On the importance of temporal and spatial variation in fisheries

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Spatial Issues in Arctic Marine Resource Governance

ACCESS
Arctic Climate Change
Economy and Society

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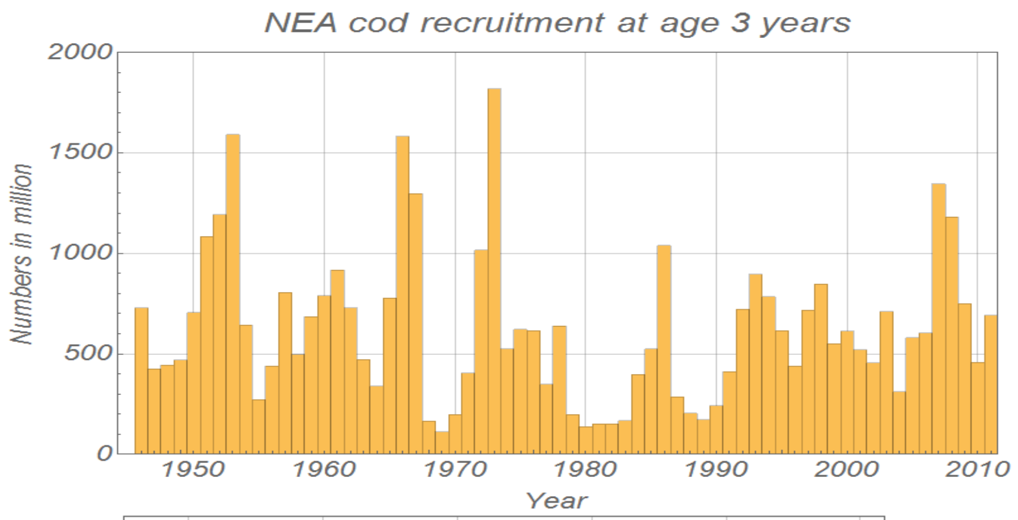
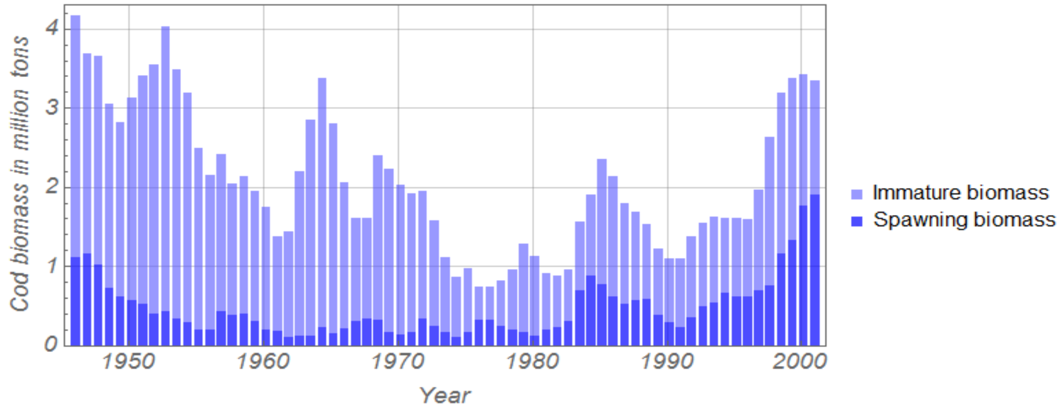
The failure of bioeconomics

- Gordon and Scott demonstrated in the mid fifties how resource rent is wasted in a pure open access fisheries, utilising a simplistic modelling framework
- Only the most cost-efficient vessels could in the long run survive in their simple model of an open access fishery economic (assuming rational behaviour)
- Fleet diversity: Model contradicting observations
  Scott (2011): "Unlike biologists and anthropologists, who naturally observed wide differences everywhere in the fishery, economists of the 1950s and 1960s had progressed by assuming homogeneity: uniformity in the fishery, ocean resources, and institutions."
- *Wilen (1999): "What differences have we made?"*

The impact of natural variation

- Fluctuating recruitment
- Unpredictable growth variation (depending on physical and biological environment)
- Variation in spatial distribution is not the only complicating factor in fisheries modelling





Hjort (1914): Sun in – Cod out

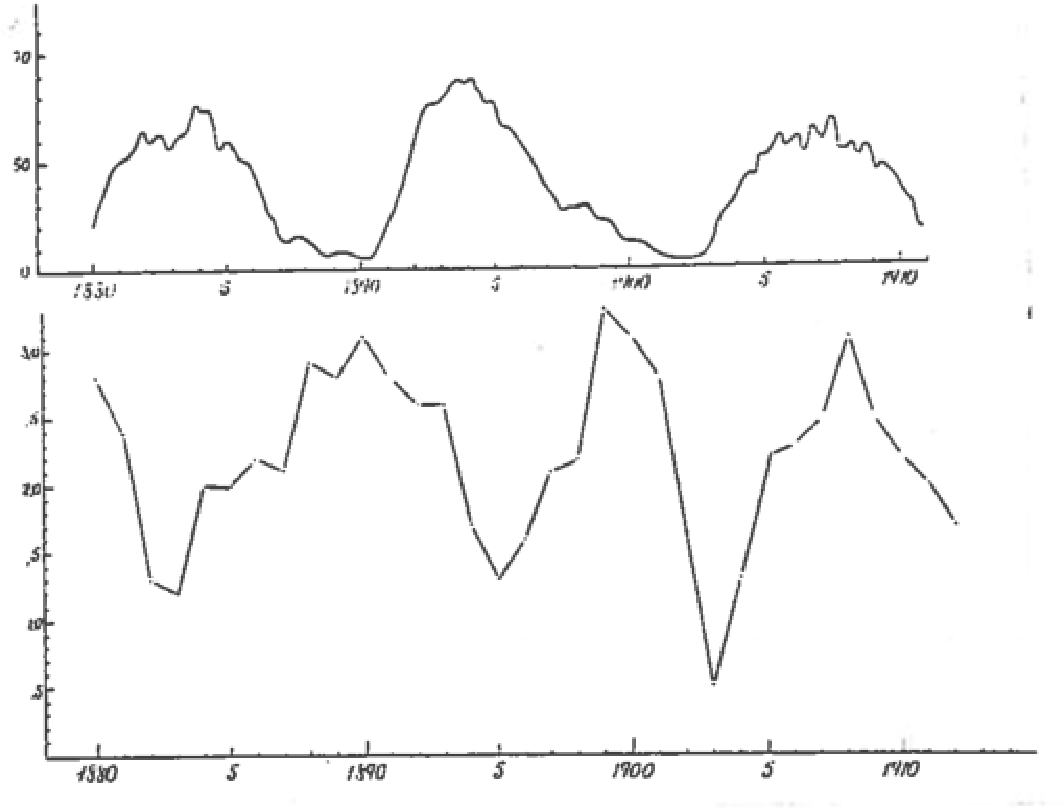


Fig. 116. Curve showing no. of sun spots for the years 1880—1911 (uppermost); below, curve showing quantity of liver in Lofoten skrei for the same years.

- 100 years ago Johan Hjort published his work on the fluctuations in the great fisheries in the Northern Europe.
- On page 186 he shows a striking correlation between number of sun spots and the liver quantities in the Lofoten cod fisheries
- (The good correlations did not last…)

Periodical variation between stocks

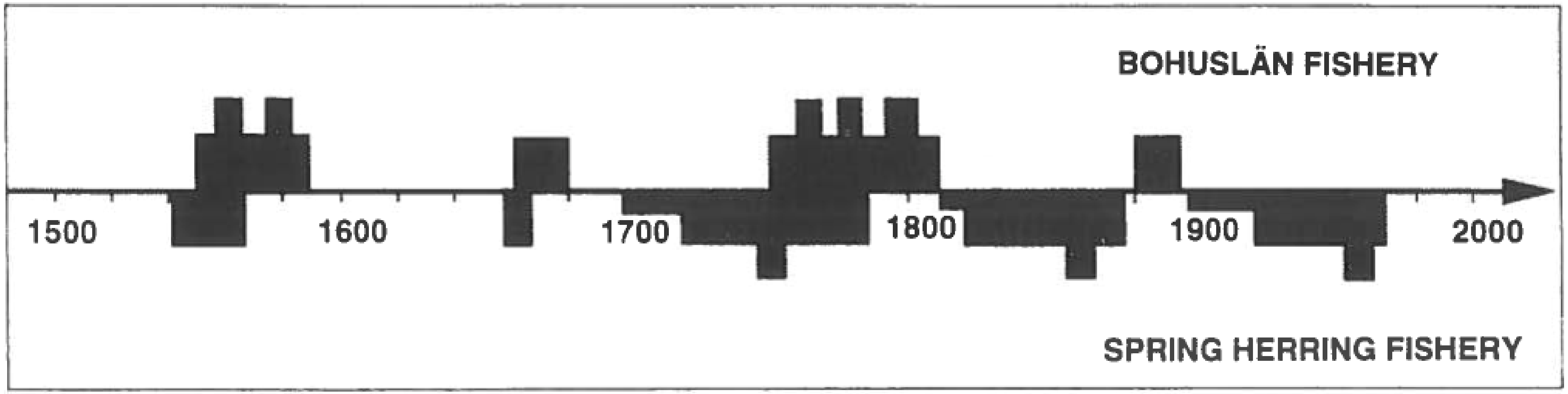


Figure 7. Herring periods off the coat of Bohuslän (above line) and the Norwegian coast; only periods with occurrence of Norwegian spring-spawning herring have been indicated. Culminations are indicated by peaks (Boeck, 1871; Ljungman, 1882; Pettersson, 1922).

