

# **Microbial specialists in high-altitude forest soils: environmental sensitivity and ecological significance**

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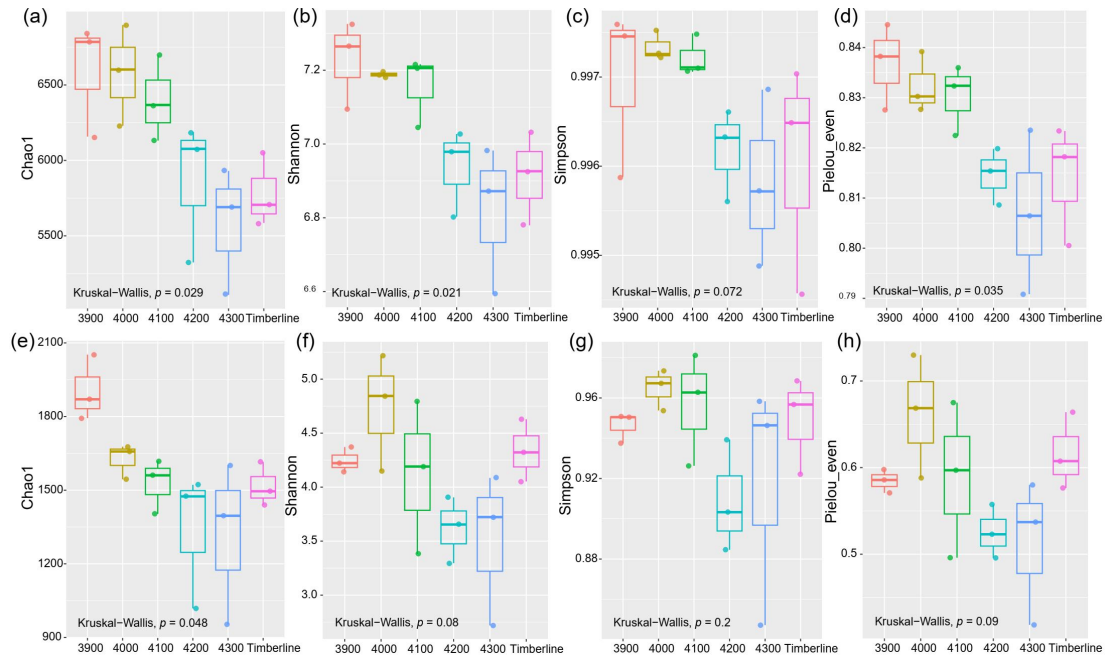
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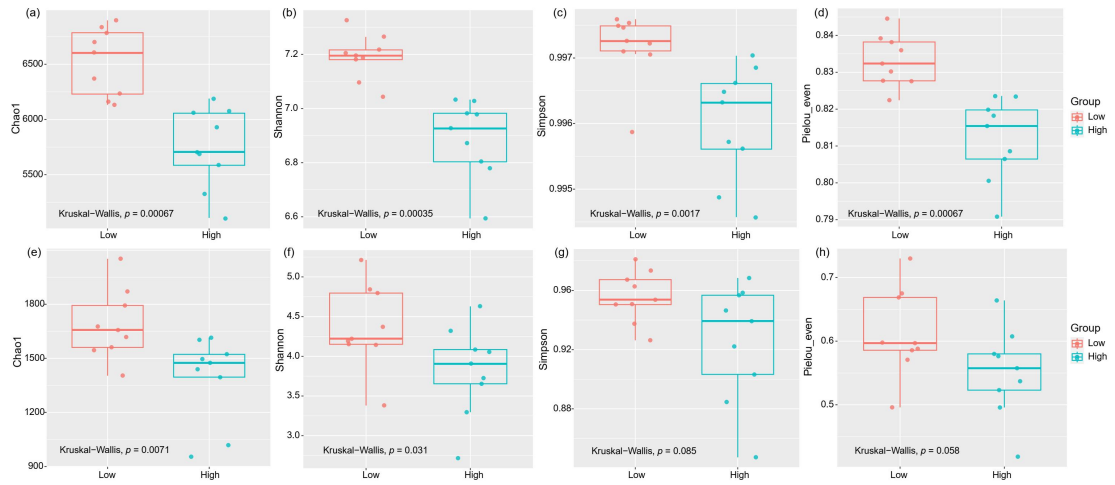
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## Supplementary information



**Fig. S1  $\alpha$ -diversity indices of soil bacterial and fungal communities at different elevations.** Panels (a-d) depict soil bacteria, while panels (e-h) represent fungi. P values from the Kruskal-Wallis test are displayed in each plot.



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**Fig. S2 Chao1, Shannon, Simpson, and Pielou even indices of soil microbial communities at low (3900 m to**

