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Supplement of

Co-occurrence patterns in aquatic bacterial communities across changing permafrost landscapes

J. Comte et al.

Correspondence to: J. Comte (jerome.comte@takuvik.ulaval.ca)

Supplementary information

Figures

Figure S1: UPGMA clustering based on unweighted UniFrac distances among bacterial community samples. Color refers to valley identity with SAS: brown, KWK: purple, BGR: green, NAS: orange, RBL: blue. The complete names of the valleys are given in the main text.

Figure S2: Rank abundance curve of the bacterial communities originating from the 5 different valleys. Color refers to valley identity with SAS: brown, KWK: purple, BGR: green, NAS: orange, RBL: blue. The complete names of the valleys are given in the text.

Figure S3: Taxonomic uniqueness as determined by the local contribution to β -diversity (LCBD) among the different sampled valleys. The solid black horizontal and vertical lines represent the mean and standard deviation respectively.

Figure S4: Heatmap representation of habitat preference of the 2166 bacterial OTUs detected in the dataset. Habitat preference was determined by point biserial correlation.

Figure S5: Association networks between co-occurring bacterial OTUs and with the abiotic and biotic local conditions based on maximum interaction coefficient (MIC). Significant associations ($MIC > 0.44$, $P_{fdr} < 0.03$) are presented. The color of the edges refers to the strengths of the relationship between two nodes and is proportional to MIC values with black lines corresponding to strong links). The size of the nodes is proportional to node degree that is the number of connection that a node has with other nodes. The associations between the major bacterial classes (bacterial OTUs colored by taxonomy) and with abiotic (white nodes) and biotic (black nodes) variables are presented in panel A. Panel B presents the associations between the different environmental variables (colored by variable) and with bacterial OTUs.

Figure S6: Distribution of nodes abundance as a function of their connectivity.

Figure S7: Relationship between OTUs connectivity and abundance among the major bacterial phyla (Actinobacteria, Proteobacteria, Bacteroidetes, Verruccomicrobia) detected in co-occurrence networks. Dots represent individual OTUs.

Figure S8: Association networks between co-occurring bacterial OTUs and with the abiotic and biotic local conditions based on maximum interaction coefficient (MIC). Panel A presents all significant associations (MIC> 0.44, P_{fdr}<0.03) between the bacterial OTUs. Impact of the removal of bacterial hubs (most connected nodes) on the topology of the association network is presented in panels B. Node color corresponds to the type of variable with grey referring to bacterial OTUs, white to abiotic variables and black to biotic variables.

Tables

Table S1: Bacterial phylogenetic structure, taxonomic uniqueness and abundance across the sampling sites. N taxa represent the total number of detected taxa and PSR, PSE PD refer to phylogenetic species richness, evenness and diversity respectively. NRI corresponds to Net Relatedness Index. LCBD and BA refer to local contribution to beta-diversity and bacterial abundance (10^6 cells ml^{-1}) respectively.

Table S2: Some physico-chemical characteristics of the thaw ponds and lakes sampled from the study area. Land. refers to the type of landscape (spo: sporadic permafrost, dis: discontinuous permafrost, rock: rock basin). Location of sites is presented with latitudinal (Lat) and longitudinal (Long) coordinates. Temp, Cond, DO, TP, TN, $SUVA_{254}$ and DOC mean temperature, conductivity, dissolved oxygen, total phosphorus, total nitrogen, specific ultraviolet absorbance at 254 nm and dissolved organic carbon respectively. NA: Not Applicable, ND: Not determined, * data from Laurion et al. (2010), # data from Laurion I. (unpublished data).

Table S3: Taxonomic identity of network ‘hubs’. Top 24 is presented, which corresponds to 10% of total nodes number in the network. Taxonomic assignment was realized at a 97% similarity threshold. RA refers to relative abundance (% of total reads)

