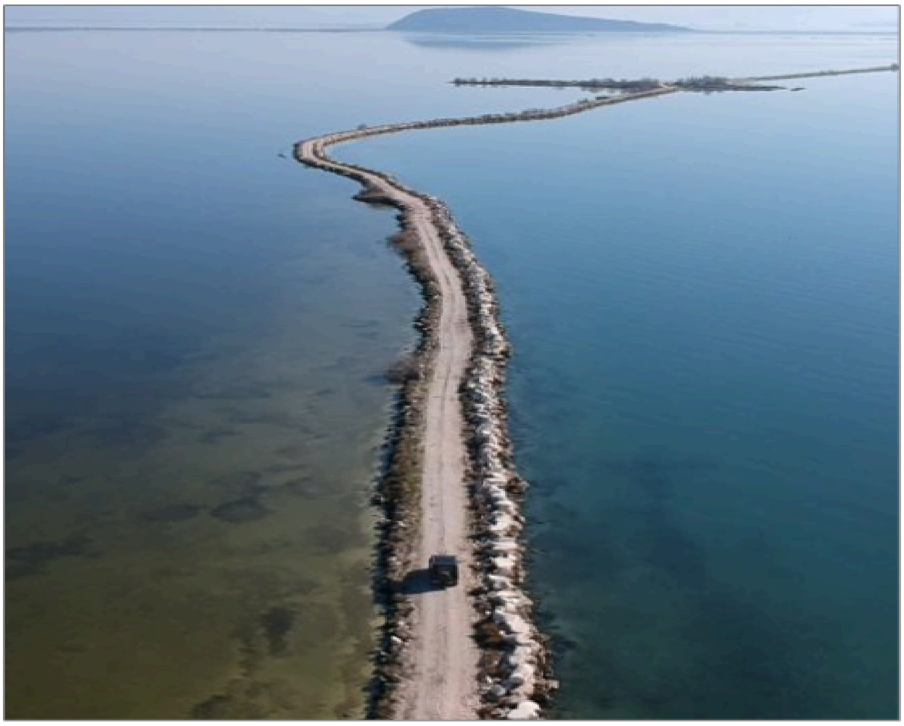
LIFE19NAT/IT/000264 LIFE-TRANSFER
Seagrass transplantation for transitional Ecosystem Recovery

ACTION D.4: Final Monitoring report of C4 action

SubAction D.4.1 Monitoring angiosperm growth

SubAction D.4.2 Monitoring biodiversity and the environmental quality status



Beneficiary responsible for implementation: HCMR

Status: Final

Deadline: 01/11/2025

Contributors: Laura Bray, Vasilis Gerakaris, Nikolaos Providakis, Anastasios Triantafylidis, Nikolaos Katsiaras, Emmanuela Voutsinas, Ioanna Drakolopoulou, Georgia Sarafeidou, Giorgos Arvanitakis, Evgenia Apostolakis, Sofia Reizopoulou

Page left blank for printing

Executive Summary

This report presents the full scope of restoration and monitoring activities conducted in the Amvrakikos lagoon complex, Greece, under the LIFE-TRANSFER project (Actions C4 and D4) from 2021 to 2025. The primary aim was to restore degraded *Zostera noltei* meadows in Logarou Lagoon through transplantation from the healthy donor site of Mazoma lagoon, and to rigorously monitor the ecological, physico-chemical, and socio-economic impacts of these interventions. This work represents the first large-scale *Zostera noltei* transplantation effort in Greece and provides a comprehensive case study for seagrass restoration in Mediterranean lagoons.

The project's approach combined technical innovation, adaptive management, and strong stakeholder engagement. Transplantation protocols were adapted from established LIFE methodologies but required significant modification for Greek lagoon conditions, including the development of new tools and techniques for sod extraction, handling, and hand-planting. Restoration sites were selected based on proximity to existing healthy meadows, substrate suitability, and environmental monitoring data. The project also tested novel planting patterns, such as the "dice" (quincunx) configuration, to evaluate their effect on survival and clonal expansion.

Rigorous monitoring was central to the project. Survival, rooting, and expansion of transplanted sods were tracked alongside comprehensive assessments of water and sediment quality, benthic macrofaunal and macroalgal communities, and ecological status using multi-metric indices (M-AMBI, BITS, MaQI). The monitoring programme was responsive, with increased frequency and the installation of permanent loggers after the first year to capture key stressors such as high summer temperatures and turbidity.

Initial results from 2021–2022 revealed significant challenges, with low survival rates and high failure of pilot plots, largely due to macroalgal blooms and episodic environmental stress. In response, the project implemented a strategic shift: failed sites were abandoned, and new plots were established adjacent to existing healthy meadows. This adaptive approach, combined with precise hand-planting, led to a marked improvement in survival and meadow expansion in 2023 – 2025. Notably, survival rates rose from less than 1% in 2022 to over 37% in the most recent campaign (2025), and several plots recorded substantial net gains in seagrass coverage.

Environmental monitoring confirmed that both donor and recipient sites maintain generally suitable conditions for *Zostera noltei*, though recipient sites are characterized by higher salinity and persistent turbidity. Sediment analyses showed high organic carbon and fine particle content at both donor and successful recipient sites, supporting the blue carbon potential of restored meadows.

Biodiversity assessments demonstrated that successful transplant sites developed diverse, well-structured benthic communities, with increased species richness and prevalence of sensitive taxa. Ecological quality status, as measured by M-AMBI and MaQI, improved or was maintained at most transplant and central lagoon sites, with LOG_MON_B consistently achieving “Good” status by 2024–2025. However, the donor site, MAZ_MON_1, exhibited a decline in status in the final year, highlighting the need for continued monitoring and management.

The participatory approach, involving local fishermen, site managers, and the broader community, was key to the project’s success, building capacity and fostering stewardship. The lessons learned—particularly the importance of adaptive management, high-frequency monitoring, and evidence-based site selection—provide a transferable model for future restoration efforts in Greece and the wider Mediterranean.

In summary, the LIFE-TRANSFER project demonstrates that large-scale seagrass restoration in Mediterranean lagoons is challenging but achievable. The project’s adaptive, science-based approach resulted in measurable ecological gains and a significant increase in restored seagrass habitat coverage. Continued monitoring and flexible management will be essential to consolidate these gains, address emerging challenges, and secure the long-term conservation of priority habitat 1150 and the broader lagoon ecosystem

Introduction

The Amvrakikos Gulf, a Natura 2000 site, is one of the most ecologically significant lagoon complexes in Greece, hosting the priority habitat 1150—coastal lagoons with submerged angiosperms. The region is characterized by a mosaic of lagoons, salt marshes, and seagrass beds, which support high biodiversity and provide essential ecosystem services, including fisheries support and blue carbon storage. In recent decades, anthropogenic pressures and climate variability have led to the decline of seagrass meadows, particularly Zostera noltei, with cascading effects on biodiversity, water quality, and local livelihoods.

The Greek component of the LIFE-TRANSFER project was designed to restore degraded *Zostera noltei* meadows in Logarou lagoon via transplantation from Mazoma lagoon. In addition, the ecological impacts of restoration were quantified through comprehensive monitoring of angiosperm growth, biodiversity, and environmental quality. Stakeholder engagement was a cornerstone of the project. The two Fishermen’s Associations (Lofarou and Mazoma) played a direct role in transplantation and monitoring, supported by training from the Hellenic Centre for Marine Research (HCMR) and the Amvrakikos National Park Authority (ALMA), and the Ministry of

Environment & Energy provided regulatory oversight and strategic guidance. Local communities, students, and site managers were involved through educational events, awareness campaigns, and dissemination activities, ensuring broad support for restoration actions.

Mazoma Lagoon, was selected as a donor site for its healthy, dense *Zostera noltei* meadows and proximity to Logarou (approximately 45 minutes by car), minimizing transport stress. The recipient site was identified as Logarou lagoon, a historically important but degraded seagrass habitat. All necessary permits were secured from the National Park Authority, and the project received formal support from the Ministry of Environment & Energy and local authorities. The participatory approach ensured that restoration actions were aligned with regional conservation strategies and local socio-economic needs.

