# Predicting abundance - body mass scaling and human impacts in size structured food webs

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## Introduction

In communities sharing a common energy source, the energetic equivalence hypothesis predicts that numerical abundance (N) scales with body mass (M) as $M^{-0.75}$. However, in size structured food webs all individuals do not share a common energy source, and the energy available (E) to larger individuals is constrained by inefficient energy transfer through the food chains that support them. This is expected to lead to steeper scalings of N with M (Brown and Gillooly 2003).

Tests of the links between energy availability and abundance- body mass relationships are difficult, since ecologists often examine abundance-body mass relationships in taxon-based subsets of food webs (Gaston and Blackburn 2000) and lack accurate information on the energy available to animals of different sizes. We formalised and tested an existing model (Brown and Gillooly 2003) for predicting abundance- body mass scaling for all animals in a series of body mass classes, where the decline in E with M was calculated from the mean predator prey body mass ratio (PPMR, from size-based nitrogen stable isotope analysis) and trophic transfer efficiency (TE). This model can be applied in strongly size-structured food webs where larger predators eat smaller prey (Cohen *et al.* 1993, 2003).

## Methods

Biomass abundance (B), N and trophic level (TL) were determined for animals in a strongly size-structured marine food web in the central North Sea (Figure 1). We assumed that available energy (E) in the food web would scale as $M^0$ when the animals shared a common food resource and that the exponent would be less than 0 when larger predators fed on smaller prey. The expected scaling of $\log_{10}$ E with $\log_{10}$ M was calculated as $\log_{10}$ TE/ $\log_{10}$ PPMR. Predator-prey mass ratios were calculated from the slope of the relationship between $\delta^{15}N$ (y) and $\log_{10}$ body mass (x) ($PPMR=10^{(3.4/slope)}$), based on the assumption that the mean fractionation of $\delta^{15}N$ was 3.4 ‰ per trophic level (Post, 2002). For the calculated scaling of E and M, the scaling of N or B and M was calculated as $M^{(\log_{10}TE/\log_{10}PPMR)} * M^{-0.75}$ and $M^{(\log_{10}TE/\log_{10}PPMR)} * M^{0.25}$ respectively.

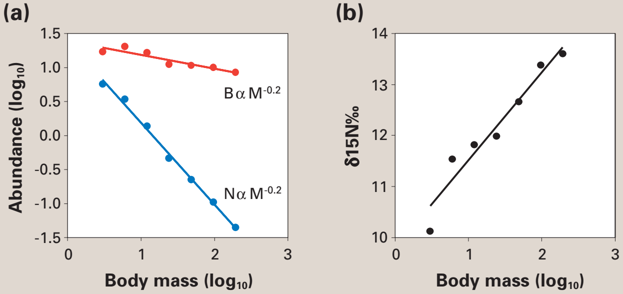

*Figure 1: Relationship between biomass abundance (**red**) or numerical abundance (**blue**) and body mass in the central North Sea food web (a) and between $\delta^{15}N$ and body mass (b).*

## Results and Discussion

Based on the model, the predicted scalings of N and B with M in the marine size-based food web we studied were $M^{-1.24}$ and $M^{-0.24}$ respectively, given a TE of 0.10 and PPMR of 106:1. These are not significantly different from the observed values of $M^{-1.20}$ and $M^{-0.20}$ (Figure 1; $p<0.05$). The scaling of N or B with M was relatively insensitive to changes in TE across the range of TE expected in temperate marine food webs (Jennings and Mackinson, 2003) (Figure 2).

We conclude that the steep scalings of abundance and body mass (N scales as $M^{-1.2}$, B scales as $M^{-0.2}$) in a marine food web are consistent with empirical estimates and can be attributed to the small predator-prey body mass ratio (106:1). Since a previous study has shown that environmental stability may favour low predator-prey mass ratios and long food chains, we predict that steeper abundance body mass relationships will be found in more stable environments. The analysis is a good example of how new types of empirical data can underpin the testing of ecological theory (Brown and Gillooly 2003; Cohen *et al.* 2003).

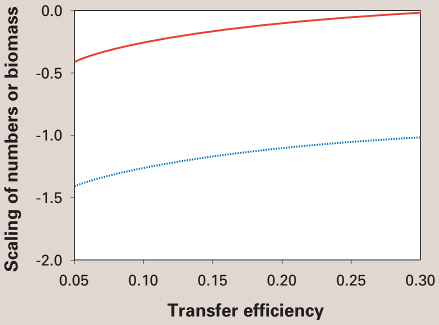

*Figure 2: Scaling of biomass (**red**) or numbers (**blue**) and body mass as a function of transfer efficiency.*

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## Applications

Intensive fishing has a dramatic effect on the size composition of marine food webs, and increased fishing causes the slope of the abundance-body mass relationship (commonly termed a 'size spectrum' by aquatic ecologists) to become steeper (Duplisea and Kerr 1995, Rice and Gislason 1996). Since fishing does not tend to alter PPMR or TE, theoretical predictions of the slope of an unexploited size spectrum (such as those previously described) can be compared with observed slope to assess the effects of fishing.

We estimated PPMR and TE at sites throughout the intensively fished North Sea and used these to predict a theoretical size-spectra in the absence of fishing (Figure 3). These were compared with size spectra observed in 2001. The differences between the theoretical and observed spectra suggested that the 2001 biomass of large fishes weighing 4-16 kg and 16-66 kg respectively was 97.4% and 99.2% lower than in the absence of fisheries exploitation, while the mean turnover time of the whole fish community was almost twice as fast (falls from 3.5 to 1.9 years) and 70% less primary production was required to sustain it (Jennings and Blanchard, 2004). The impacts of fishing predicted by this simple macroecological approach (Table 1) are quite consistent with those predicted using more complex ecosystem models (Mackinson 2002).

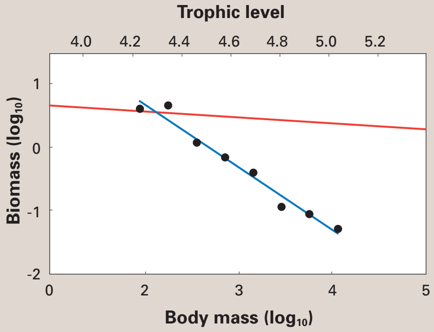

*Figure 3: The predicted slope of an unexploited size spectrum (**red**) when TE= 0.125 and PPMR=390:1 and the observed slope of a size spectrum for the exploited North Sea in 2001 (**blue**). Differences between the slopes reflect the effects of fishing on the fish community. Nitrogen stable isotope analysis was used to relate body mass and trophic level.*

**Table 1: Comparison of predicted metrics for an unexploited North Sea fish community (64g – 66 kg, for transfer efficiency of 0.125) and the fished community in 2001.**

| Metric | Unexploited | 2001 |
|---|---|---|
| Total community biomass (g $m^{-2}$) | 27.38 | 10.45 |
| Mean weight of individual (g) | 383 | 144 |
| Mean trophic level | 4.68 | 4.34 |
| Mean turnover time of biomass (y) | 3.45 | 1.89 |

## Acknowledgements

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