

An Encrusting Hard Coral Enclosing Soft Coral in the High-Latitude Asia–Pacific Marginal Distribution Zone

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Abstract: Environmentally adapted and resistant hard and soft coral communities within the high-latitude Asia–Pacific marginal distribution zone are thriving, despite their comparably stressful environment (unfavorable winter water temperature and light regimes). Korea’s Jeju Island is famous for its diverse and abundant soft coral communities, which coexist with reef-building hard corals. Although antagonistic interactions between soft and hard corals generally feature the soft coral as the winner, we observed a soft coral of the species *Dendronephthya gigantea* completely enclosed by the encrusting hard coral *Montipora millepora* accompanied by a general decrease in soft coral and increase in *M. millepora* abundances. This indicates an ongoing species/habitat shift with significant impacts on the current state of corals living at their geographic limit.

Keywords: antagonistic coral interactions; Biosphere Reserve; distribution limit; extreme environment; habitat shift; Jeju Island



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Korean waters generally are a habitat for at least 156 species of Anthozoa, 89 of which are species of soft corals (Cnidaria: Anthozoa: Octocorallia: Alcyonacea) [1]. Korea’s renowned soft coral gardens are situated along the coastline of Jeju Island, an island south of the Korean mainland at the confluence of the East China Sea, the Yellow Sea, and the East Sea (Figure 1a). Jeju Island lies within the high-latitude Asia–Pacific marginal distribution zone of corals and their associated fauna, which marks the southern waters around Korea as the northernmost distribution limit within the East China Sea. Hence, shallow marine coral species in this zone live at the edge of the environmental tolerance range. Life in such an extreme environment comes at the cost of growth and reproduction, which are comparably reduced, especially in reef-building hard corals (Anthozoa: Hexacorallia: Scleractinia) of tropical origin [2–5]. Nevertheless, a few hard corals [6], as well as many soft corals [7,8] are thriving in Jeju waters, especially in the Munseom area.

The Munseom area, located in the south of Jeju Island, includes three islets, Beomseom, Seopseom, and Munseom, and is designated as Provincial Marine Park and Natural Reserve, part of the Jeju Island Biosphere Reserve [9]. The islets are located within a government-assigned marine protected area (MPA) (Figure 1b). It is the only MPA exhibiting coral communities in South Korean waters [9]. This status was implemented in effort to protect and conserve Jeju’s remarkable soft corals. These rich soft coral gardens make the area a popular location for recreational diving and touristic submarine activities (Figure 2a). In fact, a survey on macrobenthos around Munseom has shown that Anthozoa is the most diverse and abundant group of all macrobenthic organisms within the area [10]. At least 92 species of Anthozoa, 66 of which are endemic to Jeju waters, have been reported so far (<http://english.cha.go.kr/>; accessed on 10 October 2022).

Within Jeju waters, *Montipora millepora* Crossland, 1952 (Anthozoa: Hexacorallia: Scleractinia) has successfully colonized the southern part of the island [5,11]. *Montipora*

millepora is native to the eastern Indian Ocean, as well as the western, eastern central, and southwest Pacific Ocean, where it is widespread from the tropical to the subtropical zone (Supplementary Table S1). The species exhibits an encrusting or plate-like morphology with two distinct morphotypes (Figure 2b), one with a smooth surface and wider spaced corallites and a second one with an irregular surface and narrowly spaced corallites [5].

