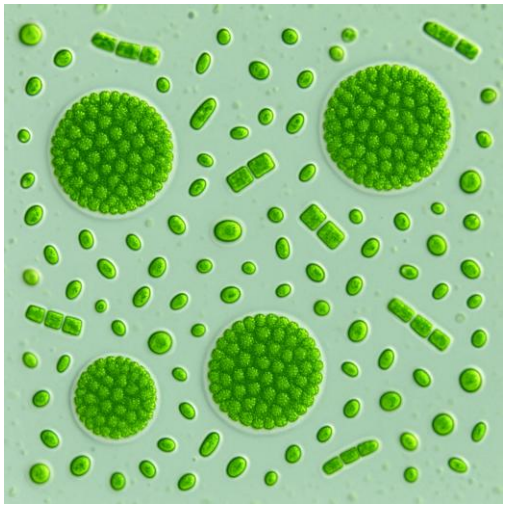
Microalgae: Nature's Ally Against Water Pollution in the Mediterranean

The Mediterranean Sea is increasingly burdened by chemical pollution, including hazardous substances such as heavy metals, pesticides, PFAS, and other persistent "forever chemicals" that threaten biodiversity, food safety, and public health [1]. These pollutants are often concentrated in hot spots, where their accumulation disrupts marine ecosystems and undermines economic sectors like fisheries and tourism.

RHE-MEDiation's Nature-Based Approach



The RHE-MEDiation Lighthouse Initiative addresses this urgent challenge by building a cross-regional governance hub aimed at intercepting chemical pollution at its source, using a nature-based, scalable remediation solution, microalgae. Microalgae are emerging as a strategic tool for chemical detoxification. These photosynthetic microorganisms can absorb, transform, and immobilize a wide range of pollutants, while simultaneously supporting co-product generation through the recovery of biomass for bioenergy, fertilizer, or feed applications [2].

Microalgae Integration in Water Treatment

Integrated into existing water and wastewater treatment systems, microalgae offer a low environmental and economic-impact alternative to conventional chemical treatments. However, despite extensive laboratory research, the transition to industrial-scale application has been slow and faces several bottlenecks related with scalability and the need to allocate substantial land areas to micro-algal systems, which may pose challenges for integration into densely populated areas [3].

From Lab to Market: Challenges in Upscaling

The path from proof-of-concept (TRL 3) to full commercial deployment (TRL 9) requires not only biological optimization but also engineering innovation, regulatory adaptation, and robust operational standards. While closed cultivation systems offer high productivity, they are capital-intensive; open systems are more cost-effective but vulnerable to contamination and environmental variability. Furthermore, co-product valorization, while promising, remains limited by market constraints and the need for clearer regulatory pathways. Few techno-economic analyses exist, and pilot-scale validation is still scarce, underscoring the need for real-world demonstrations to verify feasibility and inform future investments.

Pilot Demonstrations Across the Mediterranean

To address these challenges, RHE-MEDiation has launched three pilot demonstrations across the Mediterranean, each reflecting different stages of water treatment and distinct operational constraints.

Turkey: Secondary Treatment Under High Load Conditions

In Turkey, microalgae were integrated in a wastewater treatment plant, performing what is generally called secondary treatment. Here, the system faced high nutrient loads, particularly nitrogen and phosphorus, which promoted rapid algal growth but destabilized system performance. Elevated turbidity significantly

Funded by the European Union

EU MISSIONS
RESTORE OUR OCEAN & WATERS

reduced light penetration, impairing photosynthesis and reducing biomass productivity and high organic load led to the proliferation of bacteria. This complex combination of chemicals led to the formation of a heterogeneous microbial consortium, with fluctuating interactions between algae and bacteria. The understanding of these population dynamics and what triggers major changes in consortium composition is vital to optimize treatment efficiency and to apply microbial control strategies under high-load conditions

Greece: Tertiary Treatment with Nutrient Scarcity

In Greece, the pilot focused on tertiary treatment, where nutrient concentrations were low as the wastewater was already partially treated. While this limited eutrophication risks, it also restricted algal growth due to nutrient scarcity. Under these conditions, different microbial consortia will be formed, compared to Turkey, dominated by algae species as the organic load is much lower. The Greek demo case will be important to understand limitations imposed by totally different nutrient regimes.

Italy: Full Treatment Chain and Climate Resilience

Italy hosted the most comprehensive application of the microalgae-based system, covering the full treatment chain from primary to advanced stages. Compared to the other demo sites, the pilot is fed with even less nutrient loads and non-existence of organic matter. Additionally, in this Italian region the pilot will face intense thermal stress during the summer months. Prolonged high temperatures may lead to structural failures in the system, including material deformation, breakages, and leaks in the cultivation units. These issues will surely highlight possible vulnerabilities of the system when faced with climate-related stressors.

From Insights to Impact

Across all three pilots, the gap between laboratory expectations and real-world conditions will became clear. These operational insights are critical for refining cultivation systems, designing region-specific solutions, and ensuring scalability. Ultimately, the initiative envisions a future where nature-based solutions like microalgae become mainstream tools for water quality management, enabling cleaner ecosystems, healthier seafood, and more resilient coastal communities. As climate change and pollution continue to intensify, such integrated approaches will be essential to safeguarding the environmental and socio-economic future of the Mediterranean.

References

1. Lee, J.C.; Smaoui, S.; Duffill, J.; Marandi, B.; Varzakas, T. Forever Chemicals PFAS Global Impact and Activities, Cascading Consequences of Colossal Systems Failure: Long-Term Health Effects, Food-Systems, Eco-Systems. **2025**.
2. Rempel, A.; Gutkoski, J.P.; Nazari, M.T.; Biolchi, G.N.; Cavanhi, V.A.F.; Treichel, H.; Colla, L.M. Current Advances in Microalgae-Based Bioremediation and Other Technologies for Emerging Contaminants Treatment. *Sci. Total Environ.* **2021**, *772*, 144918.
3. Liberti, D.; Pinheiro, F.; Simões, B.; Varela, J.; Barreira, L. Beyond Bioremediation: The Untapped Potential of Microalgae in Wastewater Treatment. *Water* **2024**, *16*, 2710.

Funded by the European Union

EU MISSIONS
RESTORE OUR OCEAN & WATERS