Transplantation Protocol and Technical Adaptation

The transplantation protocol for Zostera noltei in Amvrakikos/Logarou was designed drawing on established best practices from previous successful LIFE projects (notably LIFE SeResto NAT/IT/000331), but required significant adaptation to the unique environmental and logistical conditions of the Greek lagoons. The protocol is laid out in detail in Deliverable D4 - First monitoring report, but the key technical points are highlighted below:

- Extraction method

Sods of Zostera noltei, each 15 cm in diameter, were extracted using a stainless steel corer by the local fisherman, following a strictly manual, low-impact approach. Each sod typically contained 25–30 rhizomes, with associated sediment and root structure intact to maximize post-transplant viability. Sods were immediately placed in perforated buckets filled with lagoon water to prevent desiccation and physiological stress. Sods were only extracted from robust, well-structured meadows in Mazoma lagoon, ensuring negligible long-term disturbance (<1.3 m² per 72 sods per campaign).

- Handling and transport

Sods were kept submerged and shaded at all times during handling and transport. The short distance between Mazoma (donor) and Logarou (recipient) allowed for extraction, transplantation and transplantation to occur within a timespan of approximately three hours, in line with best practice to avoid loss of plant vitality.

- Transplantation

Transplantation was performed from small boats, with sods planted in clusters within marked 10 x 10 m plots at selected stations. The initial campaign used tools and methods adapted from the Venice lagoon (LIFE SeResto), but low visibility and muddy substrate in Logarou necessitated the rapid design and testing of new tools by spring 2022 (Deliverable D4 - Second monitoring report). Transplants were scheduled for periods of optimal environmental conditions (primarily spring to co-align with suitable growth periods), and sites were selected based on substrate suitability and proximity to remnant meadows to enhance natural seed dispersal and clonal spread. All activities were coordinated with the Amvrakikos National Park Authority, local fishermen, and the Ministry of Environment & Energy, ensuring compliance and local support.

Three main areas of transplantation were initially identified within Logarou lagoon as Agios Nikolaos (LOG_MON_A), Vasiladi (LOG_MON_B), and Gimeni (LOG_MON_D) (Figure x). The sites were primarily selected based on important factors such as distance from lagoon openings, proximity to existing seagrass meadows, water depth, and turbidity (Deliverable D4 - First monitoring report).

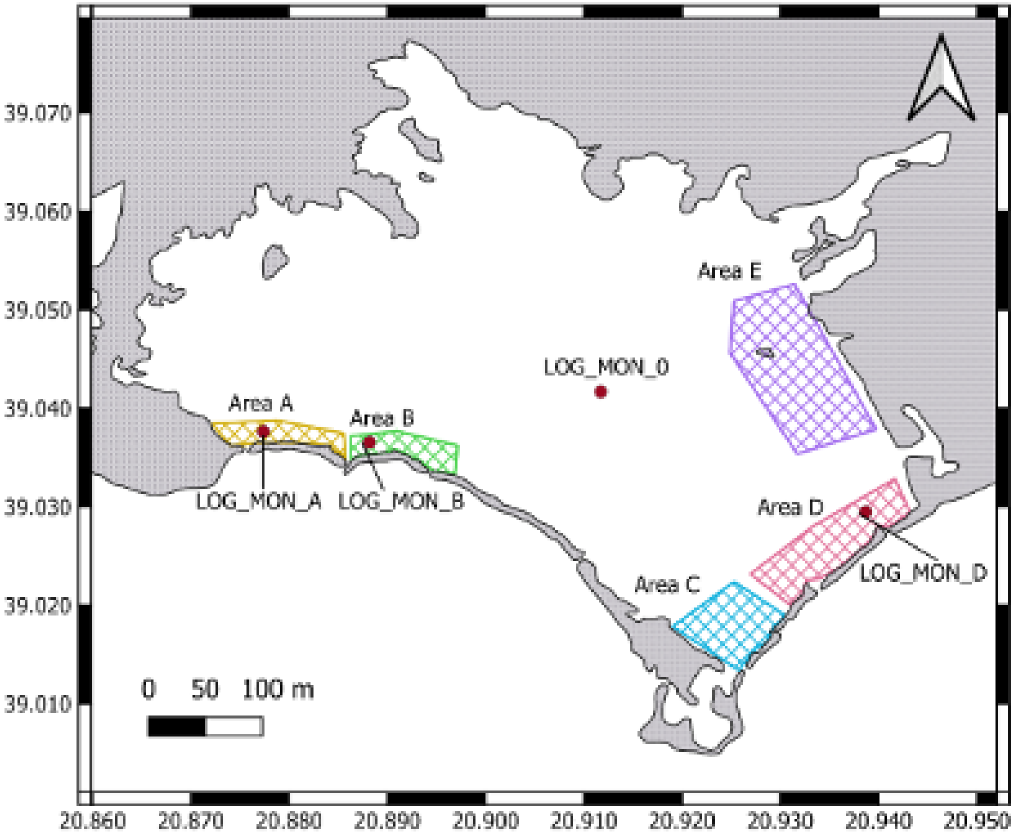


Figure 1. Map of the recipient lagoon (Logarou), as well as all main monitoring and transplantation sites.

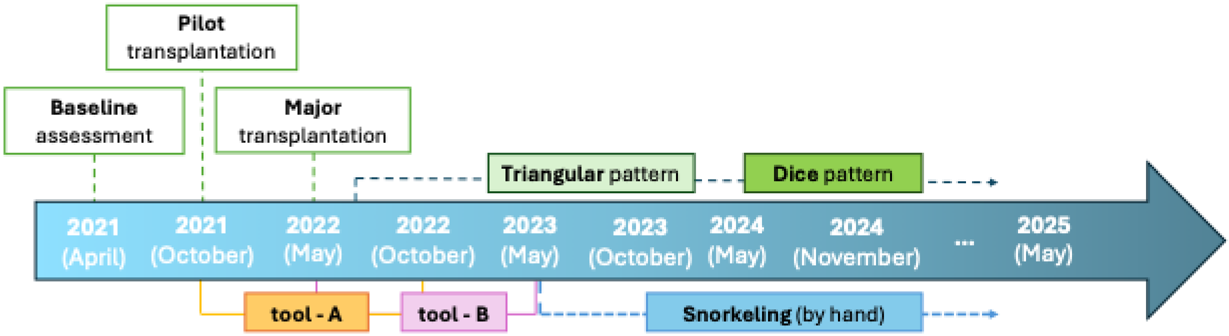


Figure 2. Timeline of key transplantation campaigns, technical adaptations, and major project milestones from 2021 to 2025.

Table 1. Summary of transplantation campaigns: number of sods, stations, and total area planted in each year (2021–2025).

	2021		2022		2023		2024	
Restoration Area	Total number of sods	Total number of Rhizomes (shoots) *	Total number of sods	Total number of Rhizomes (shoots) *	Total number of sods	Total number of Rhizomes (shoots) *	Total number of sods	Total number of Rhizomes (shoots) *
LOG_MON_A	-	-	54	900	54	900	27	675
LOG_MON_B	-	-	54	900	54	900	36	900
LOG_MON_D	18	450	54	900	-	-	-	-
LOG_MON_0	-	-	-	-	-	-	25	625

D.4.1 Monitoring angiosperm growth

In this sub-action, the monitoring of angiosperm rooting and growth was carried out by evaluating the following parameters:

i) survival rate of transplanted sods,

ii) growth rate of each transplanted sod and

iii) coverage estimation of the newly formed meadows.

Below is an overview of the monitoring results from the whole project

2021 - 2022 (Initial pilot sites)

In October 2021, 18 sods were transplanted at two stations in Area D to test the equipment and initial methodology (Figure 3A) and a further 4000 rhizomes transplanted across 16 stations in May of 2022 (Yellow symbols, Figure xB). Despite an initial positive six-month survival rate for the first two stations planted (average 78%), the average survival rate for all 18 sites after 12 months of monitoring for the sights was extremely low 0.08% (Table x).

