On the formation of coral reefs

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Coral reefs are incredibly captivating ecosystems found in our world. The vast array of diverse species that inhabit them, combined with their intricate and vibrant formations, have earned them the nickname ”the rainforests of the sea”. Beyond the interactions within the reef’s entire ecosystem, the biology of corals itself is filled with intricate phenomena. For instance, they engage in a symbiotic relationship with microalgae called *Zooxanthellae*, and exhibit remarkable properties like synchronized sexual events that occur under specific conditions. Additionally, individual polyps within coral colonies display self-organization, forming distinct structures such as massive, branching, and table corals.

While there are solitary species, coral polyps generally gather together in colonies of the same species, creating the aforementioned structures. When colonies of corals exist in the same area, they form a reef. These coral animals have the ability to synthesize aragonite, a form of calcium carbonate, during their clonal growth, which contributes to the development of a sturdy external skeleton. As one colony dies, a new polyp can settle on the remnants of the former colony’s solid structure, initiating the formation of a new colony. Over centuries, this cycle repeats, leading to the creation of large aragonite structures that exhibit recognizable patterns found worldwide. These patterns encompass closed atolls, parallel stripes, and collections of closed atolls with smaller halos inside, demonstrating a remarkable example of self-similarity within this coral reef system.

In this study, we present a novel model that successfully replicates the observed formations of coral reefs. Our proposed model is based on partial differential equations and incorporates the wealth of knowledge accumulated over the past decades regarding the physical and ecological interactions occurring at the micro- and mesoscales within these systems. These interactions include clonal growth, facilitation, the uptake of resources by corals, and the supply of these resources by ocean water currents, among others.

Through the mathematical analysis of this model using bifurcations theory, we uncover that the interplay of only a few parameters of the model is sufficient to elucidate the emergence of various reef shapes found in nature. This includes the formation of fringing reefs, closed atolls, and the inner structures within closed atolls. Our findings provide valuable insights into the underlying mechanisms driving the diverse morphologies observed in coral reefs.