Estimating trophic transfer efficiency in a size-based food web

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Cefas

Background

Methods of assessing trophic transfer efficiency are needed to predict the direct (eg. fisheries) and indirect (eg. climate change) effects of human activities on marine ecosystems [1,2]. Here, we present a simple synthesis of the complex structure and function of a marine food web, and show how size-based estimates of production and trophic level, as estimated using nitrogen stable isotope analysis, can be used to quantify trophic transfer efficiency. Our approach provides an independent validation of the outputs of existing food-web models and our estimates of transfer efficiency are consistent with those obtained from costly and labour intensive diet and ecosystem modelling studies [3].

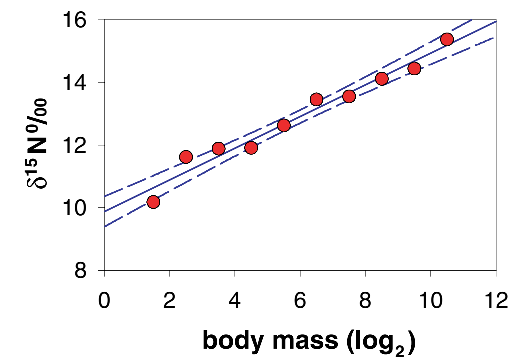

Figure 1: Relationships between biomass weighted mean δ^{15}N and log_2 body mass in the central North Sea. If we assume a 3.4 ‰ enrichment in δ^{15}N per trophic level [7], then the slope implies a mean predator to prey body mass ratio in the food web of 109:1 (mass ratio = $2^{3.4/slope}$)

Trophic level

We estimated the mean biomass and body size distributions of all animals from 2-2048 g wet mass in the central North Sea. Using corers, dredges, nets and acoustic survey methods, we took haphazardly located replicate samples of infaunal invertebrates, epifaunal invertebrates, bottom-dwelling fish and pelagic fish or squid in 2000 and 2001 [4]. All individuals in each replicate sample were weighed and assigned to log_2 body mass classes. We estimated the mean trophic level for the animals in each size class using nitrogen stable isotope analysis (δ^{15}N) [5]. Biomass weighted mean δ^{15}N, calculated across all faunal groups, increased significantly with body mass, reflecting the increase in the trophic position of animals with increasing body size (Figure 1).

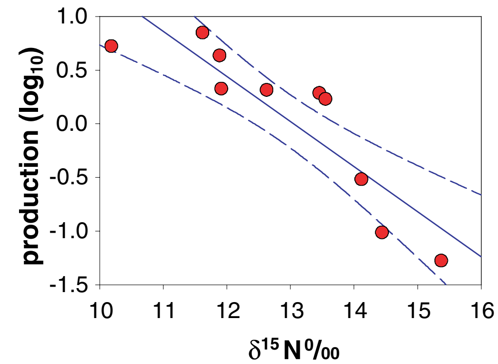

Figure 2: Relationships between log_{10} production (g m^{-2} $year^{-1}$) and weighted mean δ^{15}N. The trophic transfer efficiency is 3.7% [TE = $100(10^{3.4/slope})$], assuming a fractionation of 3.4 ‰ in δ^{15}N per trophic level [7].

Production and Transfer Efficiency

Within each log_2 body mass class, individual body mass was converted to production using allometric relationships between body mass and production: biomass ratios [6]. The slope of the relationship between production and δ^{15}N by size class implies a mean transfer efficiency of 3.7 % (Figure 2). However, high levels of fishing mortality observed in the North Sea are likely to reduce biomass and production in large body mass classes, and so we tested the relationship between production and δ^{15}N when the larger body mass classes were excluded. When individuals with body masses >1024 g and >512 g were excluded, the estimated transfer efficiencies rose to 5.7 % and 12.4 % respectively (Figure 3).

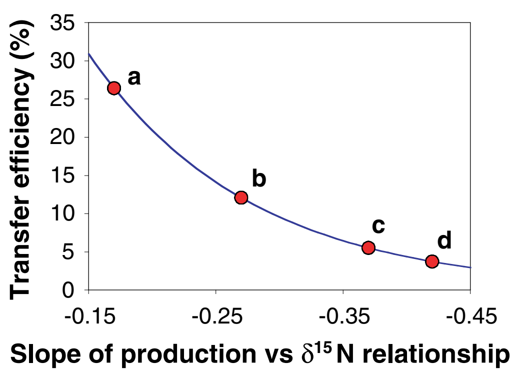

Figure 3: Relationship between transfer efficiency and the slope of the relationship between log_{10} production (g m^{-2} $year^{-1}$) and mean δ^{15}N (‰). The fractionation of δ^{15}N (‰) with trophic level is assumed to be 3.4 ‰. Circles a-d show how estimates of transfer efficiency change in relation to the size range of animals included in the analyses: a. 2-256 g included, b. 2-512 g included, c. 2-1024 g included, d. 2-2048 g included.

Conclusions

Analyses of the structure and function of ecosystems are inevitably ambitious, due to difficulties in sampling, identifying ecosystem boundaries, quantifying the import and export of production and understanding the impacts of predators that are not included in the analyses (humans, seabirds, marine mammals). The assumed fractionation of δ^{15}N with trophic level will also affect our results (Figure 4). However, our simplistic approach has produced estimates of transfer efficiency that are broadly consistent with those obtained from costly and labour intensive diet and ecosystem modelling studies. Coupled analyses of size and trophic structure provide a potentially useful method for validating ecosystem models and assessing human impacts on marine ecosystems.

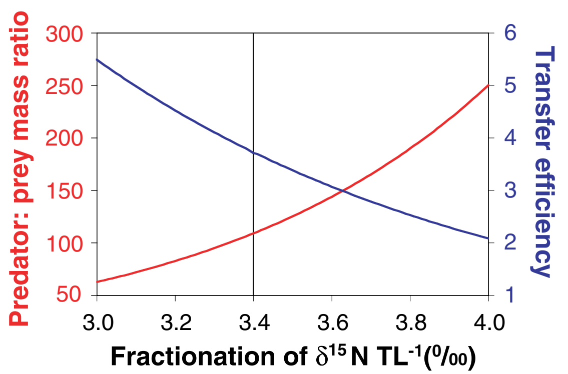

Figure 4: The effects of assumptions about the degree of fractionation of δ^{15}N (‰) with trophic level on transfer efficiency (blue) and predator-prey body mass ratios (red). The vertical line corresponds to an assumed fractionation of 3.4 ‰ per trophic level.

Acknowledgements

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