Species packing and the latitudinal gradient in local beta-diversity

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Electronic supplementary material

S1. Undersampling correction methods for β-Shannon diversity

Species accumulation curves have been applied to rarefy and extrapolate species richness with respect to sample size [1]. Chao *et al*. [2, 3] extended the species accumulation curve to the diversity accumulation curve, which corrects for the undersampling bias by asymptotically estimating the real α- and γ-Shannon diversity ($^1\widehat{D}(\infty)$) of samples in a region. The $^1\widehat{D}(\infty)$ (q=1, q is the diversity order) is calculated as:

$$^1\widehat{D}(\infty) = \exp[\widehat{H}(\infty)] \quad (1)$$

$\widehat{H}(\infty)$ is a nearly unbiased estimator of Shannon entropy [2]:

$$\widehat{H}(\infty) = \sum_{k=1}^{n-1}\frac{1}{k}\sum_{1\le X_i\le n-1}\frac{X_i}{n}\frac{\binom{n-X_i}{k}}{\binom{n-1}{k}} + \frac{f_1}{n}(1-A)^{-n+1}\left\{-\log(A) - \sum_{r=1}^{n-1}\frac{1}{r}(1-A)^r\right\} \quad (2)$$

where X_i is the species frequency of species i, k is the size of a random sample from the observed community, f_1 is the number of singletons (i.e., species represented by only one

individual in the observed sample), and f_2 is the number of doubletons (i.e., species represented by only two individuals in the observed sample). *A* is the estimated mean relative frequency of the singletons in the sample:

$$A = 2f_2/[(n-1)f_1 + 2f_2\ ] \quad (3)$$

References

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3. Chao A., Gotelli N.J., Hsieh T.C., Sander E.L., Ma K.H., Colwell R.K., Ellison A.M. 2014 Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecol Monogr* **84**(1), 45-67. (doi:10.1890/13-0133.1).

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Supplementary Table S1: Basic information of 21 forest dynamic plots.

