

Seagrass Meadows, Spain Case Study

In addition to the three demo sites in Ireland, a demo site was created in the Paraje Natural Maro Cerro Gordo in Southern Spain. While this area used to have a semi-continuous belt of eelgrass as of the early 2000s, a variety of factors led to the extinction of the species in the area. These factors are not yet agreed upon, with researchers pointing to different options such as diseases, changes in hydrodynamic conditions as consequence of the installation of breakwaters and beach nourishment, or major road works creating an increase in turbidity. In addition to meetings with stakeholders to identify the causes of the collapse of the seagrass species, restoration activities also aimed to transplant seagrass from donor meadows in Morocco to repopulate the seagrass population.

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Introduction to the site

Driving factors, motivations, and goals for initiating restoration actions

Historical records indicate the presence of *Zostera marina* and *Cymodocea nodosa* meadows in the area. However, these seagrass populations became regionally extinct in 2007. Many environmental stressors in the region have been mitigated through the implementation of

environmental management strategies. These efforts aim to restore and protect marine habitats, creating favourable conditions for the recovery of natural communities. Additionally, the rehabilitation of *Zostera marina* and *Cymodocea nodosa* meadows is among the key conservation goals of the Maro-Cerro Gordo Natural Protected Area. Restoring these meadows will enhance ecosystem functioning and services, including carbon sequestration, water quality improvement, coastal protection, biodiversity conservation, and the enhancement of nursery and breeding habitats for commercially important species. This restoration will be crucial for helping coastal human communities adapt to future global change scenarios.

Description of the restoration project location

Three locations were involved throughout the restoration project. Both La Garrofa in Almeria, Spain and Belyonech in Morocco served as donor populations. The Maro-Cerro Gordo Natural Protected Area in Malaga, Spain was the receiving site from these donors.

General description of the background and the Initial site assessment

Regarding Belyounech and La Garrofa, these were selected as procedural control sites, where we tested various methods before applying them at the receiving site. These controls were essential in case the pilot restoration action fails at the receiving site. In such a scenario, it can determine whether the failure is due to an unsuitable methodology or if it is attributed to the site's unsuitability.

The Natural Protected Area of Maro-Cerro Gordo was chosen due to historical records, ongoing environmental management efforts to mitigate anchoring and trawling—previously identified as potential causes of the species' local extinction—and a reduction in nutrient pollution.

Planning and Design Phase

Permits applied for and from where

Permits for the transplantation of *Z. marina* and *Cymodocea nodosa* in Maro were obtained from the regional government of Andalusia, and permits to collect *Z. marina* from Belyounech, Morocco and *Cymodocea nodosa* from La Garrofa were also obtained from the regional government of Andalusia.

Restoration objectives of the project

1. Identify the most effective and scalable method for seagrass rehabilitation using shoots for *Zostera marina* and *Cymodocea nodosa*.

2. Evaluate the effectiveness and scalability of seed-based techniques for *Zostera marina* rehabilitation.
3. Assess seagrass meadow rehabilitation in Maro
4. Optimize and adapt shoot- and seed-based methods for Maro.
5. Estimate ecosystem services related to carbon sequestration/retention.
6. Estimate ecosystem services related to nutrient sequestration/retention.
7. Evaluate the impact of seagrass rehabilitation on biodiversity, including infauna, seaweeds, and fishes (especially those of commercial interest).
8. Estimate the amount of calcareous organisms in seagrass leaves per square meter at the moment of maximum leaf length (August-October)

Implementation Phase

Description of the Implementation of the protocol

6 steps were followed, leading to successful implementation.

1. Literature review and meta-analysis
 - a. Global-scale assessment of seagrass restoration.
 - b. Identification of appropriate restoration techniques.
 - c. Analysis of key constraints affecting restoration success.
2. Evaluation of environmental and technical factors influencing restoration and rehabilitation outcomes
 - a. "In Situ" Methodological Assessment and Optimization
 - b. Experimental scale: 6–18 m² in the donor meadow and 60 m² at the receiving site.
 - c. Selection of suitable restoration techniques based on workforce availability, time efficiency, and environmental impact.
3. Establishment of a control site within the donor population
 - a. Monitoring the ecophysiological status of plants and meadow development through:
 - i. Number of shoots, meadow area, leaf length.
 - ii. Photosynthetic efficiency (Fv/Fm), carbohydrate reserves, C:N content, and pigment composition.
4. Evaluation of ecosystem services
 - a. This includes...
 - i. Carbon and nitrogen retention in sediments (BACI design).
 - ii. Biodiversity assessment
 1. Infauna (BACI design).
 2. Seaweed communities (control/impact design).
 3. Fish populations (control/impact design).

