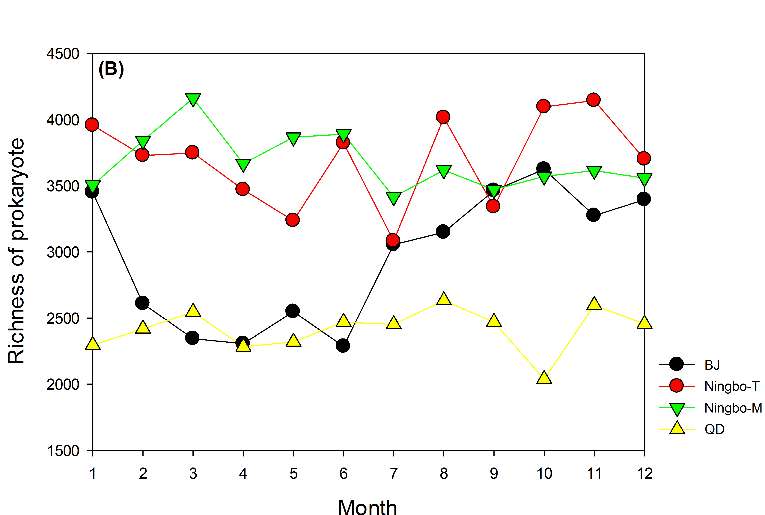
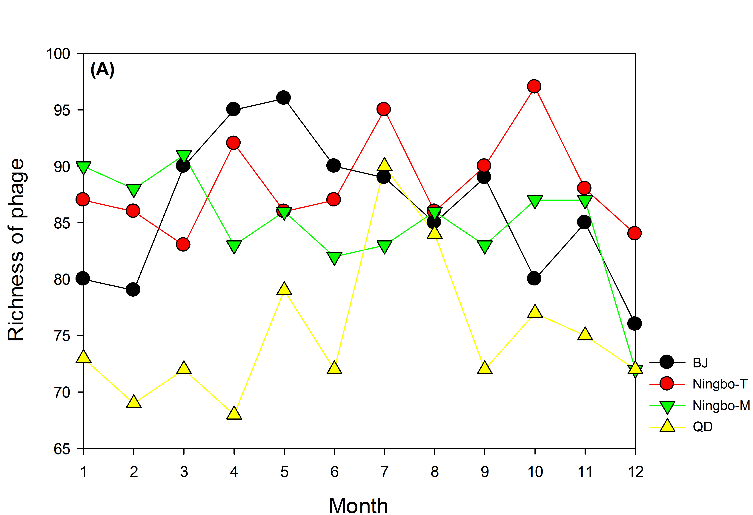
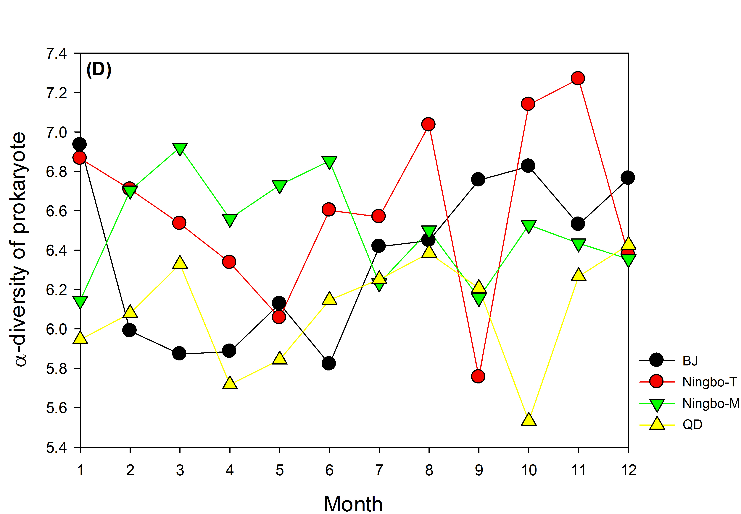
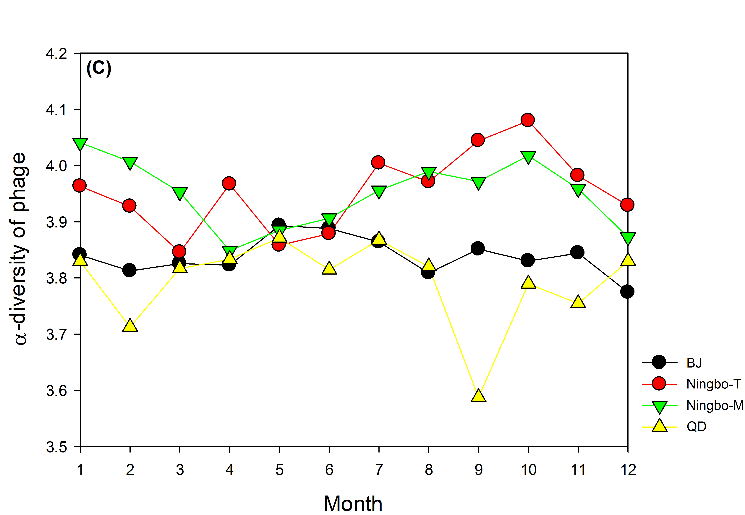
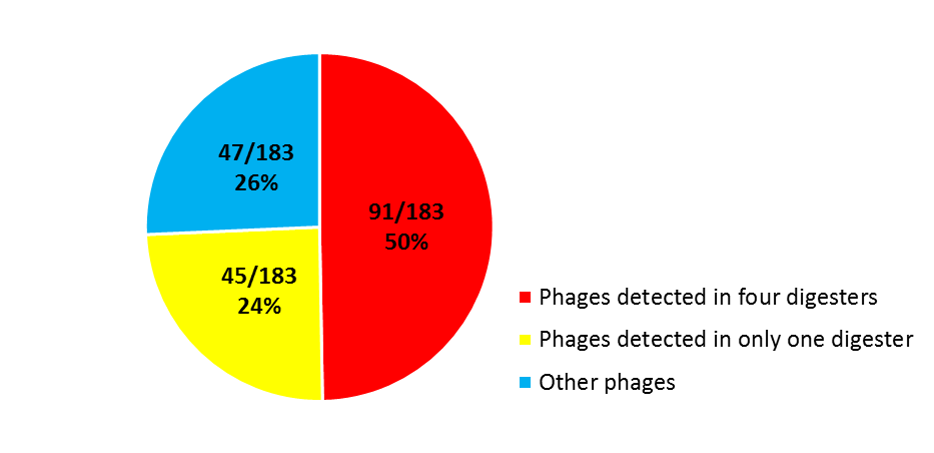
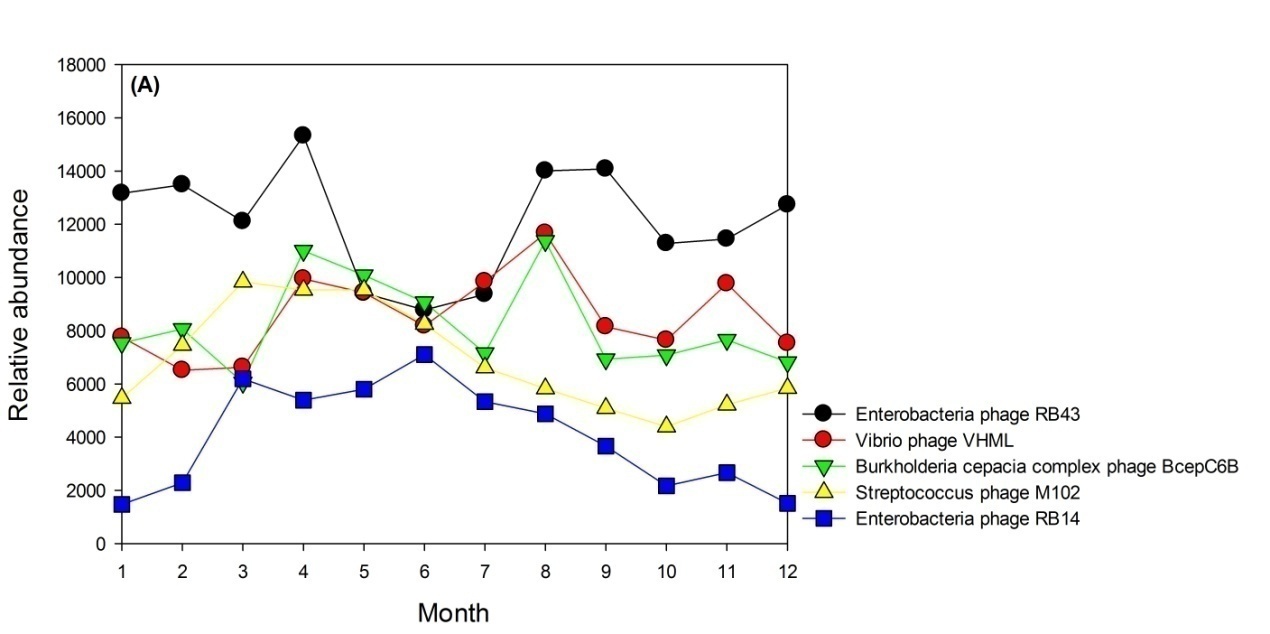
****