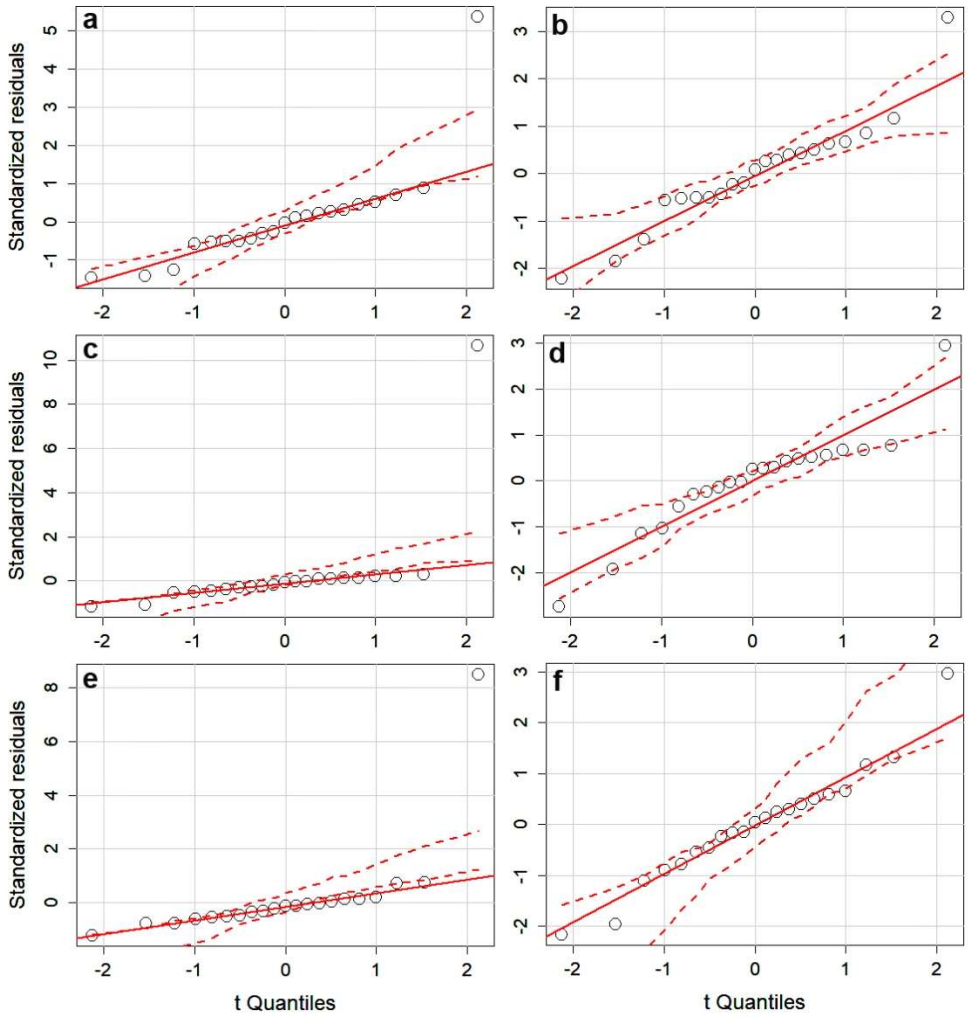
Plot name	Area (ha)	Latitude (°N)	Longitude (°E)	Mean elevation (m)	Elevation range (m)	Gamma-diversity	Number of stems
Pasoh	50	2.98	102.31	80	24	818	335400
Danum Valley	50	5.1	117.69	54.1	101.12	642	234916
Sinharaja	25	6.4	80.4	499.5	151	239	250131
Palanan	16	17.04	122.38	111	55	415	66000
Jianfengling	60	18.73	108.9	932	150.4	290	439676
Xishuangbanna	20	21.6	101.57	765.1	159.87	467	95834
Nonggang	15	22.42	106.95	260	190	223	67870
Heishiding	50	22.7	111.99	568.8	263	236	264391
Dinghushan	20	23.17	112.52	339	240	195	71617
Lienhuachih	25	23.91	120.88	765.4	178	144	153268
Chebaling	20	24.72	114.22	488	131	222	86517
Fushan	25	24.76	121.56	675.3	133	110	114500
Mulun	25	25.13	108	547	208.8	254	144679
Gutianshan	24	29.25	118.12	580.6	268.6	159	140700
Badagongshan	25	29.77	110.09	1414	101	241	186556
Tiantongshan	20	29.81	121.79	447.25	298.63	152	115536
Donglingshan	20	40	115.43	1395	219.3	53	52136
Changbaishan	25	42.22	128.53	801.5	17.7	52	38902
Muling	25	43.95	130.07	719.5	123	57	63877
Fenglin	30	48.08	129.12	439	66	46	94920
Daxinganling	25	51.82	122.98	896.7	115.3	18	126532

Supplementary Table S2: The results of simple linear regression models for beta-diversity across grain sizes in figure S2a-b.

