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

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ACTION D.5: Evaluation of the Socio-Economic Impact of Conservation Actions

Final Report on Analysis of the Local Economy of the Amvrakikos Gulf

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1. EXECUTIVE SUMMARY

The Amvrakikos Gulf, situated along Greece's western coastline, represents a vital nexus where natural ecosystems and human activities converge. This comprehensive final report provides a detailed analysis of the socio-economic landscape within this region, examining the interplay between environmental conditions, local economies, cultural heritage, and community dynamics. The analysis examines the economic structures prevalent in the Amvrakikos Gulf, investigating key sectors such as fisheries, agriculture, and commerce while addressing environmental considerations and the Gulf's ecological significance for sustainable development.

The pilot project area experienced a slight increase of 1.4% in permanent residents during the period 2001–2021, in comparison to the general decrease in the national population (−4.13%). For the wider Epirus River Basin District (EL05), there is a greater concentration of employment in the primary sector (agriculture, forestry, fishing) at 13%, compared to 10% nationally, and a general lag in the manufacturing sector (6.7% versus 9.2% nationally). The higher share of Gross Value Added (GVA) in the primary sector for the region is 7.7%, compared to 4.4% nationally, with lagging GVA in the manufacturing sector at 6.1% against 9.2% nationally. Notably, there is higher productivity per employee in the primary sector compared to the national level, with GRP per employee in agriculture, forestry, and fishing reaching €20.4 thousand, versus €18.6 thousand nationally. The main pressures for the study area are farming and livestock units, which together contribute to over 90% of the nutrient load entering the water basins. The total cost of implementing recommended conservation measures under the Water Framework Directive (WFD) is estimated at €240,000, including supplementary measures that involve key stakeholders such as the Management Authority of the Amvrakikos Wetland Protected Area, fishermen's cooperatives, and farming and breeding bodies.

The LIFE-TRANSFER project represents a transformative initiative for the region, with particular significance for local fishermen's cooperatives. Landing trends for the lagoons reveal that the most abundant typical lagoon fish species—including mullets (Mugil cephalus, Chelon labrosus, Liza saliens, Liza aurata, and Liza ramada), eels (Anguilla anguilla), and gobies (primarily Zosteriosessor ophiocephalus)—have all largely decreased over recent decades, an outcome associated with the less-than-good environmental status of the lagoons since 2013. The seagrass restoration activities initiated through the LIFE-TRANSFER project represent innovative conservation action with significant long-term potential. Through the transplantation of Zostera noltei sods from the donor site (Mazoma lagoon) to the recipient site (Logarou lagoon), the project aims to restore critical fish habitat and ecosystem services. Seagrass meadows provide multiple ecosystem benefits, including nursery habitat for juvenile fish, sediment stabilization, and carbon sequestration. However, a critical finding emerging from monitoring data is that rising water temperatures—linked to climate change—pose a greater threat to fish yields than restoration activities alone can mitigate. Water temperatures in the pilot lagoons have reached 35°C during summer months, with evidence suggesting that high temperatures inhibit seagrass growth and survival, and directly stress fish populations. The true success of the project thus unfolds in the socio-economic realm: the engagement of local fishermen in restoration activities not only results in increased income through planting endeavors but also fosters a remarkable shift in their understanding and appreciation of the lagoon's ecological significance. Educational components elevate stakeholder awareness, encouraging transitions toward more sustainable fishing practices and fostering community stewardship of the lagoon for future generations.

2. STUDY AREA

2.1 GEOGRAPHIC AND ADMINISTRATIVE CONTEXT

The Amvrakikos Gulf is located on the northwestern coast of Greece, within the Epirus region. The two primary river catchment areas associated with the Gulf and the pilot study area are the Louros and Aracthos rivers. Both discharge into the northern part of the Gulf in close proximity to the donor and recipient sites selected by the LIFE-TRANSFER project. The Aracthos river has a drainage basin of 2,209 km^2 and the Louros has a drainage basin of 963 km^2. The two main administration districts associated with the current project are Arta and Preveza, both of which are located within the Epirus River Basin District (GR05) in accordance with the Water Framework Directive 2000/60/EC. The Arta-Preveza catchment areas, which encompass parts of the Acheronta, Louros, and Arachthos river basins, are officially designated as areas vulnerable to nitrates under the RBD of Epirus. According to Common Ministerial Decree 1966/1982/1999, the urban wastewater recipients of the Amvrakikos Gulf, Metsovitikos, Arachthos River, and the Louros River have been identified as sensitive water bodies under Annex I of Common Ministerial Decree 56734/001997 (Hellenic Ministry of Environment & Energy, 2023).

Figure 1. Map of study area with regional cities (Arta, Preveza) and WFD monitoring stations (Table 1)

2.2 CURRENT ECOLOGICAL STATUS OF SURFACE WATER BODIES

Ecological status assessment concerns biological parameters, depending on water body category, and secondarily general physico-chemical conditions or other parameters specific to pollutants. In the Epirus RBD, seventeen of one hundred and six surface water bodies are estimated not to achieve good status by the established targets. The ecological status of three rivers with a total length of 44.64 km (4.06% of total RBD river length) is classified as high ecological status. Sixty-six rivers, with a total length of 928.77 km (84.43% of RBD river length), are classified as good ecological status. Six rivers, with a total length of 69.99 km (6.36% of RBD river length), are classified as less-than-good ecological status.

Of the lakes in the RBD, one lake with a surface area of 19.24 km^2 (38.35% of total RBD lake area) is classified as less-than-good ecological status. With respect to transitional waters, one transitional water body with a total surface area of 4.16 km^2 (1% of RBD transitional water surface) is classified as good ecological status, while four transitional waters with a total surface area of 407.46 km^2 (98.31% of RBD transitional water surface) are classified as less-than-good ecological status. Critically, this classification includes the two coastal lagoons—Mazoma and Logarou—selected for the current LIFE-TRANSFER project. Table 1 presents the current chemical, ecological, and overall environmental status of WFD monitoring stations (coastal, transitional, and freshwater) associated with the Amvrakikos Gulf. Sites directly related to the pilot project area are highlighted in bold.

