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Modelling Mesopelagic fish with the “StrathSpace” approach

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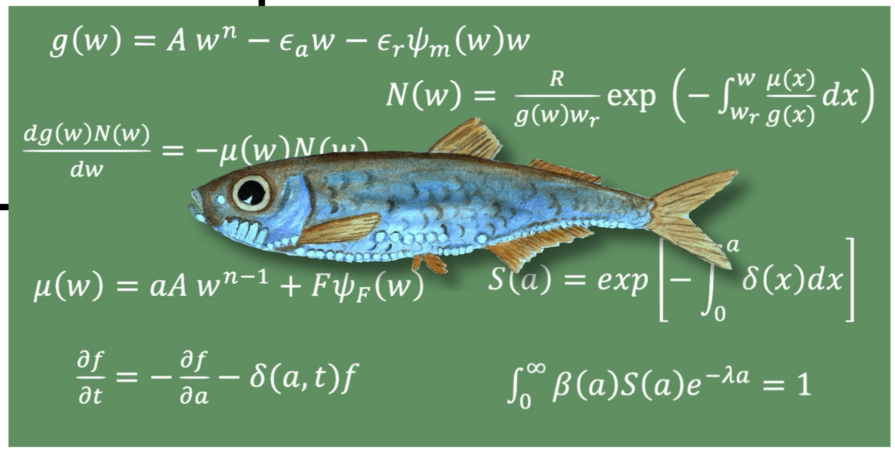
The Modelling Challenge

- Physiologically and spatially explicit demographic model
- Ocean-basin scale – advection plus diffusion
- Hypothesis tests require wide parameter exploration
- Need exceptional computational efficiency



Our Solution

- Focus on single species
- Computationally efficient discrete-space and discrete-time approach
- In space the population is divided in a grid of horizontal cells.
- Vertically, there are two layers – the surface (top 100m) and a deep layer (c. 400m) for adults.
- Separate computation of physical (movement) and biological (growth) components
- The probability of moving between cells is calculated by Lagrangian particle tracking using a General Circulation Model (GCM).
- Gives $\sim 10^4$ speed-up relative to Lagrangian ensemble

Representing Physical Transport

Update at regularly spaced times: T_i

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

$C^{-}_{q,x,T_i} \equiv$ Class abundance just before update

$C^{+}_{q,x,T_i} \equiv$ Class abundance just after update

$\Psi_{x,y,T_i} \equiv$ Transfer matrix element from y to x for period to T_i. Determined by particle tracking in flow fields from GCM plus random (diffusive) component.

Updating the Biological Model

At each spatial cell and length class

- Calculate the increase in body length that occurs in a time-step and according to the von Bertalanffy growth equation

$$\Delta L = (L_\infty - L)(1 - e^{-\gamma \Delta t})$$

$$L_\infty = L_{max} F / (F_h + F)$$

$$\gamma(T) = \gamma_0 Q_{10}^{(T - T_0)/10}$$

- For each source length class move surviving individuals (after applying a mortality rate) to destination length class
- If in spawning period calculate the eggs produced and add to the egg class

Updating the system state

For each spatial cell, in turn:

- Grow (increase in length) the population over all length over a growth time-step
- Remove individuals by applying mortality over the time-step
- If the time is greater than the next transport time-step then stop

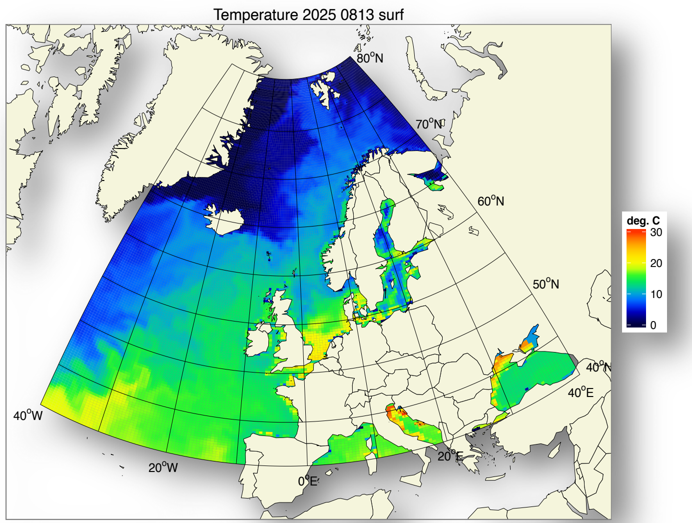
Do next transport update, output state variables and repeat.