From Øiestad (1994)

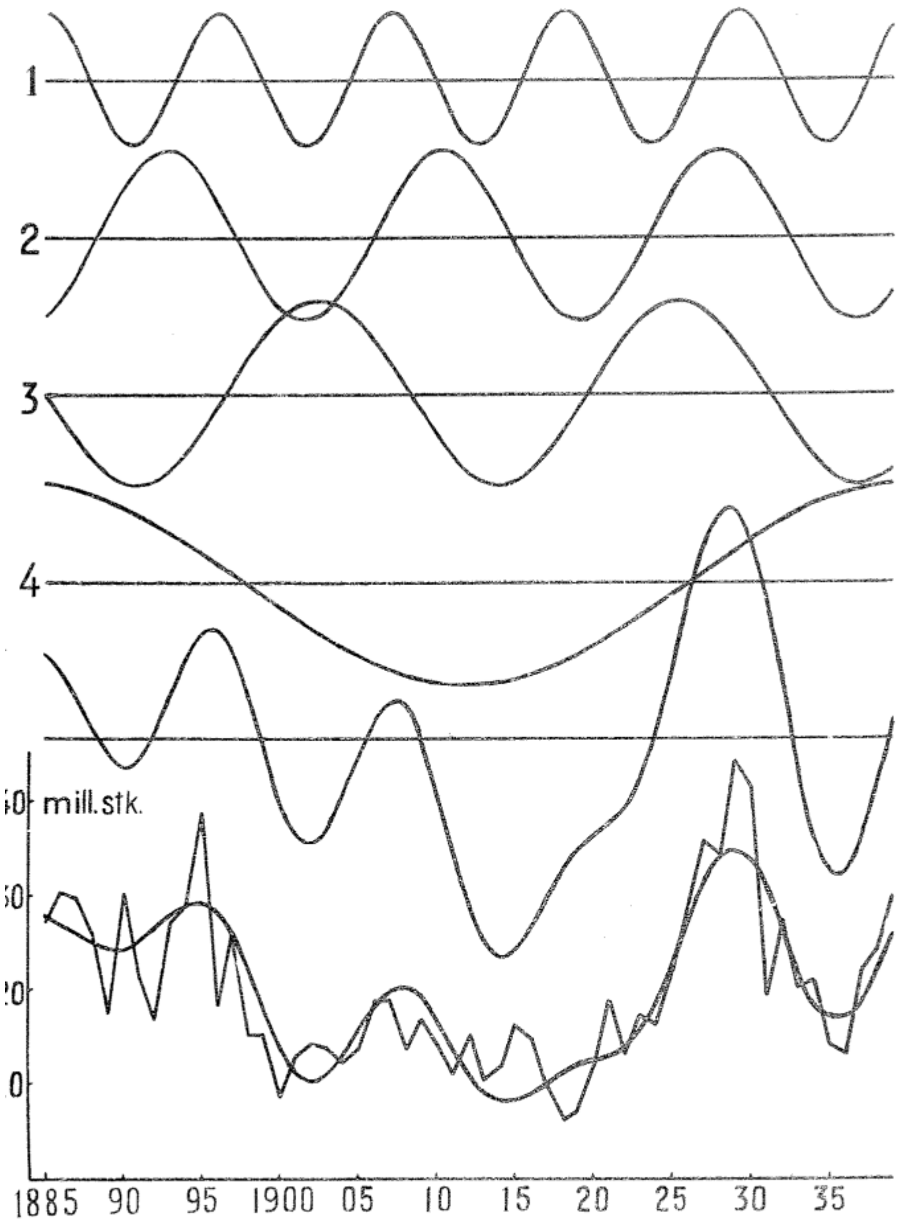


Fig. 1.

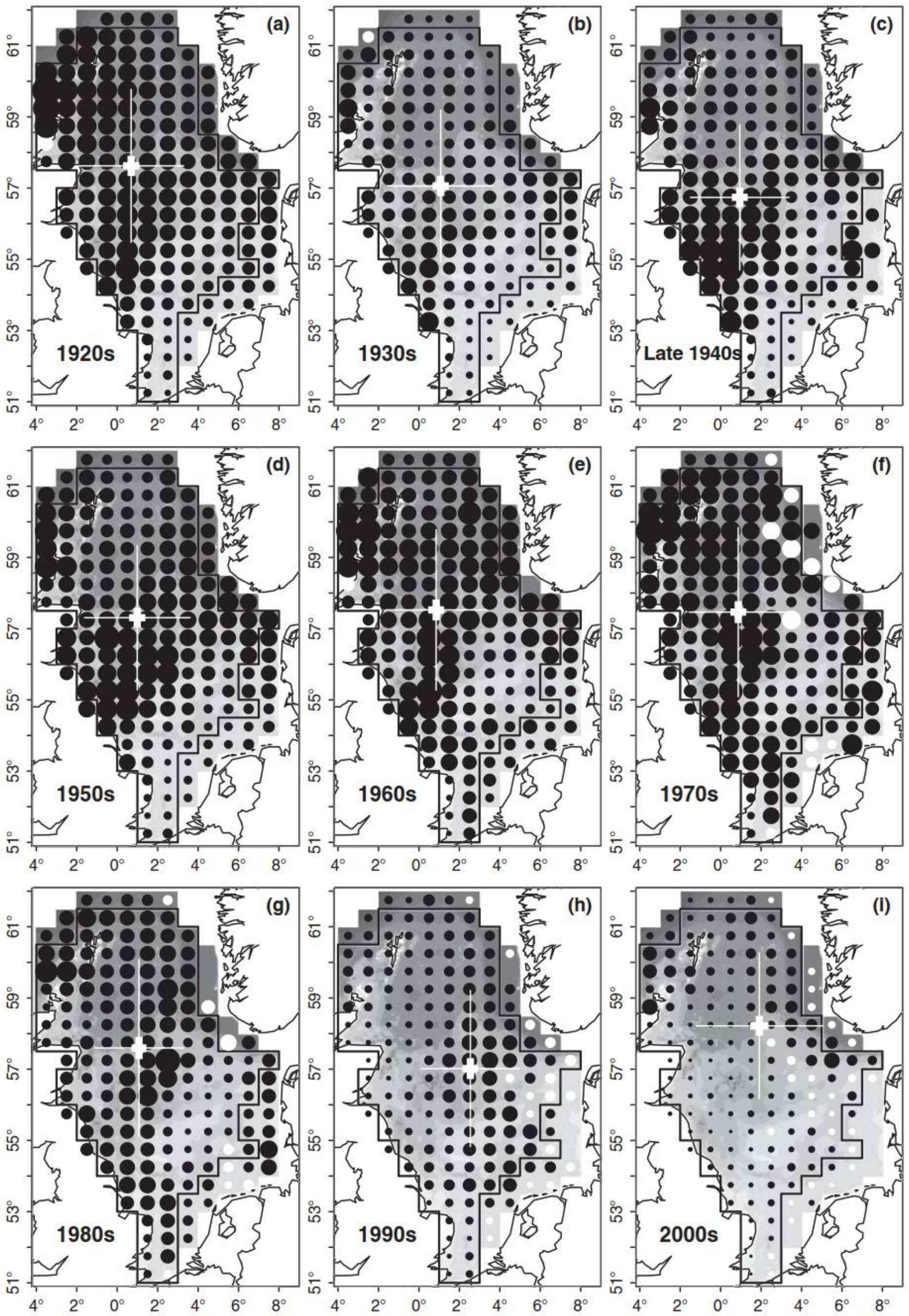
Modelling natural variation

- Per Ottestad published in 1942 a sine-model aiming to predict future catches of cod in Lofoten. The model was based on growth zones of pine and spruce (data series covering more than 500 years)
- Ottestad published an extended version in Nature in 1960

North Sea Cod distribution 1920s – 2000s

Fig. 2 Decadal changes in North Sea cod distribution, 1920s–2000s, based on fisheries lpue (landings per unit effort by British trawlers). The area sizes of the black circles are proportional to cod lpue, normalized by decade (Eqn 1) and corrected for the average spawning stock biomass (SSB) in each decade (Eqn 2), to visualize the stock's long-term biomass dynamics. In rectangles where no lpue data were available in a given decade (no effort by British trawlers), white circles represent the long-term average lpue for the given rectangle (again corrected for mean decadal SSB). For each map, the white cross indicates the centre of gravity of cod distribution, with its standard error (shorter, thick white lines) and standard deviation (longer, thin white lines) in the longitudinal and latitudinal directions. The black-lined polygon encompasses those rectangles included in the analyses on centres of gravity of distribution. Bathymetry is indicated by light to dark grey shading (from shallow to deep).

(Engelhard, Righton and Pinnegar, 2014)



Left:

Polar cod and capelin distributions

(Hop and Gjøsæter, 2013)

