StrathCal:

Spatial Modelling of Size-Structured *Calanus*

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Where StrathCal does it fit?

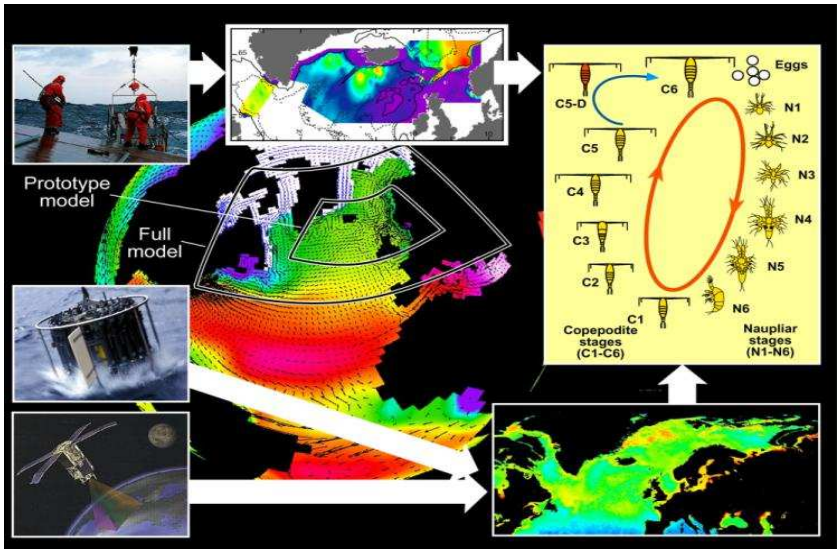
It is one of two models in **"DIAPOD WP5 Integrative spatial models of *Calanus* spp. - Evaluating the new arctic as habitat"** used to address the following:

Model Question 1: What are the limits to poleward expansion of *C. finmarchicus* in the Atlantic Arctic in the near term: advection, low temperatures, or the availability of high-quality prey?

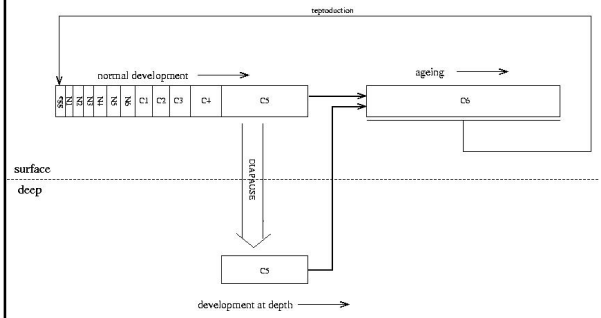
Model Question 2: How will the map of viable Arctic/subarctic habitat change over the next century for small income breeders like *C. finmarchicus*, large capital breeders like *C. hyperboreus*, and highly plastic intermediate organisms like *C. glacialis*?

Model Question 3: Are spatiotemporal changes in total primary production, and total *Calanus* lipid production (i.e. *Calanus* production times average individual lipid content) consistent with each other or distinct?

The origins of StrathCal: The NERC MarProd programme



The Model Framework



- Uniform 'physiological age' for each group of stages
- Development rate a function of temp. and food
- Diapause entry from start of C5 stage

Update all classes in given group at given location at times $\{U_{x,u}\}$ such that

$$\Delta q = \int_{U_{x,l}}^{U_{x,u}} g(t)dt$$

according to $C^{+}_{q+\Delta q,x,u} = \xi_{q,x,u} C^{-}_{q,x,u}$

where $\xi_{q,x}$ **≡ Survival of individual in q at x over increment up to u**

Update at regularly spaced times: T_i

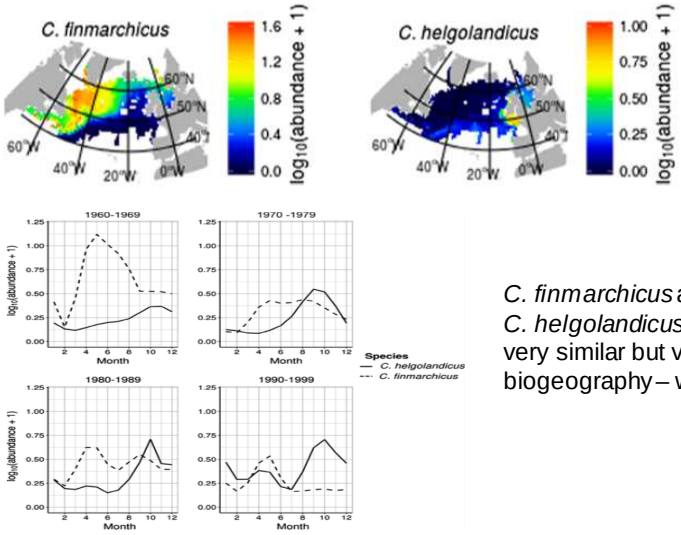
$$C^{+}_{q,x,T_i} = \sum_{y} \Psi_{x,y,T_i} C^{-}_{q,y,T_i}$$

