Divergent copies of the large inverted repeat in the chloroplast genomes of ulvophycean green algae

(Supplementary Information)

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Taxon	Technology	Sequencing reads (no.)		Fold coverage of chloroplast genome sequences						
		Total	cpDNA	Average	IR-SC1	IR-SC2	IR-SC3	IR-SC4	IR-SC5	IR-SC6
Ignatius tetrasporus	Roche 454	49,055	41,372	60	43	32	44	32	–	–
Pseudocharacium americanum	Roche 454	40,038	37,504	58	45	58	43	32	–	–
Dangermannia microcystis	Roche 454	80,710	48,067	108	117	75	36	48	–	–
Pseudoneochloris marina	Roche 454	82,351	59,134	156	161	149	152	113	–	–
Chamaetrichon capsulatum	Illumina	1,997,570	96,903	154	125	105	119	93	173	123
Trichosarcina mucosa	Illumina	4,067,674	275,477	361	320	218	167	323	–	–

Supplementary Table S1. Summary statistics of the chloroplast genome sequencing and assemblies. The sequence coverage values observed at the junctions between IR and single-copy regions (IR-SC1 to IR-SC6) are provided in the order these junctions appear in the GenBank accessions of the chloroplast genomes.

Taxon	ORF[a]	Coordinates[b]	Conserved domain or similar protein
Ignatius tetrasporus	437	22433-21120	HNH endonuclease (pfam01844) with RRXRR domain (pfam14239)
	112	46900-46562	HNH endonuclease with RRXRR domain (pfam14239)
	100	158515-158213	HNH endonuclease
	128	158980-158594	HNH endonuclease (pfam01844)
	106	159328-159008	HNH endonuclease with RRXRR domain (pfam14239)
	98	220328-220624	Transposase
Dangemannia microcystis	246	123637-122897	Group II intron maturase (pfam08388) and HNH (pfam01844) domains
	114	124647-124303	N-terminal domain of reverse transcriptase (pfam13655)
Chamaetrichon capsulatum	680	84264-86306	Hypothetical protein MVEG-06986 of *Mortierella verticillata*
	206	121843-121223	Hypothetical protein PsakCp041 of *Pseudendoclonium akinetum* (*orf239*)
Trichosarcina mucosa	190	67813-68064	DNA breaking-rejoining enzyme, phage integrase family (pfam00589)
	121	86662-87027	Hypothetical protein PsakCp022 of *Pseudendoclonium akinetum* (*orf156*)
	233	154383-155084	DNA breaking-rejoining enzyme, phage integrase family (pfam00589)
	178	155855-155319	Hypothetical chloroplast-encoded protein of *Prasiola crispa* and *Mankyua chejuensis*

Supplementary Table S2. Non-canonical genes identified as freestanding ORFs in the ulvophycean chloroplast genomes examined in this study. [a]Reported here are the freestanding ORFs larger than 100 codons that revealed similarity (*E*-value threshold of 1e-06) with proteins of known functions and/or recognized protein domains in BlastP searches. Each ORF is identified by the number of amino acid residues in the encoded protein. [b]Genomic coordinates of the ORFs in the GenBank accessions.

Number	Sequence	Strand	Genomic position (3’ end)
Ignatius tetrasporus			
1	GATGTATCAACGTCAAATCACG	+	183754
2	GATCTAGGGCTTGCTTTGCATTC	-	186657
3	TTAAAGCGATTGAGCGAAGCAG	+	188149
4	TAGAGGTATCCGATTTGCTCAG	-	192460
5	GTGACTTTAACCATGCGATGAG	-	451
6	AAGGAGTGTTGCGACTACAAAC	+	237146
7	TGCAAATAGTACTCAAAGCGTC	-	235837
8	TAAAGCTGATGGAAGACGTTTC	+	231801
Pseudoneochloris marina			
1	CAACCTACACAATCTTCCGTAC	-	103470
2	CTCGAAAGCTTGAACGTTGAAC	+	95139
3	GTAGCACCAGCTATTCAACCTC	+	128692
4	GAGTCGCACGAAAACAAGAGTC	-	419
5	AACAGGTTACTGCCTAAGGACG	+	129287
5	AACAGGTTACTGCCTAAGGACG	-	102782
6	GATGCTTTCAGCGATTATCCAC	+	95917
6	GATGCTTTCAGCGATTATCCAC	-	134412

Supplementary Table S3. Sequences of the PCR primers used to investigate flip-flop recombination in the *Ignatius* and *Pseudoneochloris* chloroplast genomes.

Taxon	**Collection**	**GenBank accession(s)**
Streptophytes		
Mesostigma viride	NIES 296	NC_002186
Chlorokybus atmophyticus	SAG 48.80	NC_008822
Prasinophytes		
Prasinococcus sp. CCMP 1194	CCMP 1194	KJ746597
Prasinophyceae sp. MBIC 10622	NBRC 102842	KJ746602
Prasinoderma coloniale	CCMP 1220	NC_024817
Pyramimonas parkeae	CCMP 726	FJ493499
Monomastix sp.OKE-1	PC O'kelly	NC_012101
Ostreococcus tauri	OTTH0595	NC_008289
Micromonas commoda	RCC 299	NC_012575
Pycnococcus provasolii	CCMP 1203	NC_012097
Nephroselmis olivacea	NIES 484	NC_000927
Nephroselmis astigmatica	NIES 252	NC_024829
Picocystis salinarum	CCMP 1897	NC_024828
Prasinophyceae sp. CCMP 1205	CCMP 1205	KJ746601
Chlorodendrophyceae		
Scherfellia dubia	SAG 17.86	NC_029807
Tetraselmis sp. CCMP 881	CCMP 881	KU167097
Pedinophyceae		
Marsupiomonas sp. NIES 1824	NIES 1824	KM462870
Pedinomonas tuberculata	SAG 42.84	NC_025530
Pedinomonas minor	UTEX LB 1350	NC_016733
Chlorellales		
Parachlorella kessleri	SAG 211-11g	NC_012978
Dicloster acuatus	SAG 41.98	NC_025546
Marvania geminata	SAG 12.88	NC_025549
Pseudochloris wilhelmii	SAG 1.80	NC_025547
Chlorella vulgaris		NC_001865
Chlorella variabilis	NC 64A	NC_015359
Core Trebouxiophyceae		
Oocystis solitaria	SAG 83.80	FJ968739
Planctonema lauterbornii	SAG 68.94	NC_025541
Koliella corcontica	SAG 24.84	NC_025536
Geminella terricola	SAG 20.91	NC_025542
Geminella minor	SAG 22.88	NC_025544
Gloeotilopsis sterilis	UTEX 1704	NC_025538
Pleurastrosarcina brevispinosa	UTEX 1176	KM462875
Parietochloris pseudoalveolaris	UTEX 975	NC_025532
Neocystis brevis	CAUP D802	NC_025535
Stichococcus bacillaris	UTEX 176	NC_025527
Prasiolopsis sp. SAG 84.81	SAG 84.81	KM462862
Chlorella mirabilis	SAG 38.88	NC_025528
Koliella longiseta	UTEX 339	NC_025531
Pabia signiensis	SAG 7.90	NC_025529
Leptospira terrestris	UTEX 333	NC_009681
Xylochloris irregularis	CAUP H7801	NC_025534
Trebouxia aggregata	SAG 219-1D	EU123962-EU124002
Myrmecia israelensis	UTEX 1181	NC_025525
Characium perforatum	SAG 28.85	NC_025543
Microthamnion kuetzingianum	UTEX 318	NC_025537
Lobosphaera incisa	SAG 2007	NC_025533
Watanabea reniformis	SAG 211-9b	NC_025526
Dictyochloropsis reticulata	SAG 2150	NC_025524
Choricystis minor	SAG 17.98	NC_025539
Botryococcus braunii	SAG 807-1	NC_025545
Elliptochloris bilobata	CAUP H7103	NC_025548
Trebouxiophyceae sp. MX-AZ01	MX-AZ01	NC_018569

Coccomyxa subellipsoidea	NIES 2166	NC_015084
Paradoxia multiseta	SAG 18.84	NC_025540
Bryopsidales		
Tydemania expeditionis	FL1151	NC_026796
Bryopsis plumosa	West4718	NC_026795
Bryopsis hypnoides		NC_013359
Ignatiales		
Pseudocharacium americanum	UTEX 2112	KY407658
Ignatius tetrasporus	UTEX 2012	KY407659
Oltmannsiellopsidales		
Dangemannia microcystis	SAG 2022	KY407660
Oltmannsiellopsis viridis	NIES 360	NC_008099
Ulvales		
Pseudoneochloris marina	UTEX 1445	KY407657
Ulva fasciata		NC_029040
Ulva sp. UNA	UNA00071828	KP720616
Ulotrichales		
Chamaetrichon capsulatum	UTEX 1918	KY407661
Pseudendoclonium akinetum	UTEX 1912	NC_008114
Trichosarcina mucosa	SAG 4.90	KY407656
Gloeotilopsis planctonica	SAG 29.93	KX306824
Gloeotilopsis sarcinoidea	UTEX 1710	KX306821
Chlorophyceae		
Floydiella terrestris	UTEX 1709	NC_014346
Oedogonium cardiacum	SAG 575-1b	NC_011031
Stigeoclonium helveticum	UTEX 441	NC_008372
Schizomeris leibleinii	UTEX LB 1228	NC_015645
Treubaria triappendiculata	SAG 38.83	NC_028578
Golenkinia longispicula	SAG 73.80	KT625092 - KT625150
Jenufa minuta	CAUP H8102	NC_028582
Jenufa perforata	CAUP H 8101	NC_028581
Bracteacoccus giganteus	UTEX 1251	NC_028586
Mychonastes jurisii	SAG 37.98	NC_028579
Acutodesmus obliquus	UTEX 393	NC_008101
Hafniomonas laevis	NIES 257	NC_028583
Carteria cerasiformis	NIES 425	NC_028585
Carteria crucifera	UTEX 432	KT624870 - KT624932
Carteria sp. SAG 8-5	SAG 8-5	KT625419
Chloromonas typhlos	UTEX LB 1969	KT624630 - KT624716
Chloromonas radiata	UTEX 966	KT625008 - KT625084
Oogamochlamys gigantea	SAG 44.91	NC_028580
Lobochlamys segnis	SAG 9.83	KT624806 - KT624869
Lobochlamys culleus	SAG 19.72	KT625151 - KT625204
Chlamydomonas asymmetrica	SAG 70.72	KT624933 - KT625007
Volvox carteri f. nagariensis	UTEX 2908	GU084820
Chlamydomonas reinhardtii		NC_005353
Phacotus lenticularis	SAG 61-1	NC_028587
Microglena monadina	SAG 31.72	KT624717 - KT624805
Chlamydomonas moewusii	UTEX 97	EF587443-EF587503
Characiochloris acuminata	SAG 31.95	NC_028584
Dunaliella salina	CCAP 19/18	NC_016732
Chlamydomonas applanata	SAG 11-9	KT625417
Stephanosphaera pluvialis	SAG 78-1a	KT625299 - KT625409
Chloromonas perforata	SAG 11-43	KT625416
Haematococcus lacustris	SAG 34-1b	KT625205 - KT625298
Chlorogonium capillatum	UTEX 11	KT625085 - KT625091