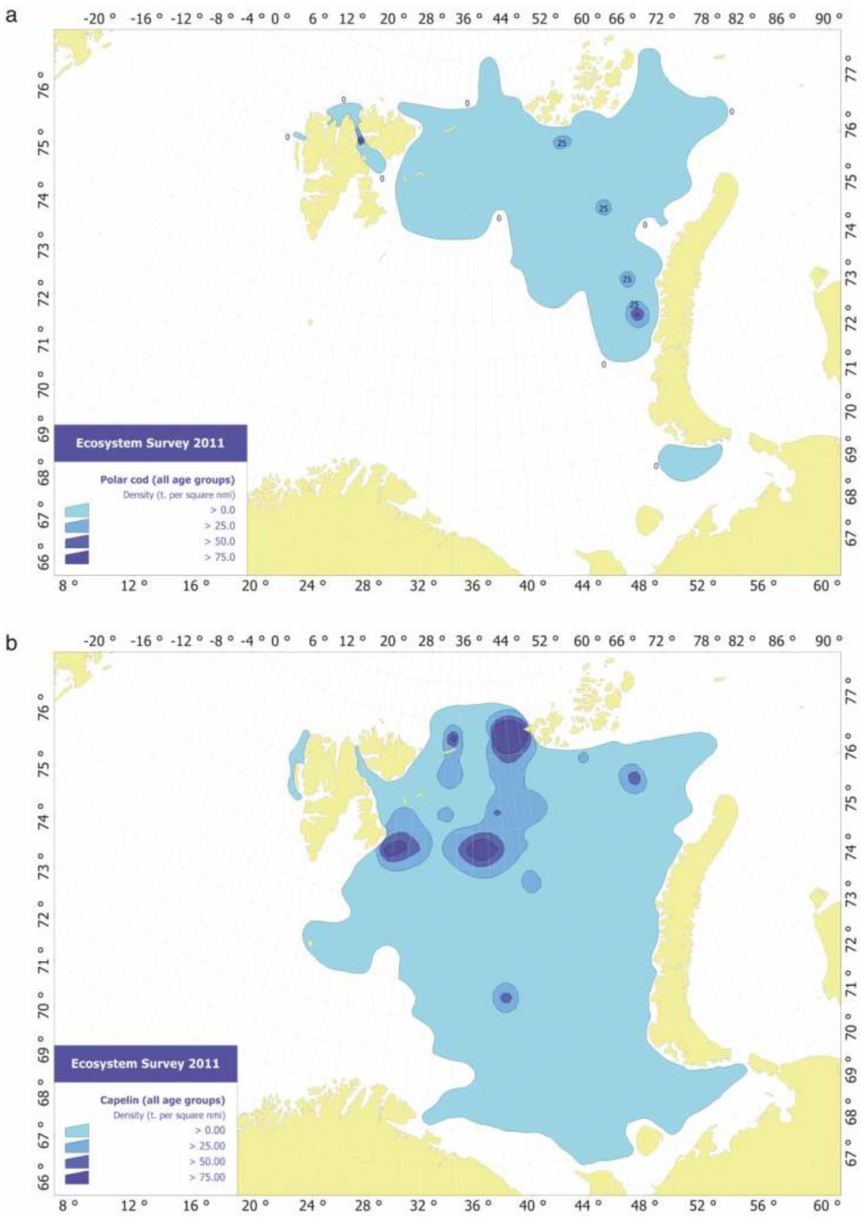


Figure 3. Distribution of biomass (t nm^{-2}) for polar cod (a) and capelin (b) in the Barents Sea during August–September 2011 (Anon 2011). Maps are drawn based on acoustic stock size estimates made during the Joint Norwegian-Russian ecosystem surveys. The contour plot of fish biomass is made from estimated fish density in 1° latitude × 2° longitude grid cells, from acoustic estimates of fish numbers combined with length–weight keys based on trawl catches in each grid cell.

Right:

Capelin distribution

(Ingvaldsen and Gjøsæter, 2013)

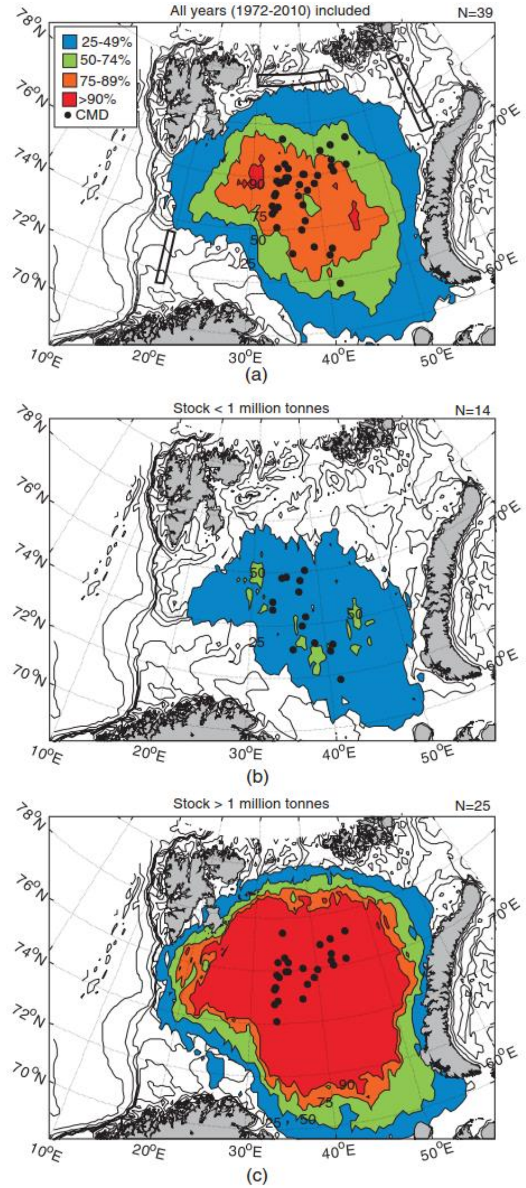


Figure 5. Capelin present/absent distribution in September–October 1972–2010: (a) for all years; (b) for years when the stock was < 1 million tonnes; and (c) for years when the stock was > 1 million tonnes. Contoured values are the number of years (in percentage of the total number of years N included) when capelin is present in each grid cell. The black dots show the centre of mass of the distribution (CMD).

In Icelandic waters

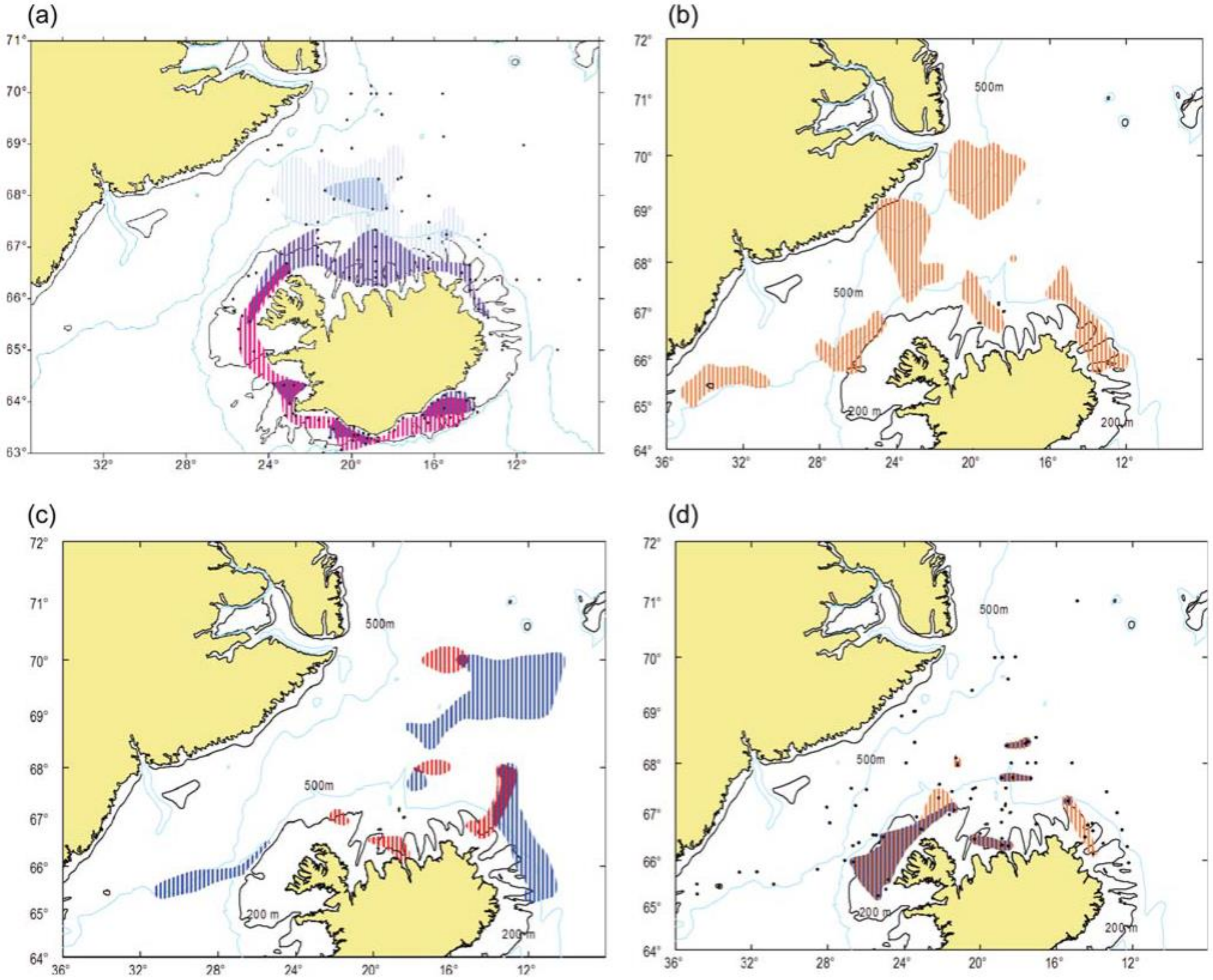


Figure 8. Spatial distributions of the main fish species, (a) capelin larvae in 2007 in April (pink), May (violet), and August (blue, trawl samples; light blue, acoustic density), (b) juvenile and adult capelin (age 1+) in July/August 2006–2008 (acoustic index), (c) adult herring (red) and blue whiting (blue) in July/August 2006–2008 (acoustic index), and (d) 0-group cod (brown) and haddock (blue) in July/August 2006–2008 (trawl samples).

(Pálsson et al., 2012)

