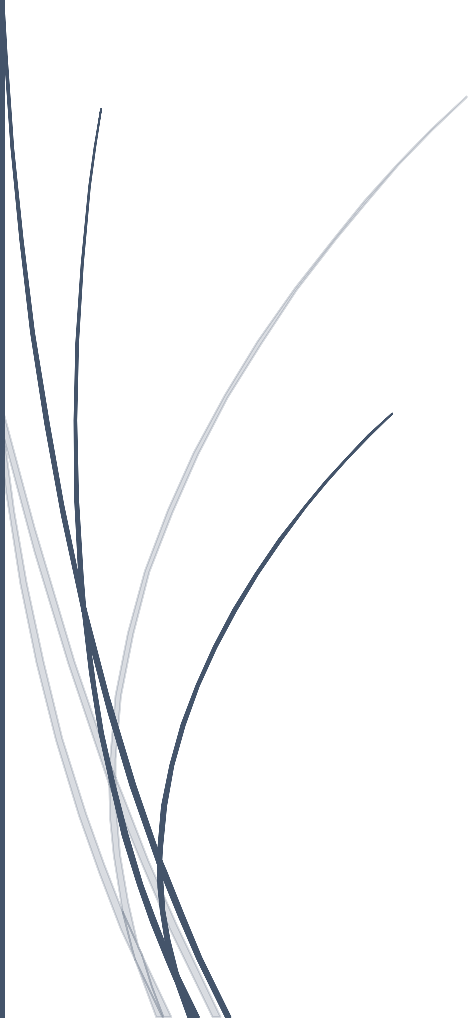
LIFE19NAT/IT/000264LIFE-TRANSFER
Seagrass transplantation for transitional Ecosystem Recovery

November 2025

ACTION D.6: Evaluation of the actions impact on ecosystem service



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Executive summary

The LIFE TRANSFER project advances the understanding of how restoration actions affect multiple ecosystem services (ES) within the Amvrakikos lagoons. Built on the MAES framework and the LIFE ES guidance, the assessment focuses on provisioning services (notably fisheries) and regulating services (blue carbon storage in seagrass meadows), while also addressing supporting and cultural services that arise from habitat restoration, biodiversity gains, and potential enhancements to recreational value. The donor–recipient comparison between Mazoma (donor) and Logarou (recipient) provides a baseline against which ES changes can be measured as restoration progresses. The findings indicate that seagrass restoration has strong potential to enhance ES delivery by improving habitat structure, nursery function for fish, and sediment stabilization that supports carbon burial. However, the magnitude and trajectory of ES gains depend on interacting drivers, including external nutrient inputs, hydrological changes, and sediment dynamics that influence carbon sources..

Introduction

Coastal lagoons are among the most productive and complex ecosystems, delivering provisioning, regulating, maintenance, and cultural services. The provisioning service of fisheries supports food security and livelihoods; regulating services include climate regulation through blue carbon storage, sediment stabilization, nutrient cycling, and water purification; maintenance services cover habitat structure and biodiversity; and cultural services embody recreation, aesthetic value, and place-based identities. The LIFE Ecosystem Services Guidance (based on MAES and CICES) provides a practical framework for evaluating how LIFE projects influence these ES, stressing that ES assessment should be distinct from broader socio-economic monitoring while remaining complementary. The guidance promotes a matrix-based approach that links MAES ecosystem types to ES (via CICES categories) and advises reporting ES results in the LIFE KPI Webtool. For LIFE TRANSFER, applying this framework to the Amvrakikos lagoons enables consistent accounting of ES delivered by restoration actions, supports stakeholder communications, and informs decision-making at both local and broader governance levels.

The project foregrounds two core ES: (i) provisioning ES through fish production and (ii) regulating ES through blue carbon storage in seagrass meadows. Yet, the framework also encourages identifying additional ES relevant to the site (e.g., habitat maintenance, biodiversity support, water quality regulation, and cultural services) to capture the full range of benefits from restoration.

