



Establishment of *Mimica gen. nov.* to accommodate the anaxiferous species of the economically important red seaweed *Eucheuma* (Solieriaceae, Rhodophyta)

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The taxonomy of the genus *Eucheuma* J. Agardh (1847) has long been considered as among the most challenging of commercially and economically important red seaweeds as it exhibits extreme polymorphism and highly plastic morphologies (Ganzon-Fortes *et al.* 2012). Efforts to clarify the taxonomy of these seaweeds were prompted by the development of a culture technology to support the growing demand for the carrageenans that they produce. Significant changes in the taxonomy and classification of eucheumatoid species were ushered in by the works of Doty & Norris (1985), who initiated discussion on the need to consistently identify the different species of *Eucheuma*, considering their practical importance for seaweed farmers, traders, and processors. At that time, only the genus *Eucheuma* was recognized, but distinct character differences had already been noted including their morphologies, anatomies (e.g., nature and arrangement of medullary cells), and carrageenan type, among others. Based on these attributes, Doty & Norris (1985) recognized four sections in *Eucheuma*: *Eucheuma*, *Anaxiferae*, *Gelatiformia*, and *Cottoniformia*. They explained that Weber-van Bosse (1928) was the first to use the term “Anaxiferae” in *Eucheuma*, when she recognized two sections, *Axifera* and *Anaxifera*. The latter was characterized by having fronds without a central axis, or core, of elongated cells, and the central region is composed of quite large cylindrical cells and more or less surrounded by “thylles”. The latter is defined as bubble-like outgrowths that develop from large inner primary medullary cells, somewhat similar to tyloses in flowering plants (Doty & Norris 1985). Weber-van Bosse (1928) included a total of 14 species in her section *Anaxiferae*, including eight that were newly described. She did not designate a type species for that section. Doty & Norris (1985) accepted Weber-van Bosse’s section *Anaxiferae* but with a significantly emended circumscription, defining it as thalli with the presence of whorls of spines on both the determinate and indeterminate branches and by the presence of mostly *iota*-carrageenan as the gel-wall matrix material. Also, axial hyphae or rhizoids are absent, and “thylles” are abundant and scattered in the medulla. Doty & Norris (1985) designated *Eucheuma arnoldii* Weber-van Bosse as the lectotype of the section.

Kraft (1972) presented the results of his in-depth investigations of *E. arnoldii* in the Philippines, which included ecological data such as depth distributions, substrata preferences, standing crops, and community associations. An interesting observation made by Kraft (1972) was that at almost every coral reef site in the Philippines that he visited *E. arnoldii* was present where branched corals were also present; but if the reef was lacking branched corals, then there was no *E. arnoldii*. Kraft (1972) emphasized the striking resemblance of *E. arnoldii* to madreporarian and alcyonid corals, including the coral genera *Acropora* Oken, *Pocillopora* Lamarck, *Porites* Link and some soft corals. Kraft also described the new var. *alcyonida* of *E. arnoldii* for its resemblance to certain soft corals of the family Alcyoniidae Lamouroux. Finally, Kraft (1972) proposed treating Weber-van Bosse’s *Eucheuma cupressoideum* (Weber-van Bosse, 1928) and Yamada’s *E. cupressoideum* var. *verticillatum* (Yamada, 1936) as within the morphological variation of *E. arnoldii* var. *arnoldii*. Doty (1988) also assigned *Eucheuma amakusaense* Okamura to *Anaxiferae*, the only other species in the genus that was included in the section. As in *E. arnoldii*, *iota*-carrageenan is produced in *E. amakusaense*.

Doty (1988) revised the taxonomy and classification of *Eucheuma* species beginning with establishing the new tribe Eucheumatoideae. He also transferred all species under the *Eucheuma* sect. *Cottoniformia* to the genus *Kappaphycus* Doty which he erected for eucheumatoid species with cystocarps that are not associated with laterals and are borne on the main axes, possess hyphal axial core (instead of a rhizoidal core typical to *Eucheuma*), and produce *kappa*-carrageenan rather than *iota*-carrageenan, which is typical of *Eucheuma* species (Doty 1988). Doty (1995) made additional change in the tribe Eucheumatoideae when he segregated all members of *Eucheuma* sect. *Gelatiformia* from the genus *Eucheuma*, transferring them to the genus *Betaphycus* Doty based on the carrageenan type that they produce (i.e., *beta*-carrageenan), and a suite of