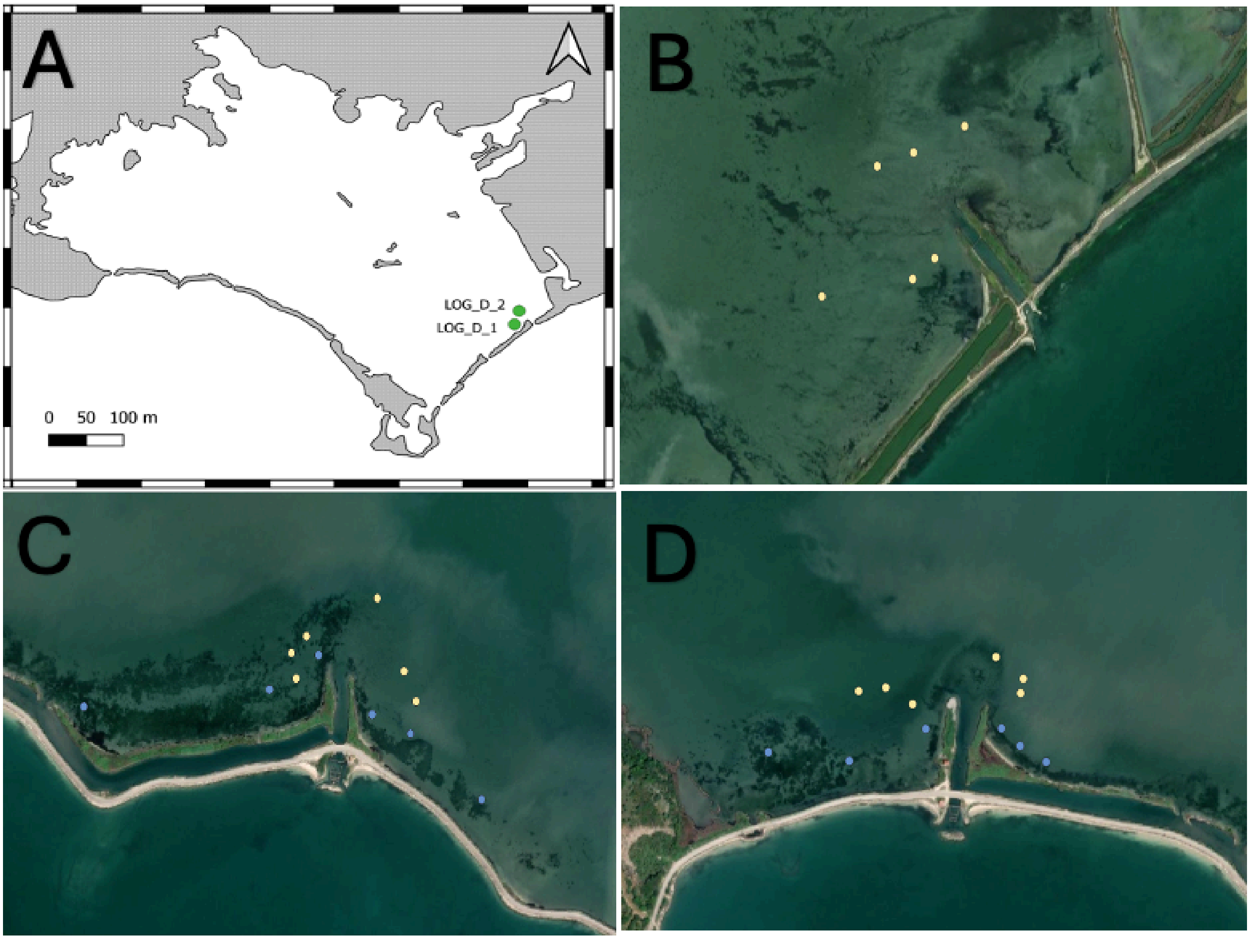


Figure 3. Maps of transplantation sites of Zostera noltei for A) the first transplantation campaign in 2021 in Area D (Gimeni), B) The total transplanted sites in Area D (Gimeni), C) The total transplanted sites in Area C (Vasiliadi) and D) the total transplant sites in Area A (Agios Nikolaus). The yellow symbols represent the sites transplanted during 2021 - 2022, the yellow sites are the areas transplanted from 2023 onwards.

Table 2. Sod survival rates and net changes in seagrass meadow surface area for all pilot sites after 12 months (2021–2022).

Station code	Average sod survival 6 months (%) (2021 - 2022)	Average sod survival 12 months (%) (2021 - 2022)	Most recent restoration site coverage (%) (2022)
LOG_D_1	100	22	0.16
LOG_D_2	56	11	0.03
LOG_D_3	11	0	0.02
LOG_D_4	0	0	0
LOG_D_5	0	0	0
LOG_D_6	0	0	0
LOG_A_1	0	78	0.12
LOG_A_2	0	0	0
LOG_A_3	0	0	0
LOG_A_4	0	0	0
LOG_A_5	0	0	0
LOG_A_6	0	0	0
LOG_B_1	0	0	0
LOG_B_2	0	0	0
LOG_B_3	0	0	0
LOG_B_4	0	33	0.05
LOG_B_5	0	0	0
LOG_B_6	0	0	0

In total for the 2021 - 2022 period, 94% (17/18) of the transplant plots completely failed and 2.48m^2 of seagrass meadows were lost (sods extracted from Mazoma lagoon which then failed to expand/survive in Logarou) due to the transplant activities of the project (Table x). In response to this a decision were made to increasd monitoring frequency and installed permanent sensors for temperature, conductivity, and light to providesuitable temporal scales for monitoring, and site selection criteria was adjusted to prioritize proximity to existing healthy meadows. Contingency plans were also established for sod replacement and site abandonment in areas with persistent macroalgal blooms (eg. Figure x).

Table 3. Changes in surface area of seagrass meadows after transplantation for pilot sites after 12 months (2021 - 2022)

Station	Area Transplanted (m²)	Gained Surface Area (m²)	Lost Surface Area (m²)
LOG_D_1	0.16	0	0
LOG_D_2	0.16	0	0.13
LOG_D_3	0.16	0	0.14
LOG_D_4	0.16	0	0.16
LOG_D_5	0.16	0	0.16
LOG_D_6	0.16	0	0.16
LOG_A_1	0.16	0	0.16
LOG_A_2	0.16	0	0.16
LOG_A_3	0.16	0	0.16
LOG_A_4	0.16	0	0.16
LOG_A_5	0.16	0	0.16
LOG_A_6	0.16	0	0.16
LOG_B_1	0.16	0	0.16
LOG_B_2	0.16	0	0.16
LOG_B_3	0.16	0	0.16
LOG_B_4	0.16	0	0.16
LOG_B_5	0.16	0	0.16
LOG_B_6	0.16	0	0.16
Total	**2.86**	**0**	**2.48**

2023 - 2025 (Strategic Shift)

After the extremely low survival rate of 0.82% in 2022, a comprehensive reassessment of transplantation strategy was undertaken for the 2023 campaign. This shift was driven by the recognition that persistent macroalgal blooms (notably Valonia aegagropila and Chaetomorpha sp.) and suboptimal physicochemical conditions in some areas, especially Site D (Aetos and Gimeni), were major contributors to the failure of previous restoration efforts. Underwater and aerial monitoring during autumn 2022 revealed dense layers of opportunistic macroalgae smothering the sediment and even floating as rafts, making these sites unsuitable for Zostera noltei establishment and prompting their abandonment as restoration targets.

In May 2023, twelve new transplant sites were selected in areas (notably Areas A and B—Agios Nikolaos and Vasiliadi) that were carefully chosen for their proximity (within 5–10 meters) to existing healthy Z. noltei meadows (Blue symbols, Fugue x). This approach was informed by ecological theory and practical experience indicating that closeness to established meadows enhances transplant survival through improved microhabitat conditions, greater genetic connectivity, and more favorable sediment and hydrodynamic regimes. Aerial drone surveys and georeferenced imagery were used to pinpoint these optimal locations, ensuring that each new plot would benefit from the environmental stability and propagule supply associated with established beds. By autumn 2023, the average sod survival rate across all new sites was 46.3%, a dramatic improvement over previous years. However, survival rates varied between sites:

- Area A (Agios Nikolaos) achieved the highest 12-month survival rate at 22.3%, with an average 6-month survival of 55.6% ± 10.2% (table x).
- Area B (Vasiliadi) showed a 6-month survival of 36.8% ± 34.2%, with some plots experiencing total loss, indicating ongoing spatial variability and the influence of microhabitat differences (Table x).

