

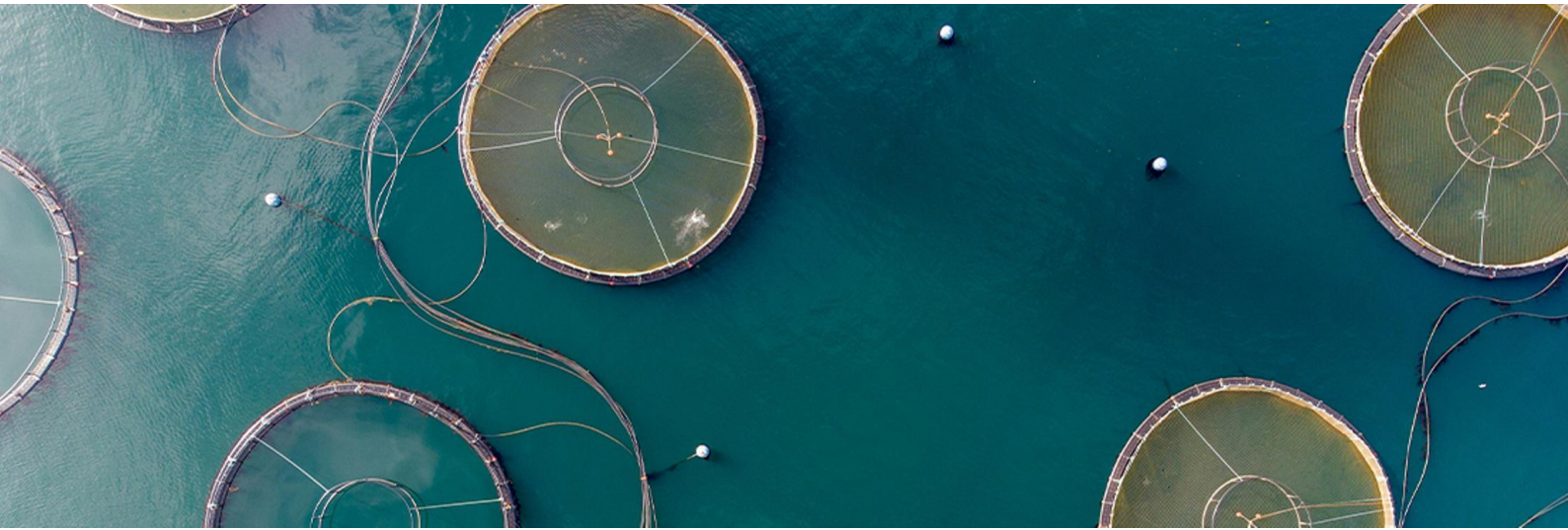


AZA4ICE

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May 2026

Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

8 AZA4ICE Action Plans

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Output ID

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Introduction

Eight (8) local/regional Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector have been developed.

They integrate the knowledge gained during the AZA4ICE methodology (Output 1.1) testing in the eight (8) AZA4ICE pilots to identify the Allocated Zones for Circular Aquaculture (C-AZAs), and during the eight (8) Living Responsible Research and Innovation Ecosystems (LiRRIEs) that were implemented in the pilot territories following the LiRRIE methodology (Output 2.1).

Also, the Actions Plans incorporate the conclusions derived by the analysis of the aquaculture legal/regulatory framework and licensing processes in each participating territory (Del. 2.3.1 Review on aquaculture legal/regulatory framework and licensing processes), the Circular Economy aquaculture practices and innovative/sustainable production/consumption models presented in detail in Del. 3.1.1 Guide with circular aquaculture business practices and opportunities, and society's perception towards aquaculture and new products.

The AZA4ICE, transferrable, common transnational strategy for drafting the AZA4ICE Action Plans (Del 3.2.1) was followed by the partnership to develop the eight (8) Action Plans which will be presented in detail in this document.

Last but not least, the MoU is signed to engage the involved stakeholders to uptake project Action Plans even after the project end.

The detailed AZA4ICE Action Plans are presented below for:

- ✚ Cadiz, Spain
- ✚ Cabras Lagoon, Sardinia, Italy
- ✚ Ria Formosa, Portugal
- ✚ Krka River estuary, Šibenik, Croatia
- ✚ Thau Lagoon, France
- ✚ Varna Bay, Bulgaria
- ✚ Šasko Lake, Montenegro
- ✚ Palaio Lagoon Lefkada, Greece

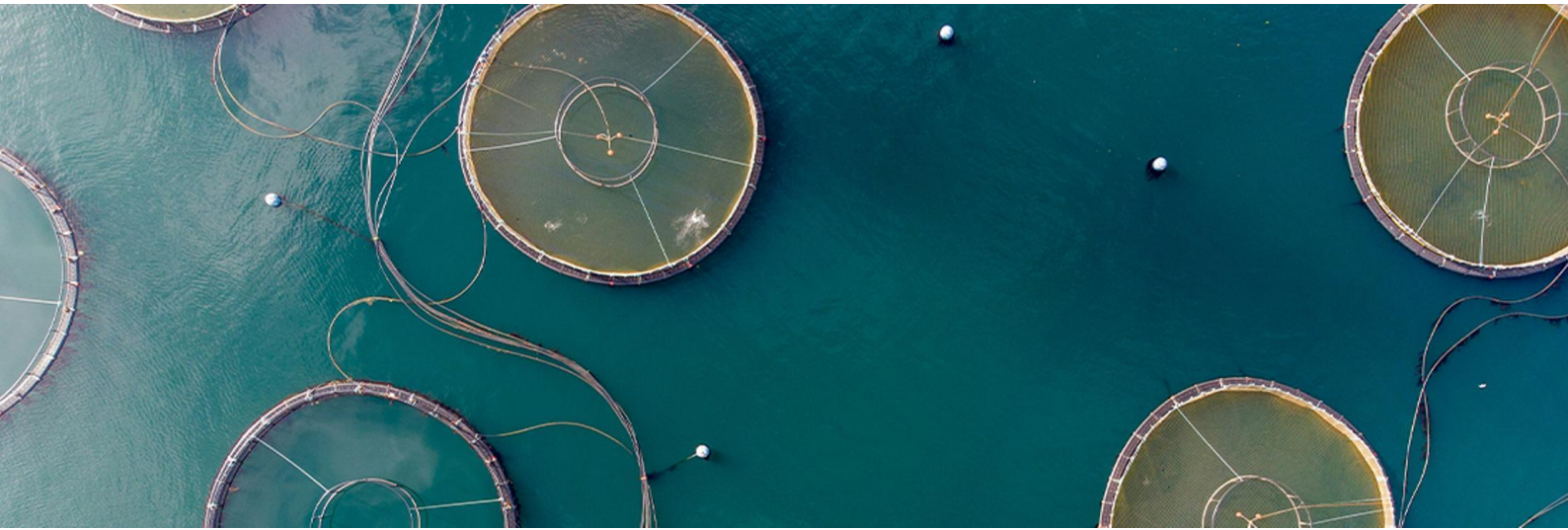


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AZA4ICE Action Plan for Cadiz, Spain

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Abbreviations

AZA	Allocated Zone for Aquaculture
C-AZA	Circular Allocated Zone for Aquaculture
C-AZAI	C-AZA Index
GES	Good Environmental Status
HAPO	Hellenic Aquaculture Producers Organisation
IMTA	Integrated Multi-Trophic Aquaculture
LIRRIE	Living Responsible Research & Innovation Ecosystems
NECCA	Natural Environment and Climate Change Agency
SAC	Special Area of Conservation
SiSI	Site Suitability Index
SPA	Special Protection Area



Executive Summary

This Action Plan outlines a strategic framework to facilitate the transition toward circular and eco-intensive aquaculture in Andalusia region (Spain), positioning the sector as a significant contributor to both the Andalusian Blue Economy Strategy (EA2) and regional objectives in sustainable aquaculture. Developed in accordance with European Circular Bioeconomy principles, the Plan proposes an integrated methodology that encompasses environmental protection, economic diversification, technological advancement, and social cohesion within coastal and protected areas.

The Action Plan examines regional needs, challenges, and opportunities related to circular aquaculture and particular in the Bay of Cádiz. Moreover, it assesses the regional regulatory information and reviews the status of the sector's adoption of circular practices. Consequently, it presents a strategy organized around five interconnected pillars designed to support the shift toward circular, resilient, and ecosystem-based production models, enhance the economic viability and competitiveness of aquaculture enterprises, promote targeted innovation and knowledge transfer, establish a proper policy framework and financing conditions and strengthen stakeholder engagement, governance, and market development.

By integrating regulatory points, advanced technology, business incentives, and participatory governance, this Action Plan extends beyond theoretical sustainability to provide actionable pathways for sectoral advancement and more competitive. It positions Andalusia as a leader in circular aquaculture, exemplifying how nature-based solutions and circular systems can restore ecosystems, generate new revenue streams, improve resilience and competitiveness in coastal economies, and ensure sustainable food security and social acceptance.



1. Introduction

The Action Plan for Circular Aquaculture constitutes a **region-specific roadmap** designed to promote and accelerate the transition of the aquaculture sector towards more inclusive, resilient, and circular production practices. Developed within the framework of the AZA4ICE project, this Action Plan aims **to identify concrete and targeted actions that facilitate this transition** adapted to the socio-economic, environmental, and regulatory context of Andalusian region.

This Action Plan centres on the **pilot site in the Bay of Cádiz** mainly characterized by coastal land-based aquaculture. Insights from LiRRIEs co-creation events and stakeholder engagement informed realistic needs and capabilities. While specifically tailored to the Bay of Cádiz, the methodology and several actions are also applicable to other Mediterranean and Atlantic aquaculture systems, including floating cages. The versatility of the methodology developed for assessment of the potential Circular Allocated Zones for Aquaculture (C-AZAs) ensures adaptability to other productive models identifying targeted actions if specific conditions are properly adjusted.

The Plan addresses the full aquaculture value chain, including production systems, waste and by-product management, logistics, governance, business models, and stakeholder engagement. It promotes the adoption of innovative circular production models such as Integrated Multitrophic Aquaculture (IMTA), Recirculating Aquaculture Systems (RAS), marine aquaponics, biofloc (BFT) and hybrid systems that enhance nutrient upcycling, biomass production and companies competitiveness.

In addition, the Action Plan considers the legal, spatial planning, and licensing frameworks required to mainstream circular aquaculture practices within existing regulatory structures. It aims to facilitate policy alignment, innovation and institutional coordination to enable the long-term deployment of circular production models.

This Action Plan is aligned with relevant EU strategies and policy frameworks, including the European Green Deal, Blue Economy Strategy, Farm to Fork Strategy, **EU Strategic Guidelines for Smart and Sustainable Aquaculture (2021)**¹ and **Strategic Framework for a Competitive and Sustainable EU Bioeconomy (2025)**². While tailored to regional needs as identified in the **New Andalusian Strategy for the Development of Marine Aquaculture [2021–2030]**³, its structure

¹ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:236:FIN>

² https://environment.ec.europa.eu/document/download/dbf8d2ba-9332-4f7a-b336-f356fa4b7236_en?filename=COM_2025_960_1_EN_ACT_part1_v10_0.pdf

³ https://juntadeandalucia.es/sites/default/files/inline-files/2023/03/Estrategia_Acuicultura_2021_2030_0.pdf



and methodology ensure high transferability potential across the wider Euro-Mediterranean region.

2. Context

The Andalusian aquaculture sector has a long tradition with two clearly differentiated types of production zones from an environmental perspective, which determine the farming systems: **land-based aquaculture zones in the South Atlantic areas (Figure 1)** and **sea-based marine aquaculture zones in the Mediterranean Sea**. In both areas, production models remain largely linear, with high dependence on external inputs, limited valorisation of side streams, and increasing regulatory and environmental constraints. We should also mention the production in freshwater for trout and sturgeon, that although a smaller sector, has also relevance for AZA planning.



Figure 1: Species and production models in Andalusian aquaculture (Credits: Manuel Machado).

In terms of number of establishments, land-based aquaculture is the most important in Andalusia. According to the latest available statistical data, this sector comprises 91 establishments, representing 89% of the authorisations for marine aquaculture in the region. However, between 2010 and 2024, the number of authorised land-based facilities has decreased by 41%. Most of this sector operates within a highly sensitive socio-ecological system characterized by protected coastal wetlands, estuarine environments, and strong interactions with tourism,



fisheries, and conservation activities. With respect to freshwater aquaculture in Andalusia, this is a small but highly specialized sector, largely concentrated in the province of Granada, which hosts around 93% of inland production, farming focuses on species of high commercial and nutritional value, notably rainbow trout (*Oncorhynchus mykiss*), appreciated for its versatility and quality, and sturgeon, cultivated both for its meat and for the production of premium caviar. Despite its limited scale, this sector plays an important role in regional diversification, combining traditional practices with emerging sustainable and high-value aquaculture models. While the sector is facing important challenges associated with environmental regulations, climate change, production costs, and social acceptance, the circular aquaculture and the blue economy policies open a new window of opportunity to boost aquaculture in important zones in Cádiz and Huelva.

The AZA4ICE project provides a strategic framework to address these challenges through the application of C-AZAs. Pilot actions in Andalusia demonstrate the feasibility of IMTA, RAS, and waste valorisation systems. This Action Plan is developed through the innovation ecosystems LiRRIEs, ensuring multi-actor participation of the following objectives:

- 1) Operationalise Circular Aquaculture in C-AZAs.** Design and scale circular production models will be promoted within identified C-AZA pilot areas optimising spatial planning and resource allocation to maximize environmental and economic performance.
- 2) Promote Innovative Production Systems.** Technological and implementation advances in IMTA, RAS, aquaponics, and hybrid systems guiding diversification in low-trophic organisms (macroalgae, halophytes, bivalves) will be supported to strengthen ecosystem services and market opportunities. Promote industrial symbiosis and business-to-business collaboration to consolidate production models.
- 3) Enhance Resource Efficiency and Waste Valorisation.** Circular practices such as sludge recovery, by-product valorisation, nutrients upcycling, more efficient feeding and genetic selection and eco-design will be fostered.
- 4) Strengthen Governance and Regulatory Integration** Alignment between circular aquaculture practices and licensing, spatial planning, and environmental regulations will be encouraged. Provide policy recommendations to support regulatory adaptation for circular production models.
- 5) Foster Social Inclusiveness and Stakeholder Engagement.** Multi-actor participation of quadruple helix promoting knowledge transfer, and capacity building within the sector will be ensured.



3. Roles and Responsibilities of Actors

Main roles and actors in the Action Plan will be:

- **Regional Authorities:**

This includes the Directorate for Fisheries Aquaculture and Blue Economy of the Regional Ministry of Agriculture, Fisheries, Water and Rural Development (CAPDR) and the environmental authorities of the Junta of Andalusia, including the Natural Parks Administration and the Regional Ministry of Sustainability and Environment. Their main responsibilities include policy integration, licensing and permitting, spatial planning, regulatory oversight, and environmental protection.

- **National authorities**

This includes the department with competences of Public Maritime-Terrestrial Domain and Public Hydraulic Domain from the Spanish Ministry for Ecological Transition and the Demographic Challenge as well as state security forces and law enforcement agencies

- **IFAPA (Andalusian Institute for Agricultural and Fisheries Research and Training)**

IFAPA will contribute to the technical coordination, monitoring, and capacity-building activities. IFAPA will also support technology transfer and training programs aimed at facilitating the transition towards circular aquaculture practices

- **Administrative Agencies of Junta of Andalusia.**

AGAPA and AMAYA will support as advisor in allocated maritime planning controls and monitoring

- **Aquaculture sector:**

This group includes producers, associations, service providers, and value-chain actors. They will be the primary agents responsible for implementing the transition to circular practices, piloting innovative production models

- **Universities and Research Centres**

These institutions will deliver technical support and applied research and develop innovative solutions for a better performance of aquaculture systems.

- **Civil Society**

Civil society organizations and local communities will contribute to foster social acceptance and shared responsibility for sustainable aquaculture development.



4. Regional Needs, Challenges and Opportunities (input from LiRRIE)

This section presents the main needs, challenges, and opportunities identified through the LiRRIE stakeholder engagement process conducted in the Andalusian region. These insights serve as key guiding elements for the Action Plan, ensuring that it responds to local conditions and supports solutions that are both feasible and meaningful for the sector in this area.

With respect to the **challenges**, they were grouped into five categories: a) Environment; b) economic viability; c) technological and knowledge gaps; d) policy and regulatory gaps and e) stakeholder engagement and coordination (**Figure 3**). These challenges reflect the key structural and contextual issues affecting aquaculture development in the Bay of Cádiz pilot site, as outlined below.

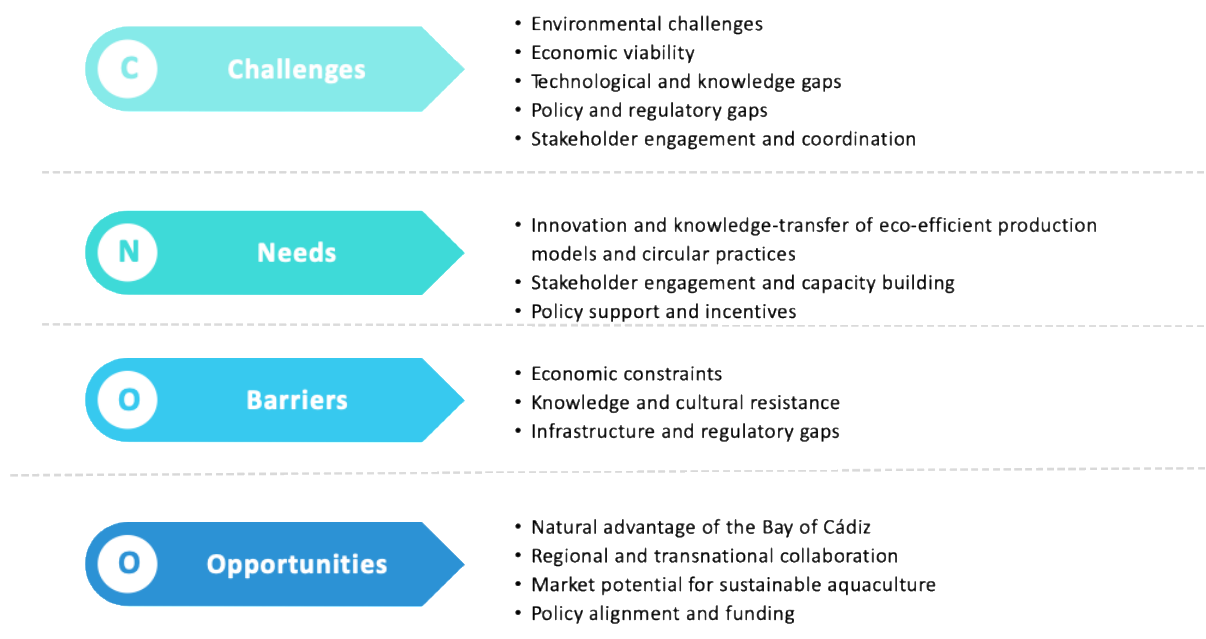


Figure 2. Main challenges, needs, barriers and opportunities in the pilot site Bay of Cádiz

a) Environmental challenges

Environmental constraints encompass a wide range of factors that directly influence the sustainability and performance of aquaculture activities in the Bay of Cádiz:

- **Eutrophication risks and nutrient discharges.** This is a major challenge for producers since non-extensive aquaculture facilities must fulfil water quality regulations controlling the levels of organic and inorganic particles in



wastewater. These regulatory frameworks are particularly strict, requiring continuous monitoring and compliance with high environmental quality standards, increasing operational complexity and costs. Currently, most productive models follow a lineal approach.

- **Pollutant associated risks** especially the presence of heavy metals in the water resulting from anthropogenic and other blue-economy activities. This issue is of particular concern for organisms with bioaccumulation capacity, such as algae and molluscs, as well as for aquaculture sludge. This is of special relevance when circular strategies aim to valorise these materials as fertilisers, feed or food services.
- **Climate change impacts**, including rising seawater temperatures, higher sea level and the increasing frequency of extreme weather events. Seasonal temperature shifts are becoming more frequent, altering reproductive cycles, requiring facilities modifications while rapid thermal fluctuations increase the occurrence of thermal stress episodes and uncontrol mortalities. Together, these changes represent an emerging challenge that requires adaptive strategies.
- **Salinity fluctuations.** The strong tidal dynamics typical of the Bay of Cádiz create significant variability in salinity and water quality. These fluctuations are further intensified during episodes of heavy rainfall, conditioning the range of species suitable to be cultivated and generating stressful conditions for cultivated organisms and increasing the risk of production losses.
- **Balancing aquaculture growth with the preservation of sensitive coastal ecosystems.** This area is protected under natura Network 2000 and it hosts high biodiversity values. Therefore, there exists several restrictions to any action that disturb birds or modify environmental conditions toward aquaculture. There exists a particular classification of productive areas according to the degree of protection and requirements imposing limitations to the type of activity and actions.
- **Underutilisation of traditional marsh ponds ("esteros").** Many esteros are not exploited leading to a reduction of extensive and semi-extensive aquaculture, the degradation of wetland ecosystems, and the erosion of cultural and historical heritage linked to traditional aquaculture practices.

b) Economic viability

Economic viability challenges are the result of structural and operational constraints that limit long-term sustainability of aquaculture activities in the Bay of Cádiz such as:

- **Uncontrolled access and theft.** Difficulties in preventing unauthorized access to production areas and theft during production cycles. The Natural Park is surrounded by big urban areas and access is easy requiring rapid responses. As consequence, significant investments in security are usually required requiring



more coordination with state security forces and law enforcement agencies.

- **Inefficient production models.** Many existing traditional aquaculture systems show limited economic performance due to suboptimal feed efficiency, high input costs, and efficiency in water management. In most traditional systems is not easy to monitor or deliver feeds effectively. Moreover, survival is not easy to control producing overfeeding frequently. Moreover, the water quality fluctuations are high modifying growth rates with high pumping costs when tides are not possible.
- **Predation losses.** Significant production losses are caused by bird predation, particularly in extensive and semi-extensive systems, where control measures are often limited or costly. In the Natural park approximately 30% of the total annual extensive aquaculture production (114.4 kg/ha) is lost by ingestion by birds (Yufera & Arias 2010). Aunque estas cifras necesitan ser actualizadas, el patrón anual es similar al de otras regiones europeas, con pérdidas de trucha en canales de cultivo que oscilan entre el 2 % y el 40 % del stock en sistemas de producción en estanques de gran tamaño. En estanques de carpa y tenca, las pérdidas promedian el 19 %, con un rango entre el 3 % y el 70 %⁴.
- **Transition costs.** The shift toward eco-efficient production systems and the adoption of circular aquaculture practices require substantial upfront investments, posing a major financial burden for operators.
- **Funding barriers.** Small and medium-sized enterprises (SMEs) and small-scale producers face significant barriers in accessing financing, investment instruments, and tailored support schemes to modernize their operations
- **Spatial planning constraints and competition for space.** Aquaculture activities must coexist with other blue economy sectors, including tourism, maritime transport, sports and recreational uses and compliance with military and security restrictions, which further limit available space and increase operational complexity.

c) Technological and knowledge gaps

- **Insufficient integration of circular aquaculture systems.** Despite the proven potential of circular production approaches already recognized in regional regulatory frameworks and the conditions to implement them in the territory, implementation **IMTA, RAS, marine aquaponics, BFT** or hybrid systems remains limited at the local level. Although one company moved toward IMRAS system, most production models continue to rely on linear approaches with low levels of effective nutrient recovery, valorization and circular practices.
- **Limited access to advanced technologies and tools.** Many producers face difficulties in accessing and adopting modern technologies, including real-time water quality sensors, aquafeeds 3.0, automated feeding systems, genetic

⁴ <https://openknowledge.fao.org/server/api/core/bitstreams/125af2f0-834c-4625-a29c-9ba118c5b59c/content>



breeding programs, decision-support tools, performance monitoring platforms and biomass management. In addition, the limited integration of improvement and selective breeding programs constrains the optimization of growth, resilience, and feed efficiency.

d) Policy and regulatory gaps

Policy and regulatory constraints remain a significant barrier to the development of circular and eco-intensive aquaculture systems:

- **Lack of clear regulatory frameworks to promote circular and eco-intensive aquaculture systems.** Existing regulations are primarily designed for conventional aquaculture models and do not sufficiently recognise or facilitate the implementation of circular and eco-intensive approaches. In Andalusia, aquaculture legislation formally recognizes IMTA as a productive system, and the currently decree regulating the activity is currently being on revision to be amended to incorporate circular practices, clearly distinguishing them from linear intensive practices that are far removed from eco-intensive models. The absence of clear definitions and classification criteria for circular practices creates regulatory uncertainty.
- **Insufficient incentives for adopting sustainable practices.** There is a lack of targeted incentives, circularity indicators, support schemes, and regulatory flexibility to encourage producers to invest in sustainable and circular practices.
- **Fragmentation of competences and regulatory complexity.** Aquaculture activities are governed by multiple regulatory bodies with overlapping responsibilities, leading to complex, time-consuming authorisation processes and uncertainty for operators.

e) Stakeholder engagement and coordination

- **Difficulty in aligning diverse stakeholder interests.** Policymakers, researchers, producers, industry representatives, and local communities often operate with differing priorities in advancing toward circularity and timelines. Perception is completely different. Producers typically prioritise energy stability and feed cost reduction, policymakers emphasise emissions, nutrient discharge, and licensing risk, while citizens value transparency, origin, and ecological responsibility. These differentiated priorities must be mediated through inclusive governance, stakeholder co-creation, and knowledge exchange protocols (Aitken *et al.* 2025).
- **Limited awareness and participation of small and medium enterprises (SMEs) in innovative circular aquaculture practices.** SMEs frequently have limited knowledge of circular aquaculture opportunities, technologies, and support mechanisms, which restricts their involvement in innovative practices.
- **Lack of coordination among stakeholders.** Weak linkages between producers, public authorities, research institutions, and advisory services hinder knowledge



exchange, co-creation, and the effective transfer of innovation into practice. These challenges are represented in the **Figure 3**.



Figure 3. Challenges identified in the pilot site Bay of Cádiz

With respect to the **needs**, the transition toward circular aquaculture requires a coordinated set of technological, social, and policy-oriented actions that jointly address structural bottlenecks in production systems, governance, and value chains. **Figure 4** synthesizes the key **needs** that shown below:

a) Reinforcement of Innovation and knowledge-transfer of eco-efficient production models and circular practices

- **Adoption and transition toward circular IMTA, RAS, BFT, aquaponics and hybrid systems.** Throughout *pilot demonstration sites and case studies*, the current linear models should make easier the transition toward IMTA, hybrid systems IMRAS, BFT and aquaponics solutions. Different combinations of fed species (fish, shrimp) and extractive organisms should be carefully assessed in each model for scalability and adaptability
- **Development and reinforcement of low-trophic species production capacity.** Priority should be given to establishing *robust, scalable farming technologies and dedicated facilities and breeding program* including genetic selection for the production and reliable supply of high-value, low-trophic aquaculture species adapted to local ecological conditions. *Species selection should prioritize those oriented toward direct human consumption* with strong consumer acceptance. Moreover, it is essential to strengthen capacities for *biomass production as a commodity* for downstream, high value-added applications in the food, cosmeceutical, nutraceutical, and aquafeed industries.



- **EcolInnovation in advanced circular aquaculture models.** New materials, resources, and *optimized workflows* should be integrated into aquaponics, IMTA, BFT, and RAS, in synergy with salt-marsh restoration practices and other nature-based solutions.
- **Technology development for by-product processing and valorization.** Design and validate *advanced technologies for the in situ processing and upscaling* of aquaculture by-products (algal or halophyte biomass) and residues (sludge, fish-by-products, shells). *In situ* technology validated to mechanize collection and cost-effective preservation methods should make cost-effective downstream valorization pathways including functional foods and feeds, biofuels and energy production, bioplastics and bio-polymers, fertilizers and biostimulants for agriculture, and integrated sludge management within circular bioeconomy frameworks.
- **Genetic and microbial innovation.** Genetic and microbiome-based innovation is essential to strengthen the resilience, health, and productivity of both fed and extractive species within circular aquaculture systems. This requires the expansion of *selective breeding and domestication programs*, the application of functional and quantitative genomics, and the strategic management of microbial consortia. In parallel, advancing in the biotechnological use of *bacteria-promoting growth bacteria*, host-microbiome interaction studies are required to support improved robustness, disease resistance, and resource-use efficiency, enabling stable performance under eco-intensive and environmentally variable conditions characteristic of circular aquaculture models.

b) Stakeholder engagement and capacity building

- **Capacity building and training for local producers.** Design and deliver tailored training programs that combine technical, economic, and environmental aspects of circular aquaculture.
- **Co-development of solutions through participatory platforms.** Actively engage producers, public agencies, research institutions, and SMEs in co-developing practical and context-specific solutions using existing participatory platforms.
- **Strengthening multi-actor collaboration in aquaculture zones.** Leverage established participatory frameworks to facilitate continuous dialogue and co-design among multiple actors within aquaculture zones.

c) Policy support and incentives

- **Alignment and adaptation of regulatory frameworks.** Review and harmonize existing regulations to remove barriers and create enabling conditions for circular aquaculture, including the reuse of by-products, nutrient recycling,



integrated systems, and innovative feed and energy solutions.

- **Financial incentives and economic support mechanisms.** Develop targeted financial instruments such as grants, subsidies, tax incentives, and access to green finance to support small and medium producers in transitioning toward eco-intensive and circular systems.
- **Definition and operationalization of Aquaculture Zones of Activity (AZAs).** Support the definition and implementation of AZAs as spatial and governance tools to identify regional needs, optimize resource use, and coordinate circular aquaculture activities.

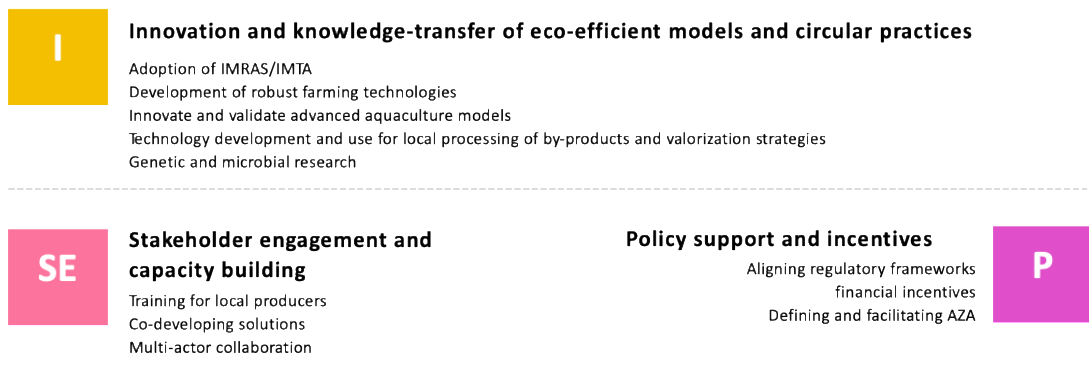


Figure 4. Needs identified in the pilot site Bay of Cádiz

With respect to the **barriers**, there are three main categories that currently hinder the transition toward circular aquaculture systems: economic constraints, infrastructure and regulatory gaps, and limitations in knowledge transfer and cultural acceptance. **Figure 5** synthesizes the most relevant obstacles that must be addressed as indicated below:

a) Economic Constraints

- **Limited access to dedicated funding and financial instruments.** SMEs often face difficulties in accessing public or private funding to transitioning existing facilities toward circular, eco-intensive systems. Investment schemes are frequently not tailored to the specific needs and risk profiles of integrated systems such as IMTA, RAS, or aquaponics.
- **Perceived high costs and risks associated with implementing circular aquaculture models.** Circular aquaculture models are often perceived as capital-intensive and technologically complex, leading to concerns regarding return on investment, operational reliability, and market uncertainty.
- **Insufficient visibility of validated business models.** Despite the existence of successful pilot projects, there is a lack of widely disseminated, well-documented business cases demonstrating the economic viability of circular aquaculture.



b) Infrastructure and regulatory gaps

- **Outdated aquaculture infrastructure not adapted for multitrophic integration.** Many existing aquaculture facilities in the Bay of Cádiz were originally designed for monoculture production systems and some of them must face with the spatial design, water management capacity, and modular design needed to effectively integrate extractive species, biological filters, or nature-based solutions. Regulatory alignment is essential to enable facility transformation while ensuring environmental protection, operational feasibility, and legal certainty for producers.
- **Regulatory uncertainty and lack of specific guidelines** for implementing eco-intensive systems in the Bay of Cádiz. The absence of clear, harmonized regulatory frameworks, circularity indicators and technical guidelines for eco-intensive and circular aquaculture systems are necessary to increase confidence of producers and public authorities and support investments. In this point, it would also relevant the long procedures, complex bureaucracy and several steps required for authorizations
- **Limited integration of circularity into spatial planning.** Current coastal and aquaculture spatial planning instruments do not sufficiently incorporate circularity principles, limiting opportunities for co-location, resource sharing, and synergies with salt-marsh restoration, wastewater valorization, or other nature-based solutions.

c) Knowledge and Cultural Resistance

- **Resistance linked to cultural heritage and traditional practices.** Long-established aquaculture practices are deeply rooted in local identity and professional experience. These methods are often perceived as more reliable and less risky, leading to scepticism toward innovative production models and technological change.
- **Limited awareness and understanding of circular aquaculture benefits.** Without targeted education, demonstration activities, and communication efforts, many stakeholders remain unaware of the environmental, economic, and social benefits of circular systems.
- **Lack of efficient mechanism for knowledge transfer.** Ineffective communication channels and insufficient training programs hinder the practical application of research findings and best practices. Strengthening robust knowledge-exchange mechanisms, including hands-on training, demonstration sites, living labs, and multi-actor collaborative networks, is essential to accelerate the transition toward sustainable, resilient, and circular aquaculture systems.

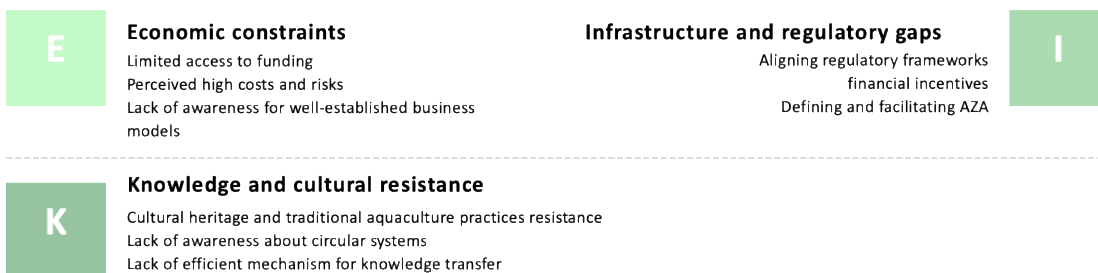


Figure 5. Barriers identified in the pilot site Bay of Cádiz

In spite of the needs and barriers identified, circular aquaculture presents several exciting **opportunities** (Figure 7) that can redefine the sustainability and productivity of the industry.

a) Natural advantage of the Bay of Cádiz

- **Unique wetlands for land IMTA-IMRAS, aquaponics and circular practices.** The Bay of Cádiz hosts extensive tidal wetlands, salt marshes, and semi-natural aquaculture areas that provide exceptional conditions for the implementation of land-based IMTA-IMRAS systems, aquaponics, and other circular practices. These ecosystems naturally support the integration of several species such as algae, halophytes, polychaetes, and shellfish, facilitating several approaches to biomass production for a commodity-approach of high-added value products and ecosystem-based production.
- **High biodiversity and availability of low-trophic species.** The area is characterized by rich biodiversity and the presence of numerous native low-trophic species with aquaculture potential. These biological resources can be sustainably exploited for food, feed, biofiltration, and bioproduct development, reinforcing the ecological and economic viability of circular aquaculture models.

b) Regional and transnational collaboration

- **Positioning Cádiz as an aquaculture innovation hub.** The Bay of Cádiz has the potential to become a regional and transnational reference hub for circular aquaculture innovation, providing validated methodologies, technical guidelines, and scalable solutions adaptable to other coastal and inland regions.
- **Strong research and knowledge networks.** Partnerships with local universities, research centres, and international institutions enable the testing, optimization, and validation of circular aquaculture systems under real operational conditions. These collaborations strengthen technology transfer, accelerate innovation uptake, and enhance regional capacity building.



c) Market potential for Sustainable aquaculture

- **Growing market acceptance and consumer demand.** There exists growing consumer demand for sustainably produced seafood and niche products like algal and halophyte biomass.
- **New market for new value-added products.** Circular aquaculture makes feasible the valorisation of by-products and waste streams, supporting the development of high-value products such as functional feeds, nutraceuticals, bioactive compounds, and bio-based materials.
- **Synergies with other blue economy sectors.** Circular aquaculture can be effectively integrated with coastal tourism, environmental education, and blue biotechnology. Activities such as aquaculture tours, demonstration sites, educational programs, and local seafood tasting experiences enhance public engagement, while biomass and metabolites derived from aquaculture systems offer new resources for blue biotechnology and pharmaceutical applications.

d) Policy alignment and Funding opportunities

- **Strong alignment with EU and regional policy frameworks.** Circular aquaculture directly supports key European and regional strategies, including the European Green Deal, the Blue Economy Strategy, and bioeconomy and climate adaptation policies, New Andalusian Strategy for the Development of Marine Aquaculture [2021–2030] reinforcing its strategic relevance for public investment.
- **Access to EU and national funding instruments for Innovation.** Circular aquaculture is eligible for multiple funding opportunities at EU and national levels (e.g. Horizon Europe, EMFAF, Interreg, and regional innovation programs), facilitating pilot projects, infrastructure upgrades, and the scaling-up of validated solutions.



Figure 6. Opportunities identified in the pilot site Bay of Cádiz



5. Current legal/regulatory/licensing framework

5.1 Lessons Learned for Stakeholders

Within the project AZA4ICE, a cross-analysis of regulatory frameworks throughout the eight countries participating in this project was carried and seven proposals to improve the governance for circular aquaculture were identified:

1) Harmonization of regulatory frameworks. Diverse legal and institutional frameworks throughout different countries and regions act as barriers to efficient licensing and compliance. A better alignment of national regulations with broader EU directives is important. In addition, collaborative efforts to develop shared standards and guidelines can enhance cross-border cooperation and improve the overall regulatory environment is required

Main European strategic plans related to circular aquaculture are aligned directly to the European Green Deal, Farm-to-Fork Strategy and Blue Economy Strategies. The European Commission's communication **COM/2021/240**⁵ outlines the **Blue Economy Strategy**, a key policy initiative aimed at fostering sustainable use of marine and aquatic resources in line with the **European Green Deal** and broader EU goals for a climate-neutral economy by 2050. In the context of *circular aquaculture*, this strategy emphasizes the importance of supporting the transition to circular economy models within blue economy sectors, aiming to reduce waste and optimize resource use. **A key priority is preventing nutrient loss into the sea and implementing innovative recycling methods for marine litter, all while promoting sustainable aquaculture practices such as IMTA.**

This blue economy strategy is complemented with the **COM/2021/236**⁶ **Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture for the Period 2021 to 2030**. This strategic plan addresses different challenges and opportunities of the EU aquaculture sector and four main objectives: (1) building resilience and competitiveness; (2) participating in the green transition; (3) ensuring social acceptance and consumer information; and (4) increasing knowledge and innovation. This strategy promotes diversification and an the added-value of productions to enhance sector resilience and competitiveness, focusing not only on farming emerging species, particularly non-fed and low-trophic species with a lower environmental footprint, but also on innovative production methods such as polyculture in pond aquaculture and IMTA. Additionally, promoting EU sustainable **aquaculture as a model of local production connected to short food supply chains** plays a key role in diversifying and adding value to EU aquaculture production.

⁵ <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0240>

⁶ <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0236>



In addition, circular models play a key role to guide in green transition. Some priority actions are:

- Applying a circular economy approach, including the reuse and valorization of waste streams to enhance resource efficiency.
- Promoting the development of environmentally friendly aquaculture systems, such as IMTA, IMRAS, and diversification into lower-trophic species, combining production of fish, molluscs, other invertebrates, and photosynthetic organisms.
- Highlighting and supporting aquaculture practices that provide ecosystem services, such as those conducted in ponds, wetlands, and brackish water systems.

This Strategic Guidelines also identifies access to *space and water* as key stakeholders contributing to building resilience and competitiveness for the aquaculture sector, especially through coordinated planning based on the designation of areas.

2) Importance of decentralized and streamlined governance Decentralized governance models, as observed in Greece, Spain and France, provide opportunities for localized solutions but often result in fragmentation and inefficiencies. Conversely, centralized systems, such as those in Croatia and Montenegro, offer consistency but lack the flexibility to address region-specific needs. A balanced approach that combines the strengths of both models can help stakeholders design governance structures that are efficient, adaptable and conducive to innovation. Digital platforms have demonstrated the potential for technology to reduce bureaucratic delays and increase transparency in aquaculture licensing processes.

3) Overcoming barriers to innovation. Legal and administrative challenges remain a significant hindrance to adopting innovative circular aquaculture systems. Outdated environmental regulations and complex licensing requirements often impede the implementation of eco-friendly techniques. Stakeholders need to apply for regulatory updates that explicitly address these systems, providing clarity and incentives for their implementation.

4) Integrating sustainability and circular economy principles. Stakeholders need to emphasize policies that promote resource efficiency, avoid nutrient loss and the use of renewable inputs in aquaculture operations. Supporting **pilot projects** and **best practices** are key drivers for scaling up sustainable aquaculture systems.



5) Addressing financial and market barriers. Financial constraints and market competition pose significant challenges, particularly for small-scale operators. High compliance costs and limited access to funding often restrict opportunities for growth and innovation. Stakeholders should work to identify and promote funding mechanisms, including subsidies and EU co-financing programs, that support sustainable aquaculture practices.