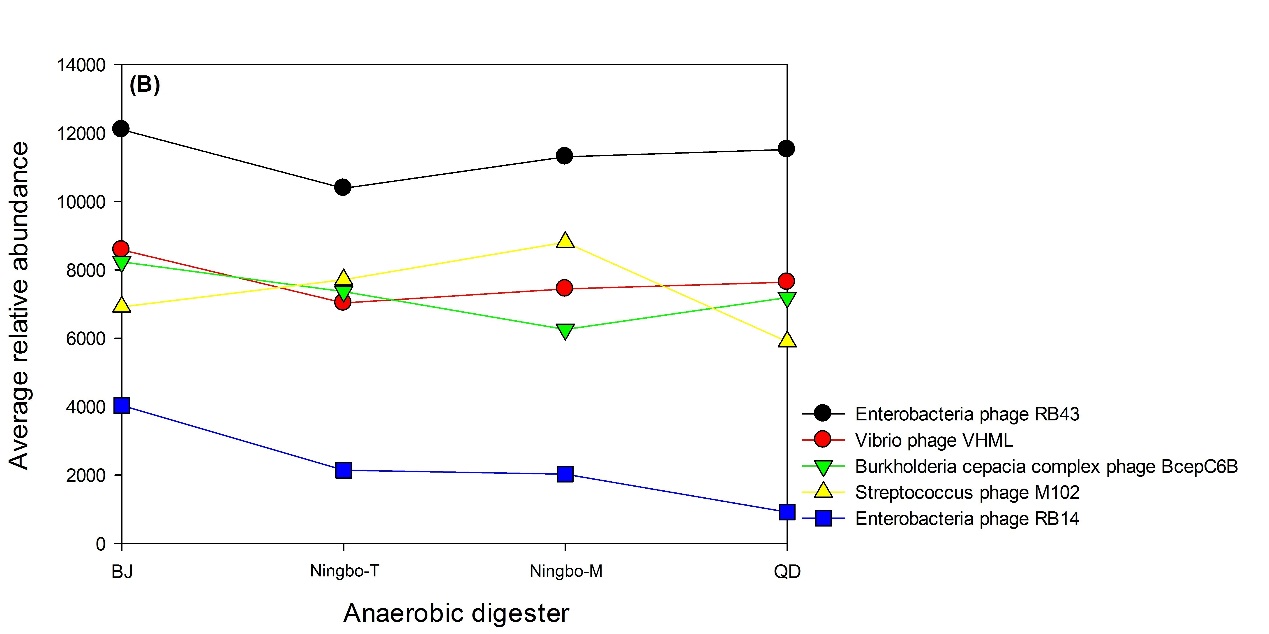
****

**Fig. S1.** Spatiotemporal changes in (A) richness of phages, (B) richness of prokaryotes, (C) the α-diversity of phages and (D) the α-diversity of prokaryotes. BJ: Beijing samples; QD: Qingdao samples; Ningbo-M: samples from Ningbo anaerobic digester maintained at mesophilic temperature, and Ningbo-T: samples from Ningbo anaerobic digester maintained at thermophilic temperature.

