



Whole-Genome Sequence of the Cyanobacterium *Synechococcus* sp. Strain WH 8101

Marcia F. Marston,^a  Shawn W. Polson^b

^aDepartment of Biology and Marine Biology, Roger Williams University, Bristol, Rhode Island, USA

^bCenter for Bioinformatics and Computational Biology, Delaware Biotechnology Institute, University of Delaware, Newark, Delaware, USA

ABSTRACT *Synechococcus* spp. are unicellular cyanobacteria that are globally distributed and are important primary producers in marine coastal environments. Here, we report the complete genome sequence of *Synechococcus* sp. strain WH 8101 and identify genomic islands that may play a role in virus-host interactions.

Synechococcus spp. are responsible for up to 16% of net primary production in the oceans (1). Significant proportions of marine *Synechococcus* communities can be lysed daily by viruses (2, 3); nevertheless, studies suggest that *Synechococcus* strains can rapidly become resistant to co-occurring viruses (4, 5). In an effort to identify the genetic determinants that lead to viral resistance, the complete genome of *Synechococcus* sp. strain WH 8101 was sequenced.

Synechococcus sp. strain WH 8101 was obtained from F. W. Valois, who isolated it in 1981 from surface seawater collected at Woods Hole, Massachusetts (41°31'34"N, 70°40'13"W), as described previously (6). The strain has been maintained in SN medium since isolation (6). Based on multiple DNA markers and physiological characteristics, WH 8101 has been assigned to *Synechococcus* clade VIII (7, 8). Only one other member of this clade (*Synechococcus* sp. strain RS9917) has been sequenced.

A single colony of WH 8101 was isolated on an SN soft-agar plate and then regrown in SN medium prior to DNA isolation (6). Genomic DNA was sequenced using both Illumina MiSeq and PacBio RS II platforms. For Illumina sequencing, DNA was isolated using the PowerWater DNA isolation kit (MoBio Laboratories), and a DNA library was prepared using the WaferGen Apollo 324 next-generation sequencing library preparation system with an IntegenX PrepX DNA library kit. The library was sequenced on the Illumina MiSeq system using the 500-cycle reagent kit v.2. For PacBio sequencing, DNA was isolated using the Genomic-tip 100/G kit (Qiagen), libraries were prepared using the standard PacBio 20-kb protocol, and fragments were size selected (>10 kb) with BluePippin (Sage Science) and sequenced on a PacBio RS II system in one single-molecule real-time (SMRT) cell, using P6-C4 chemistry (6-h movie). Reads (50,981 reads; N_{50} , 20,257 bp) were filtered (>750 bp) and assembled using HGAP.3 (seed cutoff, 6 kb). The consensus sequence was polished by additional rounds of PacBio read mapping and was circularized using information from the bridge mapper tool, all within the SMRT Analysis software (v.2.3.0.140936), using default settings. MiSeq reads were mapped to the initial PacBio assembly using Geneious v.10 with default settings and used for additional quality control and manual correction of indel errors. Coverages were 45× and 175× for the MiSeq and PacBio reads, respectively. A single circular 2,630,292-bp assembly with a G+C content of 63.3% was obtained. The genome was initially annotated using RASTtk (9) and subsequently updated with the NCBI Prokaryotic Genome Annotation Pipeline (NCBI RefSeq database). The genome includes 2,693 protein-coding genes, 41 pseudogenes, 6 rRNAs, and 43 tRNAs.

Genes for viral resistance are often localized to genomic islands (hypervariable regions) in *Synechococcus* and *Prochlorococcus* spp. (4, 10). Using previously established

Citation Marston MF, Polson SW. 2020. Whole-genome sequence of the cyanobacterium *Synechococcus* sp. strain WH 8101. Microbiol Resour Announc 9:e01593-19. <https://doi.org/10.1128/MRA.01593-19>.

Editor Frank J. Stewart, Georgia Institute of Technology

Copyright © 2020 Marston and Polson. This is an open-access article distributed under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/).

Address correspondence to Marcia F. Marston, mmarston@rwu.edu.

Received 27 December 2019

Accepted 23 January 2020

Published 20 February 2020

TABLE 1 Genomic islands in *Synechococcus* sp. WH 8101

Island	Genomic location (nucleotides, start to stop)	Length (nucleotides)	No. of genes	Comparison to strain RS9917 ^a
ISL1	45853 to 54972	9,120	9	Insertion in WH 8101
ISL2	214977 to 295023	80,047	55	ISL7 in RS9917; 29 common genes
ISL3	624692 to 634958	10,267	9	Insertion in WH 8101
ISL4	655863 to 667839	11,977	14	Same genes as ISL5 in RS9917
ISL5	764807 to 811294	46,488	40	ISL4 in RS9917; 13 common genes
ISL6	959925 to 1050615	90,691	100	ISL2 in RS9917; 6 common genes
ISL7	1142010 to 1223399	81,390	125	ISL13 in RS9711; 6 common genes
ISL8	1256253 to 1278602	22,350	28	ISL12 in RS9917; 20 common genes
ISL9	1289127 to 1322908	33,782	23	Insertion in WH 8101
ISL10	1588101 to 1721246	133,146	153	ISL10 in RS9917; 71 common genes
ISL11	1886863 to 1966465	79,603	65	ISL9 in RS9117; 39 common genes
ISL12	2264944 to 2273061	8,118	7	ISL8 in RS9917; 4 common genes
ISL13	2572188 to 2582000	9,813	11	Insertion in WH 8101

^a Islands in *Synechococcus* sp. strain RS9917 were identified by Dufresne et al. (11).

criteria (10, 11), 13 genomic islands were identified in WH 8101 (Table 1). These regions were >8 kb and/or contained at least 10 genes that were not in synteny with the genome of the other clade VIII strain, *Synechococcus* sp. strain RS9917. Genomic islands that were identified in RS9917 (11) and present in WH 8101 were also included. This genomic sequence will be used to identify genetic determinants of cyanophage resistance.