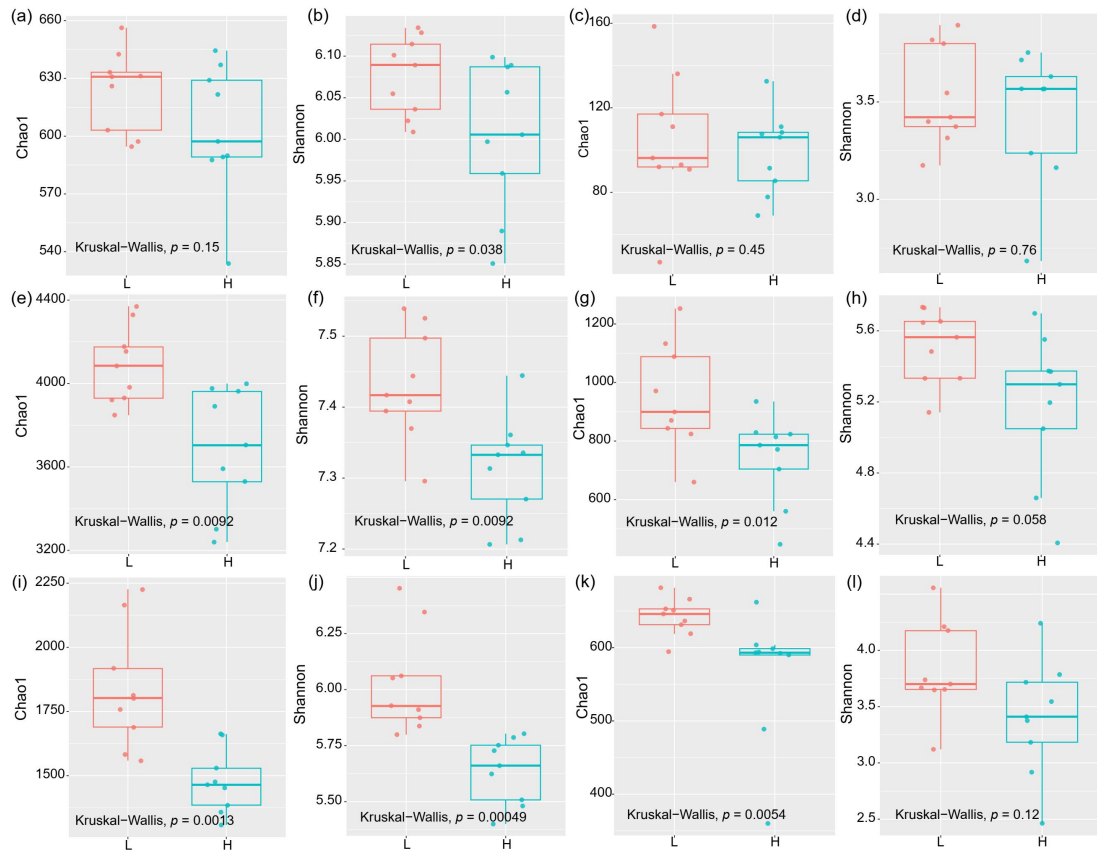
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**4100 m) and high elevations (4200 m to timberline). Panels (a-d) represent soil bacteria, while panels (e-h)**

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**depict soil fungi. P values from the Kruskal-Wallis test are displayed in each plot.**

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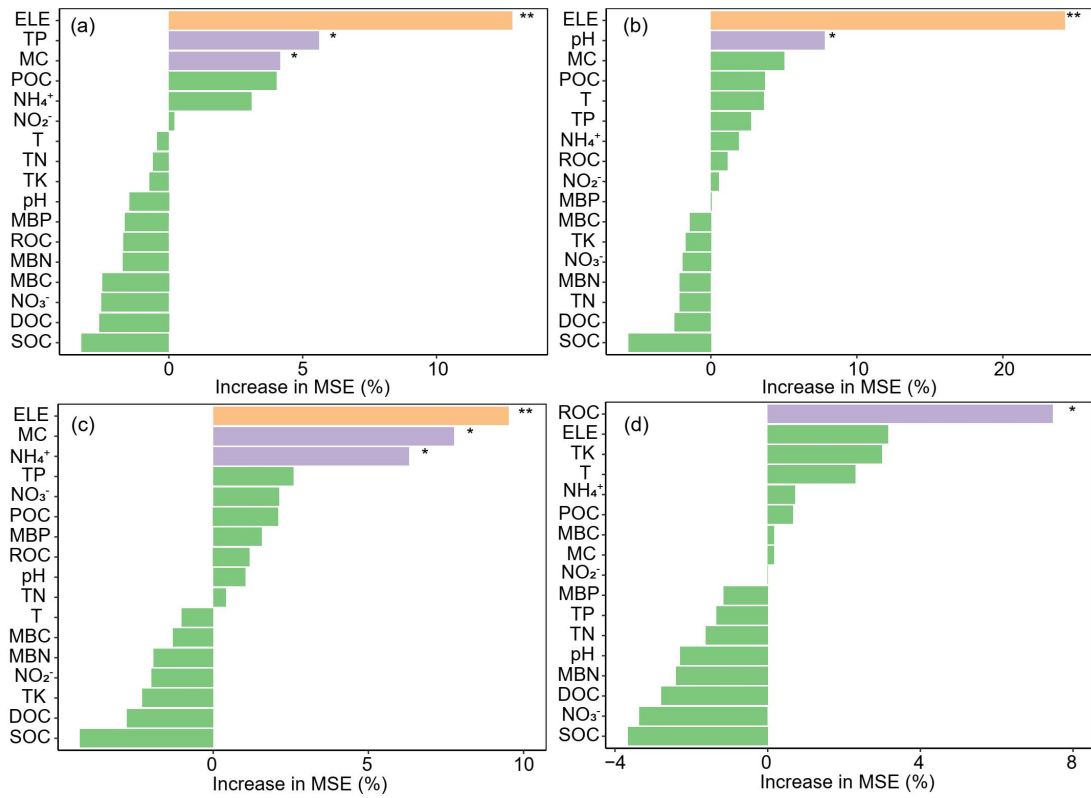
7 **Fig. S3 Chao1 and Shannon indices of microbial sub-communities at low (3900 m to 4100 m) and high**

8 **elevations (4200 m to timberline). Panels (a-b) illustrate bacterial generalists, (c-d) fungal generalists, (e-f)**

9 **bacterial intermediates, (g-h) fungal intermediates, (i-j) bacterial specialists, and (k-l) fungal specialists. P values**