Hand-Placement Technique and Restoration in 2024

Based on monitoring feedback, and to increase the survival rates restoration areas were replanted by hand while snorkeling, rather than from boats. This method allowed for more precise placement and firmer sod fixation in the substrate, which proved especially beneficial in the soft, muddy sediments of Logarou. The 2024 restoration campaign focused on replanting sods in the same favorable areas to replace any losses observed in the previous year, further refining the hand-placement approach to maximize survival. In 2024, the HCMR restoration team also decided to test a new planting methodology by arranging five Zostera noltei sods in the shape of a dice (quincunx pattern)—with one sod at each corner and one in the center of a square—to evaluate whether this spatial configuration could enhance plant establishment, promote clonal expansion, and improve overall survival rates compared to previous triangular or linear layouts (Figure 4). In the 2024–2025 cycle, with further refinement of site selection and transplantation technique, the average one-year survival rate increased to 37% (from 28% 2023 - 2024). These figures reflect the benefits of adaptive management but also highlight the persistent challenges posed by environmental variability and episodic stressors. After six months the initial survival rates of the "dice" methodology seemed promising (52% in October of 2024) the 12 month monitoring campaign registered a complete collapse of the restoration site (0% survival rate) in May 2025 (Table 4).

Table 4. Sod survival rate and transplant site (100m2) coverage for the period 2023 - 2024 and 2024 - 2025 period.

Station code	2023 sod survival 6 months	2023 - 2024 sod survival 12 months	2024 sod Survival 6 months	2024 - 2025 sod survival 12 months	Average sod survival 6 months (2023 - 2025)	Average sod survival 12 months (2023 - 2025)	Most recent restoration site coverage (%)
LOG_A_1_new	0.67	0.56	0.11	0.33	0.39	0.44	80.00
LOG_A_2_new	0.56	0.56	0.78	0.89	0.67	0.72	16.00
LOG_A_3_new	0.44	0.22	1.00	1.00	0.72	0.61	0.00
LOG_A_4_new	0.44	0.00	0.00	0.00	0.44	0.00	0.00
LOG_A_5_new	0.67	0.00	0.00	0.00	0.34	0.00	0.00
LOG_A_6_new	0.56	0.00	0.00	0.00	0.56	0.00	0.00
LOG_B_1_new	0.22	0.22	0.11	0.33	0.17	0.28	1.87
LOG_B_2_new	1.00	0.78	1.00	1.00	1.00	0.89	82.00
LOG_B_3_new	0.22	0.11	0.11	0.67	0.17	0.39	45.00
LOG_B_4_new	0.44	0.56	0.89	0.67	0.67	0.61	15.00
LOG_B_5_new	0.33	0.33	0.00	0.00	0.33	0.17	0.00
LOG_B_6_new	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LOG_MON_0	-	-	0.52	0.00	0.52	0.00	0.00

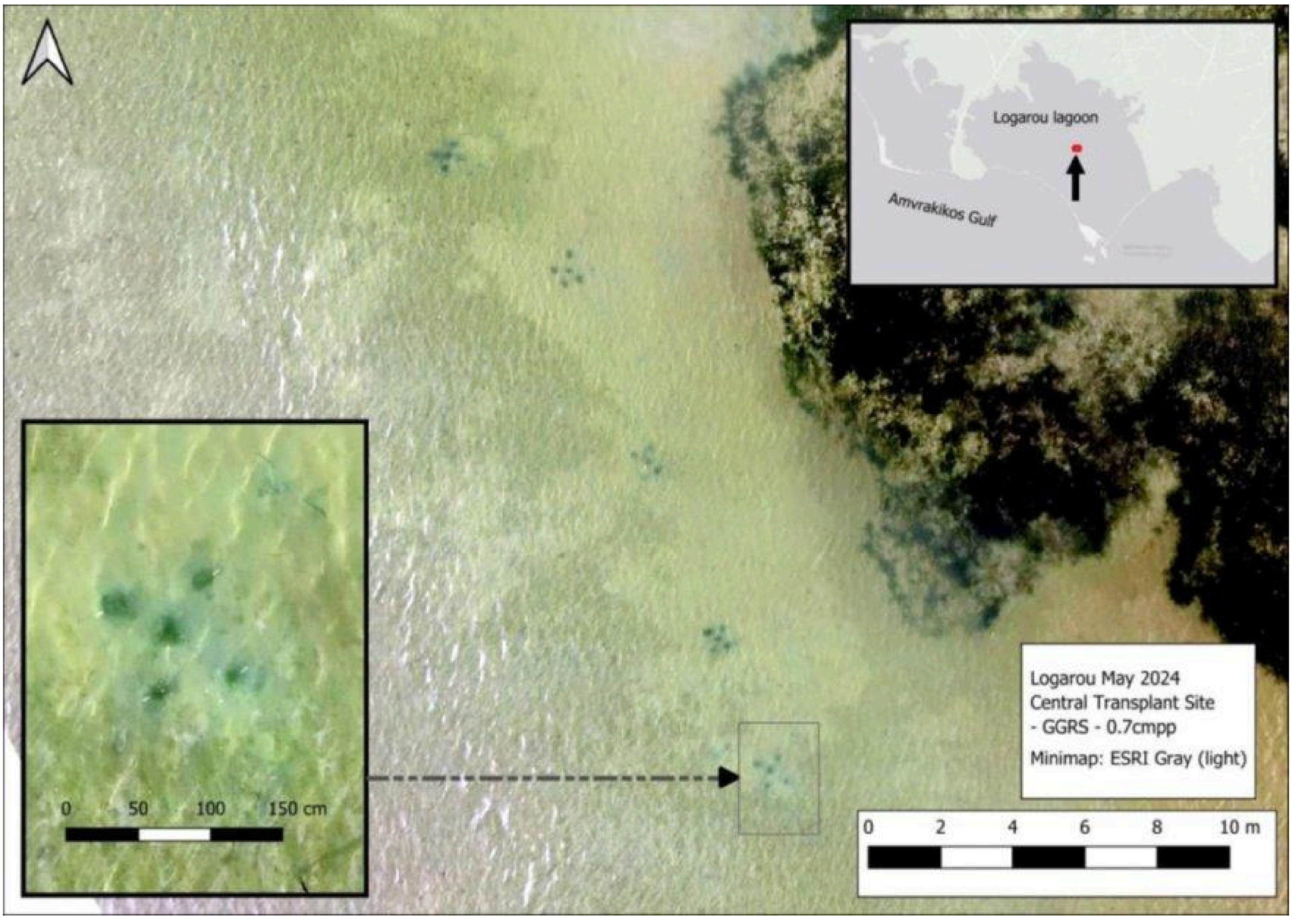


Figure 4. Example of the “dice” (quincunx) planting pattern tested in 2024 at the LOG_MON_0 site, illustrating sod arrangement for enhanced survival and clonal expansion.

For the 2023 - 2024 period, 33% of the transplants plots completely failed (4/12 plot) (Table 5), but in total there was a net gain of 72.56m^2 (Table 5). In the 2024 - 2025 period only one plot completely failed and there was a net surface area gain of 238.32m^2 (Table 5).

Table 5. Changes in surface area of seagrass meadows after transplantation for pilot sites afte 12 months (2023 - 2024, 2024 - 2025)

	2023 - 2024			2024 - 2025		
Station	Area Transplanted (m²)	Created Surface Area (m²)	Lost Surface Area (m²)	Area Transplanted (m²)	Created Surface Area (m²)	Lost Surface Area (m²)
LOG_A_1_new	0.16	19.83	0	0.16	79.84	0
LOG_A_2_new	0.16	2.96	0	0.16	15.84	0

LOG_A_3_new	0.16	0.31	0	0.16	0	0.16
LOG_A_4_new	0.16	0	0.16	-	-	-
LOG_A_5_new	0.16	0	0.16	-	-	-
LOG_A_6_new	0.16	0	0.16	-	-	-
LOG_B_1_new	0.16	0.16	0	0.16	1.71	0
LOG_B_2_new	0.16	46.91	0	0.16	81.84	0
LOG_B_3_new	0.16	0	0.14	0.16	44.84	0
LOG_B_4_new	0.16	0.19	0	0.16	14.84	0
LOG_B_5_new	0.16	2.98	0	-	-	-
LOG_B_6_new	0.16	0	0.16	-	-	-
LOG_MON_0	-	-	-	0.43	0	0.43
Total	**1.92**	**73.34**	**0.78**	**1.55**	**238.91**	**0.59**

D.4.2 Monitoring biodiversity and the environmental quality status (2021 - 2025)

Presented below is an overview of the monitoring results from the final year of transplantation based on the monitoring protocol for physico-chemical parameters, biodiversity and ecological quality outlined in the first monitoring report. In total two reference stations for each lagoon (donor site: MAZ_MON and recipient site: LOG_MON_0) are monitored to assess the overall biodiversity and environmental quality status of the lagoons as is commonly implemented in national monitoring projects (e.g. Water Framework Directitve (Executive project), the locations of which are shown below in Figure 12. In addition, the monitoring sites that are in close proximity to the seagrass transplant sites (Log_Mon_A, Log_Mon_ B).