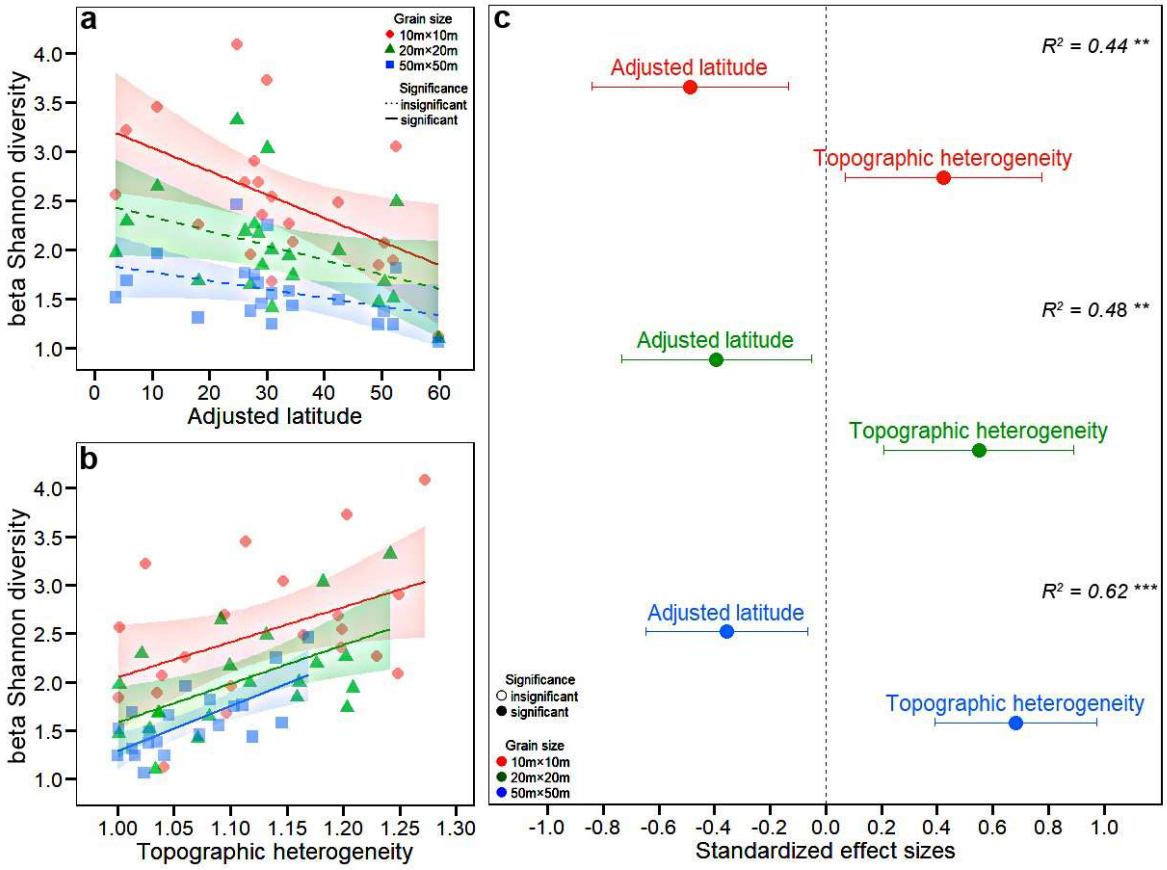
Explanatory variables	Grain size	Coefficients	Standard error	t-value	p-value	R-square
Adjusted latitude	10m × 10m	-0.024	0.01	-2.59	0.02	0.26
	20m × 20m	-0.015	0.01	-2.01	0.06	0.18
	50m × 50m	-0.0087	0.01	-1.86	0.08	0.15
Topographic heterogeneity	10m × 10m	3.62	1.65	2.19	0.04	0.20
	20m × 20m	4.00	1.33	3.02	0.007	0.32
	50m × 50m	4.63	1.08	4.28	<0.001	0.49

Supplementary Table S3: The results of simple regression models for niche specialization and marginality against adjusted latitude in Figure S6a and S6c.

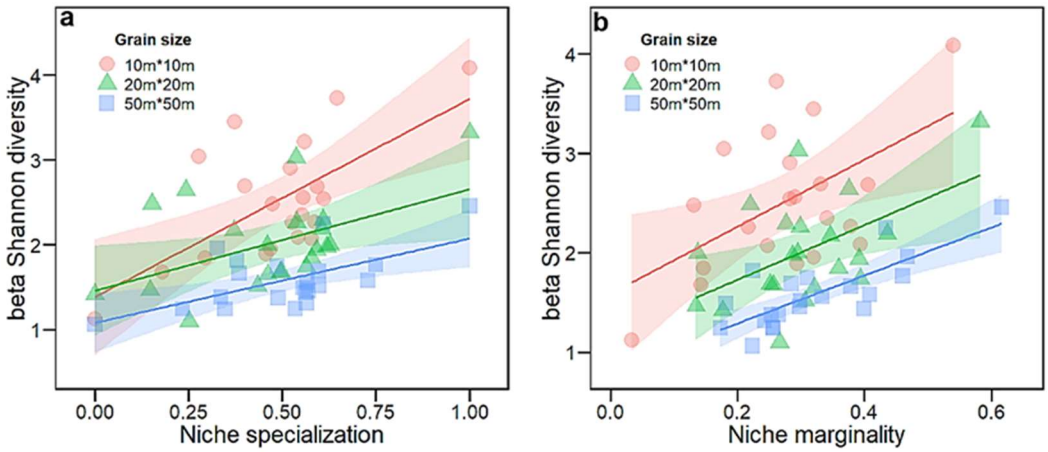
Response variables	Grain size		Coefficients	Standard error	t-value	p-value	R-square
Niche specialization	10m 10m	×	-0.0057	0.0027	-2.10	0.049	0.19
	20m 20m	×	-0.0056	0.0030	-1.88	0.076	0.16
	50m 50m	×	-0.0065	0.0027	-2.38	0.028	0.23
Niche marginality	10m 10m	×	-0.0033	0.0015	-2.15	0.044	0.20
	20m 20m	×	-0.0022	0.0014	-1.55	0.14	0.11
	50m 50m	×	-0.0031	0.0015	-2.04	0.055	0.055