Table 1. Current (2018) Chemical, Ecological, and Environmental quality status of the WFD stations located in the Amvrakikos Gulf (European Environment Agency, 2023)

Code	Name	Waterbody type	Chemical	Ecological	EQS
EL0546R000201077N	Louros R.	Freshwater	Good	Good	Good
EL0514R000201050N	Aracthos R.	Freshwater	Good	Moderate	Moderate
EL0546T0003N	Louros Delta - Rodia, Tsoukalio, Logarou Lagoons	Transitional water	Good	Moderate	Moderate
EL0513T0004N	Mazoma Lagoon	Transitional water	Good	Moderate	Moderate
EL0415C0009N	South Amvrakikos Gulf	Coastal water	Good	Poor	Poor
EL0514T0002N	Aracthos Delta	Transitional water	Good	Moderate	Moderate
EL0513C0007N	North Amvrakikos Gulf	Coastal water	Good	Moderate	Moderate
EL0415R000901066N	Voutumias River	Freshwater	Good	Poor	Poor
EL0415R001101067N	Nissis River	Freshwater	Good	Good	Good
EL0415R001301068N	Amfilochias R.	Freshwater	Good	Good	Good
EL0514R000100048N	Dipotamon R.	Freshwater	Good	Bad	Bad

The moderate ecological status of both Mazoma and Logarou lagoons reflects widespread pressures including nutrient loading, temperature stress, and habitat degradation. These conditions necessitate the conservation and restoration measures evaluated in this report.

2.3 RESIDENT POPULATION AND TEMPORAL VARIATION

The Epirus Water District (EL05) includes all local districts of Thesprotia, Preveza, Ioannina, and Corfu, and the largest part of the Arta district. The permanent population of EL05, based on water provider service areas, is estimated at approximately 424,998 inhabitants in 2021. Regarding the 2001–2011 period, there was a marginal downward trend of −0.46% per year in permanent population, in contrast to the previous decade (2001–2011), which had a marginal annual increase of 0.04%. The municipalities of Arta have shown a steady decline since 2001 (−35%), while the municipality of Preveza showed an overall increase in the 2001–2021 period (+10%). The permanent residents of the pilot project area increased by 1.4% from 2001–2021, a higher rate than the rest of the country, which experienced a −4.13% decrease over the same period.

Table 2: Permanent Residents of Municipalities Included in the Pilot Project (2001–2021)

District	Municipality	2001	2011	2021
Arta	Arta	44,136	43,166	41,600
Arta	Skoufa	14,491	12,753	11,356
Arta	Kentrikon Tzoumerkon	7,862	6,178	5,948
Arta	Georgiou Karaiskaki	7,131	5,780	5,278
Preveza	Preveza	30,137	31,733	30,841
Preveza	Zirou	7,245	13,892	13,079
Preveza	Pargas	12,597	11,866	10,762

The relatively stable population in the pilot project area, compared to national decline, reflects ongoing community engagement and economic reliance on natural resources, particularly fisheries and agriculture. However, declining populations in several municipalities, especially in Arta district, suggest potential challenges in rural sustainability and economic diversification.

2.4 LAND USES OF THE STUDY AREA

Based on the 2009 agriculture-livestock census of the Hellenic Agency for Statistics (ELSTAT), taking into account regional units entirely included in the Water Department, the used agricultural area in the Water District of Epirus is estimated at 1,060 ha, with irrigated area measured at 344 ha. The most recent agriculture-livestock census from ELSTAT (reference year 2020, published 2021) reveals a reduction in both irrigated lands and used agricultural area in both regions during 2009–2021, suggesting a downward trend in agricultural intensity.

Table 3: Agricultural Statistics by District (2021)

Category	**Arta District**	**Preveza District**
Number of agricultural holdings	11,270	7,656
Holdings with used agricultural area	11,173	7,521
Used agricultural area (thousand km^2)	204	211
Holdings with irrigated areas	9,474	5,127
Irrigated lands (thousand km^2)	110	97

Agricultural holdings dominate the landscape in both districts, with irrigation being particularly prevalent. The high proportion of holdings with irrigated areas (84% in Arta, 67% in Preveza) reflects the region's reliance on water resources for agricultural productivity, intensifying pressure on local water bodies through nutrient runoff and water withdrawal.

3. CURRENT ECONOMIC INFORMATION FOR THE STUDY AREA

In the Epirus River Basin District (EL05), the estimated product production in terms of Gross Added Value (GVA) was €4,890 million in 2019, corresponding to 3.1% of Greece's national GVA in the same year, with total employment of 142.5 thousand according to the 2011 census, representing 3.8% of Greece's total employment.The economic structure of the River Basin District, derived from the composition of GVA and employment compared to the national level and based on the share of each branch/sector in the total, reveals three key characteristics:

1. Sectoral Employment Distribution: There is greater concentration of employment in the primary sector (agriculture, forestry, fishing) at 13% in the basin compared to 10% nationally, coupled with a lag in the manufacturing sector at 6.7% versus 9.2% nationally. This indicates a region heavily dependent on primary sector activities for livelihoods, with limited manufacturing diversification.

2. Sectoral Value Added Distribution: A higher share of total GVA in the primary sector for the region is noted at 7.7% compared to 4.4% nationally, with lagging GVA in the manufacturing sector at 6.1% versus 9.2% nationally. This suggests that primary sector activities generate disproportionately high economic value, reflecting the importance of agriculture and fisheries to regional prosperity.