C^{-}_{q,x,T_i} ≡ Class abundance just before update

C^{+}_{q,x,T_i} ≡ Class abundance just after update

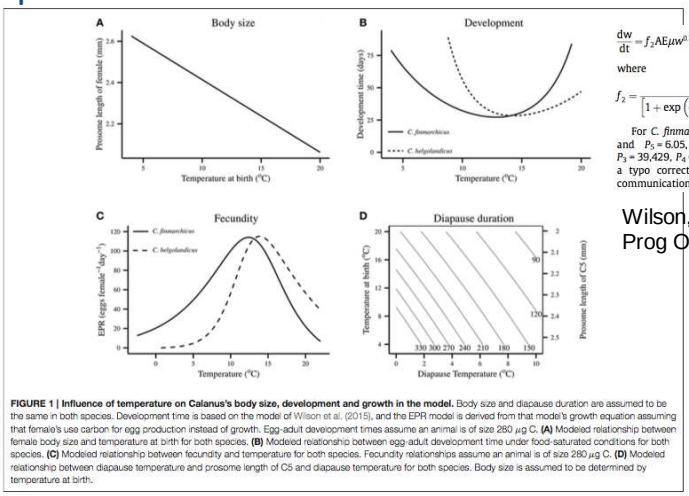
Ψ_{x,y,T_i} ≡ Transfer matrix element from y to x for period to T_i. Determine by particle tracking in flow fields from GCM plus random (diffusive) component.

Extending StrathCal to other *Calanus* species



C. finmarchicus and *C. helgolandicus*: physically very similar but very different biogeography – why?

Influence of temperature on *Calanus* feeding, body size, growth, and diapause potential



$$\frac{dw}{dt} = f_2 A E \mu w^{0.75} - Q_{10}^{T/10} \lambda w^{0.75}$$

where

$$f_2 = \frac{P_5}{\left[1 + \exp\left(\frac{P_3}{T+273} - \frac{P_3}{P_1}\right) + \exp\left(\frac{P_4}{P_2} - \frac{P_4}{T+273}\right)\right]}$$

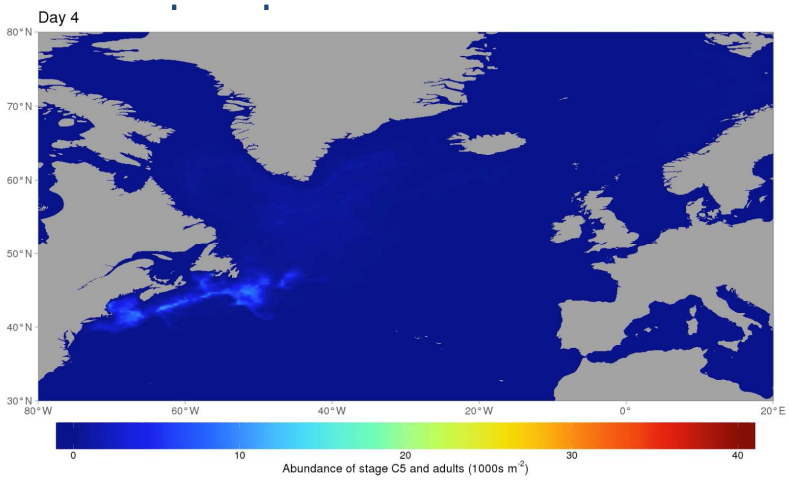
For *C. finmarchicus* $P_1 = 293$, $P_2 = 284$, $P_3 = 13{,}282$, $P_4 = 29{,}725$, and $P_5 = 6.05$, and for *C. helgolandicus* $P_1 = 289$, $P_2 = 275$, $P_3 = 39{,}429$, $P_4 = 14{,}123$ and $P_5 = 12.12$ (Møller et al., 2012). P_5 is a typo corrected from Møller et al. (2012) (Møller, personal communication).

