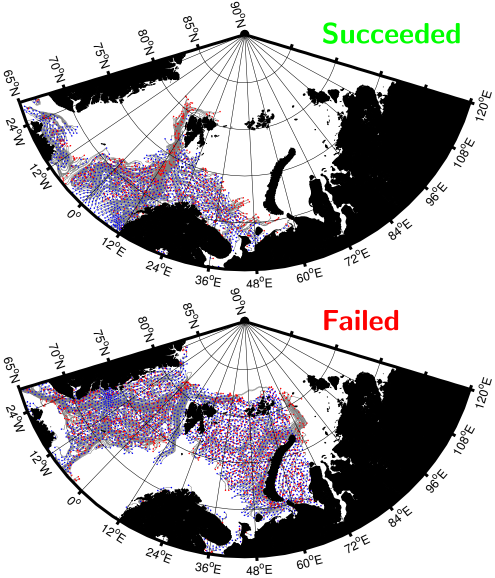


Results - *C. finmarchicus*

Case 2b

Dev=f(T,food); 50 m

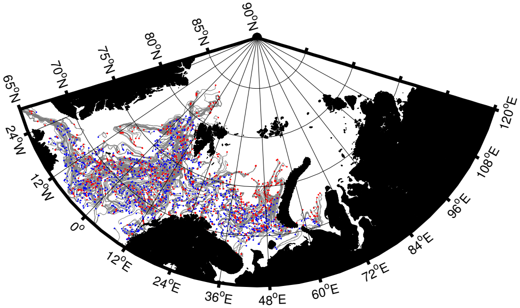
- Similar to the surface case (2a).
- Successful individuals further south (possibly due to lower summer T at 50m)
- Eastward advection of successful individuals along the shelf-break to the north of Spitzbergen.



Case 3

Advection during diapause

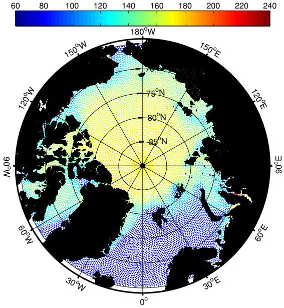
- Continued transport of successful individuals at depth (300 m or 10 m above bottom) until mid next yr
- The advection transport is very limited: few diapausing individuals advected into the Arctic Ocean during the winter



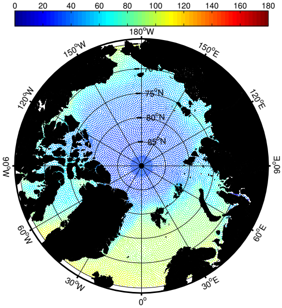
Timing and location of initial releasing

- Initial date based on the satellite-derived onset of snow melt at each grid (NSIDC).
- End of growth season based on daily mean of shortwave radiation at each grid.

Initial timing (yd)



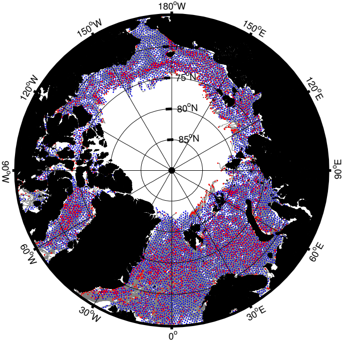
GSL (day)



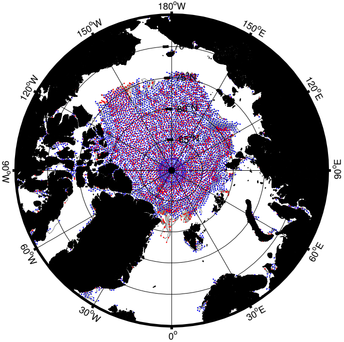
C. glacialis

- Succeeded on the Arctic shelves and surrounding marginal seas.
- Failed in the central Arctic Basin.
- The GIN Seas and S. Barents Sea diff from historial view.

Succeeded



Failed



C. glacialis

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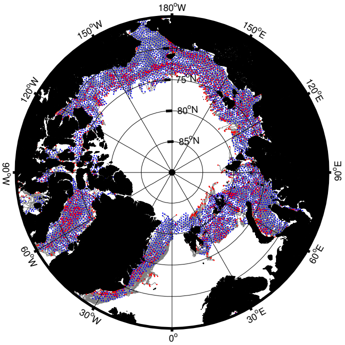
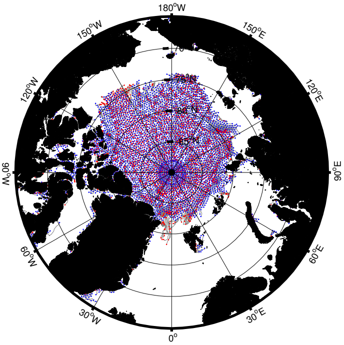
- Ice may provide favorible condition (ice algae as food) + high T.

Succeeded

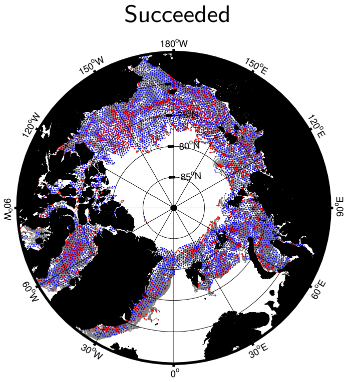


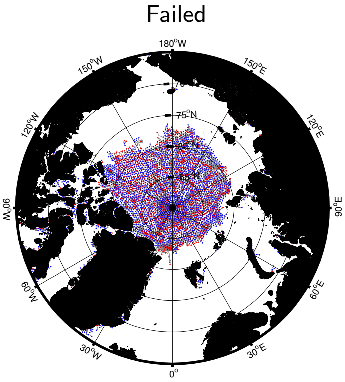
Failed



C. hyperboreus

- Show similar pattern as *C. glacialis*.
- Successful inds. extended further into the central Basin.
- Inds. in the central Basin failed to reach C3.





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- The modeled distribution matchs with the previously observed/estimated biogeographic boundries for *C. finmarchicus* and most of *C. glacialis*, but not *C. hyperboreus*.
- Model suggests that *C. finmarchicus* is unable to penetrate into the Arctic Ocean under present conditions.
- Neither *C. glacialis* nor *C. hyperboreus* can reach their diapause stages in the central Arctic Basin, suggesting either the growth parameters are incorrect or the growing season is longer; or *C. hyperboreus* is not endemic in the central Basin.

- Parameters and vital rates: Food dependency; Temperature dependency (Equiproportional rule).

Issues

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- Determination of GSL: Snow melting and light intensity as proxy for *C. glacialis* and *C. hyperboreus*.

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- Determination of GSL: Snow melting and light intensity as proxy for *C. glacialis* and *C. hyperboreus*.
- Improved mapping of current biogeographic boundary; Warming scenario testing.

Acknowledgements

- NSF Arctic SBI-3 Program
- NSF Pan-regional GLOBEC
- WHOI SSF: Jessica McNally
- WHOI GI: Xinyou Lin