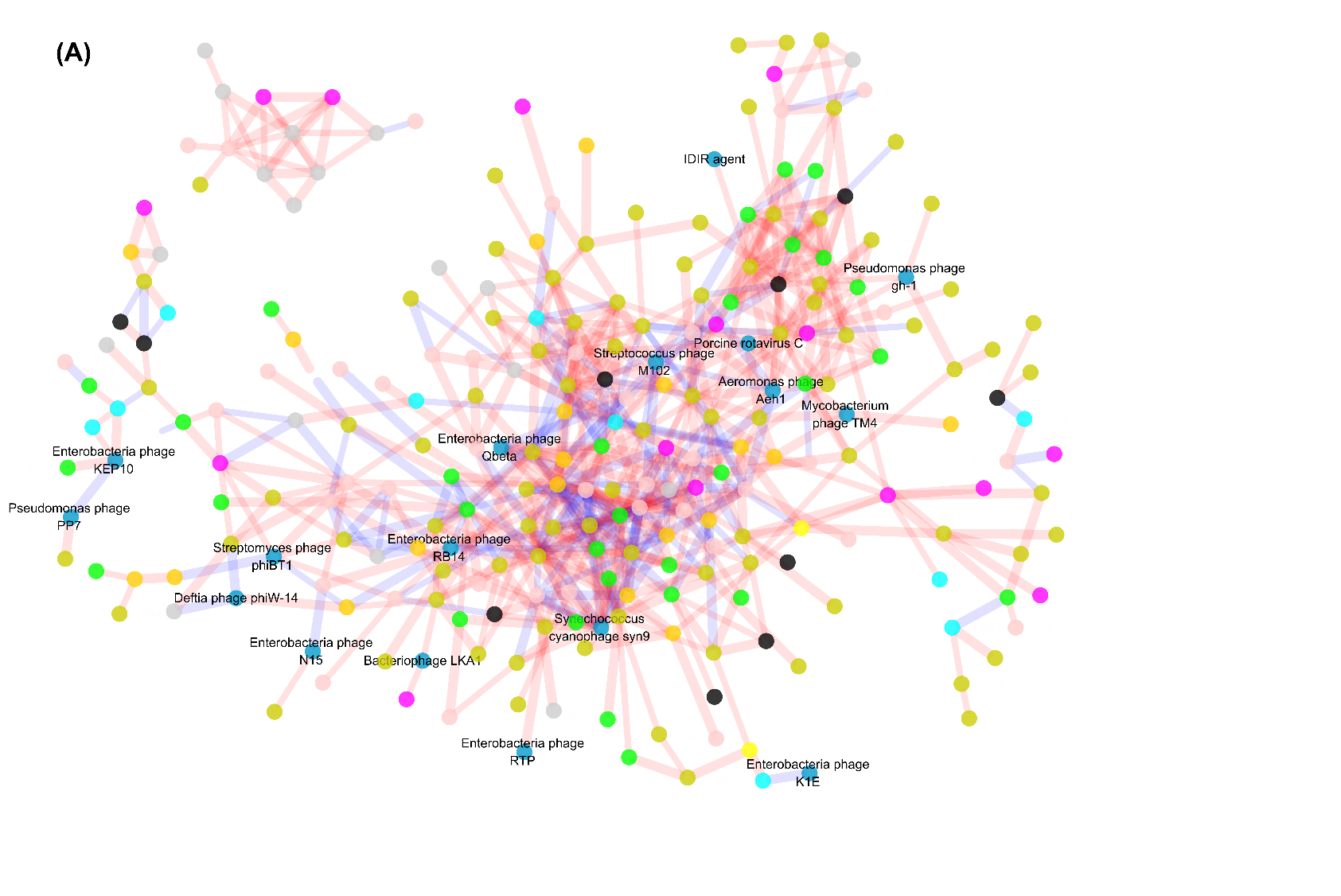


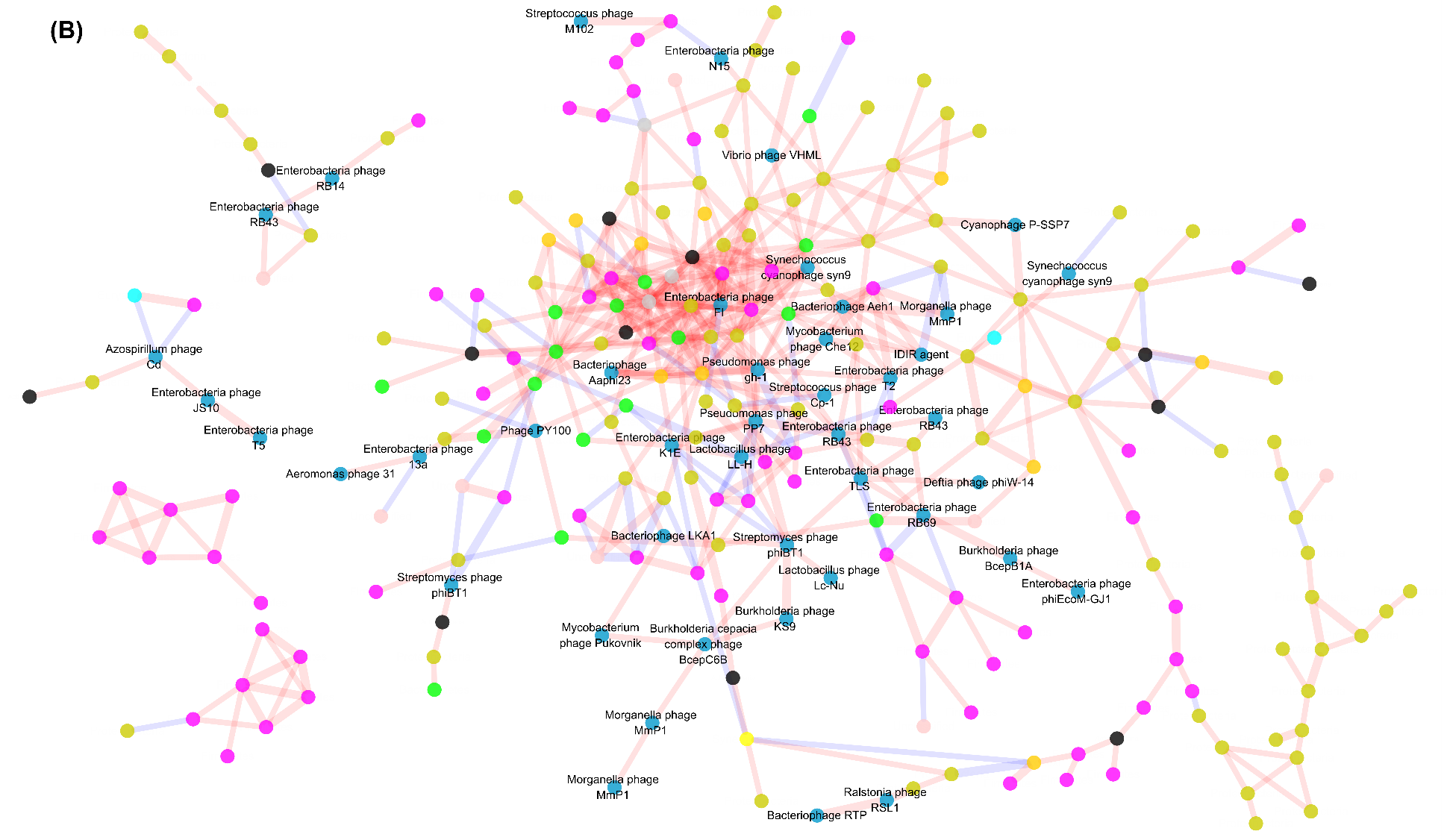
**Fig. S2.** Proportions of phages based on their detection frequencies in anaerobic digesters.