10 **from the Kruskal-Wallis test are displayed in each plot.**

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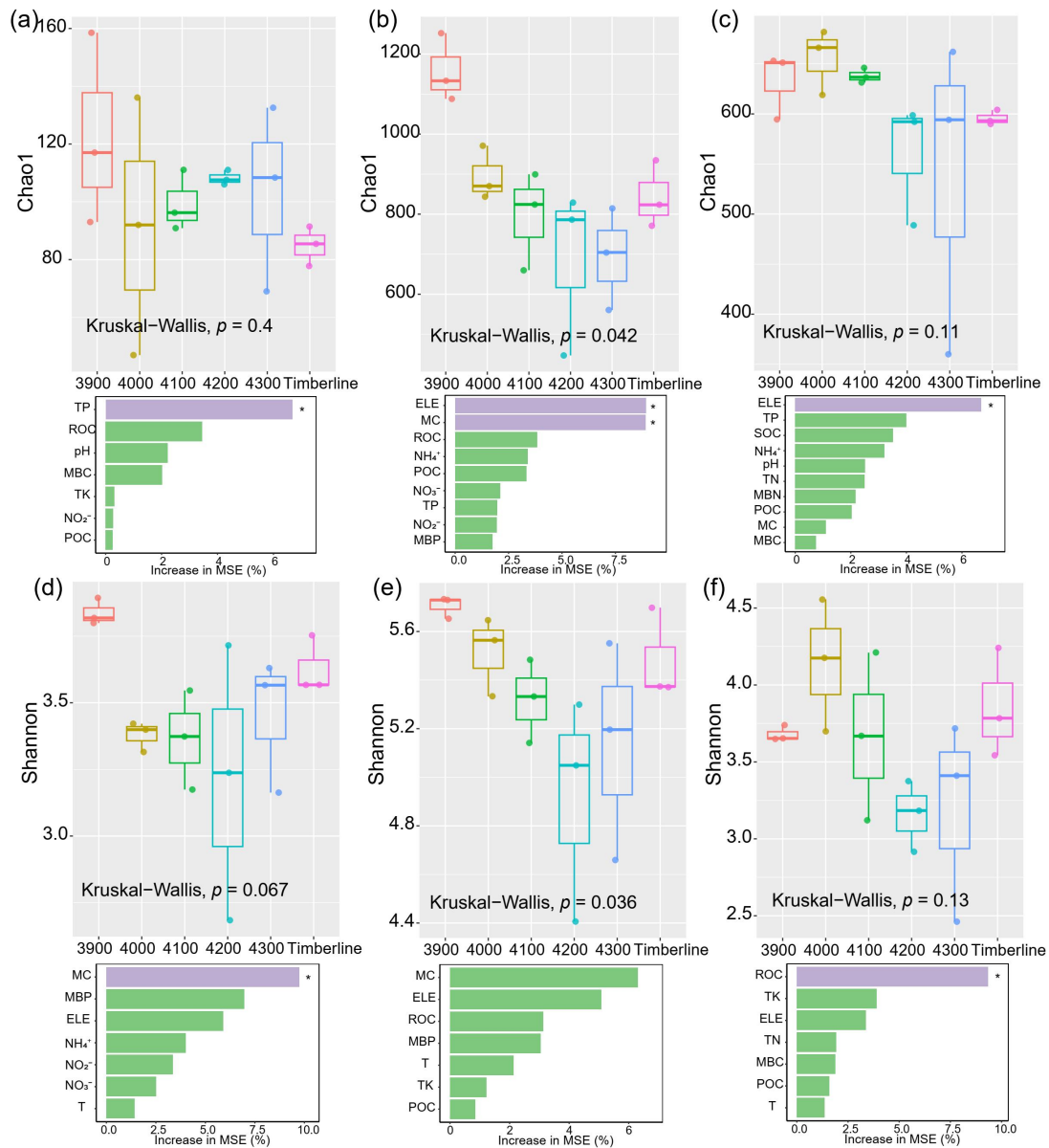
12

13 **Fig. S4 Contributions of environmental factors to Chao1 and Shannon indices for microbial communities. (a)**

14 Contributions to Chao1 index for bacteria; (b) contributions to Shannon index for bacteria; (c) contributions to

15 Chao1 index for fungi; (d) contributions to Shannon index for fungi.

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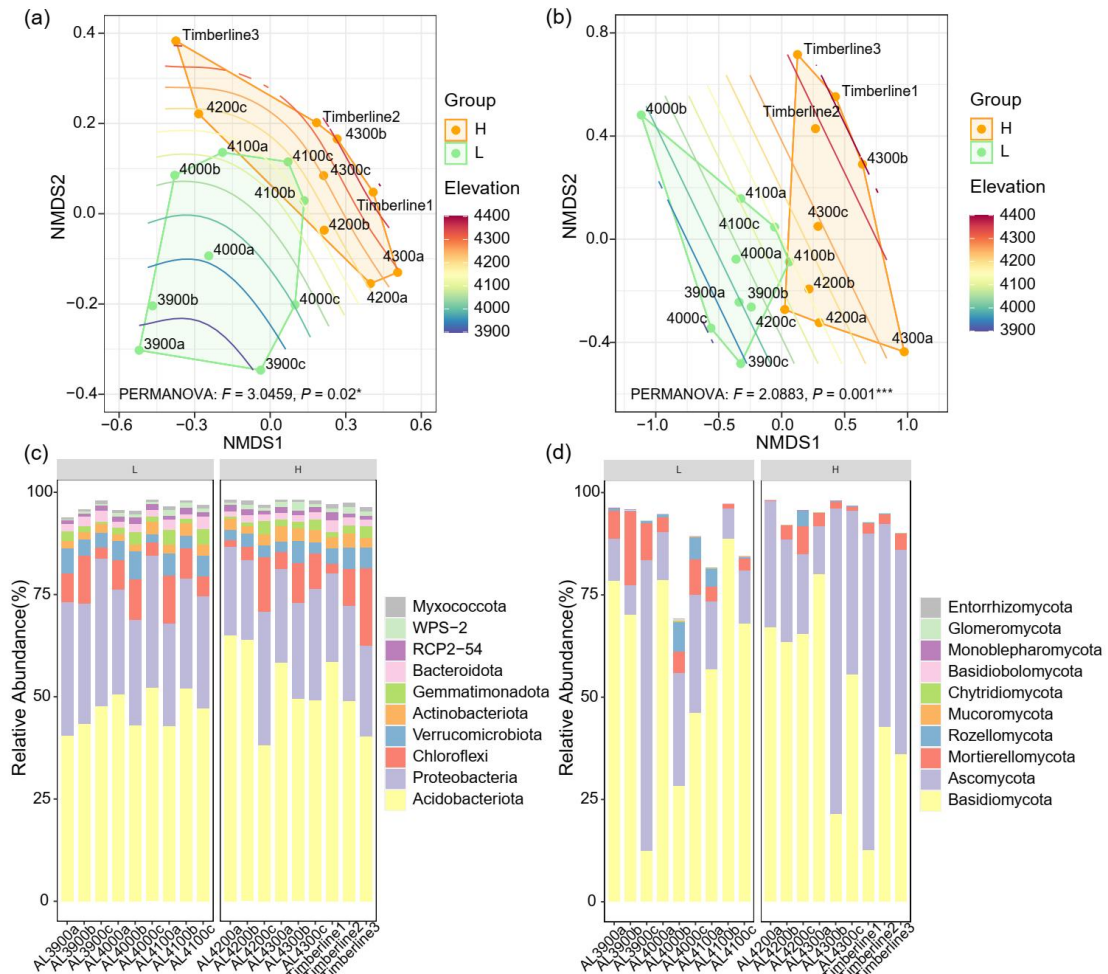
18 **Fig. S5  $\alpha$ -Diversity indices of fungal sub-communities and environmental influences.** Chao1 index for fungal