6) Enhancing stakeholder collaboration. The complexity of aquaculture governance underscores the need for robust collaboration among stakeholders. Effective communication and coordination between regulatory authorities, industry operators and research institutions are essential for overcoming institutional conflicts and aligning objectives. Initiatives such as stakeholder workshops and participatory governance models can facilitate knowledge sharing and build trust among diverse groups. Moreover, integrating public consultation processes can help to align aquaculture projects with community needs and values.

5.2 Regulatory framework in the Andalusian region

As indicated above, the regulatory framework that governs the marine aquaculture is complex since it is an agri-food industry that mostly performs its activity in zones within the Public Maritime-Terrestrial Domain. There are numerous regulations that govern the establishment, authorization, placement, and management of public domain concessions, as well as the adherence to environmental, health, and commercialization standards. In addition, there are specific regulations to warrant animal welfare and health during the transport and movement of animals, the introduction of non-native organisms for aquaculture purposes, and shellfish harvesting. These regulations play a crucial role in guiding the licensing and regulatory processes for aquaculture operations. Moreover, launching aquaculture ventures may require additional requirements, such as acquiring supplementary permits or licenses, and ensuring alignment with territorial planning frameworks.

According with the subject, regulations can be classified into six groups, although they are not entirely exclusive: 1) Activity authorizations; 2) Activity location; 3) Environmental protection; 4) Animal health; 5) Commercialization; 6) Hygiene and sanitary commitments. Although an exhaustive review of all these regulations is out of the objective of this document, we will focus on the main aspects related to circular aquaculture.

Firstly, we should highlight the **Contribution of Spain to the Strategic Guidelines**



for a More Sustainable and Competitive EU Aquaculture 2021-2030⁷. This strategy serves as a roadmap for fostering sustainability, innovation, and economic growth in the aquaculture industry while addressing key environmental and social challenges. The strategy emphasizes collaboration among Spain's regional and national authorities, stakeholders, and the scientific community. This strategy highlight the relevance of: a) *Circular economy and innovation* and incorporate waste reuse, resource optimization, and systems including IMTA and RAS to reduce environmental impacts; b) *Diversification* to expand the range of cultivated species, including low-trophic species; c) *Ecosystem services* to promote aquaculture practices that provide ecological benefits, such as nutrient cycling and habitat conservation; d) *Technology and knowledge transfer* to facilitate collaboration between the industry, academia, and policymakers to ensure the effective application of innovative solutions.

The **New Marine Aquaculture Strategy in Andalusia 2021-2030**⁸ is a comprehensive framework aimed at advancing sustainable, competitive, and innovative aquaculture in the Andalusian region. Its primary focus is to integrate environmental, economic, and social dimensions to ensure the long-term growth and resilience of the aquaculture sector. This strategy is fully aligned with the Spanish Strategy to support environmental sustainability, competitiveness and innovation, circular economy and blue growth. This strategy encourages aquaculture practices with minimal impact on marine ecosystems, promotes the efficient use of natural resources and the adoption of circular economy principles including IMTA and low-trophic species. Moreover, it drives R&D efforts to cover main innovative fields in genetics, nutrition, health and technology to develop eco-intensive systems such as RAS and IMTA for environmental integration, management, and the development of specific solutions. It should be stated that, in the mid-term review, the transition towards circular models will be a cross-cutting objective to drive the aquaculture sector forward.

Within the most important regulations, we should highlight the **Decree (58/2017 April 18th)**, regulating marine aquaculture in Andalusia. This decree is currently on revision to update and include freshwater aquaculture. It includes specific definitions in **Annex III** concerning trophic relationships and types of aquaculture systems and defined as: monoculture, polyculture and **multitrophic culture or IMTA**. All of them follow the same authorization process.

Licensing procedures in Andalusia are very well-defined but complex⁹ acting on these principles:

1. All establishment should operate in accordance with the approved project, species authorized and the conditions outlined in the authorization resolution

⁷ <https://www.mapa.gob.es/es/pesca/temas/acuicultura/plan-estrategico/estrategia-2021-2030/default.aspx>

⁸ https://www.juntadeandalucia.es/sites/default/files/inline-files/2023/03/Estrategia_Acuicultura_2021_2030_0.pdf

⁹ <https://www.juntadeandalucia.es/servicios/sede/tramites/procedimientos/detalle/116.html>



(Article 51, law 1/2002).

2. All facilities must maintain the Public Maritime-Terrestrial Domain (Article 51, law 1/2002).
3. Aquaculture projects must align with the technical criteria established by the Regional Ministry in Agriculture and Fisheries
4. Implement corrective measures to minimize environmental impact and preserve historical heritage.
5. Ensure that water discharge fulfil water quality standards (Article 51, Ley 1/2002).

Procedure is well-defined¹⁰ and structured in three main steps: a) **Initiation** in which the required documentation is submitted to start the process. b) **Processing** in which the relevant national and regional authorities review the request and make any required assessments; c) **Completion** with the final approval or rejection of the project with any necessary permits or additional requirements specified. Overall, a maximum period of 6 months is established from the date of the application's registration to the issuance of the Resolution. If this period expires without receiving the Resolution, the request may be considered as denied. For marine farming authorizations on private land, this period is reduced to 3 months

It is necessary for the applicants to request registration in the General Register of Livestock Exploitations (REGA), in compliance with Article 4 of Royal Decree 1614/2008 October 3th, regarding the zoosanitary requirements for aquaculture animals and products, as well as the prevention and control of certain aquatic animal diseases. This must be done at the same Territorial Delegation of the province where the project is to be carried out. The applicant must indicate this on the standardized joint application form (Annex I of Decree 58/2017, April 18th, regulating marine aquaculture in Andalusia).

5.3 Proposed Common Solutions in AZA4ICE

The lessons outlined above provide a roadmap for stakeholders to address the challenges and opportunities within the aquaculture sector. Main proposed solutions are:

a) A unified approach to licensing across participating countries is important to reduce delays and increase transparency. Countries should adopt digital tools to

¹⁰ <https://www.juntadeandalucia.es/organismos/agriculturapescaaguaydesarrollorural/areas/pesca-acuicultura/acuicultura/paginas/procedimiento-autorizacion-cultivos-marinos.html>
https://www.juntadeandalucia.es/export/drupaljda/procedimiento_autorizacion_cultivos_marinos.pdf



consolidate applications, streamline approvals through different administration and provide real-time updates to applicants. Harmonizing licensing criteria across the region, including clear definitions and indicators for innovative systems IMTA-RAS, can further simplify the process and foster collaboration.

b) Alignment of national and regional regulations with EU directives in Blue economy, Sustainable aquaculture and Bioeconomy. Standardizing key aspects like environmental impact assessments and operational monitoring can help to reduce jurisdictional conflicts and facilitate regional and transregional investments.

c) Investments in research and capacity-building programs are essential for regulators and operators to stay informed about innovative technologies and best practices. Establishing regional research hubs and knowledge sharing platforms can enable stakeholders to address technical challenges and adopt advanced aquaculture more effectively.

d) Financial support mechanisms, including subsidies and tax incentives, should be designed to encourage sustainable aquaculture practices. Participating countries can leverage EU funding programs to support small scale operators and projects that demonstrate innovative and environmentally friendly methods. Enhanced financial accessibility will enable broader participation in the sector.

e) Building partnerships between public institutions and private operators can drive innovation and reduce administrative bottlenecks. Collaborative frameworks can also foster transparency and accountability while ensuring that aquaculture projects align with both national goals and local community interests.

f) Countries should adopt policies that emphasize the integration of circular economy principles into aquaculture operations. Encouraging the use of renewable inputs, recycling waste, and developing closed-loop systems can enhance resource efficiency and align the sector with global sustainability objectives.

g) Proactive engagement with stakeholders, including local communities, industry players, and environmental groups, is critical for building trust and addressing resistance to aquaculture projects. Structured consultation processes and participatory decision-making models can ensure that regulatory reforms are



inclusive and reflective of diverse perspectives.

6. Current status of aquaculture businesses (input from D2.2.1 - Bluefasma self-assessment tool)

In project AZA4ICE, the Circular Economy (CE) readiness and willingness of aquaculture actors was analysed using the BLUEfasma self-assessment tool. In this analysis, different companies including producers, retailers, service providers, suppliers and sectoral organizations were investigated (Figure 7). Overall, readiness levels across the beneficiaries remain moderate, with most positioned in the “eco-thinking / green economy” stage (indices between 1.6 and 2.4). Only two companies, stood out as an advanced adopter (>2.5 readiness, Silver Medal), demonstrating tangible steps toward systemic circular integration. In contrast, the majority remain in early phases of circularity adoption, with progress primarily reflected in awareness and pilot initiatives rather than full-scale implementation.

By comparison, willingness to invest in CE practices is considerably higher across all beneficiaries, ranging from 3.0 to 4.9. This indicates strong motivation and openness to adopt circular strategies despite current limitations in readiness. All express ambitions to improve through targeted investments. The assessment highlights a clear gap between present readiness and future ambition. Most organizations have not yet consolidated circular practices but express commitment to evolve. Priority areas for action include renewable energy integration, sustainable packaging, waste valorization, local supply chain circularity, and cross-sector collaborations. With proper support, several Bronze Medal companies could rapidly progress toward Silver and beyond.

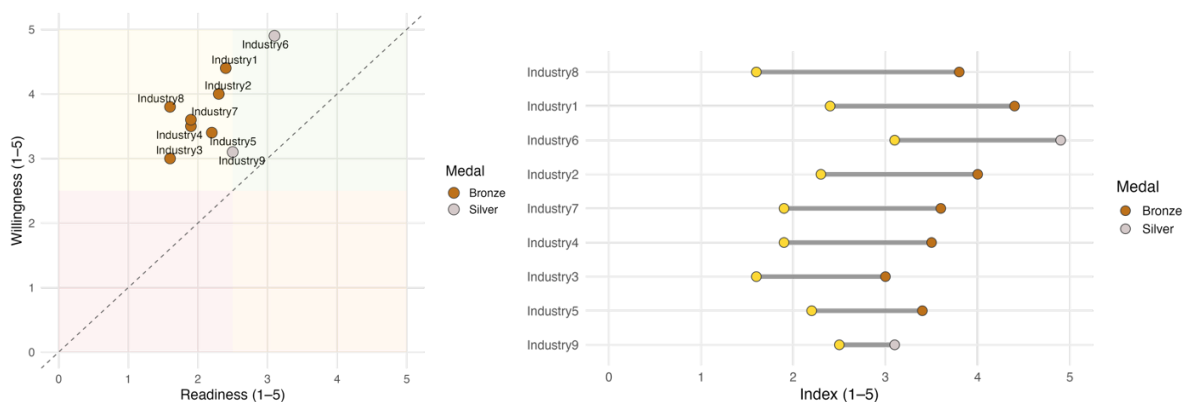


Figure 7. Circular economy readiness versus willingness to invest among aquaculture-related companies. Each point represents one company, positioned according to its readiness index (x-axis) and willingness to invest score (y-axis). The background colour zones reflect levels of adoption and commitment: red (very low), orange (low), yellow (eco-thinking), and green (advanced/leader). The



diagonal line indicates alignment between readiness and willingness. Companies located above the line show higher willingness than readiness, suggesting strong potential for accelerated circular transition.

The analysis of 65 SMEs across the Euro-MED area reveals a significant disparity between intent and action regarding the Circular Economy.

a) Generalized Circular Economy Readiness Index (CERI)

- The average CERI of 1.9 firmly places the sector in the 'Eco-Thinking/Green Economy' stage, indicating that while companies have moved past the purely linear "take-make-waste" model, **their primary focus is on basic eco-efficiency** (e.g., resource management) rather than deep, strategic CE integration.
- The readiness score is uniform across all eight participating territories, underscoring that the aquaculture sector, by its nature, remains a predominantly traditional domain that has been **slow to adopt the disruptive technological and operational changes** required for CE.
- 43.1% of surveyed SMEs entirely neglect sustainability and CE in their formal business planning, confirming that for a large portion of the community, **circularity is not a strategic priority.**

b) Generalized Willingness to Invest in Circular Economy (WICE)

- The average WICE score of 3.5 is highly encouraging, indicating that industry stakeholders are financially receptive and actively positioned to allocate capital towards systemic change. This score suggests that the financial inertia often associated with sustainability transitions is not the primary roadblock.
- The dominant motivations for adopting CE are 50.8% practical resource management and 36.9% ethical/environmental values. This suggests that messaging and policy should focus on the immediate operational benefits (e.g., cost savings from resource efficiency) alongside environmental mandates.

c) Main Areas of Linear Practice

- Waste Valorization Failure: There is a major gap in treating by-products as resources. A combined 84.0% of companies either discard fish/shellfish waste directly (56.0%) or send it for external organic treatment. Furthermore, nearly 60% of companies do not recover products' waste at all.
- Packaging and Storage: Reliance on single-use packaging remains high (50%), and nearly half of companies (46.2%) perceive item recovery for reuse as infeasible, indicating a lack of formal, systematized recovery strategies.
- Vessel Inefficiency: 88% of vessels rely on traditional, high-consumption fuels, highlighting a substantial need for investment and incentives to modernize fleets.



- Commercialization Gap: Of the small number of companies that do recover waste and produce by-products, over 90% either don't commercialize them or only sell locally on a small scale, demonstrating a significant missed opportunity in developing profitable, non- local circular business models.

Lessons Learned

The study provides critical lessons for policymakers and the industry to bridge the gap between high willingness and low readiness.

1. A high willingness to invest (3.5) does not automatically translate into high readiness (1.9). The transition to circularity requires more than capital; it needs strategic knowledge, technical capacity, and systemic infrastructure.
2. A primary bottleneck is the treatment of biomass/processing waste and packaging waste considered as disposal problems rather than resource opportunities. Interventions must focus on technologies that facilitate upscaling (e.g., transforming fish scales into collagen) and developing market linkages for by-products.
3. Given that 43.1% of SMEs lack a formal CE plan, policy should shift from broad awareness to incentivizing and co-funding the integration of CE into core business strategies. This includes support for deep-level integration and innovation (27.7% currently).
4. The high WISE score should be leveraged by policymakers to create targeted financial mechanisms (e.g., specialized loans, grants) that specifically fund the move away from linear practices.
5. The low commercialization of recovered by-products (over 90% of producers sell locally/not at all) indicates a critical need for business development support. This includes training on non-local market access, supply chain collaboration, and the creation of shared valorization facilities that can process waste volumes from multiple SMEs efficiently.

7. Vision for circular aquaculture in the Bay of Cádiz

The Bay of Cádiz is an excellent territory to become a global leader in circular aquaculture, drawing upon its exceptional natural resources, long experience in traditional aquaculture in ponds, large biodiversity, and rich cultural traditions to promote sustainable and eco-efficient practices. This vision adopts an integrated approach that combines production, innovation, collaborative partnerships, and active community participation to tackle challenges and unlock the region's potential in the blue economy.

Our vision is **“To transform the Bay of Cádiz into a hub for innovative, circular,**



and eco-intensive aquaculture, harmonizing ecological sustainability with economic growth". By addressing environmental, economic, and social challenges, this action plan aims to progressively transition the aquaculture in the bay of Cádiz region toward a model of resilience, efficiency, and circularity while maintaining high standards of social acceptance and cultural heritage.

The core pillars of the vision are:

1. Promote the transition and adoption of eco-intensive and sustainable eco-friendly systems and scaling of low-trophic biomass production

The Bay's future should be based in integrating cutting-edge technologies and practices to create a successful circular aquaculture model. While the Bay of Cádiz has traditionally linked to aquaculture, we need to increase the competitiveness and profitability of this activity while maintaining the core of this traditional features to support sustainability and environmental services. Hence, it is a priority to design site-specific, eco-intensive systems tailored to the Bay's unique tidal wetlands and biodiversity. These systems will incorporate circular principles to avoid nutrient loss, improve recycling and water quality, and minimize waste streams.

This approach is based on two complementary strategic pathways: (i) the generation of suitable biomass as a valuable resource within a biorefinery and biovalorisation framework, and (ii) the production of high-quality, sustainable aquaculture products closely linked to other blue sectors.

Two ecosystem-based models of circular aquaculture can be identified: **regenerative aquaculture** defined as *a farming approach that uses aquatic ecosystem conservation as the entry point to regenerate and contribute to provisioning, regulating, and supporting ecosystem services* (including IMTA with fed species) and **restorative aquaculture** or *extractive aquaculture (combining extractive species such as algae and shellfish) that generate net positive environmental outcomes*. This latter particularly interesting in areas of high environmental protection. While these terms are sometimes used interchangeably, incorporating extractive species in IMTA is considered regenerative if it aims to improve the environment; however, if done solely to reduce finfish farming waste without producing net positive effects, it does not qualify as restorative aquaculture (Alleway et al. 2021).

Some **potential initiatives** will be:

- **Assessing of pilot site** suitability for circular practices
- **Spreading knowledge** about circular production models and create reference models to be replicated
- **Promotion of species diversification**, including halophytes, algae, shellfish, and low-trophic fish close to the market
- **Promote biomass production**, conservation and preservation as a high-quality commodity in the core of blue symbiotic ecosystems
- **Promote valorization of aquaculture biomass** and by-products into



aquafeeds 3.0, fertilisers, and bioplastics to reduce waste.

- **Supporting advanced monitoring systems** for water quality and species performance.
- Supporting **genetic and microbial research** to enhance resilience and productivity.

2. Support economic resilience and enhance market potential

Circular aquaculture opens significant market opportunities. The growing consumer demand for sustainably produced seafood and niche products, such as algae and halophyte biomass and bioactive compounds, offers economic incentives for producers. Synergies with other blue economy sectors, such as coastal tourism, can further diversify incomes through aquaculture tours, educational programs, and seafood tastings. These activities can also promote new resources for blue biotechnology, fostering a competitive edge for Cádiz in global markets.

A key element will be supporting scalable, profitable, and sustainable aquaculture practices that drive economic growth. By tapping into the market potential of circular aquaculture, traditional markets will be consolidated while new niches based on biomass and by-products for side stream applications promoting new jobs and diversifying incomes.

Some **initiatives** include:

- **Technical assistance for companies transitioning** to circular systems.
- **Technical assistance for biomass production**, collection and preservation and selection of best candidate species.
- **Identifying good practices and niche markets** for sustainably farmed seafood, aquafeeds 3.0, bioactive compounds, and nutraceuticals.

3. Incentive applied knowledge and collaboration

The Bay of Cádiz is positioned as an innovation hub for circular aquaculture, supported by partnerships with IFAPA, technological center, local universities, research institutes, and industry stakeholders. By creating methodologies and scalable solutions, the region can drive advancements that are transferable across the Mediterranean and beyond.

By fostering participatory platforms, LiRRIE will enhance collaboration and ensure that solutions are inclusive and tailored to regional needs.

Some **actions** are:

- **Establishment of multi-actor collaboration** events to align interests and co-develop solutions.
- Develop **action plans focused on circular aquaculture practices** and



innovative technologies.

- **Support of knowledge-sharing networks** to disseminate best practices and research findings.

4. Policy advocacy

Aligned with EU sustainability policies, Cádiz should capitalize on funding opportunities to support the transition to circular aquaculture. Simplifying regulatory frameworks, offering financial incentives, and fostering transnational collaboration will accelerate the adoption of eco-intensive systems.

By aligning local policies with EU sustainability goals, the initiative will make feasible a beneficial environment for innovation and investment including:

- **Advocacy for simplified and harmonized regulatory** frameworks.
- **Introduction of financial incentives**, such as subsidies and tax benefits, to support eco-intensive systems.
- **Positioning the Bay of Cádiz as a model region** for sustainable aquaculture within European policy circles.

8. Potential of the C-AZA results

C-AZA approach represents a strategic opportunity to transform traditional aquaculture activity into a territorial, integrated, and circular production model. By combining spatial planning, environmental performance, species suitability and circular economy principles, C-AZA provides a replicable framework with high added value for policy, industry, and society.

Main outputs of C-AZA methodology across the eight pilot sites were:

- **C-AZA results demonstrated the feasibility of aligning aquaculture production with environmental protection objectives.** The integration of multitrophic systems, nutrient recovery pathways, and nature-based solutions shows that aquaculture can shift from a source of pressure to a provider of ecosystem services, including water quality improvement, nutrient retention, and habitat support. This strengthens regulatory compliance and supports evidence-based decision-making by public authorities.
- **C-AZA outcomes highlight the economic and innovation potential** of circular aquaculture at territorial scale. By enabling the valorisation of side streams (e.g. sludge, biofilters, algae, halophytes) and fostering linkages with biorefineries, feed production, agriculture, and other blue sectors, C-AZA



creates new value chains and market opportunities. This diversification reduces dependency on single production outputs and enhances the resilience and competitiveness of aquaculture enterprises.

- **C-AZA results reinforce governance and stakeholder coordination.** The multi-actor, quadruple-helix approach underpinning C-AZA facilitates dialogue between public authorities, producers, researchers, and civil society, improving social acceptance and trust. Clear spatial planning, shared indicators, and transparent monitoring tools support coordinated management and reduce conflicts with other coastal uses.
- **C-AZA provides a scalable and transferable model.** The methodologies, indicators, and lessons learned can be adapted to other coastal and inland aquaculture areas, supporting regional, national, and European policy objectives related to the Blue Economy, circularity, and climate adaptation. As such, C-AZA results offer a solid foundation for upscaling circular aquaculture practices and positioning the territory as a reference hub for sustainable aquaculture innovation.

9. Proposed Actions

This Action Plan proposes a set of actions (**Figure 8**) that simultaneously address the main environmental, economic, technological, regulatory, and governance challenges, while actively recognising the unique natural, scientific, market, and policy opportunities of aquaculture in the Bay of Cádiz. This action plan is framed not only as a theoretical roadmap, but as a transformative development pathway to support transition toward new and competitive production models

9.1 Actions and Interventions

Proposed action has been structured in five pillars that support complement actions on the activity and position circular aquaculture as a key driver of the Andalusian Blue Economy Strategy (EA2) by combining environmental protection, economic diversification, innovation, and social cohesion in Natura network 2000 coastal areas.

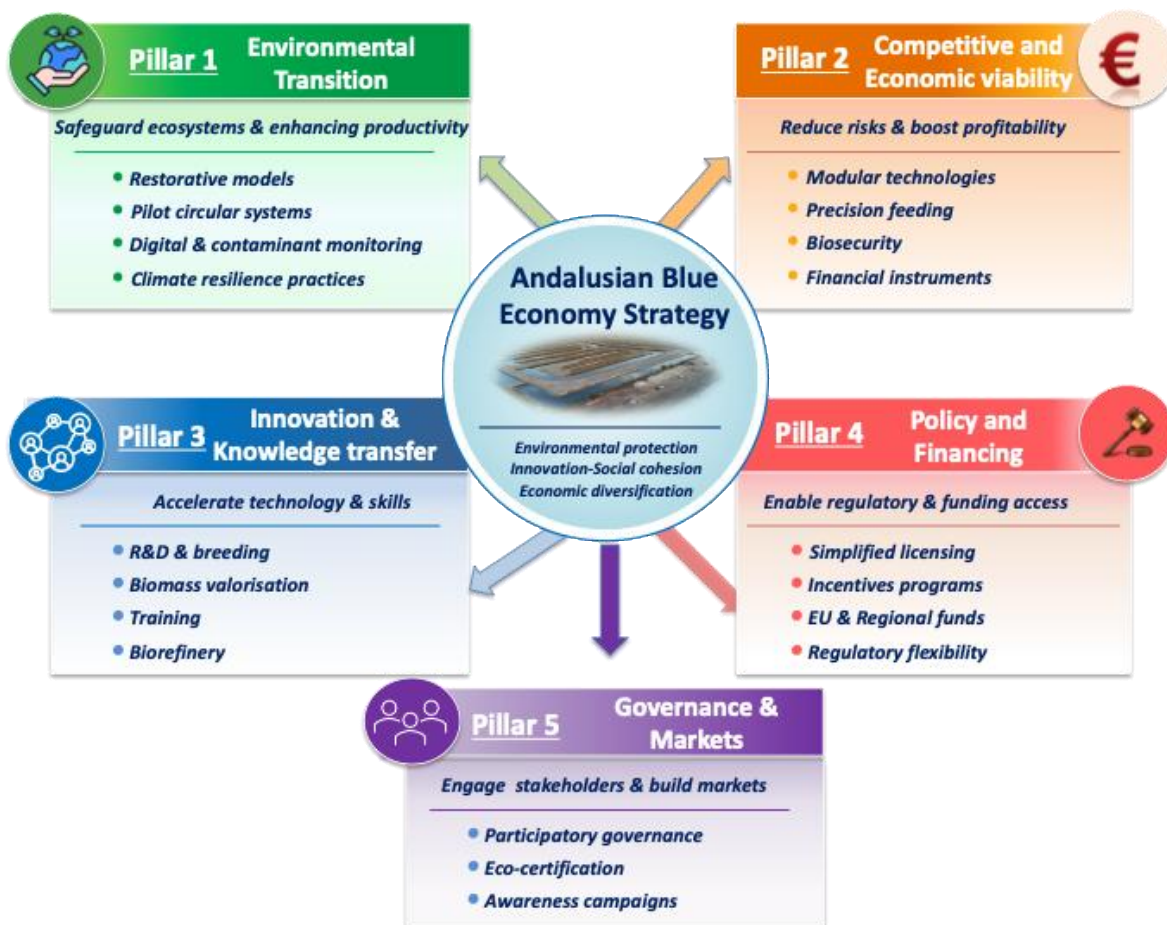


Figure 8. Pillars and actions in the action plan to support transition to circular aquaculture.



Pillar 1. Facilitate the transition toward circular, resilient and ecosystem-compatible aquaculture

Objective: Safeguard environmental integrity while enhancing productivity and resilience

Actions:

- a) Identify and assess potential circular production models in the area.** Explicitly assess the feasibility and operation of restorative and regenerative circular models compatible in the zone ensuring biodiversity conservation, habitat restoration, and minimal disturbance while support local communities and economies Support the ecological recovery of underutilised esteros by circular aquaculture.
- b) Develop and establish pilot and demonstration of circular aquaculture systems adapted to local conditions.** Support and establish pilot-scale circular aquaculture units in selected esteros and existing facilities to demonstrate how to avoid nutrient loss, waste valorisation (sludge, by-products), energy efficiency, and low-impact production under real operating conditions. Support models of circular nutrient management systems through IMTA, marine aquaponics, BFT, RAS and hybrid configurations making different combinations of compatible species.
- c) Reinforce digitalisation and environmental monitoring.** Promote real-time water quality sensors (nutrients, oxygen, temperature, salinity, turbidity), decision-support tools, and digital reporting systems aligned with C-AZA indicators to improve compliance, transparency, and adaptive management.
- d) Develop contaminant monitoring and risk assessment protocols** (e.g. heavy metals, emerging pollutants) to ensure the safe circular valorisation of sludge, algae, halophytes, and other by-products.
- e) Implement climate-resilient and model-specific production strategies,** including selective breeding for environmental fluctuation tolerance, adaptive production calendars, species diversification, shading solutions, and improved water management.

Main leverage points of this pillar 1 are:

- Shift the paradigm of linear models. Adopt **nutrient recovery to prevent loss instead of discharge** supports regulatory compliance and ecosystem services. This high-leverage approach reduces pollution, supports regulations, generates biomass and revenue, restores ecosystems, and increases public support.
- **Low-trophic biomass yield** increases performance and outputs per hectare
- **Restoration** unlocks protected areas for productive use



Pillar 2. Economically viable and competitive circular production models

Objective: Improve profitability, reduce operational risks, and strengthen competitiveness of aquaculture enterprises.

Actions:

- a) **Design modular technologies and pilot-scale demonstrators** that make feasible progressive transition reducing upfront investment risks.
- b) **Upgrade traditional production models with technological tool, digitalization and mechanization including precision feeding systems, biomass estimation, in situ collection and preservation , water quality control and genetic improvement** to improve feed efficiency, survival, and growth performance.
- c) **Strengthen biosecurity and operational protection** through smart surveillance, access control technologies, and coordinated rapid-response mechanisms adapted to public-domain and Natural Park contexts.
- d) **Develop bird predation mitigation strategies**, including nature-based measures such as adapted nets and noise measurements or adaptive pond design.
- e) **Improve access to tailored financial instruments** (grants, co-financing, guarantees, blended finance) specifically designed for SMEs and companies for uptake transitioning measures. KPIs should be clearly identified to monitor effectively the measures adopted.
- f) **Strengthen integration of circular aquaculture into maritime and coastal spatial planning** to reduce conflicts with tourism, transport, cultural heritage, security uses, and other blue economy activities.

Main leverage points of this pillar 2 are:

- **Improve feed efficiency** which is the fastest cost-reduction driver
- **Developing effective modular systems** to decrease entry barriers for companies
- **Implementing risk-sharing** strategies to encourage more private investment



Pillar 3. Innovation, technology uptake, and knowledge transfer

Objective: Accelerate the adoption and scaling of circular aquaculture through applied innovation and capacity building.

Actions:

- a) **Develop locally adapted technical guidelines, operational protocols, and best-practice manuals** to bridge the gap between research and commercial implementation.
- b) **R&D of low trophic farming and logistics focusing on upscaling biomass** not only as a food or source of high-add value product but also as a valuable commodity
- c) **Optimize and validate advanced technologies**, including real-time monitoring, automated feeding, decision-support systems, aquafeeds 3.0 optimization, and biomass management tools.
- d) Integrate **genetic improvement and selective breeding programmes** targeting robustness, feed efficiency, and environmental tolerance.
- e) **Create digital knowledge platforms, advisory services, and troubleshooting support** to enable continuous learning and innovation uptake by producers.
- f) **Innovate on biomass farming, including collection techniques, automatization, in situ processing, logistics and preservation opening feasible downstream applications** (functional feeds, nutraceuticals, bioactives, bio-based materials).
- g) Create an innovative ecosystem for transformation of side streams into **high-added-value products** following a downstream and scalable **biorefinery approach** (from biomass to final product) for functional feed ingredients, biofertilizers, biostimulants, biopolymers, energy, and nutraceutical compounds.
- h) **Capacity building and knowledge transfer.** Implement targeted training programmes for producers, regulators, and technicians focused on circular practices, licensing in protected areas, and operational management of IMTA/IMRAS systems.
- i) **Support mentoring programs and new entrepreneurship** to move into circular business

Main leverage points of this pillar 3 are:

- **Translate innovation into practice** through **technical guidelines**.
- Scale low-trophic **biomass and side-stream valorization** through improved



farming, logistics, preservation and biorefinery pathways for feeds, biostimulants, biomaterials and nutraceuticals.

- **Strengthen uptake through capacity building, mentoring, entrepreneurship and risk-sharing mechanisms**

Pillar 4. Enabling Policy, Regulatory Frameworks, and Financing

Objective: Create a supportive regulatory and financial environment for circular and eco-intensive aquaculture.

Actions:

- a) **Clarify and formalise legal definitions and classifications** for circular and eco-intensive aquaculture systems, including hybrid configurations, within Andalusian and national legislation. Produce guidance documents and regulatory roadmaps to reduce legal uncertainty for innovative systems.
- b) **Simplify and streamline licensing procedures** through harmonised criteria, standardised documentation, and digital permitting platforms.
- c) **Introduce regulatory flexibility and innovation clauses** for pilot and demonstration projects to enable controlled testing of novel systems.
- d) **Establish incentive schemes** linked to measurable circularity and environmental performance indicators.
- e) **Facilitate coordinated access** to EU, national, and regional funding instruments (Horizon Europe, EMFAF/FEMPA, Interreg Euro-MED, Andalusian programmes).
- f) **Design blended-finance and co-investment** schemes to reduce financial risk and accelerate scaling.

Main leverage points of this pillar 4 are:

- ***Inclusion of circularity criteria and eco-intensive systems in regulations and strategic plans***
- ***Safe testing environment for novel systems***
- ***Strategic bundling of funding instruments***

Pillar 5. Stakeholder Engagement, Governance, and Market Development

Objective: Strengthen social acceptance, coordination, and value creation across the aquaculture value chain.

**Actions:**

- a) **Operationalise LiRRIE-based participatory governance structures** to ensure continuous dialogue among producers, policymakers, researchers, and civil society.
- b) **Support the Andalusian aquaculture committee** as structured co-creation and mediation processes to reconcile divergent priorities related to productivity, environmental protection, and societal expectations.
- c) **Enhance SME engagement** through targeted outreach, tailored training, simplified funding access, and direct participation in pilot systems.
- d) **Strengthen science-policy-industry interfaces** through advisory boards, technical working groups, and regular knowledge-exchange forums.
- e) **Support market differentiation of circular aquaculture products** via certification, traceability, and sustainability communication.
- f) **Encourage business symbiosis** with blue biotechnology, agri-food, fertiliser, cosmetic, tourism, and education sectors.
- g) **Develop communication, visibility, and storytelling tools** to increase public awareness and trust.

Main leverage points of this pillar 5 are:

- Making stakeholder **dialogue permanent** and decision-oriented
- **Accelerate translation** of evidence into policy & practice
- **Expanding value chains** beyond aquaculture by connecting blue sectors and stakeholders

9.2 Responsible Actors

- **Public authorities** (national, regional, and local): regulatory reform, licensing, funding allocation
- **Research and knowledge institutions:** innovation support, capacity building, monitoring
- **Aquaculture producers and SMEs:** implementation and validation of circular practices
- **EU and regional programmes:** funding, coordination, policy alignment
- **Civil society and local communities:** **social acceptance**, territorial integration



9.3 Timeline

The timeline is structured into three progressive phases:

Initial phase (1–2 years)

During this initial phase, the focus will be on building strong foundations. Key actions include mapping of potential circular models in the zone for regenerative and restorative aquaculture, revision of existing regulatory landscape and identifying gaps, engaging stakeholders through participatory co-design processes, and launching pilot and demonstration initiatives. At the same time, support innovative actions and initial capacity-building and training activities will be rolled out to strengthen skills and awareness across the sector.

Key points:

- Create map of potential circular models
- Regulatory mapping and gap analysis
- Stakeholder engagement and co-design processes
- Launch of pilot and demonstration actions
- Canalize targeted innovation actions
- Initial capacity-building and training activities

Intermediate phase (3–5 years)

This phase will concentrate on consolidation and expansion. Regulatory frameworks will be adjusted and harmonised where needed, while successful pilot systems will be scaled up. Circular practices will gradually be embedded into mainstream aquaculture production, supported by the implementation of digital tools and monitoring platforms to improve decision-making and performance tracking.

Key points:

- Regulatory adjustments and harmonisation
- Scaling up of successful pilot systems
- Integration of circular practices into mainstream production
- Implementation of digital tools and monitoring platforms

Long term (beyond 5 years)

In the long run, circular aquaculture will be consolidated as a standard practice across the sector. It will be fully integrated into spatial planning and broader bioeconomy strategies. This phase will also include comprehensive assessments of long-term environmental and socio-economic impacts to ensure sustained benefits and continuous improvement.

**Key points:**

- Consolidation of circular aquaculture as a standard practice
- Full integration into spatial planning and bioeconomy strategies
- Long-term environmental and socio-economic impact assessment
- The timeline should include milestones and review points to allow adaptive management and corrective actions.

9.4 Financial aspects and Funding resources

This section outlines the financial requirements and identifies potential funding sources needed to implement the proposed actions effectively. It should address both investment costs and operational sustainability.

Financial Aspects and Funding Resources

1. Public Funding Instruments

Public funding will play a catalytic role, particularly in the early phases of system design, piloting, and validation. Key sources include:

- **European Union programmes¹¹**, such as Horizon Europe (R&I, demonstration and upscaling of circular aquaculture models), EMFAF/FEMPA (investments in sustainable aquaculture, innovation, and environmental services), Interreg (territorial cooperation and C-AZA implementation), and LIFE (nature-based solutions, biodiversity, and ecosystem restoration linked to aquaculture).
- **National and regional funding schemes**, supporting infrastructure development, technology adoption, digitalisation, and environmental monitoring, aligned with regional blue economy and bioeconomy strategies.
- **Public support for capacity building**, including training, technical assistance, and knowledge transfer to SMEs, cooperatives, and local stakeholders.

These funds will primarily support infrastructure adaptation, pilot-scale facilities, environmental monitoring systems, and applied research, reducing entry barriers for circular aquaculture operators.

2. Private Investment and Co-financing

Private investment is essential to ensure the commercial sustainability of circular aquaculture systems. Co-financing mechanisms will be promoted through:

¹¹ https://aquaculture.ec.europa.eu/system/files/2024-03/AAM_WP4_EU%20Funding%20Opportunities_Background%20Paper.pdf



- **Public-private partnerships (PPPs)** for the deployment of eco-intensive IMTA/IMRAS facilities, biorefinery units, and valorisation chains.
- **Industry co-investment**, particularly from aquaculture producers, feed companies, technology providers, and blue bioeconomy enterprises interested in secondary biomass streams (e.g. algae, halophytes, biofilters).
- **Risk-sharing instruments**, where public funds de-risk initial investments, enabling private actors to engage in innovative but capital-intensive solutions.

This mixed approach will support the transition from pilot projects to commercial-scale operations.

3. Innovative Financial Mechanisms

To reinforce financial sustainability, the Action Plan will explore innovative mechanisms, including:

- **Green and blue finance instruments**, such as green loans, sustainability-linked loans, or blue bonds, tied to measurable environmental performance indicators (nutrient recovery, emission reduction, ecosystem services).
- **Revenue diversification models**, based on the valorisation of side streams (biofertilisers, functional ingredients, bioproducts), reducing dependency on primary fish production alone.

10. Monitoring and Evaluation

10.1 Progress Indicators

The M&E system will be aligned with circular economy principles, environmental regulations, and regional Blue Economy strategies, ensuring transparency, accountability, and continuous improvement. Progress and success will be assessed through a set of quantitative and qualitative indicators, structured across environmental, technical, economic, and governance dimensions, including:

1) Environmental performance indicators

Indicator	KPI	Measurement Method	Frequency	Responsible
Nutrient efficiency	Nutrient recovery (NUE (%))	Water sampling & lab analysis	annually	Operators
Biomass efficiency	% biomass yield per hectare	Mass balance calculations	Bi-annual	Technical team
Water quality improvement	DO (mg/L), turbidity (NTU)	In-situ sensors + manual	Continuous + bi-annual	Operators



		validation	review	
Ecosystem services	Area in circular production (ha), biodiversity index	Field surveys & remote sensing	Annual	Research partners
Ecosystem services	Bird nesting areas	Field surveys & remote sensing	Annual	Research partners

2. Technical and operational indicators

Indicator	KPI	Measurement Method	Frequency	Responsible
Adoption of circular practices	<i>operators implementing</i>	Number of authorizations	Annual	Governance body
Demo cases	Number of pilot cases	number cases identified	Annual	<i>Project coordination</i>
Biomass efficiency	% biomass yield per hectare (kg/ha/year fed & extractive species)	<i>Harvest records</i>	Annual	Operators
Feeding efficiency	<i>FCR</i>	<i>Survey</i>	Annual	Operators
Digital integration	<i>farms using sensors/automation</i>	<i>Survey</i>	Annual	Operators

3. Economic and circularity

Indicator	KPI	Measurement Method	Frequency	Responsible
Production efficiency in circularity	Cost per kg produced	Financial records	Annual	Operators
Revenue diversification	% income from secondary biomass	Financial reports	Annual	Operators
Investment uptake	€ leveraged from private and public sources	Financial tracking	Annual	Project manager

4. Social and governance



Indicator	KPI	Measurement Method	Frequency	Responsible
Stakeholder participation	<i>N° participants in events</i>	Financial records	Annual	
Training outcomes	<i>N° trained persons/ satisfaction score</i>	Training reports	Annual	<i>Coordination project</i>
Public perception score	<i>N° of surveys</i>	Surveys	<i>Bi-annual</i>	<i>Proyecto</i>
Regulatory alignment	<i>N° farms compliant with C-AZA</i>	Permit reviews	Annual	<i>Governance body</i>

10.2 Follow-up and Adjustment

These indicators will be periodically reviewed and refined to reflect evolving priorities and lessons learned. Monitoring results will feed into a continuous follow-up and adaptive management process. Regular technical reviews and stakeholder consultations will be organised to assess performance, identify bottlenecks, and propose corrective actions. Where necessary, operational protocols, system designs, or implementation timelines will be adjusted to enhance efficiency, reduce risks, and maximise impact. This iterative approach will ensure flexibility and responsiveness to environmental, economic, and regulatory changes.

11 Conclusion

This Action Plan should be a roadmap to accelerate the transition towards circular and eco-intensive aquaculture in Andalusia. By structuring specific actions and priorities across five complementary pillars, it integrates environmental protection, economic competitiveness, technological innovation, enabling governance, and stakeholder engagement into a coherent strategy aligned with the Andalusian Blue Economy (EA2).

Through pilot demonstrations, regulatory facilitation, targeted financing, and strong knowledge transfer mechanisms, the Plan moves beyond theory to practical implementation, to facilitate the producers to adopt circular models that reduce environmental pressures while creating new value streams. Its adaptive monitoring framework ensures continuous learning, transparency, and evidence-based decision-making, allowing policies and practices to evolve with emerging challenges and opportunities.