Table 1.Ecosysstem services for coastal lagoons

DIVISION	GROUP	CLASS	INDICATORS
Nutrition	Biomass	Wild animals and their outputs	Fishing yield (t/km^2; landings by species and trophic level)- Mean Trophic Level (mTL) of catch - Fishing in Balance (FiB)

DIVISION	GROUP	CLASS	INDICATORS
			index - Fish species diversity and abundance in seagrass habitat - Juvenile fish abundance (nursery function indicator)
		Plants and algae from in-situ aquaculture	Seagrass biomass production (g DW/m^2) - Seagrass meadow productivity (Net Primary Production, NPP) - Macroalgae production
Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Seagrass meadow area (ha) designated for habitat/landscape protection (Natura 2000)- Seagrass shoot density (shoots/m^2) - Seagrass above- and below-ground biomass (g DW/m^2) - Sediment carbon stocks (kg Corg/m^2) for blue carbon
		Genetic materials from all biota	Genetic diversity of seagrass populations and associated fauna - Microbial diversity in seagrass sediments (for biogeochemical cycling)
Energy	Biomass-based energy sources	Plant-based resources	Blue carbon sequestration potential (tonne CO_2-eq/ha/year) - Carbon burial rates in seagrass sediments (kg C/m^2/year) - Sediment organic matter stocks (%)
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates
		Liquid flows	Hydrological cycle and water flow maintenance
			Buffering and attenuation of mass flows

DIVISION	GROUP	CLASS	INDICATORS
Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, Habitat and gene pool protection	Maintaining nursery populations and habitats	Seagrass area designated for habitat-landscape protection (Natura 2000)- Seagrass meadow extent (ha) - Shoot density as proxy for habitat quality - Fish nursery habitat area (ha within seagrass) - Macroinvertebrate diversity (species richness, abundance) - Macroalgae and epiphyte diversity in seagrass canopy
			Pest and disease control
		Water conditions	Chemical condition of salt waters
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations
Physical and intellectual interactions with biota, ecosystems, and land/seascapes	Physical and experiential interactions	Experiential use of plants, animals and land/seascapes in different environmental settings	Extent of coastal lagoon protected areas (km²/ha)- Lagoon area accessible for recreation (birdwatching, boating, fishing) - Number of visitors to lagoon-based recreation sites - Ecotourism operators and activities - Known important bird areas associated with lagoons

Methods

The assessment uses the MAES analytical framework to connect ecological condition with ES delivery, and it applies the CICES hierarchy to classify ES into provisioning, regulating, maintenance, and cultural categories. A matrix approach is employed to associate the relevant MAES ecosystem types with ES indicators, enabling normalisation to a 0–5 scale for cross-site comparison and time-series analysis. The LIFE KPI Webtool structure (Indicator Context C.1 and Specific Context C.2) is used to organize ES data consistently, including the potential for adding living green/blue infrastructure in the reporting. The Donor Mazoma and Recipient Logarou lagoons provide paired contexts for ES benchmarking, with Mazoma representing the reference state of healthy seagrass meadows and Logarou representing a degraded baseline prior to restoration.

Key data streams that feed the ES assessment:

- Long-term fisheries landings in Logarou (1980–2020) for provisioning ES, including mean trophic level (mTL) and the FiB index.
- Seagrass meadow attributes (extent, shoot density, above- and below-ground biomass) at Mazoma and Logarou to gauge habitat provision and potential for carbon storage.
- Sediment carbon stocks (kg Corg m^{-2}) and sediment texture (sand vs mud) to understand burial dynamics for blue carbon.
- Stable isotope data (δ13C, δ15N) to apport carbon sources (autochtoneous vs allochthonous).
- Water quality data (temperature, salinity, dissolved oxygen, pH, visibility) and SPOM to contextualize nutrient dynamics and habitat health.

