Macroalgal Forests and Sea Urchin Grazing, Madeira Case Study

Madeira is a volcanic archipelago in the northeast Atlantic Ocean and is an autonomous region of Portugal. Historically, the shallow, rocky reefs of the area had been dominated by macroalgae, creating a habitat of colorful seaweeds that provide shelter, food, and a complex structure to many marine organisms, including fish, crabs, and snails. Due to a variety of natural, anthropogenic and climate change-related stressors, seaweed populations have declined, resulting in the degradation of the ecosystem. Additionally, increased sea urchin populations have led to overgrazing, leaving barren seascapes behind.

To combat these sea urchin barrens, restoration actions at Madeira focus on (1) the reduction of grazer pressure when sea urchin populations are above a critical threshold and (2) the transplantation of lab-grown algae to help the recovery of local seaweed populations. The four selected restoration sites are located on the south side of the island, including two sites inside the Garajau Partial Nature Reserve, which encompasses about 6-7 kilometer of coastline. All restoration sites are being closely monitored by researchers in underwater visual surveys and a citizen scientist initiative involving local diving centers using the Dive Reporter App.

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Introduction to the site

Driving factors, motivations, and goals for initiating restoration actions

The restoration of macroalgae forests in Madeira is driven by concerns over their decline due to multiple stressors, including overgrazing by sea urchins, habitat degradation, climate change, and coastal development. These forests, primarily composed of canopy-forming brown algae, are vital to the island's shallow marine ecosystems, offering habitat, food, and nursery grounds for a wide range of marine life. Their loss has cascading effects on biodiversity, fisheries, and ecosystem resilience. The motivation for restoration stems from the ecological and socioeconomic importance of these habitats. Healthy macroalgae forests support local fisheries, improve water quality, and contribute to carbon sequestration. Restoration efforts aim to reverse degradation, promote natural recovery, and enhance ecological function by reducing grazing pressure and re-establishing canopy-forming species.

Description of the restoration project location

The restoration project is located in Madeira, an autonomous region of Portugal situated in the Northeast Atlantic Ocean, approximately 560 km off the coast of Morocco. The Madeira Archipelago comprises the inhabited islands of Madeira and Porto Santo, as well as the uninhabited Desertas and Selvagens Islands. The region's submerged habitats are characterized by rocky reefs and sandy bottoms, with occasional seagrass patches and rhodolith beds. These marine ecosystems host a unique blend of temperate and tropical species, typical of subtropical regions. Four restoration sites were selected along the more sheltered south coast of Madeira Island. Two of these—Galo House Reef (HR) and Garajau HR—are located within the Garajau Partial Nature Reserve, a marine protected area (MPA), while the other two—Carlton HR and VidaMar HR—are situated outside the MPA. This distribution allows for the assessment of restoration effectiveness in both protected and non-protected environments.

Assessment Phase

General description of the background and the Initial site assessment

Four sites were selected for restoration based on key criteria: accessibility, the availability of ecological data from previous studies, and strong local support from nearby dive centers—our primary stakeholders actively assisting in restoration actions. An initial ecological assessment was conducted at each site to establish a baseline for monitoring restoration success. This included a full community survey using underwater visual census (UVC) techniques to assess mobile fauna, while sessile organisms were documented through point counts and photoquadrats. These methods provided detailed data on species composition, abundance, and community structure, forming a robust foundation for evaluating ecological changes over time.

Planning and Design Phase

Permits applied for and from where

Restoration sites are located on the south coast of Madeira Island, two within the Garajau MPA (Garajau and Galo) and two outside along the coastline of Funchal city (Carlton and Vidamar). For the three-month monitoring program implemented, it was necessary to ask for a two-year license from the regional Institute for Nature Conservation and Forests (IFCN), where all the scientific diving activities planned for CLIMAREST inside Garajau MPA would be listed, along with the names of the divers. In addition, before each survey, it was necessary to fill out an IFCN online form indicating the location, date, hours, number of divers, and the plate of the boat that was supporting the diving activities. An external company of commercial divers was hired to deploy the modular eco-concrete seawalls. A special permit for the deployment was needed from the Captaincy of the Port of Funchal.

Restoration objectives of the project

The CLIMAREST restoration project in Madeira aims to reverse the degraded state of rocky reef habitats by addressing key ecological drivers—specifically, excessive herbivory by the long-spined sea urchin Diadema africanum and limited algal recruitment. The main objectives are: (1) to control D. africanum densities through targeted culling when local populations exceed 0.3 individuals/m², with the goal of maintaining densities well below the ecological threshold of 0.5/m² to prevent urchin barren formation (Gizzi et al., 2021); (2) to enhance algal recruitment and increase algal cover by at least 15% at restoration sites. These actions are implemented across four sites—two inside a Marine Protected Area (MPA) and two outside—to evaluate the role of protection measures such as fishing restrictions on restoration success. While not all environmental pressures are directly addressed, the monitoring program assesses broader ecological indicators, including biodiversity, abundance, and overall habitat condition.

Protocol for the restoration project

Each of the four restoration sites hosts three Modular Artificial Reef Structures (MARS), resulting in 120 m² of active restoration and over 2000 m² under monitoring.