Supplementary Table S4. GenBank accession codes of the chloroplast genome sequences used to infer phylogenomic trees.

Supplementary Figure S1. Gene map of the *Ignatius tetrasporus* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S2. Gene map of the *Pseudocharacium americanum* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S3. Gene map of the *Dangemannia microcystis* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S4. Gene map of the *Pseudoneochloris marina* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S5. Gene map of the *Chamaetrichon capsulatum* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside map are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S6. Gene map of the *Trichosarcina mucosa* chloroplast genome. Filled boxes represent genes, with colors denoting gene categories as indicated in the legend. Genes on the outside are transcribed counterclockwise; those on the inside are transcribed clockwise.

Supplementary Figure S7. Gene locations of the rapidly-evolving sites that were removed from the PCG-AA (1,303 sites) and PCG12RNA (4,492 sites) data sets by filtration with TIGER.

Supplementary Figure S8. Phylogenomic trees inferred from the PCG12RNA data set using RAxML. Bootstrap support values are reported on the nodes. A black dot indicates that the corresponding branch received a value of 100%. The scale bar denotes the estimated number of substitutions per site.

Supplementary Figure S9. Phylogenomic trees inferred from the PCG12RNA data set using PhyloBayes. Posterior probability values are reported on the nodes. A black dot indicates that the corresponding branch received a value of 1.0. The scale bar denotes the estimated number of substitutions per site.

Supplementary Figure S10. Phylogenomic trees inferred from the PCG-AA data set using RAxML. Bootstrap support values are reported on the nodes. A black dot indicates that the corresponding branch received a value of 100%. The scale bar denotes the estimated number of substitutions per site.

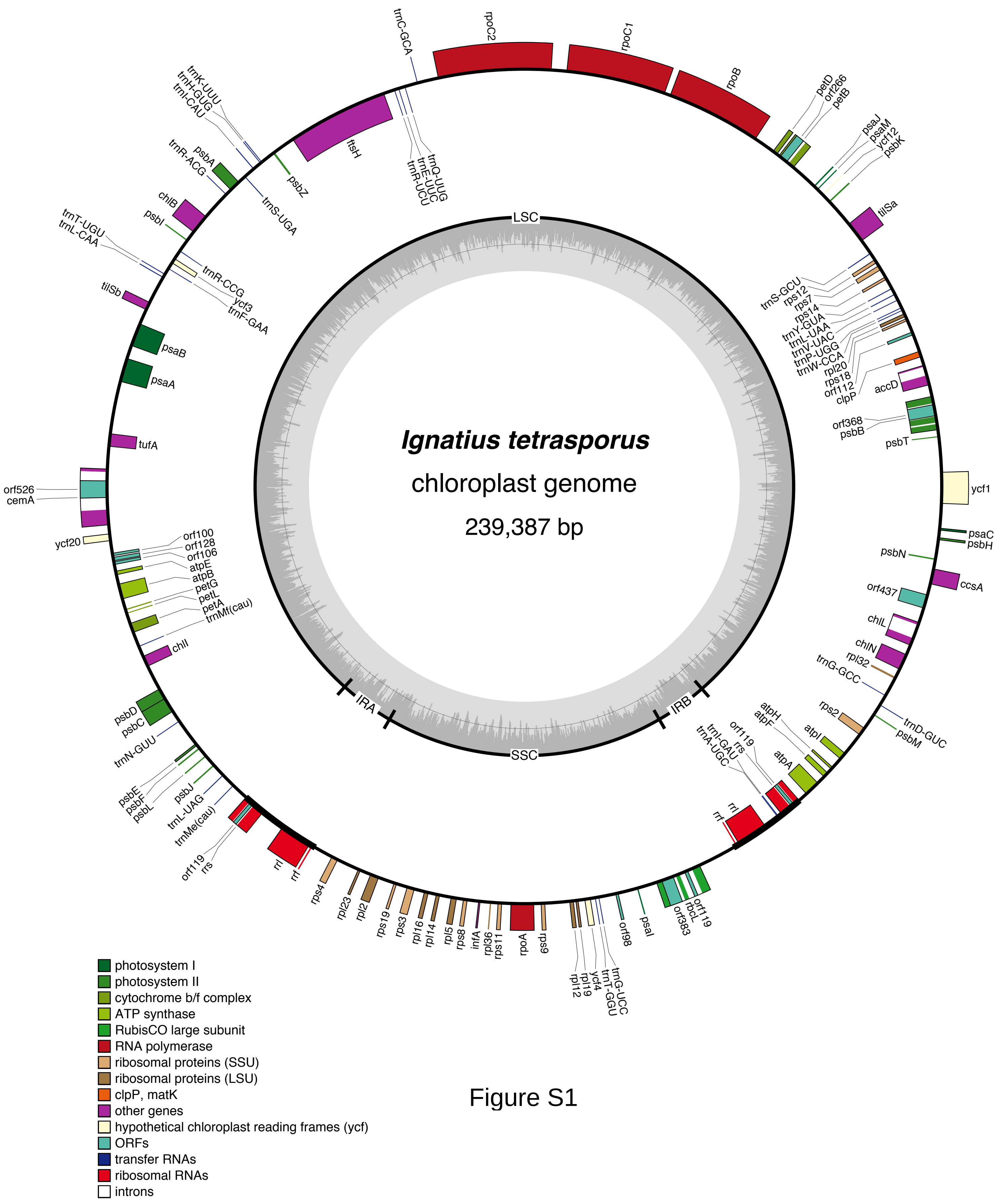
Supplementary Figure S11. Phylogenomic trees inferred from the PCG-AA data set using PhyloBayes. Posterior probability values are reported on the nodes. A black dot indicates that the corresponding branch received a value of 1.0. The scale bar denotes the estimated number of substitutions per site.

Supplementary Figure S12. Repertoires of canonical genes in the ulvophycean chloroplast genomes compared in this study. Only the genes missing in one or more genomes are indicated. The presence of genes and pseudogenes is denoted by blue and light blue boxes, respectively. Protein-coding genes that were lost only once are mapped on the cladogram. A total of 95 genes are shared by all compared genomes: *accD, atpA, B, E, F, H, I, ccsA, cemA, chlI, clpP, ftsH, infA, petA, B, D, G, L, psaA, B, C, I, J, M, psbA, B, C, D, E, F, H, I, J, K, L, M, N, T, Z, rbcL, rpl2, 5, 14, 16, 19, 20, 23, 32, 36, rpoA, C2, rps2, 3, 4, 7, 8, 9, 11, 12, 14, 18, 19, rrf, rrl, rrs, tufA, ycf1, 3, 4, 12, trnA*(ugc), *C*(gca), *D*(guc), *E*(uuc), *F*(gaa), *G*(gcc), *G*(ucc), *H*(gug), *I*(gau), *K*(uuu), *L*(uaa), *L*(uag), *Me*(cau), *Mf*(cau), *N*(guu), *P*(ugg), *Q*(uug), *R*(acg), *R*(ucu), *S*(gcu), *S*(uga), *T*(ugu), *V*(uac), *W*(cca), *Y*(gua).

References

1 Lemieux, C., Otis, C. & Turmel, M. Ancestral chloroplast genome in *Mesostigma viride* reveals an early branch of green plant evolution. *Nature* **403**, 649-652, doi:10.1038/35001059 (2000).

2 Turmel, M., Otis, C. & Lemieux, C. Mitochondrion-to-chloroplast DNA transfers and intragenomic proliferation of chloroplast group II introns in *Gloeotilopsis* green algae (Ulotrichales, Ulvophyceae). *Genome Biol Evol* **8**, 2789-2805, doi:10.1093/gbe/evw190 (2016).


