The following supplement accompanies the article

Controls on the standing crop of benthic foraminifera at an oceanic scale

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Supplement 1

Text S1. Further discussion of approach and limitations

THE CORRELATION OF ENVIRONMENTAL VARIABLES

There are significant correlations (Figure S1) between many of the environmental variables associated with each foraminiferal standing crop measurement. In the presence of such multicollinearity, the statistical model estimate of one variable's impact on the dependent variable, while controlling for the others, tends to be less precise than if predictors were uncorrelated with one another. By using backward stepwise elimination or forward selection of variables the minimum adequate models tend not to feature two strongly correlated variables. The potentially larger problem is that the biological interpretations of the relationships between response and predictor variables are dependent on accurate determination of which of the correlated predictor variables is driving the patterns in standing crop. To resolve this problem in our analysis we attempted replacement of predictor variables with strong correlation with more likely (based on macroecological theory and the body of local foraminiferal studies we would expect temperature, POC flux and oxygen concentration to be important environmental variables) correlates to see if a similarly suitable (based on significance of each variable and overall model AIC) minimum adequate model could be constructed. The only time such a replacement was made was in the abyssal depths, where a similar minimum adequate model could be constructed with either silicate or POC flux (but not both) as an explanatory variable. Our results appear robust, with similar patterns being found in two regression approaches (compare generalized and spatial linear models in Table 3 and 4). However, the possibility remains that other correlated environmental variables are important in controlling patterns in foraminiferal standing crop. In the analysis using the full dataset temperature and food supply produced similar model performance, reducing our ability to distinguish between these important environmental variables. The lower number of observations and higher correlation between the environmental variables in the abyssal samples mean that errors are more likely in this depth zone.

THE EFFECT OF BODY SIZE ON THE ENVIRONMENTAL DETERMINANTS OF FORAMINIFERAL STANDING CROP

A total of four size fractions were included in the full dataset based on the sieve size used in the determination of foraminiferal standing crop (63 µm: n = 553; 106 µm: n = 14; 125 µm: n = 350; 150 µm: n = 50). The foraminiferal standing crops were significantly different in the four size fractions (ANOVA F = 60.17, df = 3, 963, $p < 0.001$), with significant (Tukey HSD: $p < 0.001$) pairwise differences observed between all size fractions except the 125 and 150 µm sieves (p = 0.14). The 106 µm size fraction had the lowest standing crop (mean ± SD = 4.2 ± 7.8 ind. 10 cm^{-3}; note the small number of samples: n = 14), otherwise the standing crops were higher the smaller the size fraction, although there was great variation in standing crop at all size fractions (mean ± SD: 63 µm: 245.4 ± 459.1 ind.

10 cm^{-3}; 125 µm: 108.2 ± 197.7 ind. 10 cm^{-3}; 150 µm: 74.5 ± 128.3 ind. 10 cm^{-3}). There is spatial variation in the location (Figure S2) and some depth differentiation (Figure S3) of samples taken with different sieve sizes, which may partially explain these differences. Despite these differences, if size fraction was included in any of the statistical models developed as a covariate, it was not significant ($p > 0.05$) in explaining the standing crop once the environmental variables had been taken into account. There are no clear trends in standing crop from different size fractions with depth (Figure S3). Such trends would be expected if sieve-size-related patterns were highly important in driving standing crop. The explanation appears to be that variation between samples as a result of environmental variation was orders of magnitude larger than the variation cause by changes in size fraction. As a result, the data for all size fractions was combined. To further justify the decision to combine data from different size fractions, the spatial linear models were rerun separately using the 63 µm data and a combination of the 125 and 150 µm size fraction data (the 106 µm data were not analysed owing to low numbers of observations). The results of the size-differentiated modelling (Table S4) for the size fraction with the most observations are very similar to the combined results (Table 4), except that temperature is an additional significant explanatory variable for the > 125 µm data from the slope compared with the combined analysis and temperature is also revealed to be a significant explanatory variable in the combined analysis in the Abyss, where it is not significant in the larger size fractions (it is significant in the smaller size fractions). The most major differences in the size differentiated analysis are for the larger size fractions on the shelf, where additional explanatory variables were significant (temperature, dissolved oxygen and $\Delta\ CO_3^{2-}$). However, the small sample size ($n = 50$) and negative pseudo R^2 values suggest that the statistical model is not reliable for this size fraction.