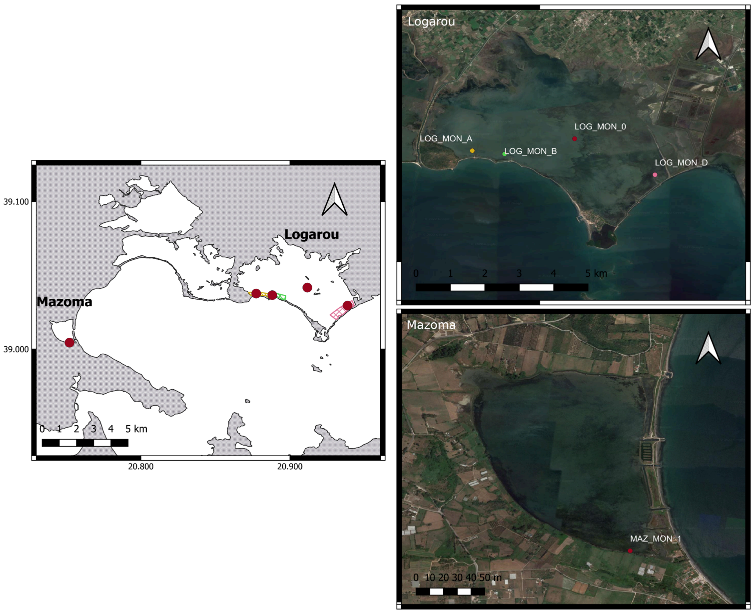


Figure 5. Map of the Amvrakikos lagoon complex showing the locations of the donor (Mazoma) and recipient (Logarou) lagoons, as well as all main monitoring and transplantation sites.

Water column hydrological parameters

Throughout the project (2021–2025), water column hydrological parameters were monitored at all main restoration and reference sites in the Amvrakikos lagoon complex, including both donor (Mazoma) and recipient (Logarou) lagoons. The monitoring protocol, harmonized with the Water Framework Directive and national standards, included temperature, salinity, dissolved oxygen, pH, and water visibility as key indicators of environmental quality and suitability for *Zostera noltei* restoration.

Across all sites, mean temperatures ranged from 18.8°C to 21.5°C (Figure 6), with seasonal peaks exceeding 30°C during summer heatwaves. High summer temperatures (above 30°C for >20 days in both 2023 and 2024) were recorded by in situ loggers (Figure 7), representing a significant stressor for *Zostera noltei*. The Logarou recipient sites showed high and relatively stable salinity (mean 39.2–45.5 PSU), typical of restricted Mediterranean lagoons with strong evaporation and limited freshwater input. Mazoma lagoon, the donor site, exhibited slightly lower salinity (mean 29.0 PSU), consistent with a system with a greater freshwater influence and more brackish conditions (Figure 6).

Most sites maintained high dissolved oxygen, generally 80–94%, indicating well-oxygenated conditions except for May 2025 when short-term hypoxia was observed. Mazoma showed the highest mean oxygen saturation (97.5%), while some recipient sites (e.g., LOG_D_1) had lower values (80%). pH values were stable and alkaline across all sites (range 8.00–8.49), with no evidence of acidification stress. Water clarity was generally low throughout the monitoring period, with mean Secchi depth values ranging from 0.23 m (LOG_A_1_new) to 0.65 m (LOG_MON_0). High turbidity is a persistent feature of Logarou, limiting light penetration and potentially constraining seagrass photosynthesis and recovery.

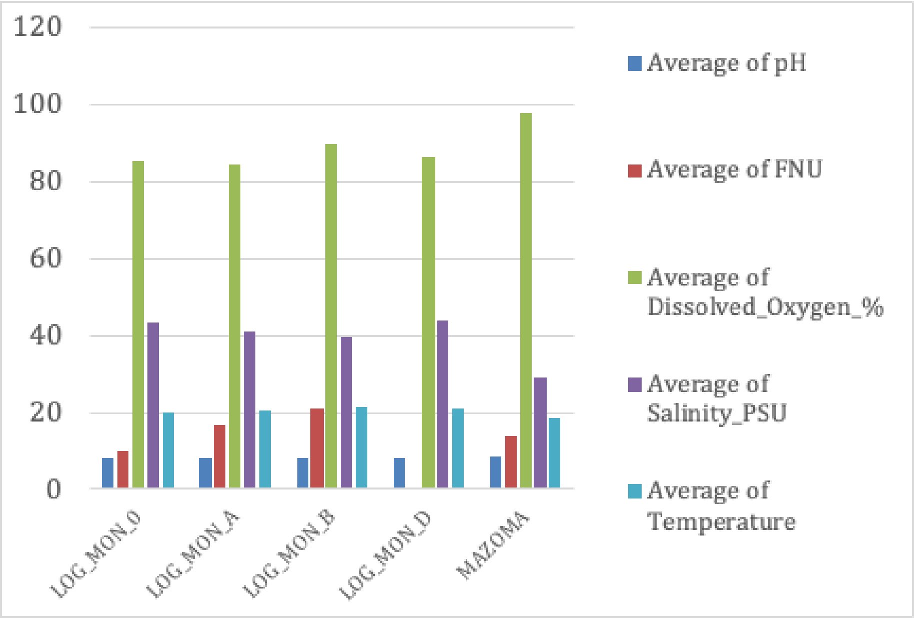


Figure 6. Mean hydrological parameters (temperature, salinity, dissolved oxygen, pH, visibility) at main monitoring stations in Mazoma and Logarou lagoons, 2021–2025.

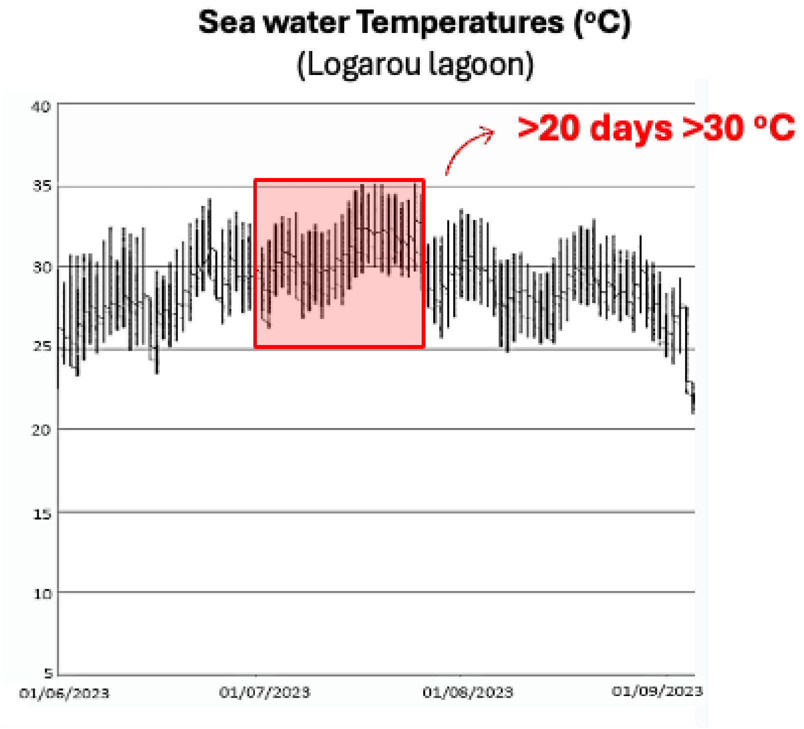


Figure 7. High-frequency logger data showing daily water temperature fluctuations at recipient sites during summer 2023 with periods exceeding 30°C highlighted.