3. Productivity Levels: The region demonstrates higher productivity per employee in the primary sector compared to national levels. Specifically, GRP per employee in agriculture, forestry, and fishing is €20.4 thousand, compared to €18.6 thousand nationally. This indicates that primary sector workers in the Epirus basin are generally more productive than their national counterparts, potentially reflecting favorable natural conditions or specialized agricultural activities.

These economic characteristics indicate a region fundamentally shaped by primary production activities, with limited industrial development but substantial economic performance in agriculture and fisheries sectors. This structure makes the region particularly vulnerable to environmental degradation and climate change impacts on water quality, fish stocks, and agricultural productivity.

4. DESCRIPTION OF PRESSURES IN THE STUDY AREA

4.1 METHODOLOGY AND APPROACH

To follow an ecosystem-based integrated approach for determining environmental status, the lagoon biodiversity in Amvrakikos was assessed in an integrated manner, closely linked to the effects of pressures from surrounding human activities. A Geographic Information System (GIS) tool/platform was developed as a risk-based assessment methodology, interrelating multiple pressures and their cumulative impacts on the status of lagoon biodiversity. The GIS tool is used by the management body of Amvrakikos to estimate management effectiveness and to design management measures, priorities, and decisions with respect to local and regional needs. The GIS platform has the major objective of defining the current state regarding pressures affecting Amvrakikos Gulf, with special reference to the restoration site and evaluating the resulting vulnerability of Logarou lagoon. To achieve this, the platform involved data mining activities on existing information regarding anthropogenic driving forces (agriculture, livestock, aquaculture, fisheries, urbanization, tourism), including remote-sensed images, data systematization, data analysis, and image analysis. The estimation of pressures on water bodies takes into consideration recorded pressures as a whole (pollution, water abstraction, morphological changes, etc.). Pressures are categorized as either point pressures (originating from a clear geographical source) or diffuse pressures (operating at wider geographical scales) for the two river basins: Aracthos and Louros rivers.

4.2 POINT PRESSURES

4.2.1 LIVESTOCK FARMING

The main point pressure for the study area, affecting both the Louros and Aracthos rivers, originates from livestock farming. In all regional units of the Epirus River basin, there is a significant number of pig, poultry, and cattle farm units. Most are located in the Kalamas and Louros river basins. Collected data concern 140 poultry farm units (2 are IPPC facilities), 9 pig farm units (2 are IPPC facilities), and 2 cattle farm units. Non-stabled livestock contributes to more than 90% of the total organic load in these river basins. Spatial information for these sites is available on the GIS platform constructed by HCMR for the LIFE-TRANSFER project.

Table 4: Total Annual Load of BOD, Nitrogen, and Phosphorus from Point Sources in Arachthos RB (EL0514)

Point Source	BOD (tonnes/year)	N (tonnes/year)	P (tonnes/year)
Waste Water Treatment Plants (WWTP)	15.68	15.94	2.92
Discharges not connected to WWTP	8.07	1.61	0.34
Hotels	0	0	0
Industrial Sites	63.66	8.95	1.77

Point Source	BOD (tonnes/year)	N (tonnes/year)	P (tonnes/year)
Livestock units	2,529.11	684.56	358.56
Aquaculture – Fish farming	922.91	258.26	41.09
TOTAL	**3,539.43**	**969.33**	**404.67**

Table 5: Total Annual Load of BOD, Nitrogen, and Phosphorus from Point Sources in Louros RB (EL0546)

Point Source	BOD (tonnes/year)	N (tonnes/year)	P (tonnes/year)
Waste Water Treatment Plants (WWTP)	3.78	1.7	0.44
Discharges not connected to WWTP	25.43	5.09	1.06
Hotels	0	0	0
Industrial Sites	57.05	33.09	13.9
Livestock units	3,432	808.64	341.5
Aquaculture – Fish farming	538.34	108.23	18.19
TOTAL	**4,056.6**	**956.74**	**375.09**

Livestock units represent the dominant point-source pollution contributor in both basins, accounting for 71.5% of BOD load in Arachthos and 84.6% in Louros basins. Nitrogen and phosphorus loadings from livestock are similarly dominant (70.6% and 74.5% of N in Arachthos and Louros respectively; 88.7% and 91.1% of P in Arachthos and Louros respectively).

4.2.2 WASTEWATER TREATMENT PLANTS

In the RBD of Epirus, fourteen wastewater treatment plants (WWTP) operate: Ioannina, Kerkyra, Arta, Igoumenitsa, Preveza, Parga, Meliteieon, Agiou Markou, Filippiada, Metsovo, Kynopiaston, Palaiokastriton, Benitson, and Agiou Stefanou. These collectively serve 300,000 inhabitants (80% of total RBD population), corresponding to 85% of the population in Priority A, B, and C agglomerations. The greatest point pressure from WWTPs originates from treatment plants serving populations over 10,000 inhabitants (Ioannina, Kerkyra, Arta, Preveza, Igoumenitsa, and Parga).

4.2.3 INDUSTRY

In the RBD of Epirus, 292 industrial facilities have been recorded, including 6 IPPC facilities (Directive 2010/75/EC) and 11 SEVESO facilities (Directive 2012/18/EC). Industrial sites are concentrated in Ioannina and Preveza and the industrial park of Thesprotia. The industrial composition reveals: 49.8% olive oil mills; 13.7% abattoirs and meat processing facilities; 20.1% other food industry (milk industry, fruit and vegetable canning); 8% metal industry; and the remainder related to refined petroleum products, metal processing, wood processing, chemical industry, and thermal power stations.

4.2.4 LANDFILL SITES AND WASTE MANAGEMENT

Four sanitary landfills operate in the RBD of Epirus, located in Igoumenitsa, Arta, Paramithia, and Kentriki Kerkyra. While these represent managed waste disposal, the potential for leachate contamination of groundwater and surface water bodies remains a concern.