DIFFERENCES IN FORAMINIFERAL STANDING CROP WITH DEPTH

Foraminiferal standing crop decreased significantly with depth (Figure S3; non-spatial linear regression: $\log_{10}$ (standing crop) = 1.92 - 7.581e–05 (depth), $R^2 = 0.03$, $p < 0.001$), although there was high variability. To reflect the nearly three-fold predicted differences between the shallowest and deepest samples we divided the data into three depth bands, reflecting textbook broad-scale ocean geomorphological classifications (e.g. Gage and Tyler 1991 Deep Sea Biology). Note that our "abyssal" zone (> 2000 m depth) combines the bathyal and abyssal zones presented by Gage and Tyler (1991). These classifications reflect the differences in broad biological, geological and oceanographic processes that are expected to occur in the different areas. These classifications align well with the literature, with many authors using some variant of these geomorphological classifications in describing their study or differentiating between depths in their sampling. Furthermore, major differences in the composition of benthic foraminiferal assemblages are known to occur between these depth zones (e.g. Schmiedl et al., 1997).

The depth groupings used had reasonable numbers of foraminiferal records in each: < 200 m: n = 416; 200 – 2000 m: n = 320; > 2000 m: n = 231. There were significantly lower foraminiferal standing crops in the deeper depth groups (ANOVA $F = 16.22$, df = 2, 964, $p < 0.001$; mean standing crop: < 200 m: 237; 200 – 2000 m: 199; > 2000 m: 64 ind. 10 cm^{-3}). Although pairwise tests (Tukey HSD) revealed no significant difference in standing crops between the < 200 m and 200 – 2000 m data ($p = 0.11$), there were differences between the > 2000 m data and the other depth bands ($p < 0.001$). We decided not to combine the shelf and slope samples in the analysis to be consistent with our *a priori* classification scheme and the expected differences in process and composition stated above.

LITERATURE CITED

Gage JD, Tyler PA (1991) Deep-sea biology. A natural history of organisms at the deep-sea floor. Cambridge University Press. Cambridge.

Schmiedl G, Mackensen A, Müller PJ (1997) Recent benthic foraminifera from the eastern South Atlantic Ocean: dependence on food supply and water masses. Mar Micropaleontol 32: 249−287