Table 6. Mean Hydrological Parameters by Monitoring Station (2021–2025) for sampling campaigns (May, October)

Station	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (%)	pH	Visibility (m)
LOG_MON_A	19.0 ± 2.0	44.4 ± 2.1	93.6 ± 8.2	8.32 ± 0.13	0.23 ± 0.07
LOG_MON_B	21.5 ± 2.2	39.5 ± 1.7	90.6 ± 9.8	8.38 ± 0.12	0.38 ± 0.10
LOG_MON_D	20.6 ± 1.9	45.5 ± 2.2	80.0 ± 10.1	8.10 ± 0.10	0.50 ± 0.12
LOG_MON_0	20.1 ± 1.8	43.2 ± 1.7	85.2 ± 9.5	8.23 ± 0.11	0.65 ± 0.13
MAZ_MON_0	18.8 ± 1.7	29.0 ± 1.5	97.5 ± 7.2	8.49 ± 0.14	0.47 ± 0.10

The broad similarity in temperature, oxygen, and pH between donor and recipient sites supports the suitability of Mazoma as a donor for Logarou restoration. However, the higher salinity and lower visibility in Logarou represent ongoing challenges for *Zostera noltei* establishment and expansion. Episodes of high temperature and low visibility, particularly during summer, were identified as key stressors that coincided with periods of low transplant survival and macroalgal blooms, especially in 2022–2023, and the installation of permanent loggers and increased monitoring frequency after 2022 allowed for more precise tracking of these parameters and informed the strategic shift in site selection and transplantation timing in later years (2023 - 2025).

Sediment parameters

Sediment monitoring was conducted at all main donor (Mazoma) and recipient (Logarou) stations throughout the project to assess the suitability of sites for Zostera noltei restoration and to track any changes associated with transplantation activities. The following parameters were measured in the upper 2 cm of sediment: organic carbon (%OC), total carbon (%TC), total nitrogen (%TN), percentage of fines (<63 µm), and dry bulk density. For Organic Carbon (%OC), All stations, both donor (MAZ_MON_1) and recipient (LOG_MON_A, LOG_MON_B, LOG_MON_0), maintained high organic carbon content (2.5–3.9%), with the highest values at LOG_MON_0 (3.9 ± 2.0%) and LOG_MON_A (3.5 ± 0.2%). This is typical of muddy, vegetated lagoon sediments and supports seagrass establishment and blue carbon storage (REFERENCE). Total Carbon (%TC): Ranged from 3.9 ± 0.0% (MAZ_MON_1) to 5.3 ± 0.0% (LOG_MON_0). These values indicate a substantial carbon pool in both donor and recipient sediments. Total Nitrogen (%TN) were highest at LOG_MON_A (0.6 ± 0.1%), with other stations ranging from 0.3–0.5%. Elevated nitrogen supports primary productivity but may also reflect organic enrichment. All sites are dominated by fine sediments.

Table 7) Summary Table of sediment parameters by Station (mean ± SD) for the duration of the project

Station	% Organic Carbon (OC)	% Total Carbon (TC)	% Total Nitrogen (TN)	% Fines (<63 µm)
LOG_MON_A	3.5 ± 0.2	4.2 ± 0.0	0.6 ± 0.1	80.7 ± 25.6
LOG_MON_B	3.4 ± 0.0	4.1 ± 0.0	0.5 ± 0.0	96.4 ± 2.8
LOG_MON_D	2.5 ± 0.0		0.3 ± 0.0	72.9 ± 30.9
LOG_MON_0	3.9 ± 2.0	5.3 ± 0.0	0.4 ± 0.3	70.7 ± 18.0
MAZ_MON_1	3.5 ± 1.2	3.9 ± 0.0	0.4 ± 0.2	88.2 ± 11.5

This fine sediment texture is optimal for *Zostera noltei* rooting and expansion, and is characteristic of confined Mediterranean lagoons. LOG_MON_0 and LOG_MON_A show higher variability in organic carbon and fines, likely reflecting both natural spatial heterogeneity and the influence of restoration activities. The more successful transplant plots (LOG_MON_A, LOG_MON_B) show sediment quality comparable to the donor site, supporting the positive impact of restoration on sediment carbon and nitrogen pools (Figure 8).

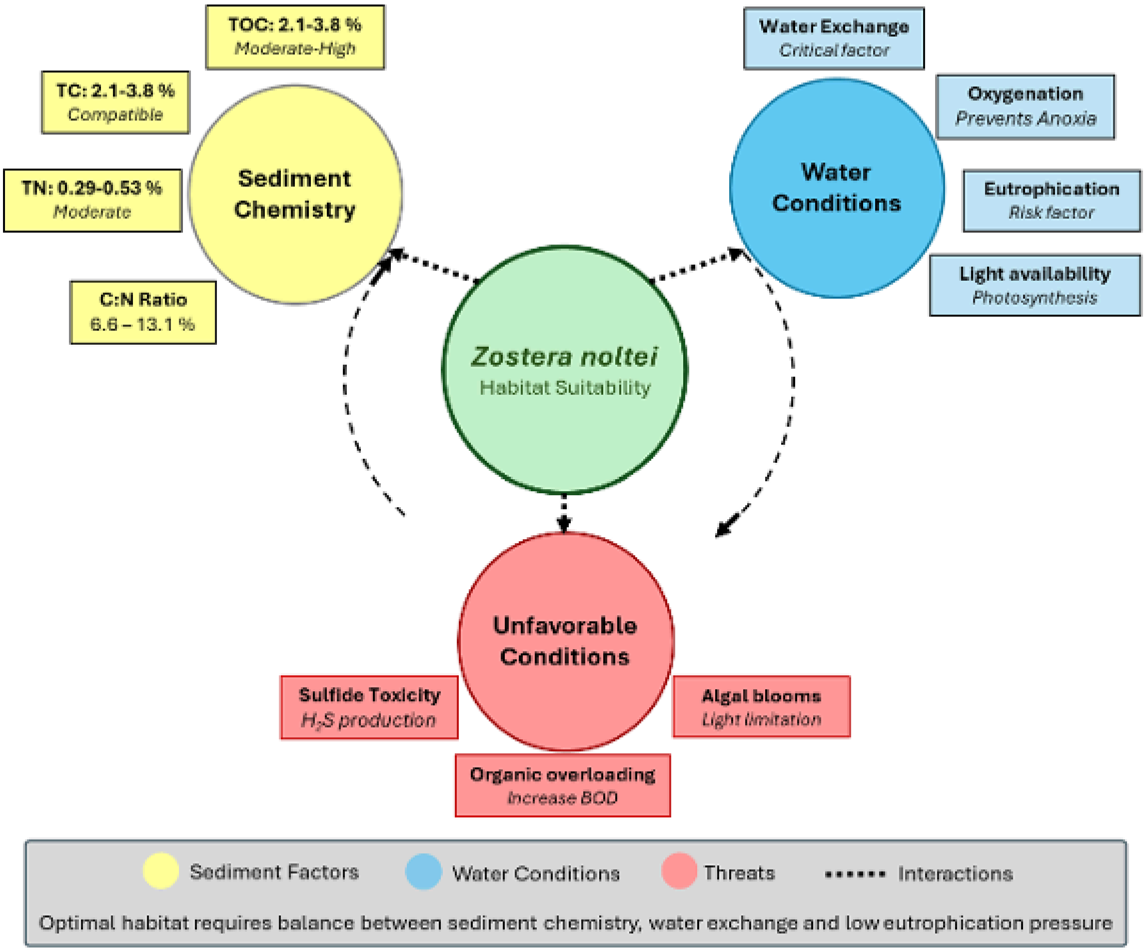


Figure 8 Summary of relationships between sediment factors, water conditions and threats from Zostera noltei restoration

Biodiversity metrics

The comparative analysis of biodiversity at the Logarou (recipient) and Mazoma (donor) sites, as summarized in the table above, highlights distinct patterns in species richness, persistence, and turnover over the five-year monitoring period. Notably, Logarou consistently supports a greater number of unique species and a higher average annual presence than Mazoma, indicating a more dynamic or variable community structure. The low number of species present across all years at both sites underscores the temporal variability and the influence of environmental or management factors on community composition. These findings, as detailed in the table, provide a clear basis for ongoing monitoring and targeted management to sustain and enhance biodiversity at both locations.