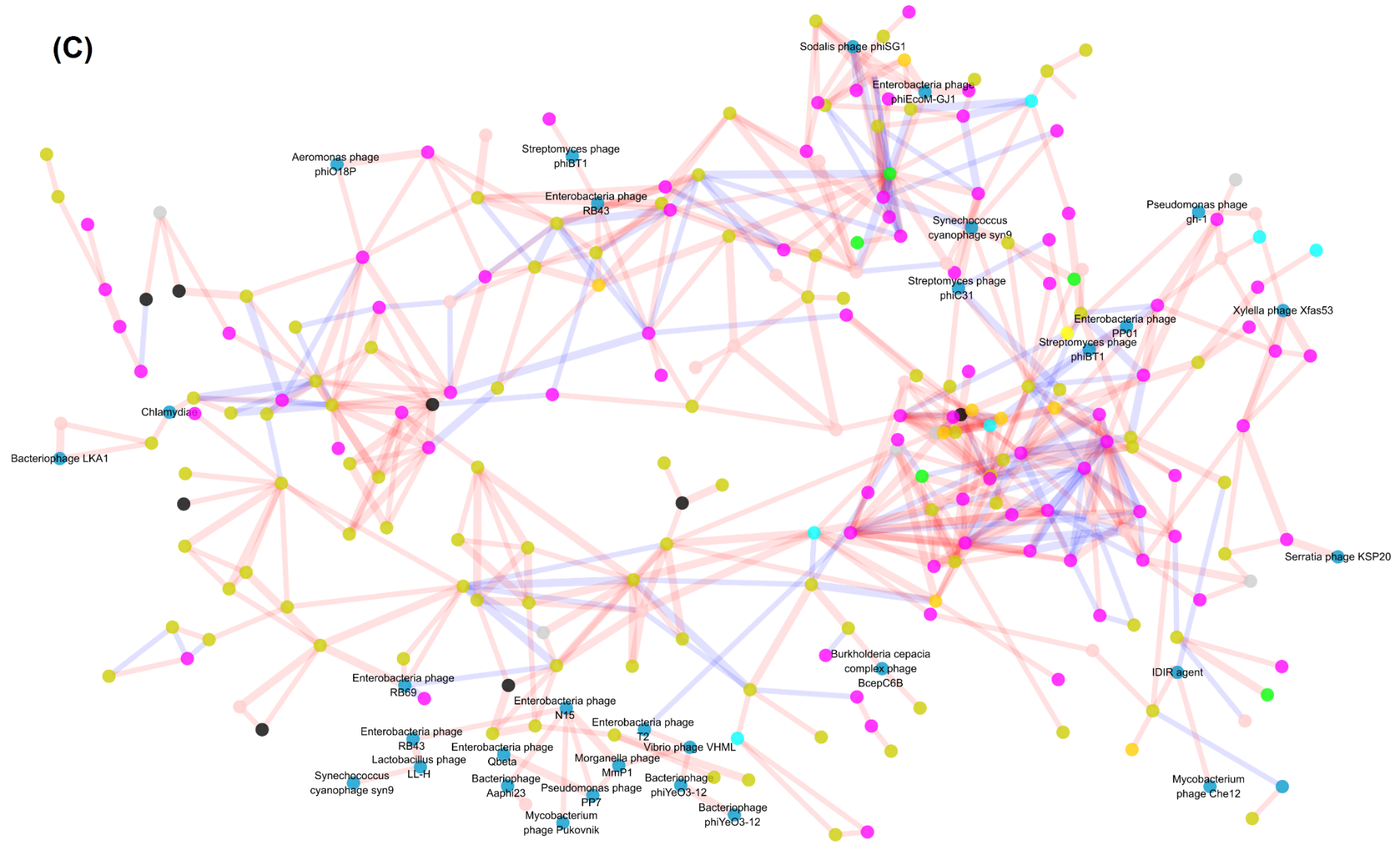
****

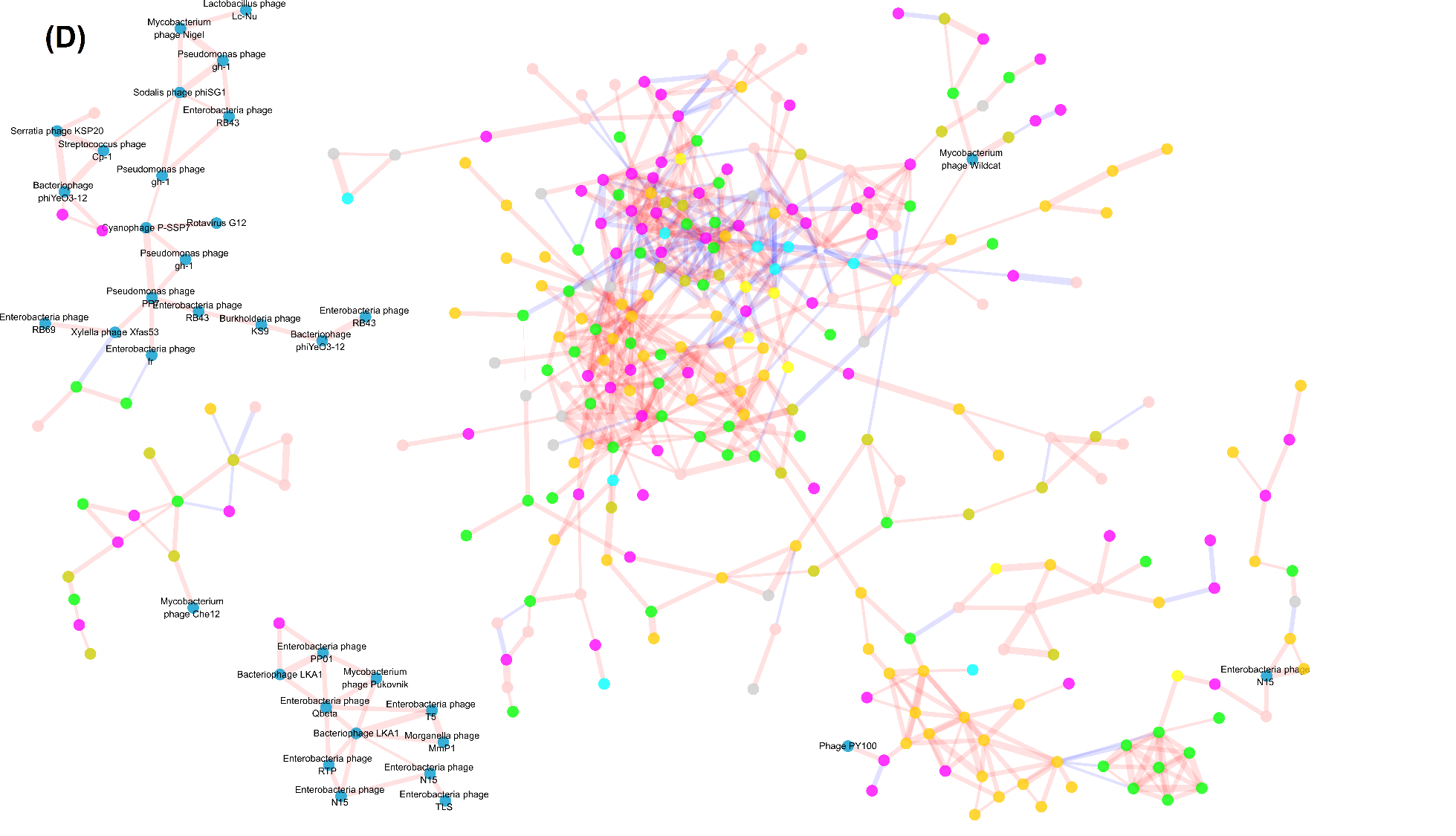


**Fig. S3.** The most abundant phages detected in Beijing samples as functions of (A) time and their average relative abundance in samples across (B) space.

