The Charmingly Simple Model – adding environmental forcing

John Pope, Henrik Gislason, Jake Rice & Niels Daan
Fitting GLMs to MSVPA Suitabilities

Diet link of each age of each predator to each age of each prey (multiple years)

- SUBSTANTIAL Variance explained by overall SIZE OF Predator covariary
- LITTLE variance explained by
  - Main Effects of Species of Predator, Species of Prey, Year
  - Interactions of the Main Effects
  - Separate Slopes for each predator
Changes in the number caught per hour of large and small species

Daan, Gislason, Rice & Pope (2005)
What is a size spectrum really?

Power law scaling:

\[ N = \kappa w^{-\lambda} \]
Slope of the size spectrum of fish in the North sea, 1980-1999

Data from the International Bottomtrawl Survey

Daan, Gislason, Rice & Pope (2005)
Which two fish are most similar?
Which two fish are **ecologically** most similar?

Size is more important than species
Ingredients...

Beverton & Holt
- age based single species

Andersen & Ursin
North Sea model
- cohort based ecosystem

Size spectrum theory
Andersen & Beyer (2006)
Hall et al (2006)

Size-based ecosystem model
Strategy of model

- Modelling FISH COMMUNITY from smallest estimated by surveys to largest
- Based on ALLOMETRIC SCALING RELATIONSHIPS (Charnov etc)
- Assumes trophodynamic relationships closer to size-based than species based
- Does not pretend to model lower trophic levels
- Allocate $L_{\infty}$ for community members and let allometric functions assign values for each “species” – total of 15 parameters for 12 species
Key Equations

- Von Bertalanffy growth (2 parameters)
  - Jones length-based cohort analysis
- Size selectivity of fishery (4 parameters)
  - Logistic selectivity (3); *Scenario dependent mean F
- Anderson-Ursin Predation Mortality (4 parameters)
  - Mean & variance of size ratio, power, constant
- Maturity at proportion of L (1 parameter)
- *Power S-R function (3 parameters)
- *Scaling M/k ratio with size (1 parameter)
## Variables for Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Key</th>
<th>Density Dependence</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>• M/K ratio</td>
<td>τ</td>
<td>0.8</td>
</tr>
<tr>
<td>• Stock Recruitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– power ssb</td>
<td>φ</td>
<td>0.45</td>
</tr>
<tr>
<td>– power Linf</td>
<td>φ</td>
<td>-3.55</td>
</tr>
<tr>
<td>• const</td>
<td>ρ</td>
<td>18.0</td>
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</table>
Constraints

- **F ~ mean F** on fully recruited size classes of all species in the North Sea (.7) with 50% selection at 30% of $L_\infty$.
- **A size spectrum slope** $\sim 0.1$ per cm that was linear over the 20cm to 100cm length range ($R^2 > 0.95$).
- **M2** such that a plot against weight (Wt) was as close as possible to the fitted relationship in MSWG reports.
- **A total fish biomass** of about 7 million t with both catch and fish consumption being about 3 million.
- **Catch fish** with $L_\infty$ of 10 and 20cm about half of the total

All these have documentation in literature
## Fits to constraints

<table>
<thead>
<tr>
<th>Target</th>
<th>Key run</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size Spectra $R^2$</td>
<td>&gt;0.95</td>
<td>0.997</td>
<td>0.997</td>
<td>0.994</td>
</tr>
<tr>
<td>M2's (year-1) &amp; $\ln(M2)$ on $\ln(Wt)$ regression</td>
<td></td>
<td></td>
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<tr>
<td>Max M2</td>
<td>1.50</td>
<td>1.61</td>
<td>1.74</td>
<td>1.37</td>
</tr>
<tr>
<td>Catch, consumption and biomass (million t)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&lt;30\text{cm } L^\infty$ groups</td>
<td>1.50</td>
<td>1.54</td>
<td>1.45</td>
<td>1.74</td>
</tr>
<tr>
<td>Total catch</td>
<td>3.00</td>
<td>2.97</td>
<td>2.98</td>
<td>3.14</td>
</tr>
<tr>
<td>Total eaten</td>
<td>3.50</td>
<td>3.50</td>
<td>3.46</td>
<td>3.48</td>
</tr>
<tr>
<td><strong>Total biomass</strong></td>
<td><strong>7.00</strong></td>
<td><strong>5.04</strong></td>
<td><strong>5.14</strong></td>
<td><strong>5.60</strong></td>
</tr>
</tbody>
</table>
What types of things can the model do?
Slope as function of F
Regression of slope on $F$

slope = $-0.0536F - 0.0566$

$R^2 = 0.9959$
Yield by 10 cm size group
M2 by size as $f(F)$
“Recruitment” and SSB of each $L_\infty$ “species” as $f(F)$

![Graph showing recruitment and SSB as functions of F.](image)
Charnov and Gillooly 2004: life history parameters scale with temperature and size

- Natural Mortality $M = \lambda_1 \exp(-E/kT) m_{\alpha}^{-0.25}$
- Age first Maturity $\alpha = \lambda_2 \exp(E/kT) m_{\alpha}^{0.25}$
- Spawning Prop. $c = \lambda_3 \exp(-E/kT) m_{\alpha}^{-0.25}$

- These were not formulated in terms of the von Bertalanffy parameters the CSM used.
- BUT WE HAVE A CUNNING PLAN
Putting in the Environment
A linear stock-recruitment relationship makes the community more vulnerable to fishing.
Charnov and Gillooly 2004: life history parameters scale with temperature and size

- Natural Mortality $M = \lambda_1 \exp(-E/kT) \cdot m_\alpha^{-0.25}$
- Age first Maturity $\alpha = \lambda_2 \exp(E/kT) \cdot m_\alpha^{0.25}$
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- **BUT WE HAVE A CUNNING PLAN**
From Beverton invariant M/K we infer

- von Bert. $K = \lambda_4 \exp(-E/kT) * m_\alpha^{-0.25}$
- Using $L_\alpha = L_\infty^{0.93}$
- Thus $K = \lambda_4 \exp(-E/kT) * L_\infty^{-0.70}$
- Very like the CSM’s form
- $K = 4.5 * L_\infty^{-0.67}$
- But with a temperature term $\exp(-E/kT)$
We can augment the CSM

Use Life History parameters by temperature to Calculate for different ecosystems

• SSB/Recruit
• Replacement Lines
• Intersect with Recruitment/ SSB relationship
• Resulting species SSB
• Resulting species total Biomass
Temperature change maintains relative SSB/R by $L_\infty$

\[ y = 9E-05Loo^{3.4044} \]

\[ R^2 = 0.9986 \]
Total Biomass: With $\phi$ close to 1.0 the system is easy to flip.