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[Multiscale Computational Models of Coral Growth in the Context of Morphological Plasticity]

A long-standing question in marine and coral biology relates to the morphological plasticity of marine sessile organisms. Understanding the interplay between environmental stressors and the development of a complex biological structure such as that found in scleractinian corals is a major scientific issue. Due to the tight coupling between the physiology of organisms and the environment, coral reefs are susceptible to anthropogenic disturbance such as ocean acidification and climate change. From a broader perspective, coral ecophysiology is a major issue in different fields of marine and coral biology, e.g., ecology, taxonomy, and paleontology, with applications in environmental studies including coral bleaching. Using the computational approach, a multiphysics coupling simulation model is developed in this study, incorporating the impact of steady-state laminar flow and the transport phenomenon to elucidate the mechanism of coral morphogenesis and the corresponding phenotypic plasticity observed in a controlled experiment, with the aim of supplementing experimental studies. Providing the *in situ* dataset of the coral *Pocillopora verrucose*, exposed to a unidirectional flow experiment, the simulation results agree with the observed asymmetrical growth response where a high density of branches dominate the upstream part of the colony where the hydrodynamic energy was high, suggesting a strong influence of local hydrodynamic and advection-diffusion processes. While the hydrodynamic conditions in the coral reef vary in response to the wave-dominated tidal cycles, this study further investigates how the symmetry of coral colonies observed ubiquitously in their natural habitat can be explained by bidirectional flow simulations. In the laminar flow dominated regime, the dynamic viscosity and velocity magnitude are limited to 1.0e^{-3} Pa s and 5.0 e^{-2} m s^{-1} with the *Péclet* number varied to study the impact of bidirectional flow. As the velocity increases, and the flow parameters fluctuate in time and space, a new multiphysics coupling was imposed to solve the Reynolds-averaged Navier-Stokes equations (RANS) using the low Reynolds K-ε, augmenting the velocity magnitude to 1.0 e^{-1} m s^{-1}. The resulting bidirectional flow-induced growth forms were quantitatively analyzed for the presence of local morphometric traits and symmetric oriented traits relevant to the incoming flow direction using multivariate higher moment statistics, i.e., MANOVA and principal component analysis (PCA). The impact of turbulent flow is found to have a prominent influence on intra-colony coral morphology, where distinct classification involved the projection of geometric oriented traits on the first two principal components in conjunction with quadratic discrimination analysis (DA), suggesting that the inherent symmetry of the branching scleractinian can be explained by the ubiquitous symmetry in the flow. A framework is provided in this study to investigate the biological pattern formation of complex forms by looking at coral, which exhibits a high degree of geometrical complexity, plasticity, and self-organization, demonstrating how its complex shape can be partially explained by local development functions and the physics of the environment. This method can be applied to other three-dimensional branching forms such as the network of channels within sponges and neuron dendrites, as well as providing a framework for studying emergent properties and the embodiment of intelligent agents in the changing environment.