Long-term trends in the biomass of commercial fish in the North Sea

fishing impacts, predator-prey interactions and temperature change

S10 Forecasting climate change impacts on fish populations and fisheries
Thursday 26th March 2015

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PICES Symposium on ‘Effects of climate change on the world’s oceans’
“Forecasting climate change impacts on fish populations & fisheries”
Requires a strong understanding about the dynamics of the system

Why?
• To give strategic advice on potential response of the system to pressure (climate, fishing, ...)
• Evaluate potential management strategies
• Explore trade-offs and sensitivities

How?
• Modelling – which can take a number of forms
Statistical approach

Empirical - data driven combined with expert guidance

Use evidence to determine key signals in the data and capture the temporal dynamics of the system

• Bottom-up control (driven by temperature)
• Top-down control (fishing pressure down)
Requires a lot of data

- Long time-series data (1964-2010)
  - Sea surface temperature (Hadley centre plus AMO)
  - Phytoplankton abundance (SAHFOS)
  - Zooplankton abundance (SAHFOS)
  - Fish stock biomass and fishing mortality (ICES)
  - Marine bird breeding success (JNCC, 1989-2010)

- Statistical modelling:
  - Generalised Additive Model (GAM)
  - threshold-Generalised Additive Model (tGAM)

- Expert knowledge of the system
simulations

Recreated solely from initial conditions for plankton and fish in 1964

+ time-series of fishing mortality by stock
+ SST
+ AMO
How generate simulations non-mechanistically?

- Behind each arrow in the interaction web is a significant relationship modelled using either GAM/tGAM.
Example – GAM fitting to the SSB of saithe

saithe in year $z$

$\sim \text{intercept}$

$+ \ s(\text{Fishing mortality year } z-1)$

$+ \ s(\text{saithe year } z-1)$

$+ \ s(\text{haddock year } z-1)$

$+ \ s(\text{N. pout year } z-1)$

$+ \ \epsilon(0,1)$
Repeat previous step separately for each component e.g. sandeels
How important are indirect effects/cascades?
### Proportion of deviance explained by groups

The table below shows the percentage of deviance explained by regression and the percentage split by groups in the model for various key species. The table is divided into two sections: **Bottom up** and **Top down**.

#### Bottom up

<table>
<thead>
<tr>
<th>Response variable</th>
<th>% deviance explained by regression and % split by groups in the model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All terms</td>
</tr>
<tr>
<td>Greenness</td>
<td>81</td>
</tr>
<tr>
<td>Diatoms</td>
<td>67</td>
</tr>
<tr>
<td>Dinoflagellates</td>
<td>54</td>
</tr>
<tr>
<td>C. helgolandicus</td>
<td>79</td>
</tr>
<tr>
<td>C. finmarchicus</td>
<td>70</td>
</tr>
<tr>
<td>Small copepods</td>
<td>79</td>
</tr>
</tbody>
</table>

#### Top down

<table>
<thead>
<tr>
<th>Key species</th>
<th>% deviance explained by regression and % split by groups in the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandeel</td>
<td>87</td>
</tr>
<tr>
<td>Herring</td>
<td>97</td>
</tr>
<tr>
<td>Sprat</td>
<td>87</td>
</tr>
<tr>
<td>Norway pout</td>
<td>76</td>
</tr>
<tr>
<td>Haddock</td>
<td>83</td>
</tr>
<tr>
<td>Saithe</td>
<td>95</td>
</tr>
<tr>
<td>Whiting</td>
<td>77</td>
</tr>
<tr>
<td>Cod</td>
<td>99</td>
</tr>
<tr>
<td>Seabirds</td>
<td>80</td>
</tr>
</tbody>
</table>
Building simulations

submodels (regressions) should be linked sufficiently to form a web

- Starting from the initial conditions 1964
- use F, SST and AMO values to predict 1965 values
  - include noise from residuals from GAMS/tGAMS (resampling)
- For the next time step (1966), use set of predictions from above plus new F, SST and AMO values ....
- Repeat for length of drivers (observed data / scenario)

saithe in year z
~ intercept
+ s(Fishing mortality year z-1)
+ s(saithe year z-1)
+ s(haddock year z-1)
+ s(N. pout year z-1)
+ ε(0,1)
Temperature scenarios to explore