ecological and morpho-anatomical features. More recently, the new genus *Eucheumatopsis* Núñez-Resendiz, Dreckmann & Senties was established by Núñez-Resendiz *et al.* (2019) based primarily on the distinct molecular phylogenetic position as well as the limited geographic distribution of its type and only species *Eucheumatopsis isiformis* (C. Agardh) Núñez-Resendiz, Dreckmann & Senties (= *Eucheuma isiforme* (C. Agardh) J. Agardh). Consequently, this increases the total number of eucheumatoid genera to four. However, when revisiting the tribe Eucheumatoideae and given the tendencies of the different sections in the genus *Eucheuma* to be representative of distinct genera, we believe that on the basis of several lines of evidences, the members of *Eucheuma* sect. *Anaxiferae* also merit segregation to a new genus.

Species under *Eucheuma* sect. *Anaxiferae* are unique from other *Eucheuma* species as well as with other members of the tribe Eucheumatoideae. Morphologically, species under sect. *Anaxiferae* are easily distinguishable from other eucheumatoids based on the compound spines that are often scattered and/or densely arranged throughout the thallus (Doty 1988). Because anaxiferous *Eucheuma* have the tendency to mimic the morphology of the coral *Acropora* (Kraft 1972, Richards & Huisman 2014), these seaweeds may be overlooked especially for those with untrained eyes. Members of the sect. *Anaxiferae* also lack axial cores, which are distinctive to other eucheumatoid genera (i.e., *Eucheuma* has the rhizoidal axial core, *Betaphycus* has tortuous axial hyphal cells, and *Kappaphycus* has cylindrical axial hyphal cells) (Doty 1988, 1995). Compared with *Eucheuma*, species under sect. *Anaxiferae* have cystocarps that are borne on the main axis (those in *Eucheuma* sect. *Eucheuma* have cystocarps that are in laterals) and lack the spines typically associated with *Eucheuma* species (Doty 1985, Fredericq *et al.* 1999). The location of cystocarp formation and absence of spines on cystocarps in anaxiferous *Eucheuma* are somewhat similar to *Kappaphycus* species. A close association between the anaxiferous *E. arnoldii* and *Kappaphycus* species is also apparent in plastid *rbcL* gene based molecular phylogenetic works on the Solieriaceae by Fredericq *et al.* (1999: fig. 2) and Núñez-Resendiz *et al.* (2019: fig. 2). Aside from these morphological and anatomical evidences, molecular-assisted systematic works conducted on the Solieriaceae since the studies done by Fredericq *et al.* (1999) showed that anaxiferous *Eucheuma* (as represented by the *E. arnoldii*) has been consistently segregated from the genus *Eucheuma*. Huisman (2018), citing the molecular phylogenetic studies of Fredericq *et al.* (1999), suggested that the exclusion of *E. arnoldii* from the *Eucheuma-Kappaphycus-Betaphycus* clade warrants the establishment of its own genus. In the recent work of Núñez-Resendiz *et al.* (2019: fig. 2), *E. arnoldii* was again segregated from other *Eucheuma* species, and was nested in between *Betaphycus* and *Kappaphycus*, with full bootstrap support (Bayesian Inference: 1.00; Maximum Likelihood: 100%). In this study, we calculated the pairwise distance values (*p*-distances) between *E. arnoldii* (GenBank sequence: AF099690) with other members of the tribe Eucheumatoideae using MEGA v6 (Tamura *et al.* 2011). The genetic distance between *E. arnoldii* and the generitype *Eucheuma denticulatum* (Burman) Collins & Hervey (GenBank sequence: JX624010) is 9.1%. This genetic distance is relatively higher compared to those computed between *E. denticulatum* and *Kappaphycus alvarezii* (Doty) Doty (GenBank sequence: JX069175) (8.1%) and between *E. denticulatum* and *Betaphycus gelatinus* (Esper) Doty ex P.C. Silva (GenBank sequence: JX069174) (8.0%). Núñez-Resendiz *et al.* (2019), echoing the opinion of Huisman (2018), also recognized the need to segregate *E. arnoldii* from *Eucheuma sensu stricto* (relative to *E. denticulatum*) but refrained from doing so primarily due to the absence of the species from Atlantic Mexico. Nonetheless, based on the morphological, anatomical, and genetic evidences outlined herein, we believe that the anaxiferous *Eucheuma* species should be segregated. Thus, we propose herein the recognition of *Mimica* *gen. nov.* to accommodate the two species of *iota*-carrageenan-producing seaweeds currently included in *Eucheuma* sect. *Anaxiferae*.

