Single-Step Thermoresponsive Hydrogels for Marine Biofouling Control: A Sustainable Colloidal Strategy for the Offshore Industry

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The invasion of sun corals (Tubastraea spp.) poses a severe threat to marine biodiversity. Current control strategies rely primarily on manual mechanical removal, which is costly, hazardous, and often inefficient due to the risk of fragment dispersion. While biocidal hydrogels have been proposed as an alternative, existing formulations depend on external crosslinking agents to increase viscosity and ensure proper coverage, adding operational and compositional complexity.

This work presents the development of a novel, crosslinker-free thermoresponsive hydrogel composed of water-soluble biopolymers (kappa-carrageenan and xanthan gum) as a viscosity modifier and sodium hydroxide (NaOH) as an alkaline biocide, which triggers rapid tissue degradation by inducing a localized high-pH environment. Prepared at elevated temperatures (50-70 °C), the formulation exhibits low viscosity, allowing for easy pumping and localized application. Upon contact with seawater, the hydrogel undergoes a rapid sol-gel transition solely driven by thermal equilibrium. This phase transition increases the storage modulus (G') and provides sufficient mechanical strength to allow the material to adhere to submerged coral colonies and withstand underwater shear forces without additional cross-linking steps.

Field trials at TRL 7 in Arraial do Cabo (Brazil) validated the technology's industrial readiness. Figure (a) illustrates the localized application of the hydrogel using an integrated Remotely Operated Vehicle (ROV) system, demonstrating its viability for diverless operations. The environmental efficacy is confirmed in Figure (b), where colonies encapsulated by the gel showed lethality rates between 95% and 100% after 7 days. This versatile, eco-friendly approach significantly simplifies subaquatic biofouling management while offering a high-performance, sustainable solution for large-scale biodiversity protection and industrial maintenance.

Keywords:

Thermoresponsive hydrogels, Sol-gel transition; Tubastraea spp.; Diverless technology; Sustainable remediati

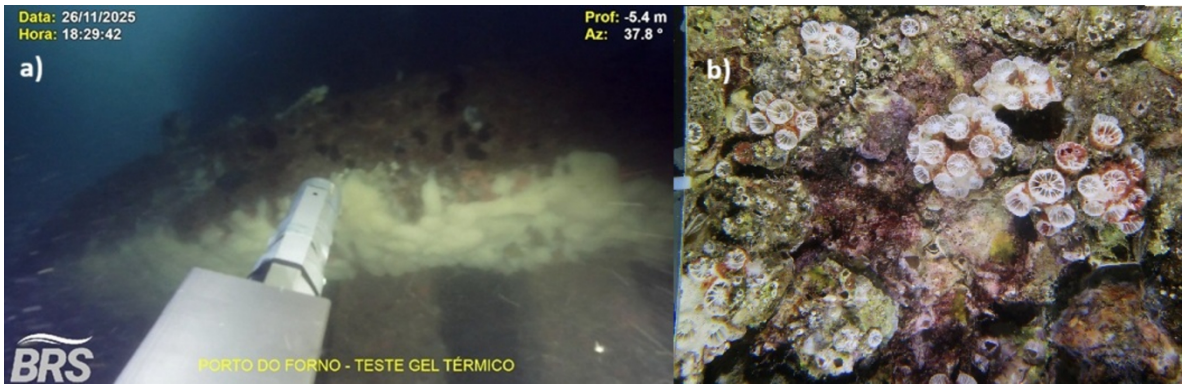

Figure 1. ROV deployment and biocidal efficacy of the thermoresponsive hydrogel. (a) Localized subaquatic application of the formulation onto colonies via a custom ROV nozzle. (b) Photograph taken 7 days post-application showing tissue degradation (whitening) mediated by the NaOH biocide.

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