Ignatius tetrasporus
chloroplast genome
239,387 bp
LSC
IRA
IRB
SSC
rpoC2
rpoC1
rpoB
petD
orf266
petB
psaJ
psaM
ycf12
psbK
tilSa
trnS-GCU
rps12
rps7
rps14
trnY-GUA
trnL-UAA
trnV-UAC
trnP-UGG
trnW-CCA
rpl20
rps18
orf112
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atpF
atpA
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trnA-UGC
rrl
rrf
orf119
rbcL
orf383
psaI
orf98
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trnT-GGU
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rpoA
rps11
rpl36
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rpl5
rpl14
rpl16
rps3
rps19
rpl2
rpl23
rps4
rrf
rrl
rrs
orf119
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psbL
psbF
psbE
trnN-GUU
psbC
psbD
chlI
trnMf(cau)
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petL
petG
atpB
atpE
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orf100
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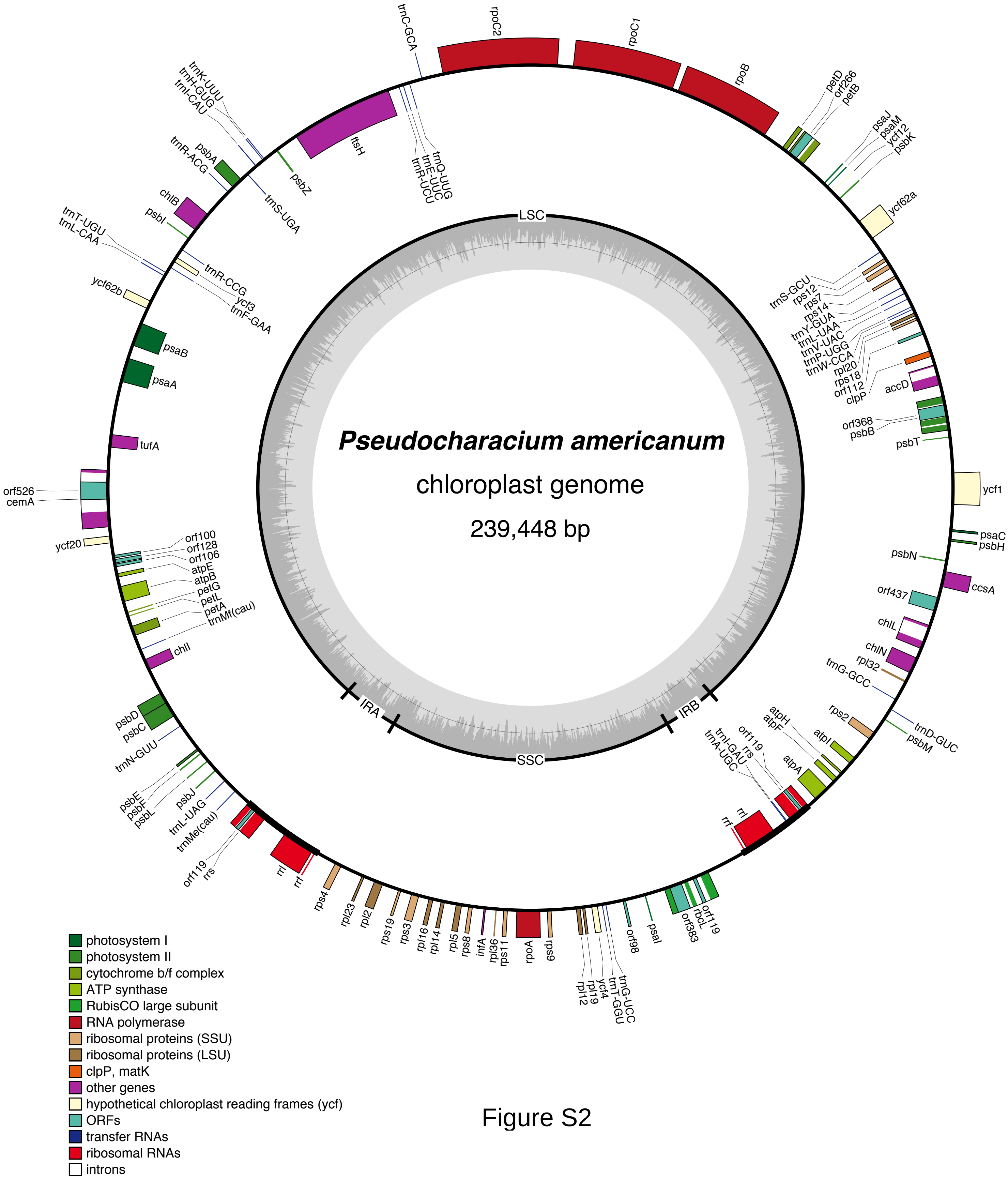
trnT-UGU
psbI
chlB
trnR-ACG
psbA
trnS-UGA
trnI-CAU
trnH-GUG
trnK-UUU
psbZ
ftsH
trnR-UCU
trnE-UUC
trnQ-UUG
trnC-GCA
photosystem I
photosystem II
cytochrome b/f complex
ATP synthase
RubisCO large subunit
RNA polymerase
ribosomal proteins (SSU)
ribosomal proteins (LSU)
clpP, matK
other genes
hypothetical chloroplast reading frames (ycf)
ORFs
transfer RNAs
ribosomal RNAs
introns

Figure S1


Pseudocharacium americanum
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IRB
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trnC-GCA
rpoC2
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petB
psaJ
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ycf12
psbK
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trnP-UGG
trnW-CCA
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rps18
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accD
orf368
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ccsA
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trnA-UGC
rrl
rrf
orf119
rbcL
orf383
psaI
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rps19
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trnT-UGU
psbI
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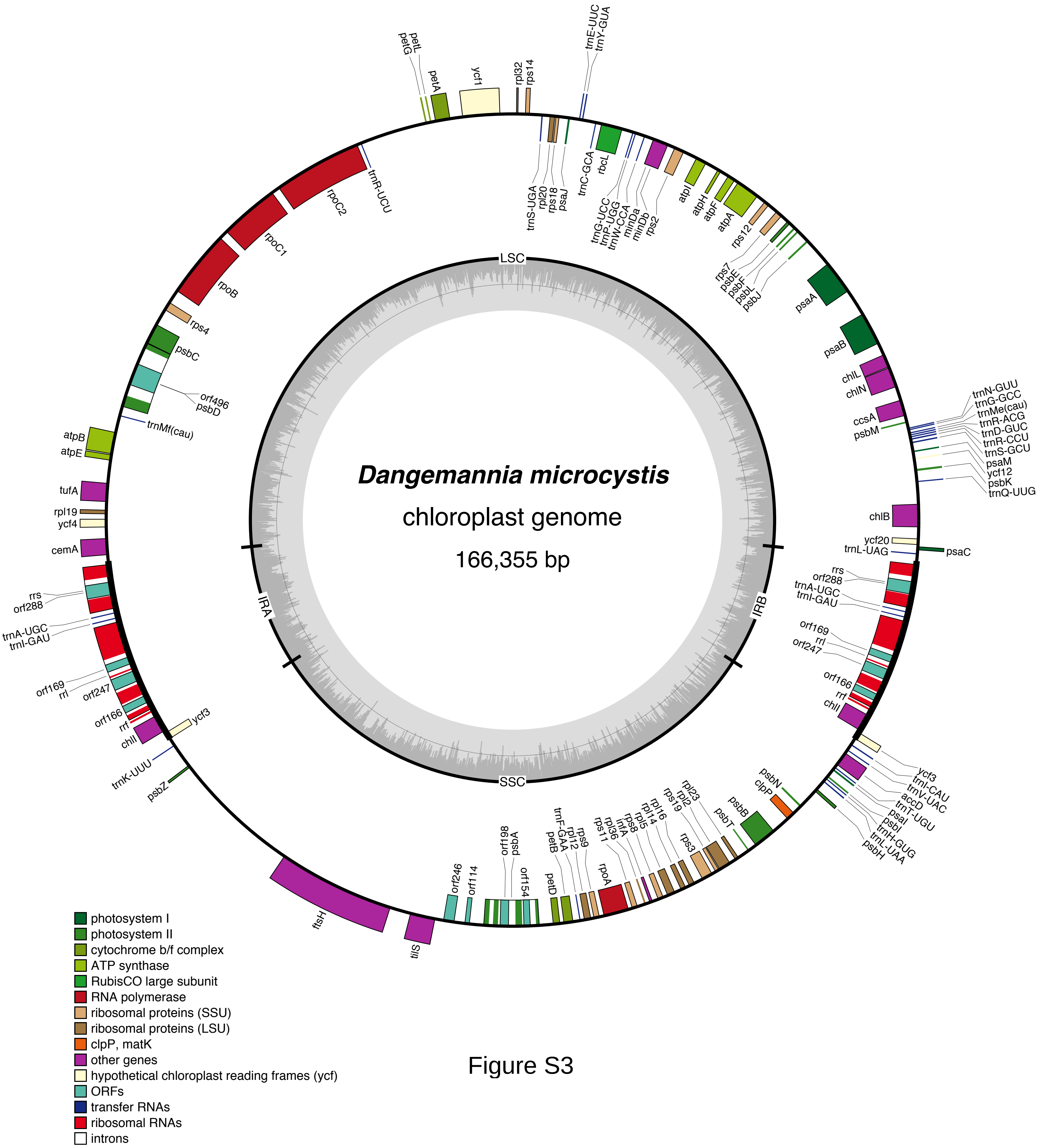
trnK-UUU
psbZ
ftsH
trnR-UCU
trnE-UUC
trnQ-UUG
photosystem I
photosystem II
cytochrome b/f complex
ATP synthase
RubisCO large subunit
RNA polymerase
ribosomal proteins (SSU)
ribosomal proteins (LSU)
clpP, matK
other genes
hypothetical chloroplast reading frames (ycf)
ORFs
transfer RNAs
ribosomal RNAs
introns