Provisioning Ecosystem Services

Fisheries

ES Definition and Rationale

Fisheries provide a direct provisioning ES by yielding fish that contribute to food security, income, and livelihoods for local communities. Seagrass meadows, as habitat, nursery grounds, and feeding habitats, support a diverse array of fish species, thereby underpinning sustainable fisheries in lagoon systems. Recognising the MAES framework, provisioning ES is linked to ecosystem condition and directly influenced by habitat structure, water quality, and food-web integrity.

Data and Methods

The Logarou Lagoon time series (1980–2020) provides the empirical basis for provisioning ES assessment. Annual landings were primarily captured through barrier traps (up to 70% of landings) and nets (trammel and fyke). Two indices operationally define the ecological dimension of fish production: mean trophic level (mTL) to quantify the trophic composition of catch, and the Fishing in Balance (FiB) index to combine yield trends with trophic structure changes. Fishing yield is expressed per unit area (t/km²) to facilitate comparisons across lagoons of different sizes. A simple linear regression framework is used to identify trends with a 95% confidence level.

Results

The results reveal a significant, continuous decline in fishing yields in Logarou between 1980 and 2020, with yields ranging from 8.94 t/km² in 1981 to 0.86 t/km² in 2020 (mean 4.39 t/km², ±1.83). This decline signifies a substantial erosion of provisioning ES over four decades. The mean trophic level (mTL) of landed fish varied from 2.39 (1989) to 3.08 (2008) and remained statistically stable ($p > 0.05$), indicating no clear shift toward lower trophic levels in the catch; overall, the trophic structure remained relatively constant. The FiB index displayed a robust negative trend ($p < 0.01$), with values ranging from 0.21 (1981) to −1.13 (2020) and a mean of −0.39 (±0.42). This negative trajectory points to ecological destabilization and deterioration of the ability of the fishery to provide sustainable benefit

Table 2. Species composition of landings from the Logarou Lagoon and trophic level (TL) values.
Source: (Fishbase, 2005).

Species Scientific name	Species common name	TL
Sarpa salpa Linnaeus, 1758	Salema	2.00
Mugilidae	Mullets	2.14
Palaemon adspersus Rathke, 1836)	Prawn	2.85
Gobiidae	Gobies	3.00
Diplodus sargus sargus Linnaeus, 1758	White sea bream	3.10
Solea solea Linnaeus, 1758	Common sole	3.28
Diplodus annularis Linnaeus, 1758	Annular sea bream	3.30
Diplodus puntazzo Walbaum, 1792	Sharp snout sea bream	3.40
Lithognathus mormyrus Linnaeus, 1758	Sand stean bras	3.40
Mullidae	Surmullet	3.42
Sparus aurata Linnaeus, 1758	Gilthead sea bream	3.45
Dicentrarchus labrax Linnaeus, 1758	Sea bass	3.47
Anguilla anguilla Linnaeus, 1758	European eel	3.85

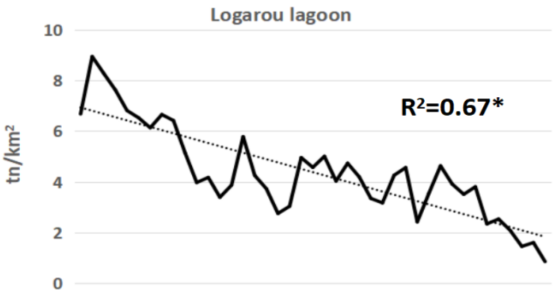

Figure 2. Annual fluctuations of the fishing yield (t/km2) in the Logarou Lagoon for the period 1980-2020 * = Statistically significant trend at level 0.05

