NOTE

VALIDATION OF THE BINARY DESIGNATION 'SYMBIODINIUM THERMOPHILUM' (DINOPHYCEAE)[1]

Benjamin C.C. Hume, Red Sea Research Center, Division of Biological and Environmental Science and Engineering, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia.

Cecilia D'Angelo, Coral Reef Laboratory. Ocean and Earth Science, University of Southampton, Waterfront Campus, National Oceanography Centre, Southampton, SO14 3ZH, UK.

Edward G. Smith, Marine Biology Laboratory, Centre for Genomics and Systems Biology, New York University Abu Dhabi, Abu Dhabi 129188, United Arab Emirates.

Jamie R. Stevens, Department of Biosciences, College of Life and Environmental Sciences, University of Exeter, Exeter, EX4 4QD, UK.

John A. Burt, Marine Biology Laboratory, Centre for Genomics and Systems Biology, New York University Abu Dhabi, Abu Dhabi 129188, United Arab Emirates.

Jörg Wiedenmann[2], Coral Reef Laboratory. Ocean and Earth Science, University of Southampton, Waterfront Campus, National Oceanography Centre, Southampton, SO14 3ZH, UK.

[1] Submitted: 29/08/2017

[2] Correspondence: joerg.wiedenmann@noc.soton.ac.uk

Running title:

Thermotolerant symbiont species

Abstract

The binary designation 'Symbiodinium thermophilum' was invalid due to the absence of an illustration as required by Article 44.2 of the ICN. Herein, it is validated. This species is the most common symbiont in reef corals in the southern Persian/Arabian Gulf (PAG), the world's hottest body of water sustaining reef coral growth.

Key index words:

adaptation; heat tolerance; symbiosis; coral bleaching, taxonomy

Abbreviations:

chloroplast 23S ribosomal RNA gene, cp23S; internal transcribed spacer 2, ITS2; mitochondrial cytochrome b, cob; non-coding region of the chloroplast psbA gene, psbAncr; nuclear ribosomal DNA, nrDNA; Persian / Arabian Gulf, PAG;

Hume et al. 2015 inadvertently published 'Symbiodinium thermophilum' as a binary designation and not a valid name under the International Code of Nomenclature for Algae, Fungi, and Plants (ICN, McNeill et al. 2012) due to the absence of an illustration as required by Article 44.2. Here, a holotype is designated along with a description and photographic image to validate *Symbiodinium thermophilum*.

Symbiodinium thermophilum **B. Hume, D'Angelo, E.G. Smith, J.R. Stevens, J.Burt, & Wiedenmann sp. nov.**

Holotype: Sample of cells preserved in a permanently inactive state (Fig. 1) extracted from a *Porites lobata* colony from 4 m depth collected in May 2010 by John A. Burt (New York University Abu Dhabi) and submitted to the Natural History Museum London, UK (BM000794154).

Description. Intracellular symbiont in scleractinian host coral species; cells spherical to ovoid ~9-11.5µm diameter; heat tolerant up to 35ºC, experiencing strong annual temperature fluctuations (~20ºC); salinity of habitats of host corals 40 to 43 (practical salinity scale 1978); diagnostic nucleotide sequences: i) nuclear ribosomal DNA (nrDNA) internal transcribed spacer 2 (ITS2) partial sequences (nrDNA ITS2 region type C3 and C3-Gulf ITS2 variant, Genbank accession numbers KM487748 and KP234524), ii) the chloroplast 23S ribosomal RNA gene (cp23S) partial sequence (Genbank accession number KP234523), iii) the mitochondrial cytochrome b (cob) gene partial sequence (Genbank accession number K234522) and iv) sequences in the non-coding region of the chloroplast psbA gene (psbAncr) (Genbank accession number KM458273-KM458294).

Type locality: "Saadiyat reef", Abu Dhabi, United Arab Emirates (2435056.400N, 5425017.400E).