Fig. S1

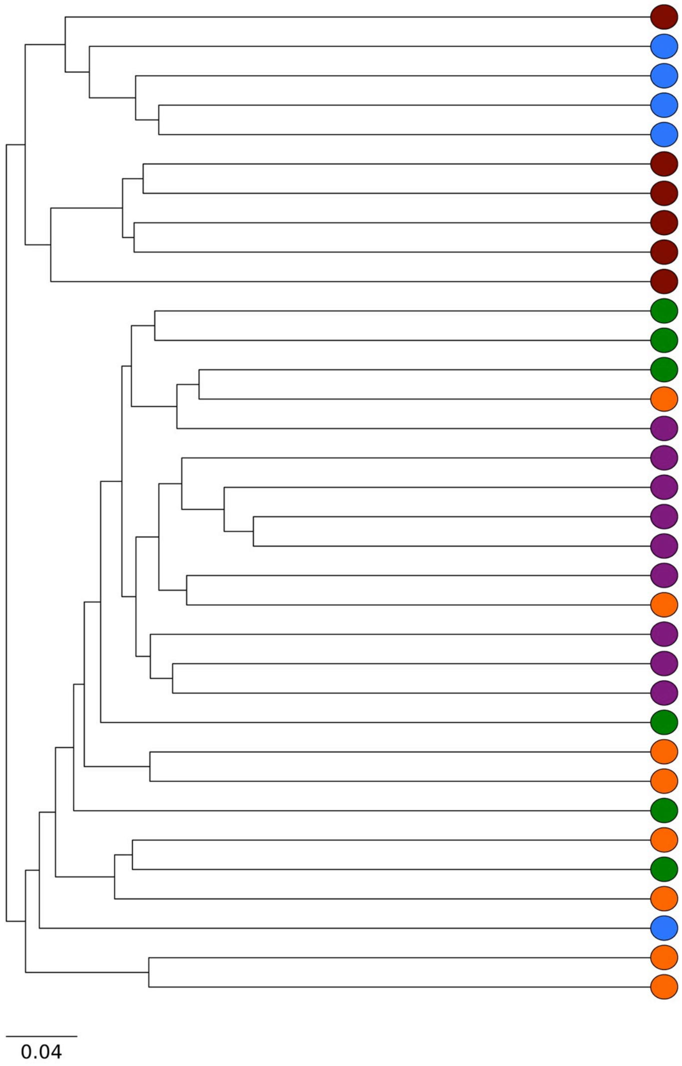


Fig. S2

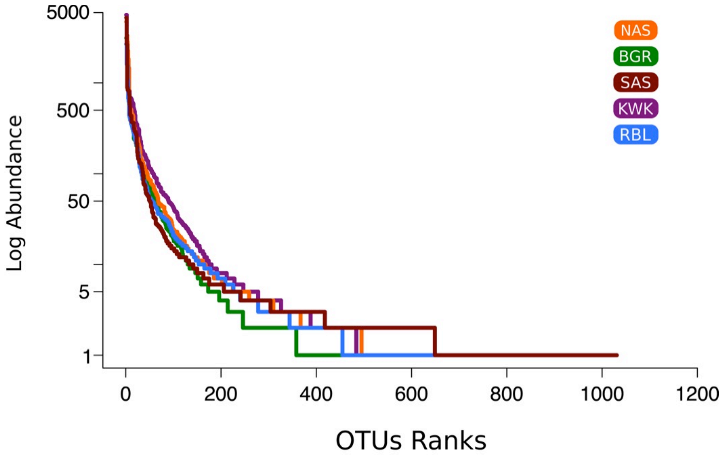

5000
500
50
5
1
Log Abundance
0
200
400
600
800
1000
1200
OTUs Ranks
NAS
BGR
SAS
KWK
RBL