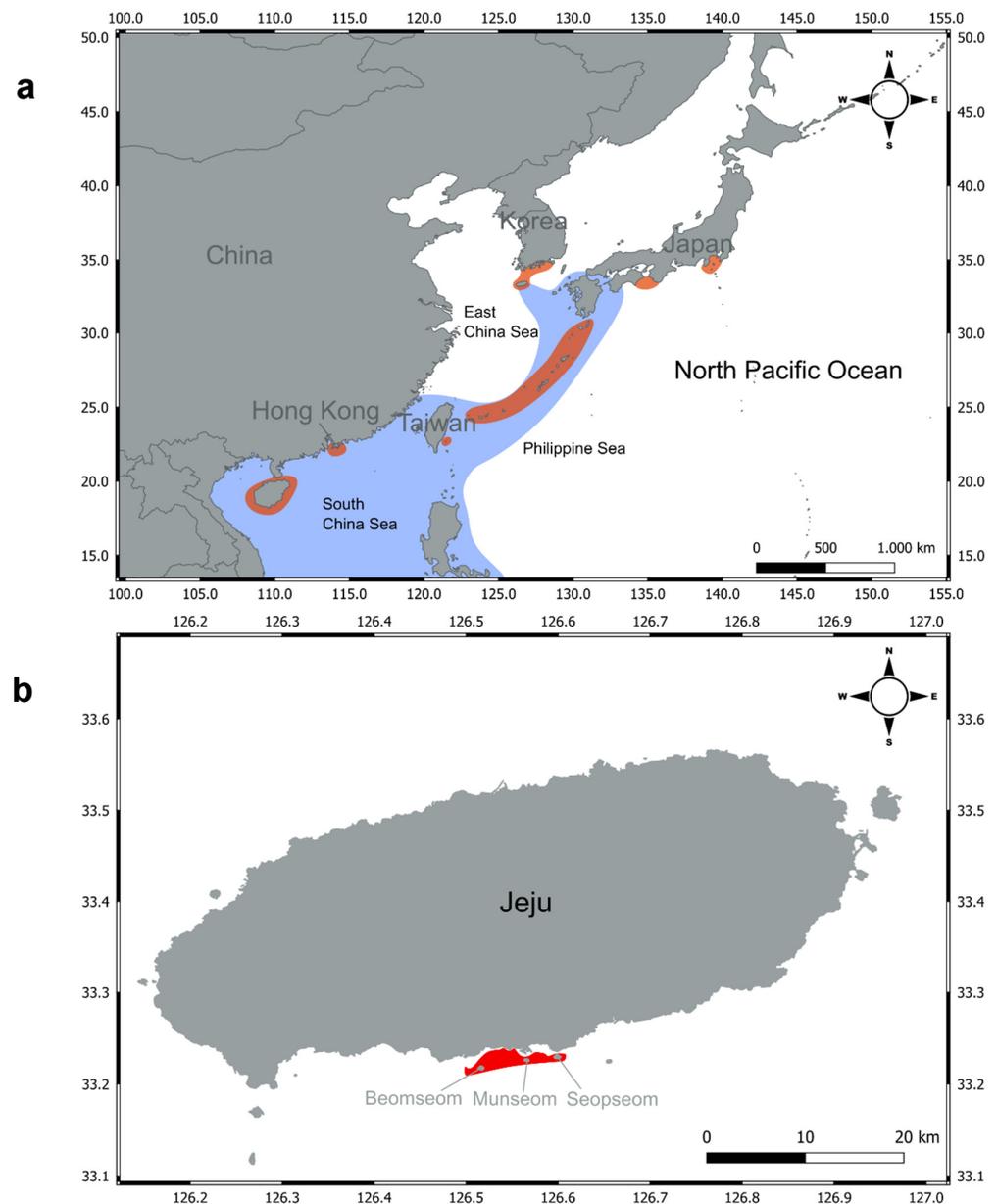


Figure 1. Maps of (a) the North Pacific and (b) Jeju Island, Republic of Korea. (a) Spatial distribution of *Montipora millepora* (blue) and *Dendronephthya gigantea* (orange) within the North Pacific; (b) location of observation of antagonistic interaction between *M. millepora* and *D. gigantea*. The red highlighted area indicates the Marine Protected Area. The distribution of *M. millepora* and *D. gigantea* is based on the information provided in supplementary materials (Tables S1 and S2).