19 generalists (a), intermediates (b), and specialists (c); Shannon index for fungal generalists (d), intermediates (e),

20 and specialists (f). Environmental factor contributions to  $\alpha$ -diversity are displayed below each plot, based on

21 random forest analysis.

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24 **Fig. S6 Nonmetric Multidimensional Scaling (NMDS) analysis of microbial communities based on**

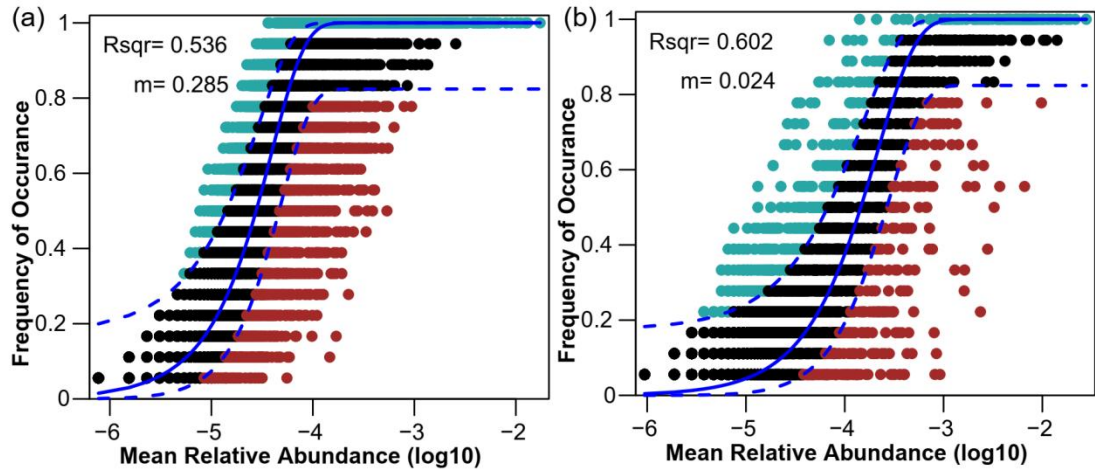
25 **Bray-Curtis distances across elevation gradients. (a) NMDS of the bacterial community; (b) NMDS of the**

26 **fungal community. Results of the Permutation Multivariate Analysis of Variance (PERMANOVA) are shown in the**

27 **plots. (c) Relative abundance of the bacterial community at the phylum level; (d) relative abundance of the fungal**

28 **community at the phylum level.**

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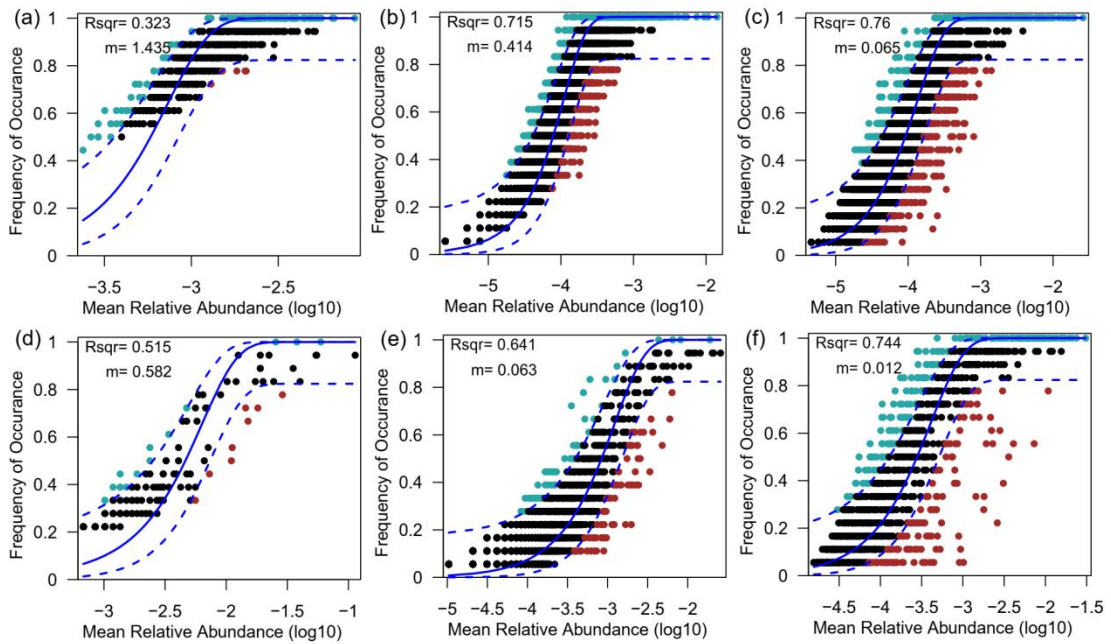
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31 **Fig. S7 Fit of the Neutral Community Model (NCM) for microbial community assembly.** (a) Fit for the

32 bacterial community; (b) fit for the fungal community.