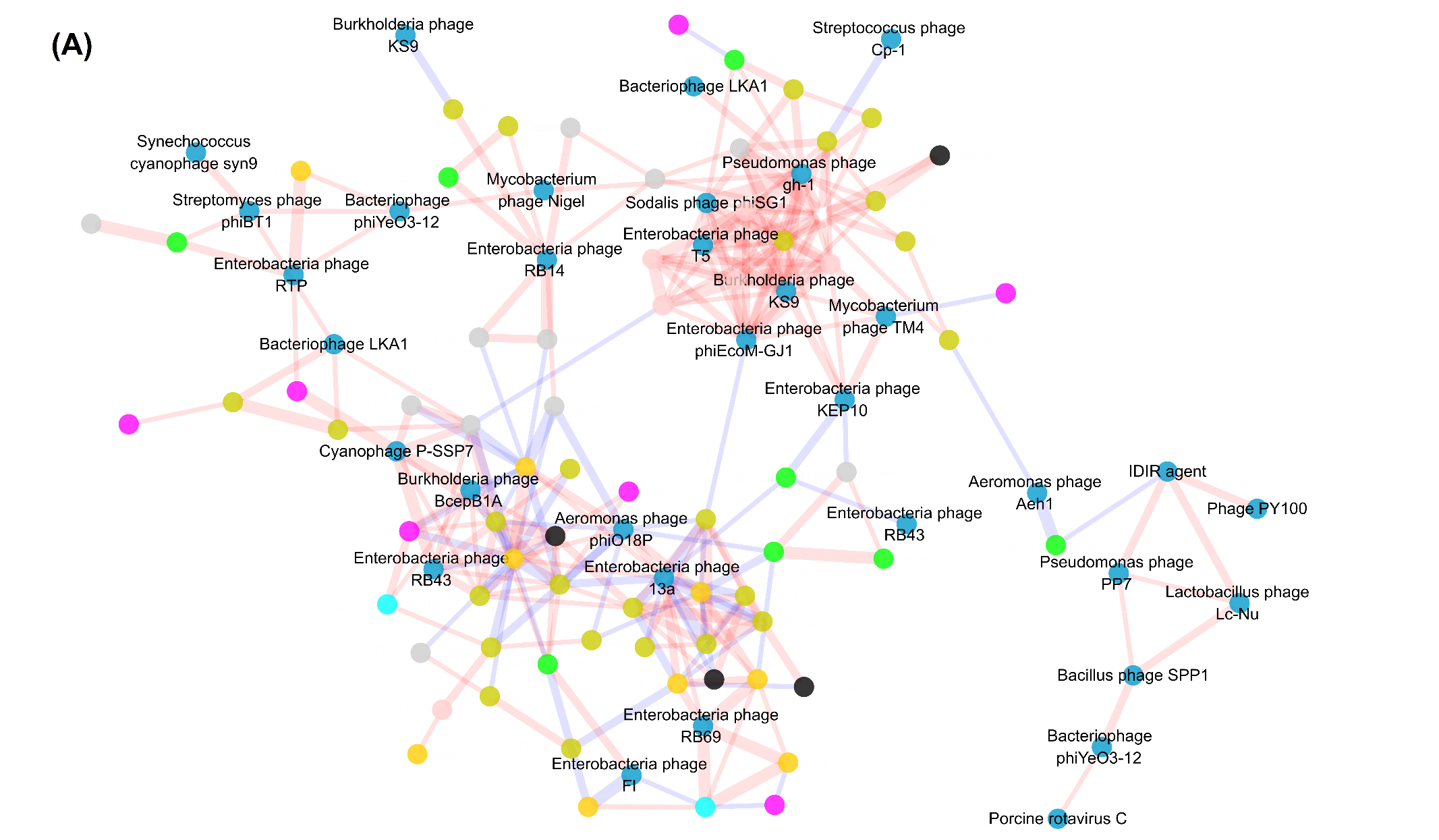


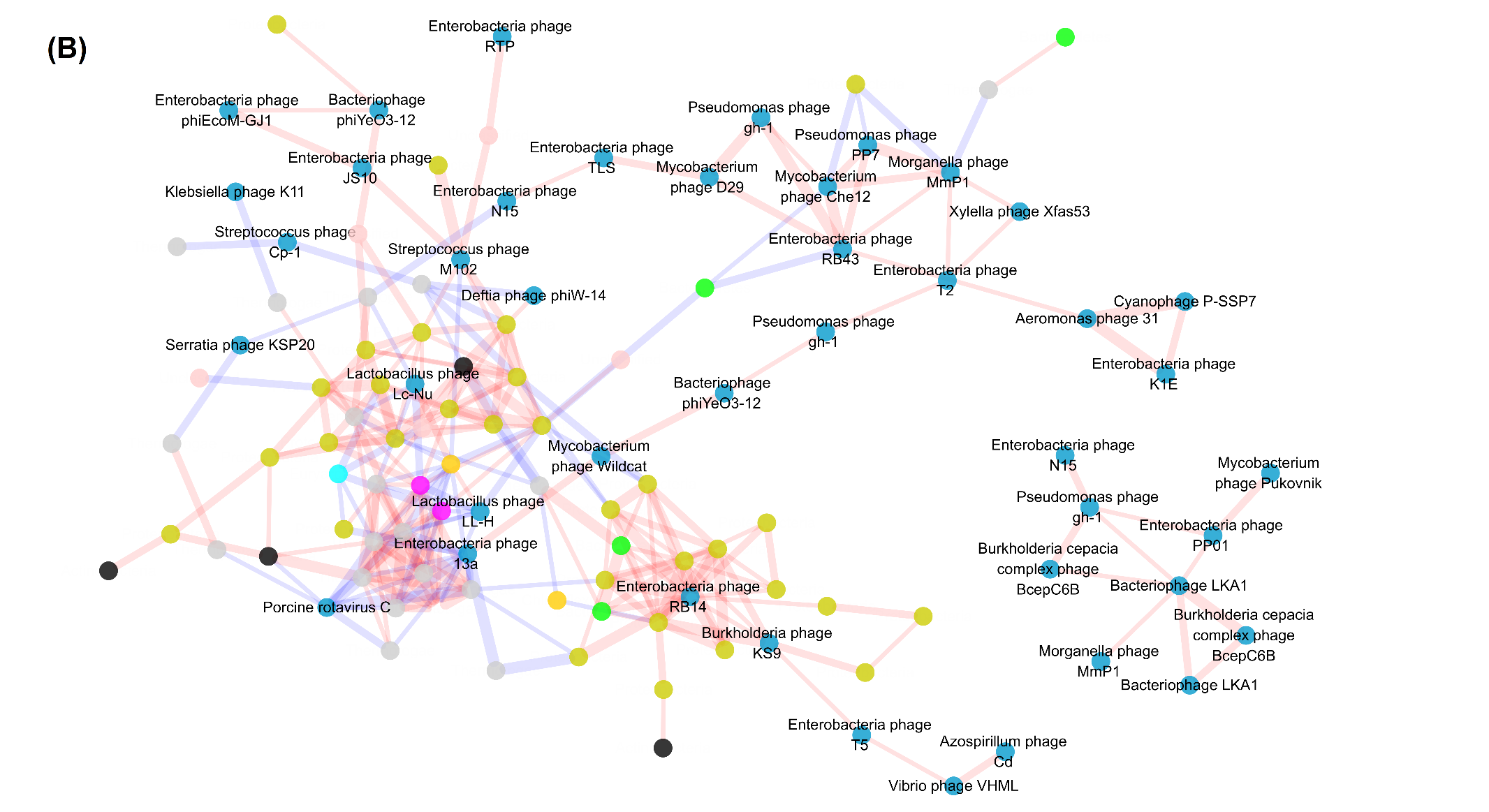
****

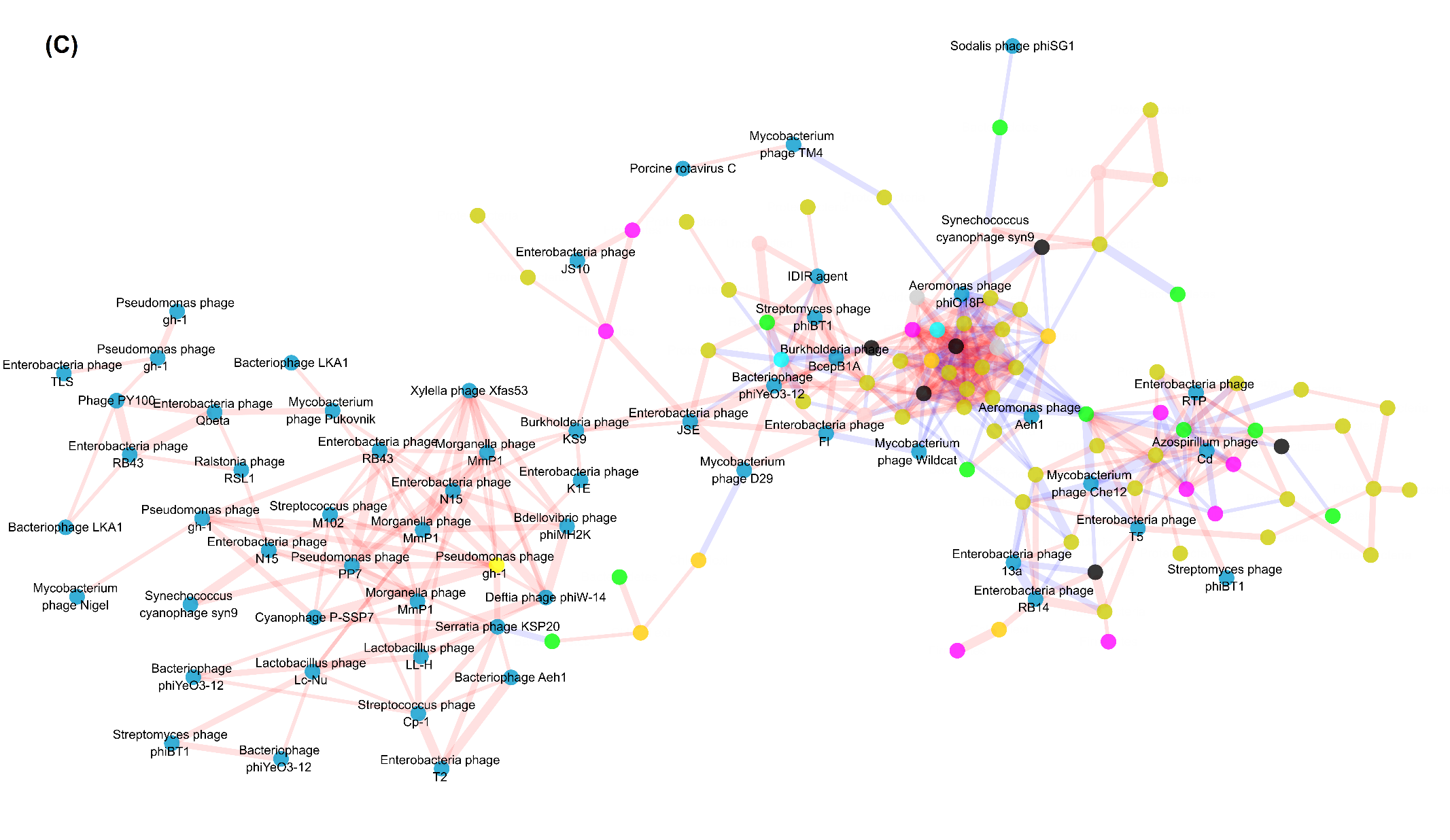
****

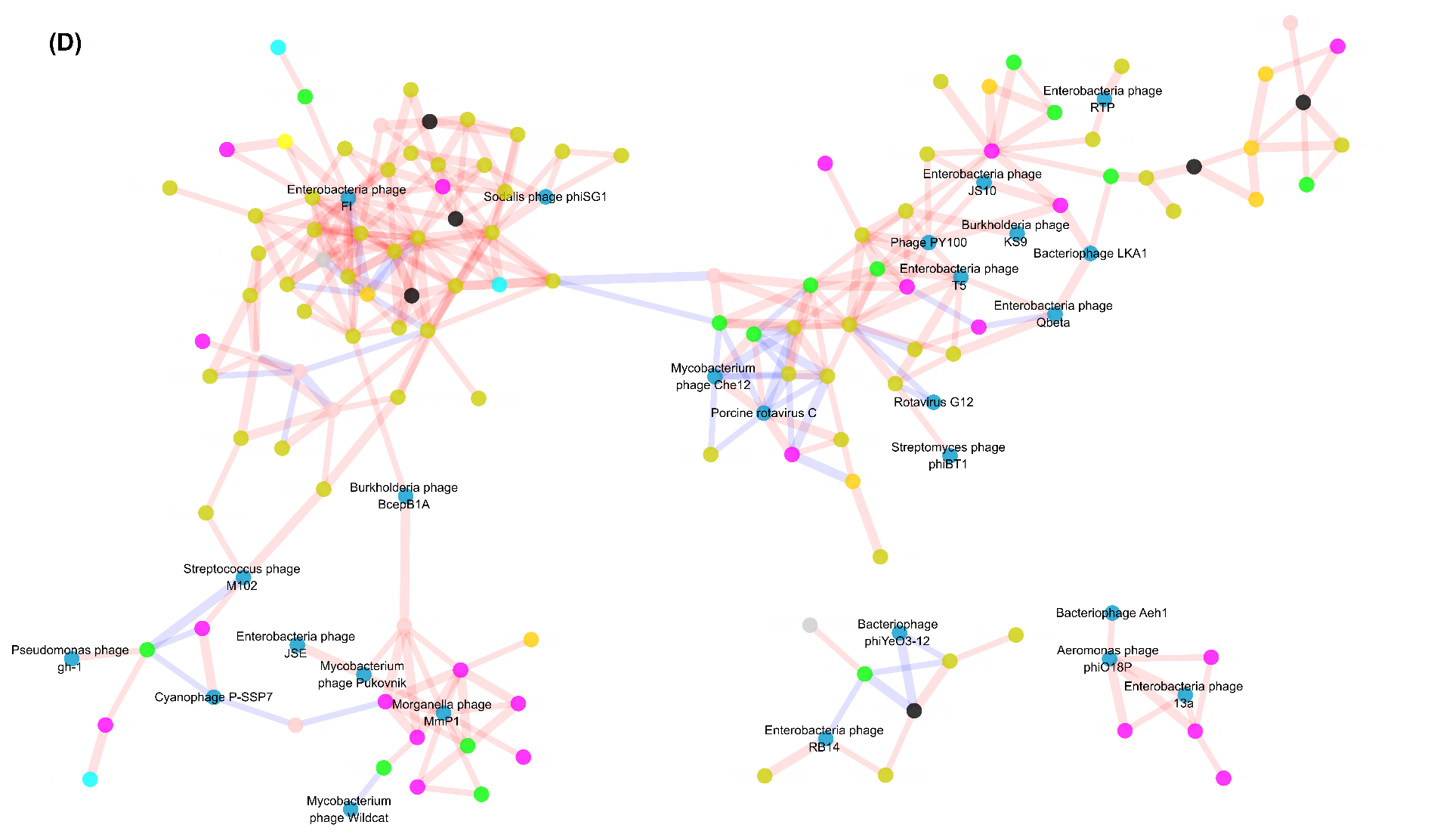
****

**Fig. S4.** Association networks generated from (A) Beijing, (B) Ningbo-T, (C) Ningbo-M and (D) Qingdao samples. Modules with equal or less than 5 nodes were omitted. Positive linkages are shown in red edges, while negative linkages are shown in blue edges. Spearman’s correlation coefficients are indicated by line width.



****



****

**Fig. S5.** Association networks generated according to seasons: (A) Winter, (B) Spring, (C) Summer and (D) Autumn. Modules with equal or less than 5 nodes were omitted. Positive linkages are shown in red edges, while negative linkages are shown in blue edges. Spearman’s correlation coefficients are indicated by line width.

**Table S1.** Dissimilarity tests of Mrpp, Anosim and Adonis on community structures.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Groups | Mrppa | | Anosim | | Adonis | |
|  | δ | P-value | Statistic R | P-value | Statistic R2 | P-value |
| BJ vs Ningbo-T | 0.183 | **0.002b** | 0.254 | **0.004** | 0.142 | **0.001** |