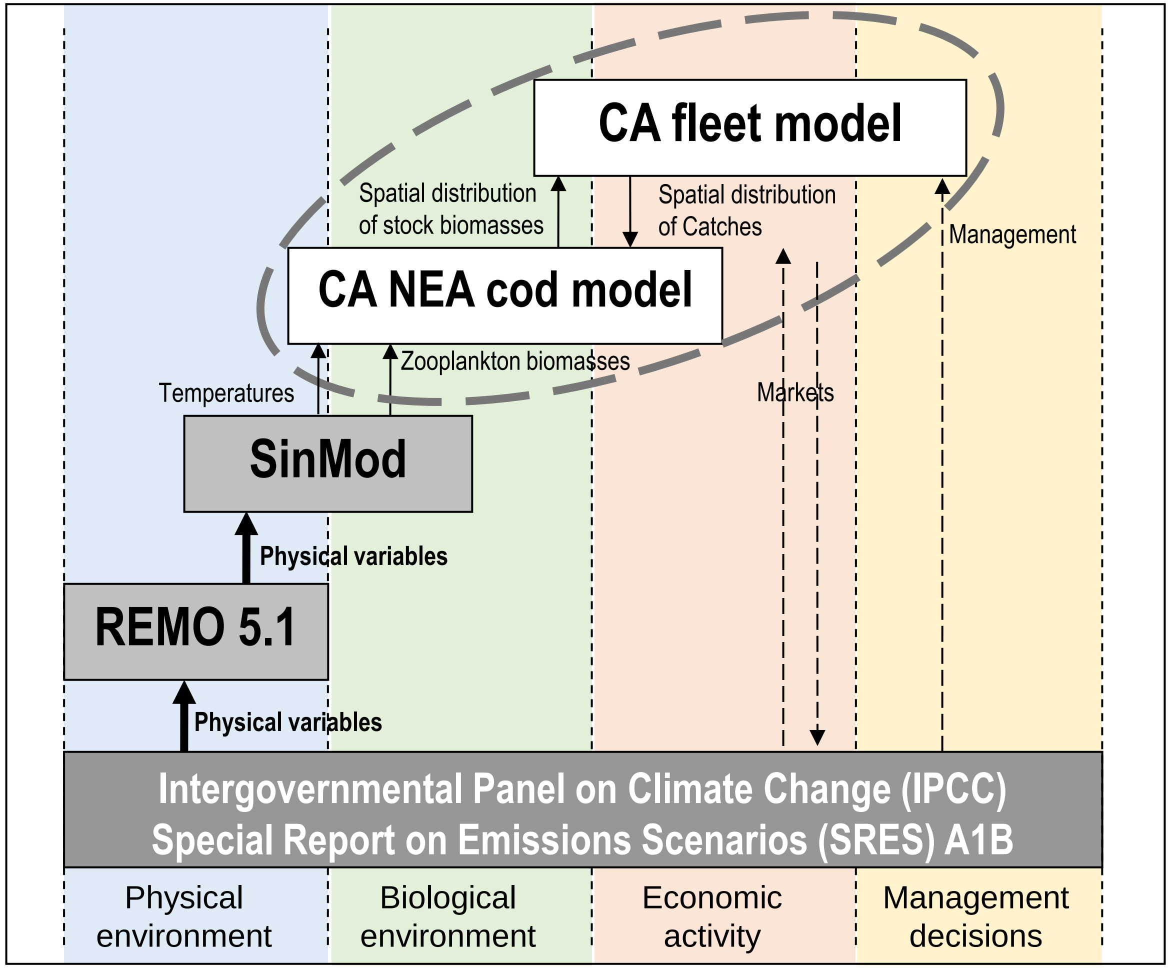
Fleet diversity

- Natural variation partly explains the observed fleet diversity
- Also different properties of vessel size, fishing gear and home port are factors of importance
- The relative cost-efficiencies of the different vessel groups vary as a consequence of the factors above (including seasonal patterns and spatial distribution)

A modelling example

The NEA cod fishery

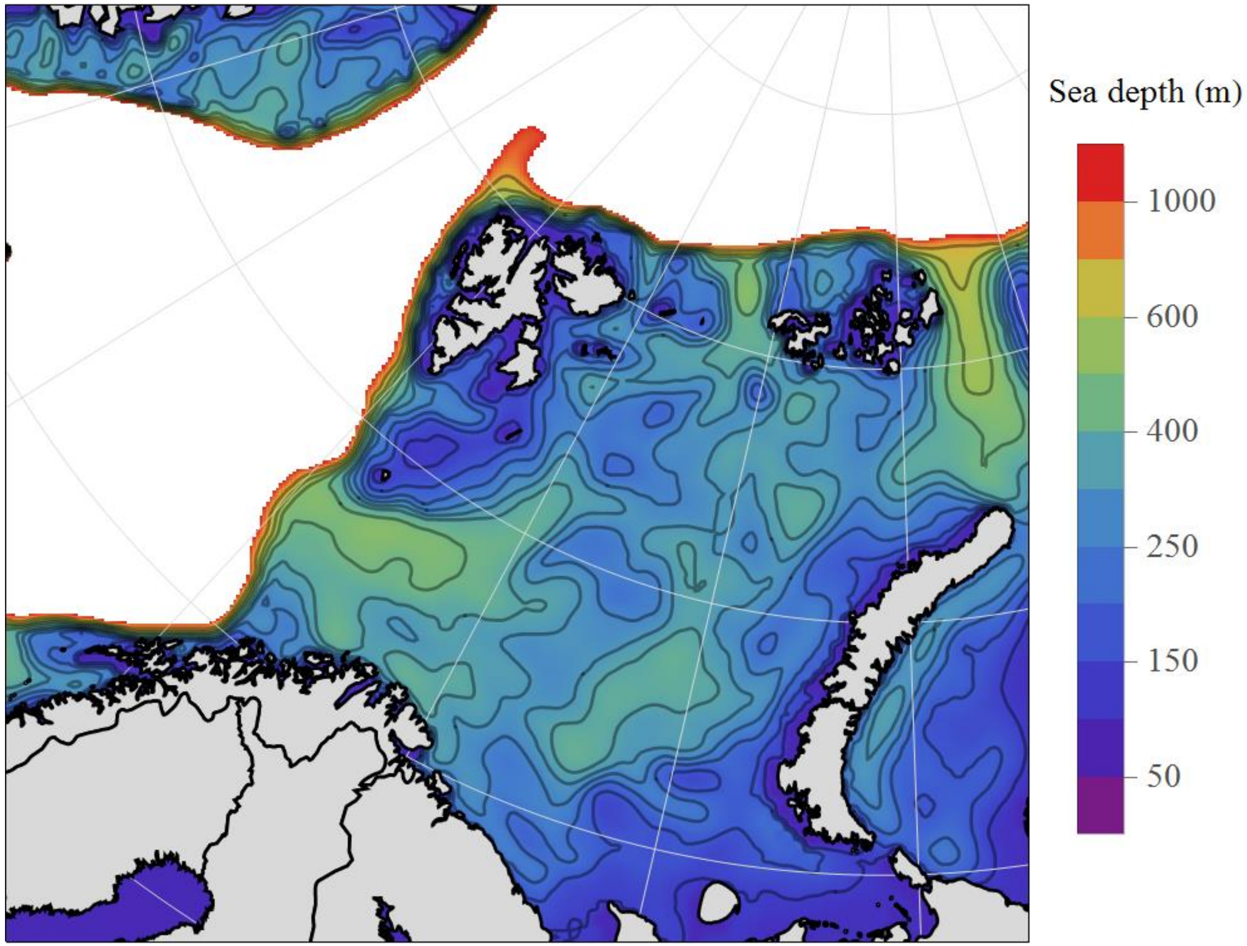
ACCESS WP3 Task 1: Model integration



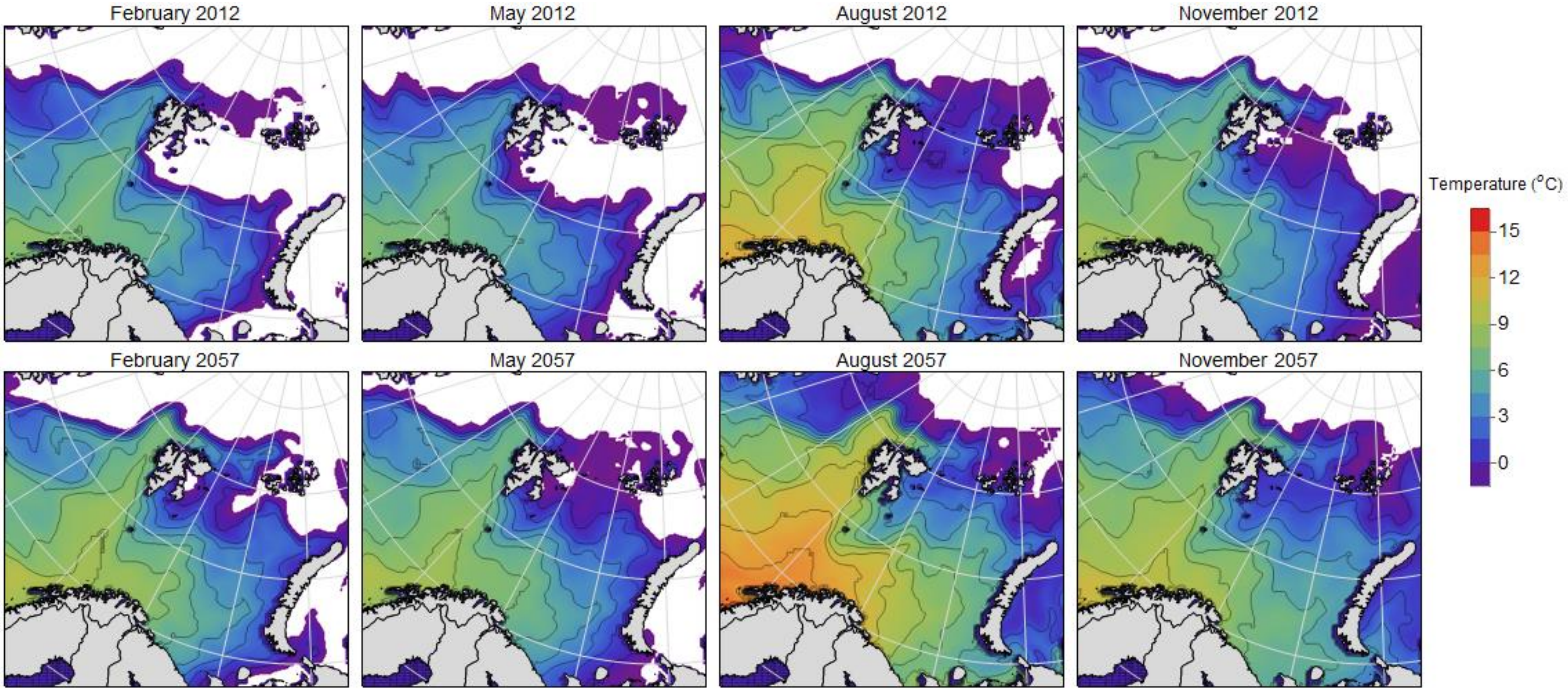
Ocean depth

Core factors:

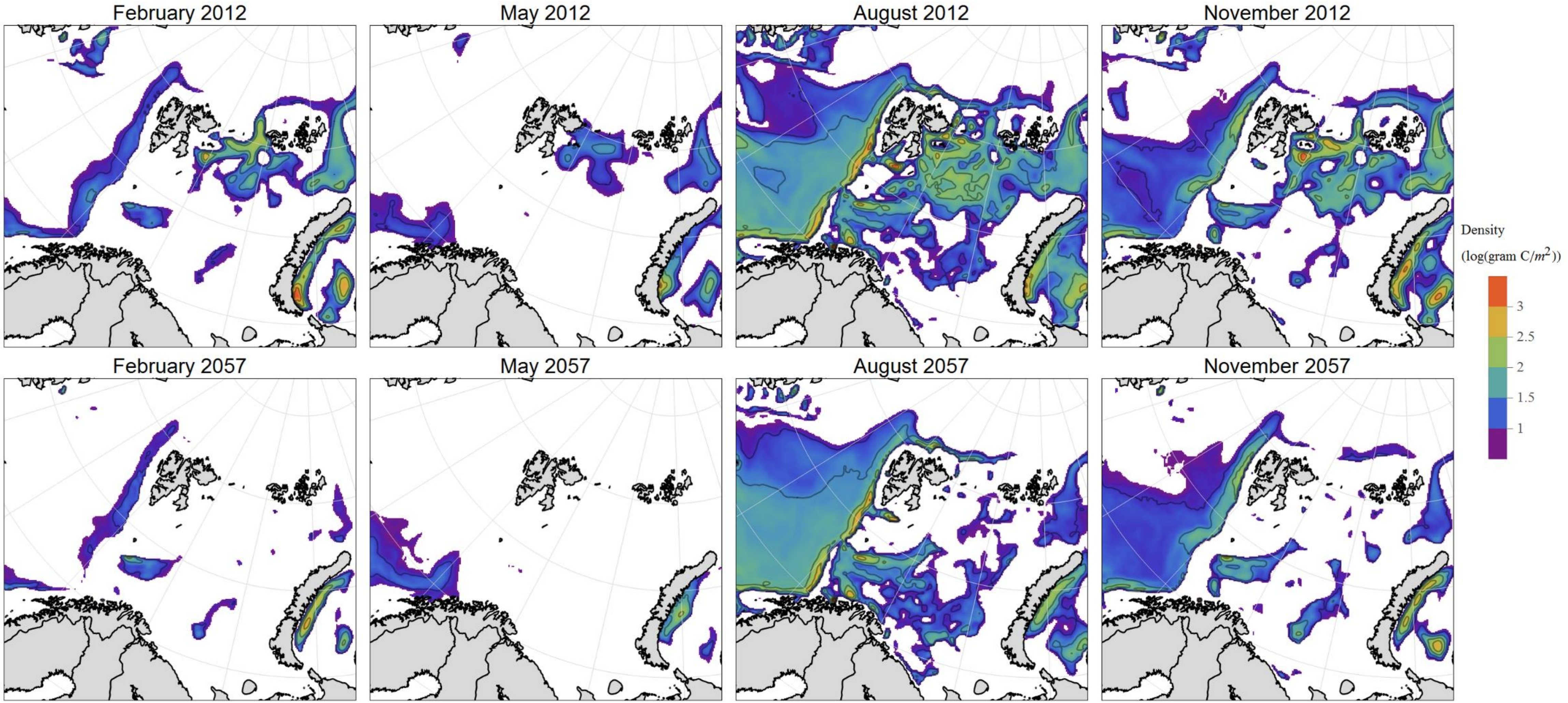
- Ocean depth
- Temperature
- Food availability
  (proxy: zooplankton biomasses)