Figure S2



Dangemannia microcystis
chloroplast genome
166,355 bp
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IRB
SSC
IRA
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petG
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trnY-GUA
trnS-UGA
rpl20
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trnP-UGG
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minDb
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atpH
atpF
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rps12
rps7
psbE
psbF
psbL
psbJ
psaA
psaB
chlL
chlN
ccsA
psbM
trnN-GUU
trnG-GCC
trnMe(cau)
trnR-ACG
trnD-GUC
trnR-CCU
trnS-GCU
psaM
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chlB
ycf20
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orf169
rrl
orf247
orf166
rrf
chlI
ycf3
trnI-CAU
trnV-UAC
accD
trnT-UGU
psaI
psbI
trnH-GUG
trnL-UAA
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psbN
clpP
psbB
psbT
rpl23
rpl2
rps19
rps3
rpl16
rpl14
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rps8
infA
rpl36
rps11
rpoA
rps9
rpl12
trnF-GAA
petB
petD
orf154
psbA
orf198
orf114
orf246
tilS
ftsH
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rrf
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rrl
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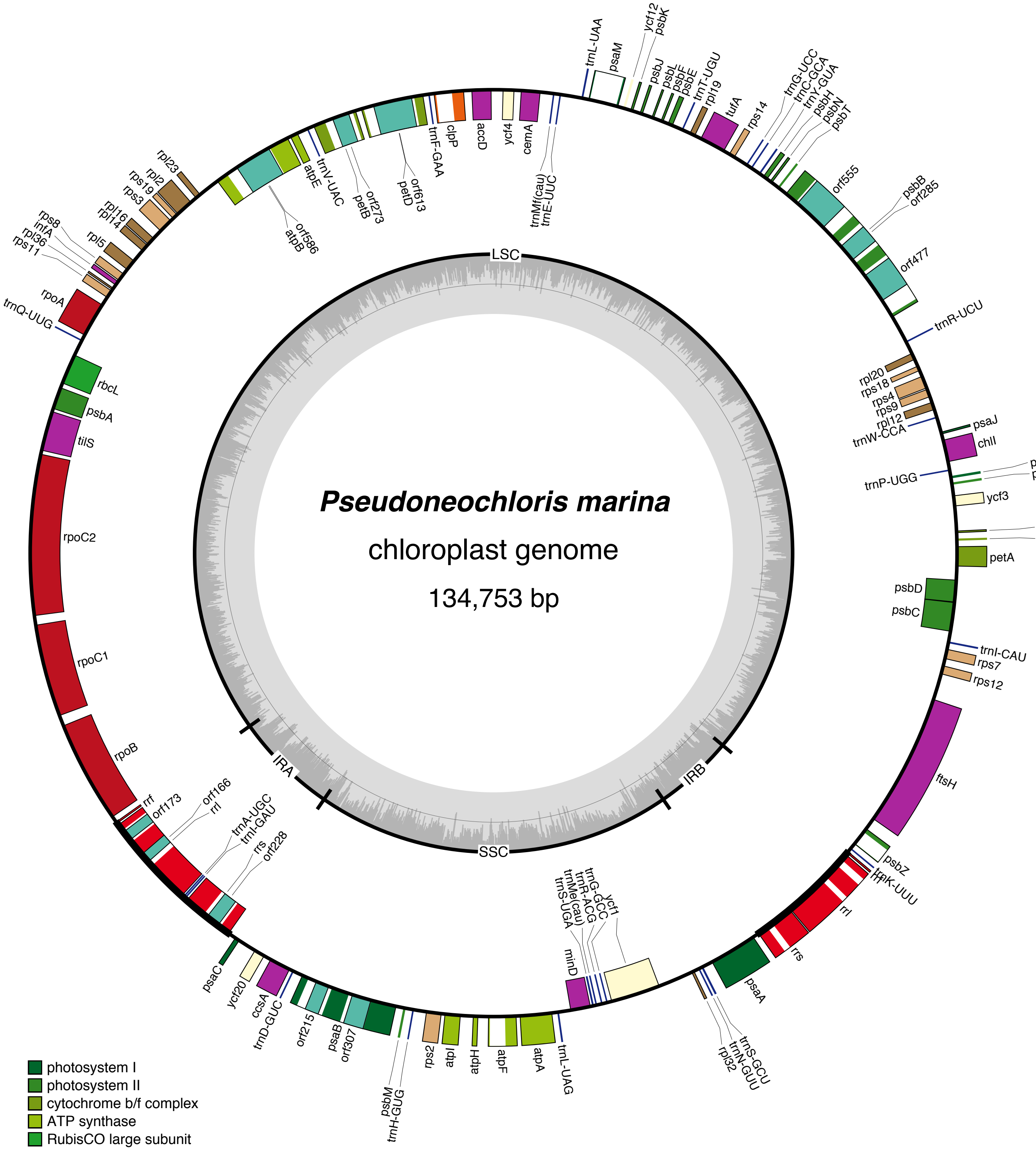
trnA-UGC
orf288
rrs
cemA
ycf4
rpl19
tufA
atpE
atpB
trnMf(cau)
psbD
orf496
psbC
rps4
rpoB
rpoC1
rpoC2
trnR-UCU
🟩 photosystem I
🟩 photosystem II
🟩 cytochrome b/f complex
🟩 ATP synthase
🟩 RubisCO large subunit
🟥 RNA polymerase
🟫 ribosomal proteins (SSU)
🟫 ribosomal proteins (LSU)
🟧 clpP, matK
🟪 other genes
🟨 hypothetical chloroplast reading frames (ycf)
🟦 ORFs
🟦 transfer RNAs
🟥 ribosomal RNAs
☐ introns

Figure S3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chloroplast genome
134,753 bp
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IRB
SSC
IRA
trnL-UAA
psaM
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psaJ
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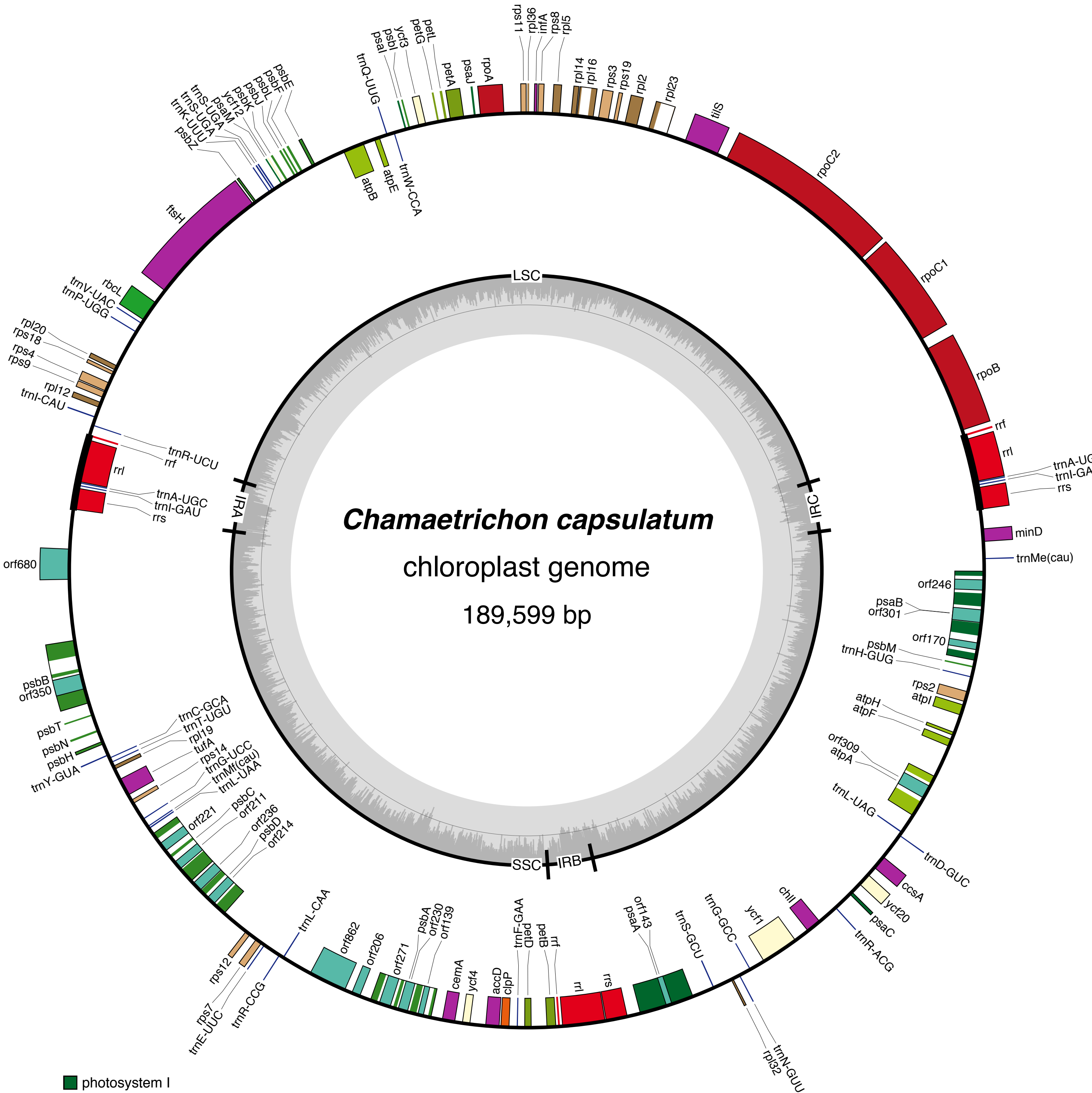
psaI
psbI
trnP-UGG
ycf3
petG
petL
petA
psbD
psbC
trnI-CAU
rps7
rps12
ftsH
psbZ
trnK-UUU
rrf
rrl
rrs
psaA
trnS-GCU
trnN-GUU
rpl32
ycf1
trnG-GCC
trnR-ACG
trnMe(cau)
trnS-UGA
minD
trnL-UAG
atpA
atpF
atpH
atpI
rps2
trnH-GUG
psbM
orf307
psaB
orf215
trnD-GUC
ccsA
ycf20
psaC
orf228
rrs
trnI-GAU
trnA-UGC
rrl
orf166
orf173
rrf
rpoB
rpoC1
rpoC2
tilS
psbA
rbcL
trnQ-UUG
rpoA
rps11
rpl36
infA
rps8
rpl5
rpl14
rpl16
rps3
rps19
rpl2
rpl23
atpB
orf586
atpE
trnV-UAC
petB
orf273
petD
orf613
trnF-GAA
clpP
accD
ycf4
cemA
trnMf(cau)
trnE-UUC
🟩 photosystem I
🟩 photosystem II
🟩 cytochrome b/f complex
🟩 ATP synthase
🟩 RubisCO large subunit
🟥 RNA polymerase
🟧 ribosomal proteins (SSU)
🟫 ribosomal proteins (LSU)
🟧 clpP, matK
🟪 other genes
☐ hypothetical chloroplast reading frames (ycf)
🟦 ORFs
🟦 transfer RNAs
🟥 ribosomal RNAs
☐ introns