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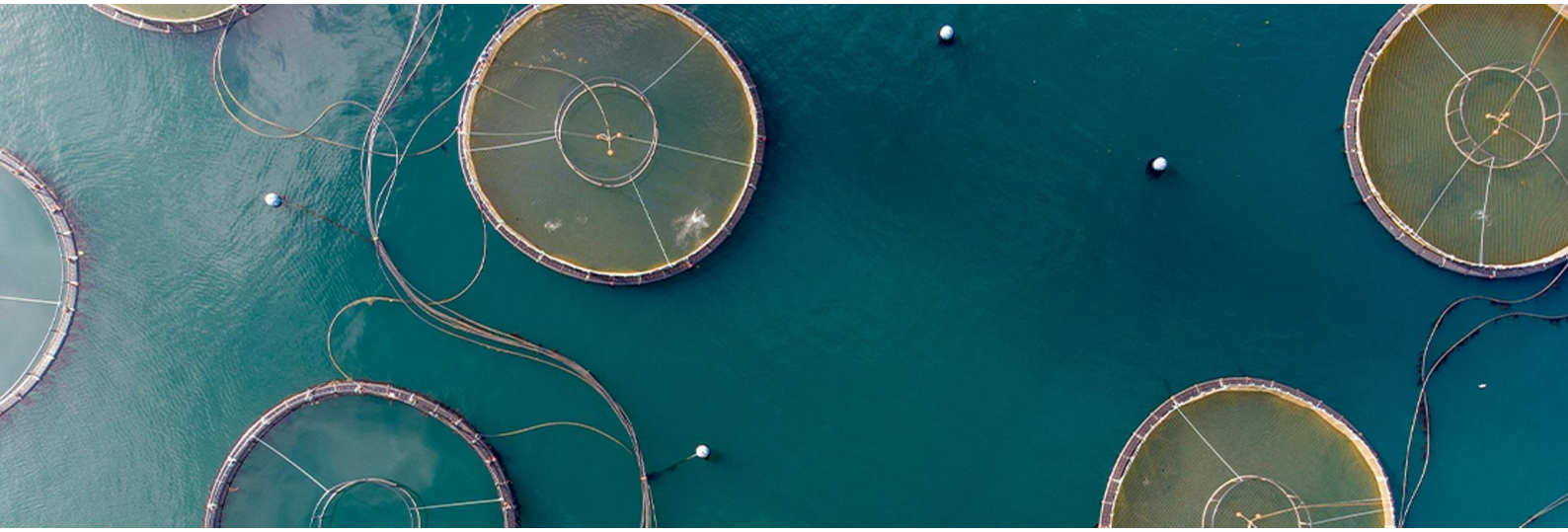


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Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Cabras Lagoon, Sardinia, Italy

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Abbreviations

LiRRIE	Living Responsible Research and Innovation Ecosystems
C-AZA	Circular Allocated Zone for Aquaculture
IMTA	Integrated Multi-Trophic Aquaculture
RAS	Recirculating Aquaculture Systems
SME	Small and medium enterprise
IPI	Intermediate Performance Index
ICI	IMTA Circularity Index
C-AZAI	C-AZA Index
SiSI	Site Suitability Index



1. Executive Summary

This Action Plan provides a structured and actionable strategy to support the transition of Sardinian aquaculture towards circular, sustainable, and socially inclusive models, positioning the sector as a central driver of the Regional Blue Economy Strategy and European sustainability objectives. Developed within the framework of the AZA4ICE project, the Plan integrates circular bio-economy principles with territorial planning, technological innovation, environmental protection, economic diversification, and participatory governance to deliver a holistic approach to aquaculture development in Sardinia. Sardinian aquaculture is rooted in long-standing traditions of inland and extensive lagoon-based production, encompassing estuaries, coastal lagoons, and ecosystems of high ecological value. These systems represent both a cultural heritage and a significant economic asset. However, current production models remain largely linear, with high dependency on external feed and energy inputs, limited reuse of nutrients and by-products, and increasing regulatory and environmental pressures. The sector's potential for circular transition is high, as evidenced by the C-AZA assessment in the Cabras Lagoon, which demonstrated strong environmental suitability, technical feasibility, and stakeholder interest in implementing Integrated Multi-Trophic Aquaculture (IMTA) systems that combine fed and extractive species to improve nutrient recycling, ecosystem functioning, and economic returns. The C-AZA results highlight that lagoon environments can host productive, diversified, and ecosystem-compatible aquaculture systems, and provide a replicable framework for regional and Mediterranean-scale policy and planning.

The Action Plan responds to these challenges and opportunities through six interconnected strategic actions. A comprehensive capacity building program addresses the technical readiness gap, delivering targeted training in IMTA/RAS systems, water management, digital traceability, and sustainability certification to over 120 operators. Demonstrative IMTA facilities in two Sardinian lagoons (*i.e.*: Cabras and San Teodoro) serve as living laboratories, validating circular production models, supporting knowledge transfer, and providing visible examples for replication. Community-based initiatives strengthen local participation, including organized waste management, educational pathways, and collective certification schemes. Environmental monitoring and safeguards ensure ecological compatibility through continuous data collection and adaptive management protocols. Commercial support and funding mobilization facilitate access to European, national, and private financing, lowering barriers to investment in circular systems. Finally, the establishment of an inclusive governance and coordination platform, based on the LiRRIE multi-actor model, ensures ongoing stakeholder engagement, transparent decision-making, and adaptive policy development. Implementation is structured across three progressive phases over



24 months. Phase 1 focuses on foundation and mobilization, including formal agreements, first training cohorts, site selection, and initial communication. Phase 2 implements pilots, expands training, activates community initiatives, and begins environmental monitoring and financial support activities. Phase 3 consolidates results through comprehensive evaluation, dissemination of lessons learned, identification of replication pathways, and planning for long-term sustainability of governance and operational practices. Key performance indicators track environmental, technical, economic, governance, and social outcomes, while adaptive protocols ensure timely response to emerging challenges in water quality, training uptake, funding availability, and stakeholder coordination.

The Plan leverages diverse funding sources, including European programs such as FEAMPA, Interreg Euro-MED, and Horizon Europe, national and regional government support, private investments, impact funds, and green financing mechanisms. This multi-source approach ensures both financial feasibility and resilience to potential delays or uncertainties in any single funding stream. By integrating regulatory clarity, technological innovation, economic incentives, and participatory governance, the Action Plan provides concrete pathways to advance Sardinian aquaculture beyond theoretical sustainability. It creates a robust framework for implementing circular systems, enhancing productivity, diversifying revenues, protecting ecosystems, and fostering social acceptance and stakeholder collaboration. In doing so, Sardinia can position itself as a Mediterranean centre of excellence for circular aquaculture, demonstrating that responsible, resilient, and inclusive aquaculture can deliver environmental, economic, and social benefits in tandem.



2. Introduction

Scope and Objectives

The Action Plan focuses exclusively on the development of circular, low-environmental-impact aquaculture in the coastal and inland wetland zones of Sardinia, applying the AZA4ICE methodology as the guiding reference framework. It addresses interventions that are environmentally feasible, as they are grounded in the C-AZA results produced for the Sardinian pilot sites; socially inclusive, as they are consistent with the vision co-created through the LiRRIE process and responsive to stakeholder needs; economically realistic, as they take into account local constraints, existing capacities, and investment potential; and scalable and transferable, allowing replication in other aquaculture zones in Sardinia and, more broadly, across the Mediterranean region. The Plan prioritises actions that can be realistically implemented using available local resources and, where appropriate, complemented by external financial support. Its underlying principle is that circular aquaculture development must emerge from genuine co-creation with local communities and sectoral actors, rather than being imposed through top-down approaches. In this sense, the Action Plan is conceived as an operational translation of the shared vision emerging from stakeholder engagement, aligned with spatial planning evidence and policy objectives.

The first objective of the Action Plan is to introduce, test, and progressively deploy circular aquaculture models that are specifically adapted to the environmental, spatial, and socio-economic conditions of Sardinia. These models include Integrated Multi-Trophic Aquaculture (IMTA) systems and Recirculating Aquaculture Systems (RAS) that work synergistically with local environmental conditions and existing production systems, while respecting site-specific constraints identified through the AZA4ICE assessment.

A second key objective is to strengthen local capacity among farmers, fishers, small and medium-sized enterprises (SMEs), and community actors to adopt and manage circular aquaculture practices. Although a high willingness to invest has been observed in the region, with an average score of 3.80 on a 5-point scale, as highlighted by the application of the BLUEfasma circularity assessment tool, this willingness is not yet matched by adequate technical readiness. The Action Plan therefore seeks to bridge this gap by translating investment interest into effective implementation capacity through the enhancement of technical skills, operational readiness, and access to practical knowledge and targeted support mechanisms.

The Action Plan further aims to improve the environmental performance of aquaculture activities through structured monitoring, impact-mitigation measures, and environmentally responsible production design. This includes the definition of baseline environmental conditions, the application of adaptive management protocols, and the integration of IMTA-based solutions that



contribute to reducing pressures on the surrounding environment while enabling diversification of production.

Another central objective is to establish inclusive and coordinated governance mechanisms that support transparent decision-making and sustained multi-stakeholder participation, in line with the LiRRIE model. This involves the creation of a permanent Technical Table, the activation of thematic working groups, and the organisation of broader stakeholder assemblies, with the aim of ensuring coherence between policy frameworks, spatial planning instruments, and on-the-ground implementation.

The Action Plan also seeks to promote economic diversification and value creation by supporting the development of circular business models, pathways for waste and by-product valorisation, and sustainable product branding strategies. These actions are intended to enhance the resilience of local production systems, generate new economic opportunities, and strengthen the market positioning of Sardinian aquaculture products.

Finally, the Action Plan aims to consolidate a replicable and policy-relevant model that can inform regional and national decision-making and support future circular aquaculture development in Sardinia and across the Mediterranean region. By documenting processes, governance arrangements, and implementation pathways, the Plan is designed to provide a transferable reference for other territories seeking to adopt circular aquaculture approaches within a spatial planning framework.

Context

Sardinia has a long-standing and well-established aquaculture tradition spanning both marine and lagoon environments, which continue to play a central role in local economies, cultural heritage, and food production systems. In particular, the lagoonal zones of the island represent ecosystems of exceptionally high ecological value, supporting important habitats and ecosystem services while also hosting traditional aquaculture activities. These areas are, however, subject to significant environmental and regulatory pressures, largely due to the presence of nature conservation designations such as Natura 2000 sites and other protected areas. As a result, aquaculture development in Sardinia must operate within a complex framework where environmental protection requirements coexist with socio-economic needs and long-established production practices. Within this context, the Sardinian aquaculture sector has shown a strong and growing interest in innovation, sustainability, and circular production models. Results from the BLUEfasma circularity assessment highlight a clear imbalance between investment willingness and technical readiness. While stakeholders expressed a relatively high willingness to invest in circular and innovative solutions, with an



average score of 3.80 on a 5-point scale, the corresponding level of technical readiness remains low, with an average score of 1.79. This gap points to a substantial transition potential, suggesting that targeted technical support, capacity building, and governance coordination could unlock concrete implementation pathways for circular aquaculture practices. This transition potential is further reinforced by a set of favourable enabling conditions present in Sardinia. These include the availability of suitable coastal and lagoon areas for the development of Allocated Zones for Circular Aquaculture (C-AZA), the presence of consolidated scientific and technical expertise provided by IMC and other specialised research centres, and a strong organisational and associative structure within the productive sector. In addition, there is a growing market demand for sustainable, traceable, and certified aquaculture products, which creates opportunities for value creation and differentiation linked to circular production models.

Against this background, the AZA4ICE project offers a strategic and operational framework for addressing the structural challenges faced by the sector. Through the application of the C-AZA methodology and the implementation of the LiRRIE participatory process, the project supports evidence-based spatial planning, stakeholder engagement, and the co-creation of shared development pathways. Pilot actions implemented in Sardinia by IMC have already demonstrated the technical and environmental feasibility of circular solutions, including Integrated Multi-Trophic Aquaculture (IMTA) systems, Recirculating Aquaculture Systems (RAS), and approaches for the valorisation of by-products and previously unutilised dissolved nutrients. These experiences provide a solid foundation for scaling up circular aquaculture practices in a manner that is compatible with environmental constraints, socially accepted by local communities, and economically viable over the medium to long term.

3. Roles and Responsibilities of Key Actors

The implementation of the Action Plan is grounded in a coordinated, multi-level governance framework in which public authorities, scientific and technical bodies, the productive sector, and civil society play complementary and interdependent roles. Clear allocation of responsibilities is essential to ensure policy coherence, technical robustness, operational feasibility, and social acceptance of circular aquaculture development in Sardinia. Within the AZA4ICE framework, these roles are not conceived as isolated functions, but as interconnected contributions aligned with the LiRRIE participatory approach.

Regional and National Authorities

At regional and national level, public authorities are responsible for providing the institutional, regulatory, and strategic framework for the implementation of the Action Plan, ensuring coherence between aquaculture development objectives



and environmental protection requirements. In Sardinia, aquaculture falls under the responsibility of the Regional Department of Agriculture and Agro-Pastoral Reform (*Assessorato dell'Agricoltura e Riforma Agro-Pastorale*), specifically through the Fishing and Aquaculture Service (*Servizio Pesca e Acquacoltura*), which is tasked with sectoral policy development, support measures, and the integration of circular aquaculture principles into regional planning and programming instruments. Environmental aspects related to aquaculture development, particularly in coastal lagoons and protected areas, are overseen by the Regional Department of Environmental Protection (*Assessorato della Difesa dell'Ambiente*), which is responsible for environmental assessments, permitting procedures, and compliance with conservation objectives. Management bodies of Natura 2000 sites and other protected areas established under different protection regimes supervise activities within their territories, ensuring that aquaculture practices remain compatible with the objectives and management plans of each site. Coastal and lagoonal municipalities contribute at local level through territorial planning, governance functions, and direct interaction with local communities and operators.

At national level, strategic direction and sectoral coordination are provided by the Ministry of Agriculture, Food Sovereignty and Forestry (*Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste*), which is responsible for aquaculture policy, national planning frameworks, and alignment with European fisheries and aquaculture strategies. Environmental policy oversight, particularly regarding Natura 2000 and other protected areas, environmental impact assessments, and compliance with national and EU environmental legislation, is the responsibility of the Ministry of the Environment and Energy Security (*Ministero dell'Ambiente e della Sicurezza Energetica*). Coordination between agricultural and environmental authorities at both regional and national level is therefore essential to enable the effective and balanced implementation of circular aquaculture initiatives in Sardinia.

Research Institutes and Scientific Organizations

Research institutes, scientific organisations, and universities provide the knowledge base and technical support necessary to underpin evidence-based decision-making and adaptive management. The International Marine Centre (IMC) acts as the scientific coordinator of the Action Plan and as the main facilitator of the LiRRIE governance process, supporting stakeholder engagement, spatial analysis, and the application of the AZA4ICE methodology. The Regional Agency for Environmental Protection contributes through environmental monitoring, data collection, and impact assessment, supporting the definition of baseline conditions and the evaluation of mitigation measures. AGRIS plays a key role in applied research, technology transfer, and professional training, facilitating the uptake of innovative and circular aquaculture solutions. Universities, including the University of Cagliari, provide additional scientific expertise, research capacity, and specialised



knowledge in aquaculture systems, environmental sustainability, and resource management. LAORE complements these roles by providing advisory services, technical assistance, and capacity-building support to operators, ensuring that scientific knowledge and project results are effectively translated into practical applications at farm and territorial level.

Aquaculture Sector and Associations

The aquaculture sector bears primary responsibility for the practical implementation of the transition towards circular production models. This includes fish farmers, small and medium-sized enterprises, cooperatives, service providers, small-scale fishers, and actors along the supply chain, who are directly involved in adopting and managing circular aquaculture practices. Their engagement is essential for testing, refining, and scaling up solutions such as IMTA systems, RAS, and by-product valorisation pathways. Sectoral and producer associations, including Confcooperative Pesca, Legacoop, AMA (Associazione mediterranea acquacoltori) and other local aquaculture associations, play an important intermediary role by representing collective interests, facilitating coordination among operators, promoting peer-to-peer learning, and supporting collective responses to regulatory, technical, and market-related challenges.

Civil Society and Local Communities

Civil society organisations and local communities contribute to ensuring the social sustainability and territorial integration of the Action Plan. Environmental non-governmental organisations, local community groups, cultural associations, and social cooperatives play a key role in fostering social acceptance of circular aquaculture, safeguarding environmental and community interests, and supporting transparent communication and awareness-raising activities. Their involvement helps to ensure that circular aquaculture development is perceived not only as an economic opportunity, but also as a shared territorial process aligned with local values, environmental objectives, and long-term sustainability goals.

4. Regional Needs, Challenges and Opportunities

Regional needs

This section presents the main needs, structural challenges, barriers, and opportunities identified for the development of circular aquaculture in Sardinia, based on the LiRRIE participatory process and stakeholder engagement conducted through the AZA4ICE project. These insights provide a key orientation for the Action Plan, ensuring that proposed interventions respond to local priorities, are operationally feasible, and support solutions that are both relevant and



sustainable.

Environmentally Compatible Aquaculture Models

Sardinia's lagoonal and coastal ecosystems require production systems that are low-impact, resilient, and ecologically coherent. Priority is given to integrated approaches such as IMTA and RAS systems, all designed to optimise nutrient efficiency and reduce dependency on external inputs. Species selection is a crucial aspect of system design, favouring those naturally adapted to local conditions, including grey mullet (*Mugil cephalus*), sea bass (*Dicentrarchus labrax*), oysters (*Ostrea edulis*), sea bream (*Sparus aurata*), native bivalves such as grooved carpet shell (*Ruditapes decussatus*), and locally relevant halophytes (*Salicornia fruticosa*) and macroalgae (*Ulva spp.*). These choices increase system stability, ensure ecological coherence, and facilitate effective nutrient recycling. Continuous monitoring of water quality and ecological parameters is essential to ensure compliance with environmental standards and to support the long-term sustainability of circular production systems.

Governance and Decision-Making Coordination

The institutional framework governing Sardinia's protected wetland areas is complex, with multiple authorities responsible for environmental protection, territorial planning, and aquaculture management. Clear, inclusive, and coordinated governance mechanisms are therefore essential. These should integrate representatives from the public administration, scientific institutions, aquaculture operators, local communities, and civil society, ensuring a participatory approach that aligns with the quintuple helix model promoted by LiRRIE. Effective coordination is necessary to streamline decision-making, reduce conflicts, and enable timely adoption of circular practices in designated zones.

Strengthened Local Capacity

Evidence from the BLUEfasma circularity assessment highlights a mismatch between high investment willingness (3.80 on a 5-point scale) and low technical readiness (1.79) among Sardinian stakeholders. This indicates that the main barriers to circular aquaculture are not financial or motivational but relate to limited practical knowledge, technical experience, and confidence in implementing integrated systems. In order to address this, targeted capacity-building programmes are required, covering technical training in IMTA, water management, circular practices, and operational procedures. These efforts must be complemented by participatory learning opportunities, demonstration sites, and knowledge exchange platforms to ensure that local operators can translate willingness into concrete implementation capacity.



Technological and Knowledge Needs

The practical application of circular aquaculture technologies in Sardinia remains limited, despite favourable environmental conditions and proven technical potential. Access to modern aquaculture technologies, including automated feeding, real-time water quality sensors, and biomass monitoring tools, remains restricted for many producers. Bridging this gap requires technology transfer, demonstration of locally adapted solutions, and strengthening the links between research institutions, advisory services, and operators. In addition, innovation in processing and valorisation of by-products, as well as the application of microbial and genetic tools to enhance resilience and efficiency, are essential to make circular systems viable and economically attractive.

Regulatory Alignment and Policy Support

Current regulatory frameworks provide limited recognition of circular aquaculture systems, often focusing on species-specific licensing rather than integrated system design. The absence of clear guidelines, circularity indicators, and supportive incentive mechanisms creates uncertainty and hinders investment. Addressing these gaps requires the alignment and adaptation of regional and national legislation, the operationalisation of Allocated Aquaculture Zones (AZA), and the creation of targeted financial and technical support mechanisms to enable small and medium-sized producers to adopt eco-efficient, circular practices.

Socio-Economic Integration and Stakeholder Engagement

Finally, the transition towards circular aquaculture in Sardinia requires fostering multi-actor collaboration, raising awareness of the benefits of sustainable production, and strengthening local capacity for co-creation. Effective engagement of producers, public authorities, research institutions, and civil society is critical to align priorities, facilitate knowledge exchange, and promote social acceptance. Opportunities exist to integrate circular aquaculture with the local economy, tourism, and emerging blue economy sectors, thereby enhancing value creation, supporting local food chains, and promoting the visibility of Sardinia as a reference for sustainable aquaculture in the Mediterranean.

Regional Challenges

Sardinian aquaculture faces a set of interrelated environmental, economic, technological, and regulatory challenges that must be addressed to enable the successful transition towards circular and eco-efficient systems.



Environmental Challenges

A key environmental concern is the management of dissolved nutrients, which requires careful calibration of production systems to prevent ecological imbalance. IMTA approaches help mitigate this issue by integrating extractive species such as algae and bivalves, which naturally absorb excess nutrients, yet their effectiveness depends on precise design and operational management. Climate change adds another layer of complexity, with rising seawater temperatures, more frequent extreme weather events, and shifting seasonal patterns affecting reproductive cycles and overall system performance. Sardinian lagoons are also subject to pronounced salinity fluctuations, driven by tidal influence and episodic heavy rainfall, necessitating the selection of species capable of tolerating such environmental variability.

Economic Viability Challenges

The economic sustainability of aquaculture operations is constrained by several structural and operational factors. Unauthorized access and theft represent serious risks, particularly in peri-urban areas and zones with high recreational use, requiring investments in physical security, community surveillance, and law enforcement coordination. Traditional production systems often exhibit low efficiency and limited profitability, due to suboptimal feeding practices, high input costs, and insufficient water management. Circular aquaculture offers the potential to improve economic outcomes through reduced inputs, valorisation of by-products, and more efficient system design. However, the transition to eco-efficient systems entails substantial initial investment in infrastructure, equipment, and training, which can be particularly challenging for small producers and SMEs with limited access to capital. Competition for aquatic space further constrains production, as aquaculture must coexist with tourism, maritime transport, recreational activities, and security-related restrictions, emphasising the importance of strategic spatial planning to protect allocated zones and ensure long-term operational viability.

Technological and Knowledge Challenges

Despite the clear potential of circular approaches, practical implementation remains limited. Many producers have little experience with integrated systems such as IMTA, or RAS, and few local examples demonstrate their operational feasibility. Knowledge gaps, coupled with uncertainties in regulatory interpretation and capital constraints, impede adoption. Access to modern aquaculture technologies, such as real-time water quality sensors, automated feeding systems, and decision-support tools, remains uneven, while communication and collaboration between research institutions, policy makers, and operators are often



insufficient to facilitate effective knowledge transfer and co-creation of solutions.

Regulatory Challenges

The current regulatory framework does not adequately recognise the distinctive characteristics of circular aquaculture. While conventional aquaculture regulations focus on species-specific licensing, they do not account for the integrated design of multi-trophic systems. Incentives for sustainable and circular production are largely absent, and market prices rarely reflect the environmental and social value of circular approaches. Bridging this gap requires the development of supportive public policies, targeted subsidy schemes, and certification programs that encourage investment, reduce uncertainty, and reward the adoption of eco-efficient practices.

Regional Opportunities

Sardinia presents a favourable context for the development of circular aquaculture, thanks to a combination of motivated stakeholders, suitable environmental conditions, and potential for economic integration. These factors create a solid foundation for scaling up innovative, low-impact production systems while generating broader socio-economic benefits for the region.

Strong Stakeholder Motivation

Despite the documented low technical readiness, local stakeholders exhibit a strong willingness to invest in circular aquaculture, with an average score of 3.80 on a 5-point scale. Fish processors, cooperatives, and small operators seeking diversification represent potential early adopters. Their successful experience can act as a catalyst for broader uptake across the sector, demonstrating that the transition to circular practices is both feasible and economically rewarding when supported with appropriate technical guidance and capacity-building.

Sardinian Positioning Potential

Sardinia has the opportunity to become a national and Mediterranean reference for circular aquaculture. The successful demonstration of systems that are both profitable and environmentally responsible could establish the island as a hub for peer-learning, technology transfer, and investment. Moreover, circular aquaculture can be integrated with the wider local economy and tourism, creating synergies with sectors such as marine biotechnology, cosmetics, and agro-food industries. Sustainable local seafood can strengthen regional food chains, reduce food miles,



and enhance economic resilience. In addition, educational tourism, farm visits, and awareness-raising initiatives linked to circular aquaculture provide supplementary income opportunities while promoting social acceptance and engagement with sustainable production practices.

5. Current Legal, Regulatory and Licensing Framework

National and Regional Legislation

Sardinia operates within a multifaceted regulatory context that integrates national, regional, and local legislation. At the national level, aquaculture falls under the jurisdiction of the Ministry of Agriculture, Food Sovereignty and Forestry Policies (*Ministero delle Politiche Agricole, Alimentari e Forestali*), while environmental protection is managed by the Ministry of Environment and Energy Security (*Ministero della Transizione Ecologica*). Key legislative instruments include Legislative Decree 152/2006 (Environmental Code), which establishes the general framework for water management and environmental protection, and Legislative Decree 30/2021 (Code of Maritime Fisheries and Aquaculture), which regulates aquaculture operations specifically. At the European level, Regulation (EU) 2021/1139 establishes FEAMPA, the financing instrument supporting sustainable fisheries and aquaculture.

Regionally, the Sardinian Strategic Blue Economy Plan defines the overarching vision and policy priorities for maritime sectors, including aquaculture, while the Regional Aquaculture Regulation provides the framework for authorisations, concessions, and compliance. The Regional Landscape Plan identifies sites subject to landscape protection constraints, and guidelines for the management of protected areas ensure that aquaculture activities are compatible with Natura 2000 sites and other protected wetlands, balancing production needs with conservation obligations.

Regulatory Framework for Innovative Systems

Although the regulatory framework recognises innovative systems such as IMTA and RAS, operational guidance for their implementation is limited. IMTA is acknowledged in legislation, yet clear classification criteria for hybrid or integrated configurations are lacking. RAS installations are considered intensive production systems, but incentives to support their transition to circular models are insufficient. Recirculating systems, while emerging as a promising solution, are not yet explicitly addressed within current regulations. The absence of detailed guidance and regulatory clarity represents a barrier to the adoption of circular and eco-efficient aquaculture practices in Sardinia.



Proposed Regulatory Solutions

To facilitate the development of circular aquaculture, regulatory improvements are essential. Circular models, including IMTA and RAS systems, should be formally classified and recognised as legitimate production approaches. Authorisation procedures for C-AZA pilot and demonstrative projects should be streamlined through fast-track review processes, reducing administrative delays and uncertainty. Regulatory incentives should prioritise circular aquaculture zones when granting concessions and approvals, encouraging early adoption. Finally, adaptive environmental monitoring should be implemented, with tailored plans allowing real-time assessment and responsive management of water quality, nutrient flows, and ecosystem impacts specific to circular aquaculture systems.

6. Current Status of Aquaculture Enterprises

Circularity Readiness Profile

The assessment of Sardinian aquaculture operators using the BLUEfasma Circularity Self-Assessment Tool reveals a clear profile in terms of readiness and willingness to adopt circular practices. Data collected from nine operators indicate an average Circular Economy readiness score of 1.79 (on a 0–5 scale), contrasted with a considerably higher average investment willingness of 3.80. This gap of 1.81 points highlights a notable disparity: while operators are motivated and recognise the value of circular approaches, their current capacity to implement them remains limited.

Examining readiness in more detail, three operators (33%) display low readiness (<1.5), five (56%) are classified as medium readiness (1.5–2.5), and one (11%) demonstrates higher readiness (≥ 2.5). Ittica Nora Soc. Coop. leads the group with a readiness score of 2.7 and holds a silver BLUEfasma medal, reflecting both commitment and partial adoption of circular practices. Overall, most operators are aware of circular principles but lack the necessary technical expertise, infrastructure, and operational experience to implement them effectively. Investment willingness presents a complementary perspective. Five operators (56%) show high willingness (≥ 3.5), one exhibits medium willingness (2.5–3.5), and three are classified as low (<2.5). Interestingly, many of the operators with lower readiness levels still express a strong willingness to invest, indicating that they perceive the benefits of circular aquaculture but encounter practical barriers to adoption.

This combination of low readiness and high willingness underscores the significant potential for transition within the Sardinian aquaculture sector. With targeted technical and financial support, capacity-building interventions can rapidly enhance operational readiness, enabling swift adoption of circular practices. Pilot projects, tailored training programmes, and hands-on demonstration sites are



identified as critical strategies to translate willingness into tangible implementation, accelerating the shift towards environmentally sustainable and economically viable aquaculture models.

7. Vision for Circular Aquaculture in Sardinia

Based on the LiRRIE co-creation process, the shared vision for circular aquaculture in Sardinia is:

"Transform Sardinia into a center of excellence for circular aquaculture in the Mediterranean, where inclusive governance, innovative practices, environmental protection, and economic opportunities converge to create a resilient, sustainable sector generating territorial wellbeing."

Sardinia has the potential to become a Mediterranean reference for circular aquaculture, building on its unique lagoonal ecosystems, high biodiversity, and longstanding aquaculture traditions. The vision integrates production, innovation, stakeholder participation, and ecosystem-based approaches, aiming to address regional challenges while unlocking economic, social, and environmental opportunities. The overarching goal is to create a resilient, sustainable sector that generates territorial wellbeing. The future of Sardinian aquaculture must be based on the adoption of eco-intensified and circular production systems tailored to the island's environmental conditions. This requires the integration of IMTA/RAS systems, with particular attention to lagoonal and coastal ecosystems. Low-trophic species such as bivalves, mullets, sea bass, sea bream, macroalgae, and other native organisms must be carefully selected to ensure adaptability and resilience. Circular principles should guide production practices, minimizing nutrient losses, enhancing recycling, and maintaining water quality. At the same time, biomass valorisation and biorefinery strategies must be promoted to transform sub-products into high-value outputs for applications ranging from functional feeds and fertilizers to bioplastics and bioactive compounds. Pilot sites and demonstrative projects will provide opportunities to test scalable practices, creating replicable models while supporting adaptive management through advanced monitoring and digital tools. This approach allows for both regenerative aquaculture, which actively restores ecosystems and enhances ecosystem services, and restorative or extractive aquaculture, which optimizes environmental net benefits by integrating extractive species.

Economic resilience is a core element of the vision. Circular aquaculture creates new market opportunities by responding to the increasing demand for sustainable seafood and niche products, including algae, halophytes, and bioactive compounds. Sardinian aquaculture can also establish synergies with other sectors of the blue economy, such as tourism, education, and biotechnology, generating diversified revenue streams through farm visits, educational programs, tastings, and biotechnological applications. The development of scalable, profitable, and



sustainable operations will strengthen traditional markets, create new niches, and foster local employment and economic resilience, supporting small and medium-sized enterprises in overcoming investment barriers and accessing financing. Equally important is the reinforcement of knowledge transfer and collaboration among stakeholders. Sardinia should become a hub for innovation in circular aquaculture, leveraging partnerships with regional and international research institutions, universities, and technology centres. Continuous dialogue and co-creation processes are essential to ensure that solutions are locally adapted, socially accepted, and effectively implemented. Strengthening multi-actor collaboration will facilitate the dissemination of best practices, accelerate the adoption of circular technologies, and sustain peer-learning networks that extend beyond initial training and pilot projects.

Finally, policy alignment and incentives are crucial to enable the transition. Sardinian regulations must evolve to formally recognize circular aquaculture models, including IMTA/RAS systems, and to simplify and streamline authorization procedures for pilot and demonstrative projects. Financial support through subsidies, tax benefits, and access to green funding is needed to reduce barriers for small-scale operators and SMEs. Aligning regional policies with European sustainability objectives will create a favourable environment for innovation, investment, and the promotion of Sardinia as a model region for circular aquaculture in the Mediterranean. Through the coordinated implementation of these strategies, Sardinia can achieve Mediterranean leadership in circular aquaculture, generate sustained economic opportunities, protect and restore ecosystems, and contribute to broader European objectives of sustainability, resilience, and blue economy development.

8. Potential of C-AZA Results

The application of the C-AZA methodology in Sardinia represents a significant step toward transforming traditional aquaculture into a circular, territorially integrated, and environmentally responsible production model. Circular Allocated Zones for Aquaculture (C-AZA) combine spatial planning, species suitability assessments, environmental monitoring, and circular economy principles to create a high-added-value framework that benefits producers, local communities, regulators, and society at large. By providing a replicable, science-based, and policy-relevant methodology, C-AZA supports evidence-based decision-making while promoting sustainable and economically resilient aquaculture practices. In Sardinia, this approach has demonstrated the potential to harmonize aquaculture with ecological protection, turning a sector traditionally viewed as a source of environmental pressure into a provider of ecosystem services. These services include the improvement of water quality through natural biological



processes, the retention and recycling of nutrients, and the enhancement of habitats for native species, all while complying with environmental regulations and supporting transparent management by local authorities.

The territorial application of the C-AZA methodology in the Cabras Lagoon provided practical insights into the feasibility and benefits of circular aquaculture in a sensitive coastal lagoon context. The methodology integrates environmental, technical, economic, and social criteria to identify areas where aquaculture can be implemented in a way that maximizes productivity while minimizing ecological impacts. In this case, the Site Suitability Index (SiSI) reached 0.7, reflecting strong suitability in terms of water quality, trophic conditions, infrastructure availability, and operational feasibility. The only moderately limiting factor was the surrounding land use, which is influenced by agricultural and urban pressures; addressing this through integrated spatial planning will be essential to ensure long-term compatibility and reduce potential conflicts. Continuous environmental monitoring confirmed that key parameters such as temperature, dissolved oxygen, salinity, nutrient concentrations, and chlorophyll-a remained within suitable ranges for both fed and extractive species for the majority of the year, demonstrating that the lagoon's ecosystem can sustainably support circular aquaculture operations. The species suitability assessment further confirmed the potential for diversified IMTA systems that combine fed species with extractive organisms. Based on ecological performance, technical feasibility, and stakeholder feedback, two IMTA systems were identified as most appropriate for implementation. IMTA system 1 combines flathead grey mullet (*Mugil cephalus*), Pacific oyster (*Crassostrea gigas*), king ragworm (*Nereis virens*), and sea lettuce (*Ulva spp.*), integrating fed species with extractive organisms to enable efficient nutrient recycling, increased biomass diversification, and improved ecosystem functioning. IMTA system 2 integrates European seabass (*Dicentrarchus labrax*), grooved carpet shell clams (*Ruditapes decussatus*), ragworm (*Hediste diversicolor*), and *Salicornia fruticosa*. Both systems exemplify the capacity of circular aquaculture to harmonise production with ecosystem services, highlighting the dual benefit of food production and environmental enhancement. By combining fed and extractive species, these systems reduce nutrient accumulation, improve water quality, and provide habitats that support biodiversity, illustrating how aquaculture can be leveraged to generate net environmental benefits rather than pressures.

In order to assess the operational and economic performance of these configurations, the Intermediate Performance Index (IPI) was applied, capturing species-level technical feasibility, market potential, and social acceptance. Results showed that key species in both IMTA systems exhibit



strong production feasibility and high market value, confirming that integrating fed and extractive species can be profitable and socially acceptable. Circular performance was further quantified through the IMTA Circularity Index (ICI), which measures nutrient recycling efficiency, resource use efficiency, energy use, species complementarity, and overall system complexity. IMTA system 1 scored 0.75, reflecting strong functional complementarity and effective nutrient recycling, while IMTA system 2 scored 0.675, slightly lower due to the higher resource demands of fed species. These results demonstrate that circular aquaculture is not only technically feasible but can also deliver high levels of ecological and operational efficiency.

The final decision-support indicator, the C-AZA Index (C-AZAI), integrates site suitability, species performance, and circularity into a single metric. IMTA system 1 achieved a C-AZAI of 0.778 and IMTA system 2 0.746, confirming that both systems are ready for practical implementation and demonstrating the high potential of the Cabras Lagoon as a pilot site for circular aquaculture. The use of C-AZAI allows stakeholders, including producers, regulators, and local communities, to make informed decisions about site selection, system design, and operational management, creating transparency and trust throughout the planning process. The combination of SiSI, IPI, ICI, and C-AZAI results illustrates the comprehensive benefits of circular aquaculture in terms of environmental performance, operational feasibility, economic opportunity, and social acceptability. Beyond technical and environmental performance, the C-AZA application in Sardinia demonstrated significant social and economic benefits. By fostering multi-actor engagement through workshops, site visits, and participatory assessments, the project strengthened collaboration among local producers, research institutions, regulatory authorities, and civil society. This quintuple-helix engagement improves social acceptance of circular aquaculture, builds trust in decision-making, and encourages local communities to actively participate in sustainable resource management. Economic opportunities are also enhanced by valorising low-trophic species and sub-products, generating new value chains in algae, halophytes, bivalves, and organic sludge, and creating linkages with other Blue Economy sectors, including local gastronomy, tourism, and biotechnology. These activities contribute to regional economic diversification, reduce dependence on single products, and improve resilience and competitiveness of Sardinian aquaculture enterprises.

The Cabras Lagoon case study highlights the importance of integrated environmental monitoring and adaptive management. Continuous collection of water quality parameters, biomass performance, and



ecosystem health indicators allows operators to make informed decisions and implement corrective measures in real time. For example, nutrient accumulation or changes in dissolved oxygen can trigger operational adjustments, such as modifying stocking densities or integrating additional extractive species, ensuring that environmental thresholds are respected. This monitoring-driven, adaptive approach strengthens the ecological performance of the systems while minimizing risks, providing a practical blueprint for other lagoon environments in Sardinia and the broader Mediterranean region.

Overall, the C-AZA test in Cabras lagoon validates the AZA4ICE methodology as a robust, evidence-based, and transferable decision-support tool for territorial planning and policy design. The results demonstrate that lagoon environments in Sardinia can sustainably host circular aquaculture systems, integrating fed and extractive species, enhancing ecosystem services, improving nutrient recycling, and providing economic diversification and employment opportunities. This evidence base strongly supports scaling up C-AZA implementation across other suitable Sardinian zones and serves as a reference for Mediterranean-level Action Plans. The findings highlight Sardinia's potential to become a centre of excellence for circular aquaculture in the Mediterranean, combining technical feasibility, environmental sustainability, economic opportunity, and social acceptance into a coherent and implementable model that can guide the region toward a resilient and circular aquaculture future.

9. Proposed Actions

Key Actions and Interventions

The proposed actions translate the shared vision for circular aquaculture in Sardinia into an integrated and operational pathway. They are designed to address the structural gap between the current low level of circular readiness among operators and their high willingness to invest, while simultaneously strengthening governance, environmental safeguards, and economic viability. The actions are mutually reinforcing and conceived to be implemented in parallel over a 24-month horizon, ensuring tangible results within the project lifetime and long-term sustainability beyond it.

Action 1: Capacity Building Program

Objective: Bridge the competency gap revealed by 1.79 average readiness vs. 3.80 average willingness through comprehensive training.

The primary objective of the capacity building program is to bridge the



competency gap identified through the BLUEfasma Circularity Self-Assessment, where an average readiness of 1.79 contrasts with an average investment willingness of 3.80. The program is structured as a comprehensive and progressive learning pathway delivered over 18 to 24 months, combining theoretical knowledge, practical skills, and peer-to-peer exchange. Training content encompasses circular aquaculture principles with a strong territorial focus, covering IMTA/RAS systems adapted to Sardinian lagoonal contexts. Financial literacy is addressed through guidance on European, national, and regional funding instruments, including FEAMPA, Interreg, and Horizon Europe, accompanied by hands-on proposal development support. Regulatory and administrative procedures for authorizations and concessions are clarified to reduce uncertainty and delays. Practical modules focus on day-to-day operation of circular systems, including water quality management, feeding strategies, biomass monitoring, and operational risk management. Digital competencies, traceability tools, and sustainability certification and branding complete the program. The initiative targets approximately 120–150 operators through workshops, field-based training, mentoring, and structured peer-learning networks. The estimated cost ranges between €80,000 and €120,000.

Action 2: Demonstrative IMTA Facilities

Objective: Validate IMTA models in authentic Sardinian contexts as learning platforms and proof-of-concept installations.

The demonstrative IMTA facilities are conceived as territorial pilot systems designed to reflect the ecological specificities and management priorities of different Sardinian lagoon contexts, while functioning as learning platforms, proof-of-concept installations, and reference models for replication. Rather than generic demonstrations, the facilities are explicitly tailored to address local environmental pressures and valorise existing production traditions through circular and regenerative approaches.

The first demonstrative site is proposed in the Cabras lagoon system, where aquaculture is historically based on extensive and semi-extensive practices. In this context, the IMTA configuration focuses on non-fed and low-trophic species, combining grey mullet (*Mugilidae*), clams (*Ruditapes* spp.), and halophyte cultivation, particularly *Salicornia* spp. This configuration enhances nutrient recycling within the lagoon by coupling fish production with benthic filtration and nutrient uptake by halophytes, while remaining fully compatible with the ecological sensitivity and conservation status of the area. The system is designed to operate over approximately 2–3 hectares, with moderate production volumes consistent with lagoon carrying capacity and ecosystem-based management principles. Beyond production, the Cabras site serves as a demonstrator of regenerative lagoon aquaculture, reinforcing ecosystem services such as water purification, sediment stabilization, and biodiversity support.



The second demonstrative site is located in the San Teodoro lagoon, a system exposed to significant eutrophication pressures linked to urban development and tourism in the wider Olbia area. Here, the IMTA model explicitly targets nutrient mitigation through the integration of fed and extractive species. The proposed configuration combines sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) with oysters and macroalgae, creating a trophic cascade that enhances nutrient assimilation and improves water quality. The system is designed at a scale of approximately 1–2 hectares, with production levels calibrated to environmental thresholds and supported by continuous monitoring. In this context, the demonstrative facility functions as a nature-based solution, showing how circular aquaculture can actively contribute to reducing eutrophication risks while maintaining economic viability.

Both demonstrative facilities implement standardized operational protocols, continuous environmental monitoring of water quality and biological indicators, and adaptive management mechanisms linked to precautionary thresholds. Transparency toward local authorities, stakeholders, and communities is ensured through open data sharing and regular site visits. The facilities are expected to become operational between months 6 and 9 and to function continuously for 18–24 months. The estimated investment cost ranges between €200,000 and €300,000 per site, reflecting infrastructure, monitoring, and operational support requirements.

Action 3: Community-Based Circularity Initiatives

Objective: Engage local communities in visible, high-impact circular practices generating immediate benefits.

Community-based initiatives aim to make circular aquaculture visible, tangible, and socially embedded, generating immediate local benefits and strengthening social acceptance. Activities include the establishment of organized waste collection points at processing facilities linked to regional recycling and composting systems, the promotion of reusable and regenerable fishing gear, and the organization of regular lagoon clean-up and habitat restoration events involving schools, associations, and local communities. Circular aquaculture facilities are also used as eco-educational pathways for citizens and visitors, enhancing awareness and environmental literacy. Collective sustainability certification schemes are promoted, enabling groups of operators to access certification processes jointly, reducing costs and reinforcing cooperation. The estimated budget for this action is €30,000–50,000.