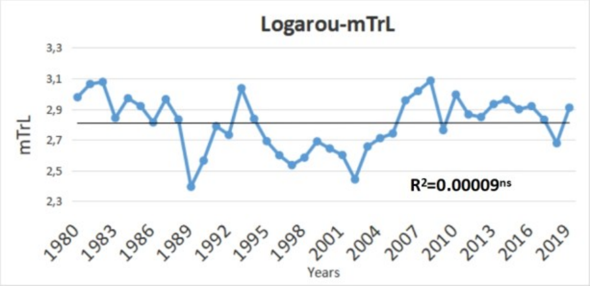

Figure 3. Annual fluctuations of the mean Trophic Level index in the Logarou Lagoon for the period 1980-2020. ns = no statistically significant trend at level 0.05

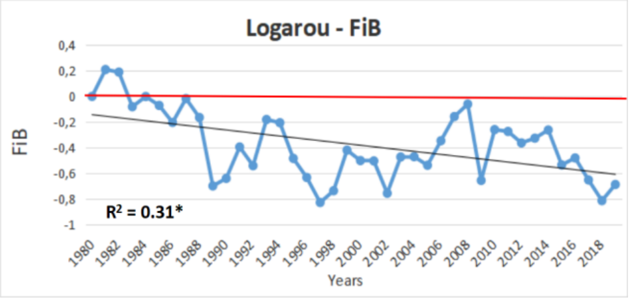

Figure 4. Annual fluctuations of the Fisheries in Balance index in the Logarou Lagoon for the period 1980-2020. * = Statistically significant trend at level 0.05

Discussion and Implications for LIFE TRANSFER Actions

The observed decline in fishing yields is substantially lower than regional or global lagoon averages, signalling degraded habitat capacity rather than overexploitation. The drivers are multi-fold: habitat degradation (notably loss of seagrass meadows), nutrient enrichment from watershed inflows, hydrological changes from dam operation, and organic loading that modifies oxygen regimes and food-web dynamics. The relatively stable mTL, together with the negative FiB trajectory, implies an erosion of energy throughput through the food web and reduced resilience, rather than a simple "fishing down" of the fishery. The under-exploitation context—low fisher density compared with regional benchmarks—supports the interpretation that the decline arises from environmental constraints rather than overfishing, suggesting restoration could recover provisioning ES over time.

Restoration of *Zostera noltei* meadows is central to reversing the provisioning ES decline by restoring habitat complexity, improving nursery function, and enhancing primary productivity that supports fish communities. Mazoma provides a reference target for habitat quality, while Logarou represents the post-restoration trajectory to be achieved. This ES assessment provides concrete baselines for measuring restoration success and provides a basis for communicating benefits to stakeholders and policymakers.

Regulating Ecosystem Services

Blue Carbon storage

ES Definition and Rationale

Blue carbon storage is a key regulating ES rooted in seagrass meadow carbon sequestration into sediments for long durations. The Amvrakikos lagoons host *Zostera noltei* and *Cymodocea nodosa* meadows*,* with sedimentary carbon stocks contributing to climate regulation and mitigation. The LIFE guidance emphasises that blue carbon dynamics are influenced by sediment properties, hydrological processes, and external allochthonous inputs.

Data and Methods

The blue carbon assessment utilised mapped meadow extents, seagrass shoot densities, above- and below-ground biomass, and sediment cores for Corg stocks and wwas conducted in two lagoons of the Amvrakikos Gulf (Western Greece), Mazoma and Logarou, during October 2021 (Fig. 5). Both systems are shallow (<2 m), but differ in ecological status: Mazoma hosts extensive *Zostera noltei* meadows, while in Logarou the species has been declining and the lagoon has remained at “Moderate” ecological status under the Water Framework Directive since 2013.

Spatial data for the Mazoma and Logarou seagrass cover areas were derived from orthophoto mosaics created using a consumer Aerial Unmanned Vehicle (AUV) (AUTEL EVO II) during May 2022. Training samples were selected based on field observations and ground-truthing surveys. The classified raster outputs were sieved to smooth classes from spill pixels and vectorized into polygon vector shapefiles.