Produces model realisations in good agreement with PDE and Lagrangian ensemble solutions, but MUCH faster.

<u>The StrathSPACE model of *Benthosema glaciale*</u>

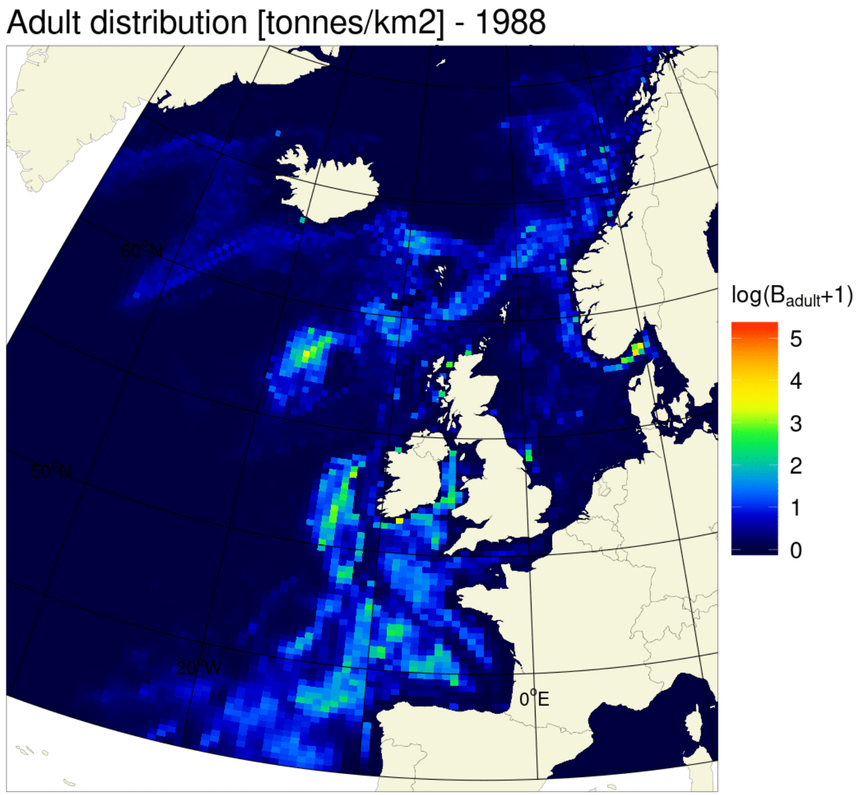
- Discrete time and space closed life-cycle population model
- Length structured population
- Von Bertalanffy growth
- Planktonic larvae
- Biodiffusive adults
- Temperature-dependent growth and mortality
- Transport and temperature from NEMO model, National Oceanography Centre (NOC), Southampton, for 1980-2099, with RCP 8.5 for forward run, for the whole Atlantic.
- Population model very fast (1-5 seconds per model year).

