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Diversity of *Halimeda* (Chlorophyta) from the Thai–Malay Peninsula

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Abstract: The Thai–Malay Peninsula separates the Andaman Sea from the Gulf of Thailand. This barrier is known to affect species distribution and genetic diversity of marine organisms. Biodiversity studies need a correct species taxonomy to interpret their biogeography; this is especially relevant in marine algae where morphological characters are few or cryptic. We address species distributions of the important macroalgal genus *Halimeda*. The combination of morphological data and chloroplast *tuf*A gene sequences were used to identify species, and to reveal the variation among *Halimeda* species around the Thai–Malay Peninsula. The morpho-anatomical and molecular analysis showed eight species of *Halimeda* in Thai and Malaysian waters: *Halimeda borneensis*, *H. discoidea*, *H. gigas*, *H. macroloba*, *H. micronesica, H. minima*, *H. opuntia*, *H. renschii*, and two undescribed species. Three species, *H. minima*, *H. renschii* and *H. micronesica*, were reported for the first time from the area. Species variation was much greater in the Andaman Sea than in the Gulf of Thailand. Our results show great variation in species composition and genetic variation between the two sides of the peninsula, which could be due to differences in sea-surface currents and environmental differences between the two sides of this important marine barrier.

Key Words: Bryopsidales, Chlorophyta, Geographic barrier, *Halimeda*, Molecular phylogeny, Sea-surface current, Southeast Asia, Species composition, Thai–Malay Peninsula, *tuf*A

INTRODUCTION

Biogeographic barriers can shape patterns of distributions of species by restricting dispersal or by limiting dispersal succession between areas of suitable habitats (Gaither *et al*. 2010) as clearly shown in many *Halimeda* species (Verbruggen *et al*. 2009). The geographic distribution of most *Halimeda* species is restricted in either the Atlantic Ocean or the Indo-Pacific Ocean by the continents of Africa and the Americas that limit their dispersal (Kooistra *et al*. 2002; Kooistra & Verbruggen 2005). There are many major tropical marine biogeographic barriers; one of these barriers is the Sunda Shelf Barrier (SSB), which is the barrier in Southeast Asia restricting exchanges of species between the tropical Indian Ocean and the western Pacific Ocean (Rocha *et al*. 2007). For example, bullethead parrotfish (*Chlorurus sordidus* Forsskål, 1775) and three-spot seahorses (*Hippocampus trimaculatus* Leach, 1814) showed significantly different population structure among locations separated by the SSB (Bay *et al*. 2004; Lourie & Vincent 2004). Carpenter *et al*. (2010) suggested that the SSB is divided between East and West Sumatra and between the Andaman Sea and the Gulf of Thailand. In seagrasses, *Halophila ovalis* (R. Brown) J.D. Hooker populations form separate clades in the Gulf of Thailand and the Andaman Sea (Ngyugen *et al*. 2014). The brown alga *Padina boryana* Thivy has one population largely restricted to the Andaman Sea and another to the Gulf of Thailand (Wichachucherd *et al*. 2014). These results suggest that the Thai–Malay Peninsula is a major geographic barrier between populations in the western Pacific and the eastern Indian Ocean. Interestingly, in the common green algal genus *Halimeda*, only *H. macroloba* is reported from the Gulf of Thailand; whereas, there were a total of eight species reported on the Andaman Sea side of the peninsula (Pongparadon & Prathep 2013).

Halimeda species show morphological variation based on ecological factors and their habitat (Verbruggen 2005a). There are many ecological factors that affect morphology, such as habitat, substrata, depth (Gilmartin 1960), light intensity (Hillis-Colinvaux 1980), wave action and currents (Wyrtki 1961; Buranapratheprat & Bunpapong 1998; Kaandorp 1999; Morton & Blackmore 2001; Latypov 2003).

Species, genetic diversity and distribution patterns of marine life are also affected by sea-surface circulation. For example, genetic studies of giant clams (*Tridacna maxima* Röding, 1798) between the lower and upper Andaman Sea distinguished two populations (Kittiwattanawong 1997). There was also a genetic break of coral populations between the Indian and Pacific oceans (Knittweis *et al*. 2009). Surface sea current patterns in the Thai–Malay Peninsula are influenced by the two monsoons: the northeast and southwest monsoons (Fig. 1). During the northeast monsoon, the upper Andaman coast is influenced by Indian Ocean water masses (current A). The current from the South China Sea (current B) affects the lower Andaman Sea coast, Malacca Straits and eastern Malaysia shore; whereas, the Gulf of Thailand is influenced by the Philippine (current C) and East China Sea currents (current D). During the

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