Predicting human impacts on coupled size-structured communities

Julia Blanchard, Simon Jennings, Matthew Castle & Paul McCloghrie
Centre for Environment Fisheries and Aquaculture Science (Cefas), Lowestoft, UK

Richard Law, University of York, UK

Marie-Joëlle Rochet, IFREMER, Nantes, France

Eric Benoît, Université de la Rochelle, France

Introduction

Dynamic models of size spectra can be used to establish baseline estimates of community size structure that take into account time-dependent processes of growth and mortality. These models can be used to evaluate the relative effects of changes in fishing and primary productivity.

Platt & Denman (1978) and Silvert & Platt (1978) defined partial differential equations for size spectra with growth and mortality as continuous functions of size and time and accounted for food-dependent growth by relating the growth at one size to mortality at another using a predator-prey size ratio. Subsequent developments have assumed that a probability density function rather than a fixed value defines realised prey size (e.g. Camacho and Solé, 2001, Benoît and Rochet, 2004, Law *et al.*, 2008). These approaches have focussed on the pelagic community where predation is governed only by body size.

To extend size spectra beyond the pelagic community, we consider a wider range of trophic interactions and recycling of material that occurs as a result of benthic-pelagic coupling in marine ecosystems. We model the dynamics of interacting predator (primarily predatory fish and squid) and detritivore (primarily macrobenthic invertebrates) communities, and validate model predictions of with data from the North Sea (Blanchard *et al.*, 2008).

Methods

The model captures the trophic interactions and recycling of material that occur in many aquatic ecosystems (Figure 1); focusing on the transfer of energy from a plankton resource to larger sized organisms (i.e. fish predators and benthic detritivores) and a detritus pathway.

We parameterised the model for the North Sea using as input estimates of annual (mean, minimum, maximum) plankton productivity obtained from a coupled physical biogeochemical model (GETM-BFM).

We applied a range of realistic size-selective fishing mortality scenarios based on estimates of fish mortality for commercial fish in the North Sea obtained from Multispecies Virtual Population Analysis (ICES, 2005).

We compare our model results with observed predatory fish and benthic detritivore size spectra in the North Sea.

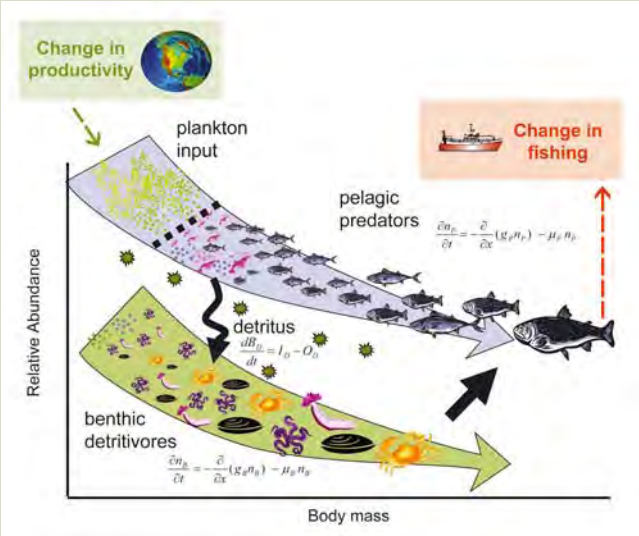

Figure 1. Conceptual illustration of two size structured communities with trophic interactions resulting in growth and mortality. The pelagic community consists of predators feeding on increasingly larger prey, as they themselves grow larger. Animals in the benthic zone share and compete for the same food: sinking detrital particles that are comprised of phyto-detritus, faeces and dead animals. See Blanchard et al. 2008 for equations.

Results & discussion

Slopes of size spectra were steeper and growth rates faster for predators compared to detritivores (Figures 2 & 3). Size spectra were truncated when primary production was either too low for predators and when detritivores experienced predation pressure (Figure 2).

Removal of large fish predators resulted in steeper predator spectra and increases in their prey (small fish and detritivores) (Figure 4).

The model predictions are consistent with observed patterns. The predicted 96% and 99% reductions in the biomass of large fish (4–16 kg and 16–66 kg, respectively) under the current exploitation pattern are also consistent with the findings reported in Jennings & Blanchard (2004) for the North Sea fish community

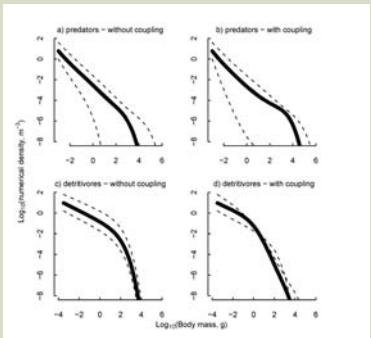

Figure 2. The effects of productivity on unexploited size spectra. Modelled $\log_{10}$ numerical density vs. $\log_{10}$body mass spectra after 50 years for the (a) predator community without and (b) with predator coupling and the (c) detritivore community without and (d) with predator coupling. Dark solid lines are simulation results based on mean plankton biomass density (bounded by dashed lines for minimum and maximum plankton biomass density scenarios below and above).

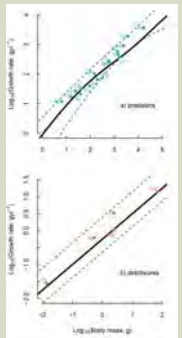

Figure 3. Model and observed growth rates (g yr^{-1}) as a function of body mass (g) shown on a log-log scale. (a) Predator community and (b) detritivore community. Blue symbols in (a) show empirically derived growth rates for a range of North Sea fish predator species and orange symbols in (b) for benthic detritivore species (see Blanchard et al. 2008).

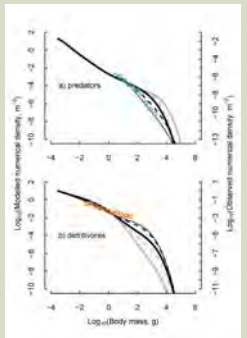

Figure 4. The effects of fishing on size spectra: model and data. Final time-step results for size spectra at mean levels of productivity and increasing levels of fishing intensity. Fishing intensity was increased by multiplying the current exploitation pattern in the North Sea by: 0 (solid grey line – no fishing), 0·5 (dashed grey line), 1 (thick solid black line – current), 2 (dashed black line) and 3 (thin black line). Symbols in (a) show predator size spectrum data (Jennings et al. 2002) and (b) benthic detritivore size spectrum data (Maxwell & Jennings 2006) from the North Sea.

Current and future applications

The above theoretical approach is being used to investigate how environmental and harvesting perturbations can alter the dynamics of the entire system by carrying out stability analyses and time-dynamic simulations.

Spatio-temporal patterns in benthic and pelagic production of the North Sea are being investigated by linking coupled physical-biogeochemical models with our size-based model (van Leeuwen & Blanchard, "Linking physical processes to higher trophic levels: results from coupling hydrological, biogeochemical and size-based food web models" presented at the American Society for Limnology and Oceanography, Aquatic Sciences Meeting 2009. Session 043: Links and levels in end-to-end food webs)

We are also using this model to investigate the effects of climate-change and fisheries on fish production and socio-economic consequences for 20 large marine ecosystems around the world (QUEST-Fish project, see Barange *et al.,* 2009).

Future model applications could employ data from observed phytoplankton size-structure, derived from ship-based measurements and satellite remote sensing.

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For further information contact julia.blanchard@cefas.co.uk

www.cefas.co.uk