Google Earth imagery was used for portions of Logarou lagoon not covered by photomosaics. Contrast and brightness enhancement were applied in QGIS to distinguish meadow edge shapes. Seagrass species were identified by expert judgment and delineated manually using polygon-creating tools while maintaining a working scale of 1:1000. The ground-truthing surveys conducted in May 2022 guided and validated both semi-automatic and manual classifications. Classified polygons from each approach were joined and dissolved into one-part polygon vector, enabling spatial calculations of the total extent covered by seagrass in the study area using the field calculator. All vectors, photomosaics, and background imagery were reprojected to the Greek Grid projection system (EPSG:2100) for consistent spatial analysis.

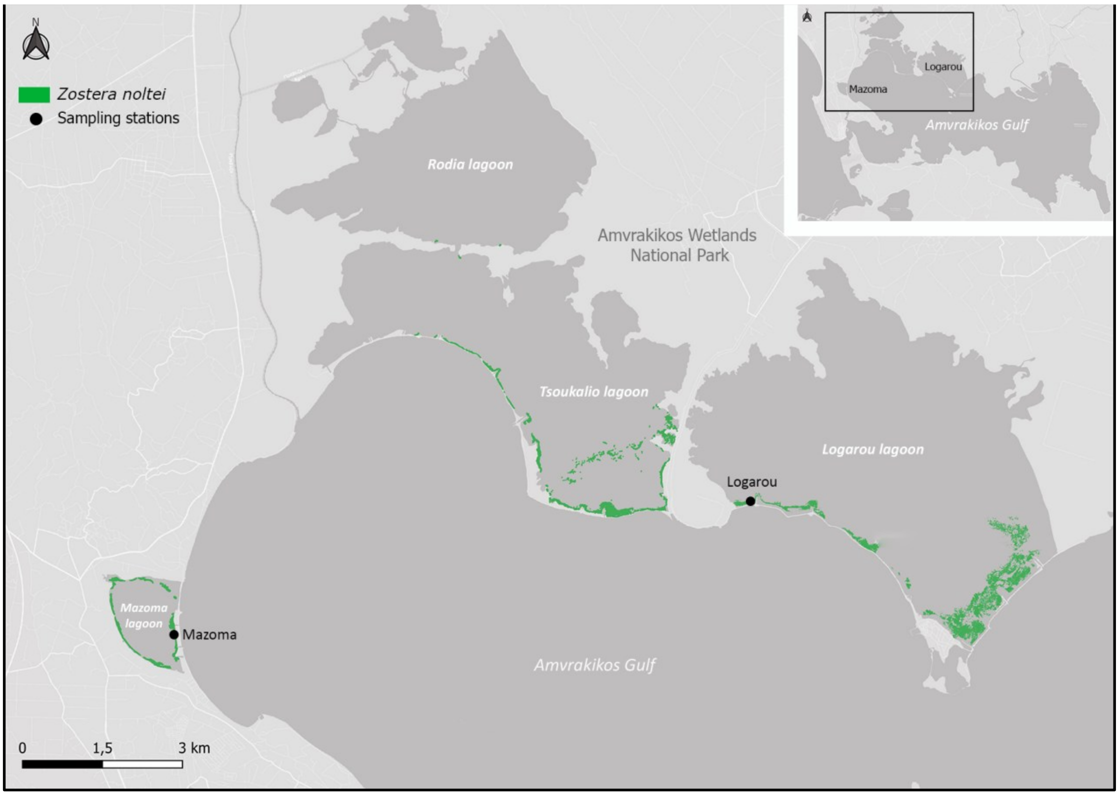

Fig. 5 Map of Amvrakikos Bay (Western Greece) with indication of the sampling stations of *Z. noltei* meadows in Mazoma and Logarou lagoons. The extent of *Z. noltei* meadows is also shown in green.

