Size based models (macroecological approaches)

Aim: predicting biomass/abundance through an ecosystem - as a function of body size and primary production

Advantage – simplification, ease of coupling to GCM models, large datasets of body size to validate against, easy to understand.

Key variables can be constrained (a bit) with relatively simple field data

General form:

- Biomass, production, size structure predicted from:
- Primary production available

$$B = B_o M^{\alpha} e^{\frac{-E_a}{kT}}$$

- Temperature (via effect on consumer metabolic rate)
- Predator Prey Mass Ratio (PPMR)
- Trophic transfer efficiency (TE)

Biomass (size structured)

$B \alpha M^{a} * M^{log(TE)/log(PPMR)}$

Log Number of Individuals



Copyright © SeaPics.com



Log Body Mass Community biomass increases less than 0.25 (may decrease)

Size-based ecosystem models

PLOS ONE

Merino et al 2012. Glob. Env. Change 22: 795-806 RESEARCH ARTICLE

Predicting Consumer Biomass, Size-Structure, Production, Catch Potential, Responses to Fishing and Associated Uncertainties in the World's Marine Ecosystems

Simon Jennings*, Kate Collingridge

Vol. 365: 187–197, 2008 doi: 10.3354/meps07414 MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser

Published August 18

Application of macroecological theory to predict effects of climate change on global fisheries potential

William W. L. Cheung*, Chris Close, Vicky Lam, Reg Watson, Daniel Pauly

Sea Around Us Project, Fisheries Centre, The University of British Columbia, 2202 Main Mall, Vancouver, British Columbia V6T 1Z4, Canada

predicting consumer biomass (macroecology model)

$$P_{CI} = e^{(c_1 - E/kT_K)} M_{CI}^{r}$$

Consumer production depends on body size and temperature

$$b_C = M_C^{(\log_{10} \varepsilon_S/\log_{10} \mu_S) + b_S}$$

Biomass size spectrum depends on PPMR and transfer efficiency

TE constant

PPMR constant



Body Size

TE and PPMR

- poorly constrained especially community / field
- 50% uncertainty on global biomass estimates 0.5 OOM (90% = 3 OOM)
- How could we constrain TE in a range of ecosystems?

$B \alpha M^{a} * M^{\log(TE)/\log(PPMR)}$

Trebilco et al 2013 TREE



size spectrum slope - measured from trawl PPMR – measure / estimate [SI]

Carbon flux in size based macroecological models

- Models essentially tracking the remaining C after respiratory LOSS
- 1-TE effectively sets C available for storage / flux
- Again TE is poorly constrained (too poorly constrained to be useful?)

Blanchard et al 2009 J. Animal Ecol.



Body mass

Table 1. Model equations and description

Equations	Units	Description
Dynamical system: $\frac{\partial n_{\rm p}}{\partial t} = -\frac{\partial}{\partial x}(g_{\rm p}n_{\rm p}) - \mu_{\rm p}n_{\rm p}$ $\frac{\partial n_{\rm B}}{\partial t} = -\frac{\partial}{\partial x}(g_{\rm B}n_{\rm B}) - \mu_{\rm B}n_{\rm B}$ $\frac{\partial b_{\rm D}}{\partial t} = I_{\rm D} - O_{\rm D}$	m ⁻³ year ⁻¹ m ⁻³ year ⁻¹ g m ⁻³ year ⁻¹	Dynamics of pelagic predators, $n_{\rm P}$, benthic detritivores, $n_{\rm B}$ and detritus, $b_{\rm D}$. Rates of change of $n_{\rm P}$, $n_{\rm B}$ are functions of x (In of body mass in grams) and time t due to growth g and mortality μ . Rate of change of $b_{\rm D}$ is a function of t , with input rate $I_{\rm D}$ from deaths and faeces in both spectra, and output rate $O_{\rm D}$ from detritivore feeding. P , pelagic predators; B , benthic detritivores; D , detritus.
Flux terms from feeding: $F_{p_{l}}(x,t) = \omega_{l}A_{p}e^{a_{p}x}\int \varphi(x-x')n_{l}(x',t)e^{-(x-x')}dx'$ $F_{B}(x,t) = e^{-x}A_{B}e^{a_{B}x}b_{D}(t)$ give relative growth rates:	year-1	F_{Pl} is the relative feeding rate of predators on size spectrum $t \in \{P, B\}$, where ω_t is the proportion of time spent in i. F_B is the feeding rate of detritivores. $A_p e^{\alpha_p x}$, $A_B e^{\alpha_B x} (m^3 \text{ year}^{-1})$ are volumes searched and filtered by predators and detritivores, respectively. Probability of a predator of size <i>x</i> eating a prey of size <i>x'</i> is given by the Gaussian probability density function of
$g_{\rm P}(x, t) = K_{\rm P}F_{\rm PP}(x, t) + K_{\rm B}F_{\rm PB}(x, t)$ $g_{\rm B}(x, t) = K_{\rm D}F_{\rm B}(x, t)$ and relative expection rates:	year ⁻¹	the logarithm of the predator: prey mass ratio, $\varphi(x - x')$; this applies in the range $0 \le x - x' \le x_{max} - x_{min}$, the limits over which $\varphi(x - x')$ is integrated being 0 to $x_{max} - x_{min}$.
$f_{\rm P}(x, t) = E_{\rm P}F_{\rm PP}(x, t) + E_{\rm B}F_{\rm PB}(x, t)$ $f_{\rm B}(x, t) = E_{\rm D}F_{\rm B}(x, t)$	year-1	$K_{\rm P}$, $K_{\rm B}$, $K_{\rm D}$ are gross growth conversion efficiencies, the fractions of each type of food converted to growth Functions f_l are relative egestion rates, where $E_{\rm P}$, $E_{\rm B}$, $E_{\rm D}$ are
Flux terms from death: $\mu_{tp}(x, t) = \omega_t A_p \int \varphi(x' - x) n_p(x', t) e^{\alpha_p x'} dx'$ $\mu_t(x) = 0.2 e^{-0.25x} + 0.2 e^{0.3(x - x_2)}$	year-1	fractions of each type of food egested. μ_{IP} is the death rate in size spectrum $t \in \{P, B\}$, due to predators of size x' feeding on prey of size x. Other mortality μ_{IO} includes an intrinsic term that decreases as a function of body size (Lorenzen 1996; Brown <i>et al.</i> 2004), and senescent
give overall death rates: $\mu_{t}(x, t) = \mu_{tP}(x, t) + \mu_{tO}(x)$	year-1	mortality. The latter increases sharply with body size at $x_r = \log(1 \text{ kg})$. Overall, this results in a u-shaped function for other mortality, consistent with the function and values given in Hall <i>et al.</i> (2006). Predation and other mortality combined give the overall mortality rate μ_r .
Flux in detritus from feeding, egestion, and death: $I_{\rm D}(t) = S \int e^{x} n_{\rm p}(x,t) [f_{\rm p}(x,t) + \mu_{\rm p}(x,t)] dx$ $+ S \int e^{x} n_{\rm pl}(x) \mu_{\rm pl}(x) dx$ $+ \int e^{x} n_{\rm B}(x,t) \mu_{B}(x,t) dx$	g m ⁻³ year ⁻¹	Flux into the detritus pool, $I_{\rm D}$, is the total rate at which mass is egested and dead mass is generated by nonpredation mortality; a term for dead plankton is also included. The proportion of detritus from the pelagic zone reaching the benthic zone is <i>S</i> . Within the benthic community, detritus is derived from dead biomass but not from egested material. The flux out of the detritus pool $O_{\rm D}$, is the biomass density consumed per unit time by all detritivores.
$O_{\rm D}(t) = \int e^x n_{\rm B}(x) F_{\rm B}(x, t) dx$	g m ⁻³ year ⁻¹	

Possible focus for size -based macroecological models?

- Open ocean
- Good reasons to expect size structure
- Data limited for bioenergetic / species based approach

• Subsidy effects

$B \alpha M^{a} * M^{log(TE)/log(PPMR)}$