SinMod: Ocean temperatures

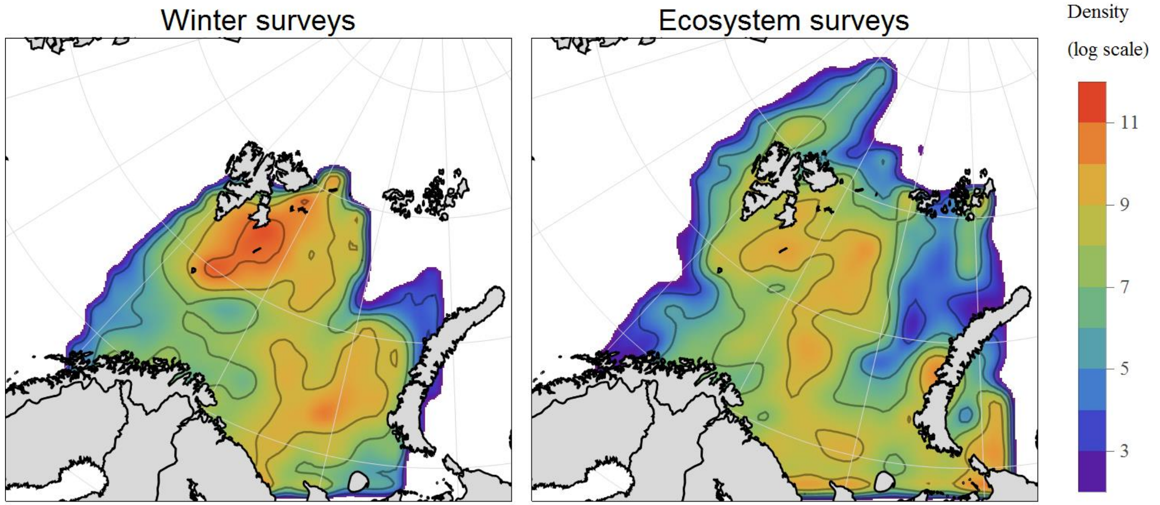


SinMod: Zooplankton densities

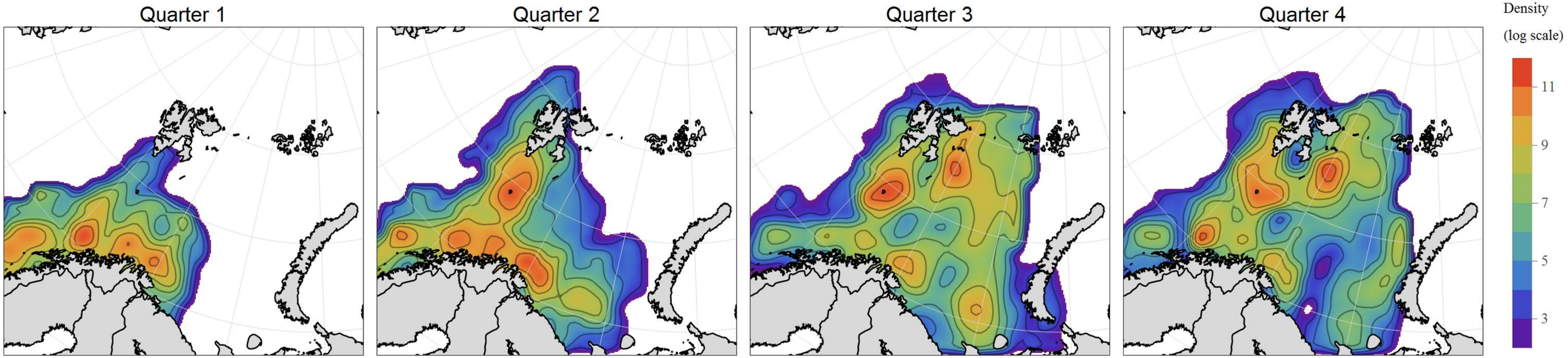


FishExChange:
Stock distribution

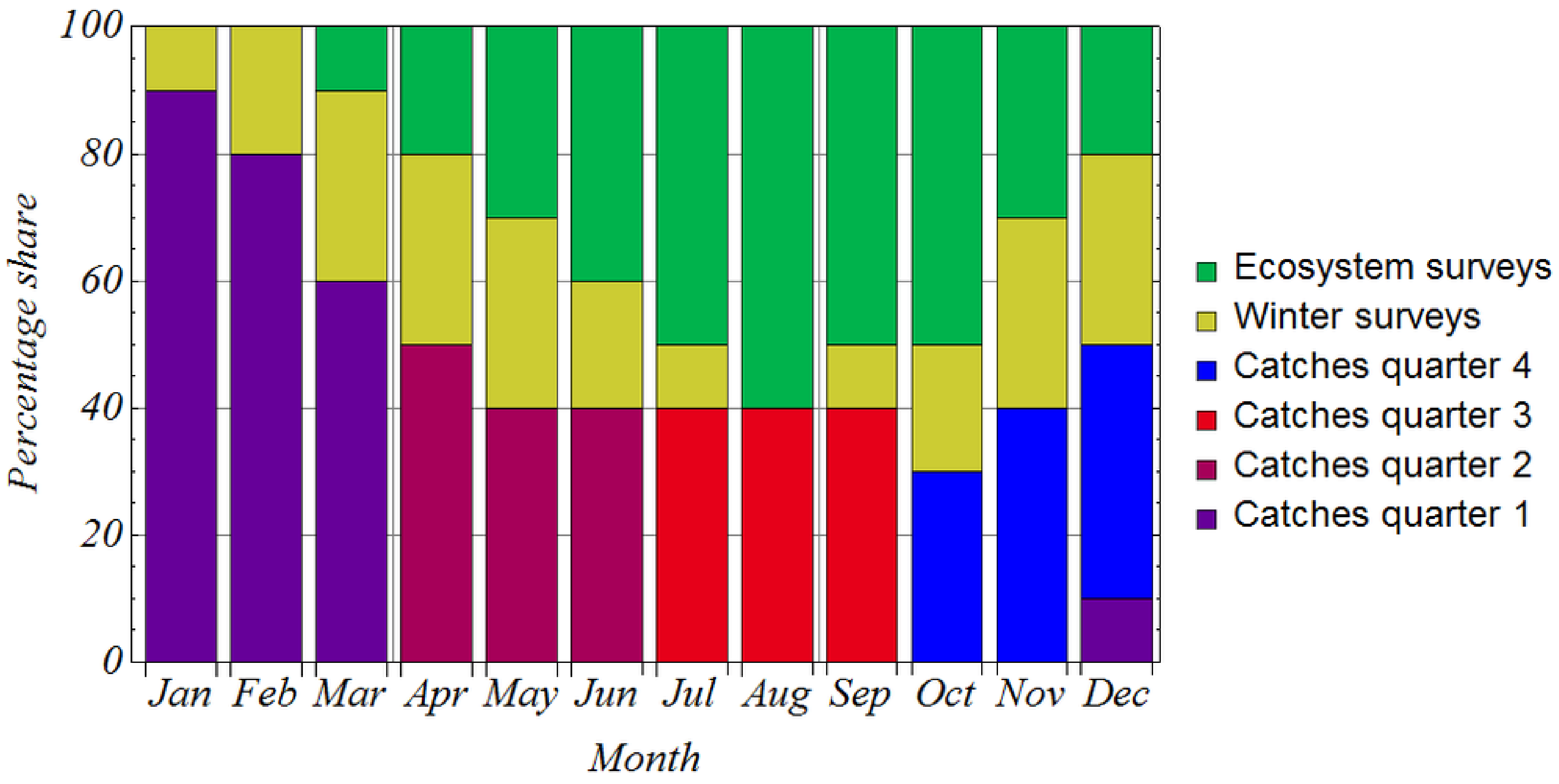
Stock surveys 2004-2010



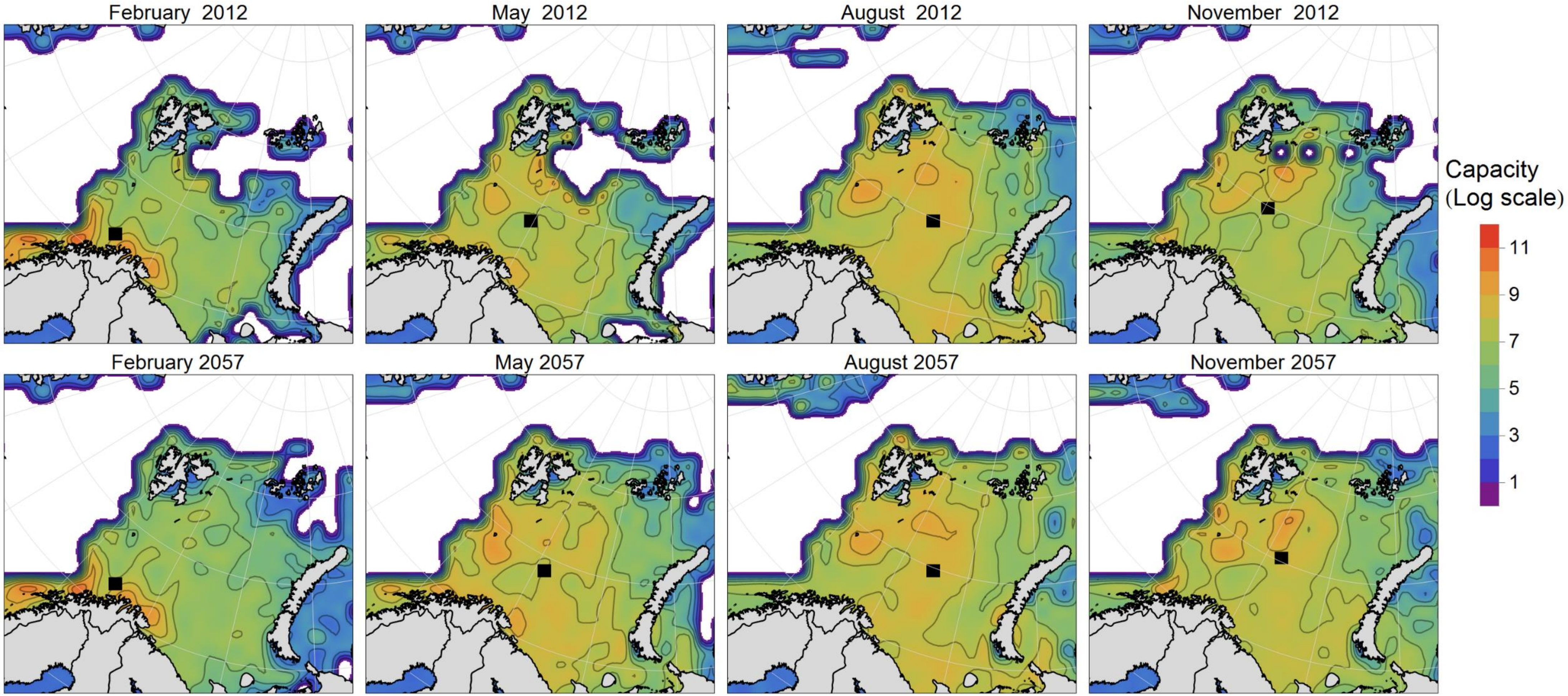
Catches 2004-2009



Monthly distribution map based on various sources

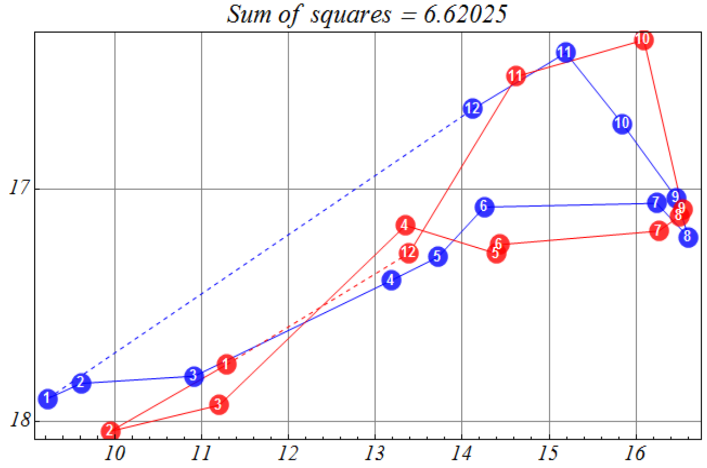


Combined:
Dynamic distribution charts



Implementing stock migration pattern in the model

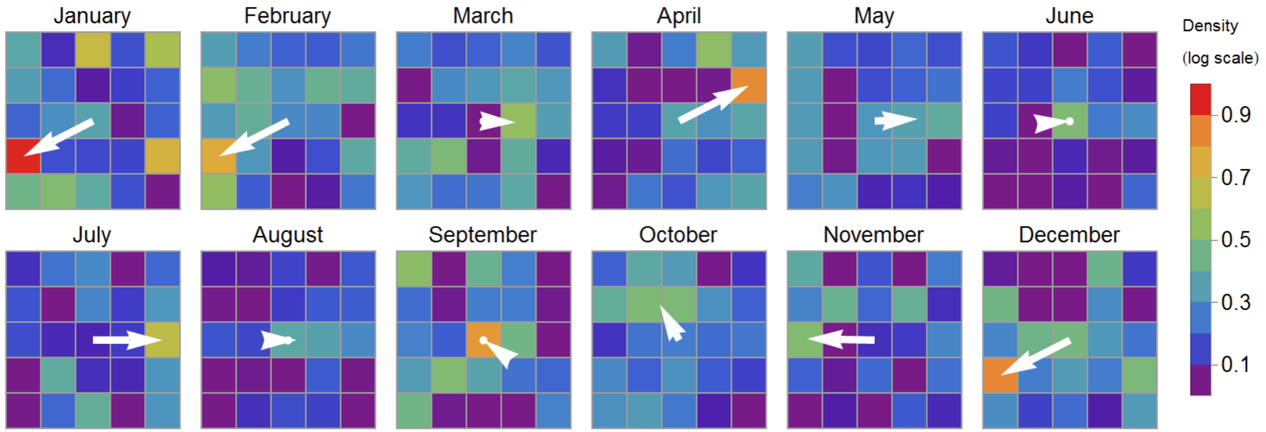
Estimated (blue) and modelled (red) centres of gravity of the spatial distribution of cod