4.2.5 AQUACULTURE

In the RBD of Epirus, 110 aquaculture sites operate, comprising 44 marine and 66 freshwater facilities. The majority are located in the Kalamas basin (43.6%), Louros (28.2%), and Acherontas (12.7%). In the Vouliastas-Mousiotitsas area of the Louros river, numerous freshwater aquaculture facilities are installed over WB Louros P.5. While aquaculture generates economic value, it contributes significantly to point-source pollution through nutrient loading, organic matter decomposition, and disease management practices.

4.3 DIFFUSE PRESSURES

Diffuse sources of pollution include all sources of nutrients (BOD, nitrogen, phosphorus) operating across broad geographical areas. These pressures include agriculture, discharges not connected to sewerage networks, farming, and other diffuse sources.

Table 6: Total Annual Load of BOD, Nitrogen, and Phosphorus from Diffuse Sources in Arachthos RB (EL0514)

Land Use	**BOD (tonnes/year)**	**N (tonnes/year)**	**P (tonnes/year)**
Urban	155.48	44.42	1.09
Agriculture	0	49.7	1.22
Farming	1,483.76	461	121.74
Other sources	0	154.14	1.04
TOTAL	**1,639.24**	**709.27**	**125.09**

Table 7: Total Annual Load of BOD, Nitrogen, and Phosphorus from Diffuse Sources in Louros RB (EL0546)

Land Use	BOD (tonnes/year)	N (tonnes/year)	P (tonnes/year)
Urban	93.61	26.74	0.81
Agriculture	0	42.76	1.32
Farming	1,428.31	338.33	68.44
Other sources	0	30.85	0.49
TOTAL	**1,521.92**	**435.68**	**71.06**

As recognized in the analysis of point sources, farming is by far the largest diffuse pressure for the region, contributing to over 90% of the nutrient load of the study area. The cumulative impact of point and diffuse sources creates a synergistic pressure on water bodies, driving eutrophication, oxygen depletion during summer months, and ecological degradation. These pressures directly compromise fish habitat quality and fishery productivity in the lagoons.

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5. IMPLEMENTATION OF CONSERVATION MEASURES

5.1 WFD BASIC AND SUPPLEMENTARY MEASURES

The Water Framework Directive identified 74 measures to be implemented within the Epirus River Basin to ensure that all water bodies obtain at least Good Ecological Status and achieve the objectives of Directive 2000/60/EC. The measures are divided into basic and supplementary measures. Basic measures result from the implementation of national and European legislation on water protection; supplementary measures are designed and implemented in addition to basic measures.

In the Epirus River Basin District, it is proposed that seventy-three measures be implemented by 2027: 39 basic measures and 34 supplementary measures. Of these, two supplementary measures are associated with recreation and restoration of wetlands, and two are related to environmental agreements following negotiation. One key negotiation includes initiatives for environmental agreements between the Management Authority of the Amvrakikos wetland protected area and the authorities of fishermen and aquaculture to limit negative effects of extensive and intensive aquaculture on the status of transitional and coastal water bodies and ecosystems.

5.2 SOCIO-ECONOMIC ANALYSIS AND COST-EFFECTIVENESS

The socio-economic impacts of management plan projections highlight two key considerations:

1. Economic Effectiveness: In the evaluation of economic effectiveness of the proposed program of measures aimed at improving qualitative and quantitative water body status, measures are evaluated as having highest economic efficiency. Recommended measures address environmental and water resource sufficiency problems with low or zero cost interventions easily integrated into existing operations. These measures have implementation horizons of either short-term (up to 2027) or medium-term (up to 2033).

2. Water System Assessment: Assessment of river basin and water systems where less stringent environmental objectives must be set takes into account socio-economic parameters, such as product produced per cubic meter of water withdrawal, to ensure quantitative and qualitative water sufficiency while maintaining rational water use without compromising economic sustainability.

5.2.1 GROSS VALUE ADDED (GVA) PER WATER WITHDRAWAL ANALYSIS

The produced GVA per river basin is an indicator of water utilization efficiency in regional production activities. In the Epirus Water District, 70.7% of total water withdrawals for industrial use occur in the Kalama watershed, but the production of added value for industrial use is only €18.66 per m^3—significantly lower than all other basin districts. In the Arachthos basin, GVA is estimated at €59.65 per m^3, substantially higher. Investigation of industrial activity mixes in each basin is necessary to improve water utilization efficiency for industrial use where required. Support for higher GVA per m^3 indicates that spending financial resources to ensure water resource sufficiency may become more feasible in the region.

5.2.2 COST-EFFECTIVENESS ANALYSIS OF SUPPLEMENTARY MEASURES

For proposed supplementary measures, a Cost Effectiveness Analysis (CEA) was conducted to assess the cost-effectiveness of potential measures for achieving environmental objectives. The analysis included parameters including: (1) degree of effect; (2) number of relevant water bodies; (3) period of implementation; (4) period of efficiency; (5) social impact; (6) economic impact; (7) environmental impact. These parameters received appropriate ratings and effectiveness rates were estimated. By accounting for discounted costs of measures, an economic efficiency factor was calculated to identify the most effective measure groups. The implementation cost of all proposed supplementary measures is estimated at €581,840. Notably, 26 of 34 supplementary measures (76.5%) have zero or low implementation cost; 7 have costs below €100,000; and 1 has costs between €100,000–€250,000.