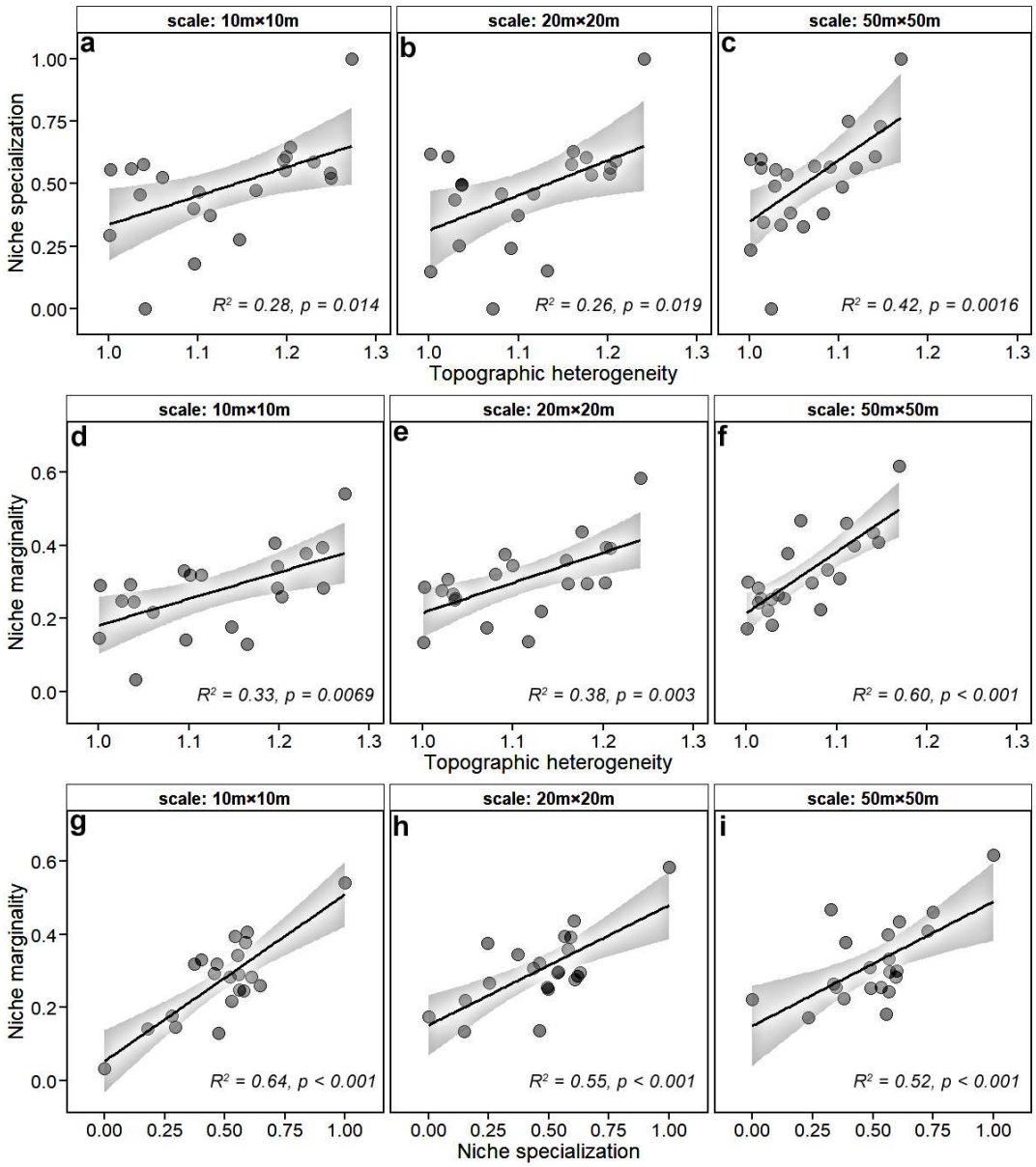
Supplementary Figure S1. **QQ-plot of residuals from the linear models (niche specialization ~ latitude) before (a, c, e) and after (b, d, f) Box-Cox transformation of niche specialization at grain size 10m × 10m (a, b), 20m × 20m (c, d) and 50 m × 50 m (e, f).**