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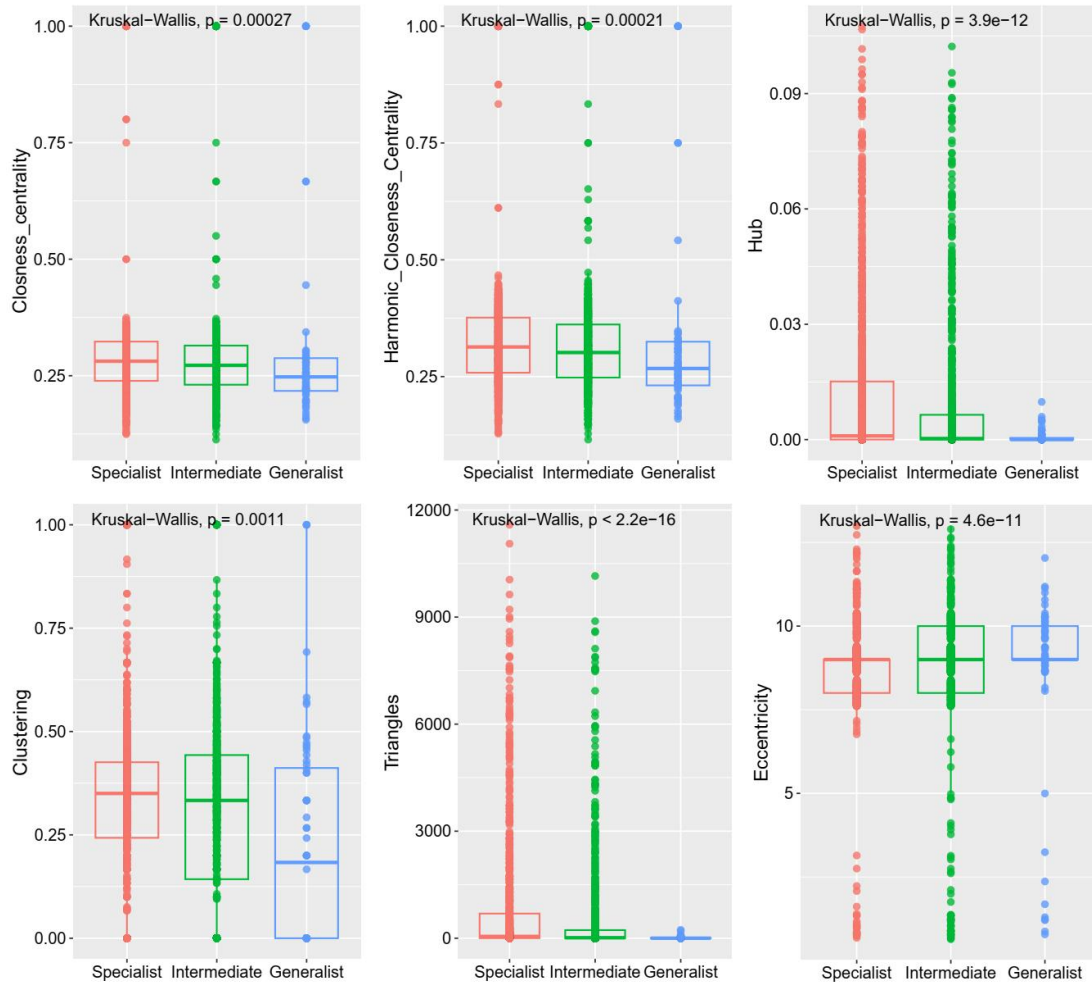
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36 **Fig. S8 Fit of the Neutral Community Model (NCM) for the assembly of microbial communities.** (a) Fit for

37 bacterial generalists; (b) fit for bacterial intermediates; (c) fit for bacterial specialists; (d) fit for fungal generalists;

38 (e) fit for fungal intermediates; (f) fit for fungal specialists.

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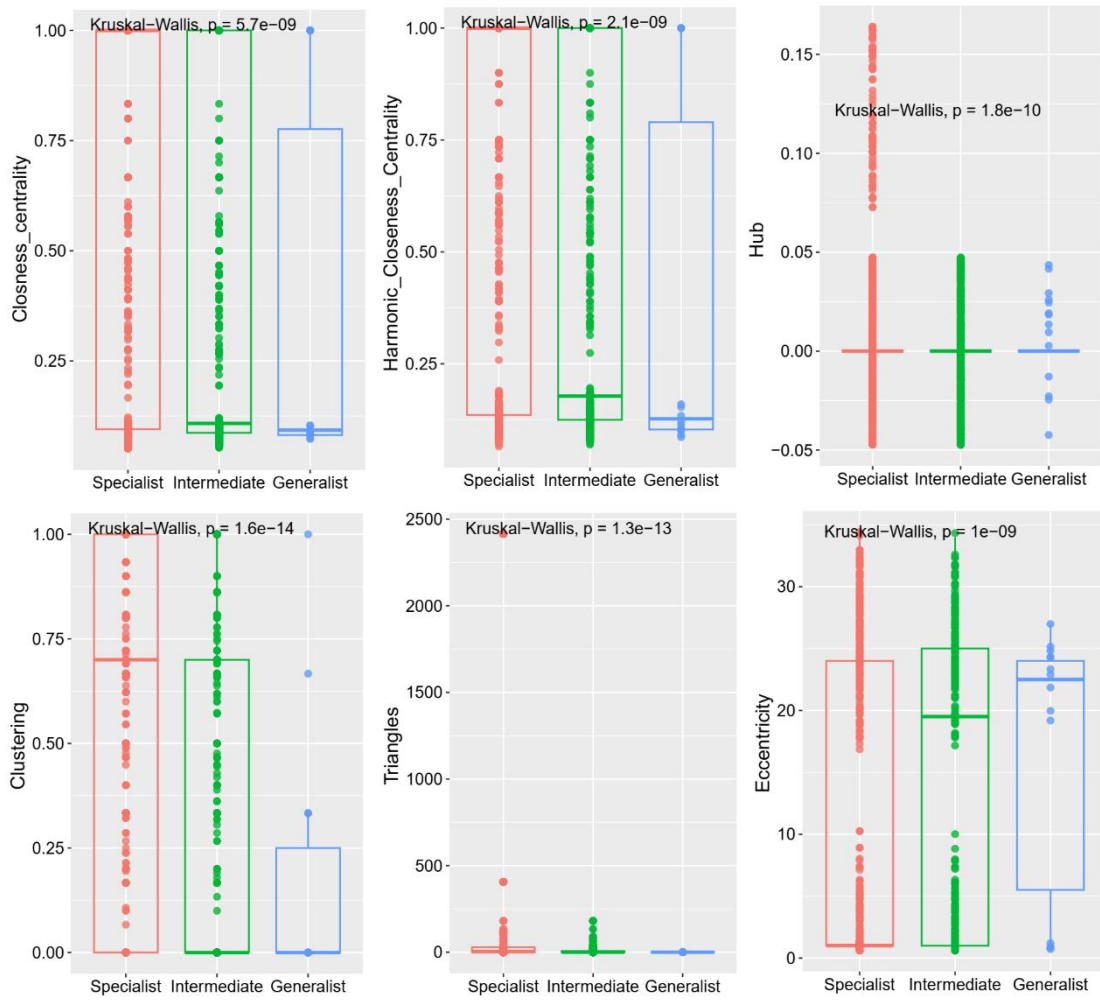
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41 **Fig. S9 Node Parameters of the bacterial co-occurrence network.** The values of Closeness Centrality,