Table 8: Primary Costs of Suggested Measures Related to Pilot Project Area

Category	Proposed Supplementary Measure	Cost (€)
Environmental Agreements	Initiatives for environmental agreement between Management Authority of Amvrakikos Wetland and authorities of fishermen and aquaculture to limit negative effects of extensive and intensive aquaculture on transitional and coastal water bodies and ecosystems	20,000
Environmental Agreements	Environmental agreement between Management Unit of Amvrakikos wetland system and farming and breeding bodies to limit agriculture effects on wetland ecosystem status	20,000
Wetland Reconstitution and Restoration	Hydrodynamic improvement works for communication between parts of Amvrakikos wetland systems facing inadequate fresh or salt water supply	100,000
Research and Monitoring/Development Programmes	Monitoring of anoxic episodes in Amvrakikos Gulf and temporal evolution through water column	100,000

6. SOCIO-ECONOMIC ANALYSIS OF LIFE-TRANSFER RESTORATION MEASURES

6.1 CONTEXT: AMVRAKIKOS LAGOONS AND LOCAL FISHERIES

The Amvrakikos lagoons, including Logarou, are recognized as critical for local fisheries and ecosystem services, but multiple environmental pressures have led to notable changes in productivity and ecological structure. Recent assessments indicate that fishing yield in the Logarou Lagoon remains low, with landings falling below average annual values reported both for Mediterranean lagoons (12.89 t/km^2) and lagoons worldwide (10.10 t/km^2). This productivity shortfall is linked to specific geophysical and anthropogenic factors. The area is characterized by high clay concentrations in sediments, indicative of calm hydrodynamic conditions, low water flow, and increased nutrient retention. While this favors the growth of plankton and benthic organisms that could serve as fish food, it also results in poor water circulation and increased risk of organic matter buildup, shaping benthic and macrophyte communities. Sediment granulometry directly affects seagrass (macrophyte) community distribution and the diversity and abundance index of the benthos, which are critical components of fish habitat.

Additionally, the deterioration of water quality in the Arachthos River, primarily due to nutrient enrichment, has resulted in loss and degradation of lagoon habitats. This is evident in the gradual decline of rooted angiosperms such as Zostera noltei, Ruppia maritima, Ruppia cirrhosa, and Cymodocea nodosa, as well as shifts toward opportunistic macroalgae and altered oxygen dynamics. Although oxygen levels have not reached anoxic conditions, these changes have reduced ecological functionality and fisheries productivity. The operation of the Arachthos dam since 1981 further affects freshwater supply and salinity patterns, reducing fish attraction to the gulf and lagoon. Limited exchange with the Ionian Sea exacerbates water quality issues, fostering a semi-closed system highly sensitive to land-based inputs from agriculture, livestock, and sewage. Given these cumulative pressures, the productivity and ecological health of the lagoon is diminished, underlining the importance of both habitat restoration and broader watershed management in sustaining local livelihoods.

6.2 FISH LANDING TRENDS AND ECOLOGICAL DECLINE

Recent ecological analyses provide nuanced insights into the functioning and fishing pressure trends in Logarou Lagoon. The stable mean trophic level (mTrL) in Greek lagoons, including Logarou, suggests the absence of typical fishing impacts such as "fishing down the food web," "fishing up," or even "fishing through". This could indicate either preserved ecosystem structure or a consistent fishing strategy over the observed period.

Trophic category assessment revealed that Logarou Lagoon is characterized by restricted trophic flow due to increased organic material in sediments, stabilizing herbivorous-detritivorous species (now over 50% of biomass/landings) and reducing populations of high-trophic-level carnivorous species, such as eels. This structure is symptomatic of environmental stress and is associated with a significant drop in overall system productivity. The fishing pressure parameter, measured with the FiB (Fishing-in-Balance) index, reveals that although traditional barrier fish traps used in Greek lagoons are highly efficient for migratory species, the declining FiB index in Logarou reflects contracting fisheries and impaired system functioning. This is attributed to excessive catchment removal and negative environmental changes both locally and in the Amvrakikos Gulf as a whole. Sustainability analysis using the Gordon–Schaefer model confirms that the Logarou system is currently under-exploited. The actual yield and number of fishermen are below the estimated sustainable levels as projected by the model. The density of fishermen, ranging between 2.84 and 3.60 per km^2, is much lower than the Mediterranean regional average (8.72 ± 2.3 per km^2), confirming the absence of overfishing effects. Finally, examination of CPUE (catch per unit effort) against FiB confirms that fishing pressure is compatible with the current low exploitation level, emphasizing that environmental factors—and not overfishing—are principally responsible for the lagoon's reduced fisheries productivity.

6.3 SEAGRASS RESTORATION AND ECOSYSTEM SERVICES

6.3.1 RESTORATION IMPLEMENTATION AND OUTCOMES

The LIFE-TRANSFER project implements seagrass restoration through transplantation of Zostera noltei sods from the donor site (Mazoma lagoon) to the recipient site (Logarou lagoon). This species was selected due to its ecological importance as a foundation species creating habitat structure and providing multiple ecosystem services.

Transplantation Progress and Survival Rates:

Initial transplantation efforts (2021–2022) encountered significant challenges. In 2022, only 0.82% of transplanted rhizomes survived—a drastic decrease from the 75% survival rate achieved in 2021. This critical failure necessitated strategic reassessment of transplantation methods and site selection. A major strategic shift implemented in 2023 yielded substantially improved results. New transplant sites were selected in proximity to existing healthy meadow patches, taking advantage of better environmental conditions. Six months after transplantation in 2023, the average sod survival at each station was 46.3%—a dramatic improvement from 2022 levels:

- **Area A (Agios Nikolaos):** 55.6% ± 10.2% survival
- **Area B (Vasiliadi):** 36.8% ± 34.2% survival

This improvement demonstrates the critical importance of site selection and proximity to existing healthy seagrass patches for transplantation success. Snorkeling-based by-hand transplantation techniques also proved superior to boat-based placement methods, achieving better sod fixation and long-term survival.

Ecological Status Improvements:

The ecological status of transplant sites assessed using the M-AMBI index with reference conditions calibrated for Greek restricted polyhaline lagoons remained in moderate condition for transplant site A and increased to good status in transplant site B. This improvement aligns with the progressive success of restoration actions and indicates positive trajectory toward ecological recovery.

