Seagrass Meadows, Ireland Case Study

Seagrasses are marine flowering plants, which form extensive meadows in intertidal and shallow water marine environments[1]. Seagrasses meadows offer an extensive array of ecosystem services. These include the provision of habitats for refuge, locations for nesting and breeding, nutrients to a broad spectrum of organisms, safeguarding the coast from coastal erosion, preserving sediment supporting the cycling of nutrients and carbon sequestration[2, 3]. Seagrass meadows face diverse threats that include biotic interactions such as diseases, wildfowl and epiphyte grazing and abiotic factors such as storms, floods, temperature changes, etc.[4]. Worldwide seagrass meadows have experience**d** decline in populations in the last decades[5, 6]. In Ireland these **reasonings** include coastal developmental projects, dredging, water pollution due to toxic contaminants, oil and eutrophication by nutrients**,** introduction of invasive species, anchoring of marine vessels**,** and farming[7, 8]. To prevent meadows reduction and explore effective strategies for seagrass restoration in Ireland three demo sites were established, specifically in Galway Bay, Killala Bay and Tralee Bay.

Introduction to the site

Driving factors, motivations, and goals for initiating restoration actions

Seagrass meadows are among the most valuable coastal ecosystems, providing essential services such as carbon sequestration, biodiversity support, and shoreline stabilization. However, these habitats are declining globally due to pollution, coastal development, and climate change. Restoration efforts aim to reverse this trend by rebuilding resilient ecosystems that enhance marine biodiversity and contribute to climate change mitigation. Protecting and restoring seagrass meadows is crucial to ensuring the long-term health of our oceans and coastal communities.

Description of the restoration project location

Four locations have been selected in Ireland; one in Galway Bay (Lettercallow, Connemara), two in Tralee Bay (Fenit Island and Spa) and one in Killala Bay (Killala). Connemara (Lettercallow, Kilkieran Bay) has the status of Special Area of Conservation (SAC, code: IE0002111) and Natural Heritage Area (NHA). Tralee Bay Nature Reserve (Co. Kerry) is on the list of Wetlands of International Importance under Article 2.5 of the Convention (1989). Killala Bay is designated as a Special Protection Area (SPA), code IE004036 and a Special Area of Conservation (SAC), code IE000458 (NPWS) environments.

Assessment Phase

General description of the background and the Initial site assessment

The *Zostera marina* meadow in Lettercallow was selected after numerous experiments assessing its health status, considering factors such as size, shoot density, water quality, and sediment stability. Following multiple small-scale trial attempts, the recipient site was chosen close to Lettercallow, as no significant pressures were identified in this area. The site also shares similar environmental conditions with the donor meadow, and research suggests that seagrass restoration efforts are more effective when conducted near the donor site.

Tralee Bay was initially selected due to its proximity to both subtidal *Zostera marina* and intertidal *N. noltei* meadows. Additionally, our strong stakeholder network in the region provides significant support for our initiatives. Moreover, small-scale experiments with *N. noltei* in Tralee Bay showed promising results, with high survival rates and successful establishment of new shoots.

Killala Bay was chosen due to its favourable conditions for experimental work, providing relief from some of the challenges faced in previous cases. Small-scale trials in the area yielded promising results, despite the original meadow having declined over the years. Additionally, a healthy donor meadow is located relatively nearby (Moy Estuary), and both sites show minimal anthropogenic pressures, making them suitable for restoration efforts.

Planning and Design Phase

Permits applied for and from where

Permits to conduct marine scientific research were requested and approved for three bays (Connemara, Killala, and Tralee Bay) by the Irish Department of Housing, Local Government, and Heritage.

Restoration objectives of the project

1. Restoration of degraded or lost seagrass meadows through transplantation.
2. Refine seagrass restoration techniques and protocols to identify the most suitable methods for successful restoration
3. Develop new methods and technologies for seagrass restoration, including earth observation monitoring, molecular studies, and other innovative approaches.
4. Enhance ecosystem services through seagrass restoration, including biodiversity maintenance, carbon sequestration, coastal protection, and more.
5. Involve local communities, policymakers, and stakeholders including education, citizen science, and conservation initiatives.
6. Establish a monitoring program to track the success of restoration efforts, assessing seagrass coverage, health, and ecological function.

Protocol for the restoration project

Small-scale restoration experiments were initially conducted to evaluate the efficacy of various restoration techniques. Based on the most successful approaches, large-scale experiments will be implemented. Several techniques were tested, and we identified three methods that yielded the most promising results: transplanting ballasted shoots for *Zostera marina*, using sediment cores for *N. noltei*, and seeding for both species. A comprehensive monitoring plan was established, with sampling occurring every one to two months across all control sites. Key parameters, including sample size, shoot density, coverage area, and growth, were measured. Additionally, indirect indicators such as organic matter and carbon content in the upper sediment layers, water quality, and the ecophysiological status of both the plants and the estuary were regularly assessed.

