Accepted: 10 April 2025
DOI: 10.1111/jpy.70019

Phycological Society of America

ALGAE HIGHLIGHT

Restoring coastal resilience: The role of macroalgal forests in oxygen production and pH regulation

Coastal marine ecosystems provide essential services (Barbier et al., 2011), including carbon sequestration (Pessarrodona et al., 2023), habitat provision (Duffy, 2006), and primary production (Duarte et al., 2010). Among these, macroalgal forests play a fundamental role in maintaining ecological balance, particularly in sheltered Mediterranean bays where they coexist with seagrasses to form diverse and productive habitats (Duarte et al., 2022). However, these ecosystems are increasingly vulnerable to environmental stressors such as pollution, habitat degradation, and climate change (see Verdura et al., 2019). This is why restoration efforts are gaining traction as a means to counteract habitat degradation, yet assessing their long-term effectiveness remains a challenge (Cebrian et al., 2021). A key question in ecological restoration is whether restored habitats can functionally match healthy ecosystems, particularly in terms of fundamental processes such as oxygen production and pH regulation. Galobart et al. (2025) evaluated the success of a decade-long macroalgal forest restoration by comparing oxygen and pH fluxes in restored, healthy, and degraded habitats. The results provided empirical evidence regarding the functional recovery of restored habitats and their potential contributions to coastal ecosystem health.

To assess the success of the functional recovery after restoration, they conducted in situ community incubations across three habitat types: (1) restored macroalgal forests, (2) naturally healthy forests, and (3) degraded habitats. Light and dark incubations were used to measure the changes in dissolved oxygen and pH within each habitat type, providing insights into primary production and respiration processes. The experimental design included the deployment of incubation chambers over representative benthic communities. During light incubations, net oxygen production was measured to quantify photosynthetic activity, while dark incubations assessed respiration rates. In addition, biomass composition was analyzed, focusing on the proportional representation of macroalgal and macroinvertebrate species. This approach enabled a direct comparison of ecosystem functionality between restored and reference habitats.

One of their major findings is that net oxygen production during light incubations in the restored forests closely resembled that of healthy habitats. On average, the net oxygen production in restored and healthy forests was 5.7 times higher than in degraded areas. This indicates a substantial recovery of primary production following restoration, suggesting that macroalgal reestablishment enhances photosynthetic activity and contributes to oxygenation in coastal waters (Layton et al., 2019). In contrast, degraded habitats exhibited lower oxygen fluxes, implying that the absence of structurally complex macroalgae limits primary production. Besides, they also found that restored and healthy forests exhibited greater pH increases during light incubations compared to degraded sites. This suggests that enhanced photosynthetic activity in these habitats contributes to carbon uptake and local pH regulation (Cornwall et al., 2012), which might potentially mitigate ocean acidification effects. Given the increasing threat of acidification in marine environments, the ability of restored forests to buffer pH fluctuations highlights their role in maintaining coastal water quality and ecosystem resilience (Ricart et al., 2021). Finally, they quantified that over 95% of the incubated biomass in both healthy and restored forests consisted of macroalgal and seagrass species, whereas degraded sites exhibited significantly lower biomass. The restored forest demonstrated a six-fold increase in biomass relative to degraded habitats, confirming the successful reestablishment of macroalgal assemblages. Additionally, the structural complexity provided by restored macroalgal forests likely supports a more diverse macroinvertebrate community. This increase in biodiversity and habitat complexity is crucial for enhancing ecosystem resilience and trophic interactions, further underscoring the ecological benefits of restoration efforts (Figure 1).

As a result, Galobart et al. (2025) provide compelling evidence that restoring foundation species, such as macroalgae, can lead to the recovery of essential ecosystem processes, with several important implications for conservation and management. First, they reinforce the potential of targeted restoration efforts to rehabilitate degraded marine habitats. More precisely, they showed that restoration efforts can enhance oxygen production and carbon assimilation. Additionally, by improving pH regulation, restored macroalgal forests may also provide a buffer against local ocean acidification, benefiting associated marine life (Edworthy