42 Harmonic Closeness Centrality, Hub, Clustering, Triangles, and Eccentricity are compared among bacterial

43 specialists, intermediates, and generalists. P values from the Kruskal-Wallis test are presented in each plot.

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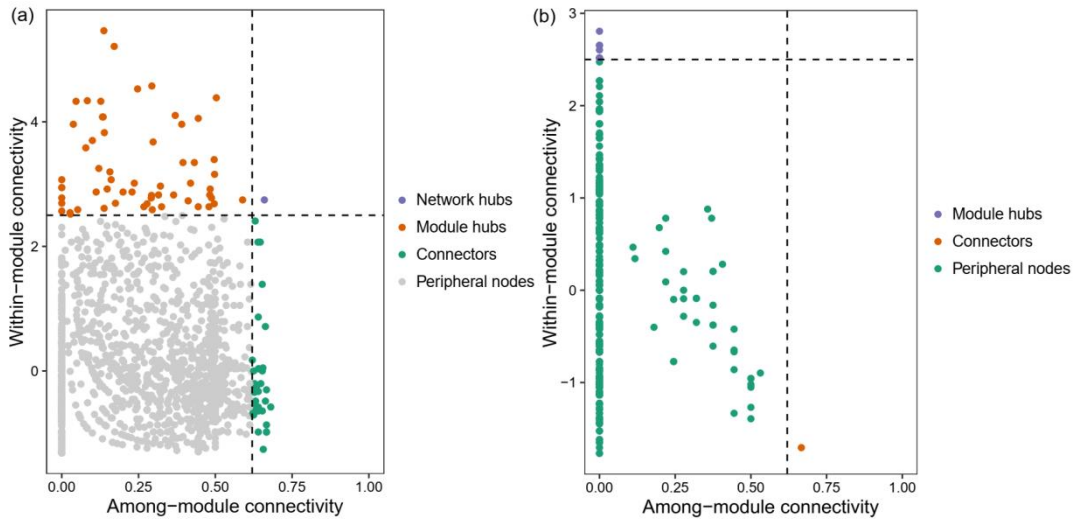
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46 **Fig. S10 Node Parameters of the fungal co-occurrence network.** The values of Closeness Centrality, Harmonic

47 Closeness Centrality, Hub, Clustering, Triangles, and Eccentricity are compared among fungal specialists,

48 intermediates, and generalists. P values from the Kruskal-Wallis test are presented in each plot.

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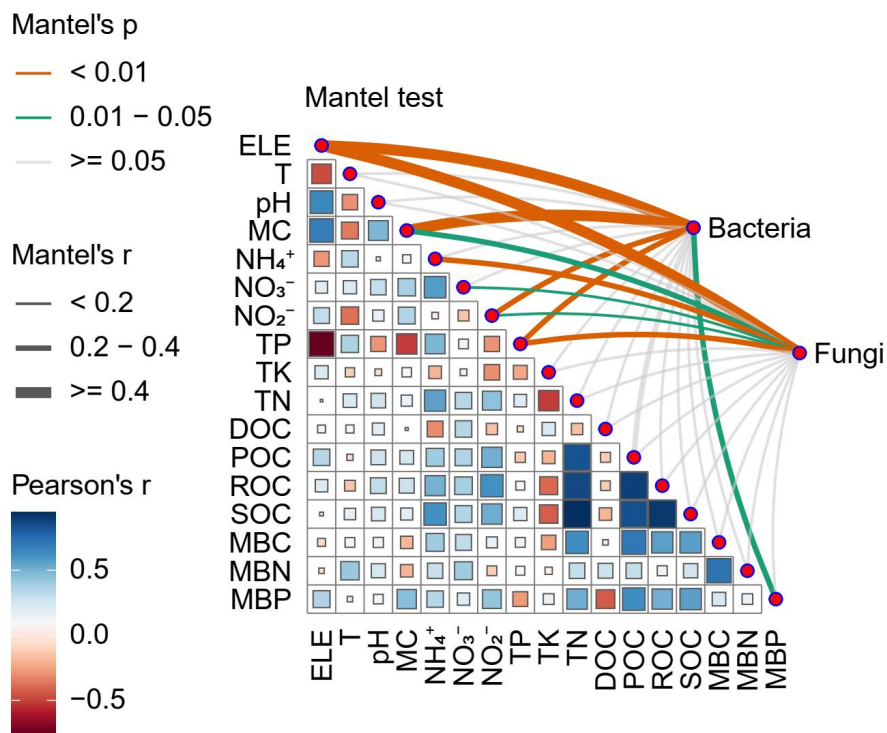