| BJ vs Ningbo-M | 0.163 | **<0.001** | 0.512 | **0.001** | 0.217 | **0.002** |
| BJ vs QD | 0.207 | **<0.001** | 0.417 | **0.001** | 0.236 | **0.001** |
| Ningbo-T vs Ningbo-M | 0.167 | **0.024** | 0.19 | **0.005** | 0.075 | 0.060 |
| Ningbo-T vs QD | 0.222 | **0.001** | 0.353 | **0.002** | 0.2 | **0.001** |
| Ningbo-M vs QD | 0.2 | **0.001** | 0.423 | **0.001** | 0.225 | **0.001** |

aAbbreviations: Mrpp, multi-response permutation procedure; Anosim, analysis of similarity; Adonis, non-parametric multivariate analysis of variance with the Adonis function.

bBoldface values indicate significant differences (P<0.050).

**Table S2.** Measurements of physicochemical properties related to process performance.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample | TSa (mg/mL) | VS (mg/mL) | Gas (m3/d) | COD (mg/L) |
| BJ1 | 14.26 | 8.44 | - | 24.26 |
| BJ2 | 17.83 | 9.67 | - | 62.18 |
| BJ3 | 23.47 | 14.35 | - | 199.12 |
| BJ4 | 14.04 | 8.60 | - | 28.41 |
| BJ5 | 17.90 | 10.67 | - | 247.31 |
| BJ6 | 5.94 | 2.80 | - | 52.63 |
| BJ7 | 20.53 | 10.01 | - | 115.79 |
| BJ8 | 29.52 | 12.65 | - | 9.43 |
| BJ9 | 15.44 | 25.08 | - | 56.34 |
| BJ10 | 15.19 | 8.86 | - | 18.00 |
| BJ11 | 3.51 | 2.01 | - | 30.00 |
| BJ12 | 12.25 | 7.73 | - | 36.00 |