Table 8. Species presence-absence matrix for fish, macroalgae, and maccroinvertebrates per year (2021 - 2025) for recipient and donor site.

	Logarou (Recipient site)					Mazoma (Donor site)				
	2021	2022	2023	2024	2025	2021	2022	2023	2024	2025
FIsh										
Aphanius fasciatus	+	-	-	-	-	+	-		-	-
Atherina boyeri	-	-	-	-	-	+	-	+	-	-
Gobiidae sp.	-	-	-	-	-	-	-	+	-	-
Knipowitschia milleri	+	-	-	-	-	+	-	-	-	-
Salaria pavo	-	-	-	-	-	+	-	+	-	-
Syngnathus typhle	+	-	-	-	-	+	-	+	-	-
Macroalgae										
Palisada perforata	-	-	-	-	-	-	-	+	-	-
Acetabularia acetabulum	+	-	-	+	-	-	-	-	-	-
Aglaothamnion caudatum	-	-	-	-	-	-	-	-	+	-
Alsidium corallinum	+	-	-	-	-	-	-	-	-	-
Ceramium sp.	-	-	-	+	-	-	+	+	-	-
Chaetomorpha aerea	-	+	-	+	-	-	+	-	+	-
Chaetomorpha ligustica	-	-	-	-	-	-	-	+	-	-
Chaetomorpha linum	+	-	-	-	-	-	-	+	-	-
Chaetomorpha sp	-	-	-	-	-	+	-	-	-	-
Champia parvula	-	-	-	-	-	+	-	+	-	-
Chondria capillaris	+	-	-	-	-	+	-	+	-	-

Chylocladia verticillata	-	+	-	+	-	-	+	-	+	-
Cladophora sp.	-	+	-	+	-	-	+	+	-	-
Cyanophyceae sp.	+	-	-	-	-	+	-	-	-	-
Gracilaria bursa-pastoris	+	-	-	-	-	-	-	-	-	-
Gracilaria gracilis	-	-	-	-	-	+	-	+	-	-
Laurencia obtusa	+	-	-	-	-	-	-	-	-	-
Lithophyllum pustulatum	-	-	-	-	-	-	+	-	-	-
Pneophyllum fragile	-	-	-	-	-	-	-	+	-	-
Polysiphonia elongata	-	-	-	+	-	-	+	-	-	-
Polysiphonia sp.	-	-	-	-	-	-	-	+	-	-
Valonia aegagropila	+	+	-	-	-	-	-	-	-	-
Macroinvertebrates										
Abra segmentum	+	+	+	+	+	-	+	+	-	-
Amphibalanus amphitrite	-	-	-	+	-	-	-	-	-	-
Amphipholis squamata	-	-	-	+	-	-	-	-	-	-
Aplysia punctata	-	-	-	+	-	-	-	-	-	-
Armandia cirrhosa	-	+	-	+	-	-	-	-	-	-
Armandia cirrhosa	-	-	+	-	-	-	-	+	-	-
Callinectes sapidus	-	-	-	-	+	-	-	-	-	-
Capitella capitata	+	+	-	+	-	+	-	-	-	-
Capitella minima	-	-	+	+	-	-	-	-	-	-
Caprella scaura	-	-	-	-	+	-	-	-	-	-
Cerastoderma glaucum	-	+	-	+	+	-	+	+	+	+
Chironomidae sp.	-	-	-	-	-	+	+	-	-	-
Chondrochelia savignyi	-	-	+	-	-	-	-	-	-	-
Corophiidae sp.	-	-	-	+	-	-	-	-	-	-
Decapoda sp.	-	-	-	+	-	-	-	-	-	-
Dexamine spinosa	-	-	+	+	+	-	-	+	+	-
Ecrobia sp.	-	-	+	-	+	-	-	-	-	-

Ericthonius argenteus	-	-	-	+	-	-	-	-	+	-
Ericthonius sp.	-	-	-	-	-	-	-	+	-	-
Ericthonius punctatus	-	-	+	-	-	-	-	-	-	-
Eumida sanguinea	-	-	-	+	-	-	-	-	-	-
Gammarus aequicauda	-	-	+	-	-	-	+	-	-	-
Gammarus insensibilis	-	-	-	+	+	-	+	-	+	-
Gammarus sp.	-	-	-	-	-	-	+	-	-	-
Haminoea navicula	-	-	-	-	+	-	-	-	-	-
Haminoea orbignyana	-	-	-	+	-	-	-	-	-	-
Harmothoe sp.	-	-	-	-	+	-	-	-	-	-
Harmothoe imbricata	-	-	+	+	+	-	-	-	-	-
Heteromastus filiformis	-	-	-	+	+	-	-	-	+	-
Hexaplex trunculus	-	-	-	+	-	-	-	-	-	-
Hydrobiidae sp.	-	-	-	+	-	-	-	-	-	-
Hydroides dianthus	-	-	+	+	+	-	-	-	+	-
Idotea balthica	+	+	+	+	+	+	-	-	-	+
Iphinoe acutirostris	-	-	-	+	-	-	-	-	-	-
Iphinoe elisae	-	-	-	+	-	-	-	+	+	-
Iphinoe sp.	-	-	-	+	-	-	-	+	-	-
Iphinoe inermis	-	-	-	+	+	-	-	-	+	-
Iphinoe maculata	-	-	-	+	-	-	-	-	-	-
Iphinoe tenella	-	-	-	+	+	-	-	+	-	+
Lekanesphaera monodi	+	+	+	+	+	+	+	-	-	-
Leptoplana sp.	-	-	-	+	-	-	-	-	-	-
Loripes orbiculatus	-	-	+	+	+	-	-	-	-	-
Malmgrenia ljungmani	-	-	-	+	-	-	-	-	-	-
Microdeutopus sp.	+	-	-	-	-	+	-	-	-	-

Microdeutopus gryllotalpa	+	-	+	+	+	+	-	-	+	-
Microprotopus maculatus	-	+	-	+	+	-	-	-	-	-
Monocorophium acherusicum	-	-	-	-	+	-	-	+	+	+
Monocorophium sp.	-	-	-	-	-	-	-	+	-	-
Monocorophium insidiosum	+	-	+	-	-	+	+	+	-	-
Mysidae sp.	-	-	+	+	+	-	-	-	+	-
Mytilaster minimus	-	+	+	+	-	-	+	+	+	-
Naineris laevigata	+	+	+	+	+	+	-	-	-	-
Nematoda sp.	-	-	-	+	-	-	-	-	-	-
Nemertea sp.	-	-	+	-	-	-	-	+	-	-
Nephtys hombergii	-	+	+	+	+	-	-	+	+	+
Nereiphylla rubiginosa	-	+	+	+	-	-	-	-	-	-
Oligochaeta sp.	-	+	+	+	+	+	-	-	-	-
Pantopoda sp.	-	-	+	-	-	-	-	-	-	-
Paranemonia cinerea	-	-	+	+	+	-	-	-	-	-
Perinereis cultrifera	-	-	-	+	-	-	-	-	-	-
Phascolosoma sp.	-	-	-	+	-	-	-	-	-	-
Phyllodocidae sp.	-	-	-	-	+	-	-	-	-	-
Platynereis dumerilii	-	-	+	+	-	-	-	-	-	-
Polydora sp.	-	-	-	+	-	-	-	-	-	-
Polydora cornuta	-	-	-	-	+	-	-	-	-	-
Pseudopolydora	-	-	-	+	-	-	-	-	-	-
Pseudoprotella phasma	-	-	-	+	-	-	-	-	-	-
Retusa crossei	-	-	-	+	-	-	-	-	-	-
Ruditapes decussatus	-	-	+	-	-	-	-	-	-	-
Scolelepis sp.	-	+	-	+	-	-	-	-	-	-
Sinelobinae sp.	-	-	-	-	-	-	+	-	-	-
Spio decorata	-	-	-	+	-	-	-	-	-	-
Syllis gracilis	-	-	-	+	-	-	-	-	-	-

Tanaididae sp.	-	-	-	-	-	-	+	+	-	-
Tanais dulongii	+	-	-	-	-	+	-	-	-	-
Tritia sp.	-	-	-	+	-	-	-	-	+	-
Tritia corniculum	-	-	-	+	-	-	-	-	-	-
Tritia neritea	-	-	+	+	-	-	-	-	-	-
Tunicata sp.	-	-	-	-	-	-	-	+	-	-
Turbonilla sp.	-	-	-	+	-	-	-	-	-	-

Based on the analysis of the species biodiversity at the Logarou (recipient) and Mazoma (donor) sites from 2021 to 2025, Logarou consistently supports a higher number of unique species over the five-year period, with 54 species observed at least once compared to 48 at Mazoma. The average number of species present each year is also greater at Logarou (16.8) than at Mazoma (13.0), indicating a more dynamic or variable community at the recipient site.