Action 4: Environmental Monitoring and Safeguards

Objective: Ensure continuous assessment of ecological compatibility through structured monitoring and adaptive response protocols.



Environmental monitoring and safeguards are essential to ensure the ecological compatibility and credibility of circular aquaculture development. A structured monitoring framework is implemented, including monthly physical-chemical water parameters, quarterly biological assessments of planktonic and benthic communities, seasonal monitoring of fish and bird fauna, and annual sediment contaminant screening. Monitoring results feed into adaptive management protocols that define precautionary alarm thresholds and operational response measures, allowing timely adjustments to farming practices if environmental pressures increase. This action ensures alignment with Natura 2000 requirements and broader environmental protection objectives. The estimated cost over 24 months is €100,000–150,000.

Action 5: Commercial Support and Funding Mobilization

Objective: Facilitate local actor access to European and national financing instruments.

To overcome financial barriers and facilitate investment, a centralized commercial and financial support mechanism is established. A dedicated financial consulting desk assists local actors in accessing European, national, and regional funding instruments, including FEAMPA, IPARD III, Interreg, and Horizon Europe. The desk supports proposal development, coordinates regional funding opportunities, and promotes consortial approaches that allow small-scale operators to participate collectively in larger funding schemes. Complementary financial instruments, such as microfinance for circular aquaculture start-ups, guarantee funds for SMEs, and training vouchers, are promoted to reduce risk and enhance access to capital. The estimated cost ranges between €50,000 and €80,000.

Action 6: Inclusive Governance and Coordination Platform

Objective: Establish a permanent multi-actor coordination mechanism aligned with the LiRRIE model.

Inclusive governance is ensured through the establishment of a permanent coordination mechanism aligned with the LiRRIE model. A Technical Table convenes monthly, with balanced representation from regional and national authorities, aquaculture operators, research institutions, environmental bodies, and civil society organizations. In parallel, a broader LiRRIE Assembly meets semi-annually to facilitate open consultation, strategic dialogue, and shared learning. Thematic working groups address specific regulatory, environmental, business, and communication challenges, while an integrated communication system maintains transparency and stakeholder engagement. The estimated cost for governance and coordination activities is €60,000–90,000.



Responsible Actors

The implementation of the proposed actions relies on a coordinated and multi-level governance framework. Regional authorities, in particular the Regione Autonoma della Sardegna – Assessorato dell’Agricoltura e Riforma Agro-Pastorale (Servizio pesca e acquacoltura), play a central role in coordination, funding alignment, and regulatory facilitation. Environmental oversight and alignment with conservation objectives are ensured by the Assessorato della Difesa dell’Ambiente, in cooperation with national environmental authorities where required.

Research and technical support are provided by research institutions and universities, including the International Marine Centre (IMC), CNR, AGRIS, LAORE, Sardinian Local Action Groups (LAGs), Università degli Studi di Cagliari, and other national and international research partners, which contribute scientific expertise, monitoring, and capacity building. Aquaculture operators, cooperatives, and SMEs act as primary implementers, particularly for demonstrative facilities and pilot initiatives. Civil society organizations, educational institutions, and local communities support outreach, awareness-raising, and community-based actions. Financial institutions and funding bodies support investment mobilization and financial sustainability.

Implementation Timeline

The implementation of the Action Plan is organised over a 24-month period and structured into three sequential and interlinked phases. This phased approach ensures a gradual transition from planning and mobilisation to operational implementation and, finally, to consolidation, evaluation, and transferability. Each phase builds on the results of the previous one, allowing adaptive management and continuous alignment with environmental, social, and regulatory conditions.

Phase 1: Foundation and Mobilization (Months 1-8)

The first phase is dedicated to establishing the institutional, technical, and social foundations necessary for effective implementation. The Action Plan is formally launched through a public event involving regional and local authorities, aquaculture operators, research institutions, sectoral associations, and civil society organisations, with the objective of ensuring shared understanding, transparency, and early stakeholder commitment. During this phase, formal agreements and Memoranda of Understanding are finalised among the key actors responsible for implementation, including site managers, research bodies, and participating enterprises. The LiRRIE governance structure becomes fully operational in this phase. The permanent Technical Table is officially constituted, its rules of procedure are defined, and thematic working groups are activated to address regulatory,



environmental, economic, and communication aspects. Regular coordination meetings are established to ensure continuous dialogue between institutions and operators. In parallel, preparatory regulatory and administrative steps are initiated, including the verification of authorisation requirements for demonstrative facilities and alignment with environmental protection regimes applicable to lagoon systems. Capacity-building activities are launched with a first training cycle targeting approximately 30–40 operators. This initial cycle focuses on building a common knowledge base on circular aquaculture principles, IMTA configurations adapted to Sardinian contexts, and the regulatory and financial framework supporting transition. At the same time, the definitive selection of demonstrative sites is completed, detailed technical designs are prepared, and baseline environmental monitoring is initiated to establish reference conditions prior to system installation. By the end of Phase 1, the governance mechanisms are fully functional, the first group of trained operators has completed the initial training modules, and demonstrative sites are secured with formal agreements and baseline data in place.

Phase 2: Pilot Implementation (Months 9-20)

The second phase represents the operational core of the Action Plan and is focused on implementing pilot actions, scaling capacity-building efforts, and generating concrete technical and environmental evidence. Capacity-building activities are expanded through successive training cycles, progressively reaching between 80 and 100 operators. Training during this phase becomes increasingly practice-oriented, combining advanced technical modules with on-site demonstrations, peer-learning exchanges, and mentoring support tailored to operator needs. Construction and operational start-up of the demonstrative IMTA facilities take place during this phase. The Cabras and San Teodoro sites progressively enter into operation, with production systems activated in line with approved technical designs and environmental safeguards. Structured environmental monitoring is fully implemented, including regular measurement of physical-chemical parameters, biological indicators, and system performance metrics. Monitoring results are continuously analysed and used to adjust operational practices through adaptive management protocols. Community-based circularity initiatives are activated in parallel, increasing the visibility and social embeddedness of the Action Plan. Educational activities, stakeholder visits to demonstrative sites, and local communication initiatives contribute to strengthening social acceptance and awareness of circular aquaculture practices. The financial support and funding mobilisation desk become operational, providing direct assistance to operators and facilitating access to European, national, and regional funding instruments. Throughout Phase 2, the LiRRIE governance framework is consolidated, with the Technical Table meeting regularly and broader stakeholder assemblies convened on a semi-annual basis. By the end of this phase, demonstrative facilities are fully operational, a critical mass of trained operators is reached, and initial technical, environmental, and socio-economic results are available.



Phase 3: Evaluation and Dissemination (Months 21-24)

The final phase focuses on assessing results, consolidating governance and technical outcomes, and preparing for replication beyond the project timeframe. A comprehensive evaluation is conducted, analysing the effectiveness of implemented actions, the performance of demonstrative IMTA systems, the uptake of circular practices by operators, and the functioning of governance mechanisms. Particular attention is given to identifying enabling factors, barriers encountered, and lessons learned across different territorial and institutional contexts. Technical, scientific, and policy-oriented outputs are produced during this phase, including operational guidelines for circular aquaculture in lagoon systems, synthesis reports for policy-makers, and dissemination materials tailored to operators and civil society. Results are shared through targeted dissemination activities, including webinars, technical workshops, and an international conference aimed at positioning Sardinia as a reference case for circular aquaculture in the Mediterranean. At the same time, pathways for replication and scaling are defined, identifying priority zones, funding opportunities, and institutional arrangements for post-project continuity. By the end of Phase 3, the Action Plan delivers a consolidated, transferable model supported by evidence, stakeholder commitment, and policy-relevant recommendations.

Financial Aspects and Funding Resources

The financial sustainability of the Action Plan is based on a diversified and complementary funding strategy that combines European, national, regional, and private financial instruments. This integrated approach is essential to support both the initial investment costs associated with the transition to circular aquaculture systems and the longer-term operational and capacity-building needs of operators and institutions involved. At the European level, the primary funding framework is provided by the European Maritime, Fisheries and Aquaculture Fund (FEAMPA), which represents the most relevant instrument for supporting sustainable, innovative, and environmentally compatible aquaculture in Italy. FEAMPA measures can support investments in IMTA systems, RAS infrastructure, environmental monitoring equipment, digitalisation, and professional training, with co-financing rates typically ranging from 50% to 75% depending on the type of action and beneficiary. The Action Plan is explicitly aligned with FEAMPA priorities related to environmental sustainability, innovation, and climate resilience, facilitating its integration into regional programming and calls managed by the Regione Sardegna. In parallel, Interreg programmes, particularly Interreg Euro-MED 2021–2027 and other Mediterranean cooperation frameworks, provide opportunities to finance pilot actions, transnational knowledge exchange, governance innovation, and dissemination activities. These programmes are especially relevant for supporting demonstrative facilities, LiRRIE-based



governance structures, and transferability actions, enabling Sardinia to position itself within a broader Mediterranean network of circular aquaculture initiatives. Complementary funding can also be sought through Horizon Europe, notably under Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment) and Cluster 2 (Culture, Creativity and Inclusive Society), which support research, innovation, and community engagement related to sustainable blue economy development.

At the national and regional levels, additional financial resources can be mobilised through dedicated budget lines for agriculture, fisheries, and blue economy development managed by the Ministry of Agriculture, Food Sovereignty and Forestry (Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste – MASAF) and by the Regione Autonoma della Sardegna. Regional programmes can provide co-financing to complement European funds, support preparatory studies, and cover governance, coordination, and capacity-building activities that are not always eligible under investment-focused schemes. The alignment of the Action Plan with regional strategic instruments, such as the Strategic Blue Economy Plan, enhances its eligibility for such funding sources.

Private and mixed funding instruments play a complementary but increasingly important role in ensuring long-term financial viability. Small and medium-sized aquaculture enterprises often face difficulties in accessing traditional credit for innovative and circular investments due to perceived risk and limited collateral. To address this constraint, the Action Plan promotes the use of blended finance mechanisms, including guarantee funds, microfinance schemes, and preferential credit lines for green investments, potentially supported by regional or national public guarantees. Impact investment funds and ethical finance institutions oriented toward environmental sustainability and circular economy principles represent additional potential partners, particularly for scaling demonstrative systems into commercially viable operations. Further financial opportunities arise from the valorisation of circular outputs and ecosystem services generated by IMTA systems. Revenues from the commercialisation of extractive species, halophytes, and macroalgal biomass, as well as from by-products directed toward feed, fertilisers, or bioproducts, contribute to improving the economic performance of circular systems. In the medium term, sustainability certification schemes, eco-labelling, and territorial branding can enable price premiums and improved market positioning, reinforcing financial sustainability beyond public support. Corporate Social Responsibility (CSR) programmes and sponsorships from companies interested in supporting environmental restoration, biodiversity protection, and climate adaptation may also contribute to financing community-based initiatives and awareness-raising actions.

Overall, the financial architecture of the Action Plan is designed to reduce dependence on single funding sources, lower investment risk for operators, and progressively shift from grant-based support toward economically self-sustaining circular aquaculture models. The establishment of a dedicated financial support and advisory mechanism within the Action Plan further ensures that funding



opportunities are effectively accessed and strategically combined to maximise impact.

10. Monitoring and Evaluation

The Monitoring and Evaluation framework is conceived as a core component of the implementation of circular aquaculture models in Sardinia, ensuring transparency, accountability and continuous improvement throughout the project lifecycle. The system is fully aligned with circular economy principles, environmental regulations, and regional Blue Economy and aquaculture planning strategies, including the AZA framework and lagoon management policies. Monitoring activities aim not only to assess progress against predefined objectives, but also to support adaptive management by providing timely evidence to adjust operational practices, governance mechanisms and investment priorities in response to environmental, technical and socio-economic dynamics. To this end, a set of quantitative and qualitative indicators has been structured across four complementary dimensions: environmental performance, technical and operational efficiency, economic and circularity outcomes, and social and governance aspects.

Progress indicators

The proposed indicators reflect the specific characteristics of Sardinian aquaculture systems, including coastal lagoons, nearshore marine farms and integrated multi-trophic solutions, and are designed to be measurable, comparable over time and scalable across different sites.

Environmental performance indicators

Environmental monitoring focuses on nutrient efficiency, ecosystem quality and the contribution of circular aquaculture systems to ecosystem restoration and resilience. Particular attention is given to lagoon environments, where eutrophication risks and water quality degradation remain critical issues in several areas of the island.

Indicator	KPI	Measurement method	Frequency	Responsible
Nutrient efficiency	Nutrient Use Efficiency (NUE, %)	Water sampling and laboratory analysis	Annual	Operators, research partners
Biomass	Biomass yield	Mass balance	Biennial	Technical



efficiency	per hectare (%)	calculations		team
Water quality improvement	Dissolved oxygen (mg/L), turbidity (NTU)	In situ sensors with periodic manual validation	Continuous + biennial review	Operators
Ecosystem services	Restored area (ha), biodiversity index	Field surveys and remote sensing	Annual	Research partners
Sediment safety	Contaminant levels vs regulatory thresholds	Laboratory analysis	Annual	Accredited laboratories

These indicators allow the assessment of whether circular and IMTA-based solutions effectively reduce nutrient loads, improve water quality and contribute to the maintenance or restoration of lagoon and coastal ecosystems, in line with regional environmental objectives.

Technical and operational indicators

Technical and operational indicators assess the degree of adoption of circular practices, system efficiency and technological integration across aquaculture sites.

Indicator	KPI	Measurement method	Frequency	Responsible
Adoption of circular practices	Number of operators implementing circular systems	Authorisation and permit records	Annual	Governance body
Demonstration cases	Number of pilot sites implemented	Project records	Annual	Project coordination
Biomass efficiency	Yield per hectare (kg/ha/year) for fed and extractive species	Harvest records	Annual	Operators
Feed efficiency	Feed Conversion Ratio (FCR)	Operator surveys and farm records	Annual	Operators
Digital	Farms	Surveys	Annual	Operators



integration	equipped with sensors and automation			
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This set of indicators supports the evaluation of operational feasibility and scalability of circular aquaculture models in Sardinia, including their integration with digital monitoring tools and smart farming solutions.

Economic and circularity indicators

Economic indicators aim to capture the added value generated by circular aquaculture, focusing on cost efficiency, diversification of revenues and the ability to attract public and private investment.

Indicator	KPI	Measurement method	Frequency	Responsible
Circular production efficiency	Cost per kg of biomass produced	Financial records	Annual	Operators
Income diversification	Share of revenue from secondary biomass (%)	Financial reports	Annual	Operators
Investment mobilisation	€ mobilised from public and private sources	Financial tracking	Annual	Project manager

These indicators help demonstrate the economic viability of circular aquaculture in Sardinia and its potential contribution to local development, particularly in lagoon and rural coastal areas.

Social and governance indicators

Social and governance indicators assess stakeholder engagement, capacity building, public perception and regulatory alignment.

Indicator	KPI	Measurement method	Frequency	Responsible
Stakeholder participation	Number of participants in events and	Attendance records	Annual	Project coordination



	consultations			
Training outcomes	Number of people trained / satisfaction index	Training reports	Annual	Project coordination
Public perception	Number of surveys conducted	Surveys	Biennial	Project team
Regulatory alignment	Number of farms compliant with AZA and CAZA frameworks	Permit and compliance review	Annual	Governance body

These indicators ensure that circular aquaculture development remains socially accepted, institutionally coherent and aligned with regional planning instruments.

Monitoring review and adaptive adjustments

Monitoring results will be systematically translated into adaptive management actions through a structured review and decision-making process. Quarterly Technical Table reviews will be convened to assess progress against predefined targets, analyse deviations from expected performance, and identify both constraints and enabling factors affecting implementation. These reviews will also serve as a platform to propose strategic and operational adjustments and to facilitate the exchange of lessons learned among operators, technical experts and institutional stakeholders. The adaptive framework is designed to respond to different implementation scenarios through predefined but flexible adaptation protocols. When environmental monitoring data indicate signs of degradation, such as declining dissolved oxygen levels, increased turbidity or nutrient accumulation, operational protocols will be promptly revised. This may include adjustments to stocking densities, optimisation of extractive components within IMTA systems, or temporary biomass reductions where necessary. In all cases, stakeholders will be informed in a transparent and timely manner to ensure shared understanding of risks, responsibilities and corrective measures. If monitoring reveals limited participation in training and capacity-building activities, the implementation strategy will be recalibrated accordingly. Training schedules and locations may be adjusted to better match operators' availability, while content will be refined based on participant feedback and local operational needs. Where appropriate, experienced farmers and early adopters of circular practices will be engaged as peer trainers, strengthening knowledge transfer through practical, context-specific learning and reinforcing trust within the farming community.



Financial monitoring will also feed into adaptive decision-making. In the event of delays in European funding disbursement, alternative funding sources at regional or national level will be activated where feasible, and implementation will prioritise low-cost, high-impact actions to maintain momentum and credibility. This flexibility is particularly important to ensure continuity of pilot activities and stakeholder engagement during critical phases of implementation. Governance-related challenges, including resistance from specific stakeholder groups or institutional bottlenecks, will be addressed through direct mediation and targeted dialogue. Decision-making protocols may be revised to enhance transparency, clarify roles and responsibilities, and improve inclusiveness within the governance structure, ensuring alignment with AZA and C-AZA planning principles.

A comprehensive final evaluation will be carried out in month 24 to assess the overall effectiveness of the implemented actions. This evaluation will quantify the level of adoption of circular aquaculture practices, assess environmental and socio-economic outcomes, and determine the readiness of pilot areas for operational scaling of C-AZA zones. The results will support the formulation of concrete recommendations for long-term policy integration and upscaling within the Sardinian aquaculture planning framework.

11. Conclusion

This Action Plan sets out a coherent and evidence-based strategy to support the transition towards circular, sustainable and inclusive aquaculture in Sardinia, grounded in scientific knowledge and reinforced through structured stakeholder co-creation. It recognises that Sardinian aquaculture is characterised by a strong cultural and productive heritage, a high level of stakeholder willingness to innovate, environmental conditions compatible with low-impact circular approaches, and the availability of technically validated solutions. At the same time, the Plan acknowledges the presence of institutional, scientific and administrative capacities that can sustain participatory governance and coordinated implementation.

The proposed approach is articulated through six interlinked actions operating across three complementary levels. At the technical level, demonstrative IMTA facilities function as learning and innovation platforms, supported by rigorous environmental monitoring to ensure ecological compatibility and continuous adaptive management. At the economic level, structured capacity-building programmes strengthen operational skills, facilitated access to European and national funding instruments lowers financial barriers, and sustainable product branding creates market incentives for circular practices. At the institutional level, a permanent LiRRIE governance framework enables coordinated multi-actor decision-making, while clarified regulatory pathways and transparent procedures reduce uncertainty and build trust among stakeholders.



Summary and Next Steps

In the immediate term, priority actions include the formalisation of agreements among key actors, the official constitution of the Technical Table, the launch of the first training cohort, and the selection of demonstrative sites through formal agreements with farm operators and land or lagoon authorities. Within the following four to eight months, initial training cycles should be completed, construction and operational set-up of demonstrative facilities initiated, targeted communication and awareness-raising campaigns launched, and access to European and regional funding sources secured. Over the remainder of the 24-month implementation period, demonstrative facilities will generate operational, environmental and economic evidence, governance mechanisms will consolidate through regular Technical Table meetings and broader stakeholder assemblies, and early policy recommendations will be developed based on monitored outcomes. These steps will lay the foundation for scaling up circular aquaculture practices and for the progressive operationalisation of C-AZA zones in Sardinia.

Long-Term Vision

Through the coordinated implementation of this Action Plan, Sardinia has the opportunity to position itself as a Mediterranean centre of excellence for circular aquaculture, capable of combining responsible innovation, environmental protection and socio-economic development. The long-term vision is the creation of a permanent community of practice that supports knowledge exchange, technology transfer and continuous improvement across the sector. Ultimately, the Plan envisages a Sardinian aquaculture system in which circularity represents a core pillar of the sustainable blue economy, where inclusive governance and adaptive management reinforce ecological resilience, and where economic benefits are generated in a durable and equitable manner for local operators, coastal communities and future generations.



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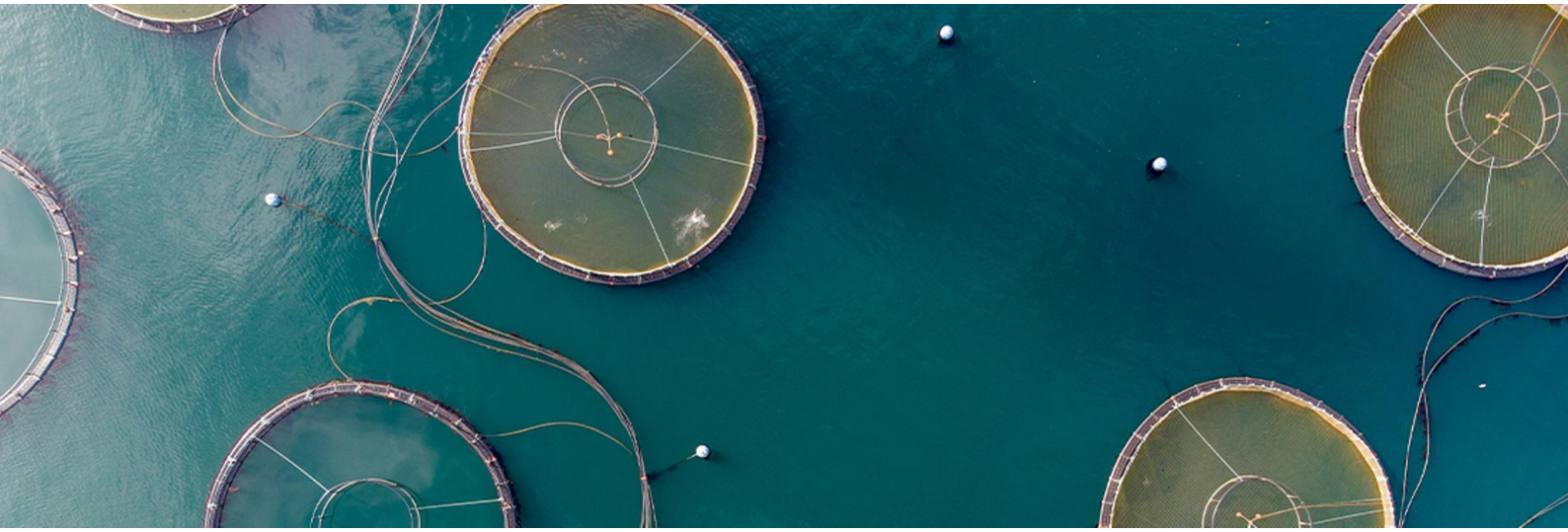


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Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Ria Formosa, Portugal

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Abbreviations

AMAL	Algarve Intermunicipal Community
AMIC	Culatra Island Residents' Association
AMN	National Maritime Authority – MARITIME POLICE
APA	Portuguese Environment Agency
ASAE	Food and Economic Safety Authority
BdE	Entrepreneur's Desk (Business Portal)
B-Mar	Electronic Sea Platform
C-AZA	Allocated Zones for Circular Aquaculture
CCDR	Regional Coordination and Development Commission
CCVALg	Algarve Life Science Centre
CIMA-UAIlg	Centre for Marine and Environmental Research, University of Algarve
DGAV	Directorate-General for Food and Veterinary Affairs
DGRM	Directorate-General for Natural Resources, Safety and Maritime Services
ENM	National Ocean Strategy
FC	Cohesion Fund
FEAMPA	European Maritime, Fisheries and Aquaculture Fund
FEADER	European Agricultural Fund for Rural Development
FEEI	European Structural and Investment Funds
FSE+	European Social Fund Plus
FTECE	Fund for Technology and Circular Economy
GALAC	Local Support Office for Circular Aquaculture
GNO	Olhão Naval Group
ICNF	Institute for Nature Conservation and Forests
IGT	Territorial Management Instruments
IMTA	Integrated Multi-Trophic Aquaculture
IPMA	Portuguese Institute for the Sea and Atmosphere
ITAC_RF	Transition Index for Circular Aquaculture in Ria Formosa
LiRRIEs	Living Ecosystems for Responsible Research and Innovation
LPN	League for Nature Protection
NGO	Non-Governmental Organization
pAqAT	Plan for Aquaculture in Transitional Waters
PEPNRF	Special Programme for the Ria Formosa Natural Park
POP NRF	Ria Formosa Natural Park Management Plan
PGRH	River Basin Management Plan
PRR	Recovery and Resilience Plan
RAS	Recirculating Aquaculture Systems
RTA	Algarve Tourism Region
SNIRH	National Water Resources Information System
SWOT	Strengths, Weaknesses, Opportunities and Threats
TAA	Aquaculture Activity License
UA Ilg	University of Algarve
VIVMAR	Associations of Shellfish Farmers and Harvesters of Ria Formosa



1. Executive Summary

At the global level, aquaculture plays a central role in food security and economic development, having surpassed capture fisheries in 2022 as the main source of aquatic animals [1]. In Portugal, the sector is primarily based on the production of bivalves and fish in brackish and marine waters, operating under extensive, semi-intensive and intensive systems [2], with the first characterized by low levels of intervention, although not entirely free from human management. Despite its potential, the sector faces structural challenges, notably the constraints imposed by territorial management instruments (IGT), which limit its development and its positioning in European and international markets.

In this context, the present Action Plan aims to promote the sustainable development of aquaculture in the Ria Formosa through the adoption of good environmental and operational practices, namely adequate water renewal, the use of appropriate stocking densities and the implementation of suitable feeding protocols, with the goal of ensuring more efficient resource use. As a lagoon system of high ecological value, the Ria Formosa presents significant restrictions on economic activities. However, the evolution of aquaculture has increasingly demonstrated its potential positive contribution to ecosystems, particularly through multitrophic and regenerative approaches. Within this framework, the Ria Formosa offers favourable conditions for the implementation and consolidation of solutions based on circular economy principles, reconciling sector development with ecosystem preservation.

Based on contributions from Living Ecosystems for Responsible Research and Innovation (LiRRIEs), the Plan integrates scientific knowledge, stakeholder participation, and public policy coordination, promoting more efficient, sustainable, and socially responsible practices.

The AZA4ICE Action Plan has the following main objectives:

- √ governance and the coherence of public policies by promoting coordination among authorities, the scientific community, and the productive sector;
- √ Encourage the development of aquaculture based on improved environmental performance of production systems, through the adoption of multitrophic and regenerative approaches, the valorisation of by-products, and greater efficiency in resource use;
- √ Promote inclusion and social innovation by encouraging stakeholder participation, skills development, and equitable access to opportunities.

The Plan defines priority actions, monitoring indicators, and implementation mechanisms, ensuring effective execution oriented toward continuous improvement. The knowledge generated by the LiRRIEs, including needs assessment, legal framework analysis, capacity building, and identification of best practices, will contribute to its consolidation. By promoting innovation,



cooperation, and responsible resource management, the AZA4ICE Action Plan aims to foster a more sustainable, resilient aquaculture aligned with circular economy principles, in coherence with regional, national, and European policies. Its structure and implementation flow are summarized in Figure 1.

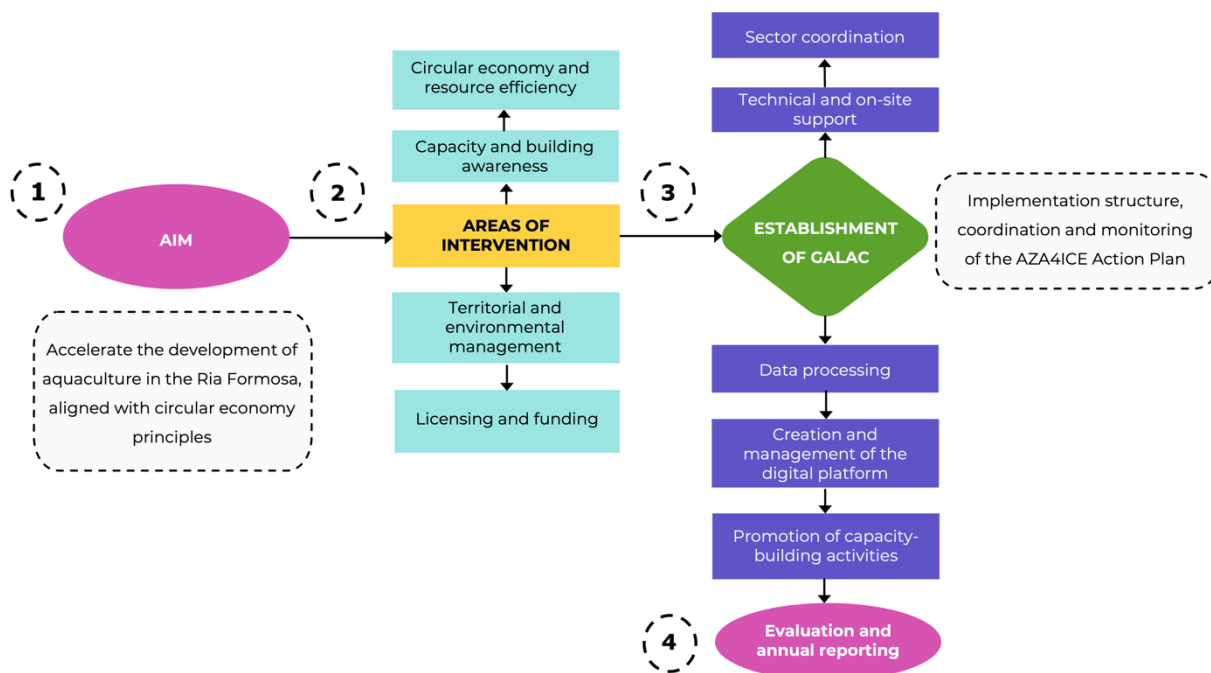


Figure 1 – Structure and implementation flow of the AZA4ICE Action Plan, including its objectives, areas of intervention and main operational actions.

2. Introduction

2.1. Scope and Objectives

This Action Plan, developed within the scope of the AZA4ICE project, provides a strategic framework to promote the development of the aquaculture sector in the Ria Formosa, based on circular and inclusive economy approaches. It aims to strengthen collaboration among multiple stakeholders and ensure that the proposed solutions are replicable, transferable, and aligned with regional and European Union sustainability objectives.



2.2. Context

National policies for the ocean and aquaculture in Portugal are guided by two key strategic instruments that define the pathway toward sustainable blue growth. The National Ocean Strategy (ENM) 2021–2030 establishes the national maritime policy, based on ten strategic objectives, including tackling climate change and pollution, restoring ecosystems, promoting employment, and developing a circular and sustainable blue economy [3].

In alignment, the Strategic Plan for Portuguese Aquaculture 2021–2030 [4] sets out a specific roadmap for the development of the aquaculture sector, promoting the sustainable use of natural resources, diversification of production, and the adoption of systems with lower environmental impact. These include solutions capable of delivering ecosystem services, such as Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS). Together, these instruments support the transition toward a more circular and sustainable model, based on nutrient recovery and reuse, energy efficiency, pollution prevention, and the promotion of innovation.

Despite this favourable framework, the development of aquaculture in Portugal continues to face structural limitations, reflected in a high dependence on imports. This situation mirrors the broader European Union trend, which in 2023 imported around 83% of the fishery and aquaculture products it consumes [5], highlighting the need for expansion and innovation in the sector. Key constraints include the complexity of administrative procedures and the restrictions associated with IGT, particularly relevant in areas suitable for aquaculture, often located in estuaries and lagoon system.

In this context, strengthening dialogue among stakeholders and improving public perception of the sector, often associated with negative impacts on ecosystems, are crucial. It is essential to promote an evidence-based approach that recognizes the potential of sustainable aquaculture to provide ecosystem services and contribute to environmental regeneration.

The Ria Formosa is a representative example of the challenges and opportunities associated with the sustainable development of aquaculture. This lagoon system, covering approximately 88 km² and extending about 55 km along the Algarve coast, is influenced by tidal regimes and characterized by a network of channels, salt marshes, mudflats, and sandy barrier islands that separate it from the Atlantic Ocean. Classified as a Natural Park, integrated into the Natura 2000 network, and recognized under the Ramsar Convention, it holds high ecological value and significant environmental sensitivity [6]. In this context, the Portuguese Environment Agency (APA), as the National Water Authority, has been developing, within the framework of the River Basin Management Plan (PGRH), an approach aligned with the principles of sustainable and circular aquaculture. This approach



promotes the use of inactive artificial areas for aquaculture development, while simultaneously enhancing the environmental quality of these areas. This concept was consolidated in the 3rd cycle PGRH, based on studies carried out by APA/ARH Algarve [7]. Following this, the Institute for Nature Conservation and Forests (ICNF) promoted the establishment of a working group known as ALREMAR, functionally led by S2AQUACoLAB and involving entities with relevant expertise, with the aim of deepening and systematizing existing knowledge. This work enabled not only the identification of aquatic areas with potential for aquaculture but also the delimitation of land-based aquaculture zones, particularly in areas adjacent to wetlands and under port jurisdiction. These areas total 645 hectares, representing approximately 33% of the artificialized areas of the Ria Formosa [7].

Currently, aquaculture, particularly bivalve production, is one of the main economic activities in the Ria Formosa, alongside coastal tourism, fisheries, and other recreational and urban uses across the municipalities of Loulé, Faro, Olhão, Tavira, and Vila Real de Santo António. Its unique ecological and socio-economic context positions this lagoon system as a living laboratory for the implementation, testing, and scaling of circular aquaculture solutions, where balancing productivity and ecosystem preservation is not only a challenge but also an opportunity to demonstrate the convergence between economic development and environmental sustainability.

3. Roles and Responsibilities of Key Actors

The development of this Action Plan resulted from a collaborative process based on the participatory approach of the AZA4ICE project, implemented through the LiRRIEs in the Ria Formosa. This process involved stakeholders representing the quintuple helix model (public authorities, academia, industry, civil society, and the environmental sector). The contributions of these actors made it possible to align the Action Plan with local realities, grounding it in scientific evidence and guiding it toward the implementation of an aquaculture model based on circular economy principles in the Ria Formosa.

a) Public Authorities

Representatives from central government bodies (DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; ICNF – Institute for Nature Conservation and Forests; AMN – National Maritime Authority – MARITIME POLICE; GNR – National Republican Guard and IPMA – Portuguese Institute for the Sea and Atmosphere), regional entities (CCDR Algarve – Algarve Regional Coordination and Development Commission; and APA-ARH Algarve – Portuguese Environment Agency – Algarve River Basin District Administration), and local entities (AMAL – Algarve Intermunicipal Community and the municipalities of Olhão, Loulé, and Vila Real de Santo António) contributed information on regulatory frameworks and



territorial development priorities. This participation ensured alignment of the Action Plan with regional policies and environmental management objectives for the Ria Formosa.

As the Portuguese entity responsible for the AZA4ICE project, IPMA coordinated the development of the Action Plan, fostering stakeholder engagement, guiding the participatory process, and providing scientific expertise in sustainable aquaculture.

b) Academia

Representatives from the University of Algarve (UAlg), the Marine and Environmental Research Centre (CIMA-UAlg), and other educational institutions such as the Algarve Life Science Centre (CCVAlg) contributed to the development of educational and research approaches aimed at integrating circular aquaculture principles into learning processes, promoting ocean and environmental literacy among students and the wider community. Their contributions were key to strengthening the educational and scientific dimension of the Action Plan.

c) Industry

Local aquaculture producers, trade unions, cooperatives, and associations—including Edulis – Comércio de Peixe e Marisco, Lda., the Association of Shellfish Farmers and Harvesters of Ria Formosa (VIVMAR), Cooperativa Formosa, and the Southern Fisheries Workers' Union, as well as other actors in the value chain, notably Mercados de Olhão, E.M., contributed practical knowledge and identified challenges and opportunities related to circular production. Entities such as the Algarve Tourism Region (RTA) and the Olhão Naval Group (GNO) provided relevant perspectives for the tourism and cultural valorisation of the Ria Formosa. These contributions ensured the feasibility and alignment of the Action Plan's recommendations with the realities of the aquaculture and tourism sectors.

d) Civil Society and Environment

Environmental associations such as Sciaena, Almargem, and the League for Nature Protection (LPN), as well as representatives of the local community, including the Culatra Island Residents' Association (AMIC), participated in the LiRRIEs, contributing perspectives on environmental conservation, public awareness, and the evolution of social perceptions of aquaculture activities in the Ria Formosa. Their input was essential to ensuring the integration of social and environmental dimensions into the Action Plan.

4. Regional Need, Challenges and Opportunities

The aquaculture sector in the Ria Formosa has favourable conditions for adopting circular economy models, supported by technical knowledge, well-established production systems, and ongoing sustainability initiatives, such as the reuse of bivalve shells and the use of solar-powered vessels. Although challenges remain, particularly in stimulating markets for by-products, strengthening specialized



training, addressing implementation costs, overcoming resistance to change, dealing with spatial constraints, and the lack of supportive policies, these simultaneously represent opportunities for value creation and innovation.

Advancing the circular economy in the Ria Formosa could benefit from stronger coordination among local entities, the implementation of capacity-building programs, and the broader adoption of renewable technologies. Strengthening governance, improving access to funding, and fostering effective collaboration among stakeholders are key to driving innovation and promoting more efficient resource use. At the same time, the creation of targeted incentives and better alignment of public policies represent concrete opportunities to enhance profitability, simplify administrative processes, and strengthen market connections. In this context, the definition of a coordinated, multi-level strategy emerges as a crucial step toward consolidating the long-term sustainability, resilience, and competitiveness of the aquaculture sector in the Ria Formosa.

Table 1 – SWOT analysis of the circular economy in the aquaculture sector in the Ria Formosa Lagoon.

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> Established aquaculture sector supported by strong scientific and technical foundations; In-depth knowledge of species life cycles and production systems; Active initiatives for recycling by-products (e.g. bivalve shells, cultivation bags); Adoption of renewable and low impact technologies (e.g. solar-powered vessels, shell crushing); Involvement of local Non-Governmental Organizations (NGOs) in promoting sustainable and circular practices. 	<ul style="list-style-type: none"> Limited market demand for aquaculture by-products; Gaps in capacity building, training and environmental awareness across the value chain; High implementation and operational costs of circular practices; Resistance to behavioural and cultural change; Limited space for aquaculture operations, storage and waste management; Lack of financial incentives and a supportive regulatory framework; Restrictions on licensed areas for aquaculture.
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> Creation of local coordination structures for by-product valorisation; Implementation of renewable and low-impact technologies to reduce costs; Development of knowledge-sharing platforms and targeted training; Availability of an inventory of inactive artificialized areas; Strengthening intersectoral collaboration and governance; Increased access to funding, innovation support and research partnerships; Enhancement of ecosystem services and biodiversity. 	<ul style="list-style-type: none"> Low short-term profitability and weak demand for circular products; Spatial constraints for aquaculture and waste management; Complex administrative and licensing procedures; Weak intersectoral coordination and limited governance; Resistance to innovation and limited recognition of long-term benefits.



5. Current legal/ regulatory/ licensing framework

The regulatory framework for aquaculture in Portugal is robust and multifaceted, reflecting efforts to reconcile the sector's sustainable development with environmental protection and administrative efficiency. The legal basis is established by Decree-Law No. 40/2017 of April 4, in its current version.

In the Ria Formosa, as a transitional water body, the coordination of licensing processes is ensured by the DGRM. A significant innovation was the creation of the Single Maritime Desk (Balcão Eletrónico do Mar, B-Mar) in 2019, a digital platform that enhances process transparency, simplifies administrative procedures, and promotes collaborative decision-making. The licensing process culminates in the issuance of the Aquaculture Activity Title (TAA), which serves as the single permit for the activity and incorporates the authorizations required for the installation and operation of aquaculture units, without prejudice to the application of specific environmental regimes when legally required. The duration of the evaluation process depends on the location of the unit and the type of license selected (Table 2).

Table 2 - Licensing conditions for aquaculture establishments in public and private domains in Portugal.

TYPE OF LICENSE	DURATION	RENEWAL	MAIN CONDITIONS
Public Domain			
Blue Licence	25-50 years*	Once	<ul style="list-style-type: none"> • Predefined government areas; • Public disclosure on DGRM website, port authority and municipalities.
General Licensing	10-25 years	Once	<ul style="list-style-type: none"> • Proposal submitted through B-Mar for the Activity License (TAA) • Coordinating authority consults all relevant public entities; • Publication of notices in local municipalities and the Entrepreneur's Desk (BdE); • If wastewater is discharged into the public domain, the maximum validity is 10 years.
PRIVATE DOMAIN			
Prior notification	10-25 years	Renewable**	<ul style="list-style-type: none"> • Simplified notification process by the applicant.
Authorization	10-25 years	Renewable**	<ul style="list-style-type: none"> • Standard authorization procedure.

* According to the conditions of the public notice; ** Subject to maintaining the conditions of the TAA.

Although the sector is highly regulated due to its environmental and public health implications, the legal framework also demonstrates flexibility, allowing for species diversification and adaptation to technological innovations. The implementation of the Plan for Aquaculture in Transitional Waters (PAqAT) in 2022 is an example of this approach, promoting alignment between aquaculture activities, spatial



planning, and ecological preservation. In this context, IMTA and RAS production systems stand out as sustainable models aligned with circular economy principles. In Portugal, their implementation falls within the existing legal framework for aquaculture, with no identified need for additional specific legislation. Furthermore, projects with these characteristics may benefit from higher funding rates under the Mar2030 program, encouraging the adoption of more sustainable and innovative solutions in the sector.

6. Status of aquaculture business

In Portugal, aquaculture is predominantly practiced in marine and transitional waters, which accounted for 98.5% of total production in 2023 [2]. Extensive systems represented 58.5% of national production, followed by intensive systems (31.5%) and semi-intensive systems (10%). Production structures are mainly composed of farms for bivalve mollusc production (88.9%), floating structures (2.4%), and tanks used for fish production (8.1%). The Ria Formosa continues to establish itself as the main aquaculture hub in the Algarve and as one of the leading centres for national bivalve production. In 2022, regional production accounted for 57% of total national aquaculture output and more than 90% of bivalve production in Portugal [8].