Discussion: Symbiodinum thermophilum is the most common symbiont of heat and high salinity-tolerant reef corals and other cnidarians in the Southern PAG but can be also encountered less frequently in the Gulf of Oman and the Red Sea (D'Angelo et al. 2015, Hume et al. 2016). In the Southern PAG, *S. thermophilum* can cope with exceptionally high seasonal temperature maxima and fluctuations (Hume et al. 2013, Shuail et al. 2016). Corals hosting *S. thermophilum* exhibit the highest known bleaching threshold, up to around 35˚C (Shuail et al. 2016, Hume et al. 2015), the temperature at which the coral-*Symbiodinium* mutualism breaks down, causing coral mortality in severe cases (Goreau and Hayes 1994, Brown 1997). The salinity of habitats of *S. thermophilum*-hosting corals in the Southern PAG is also unusually high (around 40 to 43) (D'Angelo et al. 2015). The high-level production of the osmolyte floridoside that is accumulated by this species in response to elevated salinities may also counter reactive oxygen species produced under heat stress (Ochsenkühn et al. 2017), thereby potentially contributing to the thermotolerance of *S. thermophilum*. Both, maximal temperature and salinity are lower in the marginal habitats in the Gulf of Oman and the Red Sea (Hume et al. 2013, D'Angelo et al. 2015).

Symbiodinium thermophilum belongs to a cryptic genus of dinoflagellates with no morpho-anatomical features that reliably distinguish species. Species delimitation is achieved primarily through the analysis of DNA sequence data, including the nuclear ribosomal internal transcribed spacers 1 and 2, single copy microsatellite flanker Sym15, mitochondrial cytochrome b, the chloroplast 23S rRNA gene and the *psb*A non-coding region (LaJeunesse and Thornhill, 2011, LaJeunesse et al. 2012, 2014). *Symbiodinium* spp. in their symbiotic stage are characterised by the absence of thecal plates that could be identifying features for free-living species (Fensome et al. 1993). Other morphological features of *Symbiodinium* sp. such as cell size, structure of the accumulation body and the size of lipid bodies can be highly variable depending on the nutrient environment and are rarely suitable to identify species

(Rosset et al. 2015, 2017). However, genetic data along with accompanying physiological traits unambiguously distinguish *S. thermophilum* from other *Symbiodinium* species in Clade C, the most prevalent and species diverse clade in *Symbiodinium* (Hume et al. 2015, Hume et al. 2016, LaJeunesse 2017).

Acknowledgements:

This work was supported by Natural Environment Research Council Grant NE/K00641X/1 (to J.W.), the European Research Council under the European Union's Seventh Framework Programme Grant FP7/2007-2013/ERC Grant Agreement 311179 (to J.W.)

References:

Brown, B.E. 1997. Coral bleaching: causes and consequences. *Coral Reefs* Suppl.:16:S129-S138.

D'Angelo, C., Hume, B. C. C., Burt, J., Smith, E. G., Achterberg, E. P. & Wiedenmann, J. 2015. Local adaptation constrains the distribution potential of heat-tolerant *Symbiodinium* from the Persian/Arabian Gulf. *ISME J*. 9:2551-60.

Fensome, R. A., Taylor, F. J. R., Norris, G., Sarjeant, W. A. S., Wharton, D. I. & Williams, G. L., 1993. A classification of living and fossil dinoflagellates. *Micropal.* Special publication no. 7. Sheridan Press, Hanover, Pennsylvania, USA: 351 pp.

Goreau, T. J. & Hayes, R. L., 1994. Coral bleaching and ocean "hot spots". Ambio 23:176–80.

Hume, B. C. C., D'Angelo, C., Smith, E. G., Stevens, J. R., Burt, J. & Wiedenmann, J. 2015. *Symbiodinium thermophilum* sp. nov., a thermotolerant symbiotic alga prevalent in corals of the world's hottest sea, the Persian/Arabian Gulf. *Sci. Rep.* 5: doi: 10.1038/srep08562.

Hume, B. C. C, Voolstra, C. R., Arif, C., D'Angelo, C., Burt, J.A., Eyal, G., Loya, Y. & Wiedenmann, J. 2016. Ancestral genetic diversity associated with the rapid spread of stress-tolerant coral symbionts in response to Holocene climate change. *Proc. Natl. Acad. Sci (USA)* 113:4416-21.

Lajeunesse, T. C. 2017. Validation and description of *Symbiodinium microadriaticum*, the type species of *Symbiodinium* (Dinophyta). *J. Phycol* 53:1109–1114.

LaJeunesse, T. C. & Thornhill, D. J. 2011. Improved resolution of reef-coral endosymbiont (Symbiodinium) species diversity, ecology, and evolution through psbA non-coding region genotyping. *PLoS ONE* 6: e29013.

LaJeunesse, T. C., Parkinson, J. E. & Reimer, J. D. 2012. A genetics-based description of *Symbiodinium minutum* sp. nov. and *S. psygmophilum* sp. nov. (dinophyceae), two dinoflagellates symbiotic with cnidaria. *J. Phycol.* 48:1380–91.