Figure S4



🟩 photosystem I
🟩 photosystem II
🟩 cytochrome b/f complex
🟩 ATP synthase
🟩 RubisCO large subunit
🟥 RNA polymerase
🟫 ribosomal proteins (SSU)
🟫 ribosomal proteins (LSU)
🟧 clpP, matK
🟪 other genes
🟨 hypothetical chloroplast reading frames (ycf)
🟩 ORFs
🟦 transfer RNAs
🟥 ribosomal RNAs
⬜ introns

Figure S5

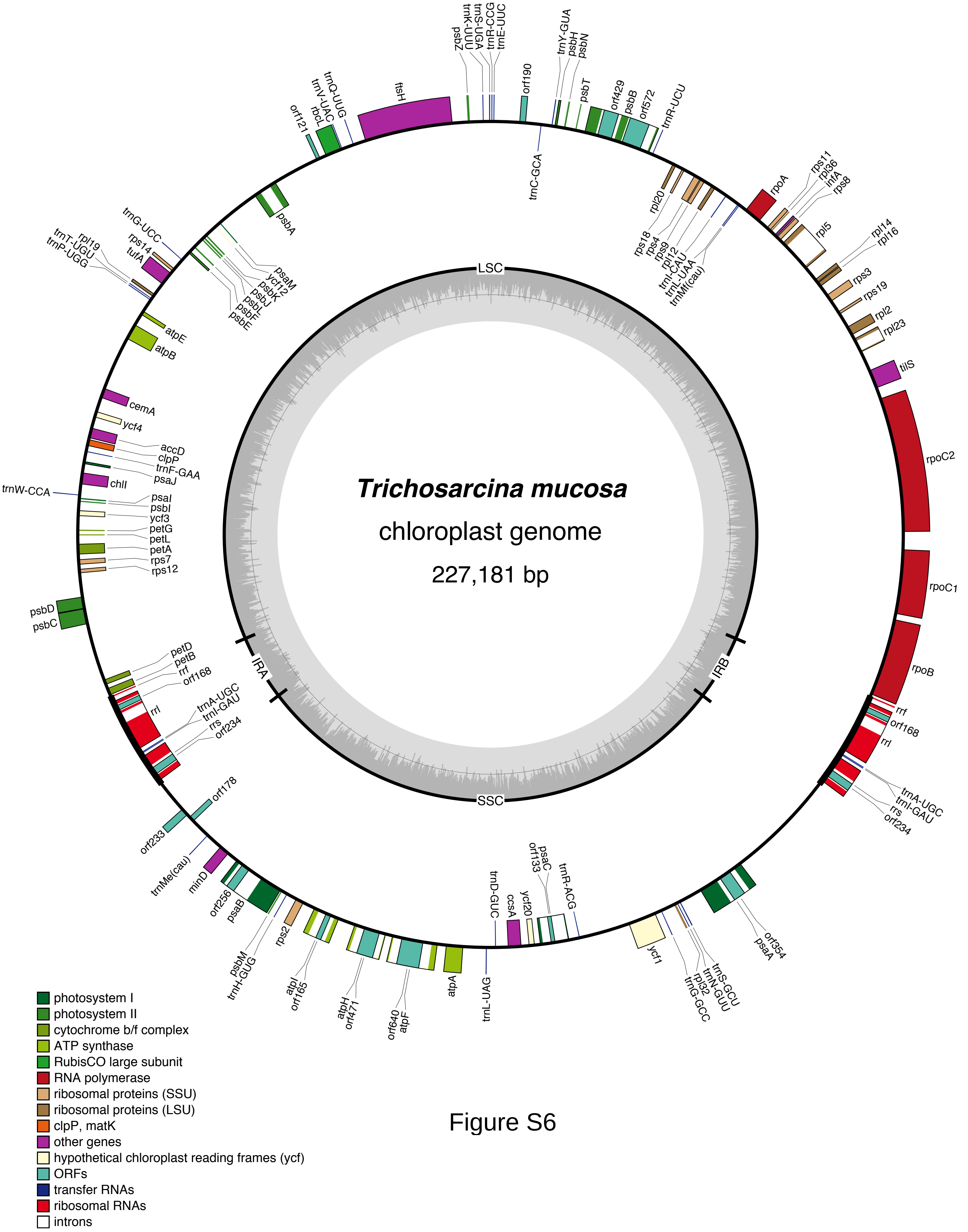
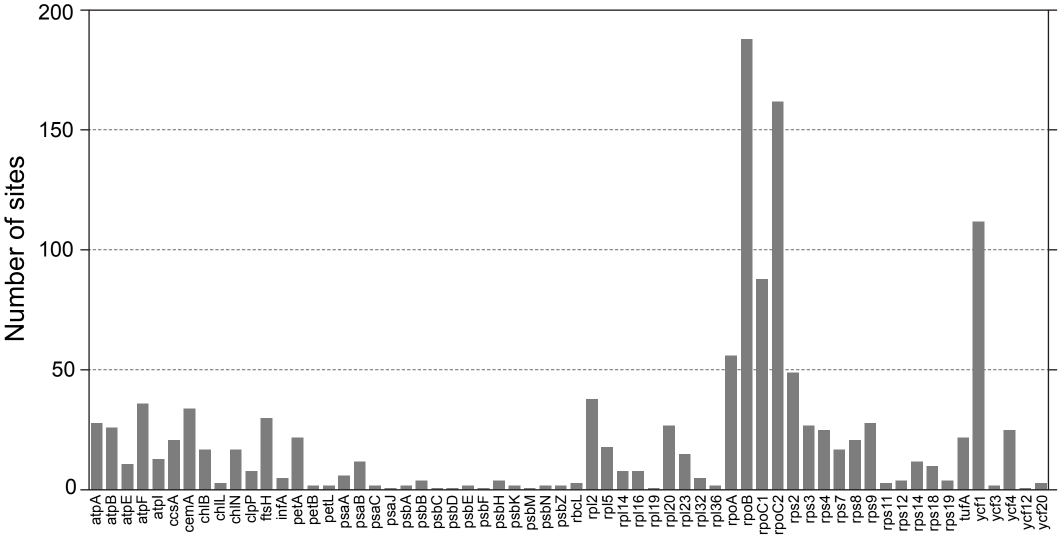

Trichosarcina mucosa
chloroplast genome
227,181 bp
LSC
SSC
IRA
IRB
psbZ
trnK-UUU
trnS-UGA
trnR-CCG
trnE-UUC
orf190
trnC-GCA
trnY-GUA
psbH
psbN
psbT
orf429
psbB
orf572
trnR-UCU
ftsH
trnQ-UUG
trnV-UAC
rbcL
orf121
psbA
rpl20
rps18
rps4
rps9
rpl12
trnI-CAU
trnL-UAA
trnMf(cau)
rpoA
rps11
rpl36
infA
rps8
rpl5
rpl14
rpl16
rps3
rps19
rpl2
rpl23
tilS
rpoC2
rpoC1
rpoB
rrf
orf168
rrl
trnA-UGC
trnI-GAU
rrs
orf234
orf354
psaA
trnS-GCU
trnN-GUU
rpl32
trnG-GCC
ycf1
trnR-ACG
psaC
orf133
ycf20
ccsA
trnD-GUC
trnL-UAG
atpA
orf640
atpF
atpH
orf471
atpI
orf165
rps2
psbM
trnH-GUG
psaB
orf256
minD
trnMe(cau)
orf233
orf178
orf234
rrs
trnI-GAU
trnA-UGC
rrl
orf168
rrf
petB
petD
psbC
psbD
rps12
rps7
petA
petL
petG
ycf3
psbI
psaI
trnW-CCA
chlI
psaJ
trnF-GAA
clpP
accD
ycf4
cemA
atpB
atpE
trnP-UGG
trnT-UGU
rpl19
tufA
rps14
trnG-UCC
psbE
psbF
psbL
psbJ
psbK
ycf12
psaM
photosystem I
photosystem II
cytochrome b/f complex
ATP synthase
RubisCO large subunit
RNA polymerase
ribosomal proteins (SSU)
ribosomal proteins (LSU)
clpP, matK
other genes
hypothetical chloroplast reading frames (ycf)
ORFs
transfer RNAs
ribosomal RNAs
introns