Fig. S3

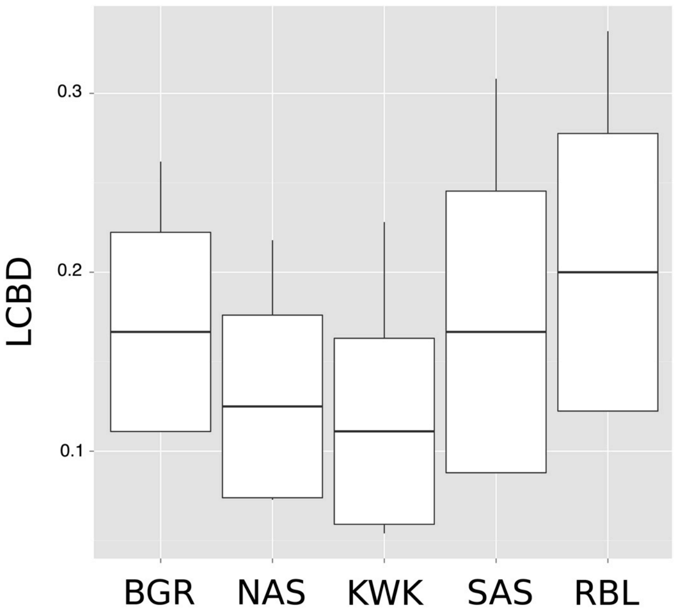


Fig. S4

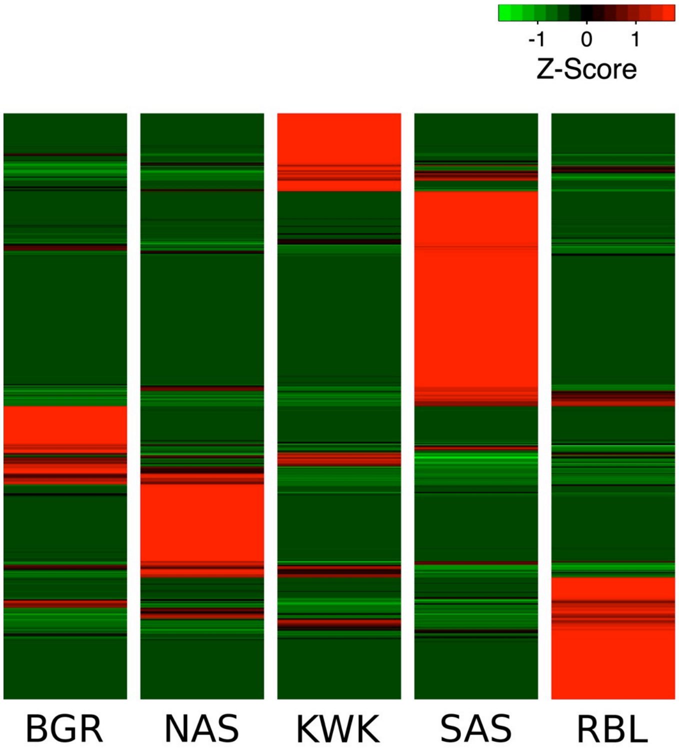


Fig. S5

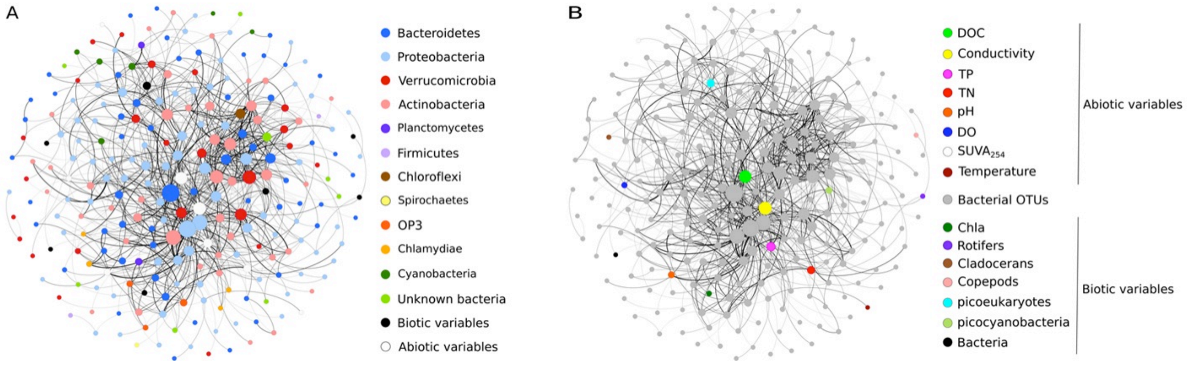

A
Bacteroidetes
Proteobacteria
Verrucomicrobia
Actinobacteria
Planctomycetes
Firmicutes
Chloroflexi
Spirochaetes
OP3
Chlamydiae
Cyanobacteria
Unknown bacteria
Biotic variables
Abiotic variables
B
DOC
Conductivity
TP
TN
pH
DO
$SUVA_{254}$
Temperature
Abiotic variables
Bacterial OTUs
Chla
Rotifers
Cladocerans
Copepods
picoeukaryotes
picocyanobacteria
Bacteria
Biotic variables

