The Scientific Naturalist

Ecology, 99(5), 2018, pp. 1236–1238

A large aggregation of self-fragmenting mushroom corals in the Arabian/Persian Gulf

The Arabian/Persian Gulf is a relatively shallow, semi-enclosed sea at high tropical latitudes, surrounded by desert land with limited water exchange, high salinities, and extreme annual fluctuations of surface temperatures (Sheppard et al. 1992). These conditions restrict the Gulf's marine biodiversity, as demonstrated by the mushroom coral family Fungiidae (Scleractinia). In the Gulf, this family has only been known to be represented by the free-living (unattached) species, *Cycloseris curvata* (Hoeksema, 1989), which is considered uncommon (Riegl et al. 2012), whereas this coral family consists of 52 described species in the entire tropical Indo-Pacific, 40 of which are unattached (Benzoni et al. 2012).

In the period March–September 2017, four biodiversity surveys were conducted on a large submerged reef in open water at 50 km north-northwest of Ras Laffan Harbour, Qatar (26°13′39″ N, 51°52′59″ E). A total of seven scuba dives at ~21 m depth, with each dive at least 100 m away from the other, revealed a dense, multi-species aggregation of free-living mushroom corals (Fig. 1a). The reef is not charted but, judging by the distribution of fishing boats gathered above, is estimated to be at least 1 km in diameter.

Based on morphological characters, three fungiid species were distinguished: *Cycloseris curvata*, *C. costulata* (Ortmann, 1889), and *C. fragilis* (Alcock, 1893). Many small, fragmented, and regenerated corals were found but relatively few (<1%) complete individuals, with a few corals overturned with their white, lower side in an upward position (Fig. 1b; Appendix S1: Fig. S1). Most fragments (>99%) belonged to *C. fragilis* and the remainder to the other two species. Coral cover was generally >50% but patches of 100% cover were found, resulting in local concentrations far over 1,000 individuals/m^2 (Fig. 1a; Appendix S1: Fig. S2).

The regenerating fragments represent the so-called *Diaseris* form, in which small mushroom corals repetitively reproduce asexually by autotomy, a process in which they split themselves up in wedge-shaped segments (Yamashiro et al. 1989, Hoeksema and Waheed 2011). Because visibility was poor (~15–20 m horizontal distance) and the mushroom coral field appeared endless, it was not possible to estimate the dimensions of the assemblage. A "*Diaseris* community" in the Galápagos Islands (with another dominant species) has been roughly indicated in a published map; the position of its boundaries suggests that such a field can reach at least 500 m in length (Colley et al. 2000). The seawater here also showed high fluctuations in temperature (Feingold 2001).

Considering that large and dense aggregations of fragmenting fungiids are rarely encountered, the question arises of how they can thrive in such harsh hydrological conditions. Clusters of free-living *Cycloseris* corals that propagate by autotomy have a habitat in common that is situated on a flat seafloor made of unconsolidated substrate. It is usually deep enough to be out of reach from storm-regenerated waves. Other examples are known from the Gulf of Thailand at depths of 8–15 m (Nishihira and Poung-In 1989) and the Galápagos Islands at 13–15 m and 33 m (Colley et al. 2000, Feingold 2001).

Based on the life history of the corals, the development of such mushroom coral fields can be hypothetically reconstructed as follows. A juvenile coral derived from sexual reproduction starts as a swimming planula larva that settles by attaching itself to a solid piece of substrate via a thin stalk and later starts to divide itself into multiple segments (Colley et al. 2000, Hoeksema and Waheed 2012). Within a year, the regenerated fragments split themselves up again, completing the cycle of asexual propagation (Yamashiro and Nishihira 1998). The loose coral fragments undergo sessile dispersal, which can be caused by currents, swell, movement by other animals, or automobility (Nishihira and Poung-In 1989, Yamashiro and Nishihira 1995, Hoeksema et al. 2017). This cycle repeats continuously and results in the cluster to spread out over the bottom, increasing its surface area.

Besides autotomy, there are two other mechanisms of asexual reproduction by which free-living mushroom corals can form large fields independent from hard substrates. Some species use budding, which can be seen when minute polyps grow on a seemingly dead parent polyp and detached corals become scattered around it (Hoeksema 2004). Furthermore, fungiid corals of species with large, thin, and fragile skeletons can easily break by mechanical force, after which the regenerating fragments pile up like tiles and move aside (Hoeksema and Gittenberger 2010).

Apparently, asexual reproduction in free-living corals allows them to colonize soft substrates that are unsuitable for larval settlement by producing much offspring, which can move away from the parent animal, which probably maximizes the chance of survival. The production of many mobile clones may decrease the risk of death by burial (Bongaerts et al. 2012) or by stress caused by fluctuating temperatures (Feingold 2001). However, more research is needed to find out (1) what is the trigger of autotomy in mushroom corals that are still in the original shape, (2) what is the maximum age of fragmenting clones, (3) what can cause their death, (4) what is the speed of sessile dispersal, and (5) what influence do long-lived clones have on the genetic variation within populations, and (6) on the speed of speciation in relation to non-fragmenting relatives.

Fig. 1. (a) A multispecies mushroom coral aggregation among red whip corals, *Junceella juncea* (Pallas, 1766), off Qatar (wide-angle shot). (b) A specimen of *Cycloseris curvata* surrounded by regenerating fragments of *C. fragilis*. Scale bar: 1 cm.

Acknowledgments

This publication was made possible by NPRP awards [NPRP 7-1129-1-201 and NPRP 8-952-1-186] from the Qatar National Research Fund (a member of the Qatar Foundation) and by the Qatar Museums Authority through the project "Research on Qatar's geological history and present-day biodiversity" granted to Naturalis Biodiversity Center. The statements made herein are solely the responsibility of the authors. The whip coral species (Fig. 1) was identified by L. P. van Ofwegen. We thank the reviewer and editor for their constructive comments.

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Manuscript received 3 November 2017; revised 23 November 2017; accepted 13 December 2017. Corresponding Editor: John Pastor.

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