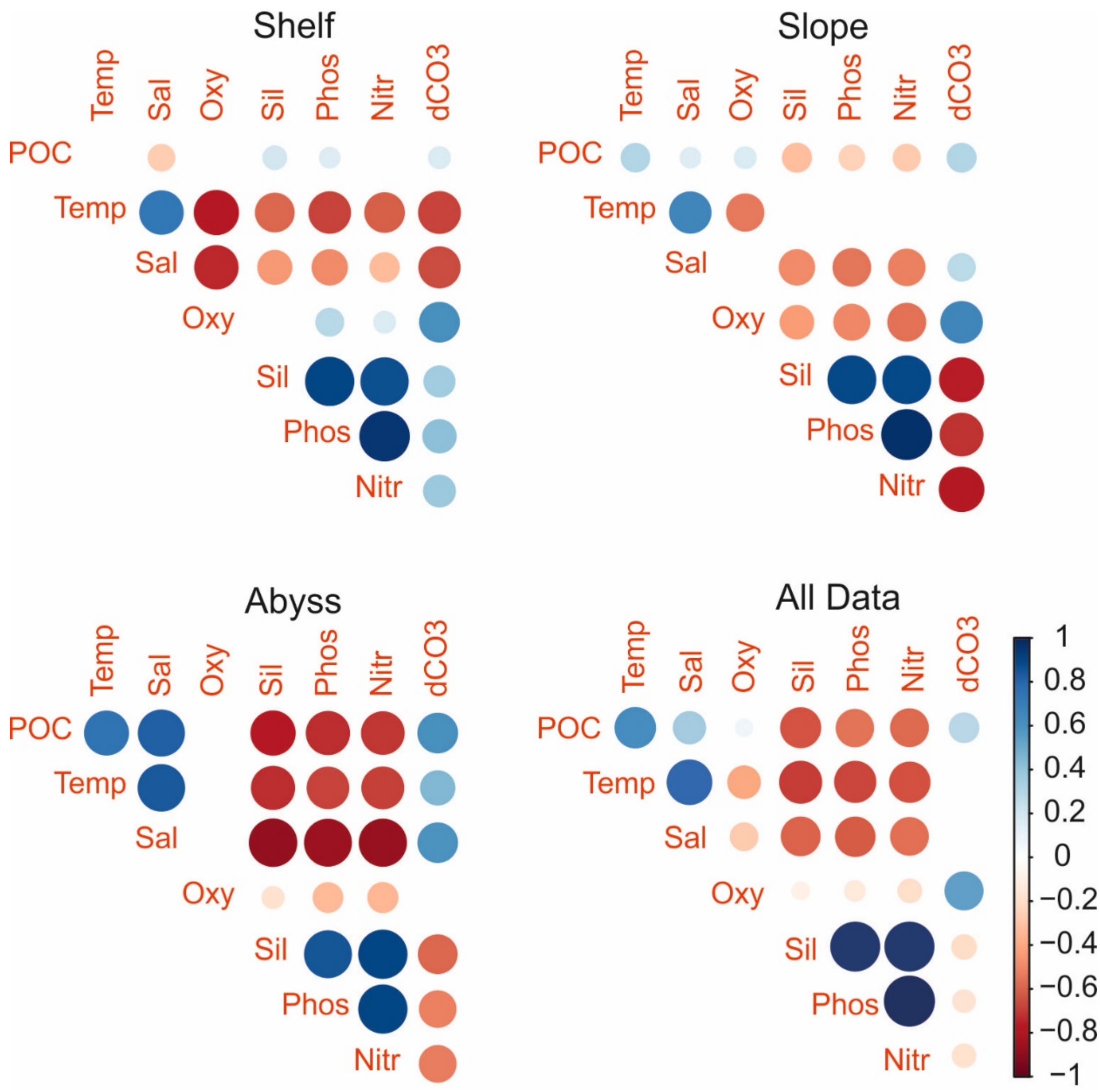

Figure S1: Correlation between environmental variables. Circle size and colour indicates Spearman rank correlation coefficient, with blue and red indicating positive and negative correlations respectively. Only significant ($p < 0.01$) correlations are shown. Temp = seabed temperature, Sal = seabed salinity, Oxy = seabed dissolved oxygen, Sil = seabed silicate concentration, Phos = seabed phosphate concentration, Nitr = seabed nitrate concentration, dCO3 = saturation state for calcite.

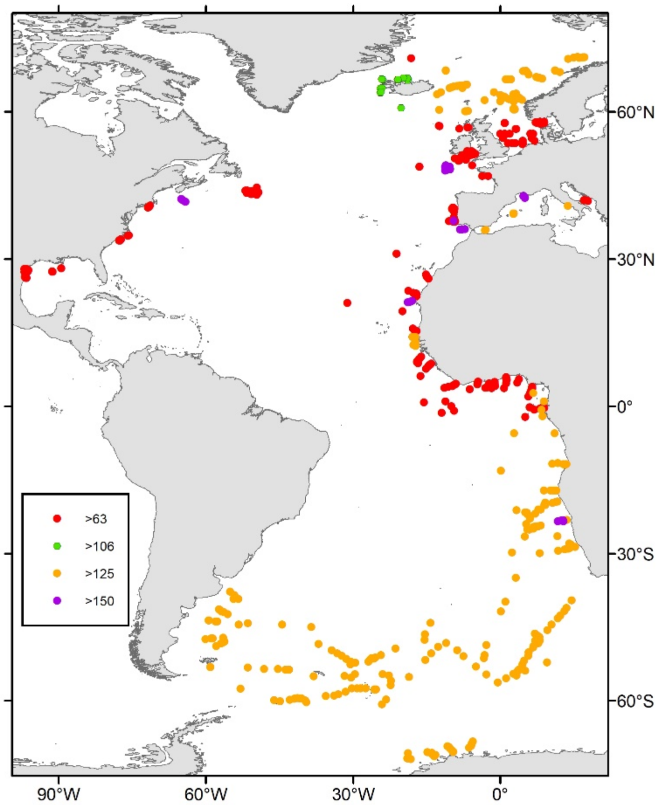

Figure S2: Map of sieve size of foraminiferal standing crop samples used in analysis.