Despite these differences in richness, both sites exhibit a low number of persistent species, with only three species at Logarou and two at Mazoma present in all five years. This suggests considerable temporal variability, likely influenced by environmental fluctuations, management interventions, or natural successional processes. Species turnover is notable at both locations. Examining the taxonomic groups, fish species show sporadic presence, reflecting their sensitivity to environmental changes or migratory behaviors. Macroalgae presence is patchy, with diversity fluctuating between years, possibly due to changes in water quality or seasonal cycles. Macroinvertebrates make up the majority of both persistent and transient species, underscoring their ecological importance and responsiveness to habitat conditions.

Overall, Logarou’s higher species richness and turnover suggest it may be subject to greater environmental variability or disturbance, while Mazoma appears somewhat more stable but less diverse. The small number of species persistent across all years at both sites emphasizes the need for ongoing monitoring and adaptive management to support long-term biodiversity. Maintaining and enhancing habitat quality, closely monitoring environmental drivers, and focusing restoration efforts on groups or species with high turnover or low persistence—particularly key fish and macroalgae—are recommended strategies for sustaining and enhancing biodiversity at both donor and recipient sites.

Ecological status

The ecological quality status (EQS) of the main monitoring stations in the Amvrakikos-Logarou lagoon (LOG_MON_A, LOG_MON_B, LOG_MON_D, LOG_MON_0) and the donor site Mazoma (MAZ_MON_1) was assessed annually from 2021 to 2025 using a suite of biotic indices: M-AMBI(macrofauna-based), BITS (macrofauna-based), and MaQI (macrophyte-based). These indices are harmonized with the Water Framework Directive and are widely accepted for lagoon and transitional water monitoring in the Mediterranean.

During the timeframe of the project, the transplant sites (LOG_MON_A, LOG_MON_B) maintenaned or improveed their benthic community structure, with LOG_MON_B emerging as the most consistently "Good" site across all indices by 2024–2025. LOG_MON_A showed moderate improvement but remained at "Moderate" status in some years, likely reflecting local environmental variability and episodic stressors. This improvement was reflected in the status of the centre of the lagoon which improved from "Moderate" to "Good" M-AMBI status by 2024–2025. The same cannot be said for the Donor site (MAZ_MON_1). While initially "Good," the decline to "Poor" in 2025 warrants further investigation, as it may reflect natural cycles, temporary disturbance, or broader environmental change. Both indices generally supported the M-AMBI findings, with BITS tending to overestimate status but MaQI confirming the "Good" ecological quality at the most successful sites. Overall, the monitoring results demonstrate that the restoration actions in Amvrakikos-Logarou have led to measurable improvements in ecological quality at key sites, with the most pronounced and sustained gains at LOG_MON_B and LOG_MON_0. Ongoing monitoring and adaptive management are recommended to consolidate these gains and address emerging challenges at the donor site and less successful transplant plots.

Table 9. Multi-biotic Indices for the Ecological Quality Status of the monitoring stations in 2023

Monitoring station	**M-AMBI score**	**M-AMBI Status**	**BITS score**	**BITS status**	**MaQI score**	**MaQI status**
LOG_MON_A	0.5	Moderate	1.58	Good	0.55	Moderate
LOG_MON_B	0.62	Good	1.90	High	0.65	Good
LOG_MON_D	0.37	Poor	1.16	Moderate	-	-
LOG_. MON_0	0.59	Moderate	1.75	Good	0.65	Good
MAZ_MON_1	0.57	Moderate	1.60	Good	0.65	Good

Table 10. Evolution of the ecological status of the monitoring sites based on the M-AMBI index from the ex-ante report until the present monitoring report.

	Ecological status (M-AMBI)				
	2021	2022	2023	2024	2025
MAZ_MON_1	Good	Good	Moderate	Moderate	Poor
LOG_MON_0	Good	Good	Moderate	Moderate	Good
LOG_MON_A	-	Moderate	Moderate	Good	Moderate
LOG_MON_B	-	Moderate	Good	Good	Good
LOG_MON_D	Moderate	Moderate	Poor	-	-

Conclusions

The LIFE-TRANSFER project in the Amvrakikos lagoon complex represents the first large-scale attempt to restore Zostera noltei meadows in Greece through transplantation, coupled with comprehensive ecological monitoring and adaptive management. Over the course of four years (2021–2025), the project has demonstrated both the significant potential and the inherent complexity of seagrass restoration in Mediterranean lagoon systems.

The initial phase of the project was marked by technical and environmental challenges, with the majority of pilot transplantation plots failing to establish due to a combination of suboptimal site selection, persistent macroalgal blooms, and episodic environmental stressors such as prolonged high temperatures and low water clarity. These setbacks, however, catalyzed a strategic shift in methodology. By prioritizing transplantation in close proximity to existing healthy meadows, refining the planting technique to hand-placement, and increasing the temporal resolution of environmental monitoring, the project team achieved a marked improvement in survival rates and meadow expansion in subsequent years. Notably, the introduction of innovative planting patterns, such as the “dice” (quincunx) configuration, and the willingness to experiment with site abandonment and sod replacement, reflect a strong commitment to adaptive management and evidence-based restoration.

Physico-chemical monitoring revealed that, while the donor and recipient lagoons share broadly similar environmental conditions—such as temperature, dissolved oxygen, and pH—Logarou’s higher salinity and persistent turbidity continue to pose challenges for Zostera noltei establishment. Sediment analyses confirmed that both donor and successful recipient sites maintain high organic carbon and fine sediment content, supporting the blue carbon potential of restored meadows and their long-term ecological function.

Biodiversity assessments showed that successful transplant sites, particularly LOG_MON_B and LOG_MON_A, developed benthic communities characterized by high species richness and diversity, and a prevalence of sensitive taxa typical of healthy lagoonal environments. In contrast, less successful sites, such as LOG_MON_D, remained dominated by opportunistic species and exhibited lower diversity, highlighting the influence of local environmental variability and the importance of targeted site selection.

Ecological status, as measured by a suite of biotic indices (M-AMBI, BITS, MaQI), improved or was maintained at most transplant and central lagoon sites over the course of the project. LOG_MON_B consistently achieved “Good” status across all indices by 2024–2025, and LOG_MON_0 improved from “Moderate” to “Good,” indicating a positive system-wide response to restoration actions. However, the decline in status at the donor site (MAZ_MON_1) in 2025 underscores the need for continued vigilance and monitoring, as well as the importance of safeguarding donor meadow resilience.

The project’s participatory approach, involving local fishermen, site managers, and the broader community, has been instrumental in building capacity, fostering stewardship, and ensuring the alignment of restoration actions with regional conservation and socio-economic objectives. The lessons learned from Amvrakikos—particularly the value of adaptive management, high-frequency monitoring, and stakeholder engagement—provide a transferable model for future seagrass restoration efforts in Greece and the wider Mediterranean.

In summary, the LIFE-TRANSFER project has shown that, while large-scale seagrass restoration in Mediterranean lagoons is inherently challenging, it is possible to achieve measurable ecological gains through a combination of technical innovation, rigorous monitoring, and flexible, adaptive management. The sustained improvements observed at key sites demonstrate the resilience of these ecosystems when given targeted support, but also highlight the necessity of long-term commitment and ongoing evaluation to secure and build upon these gains. Continued monitoring, especially at both restoration and donor sites, remains essential to consolidate progress, detect early warning signs of decline, and guide future interventions for the conservation of priority habitat 1150 and the broader lagoon ecosystem