Atlantic Multi-decadal Oscillation anomalies

North Sea SST anomalies

shift 1984 - 1990
Fishing scenarios to explore

- F saithe
- F cod
- F haddock
- F sprat
- F Norway pout
- F herring
- F sandeel

- Observed F with forecast post 2010
- 90% of Observed values post 1990
- 75% of Observed values post 1990
Simulations

Recreated solely from initial conditions for plankton and fish in 1964

+ time-series of F
+ SST + AMO
Simulation without SST rise since 1984
Simulation with 10% SST rise (1990 on)
Some effect of climate, but fishing has been such a strong effect that it has masked the full impact on the North Sea system

What would happen if we reduced fishing?
More sensitive to climate?
Blue: 80% reduction in F  Red: 10% decrease in F
Grey: 50% decrease in F  Black: observed F

<table>
<thead>
<tr>
<th></th>
<th>Observed SST</th>
<th>+10% SST</th>
<th>-10% SST</th>
<th>1970/80s SST (cold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhytoCol</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diatoms</td>
<td></td>
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<tr>
<td>Dinoflag.</td>
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<tr>
<td>C. finmar.</td>
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<tr>
<td>C. helgo.</td>
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<tr>
<td>Small cops</td>
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CPR abundance

SST: Sea Surface Temperature
CPR: Catch Per Unit Effort
PhytoCol: Phytoplankton Community
Diatoms: Diatoms
Dinoflag.: Dinoflagellates
C. finmar.: Calanus finmarchicus
C. helgo.: Calanus helgolandicus
Small cops: Small copepods
• Diatoms benefit in warm temperatures
• *C. helgolandicus* benefit from warm temperatures
• *C. finmarchicus* benefit from warm if diatoms increase

• Dinoflagellates decline when warm, increase with cold
• *C. finmarchicus* benefit during cold temperatures
• Small copepods (*Acartia, Temora, Para-pseudocalanus*) benefit from cold

• Zooplankton decline as fishing pressure lowered
• Diatoms increase as fishing pressure lowered if warm
<table>
<thead>
<tr>
<th>SSB (t)</th>
<th>Observed SST</th>
<th>+10% SST</th>
<th>-10% SST</th>
<th>1970/80s SST (cold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandeel</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
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<tr>
<td>Sprat</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
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<tr>
<td>Herring</td>
<td><img src="image9" alt="Graph" /></td>
<td><img src="image10" alt="Graph" /></td>
<td><img src="image11" alt="Graph" /></td>
<td><img src="image12" alt="Graph" /></td>
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<tr>
<td>N. pout</td>
<td><img src="image13" alt="Graph" /></td>
<td><img src="image14" alt="Graph" /></td>
<td><img src="image15" alt="Graph" /></td>
<td><img src="image16" alt="Graph" /></td>
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<tr>
<td>Cod</td>
<td><img src="image17" alt="Graph" /></td>
<td><img src="image18" alt="Graph" /></td>
<td><img src="image19" alt="Graph" /></td>
<td><img src="image20" alt="Graph" /></td>
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<tr>
<td>Haddock</td>
<td><img src="image21" alt="Graph" /></td>
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<tr>
<td>Saithe</td>
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<td><img src="image27" alt="Graph" /></td>
<td><img src="image28" alt="Graph" /></td>
</tr>
<tr>
<td>Whiting</td>
<td><img src="image29" alt="Graph" /></td>
<td><img src="image30" alt="Graph" /></td>
<td><img src="image31" alt="Graph" /></td>
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Cold preference
- Dinoflagellates
- Sandeel
- Herring
- Cod

Warm preference
- Diatoms
- *C. helgolandicus*
- Sprat, Norway pout, saithe

Key interactions during warm period
- *C. finmarchicus* benefit if diatoms increase
- Haddock benefit when both diatoms and *C. finmarchicus* do
- Whiting – mixed response – decrease if sandeel decrease (greater than sprat increase)
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