Implementation Phase

Description of the Implementation of the protocol

The protocol was implemented in the field through a series of carefully planned steps to ensure consistency and accuracy. First, site selection was based on environmental suitability, with control sites established at key locations within the study areas. For small-scale experiments, transplanting of ballasted shoots was conducted by carefully selecting healthy shoots of *Zostera marina*, which were then weighted and planted in pre-dug sediment plots. For *N. noltei*, sediment cores were extracted using a core sampler, and these cores were carefully relocated to targeted restoration areas. Seeding efforts for both species involved dispersing seed onto prepared sediment beds under controlled conditions to maximize germination success.

Data collection, analysis, and assessments of ecological Indicators

At each monitoring site, fixed plots were established using GPS coordinates to ensure consistency across sampling events. Data collection involved measuring several key parameters, including the size of individual samples, shoot density, and coverage area.

Measurements were taken using calibrated tools such as rulers, measuring tapes, and quadrats to ensure precise and repeatable results. Growth rates of transplanted shoots and seeded areas were tracked over time, with shoot density being counted and documented.

In addition to direct measurements, sediment cores were extracted for further analysis of organic matter and carbon content in the top sediment layers. Water quality was assessed taking filtered and unfiltered samples and using portable field sensors to monitor parameters such as temperature, salinity, dissolved oxygen, and nutrient levels. Data collected in the field were recorded in both digital devices and standardized field notebooks to ensure accurate data logging and ease of analysis.

The ecological health of the restored meadows was assessed through both direct and indirect indicators. Direct indicators included the physical health of the seagrass (e.g., shoot density, growth rates, and overall coverage). Indirect indicators were assessed to gain a fuller understanding of the ecosystem's functionality. These included organic matter content, carbon sequestration in the sediment, and water quality parameters such as turbidity and nutrient concentration. Ecophysiological assessments were also conducted, including visual inspections of plant health, and in some cases, leaf tissue was collected for carbohydrates and nutrient analysis.

Additionally, the overall condition of the estuary was evaluated in terms of ecological health, considering factors like sediment stability and water quality, to determine how the restoration project was contributing to the broader ecosystem. The monitoring protocol allowed for continuous assessment and adaptive management by identifying areas of success and highlighting areas that may require further intervention.

Ongoing Management, Monitoring, and Evaluation Phase

Final results of the demonstration site

Galway Bay

Transplants with ballasted and unballasted shoots have proven effective for *Z. marina* seagrass restoration in Ireland. This technique is not effective for *N. noltei*. Ballasted shoots were more effective than unballasted shoots. Survival rates and shoot densities exceed 100% in some trials with ballasted shoots after one year. Heavy ballasted shoots were more effective than light ballasted shoots. No significative differences were found between autumn-winter and spring-summer transplants. Winter challenges are mainly storms and spring challenges are temperature and seaweed blooms.

Reproductive shoots developed in our transplants. An increase of the shoot density and biomass was detected mainly due to flowering events. Organic carbon doubles after 15 and 12 months compared to time zero and bare sediment, with similar values to the original natural meadow. Site selection remains a priority as the same technique used for the same species may succeed or fail depending on the specific site.

Tralee & Killala Bay

Transplants with sediment cores have been proven effective for *Nanozostera noltei* restoration in Ireland.

Transplants with sediment cores were more successful in May increasing 10 times the shoot density in just two months. Transplants also experienced a high growth rate in August and until November.

Maximum of biomass was detected in donor meadows and our transplants in September, starting to decline since that due to fenology. Minimum was detected in winter months (January).

High density transplants were more successful than low density transplants. Constraints for seagrass restoration included: limited donor meadows due to a lack of genetic data, invasive species, streams of fresh water, seaweed blooms and eutrophication, administrative hurdles and challenging weather such as storms.

Positive Impacts

The restoration efforts contribute to the creation of new habitat, fostering increased biodiversity associated with the recovering seagrass meadows, nursey area, etc. Additionally, they enhance organic matter and carbon sequestration in sediments, improving overall ecosystem function. The restored meadows also serve as a natural barrier, offering additional coastal protection by stabilizing sediments and reducing wave energy.

Negative Impacts

Potential risks include disturbances to donor meadows during seed or shoot extraction, which must be carefully managed to minimize harm. Additionally, the placement of ballast and metal structures in the marine environment, while necessary for restoration, could introduce temporary alterations to the seabed that require monitoring and mitigation strategies.

Major Issues and problems encountered

Galway Bay (Connemara)

Several challenges arose across different areas. In Connemara, the healthiest donor meadow faces accessibility issues due to its subtidal location. Although relatively shallow (1-2 meters), its subtidal nature makes restoration work more challenging compared to intertidal meadows. In Ireland, transplantation efforts are often disrupted by adverse weather conditions, including storms, heavy rainfall, and strong winds. Additionally, increased turbidity following storms further complicates transplant monitoring and sampling.

Tralee Bay

In Tralee Bay, particularly around Fenit Island, local activities such as vehicle traffic over the transplanted meadows threaten the restoration trials success. Furthermore, balancing the differing interests of local conservationists—especially regarding seed removal for conservation purposes—has required a careful approach. To mitigate these concerns, we have followed a strict protocol for seed extraction to minimize any impact on donor meadows. Changes in land-derived water flow have also presented challenges, occasionally damaging transplants.