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51 **Fig. S11 Z-P plot showing the distribution of OTUs according to their topological roles in bacterial and**

52 **fungus communities. (a) Distribution for bacterial communities; (b) distribution for fungal communities.**

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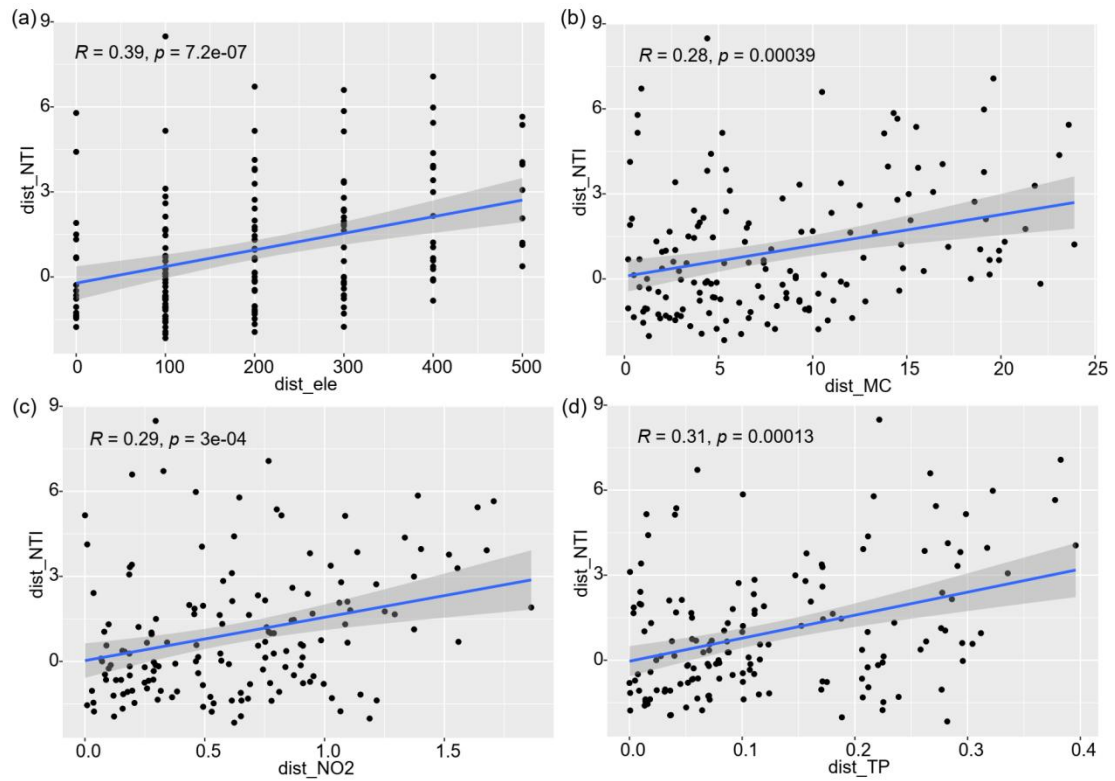
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55 **Fig. S12 Correlation between environmental parameters and the community structure of bacteria and fungi**

56 **based on the Mantel test.** The correlations of different environmental parameters are represented by rectangle size

57 and color gradient. Edge width corresponds to the r value, while edge colors indicate the p value based on 999

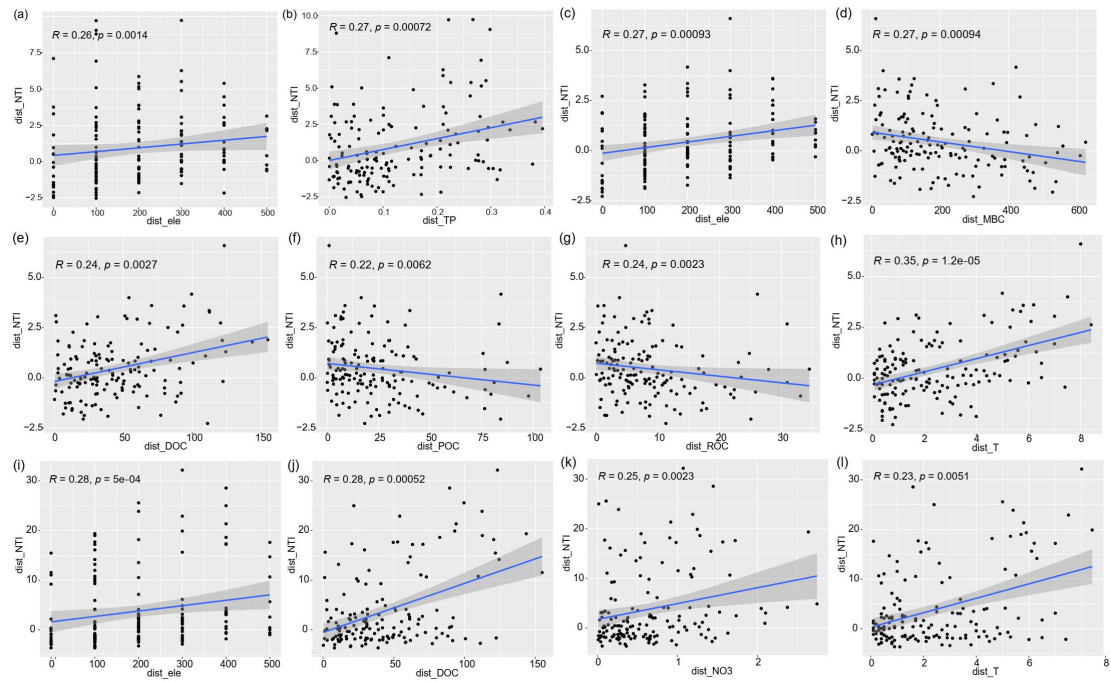
58 permutations.



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61 **Fig. S13 Linear regression analysis of the relationships between the  $\beta$ -Nearest taxon index (BNTI) of**62 **bacterial intermediates and environmental parameters. The shaded area indicates the 95% confidence interval.**63 Only correlations with Spearman's rank correlation coefficient ( $P < 0.01$ ) are displayed in the figure.