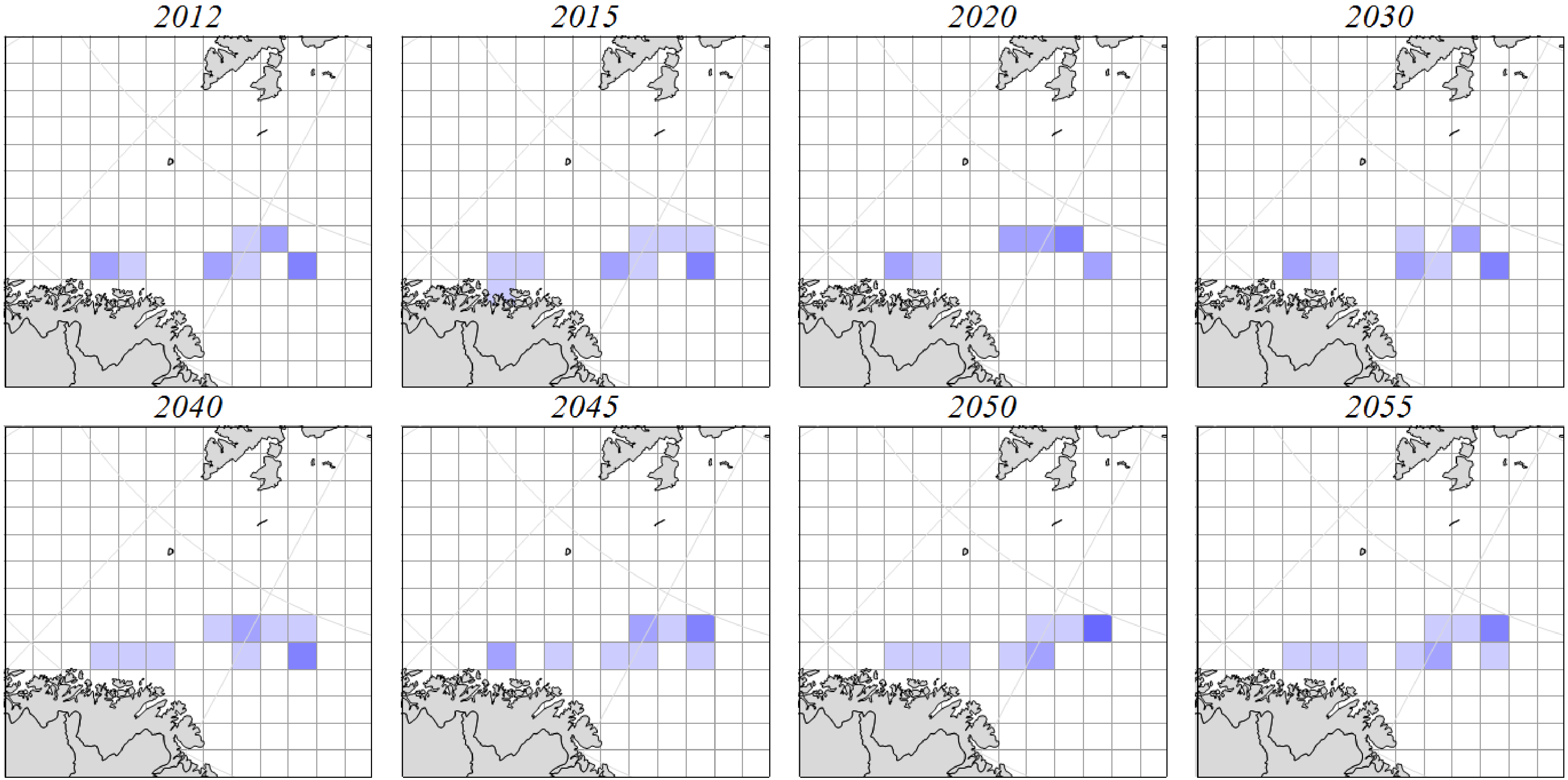
Differences

Month	South–North	East–West
1	−0.14675	2.06291
2	0.20643	0.337949
3	0.124881	0.287784
4	−0.237679	0.168786
5	−0.0149369	0.672381
6	0.161779	0.183782
7	0.119731	0.0243271
8	−0.0916978	−0.0952665
9	0.0503585	0.0737355
10	−0.361316	0.247403
11	0.101613	−0.568273
12	0.620642	−0.734871

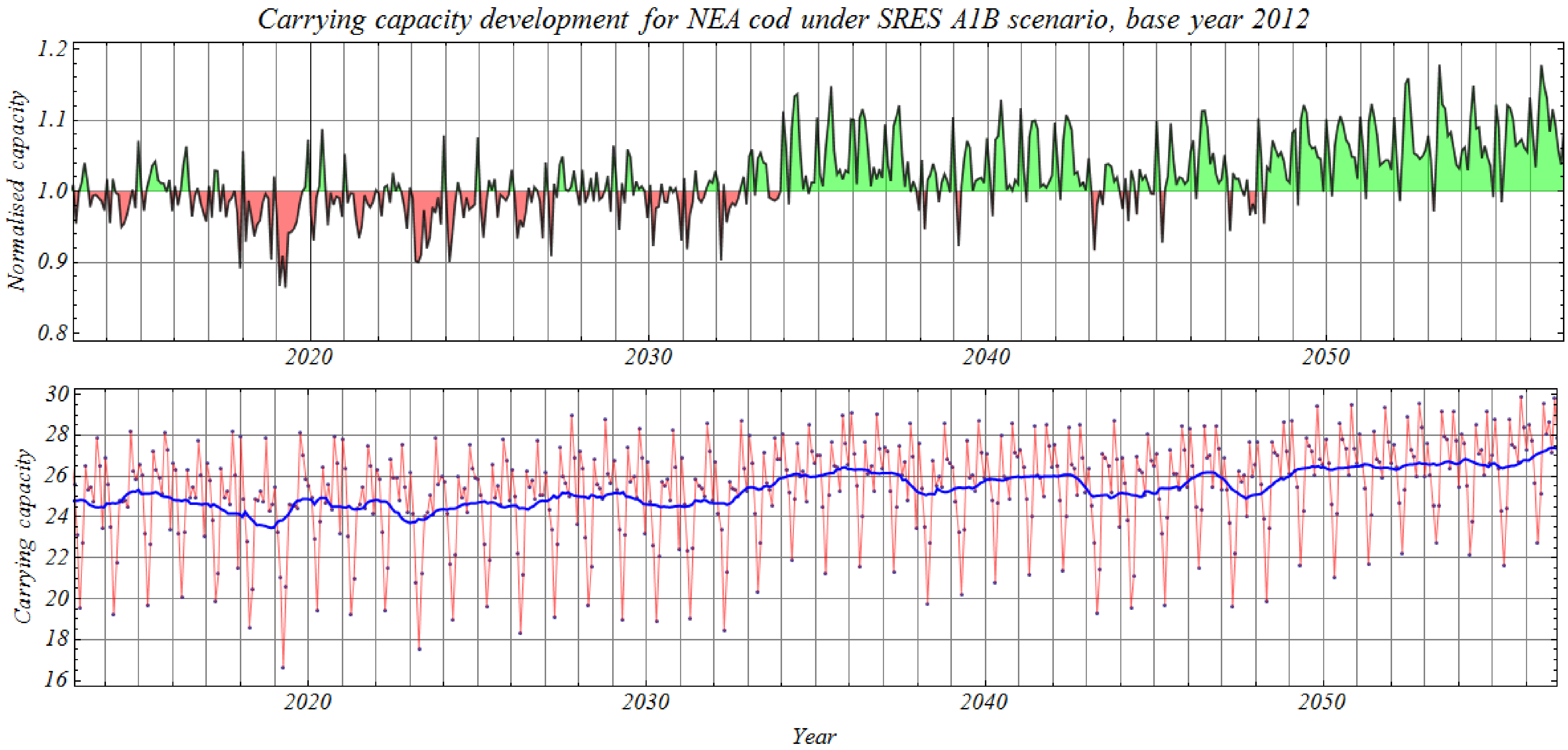
Cellular automata migration rules



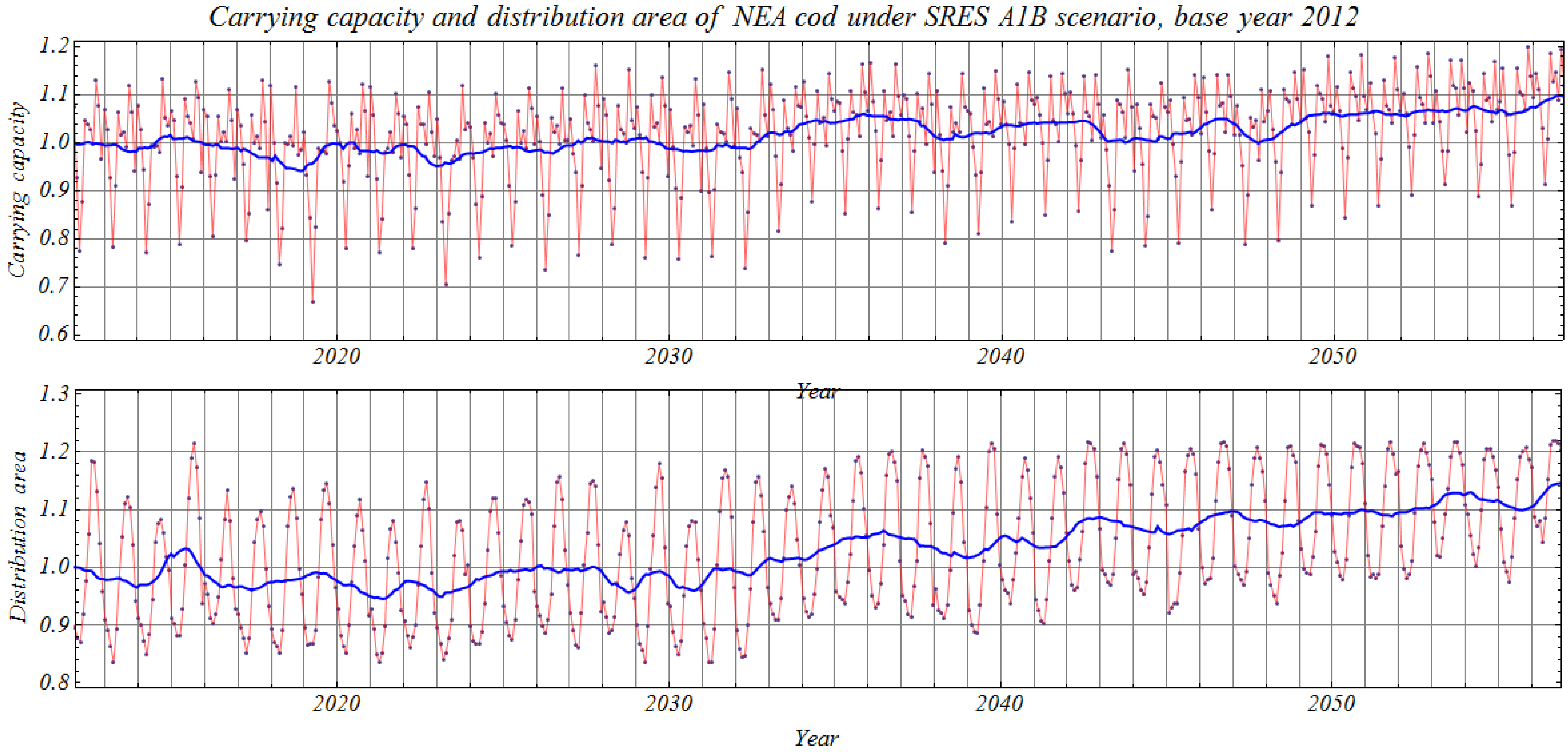
Monthly centres of gravity for cod distributions



Environmental carrying capacity for NEA cod



Extension of distribution area after 2030



Fisheries model

- Harvest in cell *i*: $h_i(e_i, x_i) = q\ e_i\ {x_i}^{\beta}$
- Total fishing effort: $E_t = \sum_{i=1}^{n} e_{i,t}$ $\quad 0 \le E_t \le F_t$
  (*F*: Total fishing capacity)
- Revenue: $re_i(e_i, x_i) = p\ h_i(e_i, x_i)$
- Variable cost: $vc_i(e_i, d_i) = (c_e + c_d d_i)\ e_i$
  (*d*: distance from homeport to cell *i*)
- Contribution margin: $cm(\boldsymbol{e}, \boldsymbol{x}, \boldsymbol{d}) = \sum_{m=1}^{12} \sum_{i=1}^{n} \{re_{m,i}(e_{m,i}, x_{m,i}) - vc_{m,i}(e_{m,i}, d_{m,i})\}$

Fisheries model (cont.)