Data availability. The complete genome sequence of *Synechococcus* sp. strain WH 8101 has been deposited in GenBank (accession number [NZ_CP035914](#)), along with raw sequence and methylation data (accession number [PRJNA518918](#)).

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation under grants OCE-1332782 (to M.F.M.) and OIA-1736030 (to M.F.M. and S.W.P.). Illumina sequencing was conducted at a Rhode Island NSF Established Program to Stimulate Competitive Research (EPSCoR) research facility, the Genomics and Sequencing Center, which is supported in part by National Science Foundation EPSCoR cooperative agreement OIA-1655221. PacBio data generation and analysis at the University of Delaware Sequencing and Genotyping Center (Olga Shevchenko and Bruce Kingham) and Bioinformatics Core Facility were enabled by infrastructure supported in part by Delaware INBRE (NIH grant P20 GM103446).

REFERENCES

- Flombaum P, Gallegos JL, Gordillo RA, Rincon J, Zabala LL, Jiao N, Karl DM, Li WK, Lomas MW, Veneziano D, Vera CS, Vrugt JA, Martiny AC. 2013. Present and future global distributions of the marine cyanobacteria *Prochlorococcus* and *Synechococcus*. *Proc Natl Acad Sci U S A* 110: 9824–9829. <https://doi.org/10.1073/pnas.1307701110>.
- Matteson AR, Rowe JM, Ponsero AJ, Pimentel TM, Boyd PW, Wilhelm SW. 2013. High abundances of cyanomyoviruses in marine ecosystems demonstrate ecological relevance. *FEMS Microbiol Ecol* 84:223–234. <https://doi.org/10.1111/1574-6941.12060>.
- Mojica KD, Huisman J, Wilhelm SW, Brussaard CP. 2016. Latitudinal variation in virus-induced mortality of phytoplankton across the North Atlantic Ocean. *ISME J* 10:500–513. <https://doi.org/10.1038/ismej.2015.130>.
- Marston MF, Pierciey FJ, Jr, Shepard A, Gearin G, Qi J, Yandava C, Schuster SC, Henn MR, Martiny JB. 2012. Rapid diversification of coevolving marine *Synechococcus* and a virus. *Proc Natl Acad Sci U S A* 109: 4544–4549. <https://doi.org/10.1073/pnas.1120310109>.
- Stoddard LI, Martiny JB, Marston MF. 2007. Selection and characterization of cyanophage resistance in marine *Synechococcus* strains. *Appl Environ Microbiol* 73:5516–5522. <https://doi.org/10.1128/AEM.00356-07>.
- Waterbury JB, Watson SW, Valois FW, Franks DG. 1986. Biological and ecological characterization of the marine unicellular cyanobacterium *Synechococcus*. *Can Bull Fish Aquat Sci* 214:71–120.
- Ahlgren NA, Rocap G. 2012. Diversity and distribution of marine *Synechococcus*: multiple gene phylogenies for consensus classification and development of qPCR assays for sensitive measurement of clades in the ocean. *Front Microbiol* 3:213. <https://doi.org/10.3389/fmicb.2012.00213>.
- Ahlgren NA, Rocap G. 2006. Culture isolation and culture-independent clone libraries reveal new marine *Synechococcus* ecotypes with distinctive light and N physiologies. *Appl Environ Microbiol* 72:7193–7204. <https://doi.org/10.1128/AEM.00358-06>.
- Brettin T, Davis JJ, Disz T, Edwards RA, Gerdes S, Olsen GJ, Olson R, Overbeek R, Parrello B, Pusch GD, Shukla M, Thomason JA, III, Stevens R, Vonstein V, Wattam AR, Xia F. 2015. RASTtk: a modular and extensible implementation of the RAST algorithm for building custom annotation pipelines and annotating batches of genomes. *Sci Rep* 5:8365.
- Avrani S, Wurtzel O, Sharon I, Sorek R, Lindell D. 2011. Genomic island variability facilitates *Prochlorococcus*-virus coexistence. *Nature* 474: 604–608. <https://doi.org/10.1038/nature10172>.
- Dufresne A, Ostrowski M, Scanlan DJ, Garczarek L, Mazard S, Palenik BP, Paulsen IT, de Marsac NT, Wincker P, Dossat C, Ferriera S, Johnson J, Post AF, Hess WR, Partensky F. 2008. Unraveling the genomic mosaic of a ubiquitous genus of marine cyanobacteria. *Genome Biol* 9:R90. <https://doi.org/10.1186/gb-2008-9-5-r90>.