Figure S6

PCG-AA data set



PCG12RNA data set

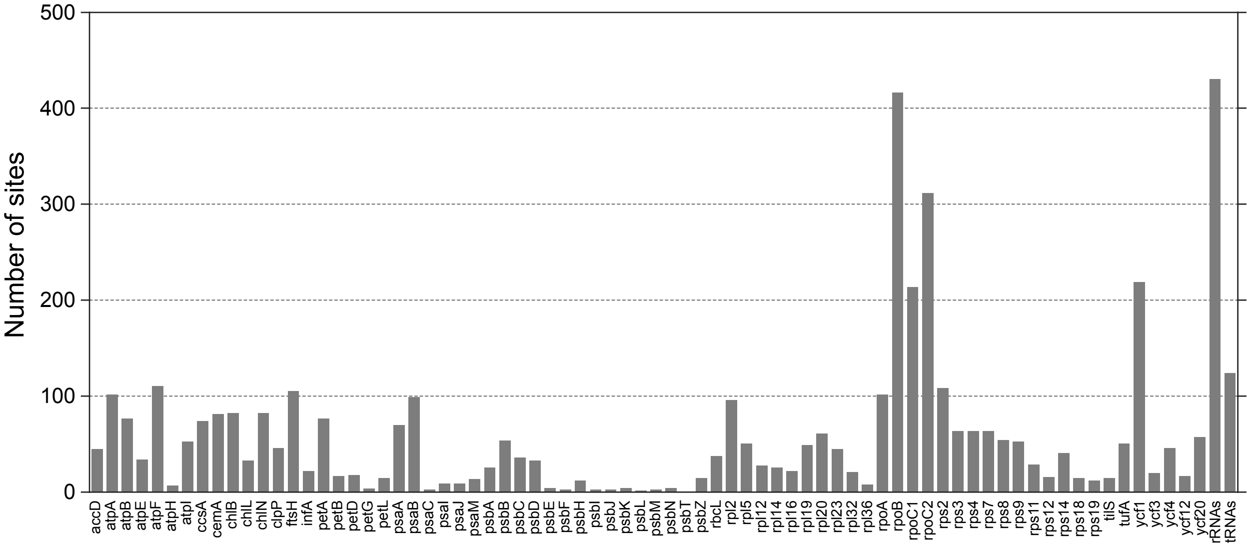


Figure S7

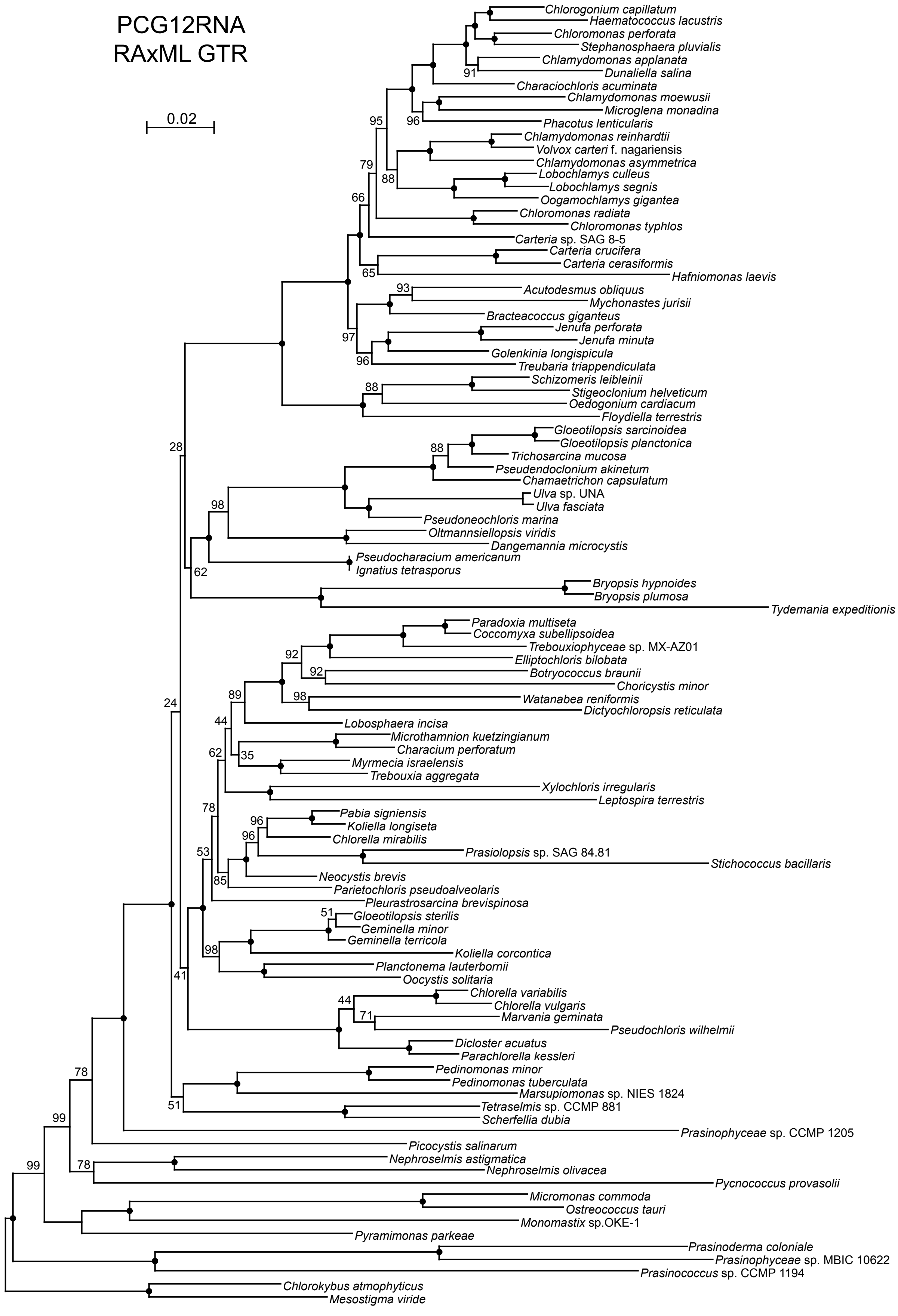
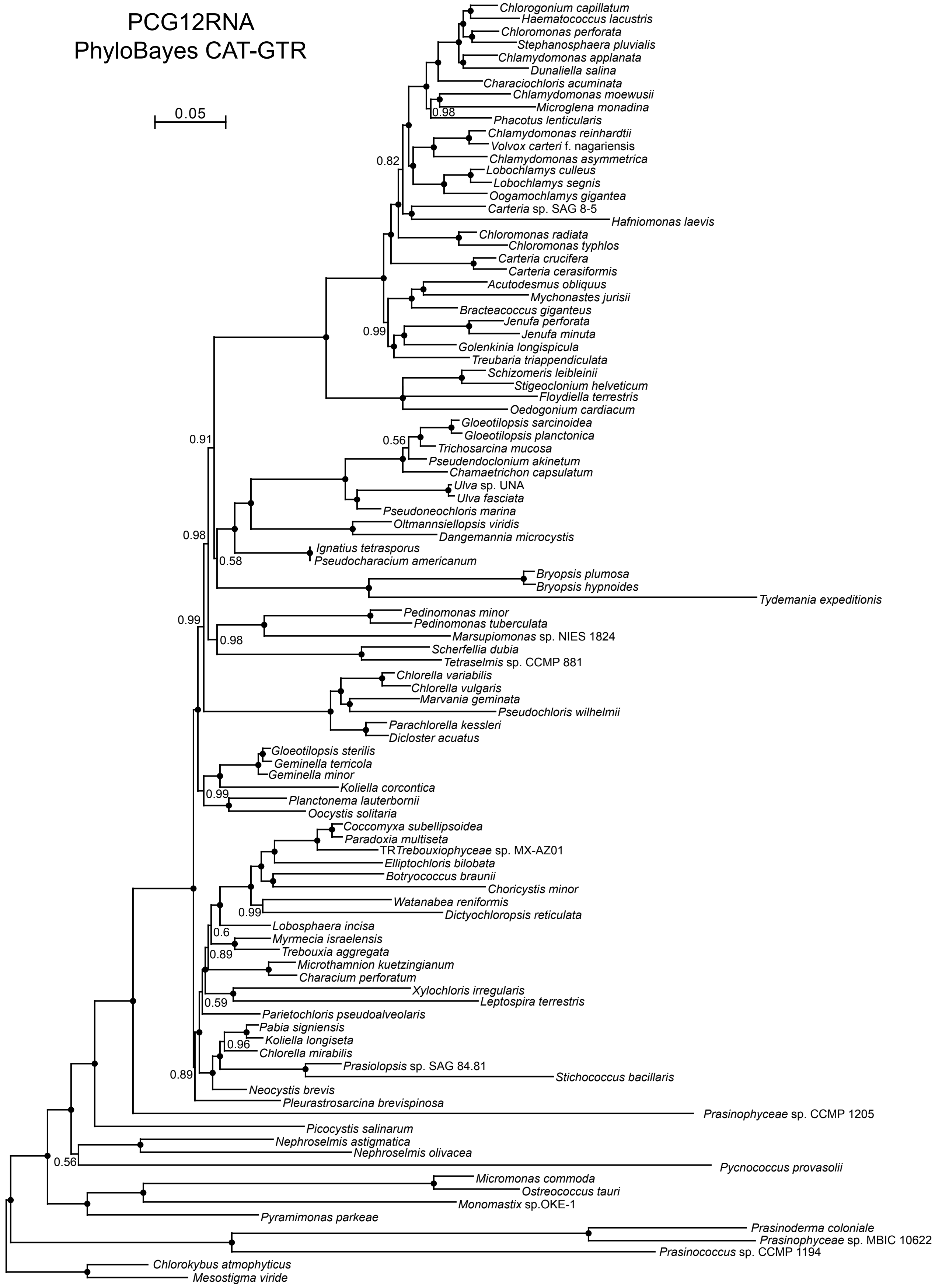