- Annual net revenue: $\pi(\boldsymbol{e},\boldsymbol{x},\boldsymbol{d}) = cm(\boldsymbol{e},\boldsymbol{x},\boldsymbol{d}) - fc$
- Growth of effort:

$$If \quad \pi(\boldsymbol{e},\boldsymbol{x},\boldsymbol{d}) < 0 \quad then \quad F_{t+1} = (1 - fd)F_t$$
$$If \quad \pi(\boldsymbol{e},\boldsymbol{x},\boldsymbol{d}) > 0 \quad then \quad F_{t+1} = (1 + fg)F_t$$

- Distribution of effort:
  (s: smartness parameter)

$$e_{j,t} = \frac{\left(\frac{re_{j,t}}{vc_{j,t}}\right)^s}{\sum_{i=1}^{n} \left(\frac{re_{i,t}}{vc_{i,t}}\right)^s} E_t$$

Fleet parameters

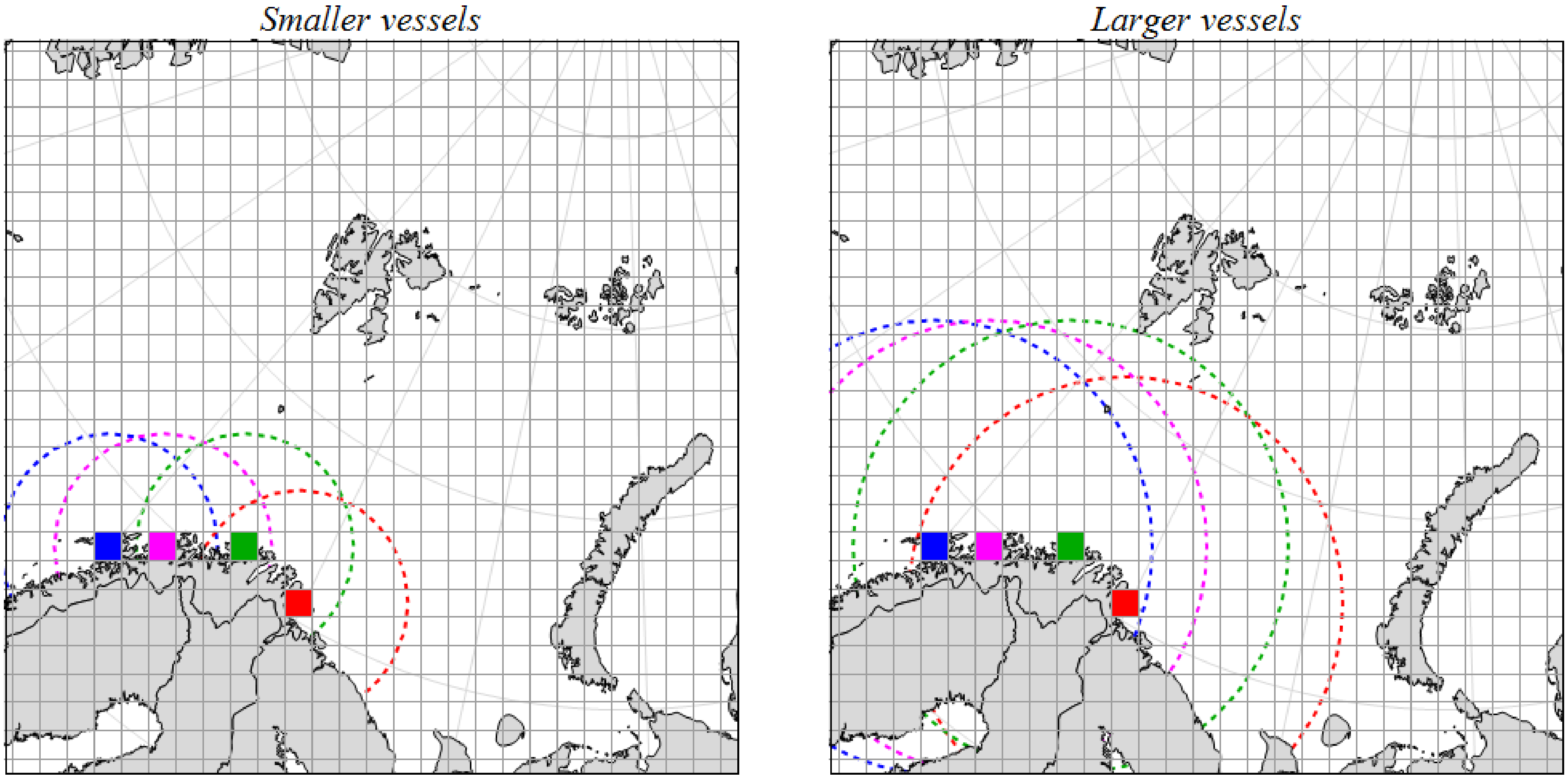
Global fleet parameter	Description
fd	Annual rate of exit (percentage fleet change)
fg	Annual rate of entry (percentage fleet change)
cl	Critically low revenue-cost ratio (below which fishing does not take place)

Fleet specific parameter	Description
q	Catchability coefficient
β	Stock-output elasticity
p	First hand price per kg harvest
c_e	Constant unit cost of effort
c_d	Unit cost of distance per effort
fc	Fixed cost per unit of time
s	Smartness parameter (prior knowledge on the spatial distribution of revenue-cost ratios)
fr	Physical range of the fleet

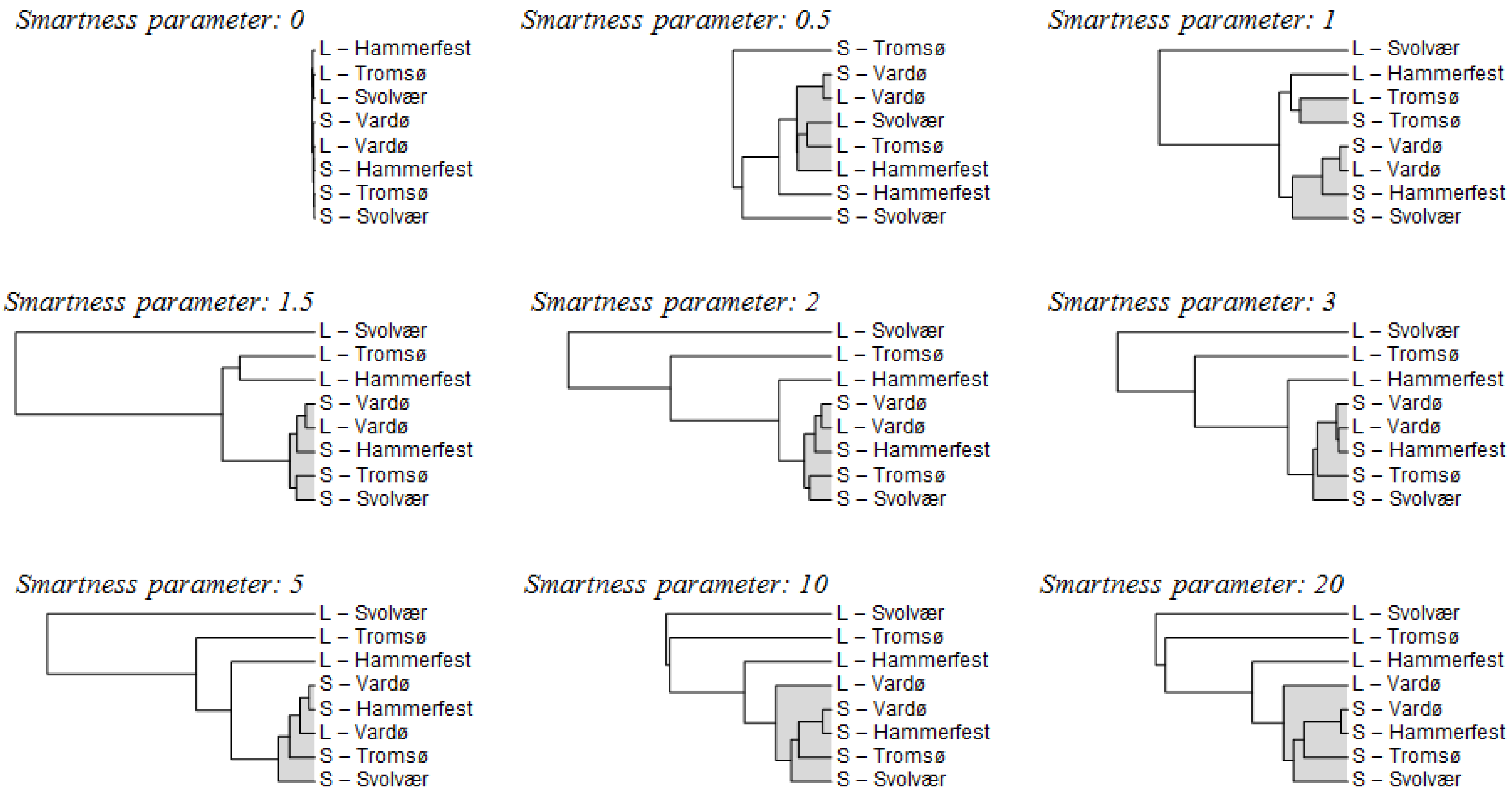
Parameter values of provided example

Parameter	Small vessels	Large vessels	Unit
q	0.60	0.25	1/(month*standardised effort)
β	0.70	0.50	-
p	13,000	13,000	NOK/ton
c_e	24,000	33,000	NOK
c_d	15,000	18,000	NOK
fc	1,800,000	3,600,000	NOK
fr	4	8	Cells (each 80 km x 80 km)
fg	4	4	%
fd	3	3	%

Spatial distribution of cod catches



Effects of changing fishing behaviour



Summing up (work in progress)

- Climate change effects may lead to increased distribution area (10-15%) and provide the cod stock with a slightly higher growth potential (about 10% increase)
- The monthly centres of gravity of the cod biomass do not change
- Management decisions, Technological development and Market changes may all (alone or together) have a stronger impact on the economics of Barents Sea fisheries than climate change will have
- As *smartness* increases fleet properties become more crucial for the overall fleet performance