Fig S6

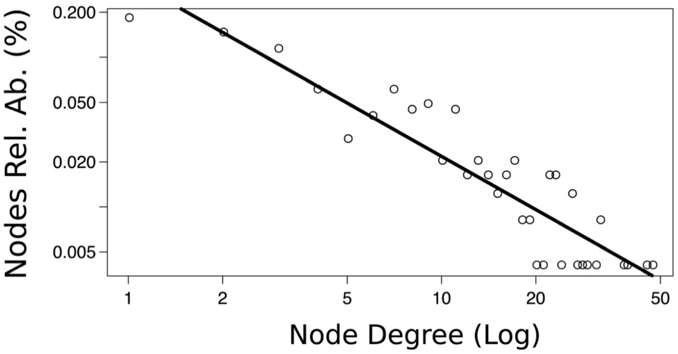
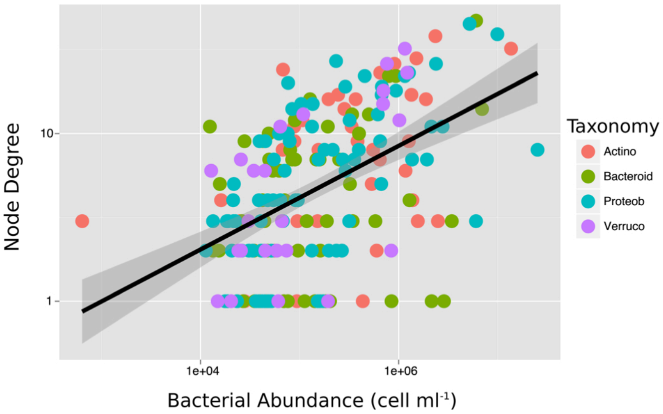


Fig S7



Node Degree
10
1
1e+04
1e+06
Bacterial Abundance (cell ml-1)
Taxonomy
Actino
Bacteroid
Proteob
Verruco

Fig. S8

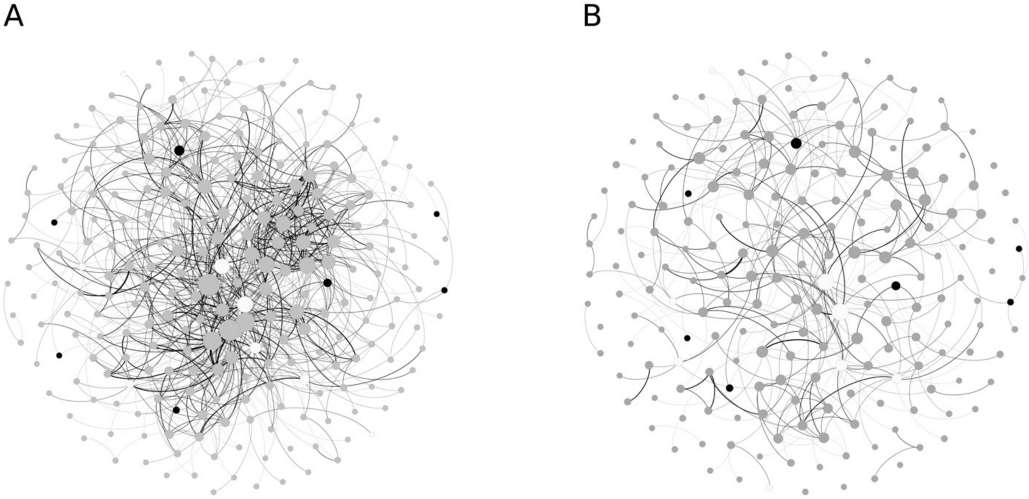


Table S1

Landscape and sites	**N Taxa**	**PSR**	**PSE**	**PD**	**NRI**	**LCBD**	**BA**
Discontinous							
BGR2	168	150.6	0.8	24.8	2.2	0.14	1.3
BGR17	120	108.7	0.7	21.9	1.0	0.21	8.7
BGR33	126	112.8	0.7	22.7	2.2	0.26	1.9
BGR40	224	200.1	0.8	27.2	2.2	0.15	1.2
BGR7	187	166.5	0.8	28.0	1.9	0.13	2.9
BGRh	200	180.6	0.8	30.7	1.1	0.12	3.9
NASa	286	256.1	0.8	37.4	3.3	0.12	1.7
NASb	223	201.1	0.5	32.4	3.7	0.22	1.0
NASc	119	103.3	0.8	16.3	1.7	0.09	13.5
NASd	154	135.9	0.8	20.9	0.9	0.11	4.3
NASe	123	110.4	0.7	22.4	2.2	0.08	19.3
NASg	192	171.9	0.8	25.6	2.0	0.07	6.0
NASh	289	258.1	0.8	36.5	2.3	0.17	8.4
NASi	104	92.9	0.7	18.5	2.0	0.15	8.4
Sporadic							
KWK1	180	156.2	0.8	24.0	2.1	0.08	6.2
KWK11	204	158.9	0.8	29.3	1.1	0.13	2.7
KWK12	190	157.7	0.9	26.6	1.4	0.15	1.9
KWK17	242	182.0	0.7	32.3	2.5	0.08	1.6
KWK19	203	157.8	0.8	27.1	2.0	0.05	1.8
KWK22	157	129.6	0.7	22.6	2.4	0.08	2.2
KWK33	202	160.3	0.8	27.7	2.8	0.10	1.8
KWK6	229	185.3	0.9	33.4	2.1	0.23	4.7
KWK7	170	141.2	0.8	24.8	1.9	0.11	2.4
SAS-S1	267	238.9	0.8	39.8	2.5	0.21	5.9
SAS-S2	365	328.9	0.8	51.7	2.6	0.12	1.1
SAS-S5	389	349.4	0.8	53.7	1.9	0.12	1.8
SAS-S8	277	250.9	0.6	41.4	2.9	0.15	2.5
SAS-N2	329	293.8	0.7	46.3	2.3	0.10	3.5
SAS-N3	192	174.0	0.8	35.7	1.2	0.31	30.0
Rock-basin lakes							
IQUAL	204	183.7	0.7	31.2	2.3	0.33	1.9
CAR	287	260.9	0.8	36.9	2.9	0.15	4.2
OLSH	248	223.7	0.8	37.3	2.8	0.19	3.5
PAC	286	260.3	0.9	37.9	3.1	0.14	4.2
WP1	155	138.2	0.6	23.5	1.3	0.18	2.0