| Ningbo-M1 | 84.15 | 34.79 | - | 246.63 |
| Ningbo-M2 | 65.43 | 26.15 | - | 99.15 |
| Ningbo-M3 | 60.15 | 24.12 | - | 78.72 |
| Ningbo-M4 | 84.16 | 34.80 | - | 107.49 |
| Ningbo-M5 | 68.38 | 27.57 | - | 197.36 |
| Ningbo-M6 | 58.44 | 26.56 | - | 62.50 |
| Ningbo-M7 | 79.72 | 32.57 | - | 395.70 |
| Ningbo-M8 | 61.72 | 24.15 | - | 84.21 |
| Ningbo-M9 | 98.96 | 36.71 | - | 136.84 |
| Ningbo-M10 | 94.27 | 31.31 | - | 89.62 |
| Ningbo-M11 | 122.09 | 42.87 | - | 169.70 |
| Ningbo-M12 | 26.07 | 22.45 | - | 81.00 |
| QD1 | 12.51 | 4.84 | 8692.97 | 70.64 |
| QD2 | 12.51 | 4.84 | 10116.07 | 82.13 |
| QD3 | 14.47 | 5.38 | 13419.16 | 131.06 |
| QD4 | 21.26 | 4.22 | 12573.21 | 101.42 |
| QD5 | 21.50 | 7.39 | 15376.43 | 116.30 |
| QD6 | 19.23 | 7.59 | 13698.46 | 103.41 |
| QD7 | 13.02 | 4.34 | 10664.73 | 298.92 |
| QD8 | 10.53 | 3.18 | 7818.60 | 84.21 |
| QD9 | 17.18 | 5.27 | 7740.30 | 31.58 |
| QD10 | 13.11 | 3.97 | 7238.42 | 42.45 |
| QD11 | 14.04 | 5.63 | 7665.04 | 107.04 |
| QD12 | 12.53 | 5.12 | 7577.07 | 66.00 |

aAbbreviations: BJ: Beijing; QD: Qingdao; TS, total solid content; VS, volatile solid content; Gas, average daily biogas production; COD, chemical oxygen demand; NH3-N, ammonia nitrogen.