Killala Bay

In Killala Bay, the area's relative isolation offers protection from major disturbances, though historical farming activities involving tractors have contributed to meadow fragmentation. To prevent further impact, we have marked the transplant and meadow areas and engaged with local communities to raise awareness about the restoration efforts. However, some monitoring equipment, such as HOBO data loggers and markers, has been lost or removed.

Sharing and Communication

Scientific publications

- Sara Haro, Jonathan Jimenez-Reina, Ricardo Bermejo & Liam Morrison (2023) BioIntertidal Mapper software: A satellite approach for NDVI-based intertidal habitat mapping. SoftwareX (24) 101520. https://www.softxjournal.com/article/S2352-7110(23)00216-9/fulltext
- Congresses and Conferences:
    - 2nd European Seagrass Restoration Workshop
        - Africa N.G. De La Morena et al. S. Haro, I. Moreu, A. Avilés, N. Korbee, J. Lugilde-Yáñez, L. Morrison, R. Bermejo. (Poster). *Evaluating Techniques for Active Restoration of Cymodocea nodosa in the Alboran Sea, Southern Spain*
        - Sara Haro, A.N.G. De La Morena, J. Lugilde-Yáñez, L. Morrison, R. Bermejo (Poster). *Assessing High-Latitude Seagrass Meadows for Restoration Using Remote Sensing: Decline of a Nanozostera noltei Intertidal Meadow in Southwest Ireland*
        - Liam Morrison Anagha Amitha, Juan Lugilde-Yáñez, Teena Thomas, Rita Hagan, Sara Haro, África N.G. De La Morena, Ricardo Bermejo (Talk). *Assessing The Ecophysiological Status Of Seagrass Meadows In Ireland Across An Anthropogenic Pressure Gradient*
        - Juan Lugilde-Yáñez et al. África N.G. De la Morena, Sara Haro, Ricardo Bermejo, Liam Morrison (Poster*) Restoring Seagrass Meadows For Climate Resilience In Atlantic Coasts: The CLIMAREST Project.*
    - World Seagrass Conference & 15th International Seagrass Biology Workshop 2024
        - Juan Lugilde-Yáñez, África Núñez García de la Morena, Sara Haro, Ricardo Bermejo & Liam Morrison. *Assessment Of Seagrass Restoration Methods At Northern And Southern European Coasts*
        - Sara Haro, Juan Lugilde-Yáñez, África Núñez García de la Morena, Liam Morrison & Ricardo Bermejo. *Assessing Spatio-Temporal Dynamics of Nanozostera noltei in Irish Intertidal Zones using Remote Sensing technologies: Implications for Restoration.*
        - África Núñez García de la Morena, Amparo Cid Iturbe, Pedro Beca-Carretero, Juan Lugilde-Yáñez, Arianna Pansinni, Sara Haro, Nathalie Korbee, Liam Morrison, Ricardo Bermejo*. A Systematic Quick Scoping Review: The State Of Knowledge Regarding Zostera And Nanozostera Restoration.*
- Presentation of the CLIMAREST project at different events:
    - 14th Annual Marine Economics and Policy Research Symposium. (Enhancing climate resilience through seagrass restoration along Europe's shores: Insights from the CLIMAREST project).
    - Presentation of the CLIMAREST project at the annual COASTWATCH IRELAND meetings (2023-2024-2025).

- Presentation of the CLIMAREST project to Galway City Council and partner involved (Green Party, ATU University, Friends of Barna Woods, local groups and authorities). Introduction of seagrass as key habitat in the Biodiversity Action Plan 2025-2030).
    - Meeting of the Irish Ocean Literacy Network (IOLN) REGIONAL MEMBERS' MEETING - MAYO. Talking about CLIMAREST project focusing on Seagrass conservation and restoration in County Mayo
    - Attendance to the event organized by Galway County Council and Galway Atlantaquaria involving Irish speaking schools to promote the knowledge of seagrass and local biodiversity
    - CLIMAREST was represented at the 10-year celebration of the Galway statement. Seminar given to Dublin City Council. Discussion of possibilities to extend our work to Dublin City. Presentation of the CLIMAREST project and evaluation of the status of seagrass meadows around Ireland and damage by human pressures
- Dissemination activities
    - Talks in the beach with different partners from for the general public and volunteers.
    - Recording videos of local seagrass from specific demo sites promoting restoration.
    - Recording for the podcast ''RESILIENT SEAS'' with the collaboration of SERE
    - Collaboration with different European partners discussing seagrass restoration
    - Collaboration with different companies and NGOS.
- Media (newspaper)
    - https://www.irishtimes.com/environment/2023/08/12/seagrasses-are-a-precious-resource-and-need-protection/
    - https://www.irishtimes.com/environment/2024/01/01/satellite-technology-that-could-help-local-authorities-predict-buildups-of-smelly-seaweed-developed/

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