Results

The area covered by Z. noltei in Logarou was 44.5 ha, while that in Mazoma was 4.3 ha (Table 1). The mean (± SE) shoot density and above- and below-ground biomass of Z. noltei in Mazoma was 571 ± 102 shoots m-2, 12.85 ± 2.48 g DW m-2 and 26.28 ± 9.17 g DW m-2, respectively, and 292 ± 74 shoots m-2, 5.34 ± 0.47 g DW m-2 and 10.84 ± 1.35 g DW m-2, respectively, in Logarou (Table 1). Elemental and isotopic composition of seagrass shoots varied among stations (Table 1), with Logarou shoots being more depleted in C and δ13C and more enriched in N and δ15N than those of Mazoma.

The top meter of sediment of Z. noltei in Mazoma was mostly characterized by fine sands (~ 55%), while the sediments of Z. noltei in Logarou were mainly muddy (62.3 ± 12.4 %) (Table 3). DBD at the top meter of sediment ranged higher at Mazoma than Logarou sediments, with mean (± SE) values of 0.75 ± 0.03 and 0.65 ± 0.02 g cm^{-3}, respectively (Table 4).The mean Corg content at the top meter of sediment was similar between the two stations, with a mean of 2.35 ± 0.13 % and 2.32 ± 0.09 %, respectively (Table 1). The mean N content in the top sediment of Logarou was 1.3-fold higher (0.19 ± 0.01 %) than in Mazoma (0.19 ± 0.01%). Logarou top meter of sediment was less ^{13}C-depleted (-17.58 ± 0.14 ‰) than Mazoma (-21.16 ± 0.2).

Table 3. Mean ± SE of seagrass variables at each station.

	Mazoma	Logarou
Area (ha)	44.5	4.3
Shoot density (shoots m-2)	571 ± 102	292 ± 74
Above-ground biomass (g DW m-2)	12.85 ± 2.48	5.34 ± 0.47
Below-ground biomass (g DW m-2)	26.28 ± 9.17	10.84 ± 1.35
C (% DW)	37.31 ± 2.97	34.69
N (% DW)	1.94 ± 0.13	2.08
δ13C (‰)	-12.99 ± 0.18	-10.66
δ15N (‰)	2.61 ± 1.03	6.73

Table 4. Mean ± SE at the top meter of sediment of each geochemical variable at both stations.

	Mazoma	Logarou
Dry bulk density (g DW m-2)	0.75 ± 0.03	0.65 ± 0.02
Very coarse sand and gravel, >1000 µm (%)	0.65± 0.27	0.06 ± 0.03
Coarse sand 500-1000 µm, (%)	7.62 ± 1.35	1.64 ± 0.43
Medium sand, 250-500 µm (%)	13.73 ± 1.44	3.26 ± 0.59
Fine sand, 125-250 µm (%)	23.27 ± 0.85	9.97 ± 1.04
Very fine sand, 63-125 µm (%)	31.81 ± 1.67	24.52 ± 1.19
Silt/clay <63 µm (%)	22.92 ± 1.58	60.56 ± 2.15
Corg (% DW)	2.35 ± 0.13	2.32 ± 0.09
N (% DW)	0.19 ± 0.01	0.25 ± 0.01
δ13C (‰)	-21.16 ± 0.2	-17.58 ± 0.16

Corg stocks at the top meter did not show significant differences between the two stations, with a range between 11.7 and 19.9 kg Corg m-2 and a mean of 15.4 ± 3.2

kg Corg m-2 and 16.8 ± 4.5kg Corg m-2 at Mazoma and Logarou, respectively (Fig. 6).