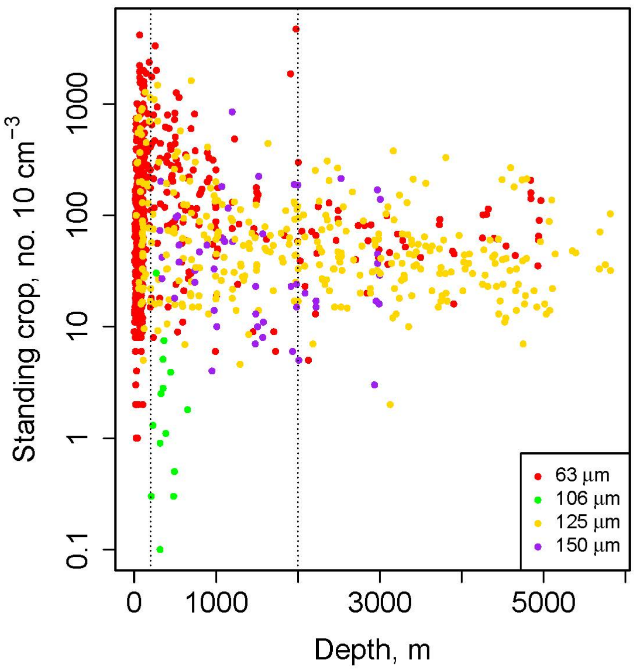

Figure S3: The variation in standing crop of foraminifera with water depth. Colours show the sieve size used in the standing crop assessment as indicated on the legend. Vertical lines show the separation between the depth zones used in this analysis (shelf < 200 m; slope 200 – 2000 m; abyss > 2000 m). Note log scale on y-axis.

Table S1 and S2 are provided in Supplement 2 (Excel File)

Table S3: Single variable regression models for foraminiferal standing crop. Sieve size is included as a covariate in all cases and is significant ($p < 0.05$) in most cases (except temperature in the SLM, $p = 0.11$). Only significant environmental variables are included. The best model (by AIC) is highlighted in bold.

	GLM t-value	Coefficient	p-value	R^2	AIC	Moran's I	SLM z-value	Coefficient	p-value	Pseudo R^2	AIC	Moran's I
POC Flux	3.23	0.0022	0.0010	0.066	1726.3	0.534 (p < 0.001)	2.69	0.0020	0.0071	0.006	1194.0	7.36e-05 (p = 0.47)
Dissolved Oxygen	**–3.64**	**–0.0686**	**0.0003**	**0.068**	**1723.5**	**0.535 (p < 0.001)**	**–3.67**	**-0.0910**	**0.0002**	**0.014**	**1187.8**	**–0.0006 (p = 0.49)**
Temperature	–3.32	–0.0099	0.0009	0.066	1725.7	0.514 (p < 0.001)	3.32	0.0144	0.0009	0.017	1190.5	–0.0018 (p = 0.52)
Salinity	–3.11	0.0699	0.0020	0.065	1727.1	0.525 (p < 0.001)			ns			
Silicate			ns				–1.99	-0.0017	0.0470	0.005	1197.3	–0.0006 (p = 0.49)
Nitrate	6.74	0.0125	<0.0001	0.098	1692.2	0.506 (p < 0.001)	2.13	0.0076	0.0332	0.004	1196.7	–0.0022 (p = 0.53)
Phosphate	7.05	0.1978	<0.0001	0.102	1688.2	0.503 (p < 0.001)			ns			
ΔCO_3^{2-}			ns						ns			

Table S4. Spatial linear model results for minimal adequate models using Atlantic data split by sieve size used in the analysis: 63 µm and >125 µm (includes 125 and 150 µm sieves). Numbers indicate z-values, asterisks indicate significance of individual predictors: * p < 0.05; ** p < 0.01; *** p < 0.001 and ns is not significant. Regression coefficients are presented in parentheses. AIC = Akaike information criterion. Moran's I is calculated on the model residuals. N is number of observations. Note negative R^2 indicates that the chosen model fits poorly (worse than a horizontal line).

	Shelf 63 µm	>125 µm	Slope 63 µm	>125 µm	Abyss 63 µm	>125 µm
Temperature	ns	2.57 (0.051) *	ns	–4.17 (–0.044) ***	3.48 (0.182) ***	ns
Salinity	ns	ns	ns	ns	–4.28 (–1.945) ***	–4.57 (–0.365) ***
Dissolved Oxygen	ns	–5.92 (–0.410) ***	ns	–6.51 (–0.213) ***	ns	ns
POC Flux	–2.33 (–0.003) *	ns	2.69 (0.004) **	4.57 (0.008) ***	ns	2.34 (0.019) *
Silicate	2.04 (0.017) *	21.39 *0.105) ***	ns	ns	ns	ns
ΔCO_3^{2-}	ns	15.12 (0.077) ***	ns	ns	ns	ns
Pseudo R^2	0.014	–0.343	0.013	0.102	0.219	0.083
AIC	513.08	71.31	153.01	160.74	–6.18	72.22
N	366	50	135	171	52	179