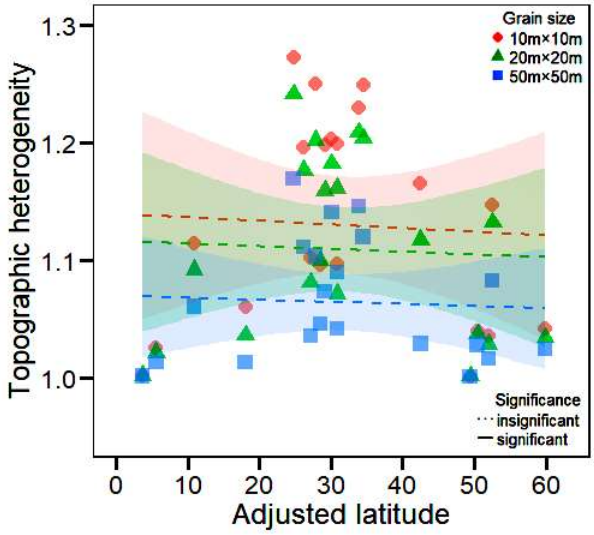
Supplementary Figure S2. Relationship of beta-diversity (measured corrected beta-Shannon diversity) and adjusted latitude (a), and local topographic heterogeneity (b) and their effect sizes (c) across grain sizes. In each panel, different colours of points and lines represent grain sizes. In panels a and b, solid and dashed lines indicate significant and insignificant linear correlations (significance level, $\alpha = 0.05$), respectively, and the shaded areas represent the 95% confidence intervals of the predictions (electronic supplementary material, table S2). In panel c, points represent the standardized effect sizes of explanatory variables that are significantly (solid circles) and non-significantly (open circles) different from zero, respectively. The significance level of the total R^2 are $\alpha < 0.001$, '***'; $\alpha < 0.01$, '**'; $\alpha < 0.05$ '*'.