4. Previous fish and seaweed data were unsuitable; future transplants will use improved methodologies.
5. Suitability models planned
 - a. Restoration suitability models for *Zostera marina* in Ireland and southern Spain.
 - b. Model development using: Presence records and pseudo-absence data, and environmental variables (bathymetry, substrate type, chlorophyll levels, temperature, wave energy, and wave height).
 - c. In situ validation through transplantation trials.
6. Genetic connectivity and diversity
 - a. Investigating *Zostera marina* genetic connectivity across Ireland and the Alboran Sea.
 - b. Assessing genetic diversity in the donor population for Málaga (Belyounech, Morocco).
 - c. Analysis using 36 microsatellite markers.

Data collection, analysis, and assessments of ecological Indicators

- Indicators of rehabilitation success:
 - counting number of shoots
 - measuring leaf length
 - estimating meadow area
 - collecting rhizomes and leaves for further biochemical analyses (e.g. pigments, carbohydrates, C:N content)
- Scale of replicates
 - 1 m² per replicate when comparing methods
 - From 0,25 m² to 6m² when optimising initial shoot density for the method identified as the most suitable and scalable.
- Estimating ecosystem services: C:N in sediments following a BACI design, identifying associated species following a control impact design (planned for May-June 2025)

Ongoing Management, Monitoring, and Evaluation Phase

Final results of the demonstration site

Until May 2025, there has not been any data about impacts on the environment, habitat, species or other ecosystem services (C and N sequestration). For now, a canopy has been generated, and higher density of fishes and cephalopods have been observed. More finalised results will follow in Autumn 2025.

Major Issues and problems encountered

The main challenge was related to bureaucracy and the time required to assess ecological restoration. It took several months to secure the necessary permits.

Sharing and Communication

Communications during the restoration projected that were aimed at informing and engaging different stakeholders

- Workshops and information sessions
 - Participated in workshops and seminars for the university community, where project goals were shared as well as challenges, and successes. These sessions allowed for discussions on the restoration's impact, biodiversity, and sustainable management practices.
- Public engagement materials
 - Developed educational content, including posters and social media posts, to inform local communities and the general public about the project's goals, activities, and ecological significance. These were distributed at events and public spaces.
- Press releases and media outreach
 - Worked with local and regional media to generate coverage for the restoration project, highlighting its environmental and social benefits. These efforts led to articles in environmental magazines, local newspapers, and news websites.
- Scientific publications
 - Two scientific articles have been published as part of the project. One of them is being integrated into the digital twin. Another three manuscripts are in preparation and are intended to be submitted before the end of the project (a review; and two original articles related with seagrass restoration). Several communications in scientific meetings and conferences have been made about seagrass ecology and ecological restoration.

Different stakeholders reached

- Local communities
 - Public workshops and social media engagements helped us connect with residents, who are directly affected by the restoration project. Their input has been invaluable in ensuring that the project meets local needs and gains community support. Examples of these communities include local residents, divers, fishermen, and tourism companies.

- Government agencies
 - Regular communications were made with governmental bodies involved in environmental protection, ensuring that the project aligns with regulations and national biodiversity goals.
- Environmental NGOs and research institutions
 - Our project communicated its progress to conservation organizations and academic researchers, allowing collaboration and the exchange of knowledge on best practices in ecological restoration. Some of the key institutions involved include BuceoNatura, Equilibrio Marino, Produnas Asociación, and University of Granada.
- Media outlets
 - Engaging the media helped to raise awareness of the project and garner public support. A wider audience was reached through articles, news stories, and interviews.
- Other researchers
 - The project collaborated with Dr. Aline Finger to assess genetic connectivity, structure and diversity of *Z. marina* across Ireland.