Restoration techniques were selected based on

- scientific literature
- local feasibility

- pilot trials

The primary objective is to increase native macroalgae cover (*Sargassum spp*.) using forestation techniques.

Key success indicators include

- changes in algae cover
- species composition
- community structure, measured through standardized visual and photographic monitoring.

In Madeira there are no true "pristine" sites that can be used as reference for algae cover or diversity. Anecdotal information sources report dense algae cover in various locations around the island that have disappeared in the 90s. As such, effects and progress of restoration actions are established via comparisons over time (i.e. initial assessment vs post restoration assessments) and by comparing post assessment algae cover, diversity and other indicators with neighbouring locations where no restoration actions have taken place. With pilot restoration sites located inside a marine reserve (with reduced human pressures) and in areas with no conservation restrictions, the experimental design allows for an assessment of ecological outcomes over time and across different protection statuses, supporting site selection for restoration practices. Furthermore, surveys, sampling and experimental trials enabled improvements on algae selection, recruitment and deployment (e.g. selecting fertile periods, substrate and deployment methods). Overall, the pilots tested helped identify the most effective approaches for restoring shallow reef ecosystems in Madeira.

Implementation Phase

Description of the Implementation of the protocol

The restoration protocol was implemented through a combination of field collection, laboratory work, and in situ deployment. Fertile material is first collected from natural Sargassum populations in the field and brought to the lab, where it is processed to obtain fertilized zygotes. These are then seeded onto small substrate units of nature-based materials like natural rock, terracotta, and ceramic. These substrate units were cultured under controlled conditions to promote germling growth. Once juvenile algae reached a suitable size, the seeded tiles were transplanted onto MARS units submerged at each restoration site. These units, made from 3D-printed ecological concrete designed to mimic natural reef complexity, serve as colonization platforms. Field deployment was carried out with logistical support from local dive centres and coordinated with relevant authorities. The goal is to facilitate the establishment of reproductive algae populations that can enhance local recruitment and promote long-term habitat recovery.

Data collection, analysis, and assessments of ecological Indicators

The monitoring protocol was designed to track ecological changes and restoration progress across selected coastal sites in Madeira. It included several complementary efforts. First, annual surveys of the whole benthic community were conducted to establish baselines and monitor long-term changes at all restoration sites. Additionally, targeted surveys of algae and sea urchin communities were carried out every three months to assess seasonal variations in key species groups. Quarterly monitoring also focused on sessile communities at transplantation sites. Data were collected using standardized methods: photoquadrats and point counts for sessile and benthic organisms, and underwater visual census (UVC) along fixed transects to assess mobile fauna. These methods allowed researchers to measure ecological indicators such as species diversity, abundance, and density.

Ongoing Management, Monitoring, and Evaluation Phase

Final results of the demonstration site

Preliminary results from the demo site show promising outcomes from both lab and early field efforts. Laboratory experiments confirmed that all three substrates—terracotta, ceramic, and natural rock—were suitable for algae seeding and transplantation. However, terracotta tiles demonstrated the highest growth and development rates, followed by ceramic, with natural rock performing least effectively. Field transplantation is still in its early stages, and given the long-term nature of ecological restoration, meaningful evaluation of success and ecosystem benefits is expected over a 5–10 year period, which is well beyond the CLIMAREST project lifetime. Initial monitoring data from summer 2023 to early 2025 illustrate seasonal dynamics in the benthic community, with a slight increase in the presence of erect and canopy-forming algae. Continued monitoring will be essential to track community development and assess long-term restoration success and benefits (i.e. algae cover, increased fish diversity and/or density/biomass).

Major Issues and problems encountered

Issue 1

The original plan included reducing grazing pressure from the long-spined sea urchin *Diadema africanum.* The plan was to monitor urchin density and conduct experimental trials comparing urchin exclusion/removal/culling vs non-reduction actions to assess the impact of grazing control in algae populations restoration. A sudden mass mortality event in 2022 decimated *D. africanum* urchin populations across all sites, eliminating grazing as a variable. The lack of *D. africanum* grazing has likely been beneficial for algae growth, however we were unable to compare the effects of reducing grazing vs increasing algae recruitment vs a combination of both.

Issue 2

Obtaining the necessary permits for fieldwork and restoration activities took significantly longer than expected. This caused delays in the implementation schedule but did not prevent the completion of planned actions.

Issue 3
The lack of large donor populations has limited the extent and scale of the transplantation activities. Despite the setbacks, the core restoration activities were carried out successfully, though timelines were adjusted to accommodate administrative requirements and natural ecological changes.

Sharing and Communication

Throughout the restoration project, we prioritized sharing results and engaging diverse audiences. Our communication efforts included the production of scientific publications, oral presentations, posters, and academic theses, contributing to scientific knowledge. We organized stakeholder workshops and meetings with local authorities, dive centers, and NGOs to promote collaboration. Public outreach included school visits, university lectures, and stands and demonstrations at public events, helping to build community awareness. We also produced and shared educational and promotional videos, which were disseminated online and during events to highlight project goals and progress visually. In addition, we released social media posts and newspaper articles to reach a broader audience and promote marine conservation. These varied communication efforts ensured wide visibility and engagement across scientific, local, and public communities.