LaJeunesse, T. C., Wham, D. C., Pettay, D. T., Parkinson, J. E., Keshavmurthy, S. & Chen, C. A. 2014. Ecologically differentiated stress-tolerant endosymbionts in the dinoflagellate genus *Symbiodinium* (Dinophyceae) Clade D are different species. *Phycologia* 53:305–19.

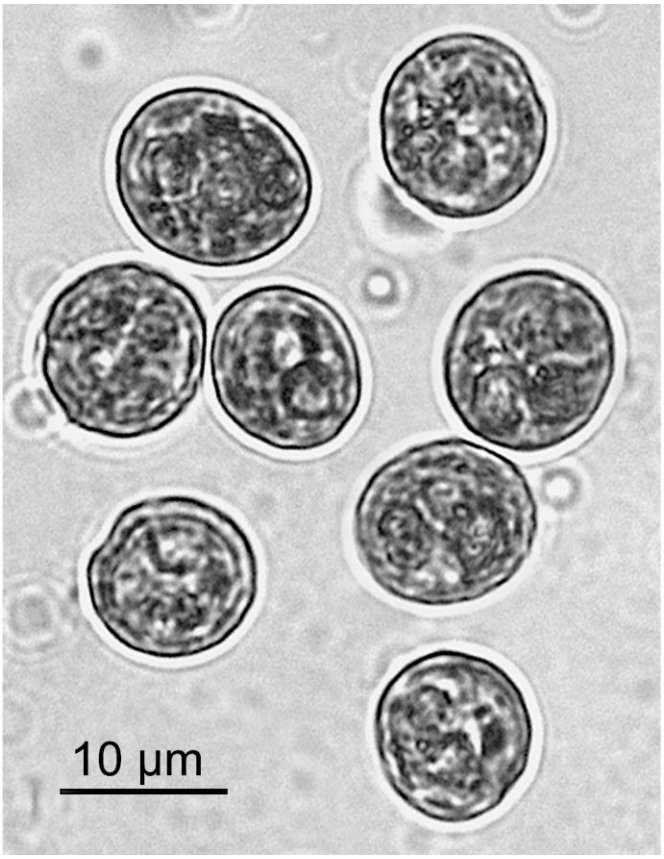
McNeill, J., Barrie, F. R., Buck, W. R., Demoulin, V., Greuter, W., Hawksworth, D. L., Herendeen, P. S., Knapp, S., Prado, J., Prud'homme van Reine, W. F., Smith, G. F., Wiersema, J. H. & Turland, N. J. 2012. International Code of Nomenclature for algae, fungi and plants (Melbourne Code) adopted by the Eighteenth International Botanical Congress Melbourne, Australia, July 2011. *Reg. Veg.* 154: 1-208.

Ochsenkühn, M. A., Röthig, T., D'Angelo, C., Wiedenmann, J. & Voolstra, C.R. 2017. The role of floridoside in osmoadaptation of coral-associated algal endosymbionts to high-salinity conditions. *Sci. Adv.* 3: doi: 10.1126/sciadv.1602047.

Rosset, S., D'Angelo, C. & Wiedenmann, J. 2015. Ultrastructural biomarkers in symbiotic algae reflect the availability of dissolved inorganic nutrients and particulate food to the reef coral holobiont. *Front. Mar. Sci.* 2: doi: 10.3389/fmars.2015.00103

145 Rosset, S., Wiedenmann, J., Reed, A.J. & D'Angelo, C. 2017. Phosphate deficiency promotes
146 coral bleaching and is reflected by the ultrastructure of symbiotic dinoflagellates. *Mar. Poll.*
147 *Bull.* 118:180-187.

148 Shuail, D., Wiedenmann, J., D'Angelo, C., Baird, A. H., Pratchett, M. S., Riegl, B., Burt,
149 J.A., Petrov, P. and Amos, C. 2016. Local bleaching thresholds established by remote sensing
150 techniques vary among reefs with deviating bleaching patterns during the 2012 event in the
151 Arabian/Persian Gulf. *Mar. Poll. Bull.* 105:654-9.



152

153 Figure 1: Light micrograph of *Symbiodinium thermophilum* holotype following isolation from
154 the tissue of the host coral *Porites lobata* from "Saadiyat reef" in Abu Dhabi, United Arab
155 Emirates. Scale bar indicates size.

156