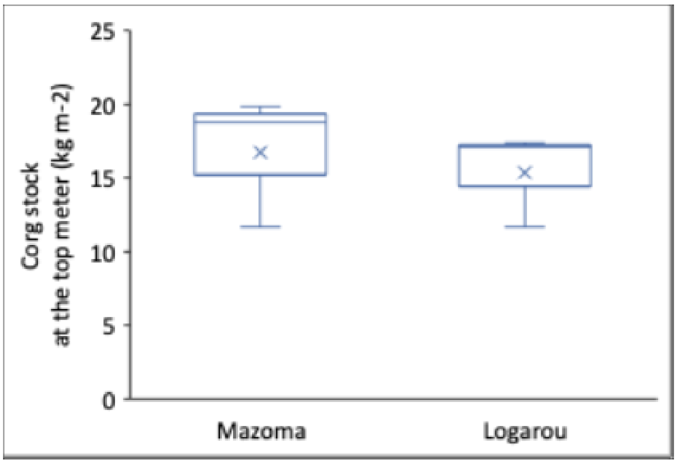

Figure 6. Box plots of Corg stocks (kg m-2) at the top meter of at each station. The boxes encompass the 25 % and 75 % quantiles; the solid lines represent the medians and the (X) symbols the mean values per station.

Stable isotope mixing models indicated that seagrass contributed by 23 % and 29 % in Mazoma and Logarou, respectively, to the organic carbon pool (Fig. 3). SPOM contributed by 31 % and 45 % in Mazoma and Logarou, respectively. In total, allochthonous contribution was 73% and 79% in Mazoma and Logarou, respectively.

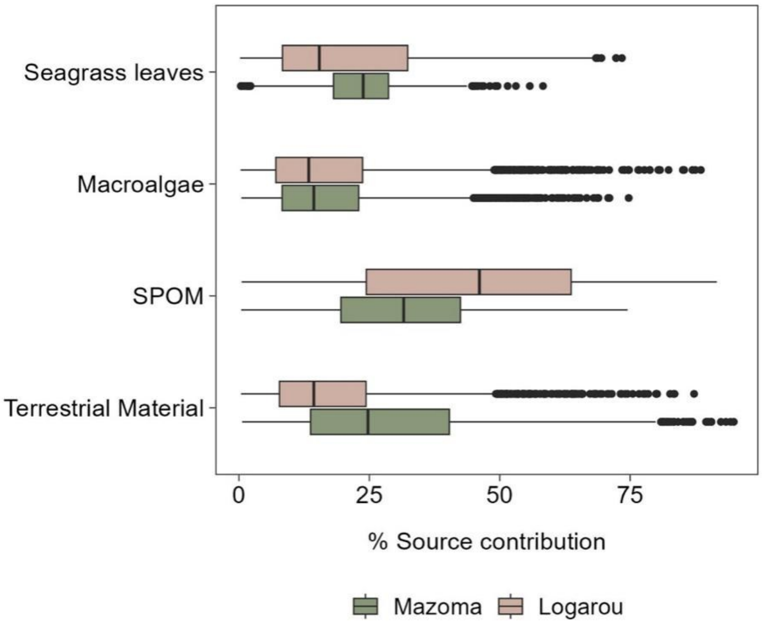

Fig. 7. Percentage (mean ± SD) of the contribution of each source to the organic carbon pool of the top 5 cm at the two stations.

Discussion and Implications for LIFE TRANSFER Actions

Two key insights emerge. First, sediment properties and external organic matter inputs strongly influence carbon burial, sometimes more than meadow biomass alone. The sandier Mazoma sediments with higher density may promote carbon preservation through compaction and reduced pore space, whereas muddier Logarou sediments may support different preservation mechanisms, including reducing conditions that facilitate carbon burial. Second, external subsidization by allochthonous inputs is high at both sites, with Logarou showing a larger share. While this external supply can enhance absolute carbon burial, it is associated with eutrophication and nutrient loading that can threaten long-term seagrass health and productivity. Nitrogen isotope data showing enrichment in Logarou corroborate nutrient pressure, reinforcing the need for watershed-level nutrient management to maximize blue carbon benefits.

Expanding the extent of Z. noltei meadows via transplantation is expected to increase the spatial footprint for blue carbon storage and improve habitat stability for long-term carbon burial, provided external nutrient pressures are managed. The baseline data from Mazoma and Logarou enable tracking of carbon stock changes over time, allowing adaptive management to maximize climate regulation services while addressing limiting factors such as eutrophication.

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