Understanding internal and external effects on the composition of marine ecosystems

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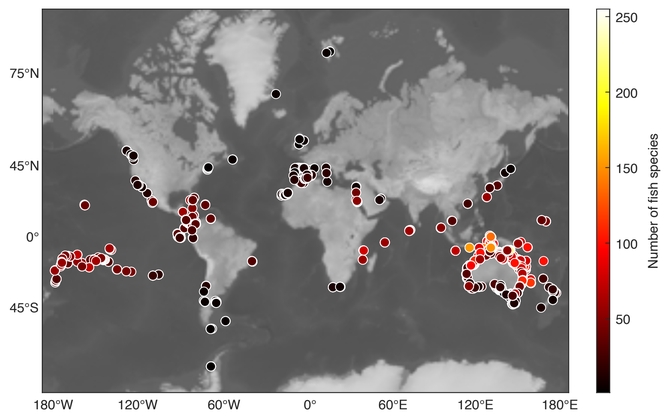
Abstract

Understanding the factors modulating the composition of marine ecosystems is paramount for improving restoration and sustainability strategies. In this direction, size-based ecosystem modeling has had a long tradition in marine research. Body size is considered as a 'master trait' scaling with many physiological and behavioral traits, which has been useful in approximating the composition of marine ecosystems. However, the extent to which internal (such as the particular collection of species in a community) and external factors (such as protected areas or temperature variability) affect species composition has not been properly measured (i.e., what body size cannot capture). Yet, this is critical in the face of global environmental change, which continues to cause biodiversity loss and climatic changes. To address this gap, we estimate internal effects by approximating species interactions using a niche overlap framework that estimates the intersection between species's body size density functions. We integrate these interactions under a Lotka-Volterra dynamics in order to analytically estimate the community composition given a collection of species. We then quantify the extent to which this methodology explains what body size alone cannot. Then, we identify external factors (e.g. climatic variables, human impact) linked to the capacity of species interactions to explain community composition.

Data



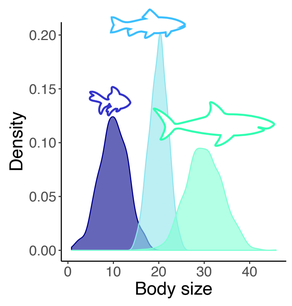
We analysed 3378 sampling sites around the planet, where population data of over 3000 species are available with individual body size information from the largest global database of marine fish species (FishBase)

Photo by: J.E. Randall

Conceptual model

Internal effects

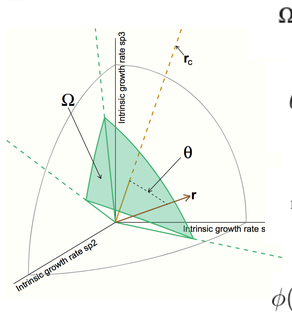
A



$$A = \begin{bmatrix} 1 & .. & \\ .. & 1 & .. \\ & .. & 1 \end{bmatrix}$$

$$NO_{ij} = w \int min(f_i(x) f_j(x)) dx$$

B



$$\Omega(\boldsymbol{\alpha}) = \frac{|\det(\boldsymbol{\alpha})|}{\sqrt[n]{\pi/2}} \int \cdots \int_{\boldsymbol{R}^n_{\geq 0}} e^{-\boldsymbol{x}^T \boldsymbol{\alpha}^T \boldsymbol{\alpha} \boldsymbol{x}} d\boldsymbol{x}$$ Size of the feasibility domain

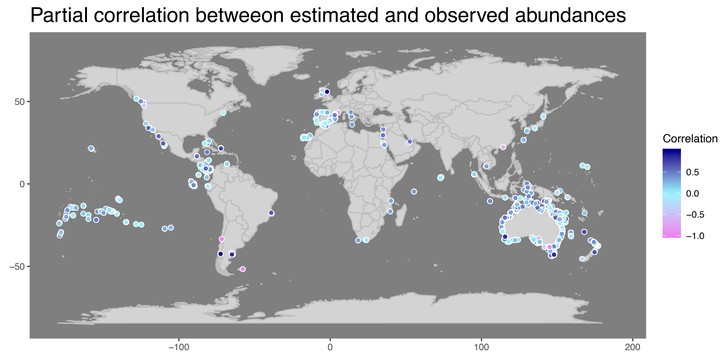
$$\theta = \arccos\left(\frac{\mathbf{r} \cdot \mathbf{r}_c}{\|\mathbf{r}\| \cdot \|\mathbf{r}_c\|}\right)$$ Performance difference

$$\mathbf{r}_c = \frac{1}{n}\left(\frac{\mathbf{v}_1}{\|\mathbf{v}_1\|} + \frac{\mathbf{v}_2}{\|\mathbf{v}_2\|} + \cdots + \frac{\mathbf{v}_n}{\|\mathbf{v}_n\|}\right)$$ Geometric centroid

$$\phi(\alpha) = \mathrm{SD}(\|v_1\|, \ldots, \|v_s\|)$$ Asymmetry of the feasibility domain

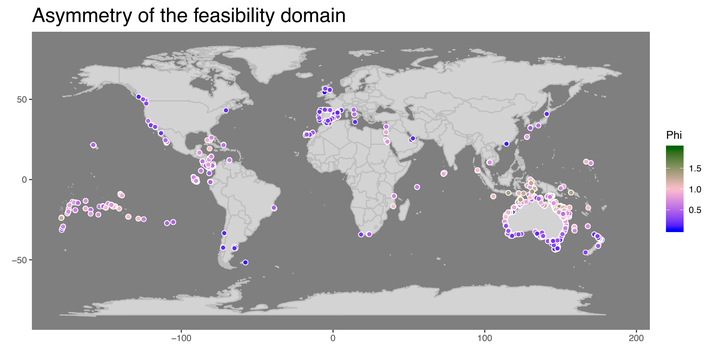
(A) First, we estimated the interaction structure of each community based on a niche overlap framework. To find a positive and globally stable steady state of our system, the equilibrium abundances were calculated assuming Lotka-Volterra dynamics, where K* is the leading eigenvector and h is the leading eigenvalue of the interaction matrix (Perron-Frobenius theorem): N*= (1/h)/K*. (B) Then, the structural measures of the system were calculated: size and asymmetry of the feasibility domain and the performance differences for each community.

Partial correlation betweeon estimated and observed abundances



We found that once we control for body size, the association between the estimated and observed compositions displayed a large variability. This variability was not driven by community size or sampling effort.

Asymmetry of the feasibility domain



Structural measures such as the asymmetry of the feasibility domain is a good indicators of vulnerability for communities. The more asymmetric, the more sensitive communities are to environmental changes.

External effects

Bioclimatic variables:
Sea surface temperature
Temperature variation
Thermal stress anomalies
…

Ocean conditions:
Upwelling
Circulation-exchange
Chlorophyll-a concentration
…

Human impacts:
Industrial fishing effort
Marine protected areas
Human density
…

External factors might overrule the effect of species interactions in some communities. Here we identify what combinations of external factors influence the composition of marine communities.

Conclusions

- We found that poor associations were linked to sites subject to harsh environmental conditions, revealing the conditions under which external factors may overrule the effect of internal effects, i.e. species interactions
- We will further investigate the how structure measures are linked to external factors
- Our findings open new possibilities to differentiate the role of internal and external factors affecting the composition of marine ecosystems