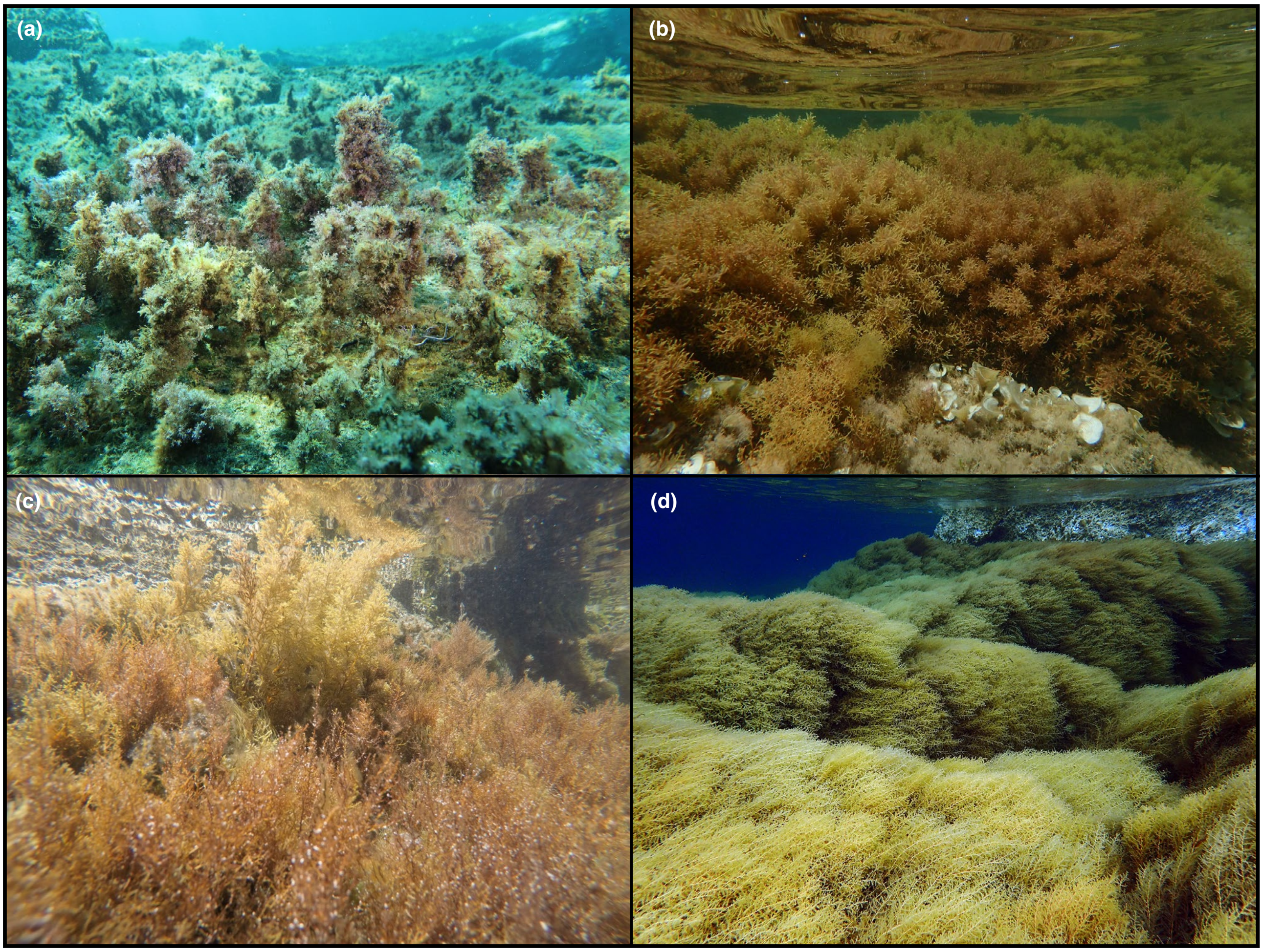

FIGURE 1 Marine forests formed by different *Fucales* communities along the French and Italian coasts. (a) *Ericaria crinita* and *Gongolaria sauvageauana* along the Cilento coast, Italy; (b) *Ericaria amentacea* at Saint-Marguerite, Lérins Islands, France; (c) *Ericaria crinita* and *Ericaria brachycarpa* in a rocky pool at Scannella, Ischia, Italy; (d) *Ericaria amentacea* at Saint-Honorat, Lérins Islands, France. Photo credits: (a) and (c), Antonia Chiarore; (b) Jana Verdura; (d) Enric Ballesteros.

et al., 2023). Second, they highlight the importance of long-term monitoring in restoration projects. The decade-long timeframe allowed researchers to capture the functional recovery of the ecosystem, emphasizing the need for extended observation periods to fully assess restoration outcomes (Smith et al., 2023). Third, they provide an operative framework to assess long-term restoration success linked to ecosystem functions. Although most evaluations in macroalgal restoration are based on metrics such as survival and density, they showcase the need to integrate functional indicators, offering valuable guidance for future macroalgal restoration efforts.

To sum up, Galobart et al. (2025) demonstrate that macroalgal forest restoration can successfully recover critical ecosystem functions, aligning restored habitats with their healthy counterparts. The significant improvements in oxygen production, pH regulation, and biomass accumulation suggest that macroalgal restoration is an effective strategy for mitigating habitat degradation in coastal environments. As marine ecosystems face mounting pressures from anthropogenic and climate-related stressors (see Wu et al., 2017), active restoration initiatives play an increasingly vital role in sustaining biodiversity and ecosystem services. Their findings support the continued development and implementation of restoration strategies, contributing valuable insights into best practices for coastal ecosystem management. By demonstrating differences among healthy and degraded habitats, they underscore the broader ecological significance of macroalgal forests and highlight their critical role in maintaining the health of marine environments. Future studies should continue to evaluate restoration outcomes over longer timeframes, including the assessment of functional recovery, and across different environmental conditions to further refine best practices for habitat rehabilitation.

KEYWORDS
degraded habitat, functional recovery, macroalgal forest, macroalgal restoration

AUTHOR CONTRIBUTIONS

Jérémy Carlot conceived, wrote, and edited/revised the article.

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