6.3.2 FISH HABITAT AND ECOSYSTEM SERVICES

Seagrass meadows provide multiple critical ecosystem services essential for fishery productivity and ecological integrity:

Nursery Habitat: Seagrass beds serve as essential nursery habitat for juvenile fish and crustaceans. The complex three-dimensional structure created by seagrass shoots provides refuge from predators and feeding grounds for early-life stages. Restoration of seagrass meadows thus directly supports recruitment into exploitable fish populations.

Sediment Stabilization: Root systems of seagrass plants stabilize soft sediments, reducing turbidity and improving water clarity. Enhanced water clarity increases light penetration to the seabed, promoting benthic primary production and enhancing food web efficiency.

Biodiversity Support: Seagrass meadows support diverse associated fauna including polychaete worms, mollusks, crustaceans, and fish. The high biodiversity within seagrass ecosystems translates to enhanced trophic complexity and ecosystem stability.

Oxygen Production: During daylight hours, photosynthetic activity by seagrass produces oxygen, counteracting hypoxic conditions that periodically affect lagoon water masses, particularly during summer stratification and high nutrient loading.

6.4 BLUE CARBON STORAGE AND CLIMATE MITIGATION

6.4.1 BLUE CARBON CONCEPT AND SIGNIFICANCE

Seagrass meadows are increasingly recognised as major Blue Carbon ecosystems because they trap and preserve large quantities of organic carbon in their sediments for centuries to millennia (Macreadie et al., 2021). However, the potential for storage varies widely among seagrass species and regions (Kennedy et al. 2022). In addition, it is strongly affected by anthropogenic pressures such as nutrient enrichment, which is driving global seagrass decline and reducing their capacity to act as carbon sinks (Fu et al. 2024). Smaller, fast-growing species such as *Zostera noltei* remain understudied despite their potential importance and resilience. In the Amvrakikos Gulf (Greece), where the species is common and where water quality degradation has already resulted in habitat loss and declining ecological status, there was no species-specific baseline measurement of blue carbon storage before the LIFE TRANSFER project.

6.4.2 CARBON SEQUESTRATION IN AMVRAKIKOS LAGOONS

Sediment Organic Carbon (SOC) Stocks:

Despite the ten-fold difference in areal extent, *Z. noltei* meadows in Mazoma were structurally more robust, with approximately double the shoot density and biomass compared to Logarou. However, this difference in meadow structure did not translate into higher sedimentary C_{org} stocks in Mazoma, where values were statistically indistinguishable from those in Logarou. This decoupling between plant structure and C_{org} storage suggests that sediment properties and organic matter sources play a stronger role than meadow biomass in controlling carbon burial in these systems (Apostolaki et al. 2024). Indeed, sediments in Mazoma were sandier and more compact, whereas Logarou was dominated by muddy sediments, likely reflecting different hydrodynamic regimes and organic matter deposition pathways. The isotopic signatures show that shoots in Logarou were more N-rich and $\delta^{15}N$ enriched, consistent with higher anthropogenic nutrient loading (Roca et al. 2016). Stable isotope mixing models confirmed that both lagoons were strongly subsidised by allochthonous inputs (>70% of the organic carbon pool), with SPOM being the dominant source, particularly in Logarou, which is indicative of seagrass extending under eutrophicated conditions (Mazarrasa et al. 2017). Together, these results demonstrate that for *Z. noltei*, sedimentary carbon storage is more strongly driven by external organic matter supply and sediment trapping characteristics than by meadow biomass alone—an important consideration for Blue Carbon assessments and for the prioritisation of management interventions.

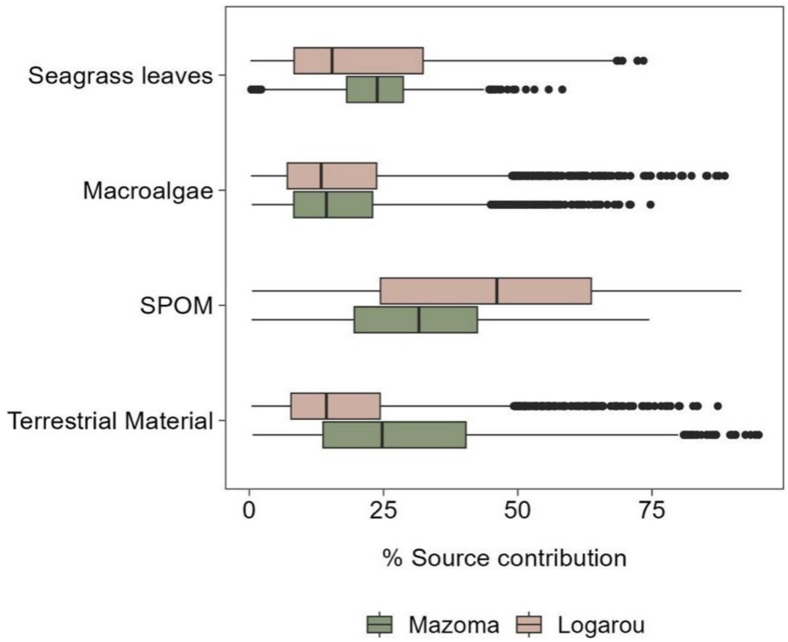

Fig. 3. Percentage (mean ± SD) of the contribution of each source to the organic carbon pool of the top 5 cm at the two stations.

Despite Mazoma hosting Z. noltei meadows roughly ten times larger in areal extent than Logarou, shoot density and aboveground biomass in Mazoma were approximately double those in Logarou; however, this structural robustness did not translate to increased sedimentary organic carbon (Corg) stocks. Measured sedimentary Corg stocks were statistically indistinguishable between sites. The results indicate a key decoupling between aboveground meadow structure (shoot density, biomass) and sediment carbon storage, suggesting that sediment characteristics and sources of organic matter play a more pivotal role than seagrass biomass alone in driving carbon burial in these systems.