Taxonomic Conclusions

Mimica Santiañez & M.J. Wynne, *gen. nov.*

Diagnosis:—Eucheumatoid macroalgae with cylindrical or dorsiventral thalli possessing compound spines that are scattered or are arranged in whorls throughout the thallus. Branches in whorls, often opposite; lacks axial core. Cystocarps borne on main axes; cystocarpic spines absent. Produce *iota*-carrageenan.

Etymology:—The derivation of the generic name is the word “mimic”, to copy or imitate closely (Latin: *mimicus*, imitative, from Greek *mimikos*, from *mimos*, imitator, which alludes to the strong resemblance of the type species to hard and soft corals, as described by Kraft (1972) and Richards & Huisman (2014).

Type species:—*Mimica arnoldii* (Weber-van Bosse) Santiañez & M.J. Wynne, *comb. nov.*

Basionym:—*Eucheuma arnoldii* Weber-van Bosse, *Siboga-Exped. Monogr.* 59d: 421, pl. XIII, fig. 1. 1928.

Taxonomic synonyms:—*Eucheuma cupressoideum* Weber-van Bosse 1928 *fide* Kraft (1972); *Eucheuma cupressoideum* var. *verticillatum* Yamada 1936 *fide* Kraft (1972).

Type locality:—INDONESIA. Gisser Island (Pulau Geser), near Seram (Silva *et al.* 1996).

Additional taxa assigned to the new genus:

Mimica arnoldii* var. *alcyonida* (Kraft) Santiañez & M.J. Wynne, *comb. nov.

Basionym:—*Eucheuma arnoldii* var. *alcyonida* Kraft, *Pac. Sci.* 26: 323, figs 5, 11. 1972.

Mimica amakusaensis* (Okamura) Santiañez & M.J. Wynne, *comb. nov.

Basionym:—*Eucheuma amakusaense* Okamura (as ‘*amakusaensis*’), *Nippon sorui-meii* [Book listing Japanese algae], p. 35. 1902. [In Japanese.]

Type locality:—JAPAN. Kumamoto Prefecture: Ushibuka, Amakusa Island (Yoshida 1992).

Remarks:—There has been some confusion about the validation of *Eucheuma amakusaense*. Yoshida (1992) provided a detailed explanation of the history of this name, saying that Okamura (1902) provided the earliest valid description that conformed to the International Code of Botanical Nomenclature (ICBN) [presumably, Yoshida (1992) was referring to the ‘Berlin Code’ (Greuter *et al.* 1988)]. Although Doty (1988: fig. 22A) designated a neotype in the Bishop Museum (BISH), Honolulu, Yoshida (1992) was able to find one specimen in the herbarium of the Faculty of Science, Hokkaido University (SAP) that was from Ushibuka, Amakusa Island, Kumamoto Prefecture (the type locality) that seemed to have been examined by Okamura; therefore, Yoshida chose that specimen as the lectotype. Doty (1988) and Segawa (1960) have depicted *Eucheuma amakusaense*, and its range now includes the Philippines (Ang *et al.* 2014) in addition to Japan (Okamura 1936, Segawa 1960).

Acknowledgements

WJES thanks Dr. Gavino C. Trono Jr. and Dr. Edna T. Ganzon-Fortes for their encouragements and support in pursuing seaweed biodiversity studies. We thank Dr. Craig W. Schneider for suggesting the generic name. We also acknowledge the constructive comments and suggestions of Dr. John M. Huisman and an anonymous reviewer which helped improve this manuscript. WJES is funded by the Department of Science and Technology (DOST) – Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) of the Government of the Philippines through the DOST Balik Scientist Program and by the University of the Philippines (UP) through the UP System Balik PhD Program (OVPAABPHD-2018-05). This is the Marine Science Institute Contribution No. 472.

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