Benthosema glaciale



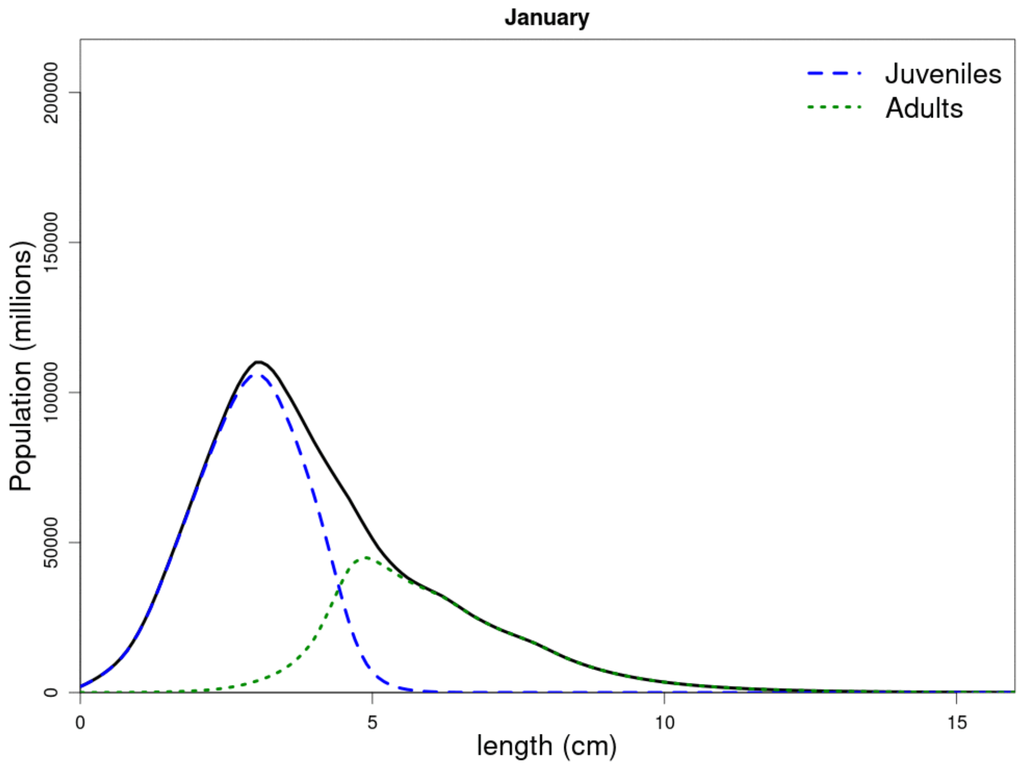
Projected (2025) surface temperature from the NEMO model

StrathSPACE *Benthosema model outputs – spatial distribution*



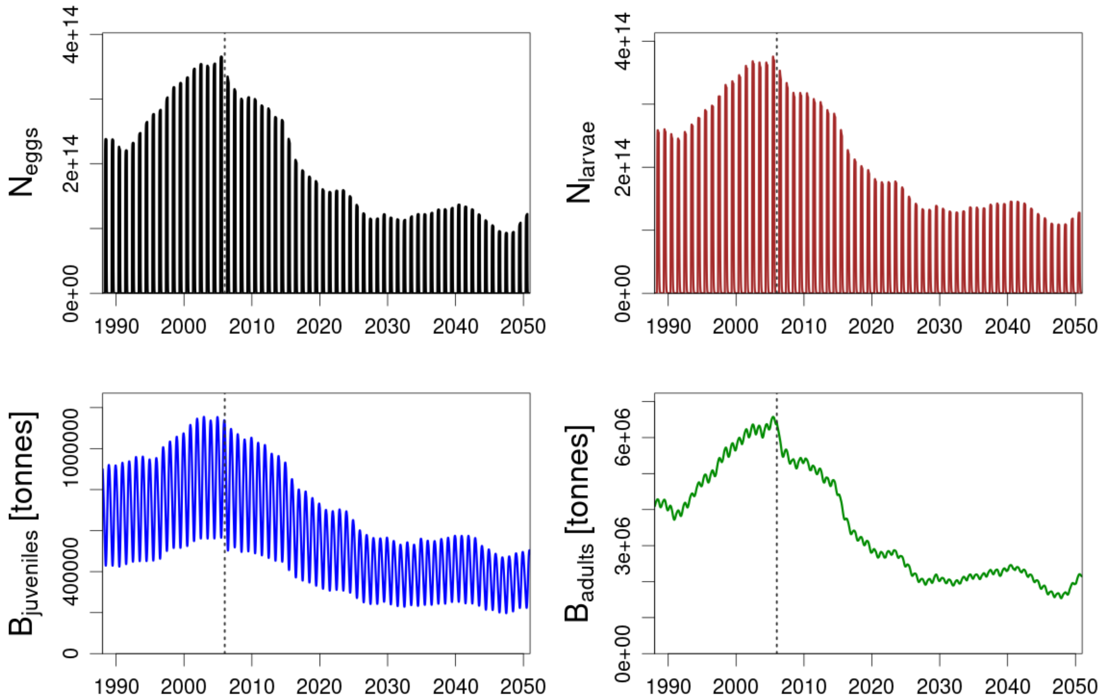
StrathSPACE *Benthosema* model hindcast and forward run 1988-2050

StrathSPACE *Benthosema model outputs – length distribution*



Modelled seasonality of *Benthosema* length distribution

StrathSPACE *Benthosema model outputs – abundance time series*



Forward run *Benthosema* model