Investigating the mechanisms underlying ecosystem structure – a multi-species, size-structured model of the North Sea demersal fish assemblage

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presented by

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• Why: to investigate effects of fishing(*) on species diversity and community structure.
• How: size-based model of the North Sea demersal fish assemblage
• When: work in progress – no results yet

(*) Time-dependent forcing (e.g. to represent environmental variability) can also be introduced
• “Rhomboidal” approach (deYoung et al., 2004):
  – maximum detail for the *focal* species
  – increasing simplifications/decreasing resolution away from the trophic scale of the focal spp.
Methodology outline

SIZE-STRUCTURED
Focal species: defined by the questions the model aims to address

UNSTRUCTURED
Resource/predator species: defined by food-web
Focal species

**SIZE-STRUCTURED:**

- Norway pout
- Haddock
- Saithe
- Plaice
- Common dab
- Starry ray
- Poor cod
- Whiting
- Cod
- Grey gurnard
- Lemon sole
- Long-rough dab
- Ling
- Angler fish
- Hake
- etc.
Non-focal (unstructured) components

UNSTRUCTURED:

• Other demersal and pelagic fish, e.g. sprat, sandeel, herring, gobies, mackerel.

• Zooplankton, e.g. copepods, mysids, amphipods.

• Zoobenthos, e.g. crabs, echinoderms, bivalve molluscs, polychaetes.

Model dynamically as unstructured populations

Model dynamically as communities of unstructured populations
Size-structured components

Species (i)

size class (j)
Number of individuals of species i and size class j = \begin{cases} \text{Recruits of species } i & \text{for } j=1 \\ \text{Surviving individuals of species } i \text{ growing from size-class } (j-1) + \text{ surviving individuals remaining in size-class } j & \text{for } j>1 \end{cases}
Total egg production
\[ E(i) = \sum_j fec_{i,j} \times n_{i,j} \]

where

\[ fec(i, j) = p_{mat} \times 0.5 \times w(i, j) \times fec_{const} \times \frac{dt}{365} \]

(derived from normally distributed spread in maturation lengths)
von Bertalanffy growth

\[ \frac{dL}{dt} = \begin{cases} \lambda (L_{\text{inf}} - L) & \text{probability } p_{ij} \\ 0 & \text{probability } (1 - p_{ij}) \end{cases} \]

Requires: grow rate \( \lambda \) and lengths \( L_{\text{hatch}} \) and \( L_{\text{inf}} \) for each species \( i \).

At each timestep, only a proportion \( p_{ij} \) of individuals meet food requirements for growth to next development class – proportion varies with \( i, j \).
For each predator \((i,j)\), define **suitability** and **preference** for prey item \((i',j')\):

\[
\xi_{ij'i'j'} = \text{suit}_{ii'} \times \text{pref}_{ix}
\]

**Suitability**: does species \(i\) eat species \(i'\) at all (any size-classes)?

\[
\text{suit}_{ii'} = \begin{cases} 
1 & \text{if yes} \\
0 & \text{if no}
\end{cases}
\]

**Preference weighting**: for predator species \(i\) [and size class \(j\), and prey \(i'\) in size class \(j'\)] normalised predator:prey length ratio \(x\)

Requires estimates of min, max and opt pred:prey.
Total uptake of food by species/stage \( \{i,j\} \) as a function (type II functional response) of total prey availability (B).

\[
u(i, j) = \frac{u_{\text{max}} \times B}{B_{\text{half}} + B}
\]

Apportioned between prey species/stages \( \{i',j'\} \) according to prey biomass (B) and preference weightings \( (\xi_{ij} i'j') \):

\[
u(i,j,i',j') = \frac{\text{Maximum uptake} \times \text{pref. weighting} \times \text{biomass of } \{i',j'\}}{\text{Half sat. biomass} + \text{biomass of all pref. weighted prey}}
\]
Size-structured – population \( (n_{ij}) \) evolution

Number of individuals of species \( i \) and size class \( j \)

\[ n_{i,j} = \begin{cases} 
R_{i,j} & \text{for } j = 1 \\
(1-p(i))s(i,j)n(i,j) + p(i)s(i, j-1)n(i, j-1) & \text{for } j > 1
\end{cases} \]

- Recruits of species \( i \)
- Individuals of species \( i \) surviving and growing from size-class \( (j-1) \) + individuals surviving and remaining in size-class \( j \)

fraction \( p(i) \) of growers \( \Phi(i,j-1) \) surviving \( s(i,j-1) \) from class \( j-1 \)

fraction \( (1-p(i)) \) of non-growers \( \Phi(i,j) \) surviving \( s(i,j) \) in class \( j \)

\[ \Phi(i,j) = \frac{u(i,j)}{u_{\text{max}}(i,j)} \]

\[ s(i,j) = e^{\mu dt} \]
OTHER DEMERSAL AND PELAGIC FISH

Mainly small prey species, e.g. sprat, sandeel.

Modelled as population of individuals of fixed length-class and weight W.

Population growth (e.g. logistic growth) modified by predation ($f(P)$) by other species:

$$\frac{dP}{dt} = rP \left(1 - \frac{P}{K}\right) - f(P)$$

Predation rate on species \{i',j'\} = Total uptake of species \{i',j'\} by all predators

Biomass of species \{i',j'\}
BENTHOS AND ZOOPLANKTON - essential food for demersal fish.

Modelled dynamically (= resource for structured species) as size-structured (biomass spectrum) community of unstructured “pseudo-species”, to distribute available biomass appropriately across lengths classes.

Each “pseudo-species” modelled as unstructured resource with particular weight, carrying capacity (K) and growth rate (r).

\[
\frac{dP}{dt} = rP \left(1 - \frac{P}{K}\right) - f(P)
\]
Fishing and environmental variability

- Fishing will be implemented as another mortality term for each species $i$ and stage $j$

\[ s(i,j) = e^{-(\mu+F)dt} \]

- Time-dependent environmental forcing to be implemented as influencing
  - growth rates
  - carrying capacity, etc.
• Current version not spatially explicit
• Spatial resolution *can* be implemented
  – **Additional difficulties, e.g.**
    • Data availability at the right resolution
    • Interactions between spatial units (e.g. migration rates)
Thank you