PCG12RNA
RAxML GTR
0.02
Chlorogonium capillatum
Haematococcus lacustris
Chloromonas perforata
Stephanosphaera pluvialis
Chlamydomonas applanata
Dunaliella salina
91
Characiochloris acuminata
Chlamydomonas moewusii
Microglena monadina
95
96
Phacotus lenticularis
Chlamydomonas reinhardtii
Volvox carteri f. nagariensis
79
Chlamydomonas asymmetrica
88
Lobochlamys culleus
Lobochlamys segnis
Oogamochlamys gigantea
66
Chloromonas radiata
Chloromonas typhlos
Carteria sp. SAG 8-5
Carteria crucifera
Carteria cerasiformis
65
Hafniomonas laevis
93
Acutodesmus obliquus
Mychonastes jurisii
Bracteacoccus giganteus
Jenufa perforata
97
Jenufa minuta
Golenkinia longispicula
96
Treubaria triappendiculata
88
Schizomeris leibleinii
Stigeoclonium helveticum
Oedogonium cardiacum
Floydiella terrestris
28
Gloeotilopsis sarcinoidea
Gloeotilopsis planctonica
88
Trichosarcina mucosa
Pseudendoclonium akinetum
Chamaetrichon capsulatum
Ulva sp. UNA
Ulva fasciata
98
Pseudoneochloris marina
Oltmannsiellopsis viridis
Dangemannia microcystis
Pseudocharacium americanum
62
Ignatius tetrasporus
Bryopsis hypnoides
Bryopsis plumosa
Tydemania expeditionis
Paradoxia multiseta
Coccomyxa subellipsoidea
Trebouxiophyceae sp. MX-AZ01
92
Elliptochloris bilobata
92
Botryococcus braunii
Choricystis minor
24
89
98
Watanabea reniformis
Dictyochloropsis reticulata
44
Lobosphaera incisa
Microthamnion kuetzingianum
35
Characium perforatum
62
Myrmecia israelensis
Trebouxia aggregata
Xylochloris irregularis
Leptosira terrestris
78
Pabia signiensis
96
Koliella longiseta
96
Chlorella mirabilis
Prasiolopsis sp. SAG 84.81
53
Stichococcus bacillaris
Neocystis brevis
85
Parietochloris pseudoalveolaris
Pleurastrosarcina brevispinosa
51
Gloeotilopsis sterilis
Geminella minor
Geminella terricola
98
Koliella corcontica
41
Planctonema lauterbornii
Oocystis solitaria
Chlorella variabilis
44
Chlorella vulgaris
71
Marvania geminata
Pseudochloris wilhelmii
Dicloster acuatus
Parachlorella kessleri
Pedinomonas minor
Pedinomonas tuberculata
Marsupiomonas sp. NIES 1824
51
Tetraselmis sp. CCMP 881
Scherffelia dubia
78
Prasinophyceae sp. CCMP 1205
99
Picocystis salinarum
Nephroselmis astigmatica
99
78
Nephroselmis olivacea
Pycnococcus provasolii
Micromonas commoda
Ostreococcus tauri
Monomastix sp.OKE-1
Pyramimonas parkeae
Prasinoderma coloniale
Prasinophyceae sp. MBIC 10622
Prasinococcus sp. CCMP 1194
Chlorokybus atmophyticus
Mesostigma viride

Figure S8


PCG12RNA
PhyloBayes CAT-GTR
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Haematococcus lacustris
Chloromonas perforata
Stephanosphaera pluvialis
Chlamydomonas applanata
Dunaliella salina
Characiochloris acuminata
Chlamydomonas moewusii
0.98
Microglena monadina
Phacotus lenticularis
Chlamydomonas reinhardtii
Volvox carteri f. nagariensis
Chlamydomonas asymmetrica
0.82
Lobochlamys culleus
Lobochlamys segnis
Oogamochlamys gigantea
Carteria sp. SAG 8-5
Hafniomonas laevis
Chloromonas radiata
Chloromonas typhlos
Carteria crucifera
Carteria cerasiformis
Acutodesmus obliquus
Mychonastes jurisii
Bracteacoccus giganteus
0.99
Jenufa perforata
Jenufa minuta
Golenkinia longispicula
Treubaria triappendiculata
Schizomeris leibleinii
Stigeoclonium helveticum
Floydiella terrestris
Oedogonium cardiacum
Gloeotilopsis sarcinoidea
0.56
Gloeotilopsis planctonica
Trichosarcina mucosa
0.91
Pseudendoclonium akinetum
Chamaetrichon capsulatum
Ulva sp. UNA
Ulva fasciata
Pseudoneochloris marina
Oltmannsiellopsis viridis
Dangemannia microcystis
0.98
Ignatius tetrasporus
0.58
Pseudocharacium americanum
Bryopsis plumosa
Bryopsis hypnoides
Tydemania expeditionis
Pedinomonas minor
0.99
Pedinomonas tuberculata
Marsupiomonas sp. NIES 1824
0.98
Scherfellia dubia
Tetraselmis sp. CCMP 881
Chlorella variabilis
Chlorella vulgaris
Marvania geminata
Pseudochloris wilhelmii
Parachlorella kessleri
Dicloster acuatus
Gloeotilopsis sterilis
Geminella terricola
Geminella minor
Koliella corcontica
0.99
Planctonema lauterbornii
Oocystis solitaria
Coccomyxa subellipsoidea
Paradoxia multiseta
TRTrebouxiophyceae sp. MX-AZ01
Elliptochloris bilobata
Botryococcus braunii
Choricystis minor
Watanabea reniformis
0.99
Dictyochloropsis reticulata
Lobosphaera incisa
0.6
Myrmecia israelensis
0.89
Trebouxia aggregata
Microthamnion kuetzingianum
Characium perforatum
Xylochloris irregularis
0.59
Leptospira terrestris
Parietochloris pseudoalveolaris
Pabia signiensis
0.96
Koliella longiseta
Chlorella mirabilis
Prasiolopsis sp. SAG 84.81
0.89
Stichococcus bacillaris
Neocystis brevis
Pleurastrosarcina brevispinosa
Prasinophyceae sp. CCMP 1205
Picocystis salinarum
Nephroselmis astigmatica
Nephroselmis olivacea
0.56
Pycnococcus provasolii
Micromonas commoda
Ostreococcus tauri
Monomastix sp.OKE-1
Pyramimonas parkeae
Prasinoderma coloniale
Prasinophyceae sp. MBIC 10622
Prasinococcus sp. CCMP 1194
Chlorokybus atmophyticus
Mesostigma viride

Figure S9

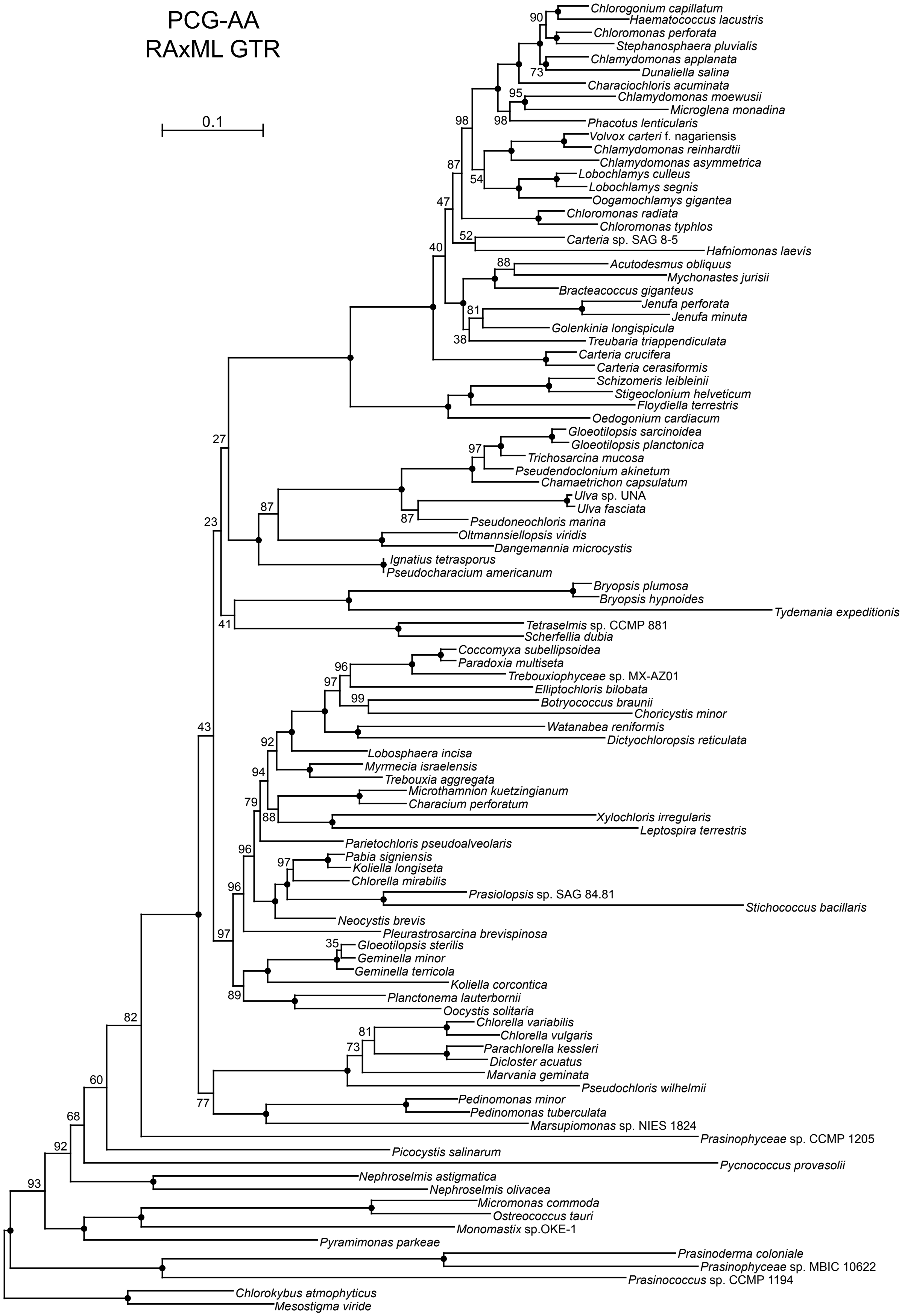
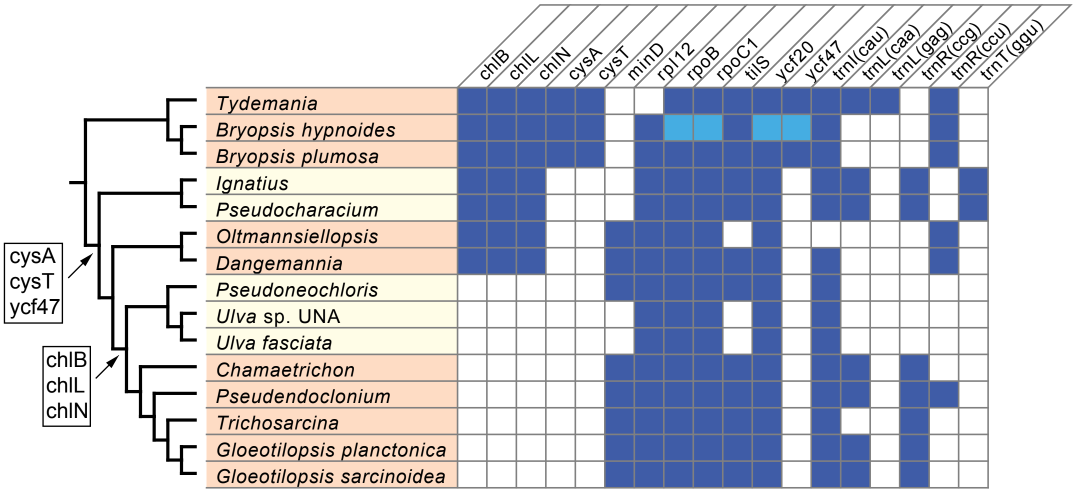