Mazoma sediments were found to be sandier and more compact, while Logarou was dominated by muddy, organic matter–rich sediments, likely the result of divergent hydrodynamic regimes and organic matter input/retention pathways. Isotopic analysis demonstrated that seagrass shoots in Logarou are richer in nitrogen and have higher $\delta^{15}N$ values—characteristics aligned with elevated anthropogenic nutrient loading. Furthermore, stable isotope mixing models revealed that both lagoons receive substantial allochthonous (external) carbon subsidies—primarily suspended particulate organic matter (SPOM), which accounts for over 70% of the organic carbon pool. This effect is particularly pronounced in Logarou, supporting the persistence of Z. noltei under eutrophicated conditions commonly associated with intensive land-based nutrient inputs.

These findings underscore that, at present, sedimentary carbon storage in Amvrakikos Gulf lagoons is governed more by external organic matter supply and sediment-trapping efficiency than by the specific biomass of seagrass meadows. This observation is essential for blue carbon management: successful management and restoration of blue carbon resources in this system should focus on reducing nutrient enrichment, addressing sediment dynamics, and considering the landscape-scale context of organic matter inputs in both the planning and assessment of restoration initiatives.

6.5 CLIMATE CHANGE AND TEMPERATURE IMPACTS ON FISH YIELDS

6.5.1 OBSERVED TEMPERATURE INCREASES IN AMVRAKIKOS LAGOONS

A critical finding from monitoring activities is the documentation of exceptionally high water temperatures in both lagoons. Temperature data loggers installed in May 2023 recorded:

- **Maximum summer water temperatures reaching 35°C** in July 2023
- Daily average temperatures in transplant sites consistently exceeding 23°C during May–October monitoring period
- Temperature fluctuations between sites, with transplant areas (Logarou) showing slightly higher average temperatures than donor site (Mazoma)

These temperatures represent critically high conditions for temperate seagrass species. Research from the Venice lagoon indicates that limited seagrass colonization and growth occurs in areas experiencing sustained temperatures above 30°C, with substantial growth inhibition above 28°C. The 35°C temperatures observed at Amvrakikos represent conditions at or beyond the physiological stress threshold for Zostera noltei.

6.5.2 MECHANISMS OF CLIMATE IMPACT ON FISH YIELDS

Rising lagoon temperatures—driven by climate change—exert multiple negative impacts on fish populations, potentially exceeding the positive effects of habitat restoration:

1. Physiological Stress on Fish: Elevated temperatures increase metabolic demands on fish, particularly during feeding and growth periods. Many lagoon fish species have evolved for cooler Mediterranean climatic regimes and experience physiological stress at sustained temperatures above historical norms. This stress manifests as reduced growth rates, increased disease susceptibility, and behavioral changes.

2. Altered Spawning Phenology: Temperature cues drive reproductive timing in most fish species. Warming lagoons may disrupt synchronization between spawning and food availability for larvae, reducing recruitment success. Earlier spawning in response to warming may expose larvae to predators or result in phenological mismatch with zooplankton blooms.

3. Oxygen Depletion: Higher temperatures reduce oxygen solubility in water while simultaneously increasing metabolic oxygen demand. Warmed, stratified lagoon water masses become increasingly hypoxic during summer, creating "dead zones" uninhabitable for most fish species. Monitoring data from 2023 campaigns show dissolved oxygen levels declining to 57–70% saturation during summer months at multiple stations.

4. Shift in Species Distributions: Climate warming drives range expansions of thermophilic species while pushing cold-water species toward extinction locally. Mullets and eels—the most commercially important species in Amvrakikos—show variable thermal tolerance, with some populations adapted to warmer conditions and others to cooler Mediterranean regimes. Wholesale shifts in community composition reduce economic value of landings.

5. Interactions with Other Stressors: Temperature stress interacts synergistically with nutrient loading, hypoxia, and habitat loss. Warm water enhances eutrophication processes, accelerating phytoplankton blooms that further reduce water clarity and oxygen availability. The cumulative effect of multiple stressors exceeds the impact of any single factor alone.

6.6 COMMUNITY ENGAGEMENT AND SOCIO-ECONOMIC OUTCOMES

6.6.1 INCOME AND EMPLOYMENT EFFECTS

Despite the ecological challenges outlined above, the LIFE-TRANSFER project demonstrates substantial socio-economic benefits through community engagement:

Direct Employment: Local fishermen hired for seagrass planting activities have earned supplementary income during project implementation phases. Estimated direct income from restoration labor: €5,000–12,000 per fisherman per year, depending on labor intensity and project phase.

6.6.2 KNOWLEDGE TRANSFER AND BEHAVIORAL CHANGE

Beyond economic gains, restoration activities catalyze important cognitive and behavioral changes in fisher communities:

Ecological Literacy: Through direct participation in seagrass transplantation and monitoring, fishermen gain tangible understanding of seagrass ecology, fish habitat requirements, and ecosystem function. This knowledge shift enhances capacity to recognize ecosystem degradation indicators and motivates conservation behavior.

Stewardship Mentality: Engagement in restoration work fosters sense of personal investment in lagoon health. Fishermen transitioning from purely extractive harvesting to active stewardship roles experience identity shifts aligned with sustainability values. This mentality shift is essential for long-term conservation success, as external regulation proves insufficient without internalized stewardship motivation.

Institutional Strengthening: Cooperative engagement in LIFE-TRANSFER activities strengthens fishermen's cooperative organizations, improving capacity for collective action, adaptive management, and negotiation with government authorities. Stronger institutions enhance resilience to external shocks and capacity to influence policy decisions affecting community interests.