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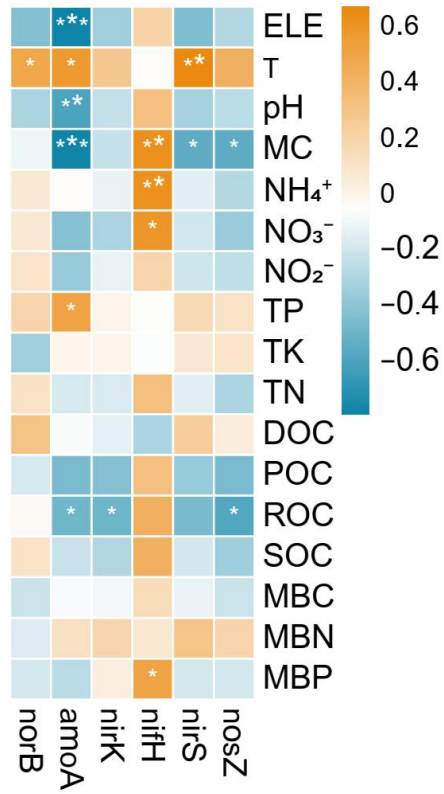
66 **Fig. S14 Linear regression analysis of the relationships between the  $\beta$ -Nearest taxon index ( $\beta$ NTI) of fungal**

67 **sub-communities with Environmental Parameters. Panels (a-b) depict fungal generalists; (c-h) depict fungal**

68 **intermediates; and (i-l) depict fungal specialists. The shaded area indicates the 95% confidence interval. Only**

69 **correlations with Spearman's rank correlation coefficient ( $P < 0.01$ ) are shown in the figure.**

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72 Fig. S15 Correlation of environmental factors and nitrogen cycling gene abundances.

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74 **Table S1 Environmental parameters in different sampling sites.** ELE: elevation; NH<sub>4</sub><sup>+</sup>: ammonia; NO<sub>3</sub><sup>-</sup>: nitrate; NO<sub>2</sub><sup>-</sup>: nitrite; TP: total phosphorus; TK: total kalium; TN: total nitrogen;

75 ROC: readily oxidizable carbon; SOC: soil organic carbon; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; MBP: microbial biomass phosphorus; DOC: dissolved organic

76 carbon; POC: particulate organic carbon; T: temperature; MC: moisture content.

Sample	ELE	T	MC	pH	NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	TP	TK	TN	DOC	POC	ROC	SOC	MBC	MBN	MBP
	m	°C	%vol	/	mg/kg	mg/kg	mg/kg	g/kg	g/kg	g/kg	mg/kg	g/kg	mg/g	g/kg	mg/kg	mg/kg	mg/kg
AL3900a	3900	9.3	33.4	6.2	3.22	1.78	1.16	0.70	9.11	1.36	148.66	3.31	11.77	36.63	189.74	18.57	3.11
AL3900b	3900	9.7	33.9	7.2	2.84	1.74	1.46	0.64	8.04	1.86	225.85	9.08	13.18	39.51	666.02	71.24	0.24
AL3900c	3900	8.9	33.1	6.9	2.95	0.31	3.02	0.58	6.49	3.36	114.72	27.37	24.48	65.29	368.82	20.18	4.20
AL4000a	4000	13.8	43.7	6.5	4.72	1.94	2.11	0.60	7.97	3.49	103.54	30.23	18.35	59.02	420.44	50.93	24.61
AL4000b	4000	14.8	42.5	7.8	3.62	2.94	1.73	0.58	7.49	3.65	258.29	22.49	20.15	59.91	393.25	55.18	2.17
AL4000c	4000	12.9	45.9	7	3.87	1.53	2.03	0.52	7.42	4.54	136.51	52.90	22.77	75.59	542.58	43.33	17.59
AL4100a	4100	8.5	53.3	8.5	5.09	2.41	1.94	0.60	7.56	3.72	133.94	19.40	23.23	67.71	361.91	43.57	12.05
AL4100b	4100	9.1	52.5	6.9	3.99	2.40	2.68	0.54	6.58	3.25	145.75	30.42	28.37	67.32	276.47	20.96	15.18

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AL4100c	4100	7.8	55.2	7.1	4.76	2.35	2.72	0.52	8.52	2.63	195.10	30.15	23.89	56.65	306.57	20.64	10.66
AL4200a	4200	9.8	47.7	7.9	5.48	3.05	2.55	0.60	7.96	5.76	158.74	106.99	46.25	105.34	814.56	58.02	25.73
AL4200b	4200	9.4	44.9	7.5	4.98	2.68	2.19	0.53	6.57	4.10	145.94	62.72	29.20	66.19	748.21	52.47	5.09
AL4200c	4200	10.2	52.3	8.4	4.44	2.04	1.93	0.61	8.10	2.74	137.73	22.68	21.21	57.40	286.24	38.59	9.98
AL4300a	4300	6.8	53.0	7.8	2.22	1.87	1.93	0.31	8.07	2.00	135.04	23.45	15.35	38.61	381.47	28.09	12.08
AL4300b	4300	7.3	57.0	7.3	1.92	1.75	2.80	0.42	8.39	3.08	204.14	39.06	23.96	57.57	359.76	34.43	12.57
AL4300c	4300	6.4	49.0	8.5	2.99	1.70	2.84	0.49	7.51	4.31	165.27	60.51	32.61	66.84	500.71	32.91	17.80
Timberline1	4400	9.0	47.9	8	3.35	2.03	2.87	0.32	9.01	2.56	164.29	45.48	20.46	57.74	473.23	65.86	19.51
Timberline2	4400	9.5	50.3	7.6	2.38	1.66	1.65	0.30	8.58	1.92	175.86	25.79	15.34	41.39	205.54	23.90	12.31
Timberline3	4400	8.6	48.6	8.3	2.39	1.96	2.22	0.54	7.39	2.98	187.74	31.20	21.45	57.16	269.18	32.59	7.57

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