

Building Climate-Resilient Corals: A Coral Restoration Strategy Integrating Molecular Repairs With Satellite-Monitored Artificial Reefs

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Coral reefs are rapidly declining due to climate change and pollution, with more than 80% of reefs worldwide at risk of bleaching. However, current restoration efforts cannot ensure long-term survival as environmental stressors may damage coral DNA. Additionally, many substrates for transplantation fail to support planulae settlement and lack hydrodynamic stability for attachment. This study proposes a novel bottom-up restoration strategy that repairs, strengthens, protects, and monitors ecological recovery across all levels. At the molecular level, stressed corals (*Palythoa grandis*) were treated with ROS scavengers and exposed to blue light, resulting in 43% and 33% DNA recovery, respectively, confirmed through GSH-Px enzyme activity and DNA integrity analysis. Next, coral thermotolerance was enhanced through epigenetic preconditioning, which reduced bleaching rates by 5-fold, as validated by transcriptomic gene expression analysis. To further protect juvenile corals during in situ transplantation, a bio-adaptive artificial reef structure was developed. The surface mimicked brain coral textures, increasing planulae and juvenile attachment 2-fold. A bio-formulation was also incorporated to promote growth. Moreover, a branching-inspired structural design was selected as it dissipated up to 88% of hydrodynamic stress in computational fluid dynamics simulations. Finally, to promote global-scale reef restoration, an LSTM predictive model was developed using data from remote-sensing satellites and on-reef sensors to monitor bleaching-prone sites and guide future management. The proposed strategy was tested on Samae San Island, Thailand, where *Acropora* coral survival improved significantly after one month, demonstrating a sustainable approach for scalable coral cultivation.

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