6.6.3 SOCIAL CAPITAL AND COMMUNITY COHESION

Beyond individual and economic dimensions, restoration activities strengthen community social capital:

Intergenerational Knowledge Transfer: Older fishermen mentoring younger participants in restoration techniques transmit not only technical skills but also ecological knowledge and cultural practices adapted to lagoon conditions.

Cross-Sector Collaboration: Fishermen working alongside scientists, conservationists, and government officials in restoration and monitoring activities dissolve sectoral boundaries and build mutual understanding. These relationships create foundation for future collaborative environmental management.

Collective Identity: Shared participation in publicly recognized restoration project elevates community identity and generates local pride. Amvrakikos fishermen increasingly identify as active conservation participants rather than passive resource users, with corresponding shifts in community narratives and regional reputation.

6.6.4 ECONOMIC VIABILITY OF RESTORATION

Current restoration costs from the LIFE TRANSFER project are estimated at 50-60000 € per year including labor, materials, monitoring travel costs) must be compared against uncertain benefit streams. Economic analysis must consider high discount rates (7–10%) standard in policy analysis, making distant future fishery benefits appear modest in present value terms. Sustained funding and institutional commitment beyond current project period remain uncertain.

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7. RECOMMENDATIONS AND CONCLUSIONS

7.1 SYNTHESIS OF FINDINGS

The Amvrakikos Gulf represents a complex socio-ecological system where conservation imperatives intersect with economic needs of fishing-dependent communities. This analysis reveals:

1. **Economic Structure and Vulnerabilities:** The region exhibits disproportionate dependence on primary sector activities, with limited economic diversification. Fisheries represent critical livelihood source despite declining productivity. This creates urgency for both conservation and livelihood support.

2. **Environmental Degradation:** Long-term declines in fish stocks correlate with less-than-good ecological status of lagoons, itself reflecting nutrient loading from livestock and agriculture. Point and diffuse pressures continue largely unchecked, creating persistent ecosystem stress.

3. **Limited Efficacy of Habitat Restoration Alone:** While seagrass restoration demonstrates technical and ecological viability with improving survival rates, the spatial scale and persistence of environmental pressures limit gains. Climate change—particularly rising water temperatures—poses greater threat to fish yields than restoration alone can mitigate.

4. **Transformation of Social-Ecological Relations:** Despite ecological limitations, LIFE-TRANSFER demonstrates remarkable social capital creation and community engagement. Fishermen transitioning from purely extractive to stewardship roles represent fundamental shift in social-ecological relations with long-term conservation implications.

7.2 INTEGRATED MANAGEMENT RECOMMENDATIONS

7.2.1 PRESSURE REDUCTION PRIORITY

Aggressive reduction of point and diffuse pressures through:

- Livestock management regulation: restricting facility numbers, implementing best management practices, utilizing treated manure

- Agricultural nutrient management: promoting precision fertilization, controlled-release fertilizers, cover crops, and riparian buffers

- WWTP enhancement: upgrading treatment to tertiary level with nutrient recovery

7.2.2 CLIMATE-ADAPTIVE RESTORATION

Expanding restoration beyond current 1–5 ha to 20–50 ha through:

- Selection of warm-adapted seagrass ecotypes and propagule sources
- Integration with hydrodynamic restoration (inlet modifications to enhance water exchange)
- Hybrid restoration combining multiple species (Zostera and Cymodocea) for thermal diversity

7.2.3 ENHANCED MONITORING AND ADAPTIVE MANAGEMENT

Establishment of lagoon-scale adaptive management framework:

- Weekly water temperature, dissolved oxygen, and phytoplankton monitoring
- Rapid response protocols for hypoxic events, algal blooms, or fish kills
- Annual management review and strategy adjustment based on ecosystem condition
- Integration of traditional ecological knowledge from fisher communities into adaptive management decisions

7.2.4 COMMUNITY CAPACITY BUILDING AND LIVELIHOOD SUPPORT

Sustained investment in community capacity and livelihood diversification:

- Training programs for fishing community in ecosystem monitoring, GIS, and data analysis
- Market development support for eco-certified lagoon seafood products
- Microfinance and business development support for fishing cooperative diversification

7.2.5 INSTITUTIONAL COORDINATION AND GOVERNANCE

Establishment of inter-agency coordination mechanism:

- Formal governance structure including fisheries, environmental, and agricultural authorities
- Quarterly management review meetings with community participation
- Formalized agreements on respective roles, authorities, and resource commitments

7.3 CONCLUSIONS

The LIFE-TRANSFER project represents an important contribution to Amvrakikos Gulf restoration and demonstrates that seagrass transplantation can succeed when technical protocols are refined and site selection optimized. Community engagement through restoration activities has catalyzed transformative social capital creation and behavioral change toward sustainable stewardship. However, the true measure of success cannot rest solely on restoration metrics. The project's long-term impact depends on whether restored seagrass persists in a degraded environmental context dominated by nutrient pressure and warming temperatures. Current trajectories suggest that restoration activities, while ecologically positive and socially valuable, address symptoms rather than underlying drivers of ecosystem degradation.

The most important finding of this report is that **climate change and observed temperature increases in the lagoon will have greater impact on fish yields than active restoration activities of planting seagrass meadows.** This finding necessitates fundamental reorientation of strategy toward climate-adaptive management, pressure reduction, and livelihood diversification, with restoration as essential but not sufficient component. Success in Amvrakikos requires integrated approach combining: (1) aggressive environmental pressure reduction; (2) climate-adaptive restoration at expanded scales; (3) institutional innovation in adaptive management; (4) community empowerment through stewardship roles and livelihood support; and (5) regional climate adaptation planning. Such comprehensive approach transcends traditional sectoral boundaries and embraces social-ecological integration essential for resilience in coupled human-natural systems.

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