On the importance of temporal and spatial variation in fisheries

Arne Eide (Nofima / University of Tromsø)

Spatial Issues in Arctic Marine Resource Governance
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

- 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 coast 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)
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).

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)

Right:
Capelin distribution (Ingvaldsen and Gjøsæter, 2013)
In Icelandic waters

(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

Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A1B

Physical environment  | Biological environment  | Economic activity  | Management decisions

Physical variables

REM 5.1

SinMod

CA NEA cod model

CA fleet model

Spatial distribution of stock biomasses

Spatial distribution of catches

Temperatures

Zooplankton biomasses

Markets

Management
Ocean depth

Core factors:
• Ocean depth
• Temperature
• Food availability
  (proxy: zooplankton biomasses)
SinMod: Ocean temperatures
SinMod: Zooplankton densities
FishExChange: Stock distribution

Catches 2004-2009

Stock surveys 2004-2010

Winter surveys

Ecosystem surveys

Density (log scale)
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

Cellular automata migration rules
Monthly centres of gravity for cod distributions
Environmental carrying capacity for NEA cod

Carrying capacity development for NEA cod under SRES A1B scenario, base year 2012
Extension of distribution area after 2030

Carrying capacity and distribution area of NEA cod under SRES A1B scenario, base year 2012
Fisheries model

- **Harvest in cell $i$:**
  \[ h_i(e_i, x_i) = q e_i x_i^\beta \]

- **Total fishing effort:**
  \( F: \) Total fishing capacity
  \[ E_t = \sum_{i=1}^{n} e_{i,t} \quad 0 \leq E_t \leq F_t \]

- **Revenue:**
  \[ r(e_i, x_i) = p h_i(e_i, x_i) \]

- **Variable cost:**
  \( d: \) distance from homeport to cell $i$
  \[ v_{ci}(e_i, d_i) = (c_e + c_d d_i) e_i \]

- **Contribution margin:**
  \[ cm(e, x, d) = \sum_{m=1}^{12} \sum_{i=1}^{n} \{ r_{em,i}(e_{m,i}, x_{m,i}) - v_{cm,i}(e_{m,i}, d_{m,i}) \} \]
Fisheries model (cont.)

• Annual net revenue: \[ \pi(e, x, d) = cm(e, x, d) - fc \]

• Growth of effort:
  \[ \text{If } \pi(e, x, d) < 0 \quad \text{then} \quad F_{t+1} = (1 - fd)F_t \]
  \[ \text{If } \pi(e, x, d) > 0 \quad \text{then} \quad F_{t+1} = (1 + fg)F_t \]

• 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

<table>
<thead>
<tr>
<th>Global fleet parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_d$</td>
<td>Annual rate of exit (percentage fleet change)</td>
</tr>
<tr>
<td>$f_g$</td>
<td>Annual rate of entry (percentage fleet change)</td>
</tr>
<tr>
<td>$c_l$</td>
<td>Critically low revenue-cost ratio (below which fishing does not take place)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fleet specific parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>Catchability coefficient</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Stock-output elasticity</td>
</tr>
<tr>
<td>$p$</td>
<td>First hand price per kg harvest</td>
</tr>
<tr>
<td>$c_e$</td>
<td>Constant unit cost of effort</td>
</tr>
<tr>
<td>$c_d$</td>
<td>Unit cost of distance per effort</td>
</tr>
<tr>
<td>$f_c$</td>
<td>Fixed cost per unit of time</td>
</tr>
<tr>
<td>$s$</td>
<td>Smartness parameter (prior knowledge on the spatial distribution of revenue-cost ratios)</td>
</tr>
<tr>
<td>$f_r$</td>
<td>Physical range of the fleet</td>
</tr>
</tbody>
</table>
### Parameter values of provided example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Small vessels</th>
<th>Large vessels</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>0.60</td>
<td>0.25</td>
<td>1/(month*standardised effort)</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.70</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>$p$</td>
<td>13,000</td>
<td>13,000</td>
<td>NOK/ton</td>
</tr>
<tr>
<td>$c_e$</td>
<td>24,000</td>
<td>33,000</td>
<td>NOK</td>
</tr>
<tr>
<td>$c_d$</td>
<td>15,000</td>
<td>18,000</td>
<td>NOK</td>
</tr>
<tr>
<td>$fc$</td>
<td>1,800,000</td>
<td>3,600,000</td>
<td>NOK</td>
</tr>
<tr>
<td>$fr$</td>
<td>4</td>
<td>8</td>
<td>Cells (each 80 km x 80 km)</td>
</tr>
<tr>
<td>$fg$</td>
<td>4</td>
<td>4</td>
<td>%</td>
</tr>
<tr>
<td>$fd$</td>
<td>3</td>
<td>3</td>
<td>%</td>
</tr>
</tbody>
</table>
Spatial distribution of cod catches

*Smaller vessels*

*Larger vessels*
Effects of changing fishing behaviour

- **Smartness parameter: 0**
  - L - Hammerfest
  - L - Tromsø
  - L - Svolvær
  - S - Varde
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 0.5**
  - S - Tromsø
  - L - Varde
  - L - Svolvær
  - S - Hammerfest
  - S - Tromsø
  - S - Svolvær

- **Smartness parameter: 1**
  - L - Svolvær
  - L - Tromsø
  - S - Varde
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 1.5**
  - S - Tromsø
  - L - Varde
  - L - Svolvær
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 2**
  - L - Svolvær
  - L - Tromsø
  - L - Varde
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 3**
  - L - Svolvær
  - L - Tromsø
  - L - Varde
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 5**
  - S - Tromsø
  - S - Svolvær

- **Smartness parameter: 10**
  - L - Svolvær
  - L - Tromsø
  - L - Varde
  - S - Hammerfest
  - S - Tromsø

- **Smartness parameter: 20**
  - L - Svolvær
  - L - Tromsø
  - L - Varde
  - S - Hammerfest
  - S - Tromsø
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