Table S2

	Valley	**Land.**	**Lat.**	**Long.**	**Temp (°C)**	**Cond (μS cm^{-2})**	**pH**	**DO (mg L^{-1})**	**TP (μg L^{-1})**	**TN (mg L^{-1})**	**SUVA**	**DOC (mg L^{-1})**
SAS-S1	SAS	spor.	55.219	-77.708	14	0.10	6.4	7.9	15.2	0.75	6.46	9.9
SAS-S2	SAS	spor.	55.219	-77.707	12.7	0.10	6	9.8	14.9	0.9	6.47	15.5
SAS-S5	SAS	spor.	55.218	-77.707	14.4	0.09	6.3	6.9	11.6	0.78	ND	ND
SAS-S8	SAS	spor.	55.219	-77.707	15.2	0.10	5.9	6.3	12.9	0.77	ND	ND
SAS-N2	SAS	spor.	55.225	-77.696	13.3	0.11	5.8	2.8	9.6	0.46	6.03	17.4
SAS-N3	SAS	spor.	55.225	-77.695	21.8	0.95	6.1	10	197.3	0.56	5.49	23
KWK1	KWK	spor.	55.331	-77.502	17.9	0.06	6.7	9.7	67.9	0.55	4.66	12
KWK6	KWK	spor.	55.332	-77.502	14	0.08	6.4	9.9	29.8	0.4	2.36	5.2
KWK7	KWK	spor.	55.332	-77.501	13.9	0.09	6.4	9.9	75.4	0.44	6.54	10.3
KWK11	KWK	spor.	55.330	-77.503	15.2	0.06	6.8	12	95.6*	0.43#	5.67	12
KWK12	KWK	spor.	55.330	-77.504	16.3	0.06	8.3	9.5	27.4	0.35	4.67	9.3
KWK17	KWK	spor.	55.329	-77.504	18.3	0.07	6	11.2	60.6	0.41	5.48	10
KWK19	KWK	spor.	55.330	-77.504	18.2	0.09	5.8	10.4	95.2	0.41	5.5	11.2
KWK22	KWK	spor.	55.333	-77.503	12	0.09	6.2	8.3	113.6	0.39	6.96	11.3
KWK33	KWK	spor.	55.332	-77.502	12.7	0.07	6.3	8.6	197.3	0.19	5.78	13.4
BGR2	BGR	disc.	56.610	-76.216	15	0.21	7.3	9.4	49.1	0.19	5.13	8.6
BGR17	BGR	disc	56.611	-76.214	14.7	0.23	6.6	4.2	28.3	0.44	4.38	6.4
BGR33	BGR	disc	56.611	-76.214	14.3	0.18	6.5	8	19.7	0.36	6.55	14.3
BGR40	BGR	disc	56.608	-76.217	17.2	0.06	6.6	7.2	25.6	0.19	8.19	3.1
BGR7	BGR	disc	56.609	-76.216	15.7	0.18	6.5	8	8.7	0.21	6.16	1.95
BGRh	BGR	disc	56.609	-76.216	13.6	0.18	6.7	6.6	29.6	0.29	5.7	5.3
NASa	NAS	disc	56.924	-76.378	11.5	0.31	7	9.9	533.4	0.29	4.44	3
NASb	NAS	disc	56.924	-76.379	14.4	0.46	7	4.3	994.5	0.34	8.75	1.5
NASc	NAS	disc	56.922	-76.380	18.2	0.3	6.9	9.2	49.5	0.31	6.45	2.7
NASd	NAS	disc	56.923	-76.380	17.8	0.11	7.3	9.1	32.9	0.56	6.68	5.7
NASe	NAS	disc	56.924	-76.378	17.8	0.2	7.2	9.2	38.5	0.44	6.56	4.4
NASg	NAS	disc	56.924	-76.380	15.2	0.22	7.3	8.6	7.8	0.44	6.88	4.5