During a survey in 2020 at Beomseom, we observed *M. millepora* completely enclosing a soft coral of the species *Dendronephthya gigantea* Verrill, 1864 (Anthozoa: Octocorallia: Alcyonacea) (Figure 2c). Species identification was mainly based on Sugihara et al. [5] and Song [12]. When we revisited the site in 2022, even more soft coral stalks were found enclosed by the encrusting hard coral, and the abundance and density of *D. gigantea*

appeared decreased (Figure 2d). Although there is lack of comprehensive monitoring data, our impression of an apparent decrease in soft coral abundance is also confirmed by verbal reports from local divers. *Dendronephthya gigantea* dominates the soft coral communities along the coast of Jeju Island [13]. Within the North Pacific, it has been reported in the Ryukyu Archipelago and the Pacific coast of central Honshu and northeast Shikoku in Japan, in the East China Sea along the southern parts of South Korea (“South Sea”), in the South China Sea around Hainan Province and Hong Kong waters, and in the Philippine Sea around Taiwan’s Green Island (Figure 1a, supplementary Table S2).

To our knowledge, this is the first report of an antagonistic interaction between hard and soft coral, marked by overgrowth of hard coral, within the high-latitude Asia–Pacific marginal distribution zone. It is especially striking, as comprehensive studies on alcyonacean/scleractinian coral biotic interactions have generally found the alcyonacean soft corals to outcompete the scleractinian hard corals, either by allelopathic inhibition of larval recruitment [14–17] or by aggressive overgrowth [17–19].