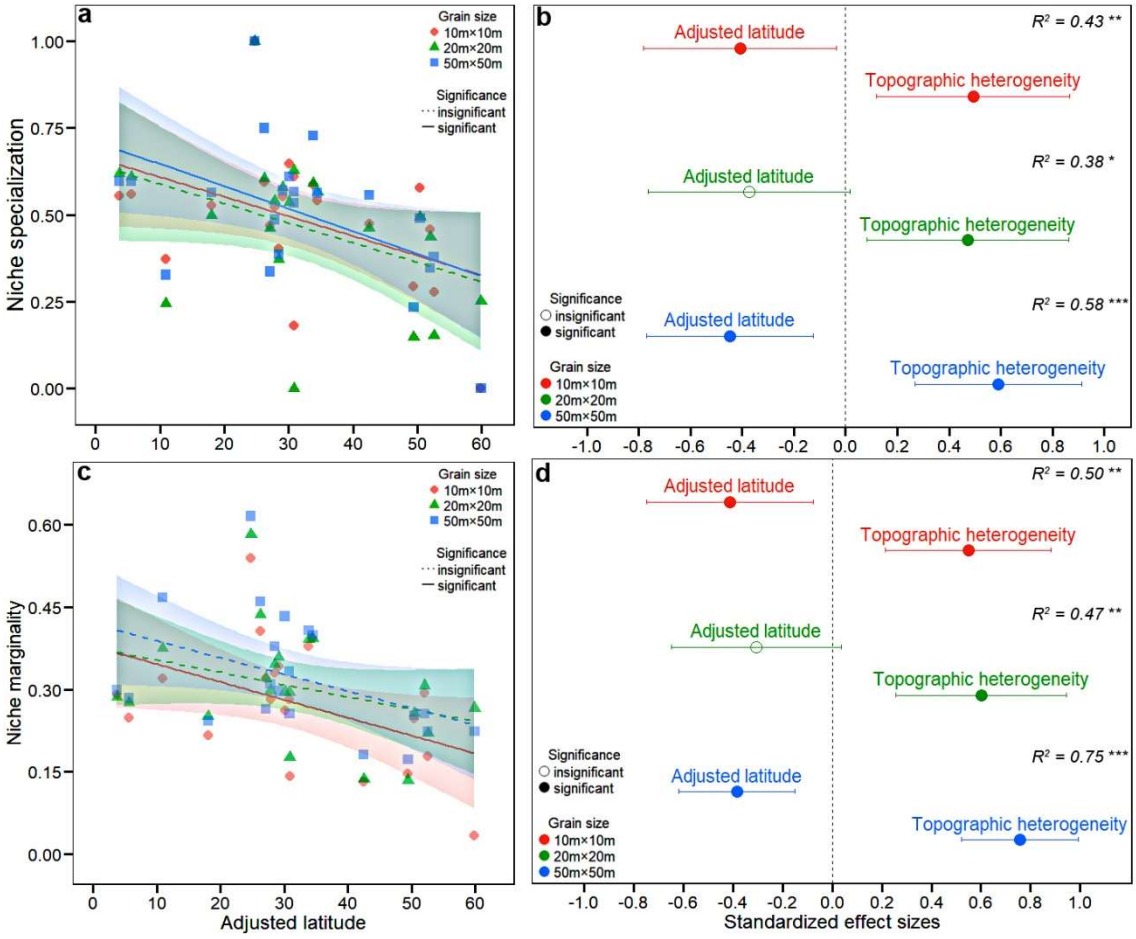
Supplementary Figure S3. The relationship of beta-diversity (measured by the corrected beta-Shannon diversity) with (a) community-level niche specialization, and (b) community-level niche marginality across grain sizes. In each panel, different colours of points and lines represent grain sizes. In panels a and b, solid and dashed lines indicate significant and non-significant linear correlations (significance level, $\alpha = 0.05$), respectively, and shaded areas represent the 95% confidence interval of the predictions. In panel a, the niche specialization was Box-Cox transformed, and then was rescaled to the range [0, 1].



Supplementary Figure S4. **Relationships between topographic heterogeneity, community-level niche specialization and niche marginality across grain sizes (a, d, and g: 10 m × 10 m; b, e, and h: 20 m × 20 m; c, f, and i: 50 m × 50 m).** The niche specialization was transformed into normality using a Box-Cox transformation, and then was rescaled to the range in [0, 1] with the min-max normalization. Topographic heterogeneity was quantified as surface: Planimetric area ratio.



Supplementary Figure S5. **The linear relationship between topographic heterogeneity (quantified by the surface to planimetric area ratio) and adjusted latitude across grain sizes (10 m × 10 m, 20 m × 20 m and 50 m × 50 m).** Dashed lines indicate insignificant linear correlations (significance level, $\alpha = 0.05$), and different colours of points and lines represent grain sizes.



Supplementary Figure S6. The relationships of community-level niche specialization (a and b) and marginality (c and d) with adjusted latitude and local topographic heterogeneity across grain sizes. Community-level niche specialization was Box-Cox transformed and was subsequently scaled to the range [0, 1] for comparison across grain sizes. In each panel, different colours of points and lines represent grain sizes. In panels a and c, solid and dashed lines indicate significant and non-significant linear correlations ($\alpha = 0.05$), respectively, and shaded areas represent the 95% confidence intervals of the predictions (electronic supplementary material, table S4). In panels b and d, points represent the standardized effect sizes of explanatory variables that are significantly (solid circles) and non-significantly (open circles) different from zero, respectively. The significance level of the total R^2 are $\alpha < 0.001$, '***'; $\alpha < 0.01$, '**'; $\alpha < 0.05$ '*'.