NASh	NAS	disc	56.924	-76.377	10.5	0.09	7.5	9.9	30.5	0.6	5.81	4.1
NASi	NAS	disc	56.924	-76.377	17	0.29	7.3	8.2	57.8	0.39	6.79	7.3
CAR	RBL	rock	55.284	-77.743	20.3	0.08	7.4	9.6	6.9	ND	3.5	7
OSH	RBL	rock	55.282	-77.740	15.4	0.09	6.1	7.6	11.4	0.6	4.96	9.2
WP1	RBL	rock	55.284	-77.725	17.6	0.03	7.1	6.4	10.7	0.22	4.9	9.9
IQAL	RBL	rock	55.370	-77.616	20.5	0.23	6.2	10	1.6	0.28	3.77	3.6
PAC	RBL	rock	55.332	-77.702	ND	ND	ND	ND	9	0.34	4.44	6.3

Table S3

OTU ID	**Degree**	**RA**	**Taxonomy**
3	47	3.3	Bacteroidetes/ Sphingobacteria/ Sphingobacteriales/ Flexibacteraceae/ *Arcicella*
2426	45	1.7	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Comamonadaceae/ Caenimonas
1	39	6.2	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Comamonadaceae/ *Variovorax*
14	38	2.0	Actinobacteria/ Actinobacteria/ Actinomycetales/ ACK-M1
2	32	9.3	Actinobacteria/ Actinobacteria/ Actinomycetales/ ACK-M1
6	32	1.3	Verrucomicrobia/ Opitutae/ Puniceicoccales/ Puniceicoccaceae /*Pelagicoccus*
795	28	0.9	Actinobacteria/ Actinobacteria/ Actinomycetales/ ACK-M1
80	27	0.2	Proteobacteria/ Alphaproteobacteria/ Rhizobiales/ Beijerinckiaceae/ *Beijerinckia*
1709	26	1.8	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Comamonadaceae/ *Limnohabitans*
24	26	1.0	Verrucomicrobia/ Opitutae/ Puniceicoccales/ Puniceicoccaceae/ *Pelagicoccus*
25	26	0.8	Actinobacteria/ Actinobacteria/ Actinomycetales/ Mycobacteriaceae/ *Mycobacterium*
126	24	0.1	Actinobacteria/ Actinobacteria/ Actinomycetales/ ACK-M1
13	23	1.1	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Comamonadaceae/ *Curvibacter*
15	23	1.1	Verrucomicrobia/ Spartobacteria/ Spartobacteriales/ Spartobacteriaceae/ *CandidatusXiphinematobacter*
28	23	0.6	Actinobacteria/ Actinobacteria/ Acidimicrobiales/ CL500-29
44	23	0.3	Actinobacteria/ Actinobacteria/ Acidimicrobiales/ CL500-29
18	22	0.9	Bacteroidetes/ Sphingobacteria/ Sphingobacteriales/ Chitinophagaceae/ *Sediminibacterium*
35	22	0.4	Proteobacteria/ Alphaproteobacteria/ Rhizobiales/ Beijerinckiaceae/ *Beijerinckia*
453	22	0.4	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Burkholderiaceae/ *Polynucleobacter*
467	22	0.4	Bacteroidetes/ Sphingobacteria/ Sphingobacteriales/ Chitinophagaceae/ *Sediminibacterium*
43	21	0.3	Chloroflexi/ SOGA31
508	20	0.1	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Oxalobacteraceae/ *Herminiimonas*
1242	19	0.7	Proteobacteria/ Betaproteobacteria/ Burkholderiales/ Comamonadaceae/ *Limnohabitans*
50	19	0.2	Proteobacteria/ Alphaproteobacteria/ Rhodobacterales/ Rhodobacteraceae/ *Rhodobacter*