FIGURE 1 | Influence of temperature on Calanus's body size, development and growth in the model. Body size and diapause duration are assumed to be the same in both species. Development time is based on the model of Wilson et al. (2015), and the EPR model is derived from that model's growth equation assuming that female's use carbon for egg production instead of growth. Egg-adult development times assume an animal is of size 280 μg C. **(A)** Modeled relationship between female body size and temperature at birth for both species. **(B)** Modeled relationship between egg-adult development time under food-saturated conditions for both species. **(C)** Modeled relationship between fecundity and temperature for both species. Fecundity relationships assume an animal is of size 280 μg C. **(D)** Modeled relationship between diapause temperature and prosome length of C5 and diapause temperature for both species. Body size is assumed to be determined by temperature at birth.

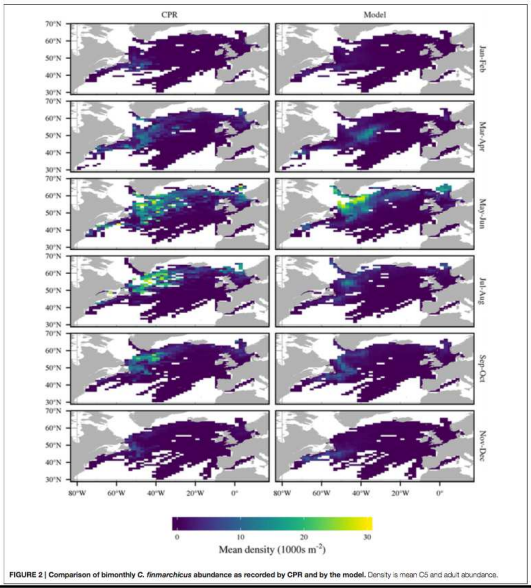
Wilson, Speirs & Heath (2015) Prog Oceanog. 134:413-431

Wilson, Heath & Speirs (2016) Front. Mar. Sci. 3:157

Modelled annual cycle of surface *C. finmarchicus*



Predicted and observed spatial distributions of surface CV & CVIs



Wilson, Heath & Speirs (2016) Front. Mar. Sci. 3:157

C. finmarchicus time series comparisons

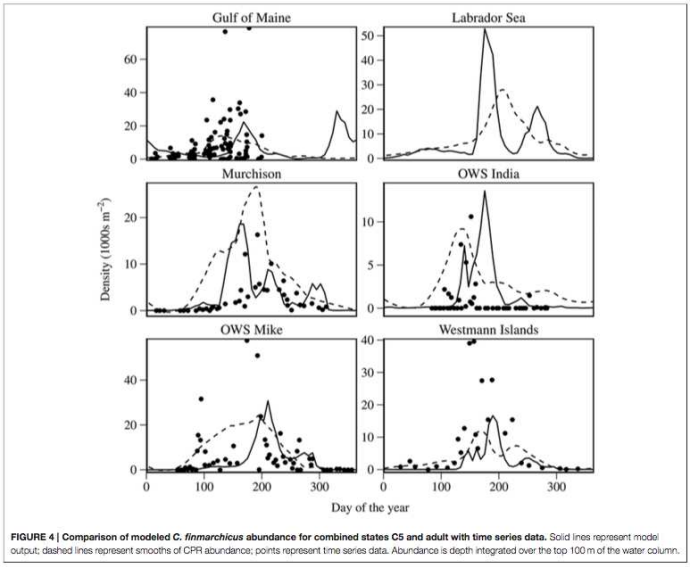


FIGURE 4 | Comparison of modeled *C. finmarchicus* abundance for combined states C5 and adult with time series data. Solid lines represent model output; dashed lines represent smooths of CPR abundance; points represent time series data. Abundance is depth integrated over the top 100 m of the water column.

Wilson, Heath & Speirs (2016) Front. Mar. Sci. 3:157

Summary of StrathCal key features

- **2.5 D in space**: lat, lon, 2 depth layers (surface 20m, and deep). Deep layer is fixed in time but variable – data-based - in space.
- **Horizontal movement** in both layers determined by ocean currents.
- **Development rate** on surface depends on temperature and food (chlorophyll). This is an emergent property of a model of temperature-dependent feeding and metabolic costs.
- **Adult body size** – and lipid content - determined by temperature at birth.
- **Fecundity** depends on temperature, food, and body size. This is an emergent property of the temperature-dependent feeding and metabolic costs model.
- **Mortality** has
  - i) a stage-dependent background rate that scales with temperature
  - ii) a starvation term below a threshold growth rate
  - iii) a density-dependent term which depends on local (model spatial cell) total biomass
- **Entry to diapause** is a growth-rate-dependent fraction of individuals entering CV stage.
- **Duration of diapause** is determined by body size (lipid content) and deep temperature.

Thank you!

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