PCG-AA
RAxML GTR
0.1
Chlorogonium capillatum
Haematococcus lacustris
Chloromonas perforata
Stephanosphaera pluvialis
Chlamydomonas applanata
Dunaliella salina
Characiochloris acuminata
Chlamydomonas moewusii
Microglena monadina
Phacotus lenticularis
Volvox carteri f. nagariensis
Chlamydomonas reinhardtii
Chlamydomonas asymmetrica
Lobochlamys culleus
Lobochlamys segnis
Oogamochlamys gigantea
Chloromonas radiata
Chloromonas typhlos
Carteria sp. SAG 8-5
Hafniomonas laevis
Acutodesmus obliquus
Mychonastes jurisii
Bracteacoccus giganteus
Jenufa perforata
Jenufa minuta
Golenkinia longispicula
Treubaria triappendiculata
Carteria crucifera
Carteria cerasiformis
Schizomeris leibleinii
Stigeoclonium helveticum
Floydiella terrestris
Oedogonium cardiacum
Gloeotilopsis sarcinoidea
Gloeotilopsis planctonica
Trichosarcina mucosa
Pseudendoclonium akinetum
Chamaetrichon capsulatum
Ulva sp. UNA
Ulva fasciata
Pseudoneochloris marina
Oltmannsiellopsis viridis
Dangemannia microcystis
Ignatius tetrasporus
Pseudocharacium americanum
Bryopsis plumosa
Bryopsis hypnoides
Tydemania expeditionis
Tetraselmis sp. CCMP 881
Scherffelia dubia
Coccomyxa subellipsoidea
Paradoxia multiseta
Trebouxiophyceae sp. MX-AZ01
Elliptochloris bilobata
Botryococcus braunii
Choricystis minor
Watanabea reniformis
Dictyochloropsis reticulata
Lobosphaera incisa
Myrmecia israelensis
Trebouxia aggregata
Microthamnion kuetzingianum
Characium perforatum
Xylochloris irregularis
Leptospira terrestris
Parietochloris pseudoalveolaris
Pabia signiensis
Koliella longiseta
Chlorella mirabilis
Prasiolopsis sp. SAG 84.81
Stichococcus bacillaris
Neocystis brevis
Pleurastrosarcina brevispinosa
Gloeotilopsis sterilis
Geminella minor
Geminella terricola
Koliella corcontica
Planctonema lauterbornii
Oocystis solitaria
Chlorella variabilis
Chlorella vulgaris
Parachlorella kessleri
Dicloster acuatus
Marvania geminata
Pseudochloris wilhelmii
Pedinomonas minor
Pedinomonas tuberculata
Marsupiomonas sp. NIES 1824
Prasinophyceae sp. CCMP 1205
Picocystis salinarum
Pycnococcus provasolii
Nephroselmis astigmatica
Nephroselmis olivacea
Micromonas commoda
Ostreococcus tauri
Monomastix sp.OKE-1
Pyramimonas parkeae
Prasinoderma coloniale
Prasinophyceae sp. MBIC 10622
Prasinococcus sp. CCMP 1194
Chlorokybus atmophyticus
Mesostigma viride

Figure S10


PCG-AA
PhyloBayes CAT-GTR
0.1
Chlorogonium capillatum
Haematococcus lacustris
Chloromonas perforata
Stephanosphaera pluvialis
0.97
Chlamydomonas applanata
Dunaliella salina
Characiochloris acuminata
0.99
Chlamydomonas moewusii
Microglena monadina
Phacotus lenticularis
Volvox carteri f. nagariensis
Chlamydomonas reinhardtii
Chlamydomonas asymmetrica
Lobochlamys culleus
Lobochlamys segnis
Oogamochlamys gigantea
0.67
Chloromonas radiata
Chloromonas typhlos
0.98
0.64
Carteria sp. SAG 8-5
Hafniomonas laevis
Carteria crucifera
Carteria cerasiformis
Acutodesmus obliquus
Mychonastes jurisii
Bracteacoccus giganteus
0.91
Jenufa perforata
Jenufa minuta
Golenkinia longispicula
Treubaria triappendiculata
0.52
Schizomeris leibleinii
Stigeoclonium helveticum
Floydiella terrestris
Oedogonium cardiacum
Bryopsis plumosa
Bryopsis hypnoides
Tydemania expeditionis
0.99
Gloeotilopsis sarcinoidea
Gloeotilopsis planctonica
0.6
Trichosarcina mucosa
Pseudendoclonium akinetum
Chamaetrichon capsulatum
0.6
Ulva sp. UNA
Ulva fasciata
Pseudoneochloris marina
0.71
Ignatius tetrasporus
Pseudocharacium americanum
Oltmannsiellopsis viridis
Dangemannia microcystis
Pedinomonas minor
Pedinomonas tuberculata
Marsupiomonas sp. NIES 1824
0.7
Scherfellia dubia
Tetraselmis sp. CCMP 881
Coccomyxa subellipsoidea
0.99
Paradoxia multiseta
Trebouxiophyceae sp. MX-AZ01
Elliptochloris bilobata
Botryococcus braunii
Choricystis minor
Watanabea reniformis
Dictyochloropsis reticulata
0.98
Lobosphaera incisa
Myrmecia israelensis
Trebouxia aggregata
Characium perforatum
Microthamnion kuetzingianum
0.9
Xylochloris irregularis
Leptospira terrestris
Parietochloris pseudoalveolaris
Pabia signiensis
0.94
Koliella longiseta
Chlorella mirabilis
Prasiolopsis sp. SAG 84.81
Stichococcus bacillaris
Neocystis brevis
Pleurastrosarcina brevispinosa
Chlorella variabilis
0.99
Chlorella vulgaris
0.55
Marvania geminata
Pseudochloris wilhelmii
Parachlorella kessleri
Dicloster acuatus
0.69
Planctonema lauterbornii
Oocystis solitaria
0.6
0.7
Gloeotilopsis sterilis
Geminella terricola
Geminella minor
Koliella corcontica
Prasinophyceae sp. CCMP 1205
0.7
Picocystis salinarum
Pycnococcus provasolii
Nephroselmis astigmatica
Nephroselmis olivacea
Micromonas commoda
Ostreococcus tauri
Monomastix sp.OKE-1
Pyramimonas parkeae
Prasinoderma coloniale
Prasinophyceae sp. MBIC 10622
Prasinococcus sp. CCMP 1194
Chlorokybus atmophyticus
Mesostigma viride

Figure S11



	chlB	chlL	chlN	cysA	cysT	minD	rpl12	rpoB	rpoC1	tilS	ycf20	ycf47	trnI(cau)	trnL(caa)	trnL(gag)	trnR(ccg)	trnR(ccu)	trnT(ggu)
Tydemania	■	■	■	■	■			■	■	■	■	■	■	■	■		■	
Bryopsis hypnoides	■	■	■	■	■		■	▣	▣	■	▣	▣	■				■	
Bryopsis plumosa	■	■	■	■	■		■	■	■	■	■	■	■				■	
Ignatius	■	■	■				■	■	■	■	■		■	■		■		■
Pseudocharacium	■	■	■				■	■	■	■	■		■	■		■		■
Oltmannsiellopsis	■	■	■			■	■	■	■		■						■	
Dangemannia	■	■	■			■	■	■	■	■	■		■				■	
Pseudoneochloris						■	■	■	■	■	■		■					
Ulva sp. UNA							■	■	■		■		■					
Ulva fasciata							■	■	■		■		■					
Chamaetrichon						■	■	■	■	■	■		■	■		■		
Pseudendoclonium						■	■	■	■	■	■		■	■		■	■	
Trichosarcina						■	■	■	■	■	■		■			■		
Gloeotilopsis planctonica						■	■	■	■	■	■		■	■		■		
Gloeotilopsis sarcinoidea						■	■	■	■	■	■		■	■		■		

Figure S12