**Table S3.** Taxonomic information of *Euryarchaeota* OTUs.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| OTU | Kingdom | Phylum | Class | Order | Family | Genus |
| OTU\_1019 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_107 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1073 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1087 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1104 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1106 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1109 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1112 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_1141 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_115639 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1162 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1169 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1174 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_1177 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1179 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_118 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1185 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1205 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1210 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1215 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1274 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1276 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_12843 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1319 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1335 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiale-  s\_incertae\_sedis | Methanolinea |
| OTU\_1351 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1358 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1359 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1391 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1393 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1409 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1443 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_1456 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanothermobacter |
| OTU\_146 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1482 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1492 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1504 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_154 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1559 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1566 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_1568 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanosphaera |
| OTU\_1576 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1599 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_1614 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_1618 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1686 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1699 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1700 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_1702 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1717 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1726 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1773 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1788 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_1802 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1812 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1828 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1855 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1896 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_1898 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_1930 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_195 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_1965 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_1979 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2007 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2036 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_2046 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2122 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2132 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_2133 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2148 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2191 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2218 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanofollis |
| OTU\_2248 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2278 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_2303 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_233 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2368 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_238 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2387 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_2398 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2415 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_2424 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2425 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_2434 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2470 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_2474 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_2525 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_2528 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2562 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2584 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2589 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_2604 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2667 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_2679 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2683 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2695 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_2704 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2743 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_2747 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_279 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2814 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2846 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2868 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_2872 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_2878 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_2901 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2906 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_2937 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_2944 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanoculleus |
| OTU\_2957 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_302 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_3025 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3057 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_3066 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3088 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_3094 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_3120 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_3123 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3127 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanocorpusculaceae | Methanocorpusculum |
| OTU\_3130 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_3131 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_3160 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3208 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_3213 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_325 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3289 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3304 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanoculleus |
| OTU\_337 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_3375 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_343 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_3434 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3464 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_3470 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_3500 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_353 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3536 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3580 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3650 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3656 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_367 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3723 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3735 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_3786 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_3807 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_3870 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_395 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_396 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_398 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_3985 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_4126 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_413 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanoculleus |
| OTU\_4130 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_41715 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_418 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_420 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_422 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_4221 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_4316 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_4332 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_439 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanogenium |
| OTU\_4402 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_4422 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_4439 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_4533 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_456 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_4596 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_4641 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_4713 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_4765 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_4784 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_4789 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_479 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_4881 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_493 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_496 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_499 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanosphaerula |
| OTU\_508 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_510 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_515 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_518 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_520 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_525 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_533 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_534 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_549 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_55 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_562 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_57 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_590 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_592 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanoculleus |
| OTU\_594 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_612 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_618 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_638 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanomethylovorans |
| OTU\_64 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_64176 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_65 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_65920 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanosphaera |
| OTU\_668 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_702 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_728 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_731 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiaceae | Methanoculleus |
| OTU\_745 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanocorpusculaceae | Methanocorpusculum |
| OTU\_746 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_748 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_777 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_797 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosarcina |
| OTU\_860 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_861 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_870 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_88 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanothermobacter |
| OTU\_88466 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosarcinaceae | Methanosalsum |
| OTU\_90 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_9042 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanosphaera |
| OTU\_910 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanoregula |
| OTU\_915 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_916 | Archaea | Euryarchaeota | Methanomicrobia | Methanosarcinales | Methanosaetaceae | Methanosaeta |
| OTU\_920 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_922 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_924 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_931 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_951 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobrevibacter |
| OTU\_96 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |
| OTU\_969 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanospirillaceae | Methanospirillum |
| OTU\_978 | Archaea | Euryarchaeota | Methanomicrobia | Methanomicrobiales | Methanomicrobiales-  \_incertae\_sedis | Methanolinea |
| OTU\_986 | Archaea | Euryarchaeota | Methanobacteria | Methanobacteriales | Methanobacteriaceae | Methanobacterium |

**Table S4.** Major properties of association networks.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Network properties | Whole | BJ | Ningbo-T | Ningbo-M | QD | Winter | Spring | Summer | Autumn |
| Threshold | 0.660 | 0.880 | 0.860 | 0.870 | 0.840 | 0.810 | 0.820 | 0.810 | 0.870 |
| Network size (n)a | 104 | 338 | 320 | 308 | 425 | 120 | 124 | 150 | 165 |
| Total links | 231 | 725 | 564 | 591 | 815 | 293 | 290 | 461 | 333 |
| R2 of power-lawb | 0.753 | 0.853 | 0.932 | 0.839 | 0.897 | 0.787 | 0.832 | 0.796 | 0.852 |
| Average degree (avgK) | 4.442 | 4.290 | 3.525 | 3.838 | 3.835 | 4.883 | 4.677 | 6.147 | 4.036 |
| Average clustering coefficient (avgCC) | 0.294 | 0.224 | 0.221 | 0.267 | 0.249 | 0.410 | 0.312 | 0.371 | 0.341 |
| Average path distance (GD)c | 4.888 | 5.074 | 6.912 | 6.269 | 7.055 | 4.633 | 4.303 | 4.937 | 6.132 |
| Modularity | 0.570 | 0.663 | 0.702 | 0.737 | 0.723 | 0.639 | 0.652 | 0.652 | 0.715 |
| No. of modules | 9 | 41 | 45 | 34 | 47 | 10 | 12 | 10 | 16 |
| No. of positive phage-prokaryote links | 48 | 72 | 73 | 41 | 17 | 88 | 29 | 71 | 69 |
| No. of positive prokaryote-prokaryote links | 81 | 485 | 365 | 402 | 604 | 99 | 139 | 159 | 205 |
| No. of positive phage-phage links | 42 | 5 | 50 | 19 | 44 | 37 | 43 | 111 | 13 |
| No. of negative phage-prokaryote links | 23 | 27 | 33 | 11 | 4 | 32 | 47 | 43 | 21 |
| No. of negative prokaryote-prokaryote links | 36 | 134 | 43 | 118 | 146 | 37 | 31 | 73 | 25 |
| No. of negative phage-phage links | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 4 | 0 |

aThe number of phage genes and bacterial OTUs (i.e., nodes) in the network.

bThe square of correlation coefficient (R2) of the linear relationship log[P(k)] ~ -γlog(k), where P(k) is the number of nodes with k degrees (connectivity) and γ is a constant.

cGD: geodesic distance.**Table S5.** Dissimilarity of phage communities between months represented as β-diversity. Boldface values indicate dissimilarities between two consecutive months.

|  |  |
| --- | --- |
| Nov | **14.4%** |
| Dec | 18.4% | **16.1%** |
| Jan | 18.8% | 17.5% | **15.7%** |
| Feb | 21.4% | 20.8% | 19.2% | **16.6%** |
| Mar | 19.9% | 18.9% | 17.0% | 13.8% | **18.8%** |
| Apr | 21.1% | 21.5% | 20.2% | 19.5% | 19.1% | **18.8%** |
| May | 17.7% | 17.5% | 20.3% | 16.3% | 20.4% | 16.1% | **15.9%** |
| Jun | 18.6% | 18.0% | 20.7% | 18.8% | 24.7% | 16.2% | 18.0% | **13.7%** |
| Jul | 17.7% | 18.5% | 20.4% | 19.1% | 22.9% | 19.4% | 17.5% | 15.1% | **16.0%** |
| Aug | 18.9% | 19.4% | 19.4% | 18.8% | 20.1% | 19.0% | 18.0% | 17.1% | 18.3% | **14.2%** |
| Sep | 16.6% | 18.4% | 18.4% | 19.1% | 21.5% | 19.2% | 20.3% | 17.8% | 18.4% | 17.5% | **16.2%** |
|  | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug |