

**Electronic Supplementary Material to:
The Synergism between Methanogens and Methanotrophs and
the Nature of their Contributions to the Seasonal Variation
of Methane Fluxes in a Wetland: The Case of
Dajiuhu Subalpine Peatland***

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Table S1. The major topological parameters of the methanogenic and methanotrophic networks.

Network		Total nodes	Total edges	Positive connections	Negative connections	Average clustering coefficient (avgCC)	Average degree (avgK)	Diameter	Average path length (GD) ^a	Density	Modularity (Modules)
methanogen	Winter	401	4567	3215	1352	0.270	22.778	12	3.088	0.057	0.501 (11)
	Spring	621	32159	8600	23,559	0.249	103.539	9	2.286	0.167	0.145 (11)
	Summer	512	8030	4241	3789	0.277	31.367	9	3.292	0.061	0.445 (7)
	Autumn	355	11319	5588	5731	0.274	63.769	10	2.560	0.18	0.154 (11)
methanotroph	Winter	531	4945	2583	2363	0.329	18.625	10	3.218	0.035	0.412 (20)
	Spring	811	37775	348,668	29107	0.187	93.042	11	2.672	0.115	0.115 (18)
	Summer	589	2715	1950	765	0.277	9.219	14	4.580	0.016	0.678 (21)
	Autumn	741	44848	13625	31223	0.303	121.047	15	2.570	0.164	0.096 (9)

^a GD, geodesic distance.

Table S2. Information of keystone specials of methanogens discerned by network analysis.

Season	Topological role	OTU ID	Class	Order	Family	Genus	Species
Winter	Module hubs	otu7921	Methanomicrobia	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu28836	Methanomicrobia	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella paludicola</i>
		otu12232	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu25071	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu8092	Methanomicrobia	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu28026	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu7973	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu22253	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu19105	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu28425	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu30825	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu6322	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanolinea</i>	<i>Methanolinea mesophila</i>
		otu9709	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu16471	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu9821	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
Spring	Module hubs	otu881	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu20895	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu28021	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu20040	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu10443	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
	Connectors	otu4795	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu10557	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu3850	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu2115	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu3714	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu19174	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu9044	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu12523	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu20919	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu6785	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanolinea</i>	<i>Methanolinea mesophila</i>
otu12968	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>		
otu2103	Methanomicrobia	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>		

Table S2. (Continued.)

Season	Topological role	OTU ID	Class	Order	Family	Genus	Species
Summer	Module hubs	otu29312	Methanomicrobacteria	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu16698	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu10110	Methanomicrobacteria	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu5054	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu30724	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu30856	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu7743	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu3682	Methanomicrobacteria	Methanocellales	Methanocellaceae	<i>Methanocella</i>	<i>Methanocella arvoryzae</i>
		otu28026	Methanomicrobacteria	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
Autumn	Module hubs	otu19085	Methanomicrobacteria	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>
		otu28628	Methanomicrobacteria	Methanomicrobiales	Methanoregulaceae	<i>Methanoregula</i>	<i>Methanoregula formicica</i>

Table S3. Information of keystone specialists of methanotrophs discerned by network analysis.

Season	Topological role	OTU ID	Class	Order	Family	Genus	Species	
Winter	Module hubs	otu19808	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	type II methanotrophic bacterium	
		otu30490	Gammaproteobacteria	Methylcoccales	–	<i>Candidatus</i> Methyloumidiphilus	<i>Candidatus</i> Methyloumidiphilus alimensis	
		otu6164	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa acidiphila</i> bacterium	
		otu14450	–	–	–	–	–	
		otu11307	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu3131	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu22810	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu763	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu5335	Gammaproteobacteria	Methylcoccales	–	<i>Candidatus</i> Methyloumidiphilus	<i>Candidatus</i> Methyloumidiphilus alimensis	
		otu31869	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu32067	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu22803	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium
		otu32536	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu15588	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu32859	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
otu23764	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>			
Connectors		otu8533	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	Methylocystis	<i>Methylocystis</i> sp. M212	
		otu28418	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu35063	Alphaproteobacteria	Rhizobiales	Methyllocystaceae	–	–	type II methanotrophic bacterium

Table S3. (Continued.)

Season	Topological role	OTU ID	Class	Order	Family	Genus	Species
Spring	Module hubs	otu33237	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu29980	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu6164	Alphaproteobacteria	Rhizobiales	Bejerinckiacae	<i>Methylocapsa</i>	<i>Methylocapsa acidiphila</i>
		otu14450	–	–	–	–	bacterium
		otu13088	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu15187	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu34788	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu29565	–	–	–	–	bacterium
		otu6016	–	–	–	–	bacterium
		otu25376	–	–	–	–	bacterium
Summer	Module hubs	otu16124	–	–	–	–	bacterium
		otu2908	Alphaproteobacteria	Rhizobiales	Methylocystaceae	<i>Methylocystis</i>	<i>Methylocystis</i> sp. M212
		otu6486	–	–	–	–	bacterium
		otu2551	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu30490	Gammaproteobacteria	Methylococcales	–	<i>Candidatus</i> Methyloiumidiphilus	<i>Candidatus</i> Methyloiumidiphilus alimensis
		otu9888	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu36265	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu13088	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu514	Alphaproteobacteria	–	–	–	methanotrophic alpha proteobacterium arc2
		otu19228	Gammaproteobacteria	Methylococcales	–	<i>Candidatus</i> Methyloiumidiphilus	<i>Candidatus</i> Methyloiumidiphilus alimensis
Connectors	Connectors	otu21124	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu31786	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu30060	–	–	–	–	bacterium
		otu18640	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu26671	–	–	–	–	bacterium
		otu15728	Alphaproteobacteria	Rhizobiales	Methylocystaceae	<i>Methylocystis</i>	<i>Methylocystis</i> sp. m231
		otu24589	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu37521	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu35711	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu38142	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
Network hubs	Network hubs	otu35267	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu1908	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu29822	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium
		otu5509	Alphaproteobacteria	Rhizobiales	Methylocystaceae	–	type II methanotrophic bacterium

Table S3. (Continued.)

Season	Topological role	OTU ID	Class	Order	Family	Genus	Species	
Autumn	Module hubs	otu4659	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu21922	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu3533	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu13211	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu8689	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu15914	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu31920	-	-	-	-	-	bacterium
		otu9820	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu29080	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu19159	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu24939	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu1769	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu13210	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu24579	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu17931	Alphaproteobacteria	Rhizobiales	Methylocystaceae	<i>Methylocystis</i>	<i>Methylocystis</i> sp. SC2	
		otu33493	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu23063	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	
		otu675	Alphaproteobacteria	Rhizobiales	Beijerinckiaceae	<i>Methylocapsa</i>	<i>Methylocapsa aurea</i>	

Table S4. Physicochemical soil properties in soil samples collected from the Dajiuhe subalpine peatland in different seasons.

Date	Depth (cm)	pH	Eh (mV)	TN (%)	NH ₄ ⁺ -N (mg kg ⁻¹)	NO ₃ ⁻ -N (mg kg ⁻¹)	NO ₂ ⁻ -N (mg kg ⁻¹)	TOC (%)	Ts (°C)	SWC	Daily average CH ₄ fluxes (nmol m ⁻² s ⁻¹)	Water table (m)
2019.01.19	0	5.21	81.5	2.83	2.380	0.226	0.006	40.60	1.50	0.781	3.64	0.746
	10	5.79	101.3	2.67	4.396	0.261	0.006	48.37	2.47	0.654		
	30	4.84	95.5	2.28	1.485	0.200	0.004	43.74	3.55	0.636		
	50	5.05	99.5	2.17	1.666	0.170	0.002	42.58	3.78	0.597		
2019.04.26	0	4.93	110.0	2.57	3.062	0.238	0.007	40.64	16.04	0.600	4.72	0.700
	10	5.18	149.7	2.80	2.619	0.149	0.008	37.93	14.30	0.638		
	30	4.72	159.0	2.27	1.288	0.249	0.004	43.81	12.67	0.564		
	50	4.76	162.7	2.13	0.800	0.156	0.004	45.32	11.13	0.528		
2019.07.22	0	4.98	86.5	2.65	2.236	0.180	0.006	38.40	21.33	0.588	49.21	0.648
	10	4.63	90.2	2.27	1.121	0.259	0.004	35.65	20.13	0.640		
	30	4.78	85.7	2.01	0.906	0.180	0.003	47.38	18.58	0.639		
	50	5.27	93.1	2.35	0.829	0.137	0.002	41.68	16.79	0.589		
2019.10.17	0	4.47	13.4	1.87	1.205	0.154	0.003	36.18	13.73	0.786	23.78	0.781
	10	4.87	28.0	2.74	0.668	0.205	0.001	39.41	12.26	0.698		
	30	5.49	48.9	2.34	0.691	0.140	0.004	47.16	12.78	0.582		
	50	5.23	37.5	2.06	0.643	0.197	0.002	43.80	11.36	0.543		

The pH, soil temperature (Ts), and Oxidation-Reduction Potential (Eh) of soil were measured in situ. Soil water content (SWC), total organic carbon (TOC), total nitrogen (TN), ammonium (NH₄⁺-N), nitrate (NO₃⁻-N), and nitrite (NO₂⁻-N) were measured in the laboratory. The CH₄ fluxes were monitored by the eddy covariance (EC) system and the water table was determined by the water level monitoring instrument.

Table S5. Pearson correlation of soil physicochemical properties.

	CH ₄	Water table	pH	Eh	TN	NH ₄ ⁺ -N	NO ₃ ⁻ -N	NO ₂ ⁻ -N	TOC	Ts	SWC
CH ₄	1	-0.539**	-0.186	-0.375	-0.231	-0.425	-0.202	-0.336	-0.234	0.757**	-0.049
Water table		1	0.228	-0.528*	-0.033	-0.044	-0.050	-0.246	0.151	-0.625**	0.308
pH			1	-0.011	0.475	0.470	-0.009	0.245	0.505*	-0.401	-0.149
Eh				1	0.183	0.302	0.141	0.493	0.188	-0.032	-0.474
TN					1	0.592*	0.276	0.580*	-0.174	-0.164	0.215
NH ₄ ⁺ -N						1	0.455	0.758**	0.044	-0.331	0.207
NO ₃ ⁻ -N							1	0.235	-0.005	-0.191	0.129
NO ₂ ⁻ -N								1	-0.116	-0.005	0.073
TOC									1	-0.384	-0.424
Ts										1	-0.258
SWC											1

* $p \leq 0.05$, ** $p \leq 0.01$

Table S6. Correlation index between keystone species and CH₄ fluxes.

	Community	P-value	Pearson's correlation coefficient
methanogen	<i>Methanoregula</i>	0.890	-0.038
	<i>Methanocella</i>	0.413	0.230
	<i>Methanolinea</i>	0.024	-0.560
methanotroph	<i>Methylocapsa</i>	0.850	0.052
	unclassified_f_Methylocystaceae	0.171	0.360
	<i>Candidatus Methyloimidiphilus</i>	0.490	-0.186
	<i>Methylocystis</i>	0.299	-0.277
	unclassified_c_Alphaproteobacteria	0.327	-0.262