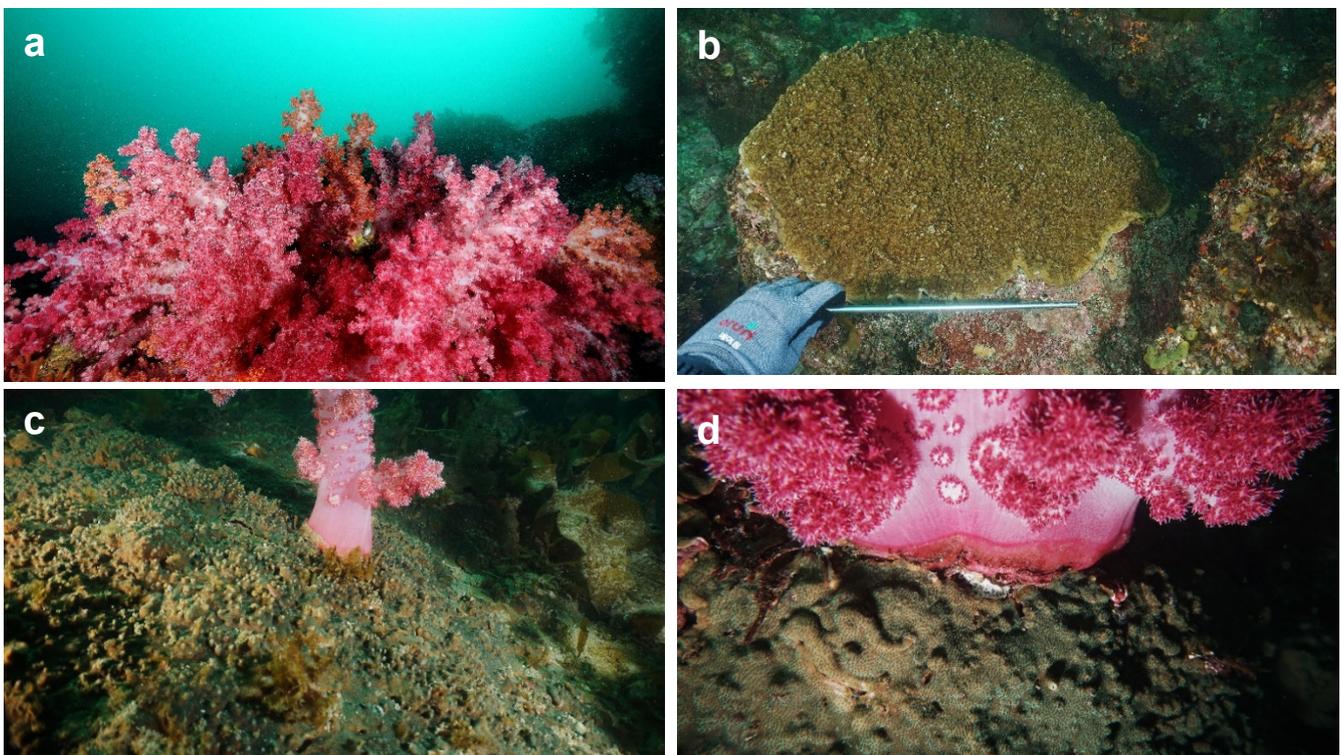


Figure 2. Photographic images of biotic interactions between soft and hard corals. (a) Communities of soft coral species *Dendronephthya gigantea* and *Dendronephthya pütteri*; (b) encrusting morphotype of *Montipora millepora*; (c) *D. gigantea* enclosed by *M. millepora*; (d) close-up image of *M. millepora* outcompeting *D. gigantea*.

Our observation could imply that increasing water temperatures due to global warming may shift, in specific environmental settings, the domination of marginally distributed corals in favor of encrusting hard corals (especially species that can switch from primarily autotrophy to increased heterotrophy). The fact that a zooxanthellate scleractinian coral of tropical origin, despite its relatively stressful environment due to the geographically unfavorable winter water temperature and different light regimes in Jeju, outcompetes temperate azooxanthellate alcyonacean communities, raises concerns related to changes in marine biodiversity. Thus, it is essential to conduct research on the corals currently living within geographical limits and environmental changes in order to understand species/habitat shifts in the near future.

With the ongoing global warming, winter seawater temperatures in Jeju waters will continue to rise [20], likely promoting the spread of encrusting *Montipora* communities within high-latitude habitats. This may further endanger the growth and distribution of Jeju's soft corals. We plan to monitor this phenomenon to obtain comprehensive data on spatiotemporal changes in inter-coral competition to detect onsets of habitat shift in advance.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d14100856/s1>, Table S1: Information on the distribution of *Montipora millepora* within the Asian North Pacific.; Table S2: Information on the distribution of *Dendronephthya gigantea* within the Asian North Pacific.

