**Supplemental Material**

**Energetic constraints on body-size niches in a resource-limited marine environment**

S. River D. Bryant and Craig R. McClain

**I. Generalized Linear Model Results**

There were no significant interaction terms between the three energetic variables (temperature, particulate organic carbon (POC), and dissolved oxygen) in the models for mean or maximum body size, skew of the distribution, or estimated number of modes (Supplemental Table 1). Significant interactions of the linear and parametric forms of temperature with the linear and parametric forms of POC were recognized in the models for standard deviation and kurtosis of the body-size distribution (Supplemental Table 1). However, in all models, including those with significant interactions, the AIC of the generalized linear model was similar to (within 2 AIC units) or lower than that of the generalized additive mixed effect model (Supplemental Table 2). Therefore, the latter models were determined to be the better fit, and the results of those were reported in the main manuscript and informed the main findings.

**II.** **Multimodal Body-Size Distributions**

Increased energy may increase availability of rare resources [65-68]. These rare resources make energy available to additional size bins allowing for multi-modal species richness-body size distributions [69]. Trends in most descriptors of the species richness-body size distribution will be idiosyncratic, depending on the order in which species are added to different modes (one example, where first a larger size class and then a smaller size class is favored. However, variance will typically increase, and a systematic increase in the number of modes is detected as energy availability increases, with pronounced increases also within the size classes closest to the new modes. Increased number of modes with increased energy should be concordant with increases of abundance in these same size classes.

The optimal number of modes that best fit each distribution was estimated using Bayesian information criterion (BIC) values initialized by hierarchical clustering for parameterized Gaussian mixture models with the “mclust” package [29, 30]. In no case did we find a significant pattern between the number of modes and any of the energetic variables (Supplemental Figure 1, Supplemental Table 3).

**III. Basin-Level Patterns in Size Distributions**

In bivalves, size-latitude trends are highly heterogeneous among hemispheres, and coastlines [50]. By proxy, size-energy trends would be expected to be equally variable, a conclusion supported by our findings as all metrics of the body-size distribution were significantly different in some ocean basins (Table 1, Supplemental Table 1). In particular, the Cape and Western European Basins stood out as consistently significantly different, which may be explained by the characteristically high and variable POC flux of these relative to other basins [51-53].

**IV. Species Richness and Particulate Organic Carbon Flux**

 Species richness peaked at intermediate POC flux, with lowered diversity at the low- and high-POC flux extremes (Supplemental Figure 2).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Terms** | **Mean** | **Maximum** | **Standard Deviation** | **Kurtosis** | **Skew** | **Est. Num. Modes** |
| **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** |
| Temperature | 0.63 | 0.5265 | 0.41 | 0.6825 | 0.64 | 0.5232 | -0.63 | 0.5307 | -0.56 | 0.5769 | 1.16 | 0.2472 |
| Temperature^2 | -0.26 | 0.7937 | -0.47 | 0.6415 | -0.63 | 0.5294 | 0.45 | 0.6565 | 0.50 | 0.6206 | -1.08 | 0.2834 |
| POC | 1.36 | 0.1749 | -0.77 | 0.4448 | 0.34 | 0.7363 | -1.77 | 0.0775 | -0.99 | 0.3227 | -0.34 | 0.7377 |
| POC^2 | -1.48 | 0.1414 | 0.62 | 0.5350 | -0.40 | 0.6894 | 1.76 | 0.0792 | 0.87 | 0.3874 | 0.40 | 0.6883 |
| Diss. Oxygen | 1.28 | 0.2013 | -0.26 | 0.7993 | 0.36 | 0.7203 | -1.46 | 0.1452 | -0.68 | 0.4983 | 0.97 | 0.3336 |
| Diss. Oxygen^2 | -1.16 | 0.2493 | 0.36 | 0.7178 | -0.18 | 0.8559 | 1.38 | 0.1696 | 0.65 | 0.5193 | -1.00 | 0.3185 |
| Argentine Basin | -1.13 | 0.2615 | -0.69 | 0.4942 | -2.11 | **0.0361** | 1.24 | 0.2181 | -0.53 | 0.5974 | 0.44 | 0.6584 |
| Brazil Basin | -0.09 | 0.9270 | -0.15 | 0.8781 | -1.18 | 0.2384 | 0.36 | 0.7160 | -1.48 | 0.1403 | 0.11 | 0.9101 |
| Canaries Basin | 0.60 | 0.5488 | 0.93 | 0.3553 | 0.02 | 0.9857 | 1.08 | 0.2808 | 0.08 | 0.9341 | 1.54 | 0.1254 |
| Cape Basin | -0.64 | 0.5225 | 2.74 | **0.0066** | 1.41 | 0.1605 | 2.65 | **0.0087** | 2.27 | **0.0241** | 0.41 | 0.6800 |
| Cape Verde Basin | -0.71 | 0.4778 | -0.51 | 0.6142 | -0.11 | 0.9164 | 0.02 | 0.9860 | -1.22 | 0.2234 | -0.22 | 0.8250 |
| Guinea Basin | 0.26 | 0.7920 | 1.03 | 0.3059 | 1.98 | **0.0492** | 0.24 | 0.8071 | 0.84 | 0.3994 | 1.44 | 0.1526 |
| Newfoundland Basin | -0.80 | 0.4235 | -0.44 | 0.6640 | -0.31 | 0.7556 | 0.77 | 0.4437 | -1.11 | 0.2704 | 1.60 | 0.1102 |
| North America Basin | -1.47 | 0.1418 | -0.34 | 0.7336 | -1.43 | 0.1536 | 1.22 | 0.2256 | -0.61 | 0.5429 | 0.71 | 0.4792 |
| Sierra Leone Basin | -0.36 | 0.7195 | -0.24 | 0.8117 | -1.77 | 0.0776 | 1.94 | 0.0544 | -0.55 | 0.5804 | 2.38 | **0.0181** |
| Surinam Basin | -1.71 | 0.0886 | -0.42 | 0.6742 | -0.18 | 0.8555 | 1.14 | 0.2553 | -2.34 | **0.0200** | 0.14 | 0.8888 |
| West European Basin | -1.54 | 0.1249 | -0.63 | 0.5300 | -2.17 | **0.0315** | 1.76 | 0.0793 | -0.05 | 0.9627 | 0.72 | 0.4729 |
| Temperature:POC | 0.49 | 0.6232 | -1.45 | 0.1498 | -1.59 | 0.1145 | -2.16 | **0.0319** | 0.84 | 0.4025 | 0.24 | 0.8142 |
| Temperature:POC^2 | -0.52 | 0.6015 | 1.55 | 0.1238 | 1.53 | 0.1271 | 2.29 | **0.0229** | -0.28 | 0.7818 | -0.59 | 0.5590 |
| Temperature:Diss. Oxygen | -0.50 | 0.6170 | 0.05 | 0.9575 | -0.33 | 0.7446 | 1.09 | 0.2756 | 0.45 | 0.6512 | -1.22 | 0.2237 |
| Temperature:Diss. Oxygen^2 | 0.32 | 0.7518 | -0.39 | 0.6983 | 0.15 | 0.8836 | -1.26 | 0.2095 | -0.51 | 0.6117 | 1.25 | 0.2127 |
| Temperature^2:POC | -1.61 | 0.1087 | 1.68 | 0.0935 | 2.05 | **0.0417** | 2.43 | **0.0159** | -0.31 | 0.7558 | -0.01 | 0.9936 |
| Temperature^2:POC^2 | 1.78 | 0.0762 | -1.83 | 0.0684 | -2.12 | **0.0352** | -2.65 | **0.0087** | -0.17 | 0.8619 | 0.25 | 0.8066 |
| Temperature^2:Diss. Oxygen | 0.32 | 0.7507 | -0.07 | 0.9486 | 0.19 | 0.8472 | -0.98 | 0.3272 | -0.39 | 0.6961 | 1.09 | 0.2765 |
| Temperature^2:Diss. Oxygen^2 | -0.14 | 0.8885 | 0.39 | 0.6983 | -0.01 | 0.9895 | 1.11 | 0.2704 | 0.43 | 0.6708 | -1.11 | 0.2666 |
| POC:Diss. Oxygen | -1.39 | 0.1661 | 0.60 | 0.5493 | -0.10 | 0.9217 | 1.59 | 0.1130 | 0.60 | 0.5496 | 0.27 | 0.7901 |
| POC:Diss. Oxygen^2 | 1.36 | 0.1760 | -0.35 | 0.7258 | -0.07 | 0.9437 | -1.13 | 0.2594 | -0.35 | 0.7281 | -0.31 | 0.7601 |
| POC^2:Diss. Oxygen | 1.50 | 0.1349 | -0.45 | 0.6504 | 0.15 | 0.8824 | -1.58 | 0.1154 | -0.51 | 0.6129 | -0.24 | 0.8146 |
| POC^2:Diss. Oxygen^2 | -1.45 | 0.1500 | 0.23 | 0.8153 | 0.10 | 0.9244 | 1.11 | 0.2703 | 0.23 | 0.8157 | 0.26 | 0.7967 |

**Supplemental Table 1.** Results of the Generalized Linear Models. P-values < 0.05 shown in bold.

**Supplemental Table 2.** AIC comparison table for generalized additive mixed effect models (GAMM) versus generalized linear models (GLM).

|  |  |  |
| --- | --- | --- |
| **Model** | **GAMM AIC** | **GLM AIC** |
| **Mean** | 299.54 | 297.82 |
| **Maximum** | 616.29 | 629.24 |
| **Standard Deviation** | -18.07 | -10.31 |
| **Kurtosis** | 690.16 | 703.43 |
| **Skew** | 378.84 | 388.86 |
| **Est. Number of Modes** | 1029.89 | 1052.81 |

**Supplemental Table 3.** Generalized Additive Mixed Model (GAMM) results for estimated number of modes modelled as a function of energetic variables. Term type: S: smooth terms, P: parametric terms. EDF: estimated degrees of freedom, F-value: F-ratio test score; t-value: t-test score. Bold p-values are less than α = 0.05. EDF, residual df, F-values shown for smooth terms; t-value shown for parametric coefficients.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | **Terms** | **Term Type** | **EDF** | **Residual df** | **F-value** | **t-value** | **p-value** | **Adj. R-sq** | **Deviance explained** | **n** |
| **Estimated Number of Modes** | log(Temperature) | S |  <0.01 | 229.61 | 0.00 | - | 0.5920 | 0.02 | 6.68% | 242 |
| log(POC) | S | 0.39 | 229.61 | 0.07 | - | 0.2010 |
| log(Dissolved Oxygen) | S | <0.01 | 229.61 | 0.00 | - | 0.3900 |
| Ocean Basin (Intercept) | P | - | - | - | 4.13 | **<0.0001** |
| *Sierra Leone Basin* | P | - | - | - | 2.84 | **0.0050** |



**Supplemental Figure 1.** Generalized additive mixed model (GAMM) derived effects of log10 temperature, log10 POC flux, and log10 dissolved oxygen on the estimated number of modes in the body-size distribution.



**Supplemental Figure 2.** Generalized additive mixed model (GAMM) derived effects of log10 POC flux on species richness. Solid line indicates model fit; dashed lines indicate the 95% confidence interval.