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References

1. Woo, S.; Yang, S.H.; Chen, H.J.; Tseng, Y.F.; Hwang, S.J.; De Palmas, S.; Denis, V.; Imahara, Y.; Iwase, F.; Yum, S.; et al. Geographical variations in bacterial communities associated with soft coral *Scleronephthya gracillimum*. *PLoS ONE* **2017**, *12*, e0183663. [[CrossRef](#)] [[PubMed](#)]
2. Chan, B.K.K.; Xu, G.; Kim, H.K.; Park, J.H.; Kim, W. Living with marginal coral communities: Diversity and host-specificity in coral-associated barnacles in the northern coral distribution limit of the East China Sea. *PLoS ONE* **2018**, *13*, e0196309. [[CrossRef](#)] [[PubMed](#)]
3. Denis, V.; Ribas-Deulofeu, L.; Loubeyres, M.; De Palmas, S.; Hwang, S.-J.; Woo, S.; Song, J.-I.; Chen, C.A. Recruitment of the subtropical coral *Alveopora japonica* in the temperate waters of Jeju Island, South Korea. *Bull. Mar. Sci.* **2015**, *91*, 85–96. [[CrossRef](#)]
4. Vieira, C.; Keshavmurthy, S.; Ju, S.-J.; Hyeong, K.; Seo, I.; Kang, C.-K.; Hong, H.-K.; Chen, C.A.; Choi, K.-S. Population dynamics of a high-latitude coral *Alveopora japonica* Eguchi from Jeju Island, off the southern coast of Korea. *Mar. Freshw. Res.* **2016**, *67*, 594–604. [[CrossRef](#)]
5. Sugihara, K.; Yamano, H.; Choi, K.-S.; Hyeong, K. Zooxanthellate scleractinian corals of Jeju Island, Republic of Korea. In *Integrative Observations and Assessments*; Nakano, S., Yahara, T., Nakashizuka, T., Eds.; Ecological Research Monographs; Springer: Tokyo, Japan, 2014; pp. 111–130.
6. Denis, V.; Ribas Deulofeu, L.; De Palmas, S.; Chen, C.A. First record of the scleractinian coral *Psammocora albopicta* from Korean waters. *Mar. Biodivers.* **2013**, *44*, 157–158. [[CrossRef](#)]
7. Kang, D.-H.; Song, J.-I.; Choi, K.-S. Image analysis of typhoon impacts on soft coral community at Munseom in Jeju, Korea. *Ocean Polar Res.* **2005**, *27*, 25–34.
8. Hwang, S.J.; Song, J.I. Sexual reproduction of soft coral, *Scleronephthya gracillimum*, (Alcyonacea: Nephtheidae) based on long-term collection from Jeju Island, Korea. *Galaxea J. Coral Reef Stud.* **2009**, *11*, 155–167. [[CrossRef](#)]
9. Kwon, Y.-J.; Kim, H.-J.; Yoo, S.-H. Assessment of the conservation value of Munseom area in Jeju Island, South Korea. *Int. J. Sustain. Dev. World Ecol.* **2018**, *25*, 739–746. [[CrossRef](#)]
10. Ko, J.-C.; Koo, J.-H.; Yang, M.-H. Characteristics of ocean environmental factors and community structure of macrobenthos around Munseom, Jeju Island, Korea. *Korean J. Malacol.* **2008**, *24*, 215–228.
11. De Palmas, S.; Denis, V.; Ribas-Deulofeu, L.; Loubeyres, M.; Woo, S.; Hwang, S.J.; Song, J.I.; Chen, C.A. *Symbiodinium* spp. associated with high-latitude scleractinian corals from Jeju Island, South Korea. *Coral Reefs* **2015**, *34*, 919–925. [[CrossRef](#)]
12. Song, J.-I. *Cnidaria 2: Anthozoa*; Korea Research Institute of Bioscience and Biotechnology (KRIBB): Daejeon, Korea, 2000.
13. Hwang, S.-J.; Song, J.-I. Reproductive biology and larval development of the temperate soft coral *Dendronephthya gigantea* (Alcyonacea: Nephtheidae). *Mar. Biol.* **2007**, *152*, 273–284. [[CrossRef](#)]
14. Maida, M.; Sammarco, P.W.; Coll, J.C. Effects of soft corals on scleractinian coral recruitment. I: Directional allelopathy and inhibition of settlement. *Mar. Ecol. Prog. Ser.* **1995**, *121*, 191–202. [[CrossRef](#)]

15. Maida, M.; Sammarco, P.W.; Coll, J.C. Preliminary evidence for directional allelopathic effects of the soft coral *Simularia flexibilis* (Alcyonacea: Octocorallia) on scleractinian coral recruitment. *Bull. Mar. Sci.* **1995**, *56*, 303–311.
16. Atrigenio, M.P.; Aliño, P.M. Effects of the soft coral *Xenia puertogalerae* on the recruitment of scleractinian corals. *J. Exp. Mar. Biol. Ecol.* **1996**, *203*, 179–189. [[CrossRef](#)]
17. Griffith, J.K. Occurrence of aggressive mechanisms during interactions between soft corals (Octocorallia: Alcyoniidae) and other corals on the Great Barrier Reef, Australia. *Mar. Freshw. Res.* **1997**, *48*, 129–135. [[CrossRef](#)]
18. Dai, C.F. Interspecific competition in Taiwanese corals with special reference to interactions between alcyonaceans and scleractinians. *Mar. Ecol. Prog. Ser.* **1990**, *60*, 291–297. [[CrossRef](#)]
19. Alino, P.M.; Sammarco, P.W.; Col, J.C. Competitive strategies in soft corals (Coelenterata, Octocorallia). IV. Environmentally induced reversals in competitive superiority. *Mar. Ecol. Prog. Ser.* **1992**, *81*, 129–145. [[CrossRef](#)]
20. Kim, T.; Kim, T.; Yang, H.-S.; Choi, S.K.; Son, Y.B.; Kang, D.-H. *Alveopora japonica* Conquering Temperate Reefs despite Massive Coral Bleaching. *Diversity* **2022**, *14*, 86. [[CrossRef](#)]