The adoption of circular production systems, such as Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS), is still in a consolidation phase in Portugal, with limited data available at the national level. Nevertheless, innovative initiatives have emerged that demonstrate the potential of these models. Notably, SEAentia (<https://www.seaentia.pt/about-us/>), a Portuguese start-up dedicated to the production of meagre (*Argyrosomus regius*) using RAS technology, standing out as an example of technologically advanced aquaculture focused on resource efficiency.

Regarding IMTA systems, their large-scale economic viability remains generally less established compared to RAS systems. However, this model may prove more viable when integrated into larger aquaculture units as a complementary system. In such cases, it primarily serves an ecosystem service function, contributing to the mitigation of environmental impacts, the valorisation of effluents, and the overall sustainability of operations, rather than acting as a direct source of production and revenue. In Portugal, many IMTA-related initiatives still have a predominantly scientific nature, being mainly linked to research and development activities rather than commercial exploitation, with the IPMA playing a key role in this domain. These projects generally focus on polyculture systems integrating three trophic levels, combining macroalgae, bivalve molluscs, and fish species such as meagre (*Argyrosomus regius*), white seabream (*Diplodus sargus*), and flathead grey mullet (*Mugil cephalus*) [9]. Also noteworthy is ALGApplus (<https://www.algaplus.pt/>), based in Ílhavo, which is dedicated to the production and commercialization of marine



macroalgae for the food, cosmetic, scientific, and biotechnology sectors. Operating within an IMTA system, the company uses nutrients derived from semi-intensive aquaculture of seabass and seabream, promoting effluent valorisation, reducing environmental impact, and demonstrating the practical application of circular economy principles.

7. Vision

The development of aquaculture based on circular economy principles is increasingly recognized as a key pathway to ensuring the sector's long-term sustainability. This approach is reflected in the Strategic Plan for Portuguese Aquaculture 2021–2030, which promotes the efficient use of aquatic resources, diversification of protein sources, and the adoption of low-carbon production systems [4]. Despite this strategic direction, the development of the sector and the transition toward more circular and sustainable practices continue to be constrained by technical, environmental, and economic challenges.

An analysis carried out on nine aquaculture companies in the Ria Formosa, using a tool developed under the BLUEfasma project (http://bluefasma.upatras.gr/pt_PT/authentication/login), indicates that local operators show a strong orientation toward green economy and sustainability practices. All assessed participants were classified at the same level of circularity, standing out positively among the territories involved in the AZA4ICE project within the Euro-MED region, which includes eight regions across Bulgaria, Spain, Portugal, France, Italy, Croatia, Greece, and Montenegro, involving 65 stakeholders from the aquaculture value chain. In addition, operators expressed interest in investing in new circular economy measures. However, particularly among small-scale producers, challenges remain regarding the adoption of more investment-intensive environmental solutions. This situation highlights the need for targeted training, financial incentives, and stronger institutional support, especially in areas such as waste valorisation and by-product commercialization.

In the Ria Formosa, there are already promising examples of circular aquaculture practices, namely the reuse and valorisation of bivalve shells, which contribute to waste reduction and value creation within local production systems [10]. Building on these initiatives, the Ria Formosa has strong potential to consolidate a circular and sustainable aquaculture model that is environmentally responsible, economically viable, and socially beneficial. In this context, the future of the sector in this territory is grounded in the principles of circular economy and sustainability, structured around six interconnected pillars that support a resilient, innovative, and efficient production model (Figure 2).



Figure 2 - Strategic vision for the development of aquaculture in the Ria Formosa Lagoon, framed within the principles of circular economy and sustainability. C-AZA – Allocated Zones for Circular Aquaculture.

Efficient resource management focuses on optimizing production processes, promoting waste reduction, reuse, and the valorisation of by-products. Local economic value prioritizes regional products and encourages production for local consumption, strengthening economic resilience and regional development. Ecological balance ensures that aquaculture develops within the limits of the Ria Formosa, promoting the adoption of systems such as IMTA, which contribute to more balanced environments, diversification of native species, and the maintenance of the ecosystem's regenerative capacity.

Value chain capacity building focuses on enhancing the skills of stakeholders and facilitating knowledge transfer, promoting the adoption of innovative practices and continuous improvement throughout the entire production chain.

Regulation and institutional support ensure a solid framework, supported by instruments that encourage sustainable practices and innovation, in coordination with other economic activities in the Ria Formosa. The Allocated Zones for Circular Aquaculture (C-AZA) methodology, developed within the AZA4ICE project, serves as a decision-support tool, guiding the selection of species and production systems that maximize circularity while minimizing environmental impact.

Together, these pillars support a circular, sustainable, and economically viable aquaculture model, tailored to the ecological and socio-economic context of the Ria Formosa.



8. Potential of the C-AZA results

The AZA4ICE project developed a technical-participatory methodology to identify and delineate the Allocated Zones for Circular Aquaculture (C-AZA), based on environmental, spatial, socio-economic, biological, and legal criteria. This approach integrates scientific analysis, land-use compatibility, and circular economy principles, and can serve as a decision-support tool for selecting species and production systems that promote more sustainable and resource-efficient aquaculture.

In the Ria Formosa, aquaculture coexists with other economic activities, particularly tourism. Production under extensive systems, carried out in ponds, is the most prevalent. For this reason, the methodology was applied to assess the suitability of the area for other production systems, namely semi-intensive systems in earthen ponds and intensive systems using recirculating aquaculture systems. The application of the methodology indicated that:

- Most of the native species analysed showed suitable conditions for aquaculture in the Ria Formosa, demonstrating the ecosystem's capacity to support a relevant diversity of species;
- Several species showed potential for integration into multitrophic systems, although factors such as market value, social acceptance, and production performance may influence their viability;
- The multitrophic models assessed, both in earthen ponds and in RAS, proved suitable for the Ria Formosa, with the potential to increase circularity through measures such as the use of recycled materials and greater reliance on solar energy.

Considering that the Ria Formosa is divided into five water bodies with distinct characteristics, collecting environmental data for each would allow for a more precise assessment of their potential for aquaculture development in this region. In this context, the C-AZA methodology may serve as a decision-support tool for evaluating the potential of circular models in different locations, while also showing potential for application and adaptation to other regions.

9. Proposed Actions

9.1. Key Actions and Interventions

The development of aquaculture in Portugal requires strengthened cooperation, capacity building, and intersectoral communication among the different stakeholders in the value chain. In the context of the Ria Formosa, the working group identified priority actions (Table 3), organized into complementary areas of



intervention that address specific technical, economic, environmental, and administrative challenges of the territory.

Table 3 - Priority actions for the development of aquaculture in the Ria Formosa identified within the AZA4ICE project.

AREA OF INTERVENTION	KEY ACTIONS
Capacity building and awareness	<ul style="list-style-type: none"> • Capacity-building of value chain stakeholders in circular economy principles; • Environmental education and awareness targeting children and adults not directly linked to the sector.
Environmental Management	<ul style="list-style-type: none"> • Continuous monitoring of environmental parameters • Selective dredging to improve water circulation and sediment management; • Proper management of obsolete or damaged equipment.
Circular economy	<ul style="list-style-type: none"> • Valorisation of co-products and by-products; • Promotion of intersectoral synergies; • Transition of production systems toward circular models, where feasible.
Territorial management	<ul style="list-style-type: none"> • Reuse and rehabilitation of artificial and abandoned areas; • Creation of collective infrastructure and shared support zones; • Update of the Plan for Aquaculture in Transitional Waters (pAqAT); • Approval of the Special Programme for the Ria Formosa Natural Park (PEPNRF).
Sustainability	<ul style="list-style-type: none"> • Definition of good practice guidelines; • Establishment of production limits based on ecosystem carrying capacity.
Licensing	<ul style="list-style-type: none"> • Licensing processes based on scientific evidence and sustainability criteria; • Adaptation of the legal framework to facilitate resource sharing.
Financing	<ul style="list-style-type: none"> • Funding mechanisms and incentives to support the adoption of sustainable and circular practices.

The proposed measures include strengthening the capacity of aquaculture sector stakeholders, with the aim of clarifying the concept of circular economy and developing skills through the sharing of practical success examples, preferably at the local level. In parallel, promoting environmental education and awareness initiatives targeting different audiences plays a strategic role in achieving sustainable development.

Environmental management of production areas is another key pillar, aiming to increase production efficiency through continuous monitoring of environmental parameters, selective dredging of production channels to improve water circulation and sediment management, and preventing the accumulation of obsolete or damaged production equipment within the ecosystem. The definition of sustainability guidelines based on the ecosystem's carrying capacity is also essential, enabling the assessment of cumulative pressures associated with different uses of the lagoon. In addition, the development of intersectoral synergies



is encouraged for the valorisation of co-products, namely through the reuse of bivalve shells or the use of sludge for agricultural purposes.

In terms of territorial management, particular emphasis is placed on the need to approve the Special Programme for the Ria Formosa Natural Park (PEPNRF), which will update the current framework defined by the Ria Formosa Natural Park Management Plan (POPNERF), approved by Council of Ministers Resolution No. 78/2009 of September 2. Furthermore, the reuse and renaturalisation of currently inactive artificial areas, such as former salt pans and abandoned fish farms, is proposed, as these present potential for aquaculture development, as identified by the ALREMAR working group. These findings highlight priority areas for intervention in territorial rehabilitation and valorisation. In this context, updating the PAqAT is a key strategic measure.

The creation of land-based support areas for aquaculture is also essential, particularly spaces for storing materials used in bivalve production (bags, floats, racks, among others) and sites for shell deposition. In fish production, this also includes storage areas for feed, nets, buoys, and other equipment. When designed as shared infrastructure, these facilities optimize the use of space and resources, while ensuring efficient storage, management, and handling of co-products, by-products, materials, and production surpluses (e.g., bivalve shells, non-commercial biomass, organic sludge, and algae associated with cultivation), as well as end-of-life equipment management.

Finally, funding mechanisms and economic incentives are needed to support the adoption of innovative and low environmental impact practices. In this context, it is important to review the evaluation criteria of funding programs, particularly Mar2030, to prioritize more sustainable and circular solutions rather than focusing exclusively on lower costs.

The application of planning and licensing tools based on scientific evidence, such as the C-AZA methodology, enables the alignment of aquaculture development with environmental protection. At the same time, the sharing of logistical resources among producers (e.g., joint transportation of production) contributes to improving operational efficiency and reducing environmental impact. However, the current legal framework does not yet clearly address these collaborative solutions, which may be subject to oversight by competent authorities, notably the Maritime Police, within the scope of the Maritime Public Domain.

Taken together, these actions establish a favourable framework for the development of aquaculture based on circular economy principles, ensuring its environmental sustainability and economic viability in the Ria Formosa.

9.2. Responsible Actors

Aquaculture in Portugal involves multiple public entities with responsibilities in



environmental management, licensing, spatial planning, food safety, and sector sustainability. The main institutions include the DGRM, APA, ICNF, IPMA, DGAV and CCDRs.

In the context of the Ria Formosa, the transition toward circular aquaculture requires strengthened coordination among these entities, as well as greater integration with scientific institutions, non-governmental organizations (NGOs), science education and outreach bodies, municipalities, cooperatives, associations, and R&D and industry companies. Within this framework, the creation of a Local Support Office for Circular Aquaculture (GALAC) could play a central role in facilitating coordination among stakeholders and supporting the implementation of the Action Plan (Figure 3). It is recommended that these functions be integrated into existing municipal structures in the Ria Formosa, ensuring proximity and local support for stakeholders. Clarifying responsibilities and strengthening intersectoral communication are therefore essential for the effective implementation of the proposed Action Plan.

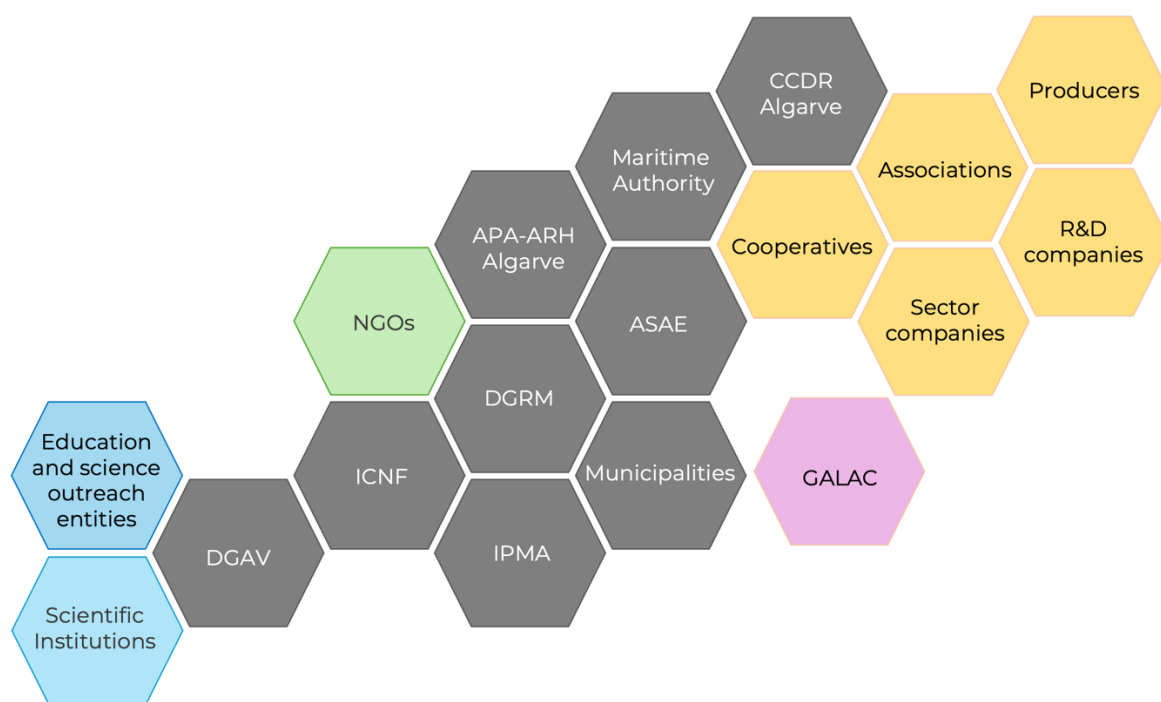


Figure 3 - Entities involved in the transition toward circular aquaculture in the Ria Formosa. DGAV - Directorate-General for Food and Veterinary Affairs; ICNF – Institute for Nature Conservation and Forests; IPMA – Portuguese Institute for the Sea and Atmosphere; NGOs – Non-Governmental Organizations; DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; APA-ARH Algarve – Portuguese Environment Agency; ASAE – Food and Economic Safety Authority; GALAC – Local Support Office for Circular Aquaculture; CCDR – Regional Coordination and Development Commission; R&D – Research and Development.

9.3. Timeline

The development of aquaculture in the Ria Formosa, based on circular economy principles, can be implemented in phases through a progressive model that integrates structural, operational, capacity-building, and consolidation actions, organized according to implementation priority. This approach enables gradual and adaptive development, distinguishing between short-, medium-, and long-term interventions (Figure 4).

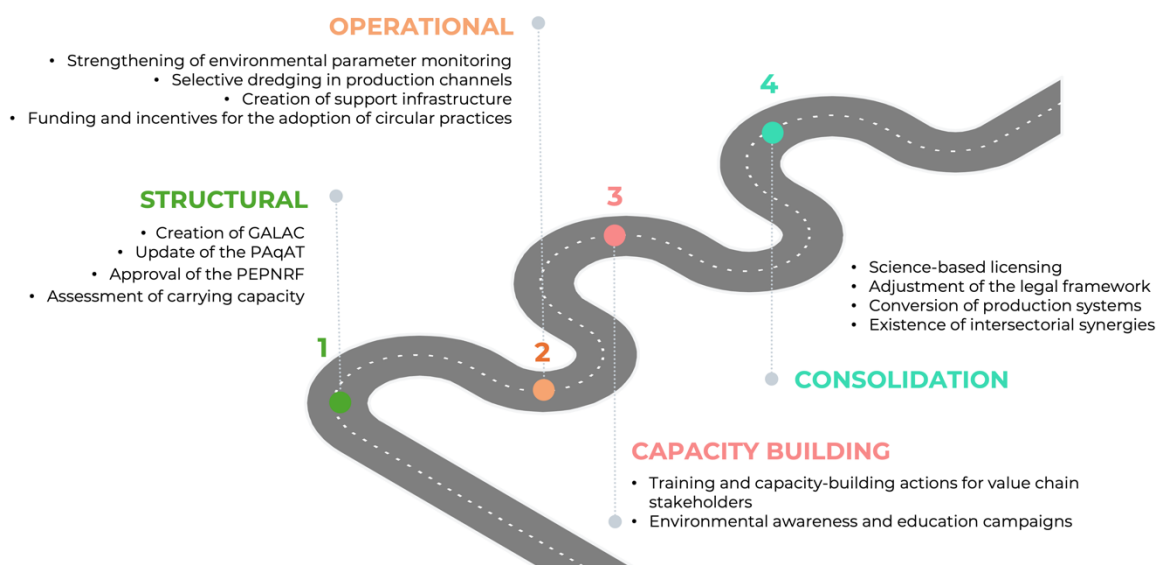


Figure 4 - Timeline for the development of aquaculture in the Ria Formosa, based on circular economy principles, proposed within the AZA4ICE project. The diagram presents the development phases and the priority of actions, distinguishing between short-term (immediate priority) and medium- to long-term interventions. GALAC – Local Support Office for Circular Aquaculture; pAqAT – Plan for Aquaculture in Transitional Waters; PEPNRF – Special Programme for the Ria Formosa Natural Park.

In the short term, the structural phase focuses on establishing institutional and planning foundations, including the creation of GALAC as a technical support structure, the update of the pAqAT, and the approval of the PEPNRF. The preparation of the latter was determined by Order No. 2069/2025 of February 13, as a key spatial planning instrument for the development of the aquaculture sector in the Ria Formosa. The use of inactive artificial areas identified by ALREMAR in the Ria Formosa, both for the provision of ecosystem services and for aquaculture development, is considered essential and urgent for improving the environmental conditions of the areas in which they are located. In this context, it is important to recognize, within the development of aquaculture based on circular economy principles, its potential positive contribution to ecosystems, which should be reflected in updates to IGT. In parallel, an assessment of the carrying capacity of the Ria Formosa should be conducted to ensure that aquaculture development is grounded in scientific evidence and respects the system's environmental limits.



In the medium term, the operational and capacity-building phase focuses on implementing on-the-ground measures and strengthening stakeholders' competencies. This includes reinforcing continuous monitoring of environmental parameters, ensuring regular oversight of activities across different water bodies, independently of isolated projects, and integrating data into modelling and forecasting platforms, such as the one developed under the CONNECT+ project (<https://connect.lnec.pt>). It also includes selective dredging of production channels, where technically justified, and the development of shared infrastructure for the storage, management, and valorisation of materials, equipment, and by-products.

At the same time, funding mechanisms should be implemented to incentivize the adoption of circular practices, with evaluation criteria that prioritize sustainable solutions beyond cost considerations. Despite a 16.2% increase in vocational training in the fisheries and aquaculture sectors, processing industry, and maritime activities in 2024 [2], there remains a need to strengthen technical and environmental capacity in the sector, given the growing demands and challenges associated with sustainability. In this context, the development of specialized training actions and environmental awareness and education initiatives is proposed, aimed at promoting best practices, enhancing environmental literacy, and engaging stakeholders across the value chain, highlighting local examples of economic success. Additionally, the creation of a dedicated digital platform for circular aquaculture is recommended, with a user-friendly design to facilitate knowledge sharing, promote collaboration among researchers, policymakers, and aquaculture operators, and centralize information on available government support.

In the long term, the consolidation phase aims to ensure the sustainability of the proposed model through the implementation of science-based licensing processes, the adaptation of the legal framework, and the conversion of production systems toward models that balance production with environmental enhancement. Furthermore, coordination with other economic sectors should be promoted, fostering synergies that support the development of circular value chains.

9.4. Financial aspects and Funding resources

The transition to a circular economy in the aquaculture sector requires the coordinated mobilization of public and private financing, including European and national funds, as well as direct investment from banks, venture capital, companies, and other actors in the value chain. At the European level, key direct management programs include Interreg, Horizon Europe, LIFE, and Digital Europe, which operate under autonomous application procedures and complement the European Structural and Investment Funds (FEEI). These include the European Regional Development Fund (FEDER), the European Social Fund Plus (FSE+), the Cohesion Fund (FC), the European Maritime, Fisheries and Aquaculture Fund (FEAMPA), and

the European Agricultural Fund for Rural Development (FEADER).

In Portugal, the FEEI are implemented through Portugal 2030, the national Partnership Agreement that defines development priorities up to 2030, approved by Council of Ministers Resolution No. 98/2020 of November 13. In the areas of the sea, fisheries, and aquaculture, MAR 2030 is the program responsible for implementing the FEAMPA. In parallel, there are complementary national financial instruments, such as the Recovery and Resilience Plan (PRR), the Environmental Fund, and the Fund for Technology and Circular Economy (FTECE). Although not formally part of Portugal 2030, these instruments are aligned with its strategic objectives, supporting the green, digital, and circular transitions. The PRR, in this context, is temporary in nature, with implementation scheduled until 2026 (Figure 5).

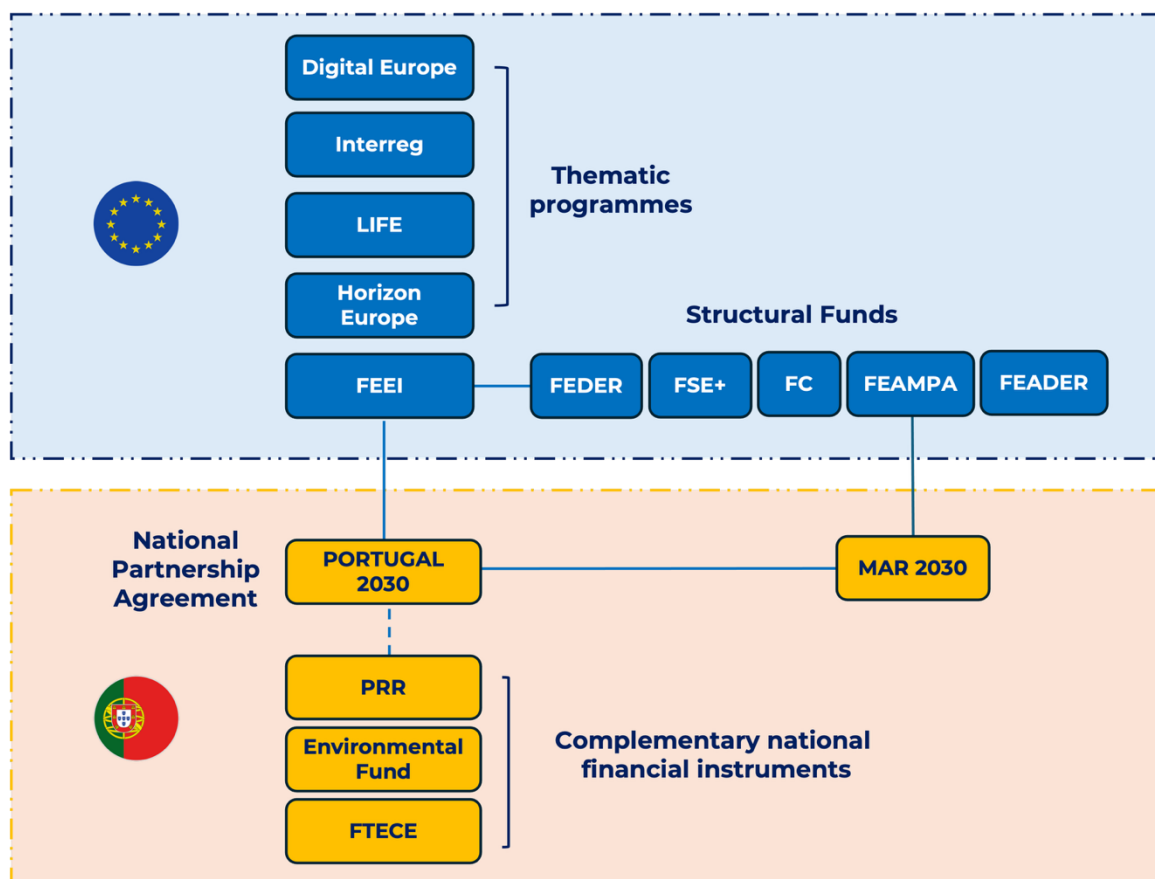


Figure 5 - Structure of European and national public funding for aquaculture. – European Structural and Investment Funds; FEEI – European Structural and Investment Funds; FSE+ – European Social Fund Plus; FC – Cohesion Fund; FEAMPA – European Maritime, Fisheries and Aquaculture Fund; FEADER – European Agricultural Fund for Rural Development; PRR – Recovery and Resilience Plan; FTECE – Fund for Technology and Circular Economy.

Although relevant support mechanisms already exist, there is still scoped to improve access to funding, particularly for small-scale producers, through better dissemination of available instruments and simplification of application processes. At the same time, the evaluation criteria of funding programs, especially MAR 2030,



should be reviewed to prioritize more sustainable and circular solutions, rather than predominantly favouring lower-cost options. The development of national and regional incentives specifically targeted at circular aquaculture approaches could accelerate the adoption of more sustainable production models.

Currently, many producers in the Ria Formosa operate under economically viable business models and do not perceive immediate benefits from changing their practices, particularly when such changes involve higher investment, effort, and operational complexity. In this context, it is essential to promote incentives across the entire value chain, from production to processing, marketing, and consumption, that support the creation of added value. These should include certification mechanisms, product valorisation strategies, and the development of collective or sustainability-based brands, translating into tangible economic benefits that offset the additional effort and make the adoption of this aquaculture model more attractive and financially viable.

10. Monitoring and Evaluation

10.1. Success Indicators

To support the development of aquaculture based on circular economy principles, it is essential to define clear, measurable, and comparable performance indicators over time. These indicators enable the monitoring of circular practice adoption, the assessment of environmental, economic, and social impacts, and support decision-making, as well as the adjustment of implemented measures. Table 4 presents the set of indicators proposed for monitoring a circular aquaculture approach in the Ria Formosa within the framework of the AZA4ICE project. The indicators are organized by dimension of analysis, including their respective weight, data collection frequency, and suggested data sources.

Table 4 - Monitoring indicators for aquaculture based on circular economy principles in the Ria Formosa, proposed within the AZA4ICE project.

DIMENSION (WEIGHT)	INDICATOR	FREQUENCY	PROPOSED DATA SOURCES
Circular Economy (25%)	Number of aquaculture units with circular practices	Annual	<ul style="list-style-type: none"> • Producers • Associations • Cooperatives • DGRM
	Number of products with traceability systems	Annual	<ul style="list-style-type: none"> • Producers • Cooperatives • Associations • Sector companies
	Number of new circular economic activities	Annual	<ul style="list-style-type: none"> • Producers • Associations • Cooperatives



Environmental Management (20%)	Number of new species in production areas	Annual	<ul style="list-style-type: none"> • ICNF • NGOs • IPMA
	Number of species produced per trophic level	Annual	<ul style="list-style-type: none"> • DGRM
	Productivity of carpet shell clam (<i>Ruditapes decussatus</i>) (ton/ha)	Annual	<ul style="list-style-type: none"> • Producers • Associations • Cooperatives • DGRM
	Number of water quality data records collected	Annual	<ul style="list-style-type: none"> • APA • Scientific institutions
	% of units by production system type (extensive, semi-intensive, intensive)	Annual	<ul style="list-style-type: none"> • DGRM
Energy Efficiency (15%)	Number of aquaculture units using renewable energy	Annual	<ul style="list-style-type: none"> • DGRM
Spatial Planning (10%)	Number of interventions in aquaculture infrastructure (rehabilitation, adaptation or conversion)	Annual	<ul style="list-style-type: none"> • Municipalities
	Recovered artificialized areas (ha)	Annual	<ul style="list-style-type: none"> • Municipalities • Associations • DGRM
Licensing (10%)	Number of licensed aquaculture units using IMTA and/or RAS systems	Annual	<ul style="list-style-type: none"> • DGRM
Financing (15%)	Amount of funding approved for circular aquaculture projects (€)	Annual	<ul style="list-style-type: none"> • Scientific institutions • R&D companies • CCDR Algarve
Capacity Building and Awareness (5%)	Number of training and awareness actions on circular economy	Annual	<ul style="list-style-type: none"> • Education and science outreach entities • Scientific institutions

DGRM – Directorate-General for Natural Resources, Safety and Maritime Services; IPMA – Portuguese Institute for the Sea and the Atmosphere, I.P.; APA – Portuguese Environment Agency; ICNF – Institute for Nature Conservation and Forests; NGOs – Non-Governmental Organizations; CCDR – Regional Coordination and Development Commission; R&D – Research and Development.

The collection of information associated with these indicators may be progressively integrated into aquaculture licensing processes and surveys, particularly regarding production systems, the use of renewable energy, species produced, and the adoption of circular practices. This integration will enable DGRM to ensure systematic monitoring of production units and the level of adoption of circular models.

Circular economy indicators allow the assessment of the level of adoption of circular practices in production units (e.g., use of recyclable materials), in products, and in associated economic activities. They also include initiatives for the valorisation of aquaculture by-products, regardless of their formal link to production units, reflecting the expansion of circular value chains in sectors such as construction, agriculture, and the pharmaceutical industry. The traceability of



aquaculture products derived from circular practices is based on batch identification and the recording of information throughout the value chain, including origin, production system, and practices adopted. This process should be ensured by producers, associations, and cooperatives, guaranteeing the validation and continuity of information up to the commercialization stage. Examples of products include:

- Gilthead seabream produced in RAS systems, partially powered by renewable energy;
- Mussels produced in offshore suspended structures;
- Oysters cultivated on tables using recycled bags.

The environmental management dimension includes both direct and indirect indicators of the ecological status of production areas. Species diversity and the trophic structure of production systems help assess ecological balance, while the productivity of carpet shell clams (*Ruditapes decussatus*) (ton/ha) can serve as an indirect indicator of environmental health and the regenerative capacity of the Ria Formosa. Monitoring is complemented by the volume of data collected on water quality, reflecting the effort and consistency of observation systems. This data collection may be primarily ensured by the APA through the National Water Resources Information System (SNIRH - <https://snirh.apambiente.pt/>) and complemented by systems operated by scientific institutions such as CCMAR, CIMA-UAlg, and S2AQUAcoLAB (Collaborative Laboratory for Sustainable and Smart Aquaculture) within research projects.

The spatial planning dimension can be monitored through the number of interventions in aquaculture infrastructure, including rehabilitation, adaptation, or conversion of production systems. These interventions may include the upgrading of ponds or tanks, the adaptation of salt pans for aquaculture production, the implementation of RAS or IMTA systems, as well as improvements to energy infrastructure.

Energy efficiency can be assessed through the adoption of renewable energy sources in production units, reflecting reduced dependence on fossil fuels and enhanced energy sustainability within the sector. The licensing dimension allows monitoring of the formal adoption of IMTA and RAS systems within the legal framework of aquaculture activity. Financing can be evaluated based on the amount of investment (€) approved for aquaculture projects based on circular economy principles, reflecting access to support instruments and the level of financial mobilization for sector development.

Finally, capacity building and awareness are monitored through the number of training and outreach actions carried out, reflecting the strengthening of skills and the level of engagement of different stakeholders in adopting more sustainable practices.



10.2. Follow-up and Adjustment

The development of aquaculture in Portugal requires a continuous process of monitoring, evaluation, and adjustment, focused on results and aligned with the needs of producers and the value chain. For this purpose, the AZA4ICE Plan defines the main monitoring and enforcement actions associated with the established dimensions and indicators, as presented in Table 5.

Table 5 - Monitoring and enforcement actions for the development of aquaculture based on circular economy principles in the Ria Formosa within the AZA4ICE project.

DIMENSION	ACTION	MONITORING	ENFORCEMENT
External pressure	Identification of external vessels and abandoned materials	<ul style="list-style-type: none"> Local maritime authorities 	<ul style="list-style-type: none"> Local maritime authorities
Environmental management	Operation of environmental monitoring sensors	<ul style="list-style-type: none"> APA Scientific research entities 	<ul style="list-style-type: none"> APA Scientific research entities
Circular economy	Monitoring the traceability of circular products along the value chain	<ul style="list-style-type: none"> Cooperatives Associations Depuration facilities Markets 	<ul style="list-style-type: none"> DGAV ASAE IPMA
Governance	Data processing and annual monitoring report	<ul style="list-style-type: none"> GALAC 	<ul style="list-style-type: none"> GALAC

APA – Portuguese Environment Agency; DGAV – Directorate-General for Food and Veterinary Affairs; ASAE – Food and Economic Safety Authority; IPMA – Portuguese Institute for the Sea and the Atmosphere; GALAC – Local Support Office for Circular Aquaculture.

In terms of external pressure, local maritime authorities are responsible for monitoring and enforcing the presence and circulation of vessels and motorized vehicles not associated with aquaculture activities, within their competencies related to surveillance, safety, and maritime spatial management. This monitoring also includes identifying abandoned equipment or materials that may interfere with activities or compromise the ecological condition of production areas.

Environmental management is proposed to be ensured by the APA through the operation and maintenance of environmental monitoring sensors integrated into the SNIRH network. This system may be complemented by equipment installed by research entities within scientific projects, ensuring the continuous collection of data necessary to assess the ecological status of aquaculture areas.

Within the circular economy dimension, the traceability of aquaculture products may be operationally monitored by cooperatives and producer associations, purification plants, and markets, ensuring the continuity of information along the value chain. Legal enforcement of product traceability and food safety falls under DGAV and IPMA, particularly through the National Bivalve Monitoring System (SNMB), while ASAE ensures compliance with labelling rules and commercial practices at the consumer level.



Finally, the governance dimension is proposed to be ensured by GALAC, responsible for collecting and consolidating information from relevant entities and preparing the annual evaluation report. This report should assess progress achieved, identify potential deviations, and provide recommendations for adjusting measures and defining priorities for the following period. This integrated monitoring system strengthens the effectiveness of implemented measures and supports decision-making. GALAC may operate in coordination with existing local structures, such as Fisheries Local Action Groups (GAL/GALP) or municipal offices linked to the maritime sector. Its main functions include:

- Data processing and preparation of the annual monitoring report;
- Technical and on-site support to producers in adopting circular aquaculture practices;
- Creation and management of a digital support platform dedicated to aquaculture development in the Ria Formosa, facilitating knowledge sharing and dissemination of funding opportunities;
- Promotion of capacity-building activities in collaboration with researchers and policymakers;
- Promotion of intersectoral coordination.

The weights assigned to the different dimensions (Table 4) reflect their relative importance in aquaculture development and were validated with stakeholders in the Ria Formosa during the 4th LiRRIE meeting. Circular economy carries the greatest weight, as it directly reflects changes in production practices and value creation. Environmental management, energy efficiency, and licensing have intermediate weights, while spatial planning, financing, capacity building, and governance play a structural supporting role.

To assess the progress of circular aquaculture development in the Ria Formosa, the calculation of the Transition Index for Circular Aquaculture in the Ria Formosa (ITAC_RF) is proposed, based on the positive variation of defined indicators compared to the previous year. The index takes a value of zero when no progress is observed and values above zero when there is improvement. The score for each indicator is calculated based on the percentage change between the evaluation year (t) and the baseline year:

$$\text{Indicator score} = \frac{\text{Value in year } t - \text{Value in baseline year}}{\text{Value in baseline year}} \times 100$$

In cases where the baseline value is zero, the score is not calculated as a percentage change. Instead, a value of zero is assigned when no progress occurs, and 100 when the indicator becomes positive, reflecting the start of the transition.

The ITAC_RF results from the weighted aggregation of indicator scores, according to the weights assigned to each dimension:

$$ITAC_{RF} = \sum (Indicator\ score \times Weight)$$

The index is normalized on a scale from 0 to 100, allowing a concise assessment of the level of implementation of actions and the evolution of indicators over time. In this way, the ITAC_RF serves as a tool to support annual monitoring, identify deviations, and adjust the measures defined in the Plan.



Figure 6 - Transition Index for Circular Aquaculture in the Ria Formosa (ITAC_RF), proposed within the AZA4ICE project.

Figure 6 presents the index classification scale on a continuous bar from 0 to 100, allowing interpretation of the level of progress in the transition. This graphical representation facilitates understanding of the transition status, monitoring of annual progress, and support for decision-making.

11. Conclusion

11.1. Summary and Next Steps

This plan, developed within the framework of the AZA4ICE project, sets out guidelines for the development of aquaculture in the Ria Formosa toward models based on good practices and circular economy principles that are sustainable and resilient. The definition of indicators, monitoring actions, and a monitoring system enables the assessment of the implementation of measures, the tracking of progress, and supports decision-making. In this context, the ITAC_RF serves as a tool to support monitoring and the adjustment of planned actions.

The next steps focus on operationalizing the proposed actions, strengthening coordination among entities, integrating information into licensing processes, enhancing the traceability of products derived from circular aquaculture practices, and building capacity among producers and other stakeholders in the value chain. The annual preparation of a monitoring report, coordinated by GALAC, will make it possible to track results and adjust priorities. The implementation of this plan will contribute to promoting the development of aquaculture in the Ria Formosa through a circular approach, strengthening the sustainability of the activity, the protection of ecosystems, and its integration into the territory, and may serve as a reference for other production areas in Portugal.



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Glossary

Blue Economy

A set of economic activities associated with oceans, seas, and coastal areas that use marine resources in a sustainable way. It includes sectors such as aquaculture, fisheries, biotechnology, shipping and shipbuilding, renewable energy, and coastal tourism, promoting a balance between economic development, environmental protection, and responsible use of marine resources.

Circular Economy

A production and consumption model that seeks to keep resources in use for as long as possible by promoting reduction, reuse, repair, recycling, and the valorisation of materials and by-products. In contrast to the traditional linear model (“take, make, dispose”), it aims to minimize waste generation, reduce pollution, and increase resource-use efficiency.

Ecosystem Services

The direct and indirect benefits that people obtain from ecosystems, natural systems composed of living organisms, physical environmental elements, and the interactions between them. In the context of aquaculture, these include natural processes such as water quality regulation, nutrient recycling, biodiversity maintenance, and food production.

Artificialized and Non-natural Areas

Areas whose natural morphology has been altered by hydromorphological pressures resulting from human intervention, particularly along the margins of aquatic systems influenced by tidal dynamics.

IMTA (Integrated Multi-Trophic Aquaculture)

An aquaculture production system that combines species from different trophic levels (fish, bivalves, algae), promoting biological complementarity among them. By allowing the by-products of one species to be used by another, IMTA increases production efficiency, reduces waste accumulation, and contributes to improved environmental quality.

RAS (Recirculating Aquaculture System)

An intensive aquaculture production system using tanks, in which water is continuously recirculated through filtration and treatment processes, allowing its reuse within the system. It reduces water consumption, isolates the cultured stock, and minimizes discharges into the environment, ensuring highly controlled production conditions. These systems can be further optimized through energy efficiency solutions and the use of renewable energy sources, particularly solar energy.



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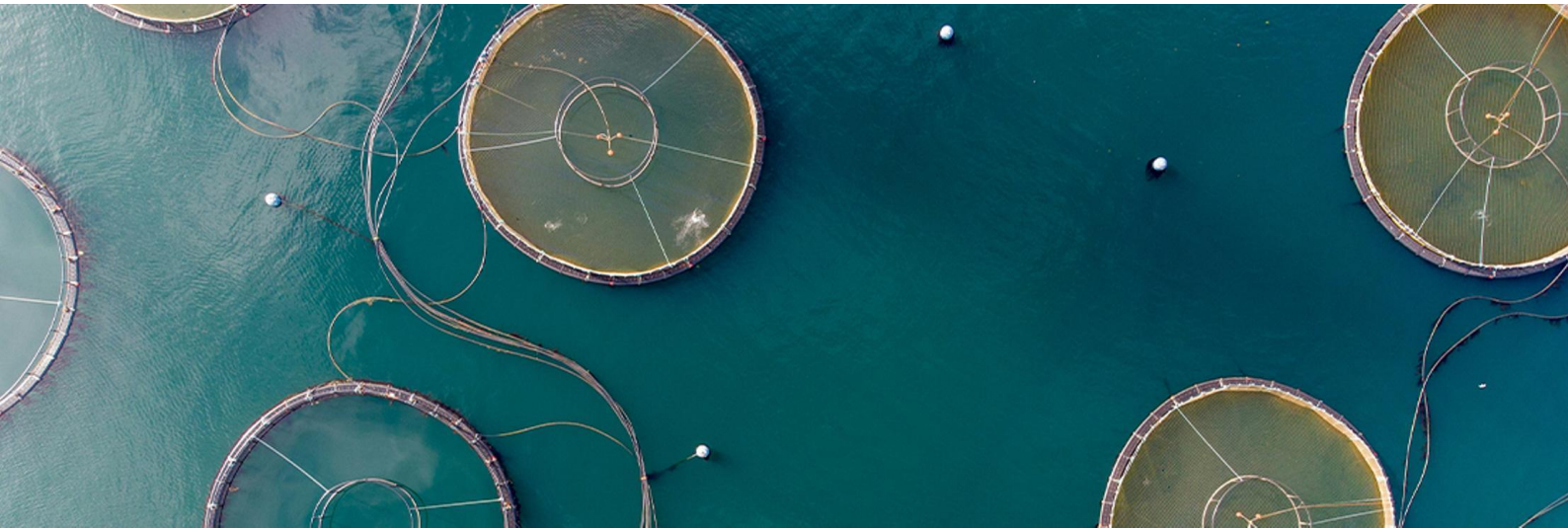


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Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Krka River estuary, Šibenik, Croatia

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Abbreviations

ASC - Aquaculture Stewardship Council certification

AZA - Allocated Zones for Aquaculture

BRAVE - Building Resilience and Adaptive Vision for the Adriatic Sea Environment

C-AZA - Circular- Allocated Zones for Aquaculture

EMFAF - European Maritime Fisheries and Aquaculture Fund

Euro-MED - EURO Mediterranean

IMTA - Integrated Multi-Trophic Aquaculture

INTERREG - Interregional Regions

IOF - Institute for Oceanography and Fisheries

IRB - Institute Ruder Boskovic

KPI - Key performance indicators

LiRRIE - Living Responsible Research Innovation Ecosystems

MPA - Marine Protected Area

NGO - Non-Governmental Organization

PO - Producers organization

RAS - Recirculation Aquaculture System

SKC - Sibenik-Knin County

SME - Small and Medium-sized Enterprises

VUS - Sibenik University of Applied Science

WWF - World Wildlife Fund



Executive Summary

AZA4ICE project aims to trigger the transition to an **Inclusive and Circular Economy** in the aquaculture sector, fostering new business opportunities and eco-consciousness society or implementing an innovative ecosystem spatial planning approach embedded with circular practices-production systems in close-to-coast and inland waters. Lack of strategies for sustainable development and public sector's relevant low capacity, linear economy models traditionally used in aquaculture, complicated legal/licensing framework, as well as lack of dialogue between stakeholders and limited access to space are the main challenges jointly tackled in AZA4ICE through the **Allocated Zones for Circular Aquaculture (C-AZA)** instrument.

The present document has been implemented under the INTERREG Euro MED 2021- 2027 AZA4ICE project, in the framework of the activity "3.2. Delivery of Action Plans for the transition to Inclusive and Circular Economy in the aquaculture sector". This activity aims to develop a regional, multi-stakeholder-driven Action Plan that integrates circular aquaculture practices. It draws on the insights and methodologies developed through the project's **Living Responsible Research Innovation Ecosystems (LiRRIEs)**, ensuring the inclusion of diverse stakeholders and alignment with local needs.

This document emphasizes transferability and scalability, offering a flexible framework that can be adapted to other regions and sectors. Key outcomes include a well-defined methodology, effective stakeholder engagement, and mechanisms for long-term implementation and sustainability of the Action Plan. It serves as a practical guide for stakeholders involved in the transition to a sustainable, circular aquaculture system across the Euro-Mediterranean region and beyond.



1. Introduction

The transition to an Inclusive and Circular Economy in the aquaculture sector is essential for ensuring environmental sustainability, economic resilience, and social inclusiveness in the Euro-Mediterranean region. However, achieving this transition presents significant challenges, including regulatory fragmentation, resource limitations, and the need for cross-sectoral collaboration. Addressing these challenges requires a structured and coordinated approach, and this is precisely what AZA4ICE project aims to provide. This document presents a roadmap for implementing circular aqua practice in Sibenik-Knin County (SKC) by valorising the results of the AZA4ICE methodology testing actions in the pilot site of **Krka River estuary (Krka)** and the multi-participatory co-creative work carried out in the LiRRIEs in this Adriatic region.

Because of admissibility that this method offers, guides from this document can be adapted on the areas that have similar environmental characteristics as the pilot site Krka.

1.2 Scope and Objectives

Action plan was adopted based on the results of the activities carried out as part of the project. Each activity contributed to a certain aspect of the set topic, and all together contribute to the basis for the introduction of a circular aquaculture system in areas that have similar environmental parameters that are found in the pilot area of the Krka.

The activities carried out in the project were as follows:

- **D.1.2.1 Result of the testing in pilot site Krka River estuary** - The results were obtained based on one-year research conducted according to the AZA4ICE methodology to define the Allocated Zones for Circular Aquaculture (C-AZA) for defined pilot area. The results that were collected and evaluated for parameters such as - site suitability and species suitability, evaluation of suitable IMTA/RAS models and circular practices, presentation and evaluation of the results, and data evaluation through the stakeholders' involvement.
- **D.2.2.2 Report of the LiRRIEs** - Implementation description of the LiRRIE methodology that ensures stakeholder involvement and co-creation, making it a versatile mechanism that can be applied in other regions and policy domains.
- **D.2.3.1 Review on aquaculture legal/regulatory framework and licensing processes** - Analysis of the current legal/regulatory context and licensing processes that frame aquaculture development activities and relevant



innovative circular production systems (e.g. IMTA/RAS).

- **D.2.2.1 Identifying the circularity baseline with the BLUEfasma Circularity Self-Assessment Tool** - Socio-economic research between SME-s from local area from fishery and aquaculture sector with circularity self-assessment tools. The aim of questionnaire is to value their commitment to proceed developing their business in environment friendly management method.
- **D.3.1.1 Guide with circular aquaculture business practices and opportunities** - Document focused on circular economy principles, sustainability, zero-waste practices, and good environmental status. This template is designed to collect information from partner countries from the AZA4ICE project to support the development of the guide "Transitioning to Circular Aquaculture - A Guide to Sustainable Business Practices and Opportunities".

Within the various activities and processes carried out through the project implementation, the emphasis was on cooperation and communication as well as education of stakeholders through LiRRIE processes.

The Action plan will seek to detect shortcomings that were observed through the implementation of project activities such as:

- Legislative *framework* that is insufficiently adapted to circular practices in aquaculture sector.
- Lack of *active management* and *stakeholders' involvement* in conservation measures and environmental protection.
- Lack of *available data* needed to adapt the IMTA innovative model into the existing trophic marine system.
- Linear *waste management* in aquaculture sector.
- Lack of *infrastructure and technology* for circular processes in waste management and utilization of aquaculture by-products.
- Increase in *climate instability* and the accompanying negative consequences of these changes.
- Lack of *market* for circular economy products.
- Lack of *education, skills and dialogue* among the quintuple-helix model for stakeholders.
- Lack of *public information* about circular and inclusive economic activities.

This Action plan will try to cover all the listed shortcomings to set realistic goals for the introduction of circular processes in local and regional aquaculture practices.

Primarily, target audience for this Action plan is the **quintuple-helix** model gathering stakeholders from aquaculture sector, that were already identified and involved in the LiRRIEs workshops, which have been providing the participatory framework for stakeholder engagement in the project. Furthermore, studying this



document is useful for all those who are involved in the transition to an Inclusive and Circular Economy in the aquaculture sector. It can also be of use for **policy** and **regulatory bodies** shaping sustainability policies within the sector, because they play a crucial role in creating the enabling environment for circular economy practices. The **private sector** and in particular aquaculture **industry** stakeholders - including producers, processors and technology providers - are also potential users of these pages, since they are directly involved in implementing sustainable practices. Furthermore, **researchers** and **NGOs** with expertise in circular economy principles and aquaculture sustainability are encouraged to review this Action plan in search for latest knowledge, scientific achievements and best practices.

1.1.1 Location and Geographical Features of the Krka Estuary

The Krka River rises under the Dinara Mountain in the hinterland of northern Dalmatia and flows for 50 km through the North Dalmatian karst plateau (*Roglic, 1957*). Its canyon cuts through the Dinaric carbonate platform (*Herak, 1972*). The river has a complex underground course, and the basin area is 469 km² (*Bonacci and Ljubenkovic, 2005*). The average inflow of the Krka River is 48.9 m³/s at Skradinski buk (*Bonacci and Roje-Bonacci, 2017*). After Skradinski Buk, the water flows into the sea - it gently rests on the marine (dense) layer and creates a highly stratified estuary system (*Zutic and Legovic, 1987*).

Below the Krka River is estuary which is 22 km long and because of its specific protected landscape united with fish and shellfish farms we choose this area for our pilot site.

On a picture in *figure 1*. parts of the whole area are marked as:

E1 – the Krka River creates the naturally accumulated Visovac lake and seven travertine barriers, the last of which is the Skradinski buk, through which water flows at a speed of 48.9 m³/s.

E2 and *E3* - after Skradinski buk, the river flows into the sea, creating a highly stratified estuary system. This upper part of the estuary extends along the town of Skradin, widens into Lake Prokljan and continues to the canyon along the arm with the settlement of Zaton to the Sibenik bridge.

E4 and *E5* – lower part the estuary widens in Sibenik port. Such a division coincides with the sedimentation characteristics of the estuary (*Cukrov et al., 2010*). The St. Ante Channel continues to the Sibenik port, and the estuary ends at the fortress of Saint Nikola, where the axis of the St. Ante Channel intersects with the coastline of the Sibenik Channel.

The depth of the estuary gradually increases from 2 m at the head of the estuary to 42 m at its end.

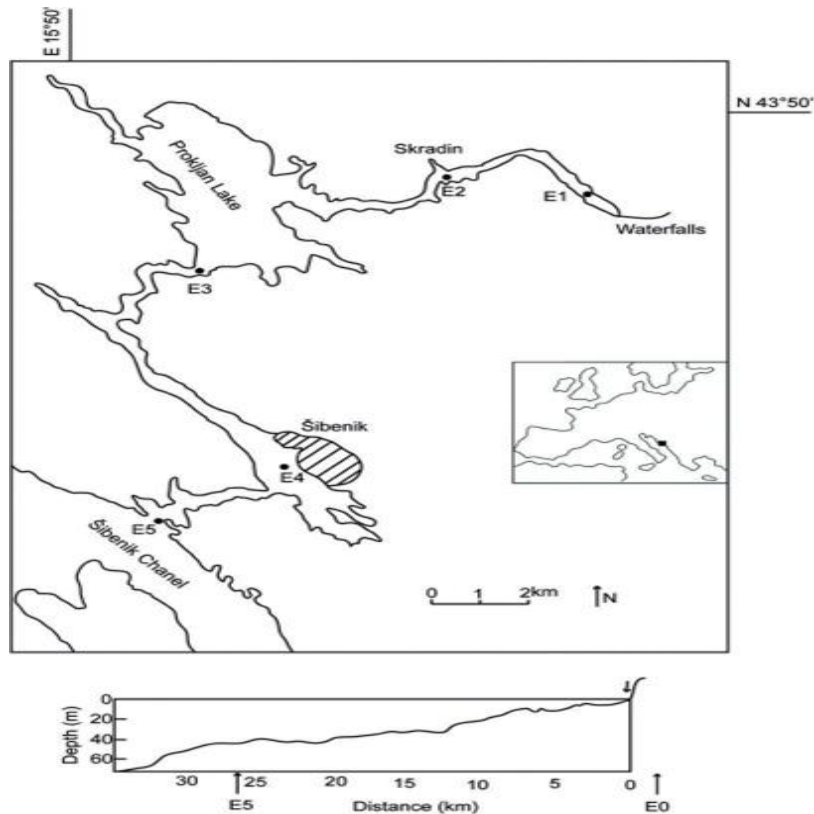


Figure 1. The provision of the Krka estuary from Skradinski buk to the fortress of St. Ante (Vilicic et al., 1989.)

1.2 Context

The pilot project area of Krka is located entirely within the administrative part of the city of Šibenik and extends through the areas of the settlements of Raslina, Zaton and Šibenik, while in the immediate vicinity, outside the project area, is the settlement or Municipality of Bilice. In all these inhabited areas live around 50.000 people.

Due to its characteristics, the pronounced stratification of nutrient-rich water in Krka area is a biologically very **productive ecosystem** and is an important spawning ground, nursery ground and feeding ground for numerous organisms, primarily fish.

Because of the large quantity of phytoplankton in the upper layer of the sea, the ecosystem has a high proportion of filter feeders.

Above the natural features, this entire area is suitable for **shellfish** and **fish farming**. The zone for growing shellfish consists of 54 fields and 6 fields for fishes.

Shellfish farming is particularly important due to the tradition and specificity of the area for mariculture activities.

According to the submitted national data, nine Estuary farmers are engaged in shellfish farming.

One company owns concessions whose total farming fields occupy almost 50% of the surface of the full cultivation area capacity. Other concessionaires carry out mussel farming in areas that occupy 10 - 15% of the total cultivation area (*Figure 2*).

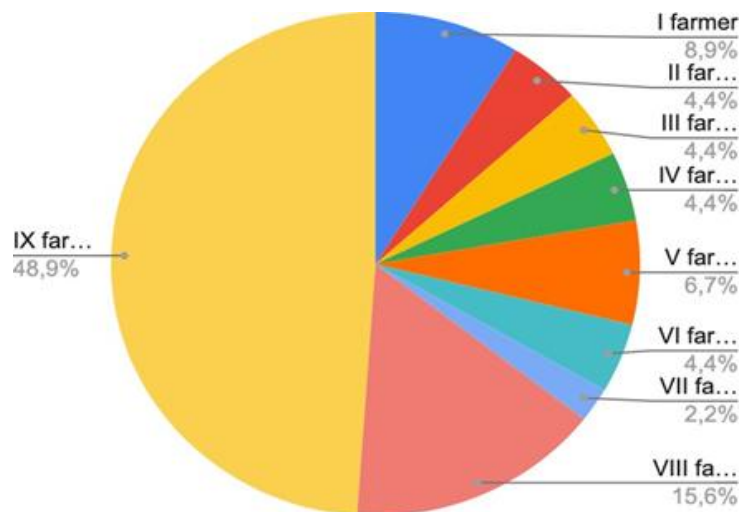


Figure 2. Size of farming areas in Krka River estuary (Zaninovic, 2022.)

In 2021, the potential maximum cultivation capacity is 3.691 t/year. However, despite the possibilities, production is declining according to the collected alternative data from the past years.

Krka is also protected in the category of **significant landscape** and all interventions in the space were carried out in accordance with the integrity and structure of the space.

Conservation of this protected landscape from the anthropogenic impact of established economic activities and pollution, can be reduced by **circular management** into all area activities. Due to the improved water quality and the additional source of food that IMTA provides for breeding organisms, it is also possible to increase the production of shellfish in the Krka pilot area.

Considering all necessary actions to improve activities in this area, in conjunction with communication with relevant stakeholders, the Action Plan will define guidelines for sustainable practices that can be replicated not only in the local area but also in areas with similar environmental, biotic characteristics and social conditions.



2. Roles and Responsibilities of the Key Actors

AZA4ICE develops a multi-level and multi-sectoral stakeholders' engagement methodology to be followed by PPs to set up cooperation patterns, the LiRRIEs. The methodology is built on **BLUEfasma Living Lab methodology (BLUEfasma)** enriched with Responsible Research Innovation-RRI (European Commission) principles following RRI Roadmap (MARINA project). Thus, AZA4ICE goes beyond Living Lab (LL) focusing on co-creation and co-decision of involved stakeholders based on a common vision to be drafted at LiRRIEs beginning. The stakeholders-members of LiRRIEs represent the Quintuple Helix model (a.k.a. academia - industry - government - civil society - environment) and several sectors (e.g. tourism) due to the co-existence of aquaculture with other economic operations.

Academia (Education System): Focuses on knowledge transfer, innovation, social-economic analysis and technology upgrading to reduce uncertainty.

Industry (Economic System): Accelerates innovation based on academic research, manages the adoption matrix of new products, and promotes eco-friendly solutions.

Government (Political System): Develops rigorous, transparent, and scalable science and innovation policies, and provides technology assessment for democratic decision-making.

Civil Society (Public/Media-Based): Highlights bottom-up innovations, promotes a culture of sustainability, and acts as a bridge for transparency and accountability.

Natural Environment: Acts as the context for eco-innovation, ensuring sustainable development, reducing negative environmental impact.

3. Regional Needs, Challenges and Opportunities

During the initial phase of the LiRRIE, exchanges with stakeholders were conducted to identify local needs, challenges, and opportunities. The key information gathered is summarised below.

Needs

- Better organize the market and independent performance skills of the farmers – education.
- Find a solution to reduce the grey and black markets.
- Developing marketing strategies.
- Given the possibilities of the production area, farming potential needs to be better managed to obtain larger quantities of consume shellfish.
- The introduction of strategic guidelines for sustainable aquaculture into the legislative framework, spatial plans and relevant, mandatory efficiency.



Challenges

- Maintain highly productive brackish area designated by the spatial plan for aquaculture - enables rapid growth of shellfish.
- Maintain stable quantity of juveniles of farmed species.
- Keep the tradition of aquaculture in estuary of Krka.
- Provide the infrastructure for indoor experiments through the local aquaculture facility – Centre for mariculture development – Alu-tech.
- Maintain good cooperation between 5- helix local public authorities, science, civil society, industry and the environment at the local level.

Opportunities

- Employment of local population by increasing production of farming species and by introducing new IMTA species.
- Better management of protected area of Krka.
- Development of farming a new species of shellfish (scallops, algae, sea cucumbers).
- Expanding the market by branding the Krka estuary as an ecological area (by introducing IMTA).



Figure 3. Krka River Estuary



4. Current legal/regulatory/licensing framework

4.1 Key legislative acts, regulations, and authorities responsible / involved

The national legal framework is composed of the main Law on aquaculture and additional regulations (*Appendix 1*).

The Law of Aquaculture (hereinafter defined as Law) (National newspaper number - 130/2017, 111/2018, 144/2020, 30/2023, 14/2024) is the main document on rules within the aquaculture sector. It is based on the documents of the Common Fisheries Policy of the European Union, the implementation of which is prescribed in the part related to aquaculture. The aquaculture in Croatia has a strategic economic value so it is part of many national strategic documents.

The Operational Maritime and Fisheries Program from the previous financial period (2016-2020) has now been renamed as **Programme for Fisheries and Aquaculture (2021-2027)** (hereinafter defined as Program). The Program is the main document which describes priorities and objectives chosen to be achieved through the implementation of structural policy measures in the aquaculture sector, co-financed under the EMFAF (European Maritime, Fisheries and Aquaculture Fund).

In the Law there are defined goals for aquaculture development and its economic, ecological and social role:

- a) improving the competitiveness of aquaculture and its sustainability in the socio-economic sense.
- b) increasing the total production in aquaculture while respecting the principles of economic, social and ecological sustainability.

Through a legal framework of the Law, the national goals of aquaculture development are determined, which are defined within **The National Development Plan for Aquaculture for the period up to 2027** (hereinafter defined as Plan).

Plan is proclaimed and planned from article 5. in Law of Aquaculture which prescribes the adoption of a multi-year national aquaculture development plan by the Government of the Republic of Croatia, and in accordance with Article 34 of Regulation (EU) no. 1380/2013 of the European of the Parliament and the Council of December 11, 2013 on common fisheries policy, amendment of regulations Council (EC) no. 1954/2003 and (EC) no. 1224/2009 and repealing Regulation (EC) no. 2371/2002 and (EC) no. 639/2004 and Council Decision 2004/585/EC (OJ L 354, 28 December 2013).

Within Plan 4 specific goals for the development of aquaculture are stated:

- 1) increasing productivity and resistance of production in aquaculture to climate change.



- 2) strengthening the competitiveness of the aquaculture sector.
- 3) by strengthening the aquaculture sector, contributing to the restoration of the economy and the improvement of living conditions in rural and coastal areas.
- 4) encouraging innovation in the aquaculture sector.

The competent authority for enforcement of this law is the **Ministry of agriculture** (hereinafter defined as Ministry). The **Directorate of Fisheries** is the part of the Ministry. It is a service which manages all the fishery and aquaculture activities, issues their permits, collects statistical data of the whole sector, manages and controls the implementation of structural policy measures of the Program.

The Ministry sets the criteria for convenience of parts of the maritime property to ensure the basic assumptions for determining areas for aquaculture. The spatial plans prescribe criteria for determining the suitability of parts of the maritime property, land and inland waters for the performance of aquaculture activities. Prior consent is granted by the Ministry responsible for environmental and nature protection, the Ministry responsible for construction and spatial planning and the Ministry responsible for maritime affairs.

The Department of Aquaculture, as part of the Directorate of Fisheries is a vital institution for managing affairs related to fishery and aquaculture. The administrative unit responsible for all these matters is the Service for Aquaculture. The Service's priorities are professional training for the performance of aquaculture activities, the approval of the performance of farming activities, and the issuance of permits for aquaculture.

Additional institutional support includes the activities of state administration bodies, local and regional self-government units, scientific organizations, professional institutions, providing services in aquaculture, chambers, associations, and aquaculture cooperatives and producer organizations recognized in accordance with special regulations.

Aquaculture is also defined through the **National Development Strategy of the Republic of Croatia until 2030**, as a sustainable development of the aquaculture sector through the improvement of aquaculture productivity in a climate-smart and sustainable way, with the application of new digital technologies and innovations, strengthening competitiveness sector and the contribution of the aquaculture sector to the development of the economy in rural and coastal areas, which is in accordance with the separate development directions of this document.

Summarising, the main challenges of new strategic documents are:

- competitive and innovative economy,
- ecological and energy transition for climate neutrality,
- food self-sufficiency and development of the bioeconomy,
- digital transition of society and economy,
- development of assisted areas and areas with development specificities,



- strengthening regional competitiveness.

4.2 Integration of IMTA and RAS in Legal / Regulatory / Licensing Contexts

In the new **Ordinance on Organic Agricultural Production** (OG 103/2024), as well as in the umbrella Regulation (EU) 2018/848 on which it is directly based, IMTA (Integrated Multitrophic Aquaculture) is not defined as a separate "bureaucratic term" but is regulated through the concepts of sustainable waste management and species synergy.

Here are the key segments in which these regulations encourage development of IMTA systems:

1. Wastewater and nutrient management

The Ordinance and Regulation require that each organic entity has a Sustainable Management Plan. In this sense, IMTA is listed as the preferred method because it allows the use of natural filters (such as algae and shellfish) for water purification.

It also directly responds to the requirement to "reduce nutrient discharges" because species from lower trophic levels (shellfish, algae) consume excess nitrogen and phosphorus generated by fish farming.

2. Polyculture farming and biodiversity

Although this is rare in conventional farming, in ecological terms IMTA is an ideal example because it encourages the use of different niches in the water column (fish in the upper part, bivalve molluscs on the sides, decapod crustaceans or echinoderms on the bottom). Farming systems must maintain a high level of biodiversity, which is the basis of the IMTA concept.

3. Animal nutrition

The regulation has a strict rule on food. In the IMTA system, this is regulated so that species that do not feed actively (such as bivalve molluscs and algae) must obtain food exclusively from nature (the ecosystem), which also includes organic residues from the fish part of the farm, thus closing the circle of the circular economy.

4. Monitoring of environmental impacts

In systems where multiple species are farmed (IMTA), the Regulation requires systematic monitoring of effluents. IMTA is treated here as a mitigation measure – if the farmer proves that the algae/bivalve molluscs effectively absorb waste, it is



easier to meet the strict ecological criteria on water quality that have become more rigorous in the 2024 version.

IMTA in the new Regulation serves as a practical solution to meet the obligations of "minimum environmental impact" and "circular use of resources", making it easier for the entity to obtain and maintain the eco-label.

The Ordinance on the Control System for Organic Farming (OG 110/22) (hereinafter defined as Ordinance) in Croatia establishes a framework for mandatory control, certification and registration in the Register for organic aquaculture operators, referring to New EU Organic Regulation 2018/848 for detailed production rules. The Ordinance lays down standards for the origin of animals, stocking density and feeding, while support for this sector is regulated by special regulations. This Ordinance rarely mentions the terms IMTA and RAS, but they are included in the broader framework of organic production and sustainable aquaculture. Regulation (EU) 2018/848, which this Ordinance implements, encourages sustainable polyculture and systems that mimic natural ecosystems.

The main problem with the current IMTA system (especially in Croatia) is that the legal framework still treats aquaculture through monoculture, while IMTA requires a polyculture approach. In addition, spatial plans generally provide for the cultivation of one. There is also a conflict of environmental and sanitary regulations, as shellfish are placed next to fish cages to filter excess nutrients (organic waste), and according to the Food Hygiene Ordinance (99/07), shellfish grown in close proximity to sources of potential pollution (which fish cages due to feces can be) may have problems with the classification of the area (Zone A, B or C), which makes it difficult to sell them for direct human consumption.

Problems also arise with other regulations that farmers are required to comply with when setting up farms, which are linear and not in line with.

4.3 Overview of licensing processes and authorities responsible / involved

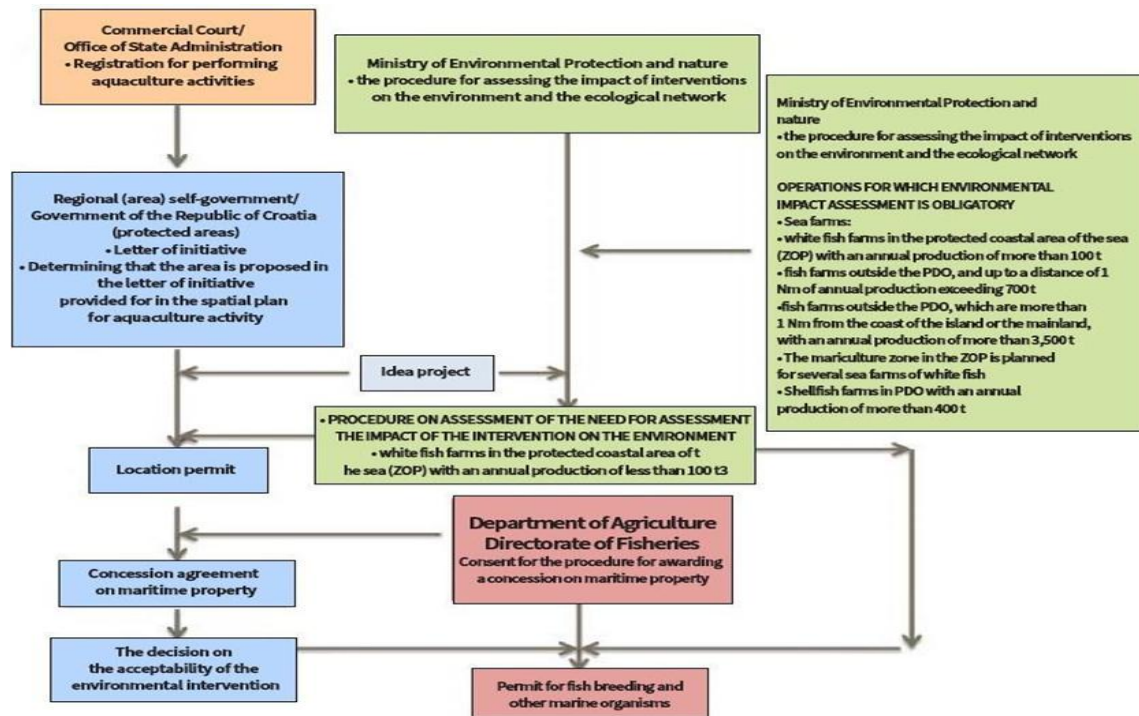


Figure 4. Procedure for issuing an aquaculture license (Directorate of fisheries, 2014.)

The criteria for determining areas for aquaculture on the maritime domain are defined by the national **Concession law** (No. 69/2017, 107/2020) and the other relevant regulations - Law on Maritime Property and Seaports (No. 83/2023), Regulation on the procedure for granting a maritime property concession (No. 10/2017).

The foundation for the success of aquaculture as a local economic asset is the choice of location and its protection, with all mandatory environmental measures assessed through an adequate study. The direct action of creating an aqua-cultural locality is a spatial plan. Aquaculture interventions in the area that are determined for this purpose are- the Spatial Plan of a County, the Spatial Plan of the City and the General Urban Plan of the City, the adoption of which is based on the Law on Spatial Planning (No. 67/2023).

In preserving the landscape environment, it is necessary not to change the environment's elements and maintain the natural state, so it is necessary to respect Council Directive 92/43/EEC on the conservation of natural habitats and wild fauna and flora and areas that are under Natura 2000. Furthermore, the spatial plan, among the general goals of the County's spatial development and planning, states the selective effect of mariculture following other users of space, so based



on these goals, localities suitable for the cultivation of fish, crabs and shellfish are determined.

Before the new location permit can come into force, it is necessary to make a procedure called an Assessment on the need to assess the impact of the process on the environment, a document for which the Ministry of Environmental Protection and Green transition is responsible. And above all the Environmental Impact Study needs to be prepared, which is prescribed by the Environmental Protection Law (No. 80/2013, 153/2013, 78/2015, 12/2018, 118/2018). The Study is the base document on which the competent Ministry of Environmental Protection and Green transition issues a decision allowing aquaculture activities in the area.

All this document can reveal the total capacity of all farms in the same area that is determined for aquaculture. Such capacity is conditionally determined with environmental protection measures and program for monitoring the state of the environment, breeding installations - floating parks, cages and facilities that must be placed within the farming zone.

The local government, County issues concession agreements, based on spatial plan and location permits which are determined for whole aquaculture area.

After the concession agreement was assigned to private entity, it can issue the aquaculture license from Ministry. Pursuant to Article 10, Paragraph 4 of the Law, the Ministry of Agriculture maintains the Register of Permits in Aquaculture, which is pursuant to paragraph 5. publishes the same article on its website. The content and manner of keeping the Register are prescribed by the **Ordinance on License for Aquaculture (No. 17/2018)**. (Figure 4.)

Obtaining a permit for IMTA (Integrated Multitrophic Aquaculture) in Croatia is a complex process because it requires the coordination of spatial planning, environmental protection, and specific permits for the cultivation of several different groups of organisms (e.g. fish and algae).

Due to the introduction of multiple species into production and the need to prove them, the technological study is very complicated, and it is difficult to prove clean sanitary conditions, even though IMTA is an environmentally sustainable system according to its principles.

4.4 Financing and Integration of Innovative Aquaculture Products in Legal / Regulatory / Licensing Contexts

Specific objective of the Plan is to encourage innovation in the aquaculture sector and through that the first goal is to increase productivity and resilience of aquaculture production to climate change:

Measure 1.1. Increasing investment in efficient and sustainable technologies in aquaculture



This measure will strengthen and support projects that focus on the use of climate-smart digital technologies and solutions in aquaculture that promote production and environmental sustainability, with priority given to projects that increase the profitability of aquaculture companies. In this context, priority will be given to projects that focus on investments in environmentally sustainable intensification of aquaculture production systems, combining intensive-extensive aquaculture systems, recirculating systems (RAS) or integrated multitrophic aquaculture (IMTA) systems, as guarantees for controlled farming conditions with a shorter production cycle that also ensures a safe product.

This objective of the Plan is also connected to the goals and relevant parts of the document Climate Change Adaptation Strategy for Realizing the Development Vision - A Republic of Croatia Resilient to Climate Change.

Within the Program, IMTA systems and organic farming are directly prioritized through specific measures and scoring criteria that give applicants a significant advantage.

Here are the key measures for aquaculture activity (among the others) and the ways in which additional points are obtained:

1. Measure II.10. "Aquaculture providing environmental services"

This measure is directly intended for entities that apply environmentally friendly methods and the IMTA uses natural filters like algae and bivalve molluscs to absorb nutrients that are treated as an environmental service, which allows beneficiaries to be compensated for additional costs or lost profits due to such a way of working.

2. Measure II.1. "Innovations in aquaculture"

This measure finances cooperation between scientists and growers. Special emphasis is placed on the development of a circular economy and reduction of the environmental footprint.

Projects focused on the development of the IMTA protocol (e.g. optimization of the cultivation of different species in the same location) are scored more because they contribute to the diversification and sustainability of the sector.

3. Measure II.2. "Productive investments in aquaculture"

Promoting sustainable aquaculture activities, strengthening the competitiveness of aquaculture production, while ensuring the long-term environmental sustainability of the activities.



5. The current status of aquaculture businesses

5.1 Circular Economy Maturity Analysis in Šibenik-Knin County

The survey was conducted on a sample of 9 key stakeholders, dominated by the fisheries sector (55.6%), while the rest are companies from aquaculture or mixed business. The results indicate a significant lack of strategic planning towards a circular economy. Although some entities have included the general term "sustainability" in their documents, only one company has the circular economy as an integral part of its business strategy. This result is a direct consequence of the low level of knowledge of the concept itself and the lack of understanding of how circular processes can be operationally integrated into everyday work (*Appendix 2.*)

A) Waste, Packaging and Resource Management

Materials management practices are still firmly rooted in linear models:

Packaging - None of the respondents use reusable packaging. Single-use plastic packaging prevails, while more environmentally friendly variants are rarely used.

Production waste - Although the sector generates large amounts of biological waste (shells, bones, leather, shellfish), only one test subject systematically processes this kind of waste.

Fishing and farming equipment - In fisheries, nets and ropes are repaired and reused to a small extent (up to 30%), except for one respondent who reaches 70%. In aquaculture, the only company that repairs cage parts (30%), while the others directly dispose of such equipment.

B) Quantitative assessment: "CE scale" and readiness to invest

Through a cumulative analysis of nine entities, the following average scores were obtained (*Figure 5*):

Position on the circular economy scale: 1.6

This low score confirms that the sector in the county primarily functions according to the classic "take-make-discard" model. The level of maturity is low, and the entities are only at the beginning of the transition.

Willingness to invest in CE: 3.2

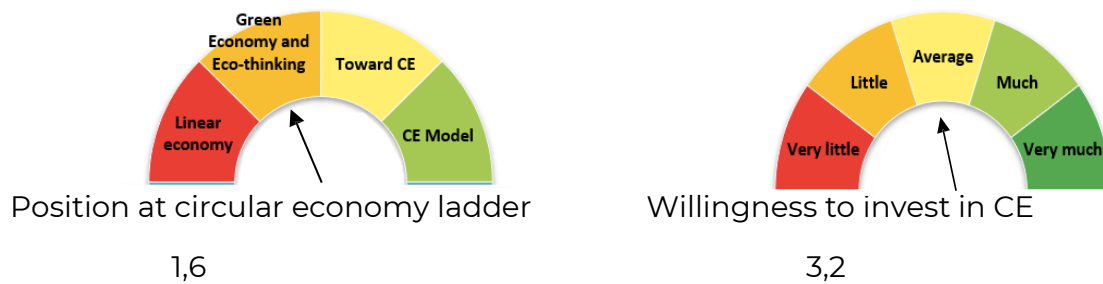


Figure 5. The average score of circular economy readiness and willingness of the companies in Sibenik-Knin County

The willingness to invest is rated as **average**. There is some interest in change, but it is not strong because companies do not yet see a clear economic benefit from circular innovations.

Currently, the circular economy in fisheries and aquaculture in Sibenik-Knin County is **underdeveloped**. The key barrier is not only the lack of capital, but primarily the **low level of awareness and knowledge**. The fact that companies do not recognize the concrete advantages of the circular model (such as reducing raw material costs or new sources of income from by-products) directly limits their motivation for more serious investments. Without targeted education and demonstration of successful models, the sector will remain trapped in inefficient linear processes.

6. Vision

The vision for LiRRIE in Croatia within the AZA4ICE project is to implement innovative, circular IMTA practices in the existing fish and shellfish farming within the Krka pilot area.

By encouraging collaboration between local stakeholders, farmers, public authorities, industry and academia, the project aims to improve aquaculture practices in circular IMTA processes to achieve environmental sustainability of the protected pilot area and to improve farming practices.

The near future LiRRIE vision:

- Changes of spatial plans have been made, and appropriate documentation has been prepared for the development of the necessary infrastructure and production of new species of aquatic organisms in the circular IMTA system.
- The pilot project of the IMTA system has been set up in a natural environment.



- Reduction of the amount of organic and inorganic waste in the environment.
- Introduction of innovative farming methods and breeding species (diversification of aquatic organism production).
- Improved social perspective on aquatic organism farming.
- Improvement of the resilience of the natural environment to climate change, and consequently increased resilience of cultivated organisms and with increasing rate of their production.
- Reduced transmission of diseases and parasites
- Sustainability of production processes and income from farming of additional species and increased production of traditional cultivated species in Krka.

The broader picture of the LiRRIE vision:

- Improved infrastructure required for research into new farming methods and opportunities.
- Research into innovative methods of spawning new organisms (lobster, sea urchins, algae, mussels).
- Amendment of national, regional and other regulations relating to the introduction of new production processes, necessary infrastructure and species.
- Finding markets for newly farmed products (established association of organic producers).

Descriptive vision:

Amendments and changes of spatial plans have been made, adapted to the results and recommendations of the AZA4ICE project guidelines with the possibility of establishing circular processes in aquaculture. The proposed plan has also been expanded according to the guidelines of the strategic document Coastal Plan of SKC and other strategic documents proposing sustainable economic development of aquaculture production processes. The production of existing farmed species (mussels, oysters) has increased due to improved and stable environmental conditions achieved by introducing new circular aquatic organism production systems (IMTA). New, commercial species of marine organisms (such as algae, sea urchins, sea cucumbers etc.) have been grown in the established circular systems. Due to increased primary production (caused by the installation of installations with primary producers of algae), improved cultivation of rarely cultivated species in the local area (such as scallop (*Pecten jacobaeus*) and carpet shell clam (*Ruditapes decussatus*) have been established. Experimental spawning of species necessary for introduction into circular practices systems (e.g. sea urchins, scallops or oysters) is carried out in a facility equipped for this. The newly formed association of ecological producers in cooperation with various scientific, public and private bodies invents marketing activities for new products on the local



and global market is setting the challenges and barriers for local aquaculture area and through LiRRIE communication and AZA4ICE action plan is trying to solve issues that are putted in front of them. The Krka becomes a brand for ecological and circular production area of aquatic organisms.

7. Potential of the C-AZA results

Project partner **Development Agency of Šibenik Knin County** in AZA4ICE were testing the project methodology which guided them to define Allocated Zones for Circular Aquaculture (C-AZA) (*Figure 6.*) The steps which are placed to encompass data collection were assessment of **site suitability** and **species suitability**, evaluation of **suitable IMTA/RAS models** and **circular practices** and **data evaluation**. All these steps are defined through the involvement of stakeholders in each part of the mentioned processes through LiRRIE workshops (*Appendix 3.*)

The basis of C-AZA results is one-year environmental monitoring and data collection in the Krka.

The “*species suitability*” was based mainly on the physiological tolerance range, technological culture development, the environmental characteristics of the water body considered, the market demand, regulatory requirements, and on the economic feasibility. The species suitability represents the baseline for the final step of the C-AZA methodology, the “*circularity suitability*” assessment.

Species that could be implemented in IMTA system in Krka pilot site and depths on which they should be placed in water column are defined because of all parameters for “*species suitability*”:

<u>Fed species:</u> <i>Dicentrarchus labrax</i>	- 20 m
<u>Suspension feeder:</u> <i>Ostrea edulis</i>	- 20 m
<u>Deposit feeder:</u> <i>Holothuria tubulosa</i>	- 20 m
<u>Inorganic extractive species:</u> <i>Ulva sp.</i>	- 2 m

A key point to keep in mind when elaborating future IMTA options in the Krka is that there are significant differences in farming conditions at different depths in the water column.

Surface waters should be reserved for low-salinity-tolerant species, preferably inorganic extraction species like *Ulva sp.* which enjoy prominent levels of sunlight, while other species should be moved below the oscillating halocline, which can sometimes be over 3 or 5 meters from surface.

Continuous monitoring system should be established at every 2 m from the surface for parameters such as temperature, salinity and chlorophyl. This kind of monitoring in the pilot area can be placed in environment to better determine the combination of technology and species that could be introduced like part of IMTA in this specific estuarine area.

Furthermore, some of the species' profiles can and should be updated over time. For example, new light was shed on *Ostrea edulis* salinity tolerance during the writing of this report, increasing the maximum to 60, and the optimal range to 20 – 50, which changed the species' SSI values by around 0.2 for the area.

Conditions between the different sampling points did not significantly differ, however obvious findings indicate that deposit feeders should be associated with farming of fed species because this is the location where the organic content of the sediment was highest. This is not a factor that was considered in the AZA4ICE calculations but should be considered in the future monitoring of this area.

The pilot Krka has extremely high aquaculture potential because current capacity allocated for aquaculture is not being used to its fullest for seashell production. The reason for this situation needs to be further investigated, and the increase in current capacity is not defined by this research. C-AZA result suggested diversification of species and production. The biggest innovation of this methodology would be to include inorganic extraction species and deposit feeders into IMTA aquaculture operations which can be carried out in this area, as fed species and suspension feeders are already present. However, only native species should be considered to incorporate into this new aquaculture system.

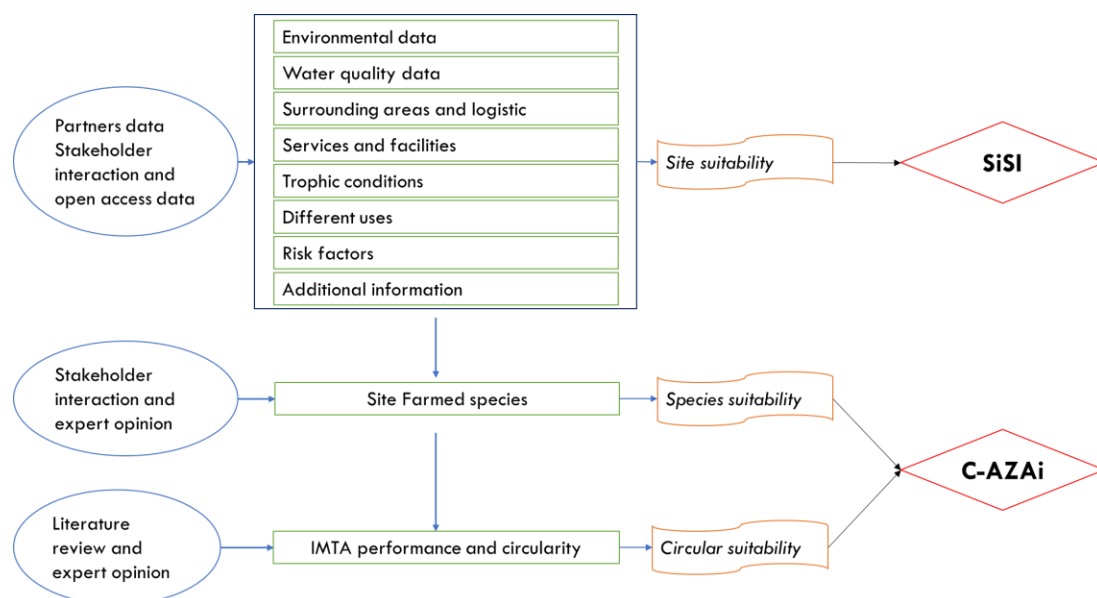


Figure 6. Methodological framework for AZA4ICE methodology implementation



Qualitative information related to SiSi, IPI (IMTA performance index) and ICI (IMTA circularity index) were difficult to complete due to site specificity or availability of information. It is something that could be explored further if the IMTA the system comes to life in this area, but for the current phase, we believe this research has served its purpose well.

The testing phase has been highly informative and strategic towards developing the site's potential for marine-based IMTA systems.

8. Proposed Actions

8.1 Key Actions and Interventions

As we have defined in the Chapter 1.1 Scope and objectives, there are several important challenges that define obstacles to the introduction of the Inclusive and Circular Economy in aquaculture pilot area and in Croatia in general.

This chapter deals with a more detailed analysis of these shortcomings and proposes adequate solutions to each of these problems:

- a) **Regulatory and policy challenges** (administrative burden and complexity)
The process for obtaining licenses and permits for aquaculture can be lengthy and complex. Currently, the legislative framework in Croatia is focused more on monocultures and planning the introduce IMTA in farming operations are mostly in conflict with local spatial plans. Investment costs in the innovative IMTA processes are high, but in a long-term profitable and more environmentally friendly than traditional cultivation, however, there is a lack of legal frameworks that would turn these advantages into financial incentives or a reduction in environmental fees for producers.

Problem solving: Addressing the regulatory and strategic challenges for introducing the IMTA system in Croatia requires an integrated approach that connects legal reforms, technological innovations, and cross-sectoral cooperation. Businesses and policymakers in LiRRIE processes have noted the need to streamline bureaucracy to facilitate innovation and investment what are the possible solutions for better circular inclusiveness of economic sector. To avoid a possible conflict of sectors that use marine space such as tourism, maritime transport and nature protection at an early stage, it is necessary to implement an integral approach to the management of the coastal area.

In most regions in Croatia definition of zones for aquaculture within maritime spatial planning needs to be more precise. Spatial plans in some regions are well out of date, and it is necessary to restructure them in favour of the expansion of areas related to innovative aquaculture if necessary.

**b) Lack of specific management plans for MPAs/Natura 2000**

While Croatia has a significant marine area covered by national designations and the Natura 2000 network (about 16% of territorially Adriatic Sea), many of these areas lack specific, detailed, and effectively enforced management plans. This can result in "paper parks" and limited protection of marine biodiversity in practice.

Problem solving: Conservation measures need to be more included in every sectoral plan for fisheries, tourism and maritime transport. Transition from designation to active management needs to be developed in detailed plans that involve local stakeholders (fishermen, tourism operators, and local communities). As of 2026, many sites have begun these processes through projects like "Development of management plans for Natura 2000".

c) Data collection

Persistent issue is the lack of reliable, real-time data collection systems across the sector. This gap in data on production, environmental impacts, and consumer preferences makes it difficult for policymakers to make informed decisions and businesses to optimize operations and marketing.

Problem solving: Standardizing data collection through platforms that are accessible and simple to understand to stakeholders from all sectors (activity planned in the Interreg strategic project BRAVE - "*Building Resilience and Adapting Values of the Adriatic Sea*", which is currently being implemented). Also, to obtain real socio-economic data, it is important to communicate with stakeholders from the fisheries and aquaculture sector and seafood consumers through workshops that include a quintuple helix approach, such was the LiRRIE workshop from this project.

d) Technology access and business structure challenges sector fragmentation

The Croatian aquaculture sector is composed of many small-scale companies, particularly freshwater and shellfish farming. This fragmentation makes cooperation difficult and investing capacity of these small organizations are also limited. The role of producers' organizations (PO) in aquaculture is crucial for market stability and strengthening the position of small growers. There are only few producers' organization in Croatian fishery and aquaculture sector for now.

Problem solving: There are few financial funds who can resolve this issue:

EMFAF is prioritized small-scale producers for grants targeting modernization and energy transition. This funding specifically aims to bridge the "investment gap" by subsidizing expensive technologies like Recirculating Aquaculture Systems (RAS) for freshwater farms and advanced waste management for shellfish operations.



Digital Innovation Hubs (EDIHs): Small-scale farmers are utilizing Croatia's EDIH network (e.g. EDIH CroBOHub++ and EDIH Adria) to access "test before invest" services. These hubs allow small farms to pilot smart monitoring systems - such as sensors for water quality and automated feeding - without the upfront capital risk.

PO allow small family businesses to pool resources for shared infrastructure, such as cold-chain distribution centres and joint marketing initiatives, which are critical for shellfish farmers who face high production costs. There is a trend also for science-industry partnerships which are very useful in solving gaps in small scale operation business. It is necessary to further encourage the establishment of such organizations within **Measure IV.1. "Production and marketing plans"** of the Fisheries and Aquaculture Programme, which are intended for POs. The state should provide larger advances for the operating costs of the cold storage facility (offices, employees) before the first sales start. It is also necessary to reduce the administrative hassles when establishing these organizations and offer full assistance within the bodies that assist stakeholders in their establishment (e.g. the Fisheries Administration, the Croatian Chamber of Commerce and Crafts).

e) Insufficient processing capacity

There is a lack of sufficient processing facilities and capacity to produce higher value-added products, especially for freshwater and some marine species. This forces producers to sell raw products at lower prices or face increased competition from processed imports.

Problem solving: Defining regional economic priorities and managing vertical integration in aquaculture requires a strategic shift away from the traditional, fragmented model towards a connected ecosystem. Local authorities that are directly linked to fisheries and aquaculture at the regional level play a key role in these actions. A Centre for mariculture development Alu-tech that has been established in SKC, currently offers purification and packaging of products to local shellfish farmers. The support of such facilities to small food producers needs to cover every aspect of their businesses with additional help of detecting the needs of new markets as well as realizing the competitiveness of these local small producers for better markets status.

f) Import dependence

The sector is highly dependent on imports for critical inputs such as fish fry/juveniles (e.g., seabass/seabream fry), specific feed ingredients, and advanced equipment.

Problem solving: Increasing the market required aquaculture production through changes of existing spatial plans aligned with vertical aquaculture integration development and strategic investments in local infrastructure.

**g) Environmental and operational challenges impact climate change**

This is a key and growing challenge. Rising sea temperatures, increased extreme weather events (floods and droughts affecting freshwater ponds), and ocean acidification increase operational risks and costs.

Problem solving: Constant monitoring that tracks environmental conditions in accordance with climate change and cooperation with the scientific community can help detect key challenges and adaptation to new situations. The results of monitoring can be of use for moving forward toward adaptive, "problem-solving" governance (like early warning systems, for marine heatwaves and relocating farms to deeper, more thermally stable layers within the stratified estuary).

h) Predation - fish-eating birds and predator fish (seabream at seashell farms) are an increasing problem for farmers, causing significant economic losses with a lack of effective, coordinated management strategies at the national or EU level.

Problem solving: There is technology for defence on fish predators (e.g. HNP protective sleeves for mussel socks or acoustic devices for deterrence of fish predators on shellfish farms or acoustic deterrents) or to encourage local commercial fishermen to do the fishing around area farms. There is also developed deterrent technology for bird defence, and it is also necessary to properly document the damage caused by predatory bird strikes due to the compensation offered by the state (ML-integrated cameras).

The IMTA is also a very good defence against predators, as a barrier and first defence system.

i) Lack of skills and expertise

There is a significant gap in the necessary skills and experience throughout various sectors to implement circular economy strategies effectively, including in design for disassembly, waste mapping, and circular business model management.

Problem solving: The education carried out in the AZA4ICE project through LiRRIE workshops brought the circular economy system closer to people in the sector through a process of communication with stakeholders, including the scientific community and local authorities. It is necessary to establish the education process as sustainable through sector mapping and constant education of the population and young people (e.g. through Erasmus or Life projects).

j) Limited consumer awareness and demand and lack of market

A knowledge gap exists at the consumer level, with low awareness of circular products' benefits and a lingering perception that reused or recycled items are of lower quality. Products such as aquaculture by-products often do not



have a clearly defined place on the shelves or in the industrial chain.

Problem solving: Regaining customer trust must be encouraged by introducing transparency into your marketing strategies. Certification and narrative are also options that need to be included when creating products to further attract customers. **Measure IV.3. Placing fishery and aquaculture products on the market** is support for activities aimed at improving conditions for placing on the market and promoting quality, added value and sustainability with the aim of exploiting the potential for placing on the market and branding high-quality fishery and aquaculture products.

8.2 Responsible Actors

LiRRIEs goal was to bring together stakeholders of **quintuple-helix** to increase their knowledge and skills, exchange experience and collaborate in drafting their vision and this Action Plan for the sector's transition thus, filling the lack of dialogue and blunting conflicts of different uses.

In the context of regional level of SKC, aquaculture and circular economy stakeholders from quintuple-helix are:

1. Academia (R&D and science)

Focus on the development of ecological solutions.

Institute for Oceanography and Fisheries (IOF)

The Institute is engaged in researching the complex interactions that shape the marine environment and tries to understand the functioning of the ecosystem to create measures, therefore it is crucial that this organization participate in the processes of establishing circular aquaculture in regional areas throughout Croatia.

Ruder Boskovic Institute (IRB) - Institute for Marine and Environmental Research

The Institute is a centre of excellence in fundamental and applied research into systems, processes and environmental conditions; therefore, its role is crucial in the interpretation of environmental parameters and defining the placement of circular systems in the marine environment.

Alu-Tech Development and Innovation Centre - Centre for Mariculture Development

The purpose of establishing the Centre is to advance and improve the quality and quantity of mariculture products in an environmentally sustainable manner, strengthen the knowledge and professionalism of shellfish and fish farmers,



develop innovation potential and encourage further processing, and improve the placement of mariculture products, especially Sibenik mussels, in Croatia and abroad. The Centre could play an important role in the further regional development for farmers who want to establish IMTA in their aquacultural practices through promotion of this circular system and further education in this direction.

Sibenik University of Applied Sciences (VUS)

Plays a key role in promoting the circular economy through the integration of sustainable practices into its study programs, scientific research work, and international projects.

2. Industry (Economic System)

The Croatian aquaculture industry is increasingly adopting circular economy models, turning biological waste into resources and optimizing production processes with the support of scientific institutions.

Cromaris

Cromaris has implemented advanced smart feeding systems that use underwater cameras, sensors and algorithms to precisely dose food according to the fish's appetite in real time. This technology is key to reducing food waste that falls to the seabed, thereby minimizing the nitrogen and phosphorus load on the ecosystem. They are pioneers in introducing circular bio-waste management in these areas and as such play an important role in educating others who want to introduce circular processes into their businesses.

By-product management companies

Focus on converting fish waste into high-value raw materials (e.g. fish meal or collagen). The role of by-product management companies in the future of Croatian circular production is transforming from "waste disposal" to biotechnological production of new values. (Sardina, Cromaris).

3. Government (national and local authority)

Creating a framework for the blue economy.

Ministry of Agriculture – Fisheries Department

The Ministry of Agriculture serves as the competent regulatory authority responsible for the strategic governance of aquaculture, encompassing the development of legislative frameworks, the issuance of farming licenses and concessions, and the administration of national and international subsidies to ensure environmental sustainability and food safety standards.

Local government (Sibenik-Knin County)



Sibenik-Knin County acts as the regional authority responsible for spatial planning and the management of maritime domain, specifically through the allocation of concessions for aquaculture sites and the implementation of environmental protection measures within its jurisdictional waters.

4. Civil Society (community and associations)

Education and advocacy for sustainable consumption.

WWF Adria

WWF Adria advocates for certifications such as the ASC (Aquaculture Stewardship Council), which highly values IMTA systems for their ability to reduce eutrophication (overfeeding of the sea).

They also educate consumers about the benefits of seafood through campaigns.

Sunce Association

Monitoring marine waste in cooperation with fishermen. They also connect nature protection with concrete data from the field through monitoring and promoting the circular economy, and advocates solutions that prevent chemical pollution.

The association participate in public debates on county spatial plans to ensure that aquaculture does not endanger NATURA 2000 areas.

Fishery cooperations Adria (Tribunj), Omega 3

Operational synergy cooperatives are key to the practical application of IMTA at the local level because IMTA can enable members of cooperative to develop secondary products (e.g. high-quality mussels) in addition to the primary catch/farming of fish.

Cooperative Omega 3 is focused on quality and standardization.

Cooperative Adria offers a wide range of marine products and services for small-scale fishermen and participates in environmental protection through various projects.

5. Natural environment (Ecological context)

Natural environment as a fifth pillar becomes an equal partner and end user of innovations.

This pillar presents the ecological imperatives that dictate the direction of innovation and further aquaculture development in Croatia.



8.3 Timeline

In this Action plan, we separated regional and local activities because we believe that there is a difference in coverage, precision of data and direct impact on the community. While regional indicators monitor broader trends and strategic goals, local indicators are focused on specific operational results and immediate needs of citizens.

In aquaculture, the setting of success indicators at the regional and local level differs significantly in terms of focus, type of data and end goal, although they are mutually complementary.

Planning regional activities that would lead to the improvement and the involvement of local and regional actors in the processes of circularity must be aligned with global trends to keep up with the fight against negative environmental changes.

The Decade of the Circular Blue Economy initiative (2026 – 2036) was formally launched and proclaimed by the World Ocean Council (WOC) in cooperation with international partners at major global summits. It is a strategic shift that brings together several key documents and policies that "meet" in 2026.

The key priorities for the aquaculture sector of this initiative are:

- [Regenerative Aquaculture and Blue Bioeconomy](#)
- [Circular Design and Product Life-Extension](#)
- [Digitalization and Digital Product Passports \(DPP\)](#)
- [Marine Waste Valorisation and Resource Recovery](#)
- [SME Support and Local Circular Hubs Development](#)

In Europe, all eyes are on the **Circular Economy Act** as the future framework law on the circular economy, due in the second half of 2026. It aims to increase the market's competitiveness and resilience by doubling the circularity rate by 2030, reducing dependence on strategic raw materials, and strengthening recycling supply chains, in line with the direction outlined by the Green Deal, and particularly the 2020 Circular Economy Action Plan.

Croatia, with the insignificant share of the blue economy in the national GDP of the EU Blue Economy Observatory, is recognized as a potential leader. The focus should be on moving away from mass tourism towards sustainable aquaculture and maritime innovation.

The definition of **regional activities** in time frame is shown in table (*Table 1.*) Their time settings are placed in accordance with the possibilities of national and international financial support that is described in next chapter.

**Table 1.** Timeline of the Action plan for implementing circular aquaculture practices at a regional level

Phase	Period	Focus	Main goal
I. Digital and eco-transition	2026. – 2028.	Risk reduction: Mass implementation of AI sensors for early warning of sea heat waves and ML cameras for monitoring predators (birds and predatory fish). "Smart" farms resistant to climate change. Framework adaptation and MSP adjustment to circular processes.	"Smart" farms resilient to climate change Adjusted regional spatial plans to new innovative and environmentally friendly aquaculture.
II. Integration and vertical growth	2029. – 2032.	Processing and IMTA: Expansion of Integrated Multitrophic Aquaculture (fish farming with algae and shellfish) for natural filtration and added value. Infrastructure and sectoral plans on long term strategic changes according to circular innovation systems settings.	Reducing ecological footprint and dependence on imported aquaculture products. An integrated approach to strategic planning at the regional level.
III. Complete circularity	2033. – 2036.	Zero Waste & Branding: Establishment of regional centres for processing by-products into pharmaceutical raw materials and biofertilizers.	100% utilization of biological waste and recognition on the EU market.

Priority actions on a local level of SKC, pilot area Krka:

a) Reform of spatial plans

Urgent determination of new locations for aquaculture that would be harmonized with new sectoral policies and adapted to climate change, as well as the introduction of polyculture (IMTA) farming within certain existing location permits.

b) Operationalization of Natura 2000

Completion of management plans that include fishermen and aquaculture farmers as custodians of nature and not just as users, thus eliminating "paper parks".



c) Setting local sectoral priorities and vertical integration in aquaculture

The determination of priority economic activities at the local level must be based on comparative advantages in aquaculture. Diversification of breeding species is selected regarding locational characteristics and the secured market. After the adjusted regulation, the circular principles in aquaculture, the species that participate in these processes and the waste by-products of this type of economy must also be taken into the integration process. It is necessary to invest in logistics and distribution centres that would be gravity points for small growers (in SKC, such a concept can be part of the **Centre for Mariculture, Alu-tech**).

Vertical integration implies the control of several stages of the value chain in aquaculture. Such values are defined through 3 levels which are shown in the following table (*Table 2*).

d) Sectoral organisation as a Hubs and encouraging the establishment of producer organizations

Building on the previous activity it is necessary that the aquaculture facilities are transformed into a regional logistics terminal for small producers, providing them with all the support to establish environment friendly circular practices. The determination of regional priorities must be defined in such a way that regions rely on each other and complement each other in terms of the aquaculture activities for which they have been predestined.

e) Education

Integration of the curriculum on circular design and waste management in secondary vocational schools and colleges through Erasmus+ projects or other funds.

Table 2. Vertical integration in aquaculture on a local level

Integration Level	Description	Objective / Goal
Backward Integration	Control over the production of shellfish/fish juveniles and fish feed .	Reducing dependence on imported inputs and price fluctuations.
Horizontal Integration	Linking small-scale producers into cooperatives or clusters .	Achieving economies of scale and collective market presence.



Forward Integration	Establishing in-house facilities for processing, filleting , and direct sales channels.	Retaining added value within the region instead of selling raw materials.
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8.4 Financial aspects and Funding resources

Although the initial investment in circular systems is high, the return on investment comes through:

- a) **Increased efficiency** - Reduced fish mortality and optimized feed consumption.
- b) **Reduced operating costs** - Energy efficiency of RAS systems and reduced import dependency.
- c) **Premium prices** - Consumers are willing to pay more for products with transparent, circular certificates.
- d) **Waste valorisations** - Converting the cost of waste disposal into revenue (fishmeal, oil, collagen).

1.) European Funds (Financing Framework)

These are the most important sources of grants, aligned with the EU Green Deal:

European Maritime, Fisheries and Aquaculture Fund (EMFAF) 2021-2027

- **Priority** - Subsidizing expensive but circular technology. Funds are directed towards small producers for modernization and energy transition.
- **Specific** - Funds Recirculating Aquaculture Systems (RAS), advanced waste management systems, and investments in ports for receiving marine litter ("Fishing for Litter").

National Recovery and Resilience Plan (NRRP) - Funds focused on digitalization and green transition, often through vouchers for digital services.

Competitiveness and Cohesion Programme - Funding larger infrastructure, such as the SKC Aquaculture Centre or regional by-product processing centres.

EU Programs Horizon Europe and LIFE - Sources of funding for scientific research, development of innovative defence technologies (e.g. HNP protective nets against predators) and pilot education projects (such as AZA4ICE).

2.) Innovative financial mechanisms and partnerships

In addition to direct support, other mechanisms also play a key role:



EDIH Network (European Digital Innovation Hubs)

They offer the "Test Before Invest" model. Small farmers use the services of EDIH Adria and EDIH CroBOHub++ for free testing of smart sensors for monitoring farms before committing to a full investment.

This significantly reduces the initial capital risk.

Loans from HBOR and HAMAG-BICRO

Favourable credit lines and guarantees for investments that banks may consider too risky.

3.) Successor to the EMFAF (EMFAF post-2027)

The new fisheries fund is announced to focus on:

- **Blue Innovations** - Financing the transition to zero-emission vessels (hydrogen, electric propulsion).
- **Regenerative aquaculture** - Direct support for systems that "heal" the sea, such as algae and shellfish farming under the IMTA system.
- **Climate resilience** - Funding to move cages to deeper sea layers and protect against extreme weather events.

4.) Modernisation Fund and EU Innovation Fund

These funds, financed by revenues from emissions trading (ETS), are becoming more accessible to the fisheries sector:

- **Circular drives** - Building regional factories to process fish waste into biofertilizers and cosmetics.
- **Decarbonising the cold chain** - Solar energy and smart storage in ports and packing centres.

5.) "Blue Invest" and private capital

The EU BlueInvest platform will become the main bridge to private investors:

- **Venture Capital for BlueTech** - For startups developing ML-sensors for predators or biodegradable fishing gear.
- **Guarantee schemes** - InvestEU will enable small-scale farmers to obtain loans with minimal interest for transition to circular business models.

6.) Local development (FLAGs 3.0)

Local action groups in fisheries will be given greater powers for:

- **Short supply chains** - Financing local fish markets using digital platforms for direct sales (eliminating intermediaries).
- **Education centres** - Sustainability of projects like AZA4ICE through permanent centres for educating young about the blue economy.



7.) National sources (Environmental Protection and Energy Efficiency Fund)

The Croatian fund (FZOEU) will have specific lines after 2027 for:

- **Marine litter removal** - Co-financing equipment for fishermen participating in "Fishing for Litter" actions.
- **Rehabilitation of "ghost gear"** - Funding for finding and recycling lost networks.

9. Monitoring and indicators

9.1 Success Indicators

Regional level indicators are represented in this section (*Table 3*).

Phase I: Digital & Eco-Transition (2026–2028)

Focus: Resilience, Risk Mitigation, and Early Adoption.

Percentage of digitalization: Number of farms equipped with AI sensors and ML cameras compared to the total number of active concessions.

Reduction of losses (Climate Resilience): Decrease in fish mortality rates caused by heat waves by X% thanks to early warning systems.

Administrative progress: Number of counties that have adopted modified spatial plans (MSP) with defined zones for circular aquaculture.

Phase II: Integration & Vertical Growth (2029–2032)

Focus: Resource Efficiency and Ecosystem Services.

IMTA coefficient: Share of IMTA systems in total national production (target: replacing monoculture systems with polycultures).

Bioremediation effect: Amount of nitrogen and phosphorus absorbed from the system by algae and shellfish (measured per ton of fish produced).

Reduction of import dependency: Increase in the share of domestically produced juveniles and aquaculture feed on the market.

Integrated strategic documents: number of documents implemented

Phase III: Complete Circularity (2033–2036)

Focus: Waste Valorisation and Market Positioning.

Zero Waste Index: The percentage of biological waste that is processed into secondary raw materials (target: 100%).



By-product value: Income generated by the sale of raw materials for the pharmaceutical industry and bio-fertilizers from aquaculture waste.

Branding and market position: Number of products with the "Circular/Eco-Brand" certificate placed on the EU market with a premium price.

Table 3. Target value of KPI for implementing circular aquaculture practices in regional areas till 2036

Category	Success indicator	Target value (2036.)
Technology	Farm coverage with AI/ML systems	> 90%
Ecology	Reduction of carbon footprint per kg of product	- 50%
Economy	Utilization of biowaste	100%
Area	Zones dedicated exclusively to IMTA/Circular	Integrated into all MSP

We define indicator of success (KPIs) for each local priority actions:

1. Reform of Spatial Plans

- Number of newly designated aquaculture zones harmonized with climate adaptation data and sectoral policies.
- Percentage of active concessions updated to permit polyculture farming (IMTA - Integrated Multi-Trophic Aquaculture).

2. Operationalization of Natura 2000

- Approval status of Management Plans that formally define fishermen/aquaculture farmers as "nature custodians" with active monitoring roles.
- Number of collaborative conservation projects launched jointly by protected area managers and local producers to eliminate "paper parks."

3. Local Sectoral Priorities & Vertical Integration

- Number of diversified species (e.g., seaweed, new shellfish types) commercially introduced based on site-specific advantages.



- Operational status of a Logistical/Distribution Hub (e.g. Alu-tech Centre integration) measuring the volume of products processed from small-scale growers.
- Tonnage of aquaculture by-products diverted from waste streams into circular economy processes (e.g., shell recycling, nutrient recovery).

4. Hub Organization & Producer Organizations (PO)

- Number of officially recognized Producer Organizations (POs) established to share regional logistics and environmental infrastructure.
- Level of regional complementarity, measured by the number of joint supply chain agreements between Krka area producers and neighbouring regions.

5. Education

- Number of new curricula modules on circular design and waste management implemented in vocational schools and University of Zadar or local Sibenik colleges (VUS).
- Total funding secured via Erasmus+ or EU maritime funds for sectoral workforce upskilling.

9.2 Follow-up and Adjustment

Every year in the fourth quarter (Q4), an audit is conducted according to the following matrix:

Table 4. Follow-up and adjustment of regional level KPI

Phase	Follow-up	Adjustment
I. Phase (2026– 2028)	The effectiveness of AI systems in predicting fish mortality during heat waves.	If mortality does not decrease (KPI < X%), we adjust the depth of the cages or introduce aeration systems.
II. Phase (2029– 2032)	Laboratory analysis of the sea (nitrogen/phosphorus) to confirm the real bioremediation effect of IMTA.	If algae do not absorb enough nutrients, we change the species ratio (e.g. more algae compared to fish) or the type of fry.
III. Phase	Market price analysis of "Eco-Brand" products compared to standard	If the market does not pay a premium price, we redefine the marketing



(2033–2036)	products on the EU market.	strategy or change the final product (e.g. more pharmaceutical raw materials).
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Instead of waiting for the end of the year, certain events trigger an immediate change in strategy:

- If the "Climate Resilience Index" falls below 60% during a heat wave, the priority shifts from growth to the immediate installation of deep cooling/aeration systems.
- If the price of AI sensors drops by >40%, the Sensor Coverage Rate is accelerated from the planned 50% to 100% in one year.
- If the European Commission tightens nitrogen rules, Nutrient Recovery Rate becomes the primary KPI instead of the secondary one.

Table 5. Follow-up and adjustment of local level KPI

Priority Action	Key Performance Indicator (KPI)	Suggested Target (by 2027/2030)	Data Source / Verification
1. Spatial Plan Reform	Number of newly designated aquaculture zones harmonized with climate/sectoral policies.	Min. 2-3 new/ revised zones	Official Gazette of Sibenik-Knin County
	% of active concessions updated to permit polyculture (IMTA) .	30% of existing sites	Ministry of Agriculture / County Concession Registry
2. Natura 2000 Ops	Approval status of Management Plans defining farmers as "nature custodians."	100% Approval for Krka/Estuary plans	Public Institution "Nature" of ŠK County
	Number of collaborative conservation projects (farmers + managers).	Min. 2 pilot projects	Project contracts / Monitoring reports
3. Local Priorities	Number of diversified species commercially introduced (e.g. seaweed).	2 new species in commercial trial	Site-specific biological reports
	Operational status of Logistical/Distribution Hub (Alu-tech/Mariculture)	Fully operational (serving min. 5-10 small)	Hub annual business report



	Center).	growers)	
	Tonnage of aquaculture by-products diverted to circular economy.	50 tons/year (e.g., shells for calcium/substrate)	Waste management logs / Circular economy audit
4. Hub & POs	Number of officially recognized Producer Organizations (POs) established.	1 newly formed PO	Registry of Producer Organizations
	Number of joint supply chain agreements between Krka and neighboring regions.	Min. 3 inter-regional agreements	Signed MoUs or commercial contracts
5. Education	Number of new curricula modules on circular design/waste management.	2 specialized modules	School/University (VUS) curriculum plans
	Total funding secured for workforce upskilling (Erasmus+/EMFAF).	Min. €250,000	Grant Award Decisions

10. Conclusion

Introducing circular processes into regional and local aquaculture is not only an **ecological imperative**, but also a **strategic opportunity** to increase the competitiveness of the Croatian coastal region. Such an approach represents a civilizational shift from the linear "take-use-discard" model towards a regenerative system that protects the Adriatic ecosystem. By identifying key challenges, this paper confirms that the solution does not lie in isolated technologies, but in **institutional support** and **vertical integration of small producers**.

Synergy through the Quintuple Helix model is the key to success, which lies in the integration of science, industry, local authorities, civil society and environmental standards.

All stakeholders must play a key role, and in the beginning, local and national authorities are particularly important, as they must review the **readiness to implement circular processes** in their strategies and legislative frameworks. Science must be a constant **support** for stakeholders in the aquaculture sector.

Workshops such as LiRRIE have shown that **horizontal linking of stakeholders** into PO or similar association directly addresses the problem of sector



fragmentation and lack of skills.

A technological leap as a solution of real-time digital data monitoring and advanced predator protection systems enables the transition from reactive to proactive and **adaptive management**. This directly mitigates the risks of climate change and operational losses.

Local self-sufficiency and value can be reached by defining economic priorities and with vertical integration carried out in aquaculture sector. This approach **reduces region dependence** on imports and ensures **retention of added value** within the local community.

Aquaculture facilities organized after the integral connectivity within the sector and sectoral organizations of producers can become hubs of **knowledge transfer** and **stimulation of innovation development**, and not just places of production.

Introducing transparency into marketing and consumer education is key to **long-term sustainability**. Only when the end customer recognizes the "**circular product**" as top quality, the transformation process will be complete.

The transition to a circular blue economy by 2036 requires courage in debureaucratization and consistency in the application of management plans for Natura 2000 areas. The regional approach, tested through pilot projects, serves as a replicable model for the rest of the Adriatic, turning ecological defaults into **economic advantages**.



Annex 1 – Key legislative acts, regulations, and authorities responsible/involved

Applicable Legislation:

- Aquaculture Law (No. 130/2017, 11/2018, 144/2020, 30/2023, 14/2024)
- Ordinance on the Register of licenses for the use of alien and locally absent species in aquaculture, the Register of Imports and Transfers and the List of Closed Aquaculture Facilities (No. 10/2018)
- Ordinance on License for Aquaculture (No. 17/2018)
- Ordinance on Professional Training for Aquaculture Activities (No. 56/2018)
- Ordinance on Criteria for Establishing Areas for Aquaculture on the Maritime Domain (No. 106/2018)
- Ordinance on the collection of statistical data on aquaculture: (No. 137/2021, 87/2022)
- Ordinance on approval for performing aquaculture activities on family agricultural farms (No. 15/2019)
- Ordinance on the disposal of tuna farming capacity and permitted input quantities of caught wild tuna (*Thunnus thynnus*) to farms: (No. 22/2021, 9/2022, 8/2023, 9/2024, 30/2025)
- Ordinance on labelling of farming installations, monitoring of operations on farms and traceability during bluefin tuna farming (*Thunnus thynnus*) (No. 63/2022, 46/2025)
- Ordinance on Registry of aquaculture vessels (No. 61/2023)

Regulations:

- National plan for aquaculture development for the period until 2027 (NPRA 2027)

Authorities responsible/involved:

- Ministry of Agriculture (MA)
- Directorate of Fisheries (DoF) of the Ministry of Agriculture
- Sibenik-Knin County

Licensing process (Ordinance on License for Aquaculture no. 17/2018):

1. Submission of an application for the issuance of a permit for aquaculture
2. Issuing a permit for aquaculture
3. The Ministry of Agriculture enters the license in the Register

Applicable Legislation for Licencing:

- Aquaculture Act: (No. 130/2017, 11/2018, 144/2020, 30/2023, 14/2024)
- Ordinance on License for Aquaculture (No. 17/2018)
- Concession law (No. 69/2017, 107/2020)
- Law on Maritime Property and Seaports (No. 83/2023)



- Regulation on the procedure for granting a maritime property concession (No. 10/2017)
- Law on Spatial Planning (No. 67/2023)
- Environmental Protection Law (No. 80/2013, 153/2013, 78/2015, 12/2018, 118/2018)

IMTA implementation important documents:

- Ordinance on Organic Agricultural Production (OG 103/2024)
- Ordinance on the Control System for Organic Farming (OG 110/22)
- Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007

National financing measures:

- Programme for Fisheries and Aquaculture of the Republic of Croatia for the period 2021-2027
- Measure II.1. Innovations in aquaculture
- Measure II.2. Productive investments in aquaculture
- Measure II.5. Advisory services in aquaculture
- Measure II.6. Compensation for damages from predators in aquaculture
- Measure II.7. Increasing the potential of localities for aquaculture

Annex 2 – Result of the BLUEfasma

Diagrams in this part summarize the answers received on the specific questions of the tool. This enables us to measure the level of circularity in Šibenik-Knin County in a qualitative way.

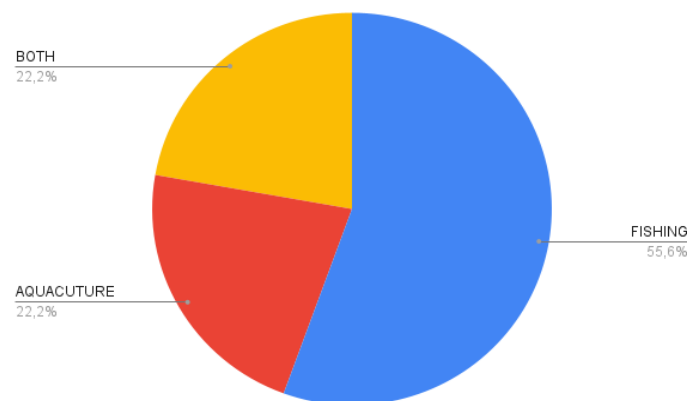


Figure 7. Status of interviewed shareholders

Among the interviewed shareholders majority are from the fishing sector (55,6%). Aquaculture represents about 22,2% farmers and 22,2% are spread in both sectors (Figure 7.). There were only 9 representatives who were willing to be a part of this questionnaire.

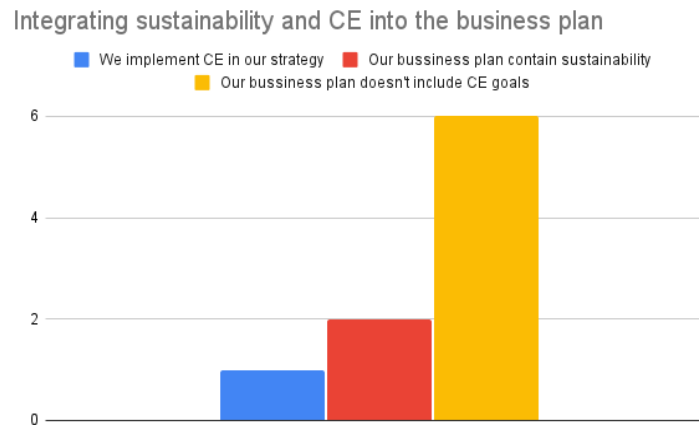


Figure 8. Integrating sustainability and CE into business plan

Most of the stakeholders haven't integrated CE in their business document but few of them have implemented sustainability. Only one company has CE incorporated in their business strategy (Figure 8).

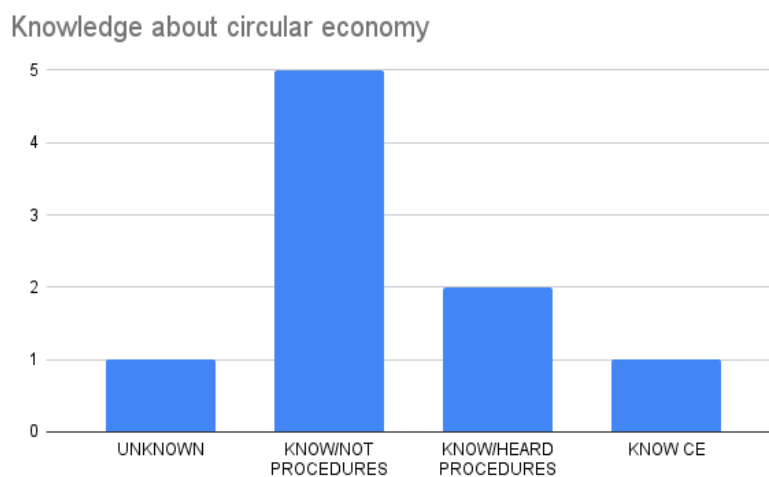


Figure 9. Knowledge about circular economy

Perhaps such an attitude towards innovative circular processes is because only a small number of respondents know CE well, and even fewer understand how such processes could be integrated into their work activities (Figure 9).



Figure 10. Type of packaging used to store goods

That is why the result of type of packaging investigation doesn't surprise, revealing that none of interviewed beneficiaries are using reusable containers. Mainly they use single-use or eco-friendly packaging (Figure 10).

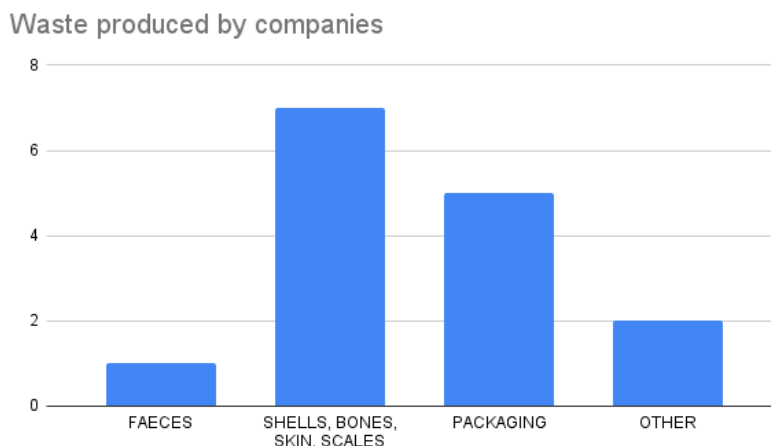


Figure 11. Waste produced by companies

When it comes to waste most stakeholders produce waste like shells, bones, skin and scales, but only one company, co-operative Adria, really processes production waste systematically. Packaging presents also a big part of the waste. Both feces and others represent smaller amounts of waste (Figure 11.).

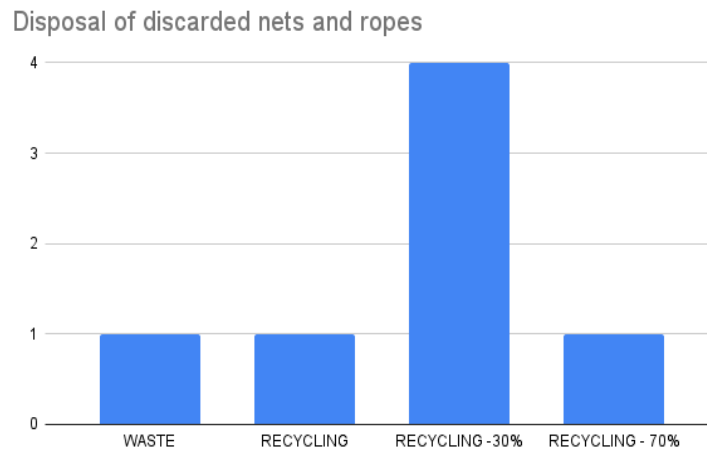


Figure 12. Disposal of discarded nets and ropes

Since most respondents are from the fishing sector, most of the waste that needs to be disposed of is nets and ropes, and most respondents repair and reuse up to 30% of such waste. Only one respondent reuses his nets and ropes around 70%.

Within the aquaculture sector, only the company Seashell repairs 30% of discarded cage parts, the rest discard them directly as waste.

Most companies mainly dispose of other solid waste (mainly plastic) in containers with sorting (Figure 12.).

Generalized level of circularity

Cumulative analysis is final analysis of the circularity level at the territory of Sibenik-Knin County. Results for individual companies are provided in the table below (Table 6.):

Table 6. Position at CE ladder and willingness to invest in CE for SKC stakeholders

Name	Position at CE Ladder	Willingness to invest in CE
Adria	1,9	4,3
Blitvenica	1,5	3,4
Fishing with Frankie	1,5	3,5
Hippocampus	1,9	3,2
Fish Maris	1,5	3,3
Nanini	1,4	2,9
Sinisa Pauk	1,2	2,8
Platforma 022	1,8	2,8
Seashell	1,7	2,8
TOTAL	1,6	3,2

The average score of circular economy readiness for Sibenik-Knin County is 1.6. This

suggests that fishing and aquaculture sectors of Šibenik-Knin County operate on principles of classical linear economy model. It can be thus concluded that the level of readiness for circular economy is low. The situation is not much better if one observes the willingness of companies to invest in circular economy. Average score on this item was 3.2 which puts it in the rank of average openness towards investment in circular economy.

Overall, what this tells us is that in Šibenik-Knin County the circular economy is underdeveloped and there is little awareness about the benefits it brings to companies. The fact that companies are not aware of circularity directly translates into their willingness to invest in this issue.

Annex 3 – Data collection from D 1.2.1 Results of the test



Figure 13. Sampling points at the Krka River estuary pilot site (source: Google maps)

Field measurements were performed at three sampling points within the pilot area (Figure 13.). Samples were taken at two depths (2 m and 20 m) at each of the sampling stations once per month over a period of 12 months (September 2024. - September 2025.).

Sampling station 1 was close to the oyster and mussel farm Bivalvi ltd. (43.739681, 15.876003), sampling station 2 was close to the oyster and mussel farm Platforma 22 ltd. (43.758297, 15.858078) and sampling station 3 was close to a finfish (seabass



and seabream) farm Seashell Ltd. (43.769643, 15.847710). These stakeholders collaborated in the sampling processes and communicated with experts through Lirrie's workshops.

The following parameters were measured at each depth: sea temperature, salinity, pH, dissolved oxygen (DO), turbidity, chlorophyll, ammonia (NH₄⁺), nitrites (NO₂⁻), nitrates (NO₃⁻), phosphates (PO₄), total suspended solids, organic fraction of suspended solids, while organic content of the sediment was measured in triplicate for each location.

Water samples were taken using a Standard Water Sampler acc. to Ruttner of 1000 ml (HydroBios, Denmark). **Temperature** and **DO** were measured using a handheld probe with 20 m cable (Oxyguard Polaris). **Salinity** was measured in water samples collected by the sampler using an analog refractometer *in situ*.

Turbidity, chlorophyll and **pH** were measured in water samples collected by the sampler in a wet lab using the Manta Plus 35 Water Quality multiparameter probe (Solinst, Canada).

A liter of seawater collected by the sampler was stored in a dark bottle and refrigerated before analyzing nutrients the same day. **Ammonia, nitrites, nitrates, and phosphates** were analyzed using a PF-3 Fish Photometer (Machery-Nagel, Germany) and VISOCOLOR ECO rapid test kits. **Dissolved inorganic nitrogen** (DIN) was calculated as a sum of the measured nitrogen-based nutrients.

For analysis of **total suspended solids** (TSS) and **total organic solids** (TOS), 1000 ml of seawater in triplicate was analyzed from each depth. The samples were stored in dark bottles and refrigerated until laboratory analysis. Each 1000 ml of seawater was filtered through an MGC filter using a vacuum pump under low pressure. The filters with the contents were dried in a pre-heated drying oven at 100°C until constant mass (24 hours). They were then weighed on an analytical scale (precision 0.001 g). TSS were measured using the formula:

$$\text{TSS} = \text{mass of dry filter} - \text{mass of clean dried filter} \text{ [mg/l]}$$

The weighed and dried filters were then ashed in a muffle furnace (pre-heated to 450°C) for five hours. The cooled filters were weighed again on an analytical scale. TOS were then measured according to the formula:

$$\text{TOS} = \text{mass of ashed filter} - \text{mass of clean ashed filter} \text{ [mg/l]}$$

Organic fraction of particulate matter (f) was calculated as:

$$f = \text{TOS} / \text{TSS} \times 100 \text{ [%]}$$

The **organic fraction in sediment** was measured using the Loss of ignition (LOI) method. Sediment samples were taken for each sampling station in triplicate using a 250 cm² Van Veen Grab (KC Denmark A/S, Denmark). Samples were shortly refrigerated and then frozen until analysis. Ceramic cups with sediment were dried the filters with the contents were dried in a pre-heated drying oven at 100°C until constant mass (24 hours). They were then weighed on an analytical scale (precision 0.001 g) and ashed in a muffle furnace (pre-heated to 450°C) for five hours. The cooled cups and their contents were weights again on an analytical scale. The organic fraction in sediment was calculated using the formula:

$$\text{Weight of organic matter} = \text{Dry weight} - \text{Ashed weight}$$

$$\text{Organic fraction} = \text{Weight of organic matter} / \text{Dry weight} \times 100 [\%]$$

Due to significant differences in water quality parameters at the two measured depths, the results are presented in separate tables as an average for all three sampling points (AV +/- SD). During subsequent species suitability assessment, the environmental data for specific depth will be used for individual species depending on where their culture is expected.

Table 7. Average (+/- SD) of annual environmental parameters at 2 m depth

Latitude and Longitude (WGS 84)	Environmental variable name	Min-max values (monthly)	Average (monthly)
Min/max values and averages are taken from pooled measurements of three sampling stations: 43.739681, 15.876003; 43.758297, 15.858078 and 43.769643, 15.847710	Temperature [%C]	13.0 - 25.8	20.0 ± 4.5
	DO [mg/L]	5.5 - 9.5	7.4 ± 0.9
	Salinity	4.0 - 40.0	31.9 ± 9.3
	Turbidity [NTU]	0.3 - 9.4	3.6 ± 2.1
	Chlorophyll [mg/L]	0.2 - 22.51	7.6 ± 4.7
	pH	8.1 - 8.5	8.2 ± 0.1
	DIN [mg/L]	4.8 - 6.6	5.5 ± 0.4
	Phosphates [mg/L]	0.6 - 0.7	0.6 ± 0.0
	TSS [mg/L]	20,0 - 66,5	27.8 ± 5.7
	TOS [%]	9,0- 30,4,3	35.2 ± 2.9
Organic fraction in sediment (%)	2.7 - 9.1	5.3 ± 2.7	

Table 8. Average (+/- SD) of annual environmental parameters at 20 m depth

Latitude and Longitude (WGS 84)	Environmental variable name	Min-max values (monthly)	Average (monthly)
Average between stations at: 43.739681, 15.876003; 43.758297, 15.858078 and 43.769643, 15.847710	Temperature [%C]	14.0 - 24.3	19.3 ± 3.7
	DO [mg/L]	5.7 - 7.7	6.5 ± 0.7
	Salinity	30.0 - 41.0	39.1 ± 2.1
	Turbidity [NTU]	0.5 - 13.2	4.4 ± 2.9
	Chlorophyll [mg/L]	0.2 - 13.5	2.7 ± 2.7
	pH	8.0 - 8.5	8.4 ± 0.1
	DIN [mg/L]	4.6 - 6.7	5.5 ± 0.3
	Phosphates [mg/L]	0.0 - 0.7	0.6 ± 0.0
	TSS [mg/L]	14.4 - 66.0	39.1 ± 7.2
	TOS [%]	16.4 - 57.6	31.1 ± 1.3
Organic fraction in sediment (%)	2.7 - 9.1	5.3 ± 2.7	

Site suitability assessment in Krka River estuary

Stakeholders at Lirries were: Platforma 22 Ltd., Seashell Ltd., Bivalvi Ltd. They valued our weight values through six criteria of Site Suitability Index (SiSi). These values were gained from communication with stakeholders and literature.

Table 9. Scenario according to Methodology (Semi extensive)

Criteria	Raw value	Normalized value	Weight
1. Water quality data	1	0.25	0.25
2. Trophic condition	0.5	0.125	0.25
3. Services and facilities	0.4	0.06	0.15
4. Use of the water body	0.62	0.0775	0.125
5. Use of the surrounding land	0.62	0.0775	0.125
6. Risk analysis	0.752	0.0752	0.1
TOTAL	3.89	0.67	1

**Table 10.** Scenario according to Methodology (Intensive/RAS)

Criteria	Raw value	Normalized value	Weight
1. Water quality data	1	0.25	0.25
2. Trophic condition	0.5	0.125	0.25
3. Services and facilities	0.4	0.06	0.15
4. Use of the water body	0.62	0.0775	0.125
5. Use of the surrounding land	0.62	0.0775	0.125
6. Risk analysis	0.73	0.0732	0.1
TOTAL	3.87	0.66	1

Table 11. Scenario W2 from Lirries (Semi extensive)

Criteria	Raw value	Normalized value	Weight
1. Water quality data	1	0.25	0.25
2. Trophic condition	0.5	0.075	0.15
3. Services and facilities	0.4	0.06	0.15
4. Use of the water body	0.62	0.093	0.15
5. Use of the surrounding land	0.62	0.093	0.15
6. Risk analysis	0.752	0.1128	0.15
TOTAL	3.89	0.68	1

Table 12. Scenario W2 from Lirries (Intensive/RAS)

Criteria	Raw value	Normalized value	Weight
1. Water quality data	1	0.25	0.25
2. Trophic condition	0.5	0.075	0.15
3. Services and facilities	0.4	0.06	0.15



4. Use of the water body	0.62	0.093	0.15
5. Use of the surrounding land	0.62	0.093	0.15
6. Risk analysis	0.73	0.1098	0.15
TOTAL	3.87	0.68	1

Site suitability indicator and identification of the most suitable area

Due to the proximity of the three sampling points used in this study, the values of their site suitability indices (SiSi) do not vary. Even differences in the intensity of production (which are too small and far between to have any significant change on trophic condition and associated risks of farming in the area) and using alternative microcriteria values, the obtained SiSi values are similar. Furthermore, although species suitability was later adjusted for different depths of culture, the site suitability index did not defer to by depth.

Thus, a single SiSi value was elected for the pilot area, pertaining to the scenario in accordance with AZA4ICE Methodology in a semiextensive farming environment.

Table 13.

Scenario according with Methodology	
Semiextensive	
1. Water quality data	1.00
2. Trophic condition	0.50
3. Services and facilities	0.40
4. Use of the water body	0.62
5. Use of the surrounding	0.62
6. Risk analysis	0.75
SiSi	0.67

Species suitability assessment in Krka River estuary

The species considered were as follows:

Sea bass (*Dicentrarchus labrax*)

Flat oyster (*Ostrea edulis*)



Sea cucumbers (*Holothuria tubulosa*)

Sea lettuce (*Ulva sp.*)

a) Sea bass (*Dicentrarchus labrax*)

Sea bass grows up to 1 meter in length and can reach a mass of 14 kg. By its appearance, the sea bass reveals that it is a predator. It is of a solid build, robust, but at the same time elongated and elegant body lines. It swims very fast. Its head is medium-sized, with a disproportionately large mouth on which the lower lip is slightly protruded. It does not have large teeth, but they are numerous and very sharp. There are several strong spines on the gill cover.

The body of the sea bass is covered with small scales, it is light lead-grey in colour, which turns into grey-silver on the sides, and silvery-white below. Above the gill cover on the body, it has a dark spot. Younger specimens, and exceptionally adults, are black spotted on the top and sides.

It is found along the entire Adriatic coast, on every type of bottom, in murky, brackish and clear, salty sea. It is most often found around river mouths and bays where the presence of fresh water from underwater springs is felt. In warmer months, it lives near the coast, mainly at shallow depths of 2 to 5 m, and it also goes deep into river courses. During cold winters, it can migrate to deeper water and go down to 80 m younger individuals are kept in larger floats, while adults live alone or in groups of a small number of individuals. It feeds on shrimps, molluscs and fish (young mullets, eels, sculpins and oilgae). The younger one is feeding primarily invertebrates and, as it grows, more fish. Due to the shortage of the usual food, sea bass will also reach for algae.

It spawns once a year, at the end of autumn and in the first half of winter. It collects in floats and releases sexual products into the surrounding water where fertilization occurs. Fertilized eggs are pelagic and positive navigability. Puberty usually occurs between the ages of two and four.

b) Flat oyster (*Ostrea edulis*)

The oyster is a bivalve with a round or oval grey shell with a rough surface. The left and right shells are different - the left, concave, oyster holds firmly to the substrate, while the right is flat. The shell is made of a series of carbonate layers, arranged in a laminar manner. The oyster is a protandry hermaphrodite, it can change sex twice during the reproductive season. The gametes of the females are in the mantle cavity, where they are fertilized when they encounter sperm that enter the interior of the mantle from the surrounding water column by the incoming current. One female can produce up to a million eggs, which after fertilization remain in her mantle cavity for 8-10 days, and then the approximately 160 µm large larva is released into the environment by the outgoing current of water. The free-swimming larvae remains in the water column for 2-3 weeks (depending on



temperature). The crawling larva settles on a solid substrate, destroying the foot from which it uses the substance "cement" to irreversibly attach itself to the substrate. For proper growth and development of the larvae, salinity should not be below 20, and the temperature should not exceed 25°C.

c) Sea cucumbers (*Holothuria tubulosa*)

Sea cucumbers are marine invertebrates that belong, as already mentioned, to the phylum *Echinodermata*, class *Holothuroidea*. In accordance with the Ordinance on the *Protection of Sea Cucumbers (Official Gazette 76/1998)*, all species of sea cucumbers may not be collected for the purpose of processing, trade and other transportation in the Republic of Croatia.

They are benthic organisms that occur from the intertidal zone to deep-sea trenches. Sea cucumbers have an elongated body because their oral-aboral axis is much longer than their radial axes. In their natural position, they lie on the substrate so that their oral-aboral axis is parallel to the substrate. Although the lower side differs from the upper side, there is no difference between the ventral and dorsal sides of the body.

A well-developed muscular system enables them to be flexible, and thus move well (*Musin and Marukic, 2007*). The size of echinoderms ranges from a few millimetres to 2 meters (*Habdija et al., 2011, p. 490*). The digestive system extends along the entire body - from the mouth opening at the front to the intestine at the back of the body (*Matonickin, 1999*). The intestine ends in the cloaca, which is held by two branches of the water lungs (*Matonickin, 1999*). *Echinoderms* draw water into the water lungs through the cloaca and release it again (*Matonickin, 1999*). The radially arranged vascular system is the basic anatomical feature of the genus of echinoderms (*Matonickin, 1999*). The pentaradial structure of the body of echinoderms is most pronounced in the structure of the vascular system (*Matonickin, 1999*).

The common sea cucumber, *Holothuria tubulosa*, is an organism that can reproduce both sexually and asexually (many are hermaphrodites), although sexual reproduction is much more common. Asexual reproduction involves the division of the body into two or more parts, which is known as fission. Sexual reproduction involves the fertilization of sexual products in the water column. The sexual organs of sea cucumbers have developed in only one interstice, as a simple fruiting body with finger-like branches from which a duct extends to the genital opening. They are sexed separately, however, there are also hermaphrodites. Their larva is an auricularia, which often transforms into a barrel-shaped larva, a doliolaria. In nature, it is difficult to determine their sex at first glance, so the only way to determine it is to dissect them (*Pérez-Ruzafa, 1984*). From previous research, published results for the species, *H. tubulosa* indicate the beginning of spawning in August. During spawning, the wrasses raise their anterior body towards the sea bottom current, with both sexes adopting the so-called "cobra" position as shown in the, where only a third of the posterior body remains in

contact with the sea bottom. They open their genital opening, which is located just below the mouth, and release their sexual product in the direction of the sea current. First, the males emit a whitish liquid that gradually disperses in the water column. Then, the females emit a viscous mixture in response to the release of male gametes (*Asha and Muthiah, 2002*). Spawning usually lasts about 30 minutes, and the necessary conditions for spawning are a full moon and a few appropriate environmental factors, the most important of which is sea temperature, and data recorded in the Adriatic indicate values of 25 ± 3 °C. Fertilization occurs by the fusion of gametes in the water column. Larvae live a planktonic life for 7 to 13 weeks (*Despalatovic et al., 2004*).

d) Sea lettuce (*Ulva sp.*)

Sea lettuce inhabits well-lit areas in the intertidal zone and in the upper coastal zone and occurs throughout the year. It is also common in shallow polluted seas. The stele of the tubular algae can grow to more than 0.5 meters. They are leathery to touch and have a characteristic bright green colour (*Turk, 2011*). *Ulva sp.*, commonly known as sea lettuce, has enormous chemical potential. This widespread green macroalgae is an important producer in marine ecosystems and thrives in coastal waters in temperate and tropical regions worldwide. However, the importance of *Ulva sp.* goes far beyond its ecological role. Recent studies have focused on the remarkable adaptability of this alga, discovering numerous important chemical components used in various industries. The algae contain a large amount of protein, fiber and antioxidants, and is rich in iron and iodine. It is also rich in numerous vitamins and minerals, and its consumption has been proven to have a positive effect on the digestive and immune systems.

Table 14. Environmental requirements of fed aquaculture species. Optimal and tolerance range, the fuzzy membership function (FMF) and the reference are indicated. Trapezoidal (TRZ); Monotonically linearly increasing (MLI); Monotonically linearly decreasing (MLD)

Species scientific name	Environmental criteria	Critical min	Optimum	Critical max	Fuzzy membership function	Reference
<i>Dicentrarchus labrax</i>	Temp (°C)	4.6	25-30	37.4		TRZ
	Oxygen (%)	30	70-100 (115*)			MLI
	TSS (mg/L)		1-7	102		MLD
	Salinity (‰)	1	10.2 – 25.0	60		TRZ
	pH	15.9	6.5 – 8.3 (9.0*)			TRZ

Table 15. Environmental requirements for suspension of organic extractive species. Optimal and

tolerance range, the fuzzy membership function (FMF) and the reference are indicated. Trapezoidal (TRZ); Monotonically linearly increasing (MLI); Monotonically linearly decreasing (MLD)

Species scientific name	Environmental criteria	Critical min	Optimum	Critical max	Fuzzy membership function	Reference
<i>Ostrea edulis</i>	Temp (°C)	3-8	18-25	28-30		TRZ
	Oxygen (%)	15*	90-100 (115*)			MLI
	Turbidity or TSS (mg/L)		2-50	80		MLD
	Salinity (‰)	18	20-50	60		TRZ
	pH	6.5*	7.5-8.1 (9.0*)			MLI
	Chlorophyll-a (µg Chla L-1)	0.2	10-30			MLI

Table 16. Environmental requirements of deposit and suspension organic extractive species. Optimal and tolerance range, the fuzzy membership function (FMF) and the reference are indicated. Trapezoidal (TRZ); Monotonically linearly increasing (MLI); Monotonically linearly decreasing (MLD)

Species scientific name	Environmental criteria	Critical min	Optimum	Critical max	Fuzzy membership function	Reference
<i>Holothuria tubulosa</i>	Temp (°C)	12	20-25	30		TRY
	Oxygen (%)	24	80-100 (115*)			MLI
	Substrate		Sand			
	Salinity (‰)	25	38	45		TRZ
	pH	7.2	7.6-8 (9.0*)			MLI

Table 17. Environmental requirements of Inorganic extractive species. Optimal and tolerance range, the fuzzy membership function (FMF) and the reference are indicated. Trapezoidal (TRZ); Monotonically linearly increasing (MLI); Monotonically linearly decreasing (MLD)

Species scientific name	Environmental criteria	Critical min	Optimum	Critical max	Fuzzy membership function	Reference
<i>Ulva sp.</i> (<i>U. ohnoia</i>, <i>Ulva rigidab</i>, <i>U. rotundata</i>, <i>U. rotundata</i>)	Temp (°C)	4 ^a	20-25 ^a	40 ^a		TRZ
		10 ^b	18-25 ^b	25 ^e		
		11 ^c	21-27 ^c			
			20-25 ^d			
		6 ^e	12-18 ^e			
	Oxygen (%)					
TSS (mg/L)		1-400	650			MLD

<i>Ulva intestin alis, U. lattuca e</i>	Salinity	10 ^a	25-35 ^a	40 ^a	TRZ
		15 ^b	30-37 ^b	40 ^b	
		10 ^c	30-40 ^c	48 ^c	
		1 ^d	5-39 ^d	40 ^d	
		0 ^e	15-33 ^e	62 ^e	
	pH	4.7 ^b	7.3-10.1 ^a	MLI	
			7.2-8.2 ^b		
			7.3-9.0 ^c		
			8.2-10.2 ^d		
			7.5-9.5 ^e (10 [*])		
	TIN (mg L ⁻¹)	0.05	0.5-30 ^{a,b} 0.25-2.9 ^a	300	MLI
TP (mg L ⁻¹)	0.05	0.25-2.9 ^a	85	MLI	

Suitable species in Krka River estuary

In this study, a different set of environmental parameters was used depending on the depth the species is cultured at. So, for the four analysed species, environmental parameters from the following depths were used to assess individual species suitability indices:

Fed species: <i>Dicentrarchus labrax</i>	- 20 m
Suspension feeder: <i>Ostrea edulis</i>	- 20 m
Deposit feeder: <i>Holothuria tubulosa</i>	- 20 m
Inorganic extractive species: <i>Ulva sp.</i>	- 2 m

Table 18. Suitability index for each species

Species scientific name	Vernacular name	Suitability index
<i>Dicentrarchus labrax</i>	European sea bass	0.67
<i>Ostrea edulis</i>	European flat oyster	0.75
<i>Holothuria tubulosa</i>	Sea cucumber	0.67
<i>Ulva sp.</i>	Sea lettuce	0.53

IMTA/RAS and circularity suitability assessment in Krka River estuary

Table 19. Aquaculture performance indicators for each species

Species	Criteria	Sub-criteria	Normalized value	Weights	Intermediate IPI index
<i>Dicentrarchus labrax</i>	Distribution range and facilities (criterion 1)	Biogeography in the MED/Black Sea	0.4	0.1	0.4
		Aquaculture activity	0.6	0.1	0.6
	Domestication and breeding (criterion 2)	Production model	0.2	0.25	0.14
		Know-how life cycle	0.2	0.25	0.2
		Seed supply availability	0.6	0.25	0.6
	Feeding requirements (criterion 3)	Feedstuff Sustainability and knowledge	0.4	0.15	0.2
		Feeding efficiencies	0.6	0.15	0.3
	Growth and survival performance (criterion 4)	Growth rates	0.4	0.15	0.2
		Duration of production cycle	0.2	0.15	0.1
		Survival	0.4	0.15	0.4
	Market value (criterion 5)	Commercial value fresh product	0.6	0.15	0.3
		Commercial value by-products	0.3	0.15	0.15
		Target market	0.1	0.15	0.05
	Social acceptance (criterion 6)	Consumer opinion	0.5	0.2	0.5
		Satisfaction	0.5	0.2	0.5
	<i>Ostrea edulis</i>	Distribution range and facilities (criterion 1)	Biogeography in the MED/Black Sea	0.4	0.1
Aquaculture activity			0.6	0.1	0.6
Domestication and breeding (criterion 2)		Production model	0.2	0.25	0.04
		Know-how life cycle	0.2	0.25	0.1
		Seed supply availability	0.6	0.25	0.12



	Feeding requirements (criterion 3)	Feedstuff Sustainability and knowledge	0.8	0.2	0.4	
		Feeding efficiencies	0.2	0.2	0.04	
	Growth and survival performance (criterion 4)	Growth rates	0.4	0.15	0.08	
		Duration of production cycle	0.2	0.15	0.1	
		Survival	0.4	0.15	0.2	
	Market value (criterion 5)	Commercial value fresh product	0.5	0.15	0.5	
		Commercial value by-products	0.2	0.15	0.2	
		Target market	0.1	0.15	0.1	
	Social acceptance (criterion 6)	Consumer opinion	0.2	0.15	0.2	
		Satisfaction	0.5	0.15	0.5	
	Holotheurichthys tubulosa	Distribution range and facilities (criterion 1)	Biogeography in the MED/Black Sea	0.4	0.1	0.4
			Aquaculture activity	0.6	0.1	0.12
Domestication and breeding (criterion 2)		Production model	0.2	0.25	0.04	
		Know-how life cycle	0.2	0.25	0.04	
		Seed supply availability	0.6	0.25	0.12	
Feeding requirements (criterion 3)		Feedstuff Sustainability and knowledge	0.8	0.2	0.4	
		Feeding efficiencies	0.2	0.2	0.04	
Growth and survival performance (criterion 4)		Growth rates	0.4	0.15	0.08	
		Duration of production cycle	0.2	0.15	0.2	
		Survival	0.4	0.15	0.4	
Market value (criterion 5)		Commercial value fresh product	0.5	0.15	0.5	
		Commercial value by-products	0.2	0.15	0.2	

		Target market	0.1	0.15	0.02
	Social acceptance (criterion 6)	Consumer opinion	0.2	0.15	0.2
		Satisfaction	0.5	0.15	0.5
Ulva sp.	Distribution range and facilities (criterion 1)	Biogeography in the MED/Black Sea	0.4	0.1	0.4
		Aquaculture activity	0.6	0.1	0.12
	Domestication and breeding (criterion 2)	Production model	0.2	0.25	0.1
		Know-how life cycle	0.2	0.25	0.2
		Seed supply availability	0.6	0.25	0.3
	Feeding requirements (criterion 3)	Feedstuff Sustainability and knowledge	0.8	0.2	0.8
		Feeding efficiencies	0.2	0.2	0.04
	Growth and survival performance (criterion 4)	Growth rates	0.4	0.15	0.4
		Duration of production cycle	0.2	0.15	0.2
		Survival	0.4	0.15	0.4
	Market value (criterion 5)	Commercial value fresh product	0.5	0.15	0.5
		Commercial value by-products	0.2	0.15	0.2
		Target market	0.1	0.15	0.02
	Social acceptance (criterion 6)	Consumer opinion	0.2	0.15	0.2
		Satisfaction	0.5	0.15	0.5

Table 20. Species IMTA performance criteria

Species	Criteria	Normalized value	Weights	Intermediate IPI index ²
Species 1	Distribution range and facilities (criterion 1)	0.1		0.790
	Domestication and breeding (criterion 2)	0.235		
	Feeding requirements (criterion 3)	0.075		



	Growth and survival performance (criterion 4)	0.105		
	Market value (criterion 5)	0.075		
	Social acceptance (criterion 6)	0.2		
Species 2	Distribution range and facilities (criterion 1)	0.068		0.578
	Domestication and breeding (criterion 2)	0.065		
	Feeding requirements (criterion 3)	0.088		
	Growth and survival performance (criterion 4)	0.057		
	Market value (criterion 5)	0.15		
	Social acceptance (criterion 6)	0.15		
Species 3	Distribution range and facilities (criterion 1)	0.052		0.580
	Domestication and breeding (criterion 2)	0.05		
	Feeding requirements (criterion 3)	0.088		
	Growth and survival performance (criterion 4)	0.102		
	Market value (criterion 5)	0.138		
	Social acceptance (criterion 6)	0.15		
Species 4	Distribution range and facilities (criterion 1)	0.052		0.808
	Domestication and breeding (criterion 2)	0.15		
	Feeding requirements (criterion 3)	0.168		
	Growth and survival performance (criterion 4)	0.15		
	Market value (criterion 5)	0.138		
	Social acceptance (criterion 6)	0.15		

Table 21. Species IMTA performance index

Species scientific name	Vernacular name	IPI
<i>Dicentrarchus labrax</i>	European sea bass	0.790
<i>Ostrea edulis</i>	European flat oyster	0.578



<i>Holothuria tubulosa</i>	Sea cucumber	0.580
<i>Ulva sp.</i>	Sea lettuce	0.808

Table 22. IMTA suitability (IS) calculations

Species scientific name	Vernacular name	ISI
<i>Dicentrarchus labrax</i>	European sea bass	0.732
<i>Ostrea edulis</i>	European flat oyster	0.663
<i>Holothuria tubulosa</i>	Sea cucumber	0.626
<i>Ulva sp.</i>	Sea lettuce	0.668
	IS =	0.672

Table 23. IMTA circularity indicators

	Criteria	Normalized value		Weights	Intermediate ICI index
IMTA system 1	Estimated food efficiency (FE)	1		0.15	0.15
	Estimated waste management efficiency (WE)	0.5		0.2	0.1
	Estimated Resource efficiency (RE)	0.5		0.1	0.05
	Sharing economy (SE)	0.2		0.05	0.01
	Energy efficiency (EE)	1		0.15	0.15
	Multi-species complexity and biodiversity index (BI)	1		0.05	0.05
	Species complementarity (SC)	0.5		0.1	0.05
	Integration of reused/recycled materials	0.2		0.1	0.02
	Sustainable feeds (Only if fed species)	0.2		0.05	0.01
	Water use efficiency	0.2		0.05	0.01

Table 24. IMTA circularity system index

	Vernacular name	ICI
IMTA system 1		0.60

**Table 25.** C-AZA index integrating site and performance species suitability and IMTA circularity

	Vernacular name	C-AZAi
IMTA system 1		0.647

C-AZA definition and KPI**Table 26.** Key performance indicators for the AZA4ICE methodology

Area	No	Performance indicator name	Metric	Value
Pilot area and data collection	1	Number of data collected	Number	972 for environmental monitoring (not counting replicates). SiSi, IPI and ICI were qualitative and are difficult to quantify. They were collected through expertise, references and Lirries discussions.
	2	Number of variables collected in field	Number	14 variables (water temperature, dissolved oxygen, salinity, turbidity, chlorophyll-a, depth, pH, total suspended solids, total organic solids, ammonia, nitrites, nitrates, phosphates, organic fraction in sediment)
	3	Number of variables collected by secondary sources	Number	0
	4	Number of sampling field points	Number	3 (2 depths per sampling point)
	5	Number of stakeholders involved in data collection	Number	3 for field sampling
Site suitability	6	Number of areas suitable for aquaculture activities	Number	1 (the area is already used for aquaculture, but new species and imta setups were explored)
	7	Extension of areas suitable for aquaculture activities	Ha	0 (just suggestions for repurposing existing concessions)



Site Species suitability	8	Number of species considered in species suitability assessment	Number	4
	9	Number of suitable species	Number	4
Circular IMTA suitability	10	Number of ranked species by performance and trophic functional group	Number	4
	11	Number of suitable IMTA circular models	Number	1

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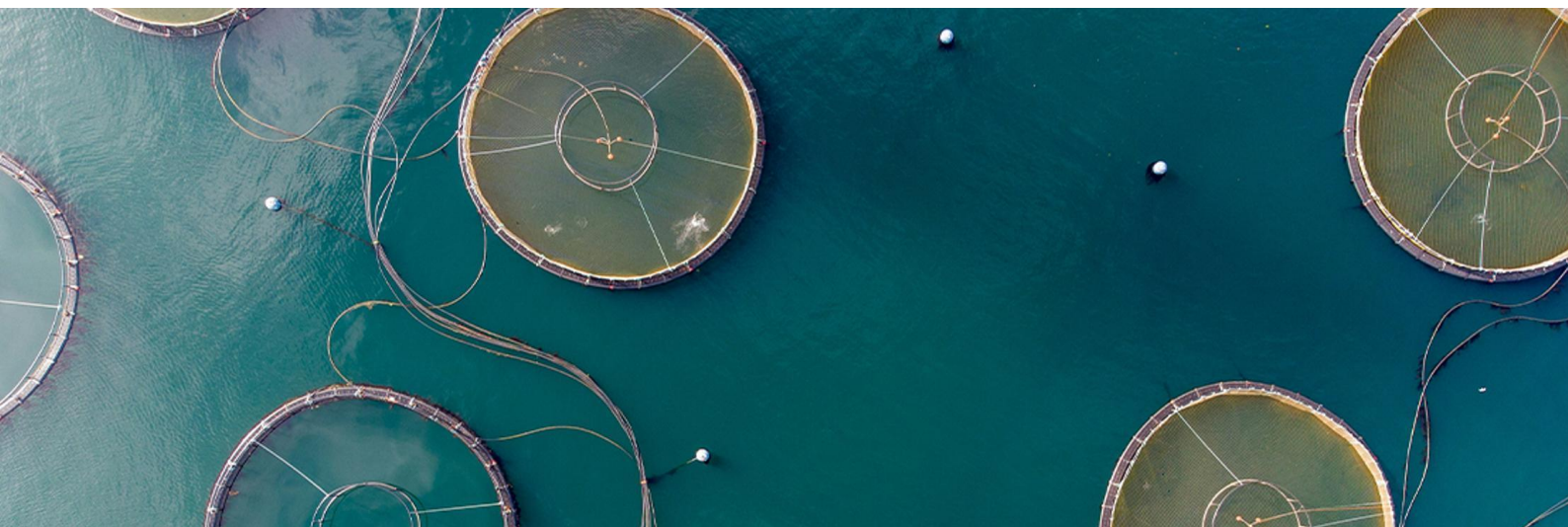


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March 2026

Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Thau Lagoon, France

<https://aza4ice.interreg-euro-med.eu>



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Liste des abréviations et définitions

AZA : *Allocated Zones for Aquaculture*, Zone dédiée à l'aquaculture.

AZA4ICE : *Allocated Zones for circular Aquaculture to trigger the transition to an Inclusive and Circular Economy*, projet européen visant à favoriser la transition vers une aquaculture durable et circulaire à travers la planification spatiale et la coopération entre acteurs.

AMTI : *Aquaculture Multi-Trophique Intégrée*, système d'élevage associant plusieurs espèces de niveaux trophiques différents afin de valoriser les nutriments et réduire les impacts environnementaux.

CGAAER : *Conseil Général de l'Alimentation, de l'Agriculture et des Espaces Ruraux*, organisme d'expertise et de conseil auprès du ministère chargé de l'agriculture.

CRCM : *Comité Régional de la Conchyliculture de Méditerranée*, organisation professionnelle représentant les conchyliculteurs de la façade méditerranéenne française.

CRPMEM : *Comité Régional des Pêches Maritimes et des Élevages Marins*, organisation professionnelle représentant les pêcheurs et les activités liées aux élevages marins au niveau régional.

DGAMPA : *Direction Générale des Affaires Maritimes, de la Pêche et de l'Aquaculture*, direction du ministère chargé de la mer responsable des politiques publiques relatives à la pêche, à l'aquaculture et aux affaires maritimes.

DIRM : *Direction Interrégionale de la Mer*, service déconcentré de l'État chargé de mettre en œuvre les politiques maritimes à l'échelle interrégionale.

DPM : *Domaine Public Maritime*, ensemble des espaces maritimes appartenant à l'État, incluant notamment le rivage et certaines lagunes, où peuvent être implantées des activités comme la conchyliculture.

DRAAF : *Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt*, service déconcentré du ministère de l'Agriculture chargé de la mise en œuvre des politiques agricoles, alimentaires et forestières au niveau régional.

IPI (*Innovation Performance Index*) : Indice de Performance des Espèces utilisé pour évaluer le potentiel technique, économique et sociétal d'une espèce dans un système aquacole.



LIRRIE (*Living Responsible Research and Innovation Ecosystem*) : Ateliers participatifs réunissant chercheurs, professionnels et acteurs institutionnels pour co-construire les orientations du projet.

SCOT : *Schéma de Cohérence Territoriale*, document de planification stratégique organisant l'aménagement du territoire et les grands équilibres d'usage à l'échelle d'un bassin de vie.

SMBT : *Syndicat Mixte du Bassin de Thau*, établissement public chargé de la gestion, de la planification et de la coordination des politiques territoriales autour de la lagune de Thau.

SMVM : *Schéma de Mise en Valeur de la Mer*, document de planification destiné à organiser les usages du littoral et des espaces maritimes.

SSI (*Site Suitability Index*) : Indice de durabilité évaluant l'adéquation entre les conditions environnementales d'un site et les exigences biologiques d'une espèce aquacole.



1. Résumé exécutif

Ce Plan d'Action présente la contribution française au projet AZA4ICE et propose une trajectoire pour accompagner la transition de l'aquaculture vers des modèles plus résilients face au changement climatique, diversifiés et circulaires. Il s'appuie sur des éléments scientifiques, des démarches participatives et des retours de professionnels de l'aquaculture, de chercheurs, de collectivités territoriales et des autorités publiques actifs dans le secteur aquacole en méditerranée française.

Ce document se fonde sur les résultats des évènements du projet, appelés LiRRIE (Living Responsible Research and Innovation Ecosystems), de l'outil d'autoévaluation Bluefasma et de la méthodologie AZA4ICE, C-AZA, développée dans le projet. Ce Plan d'Action met notamment l'accent sur des recommandations tirées des LiRRIEs, réunissant l'ensemble des acteurs de la filière (figure 1).

Centré sur le contexte méditerranéen français, et en particulier sur la lagune de Thau, le Plan d'Action souligne que la transition de la filière va au-delà des solutions techniques, par l'adaptation de la gouvernance, du cadre réglementaire et de la planification spatiale. La transition de la filière implique aussi la mobilisation et la coopération de nombreux acteurs clés.

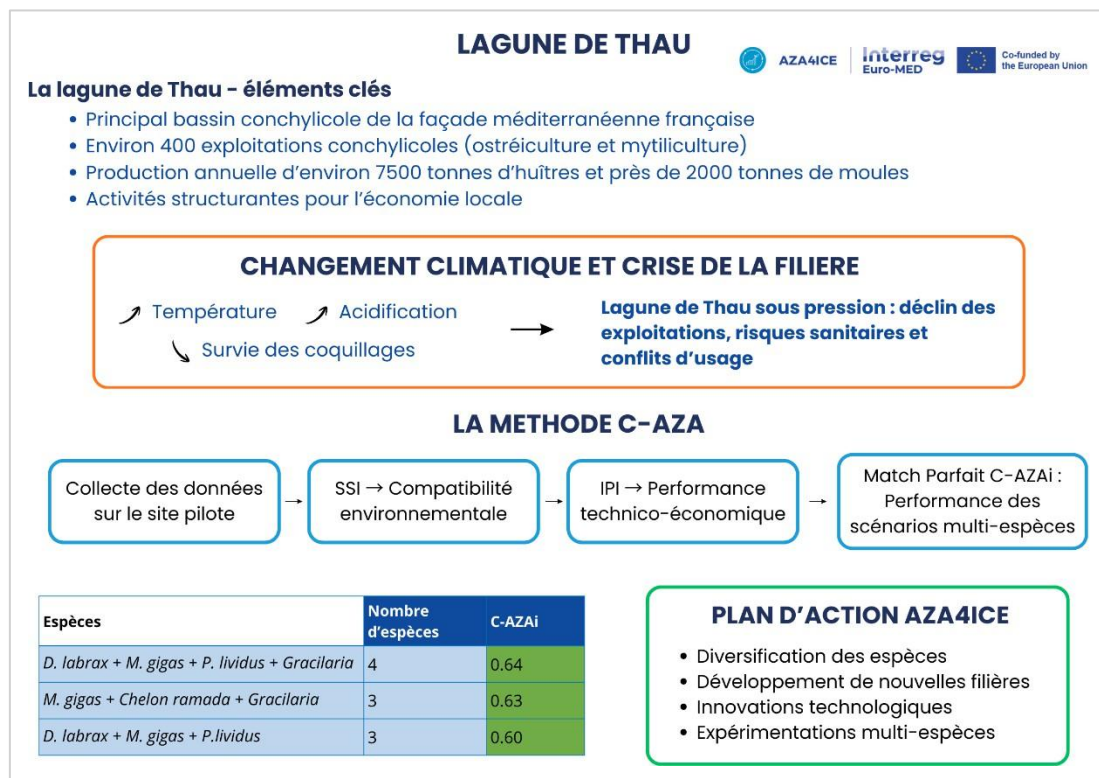


Figure 1 : Résumé du projet AZA4ICE sur le site pilote de la lagune de Thau



2. Introduction

2.1. Périmètre et objectifs

La mise en œuvre du projet AZA4ICE en France intervient à un moment charnière pour l'aquaculture. Le changement climatique ne relève plus de projections théoriques mais de réalités observables, qui impactent déjà les niveaux de productions, le fonctionnement des écosystèmes et donc la viabilité économique des entreprises aquacoles.

L'objectif de ce Plan d'Action est de traduire cette dynamique en un cadre stratégique et opérationnel cohérent. Il vise à :

- Accompagner l'adaptation des activités aquacoles existantes face au changement climatique et aux contraintes environnementales qui en découlent ;
- Encourager la diversification et le développement de systèmes aquacoles circulaires, notamment l'Aquaculture Multi-Trophique Intégrée (AMTI) ;
- Fournir des recommandations aux autorités publiques pour adapter les cadres réglementaires, la planification spatiale et la gouvernance ;
- Faciliter l'expérimentation, l'apprentissage et la réplique des solutions à l'échelle des territoires en France.

Ce Plan d'Action vise à orienter vers l'opérationnalisation. Il identifie des priorités, définit des responsabilités et propose des conditions de mise en œuvre. Il a été élaboré avec les acteurs du site pilote au travers des différents événements AZA4ICE (aussi appelé LIRRIE), figure 2.

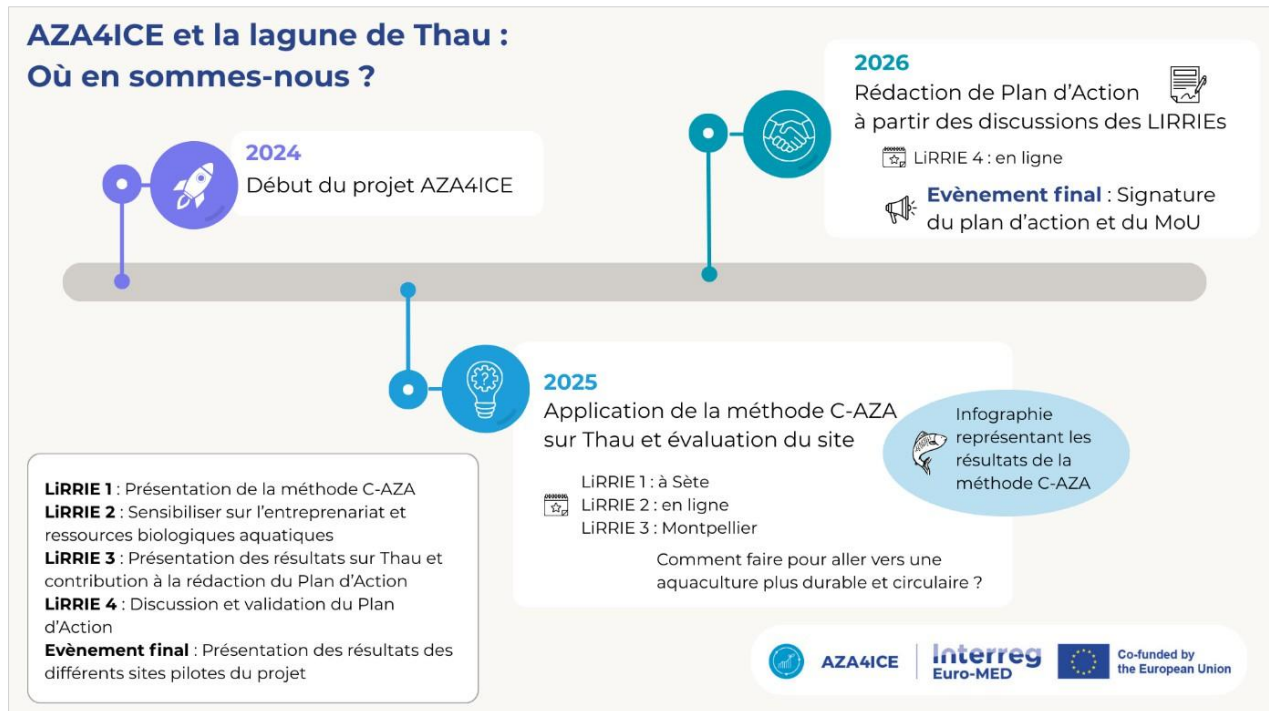


Figure 2: Résumé des actions AZA4ICE site pilote de Thau

2.2. Contexte

Le secteur aquacole français se caractérise par une diversité de systèmes de production, incluant notamment la conchyliculture, l'aquaculture continentale et la pisciculture marine. La France a produit et vendu 146 milliers tonnes de produits en conchyliculture en 2023. La conchyliculture est majoritairement représentée par les huîtres puis les moules. La conchyliculture est suivie par la pisciculture avec une production et vente totale de 39 milliers de tonnes. Elle est représentée notamment par la pisciculture continentale, plus particulièrement avec la salmoniculture, puis par la pisciculture marine.

En Méditerranée, l'aquaculture est un secteur ancien mais relativement limité. Les contraintes environnementales, la forte concurrence pour l'espace littoral et la complexité réglementaire ont historiquement freiné son développement. La production est largement dominée par la conchyliculture, en particulier les huîtres et les moules, concentrées dans les lagunes côtières telles que la lagune de Thau (Hérault, France). Cette lagune



est primordiale pour la filière en Méditerranée, puisqu'il s'agit de l'une des plus grandes lagunes méditerranéennes couvrant une surface d'environ 75 km² produisant 90% des huitres de Méditerranée.

3. Rôles et responsabilités des acteurs clés

La transition vers une aquaculture circulaire et résiliente pour faire face au changement climatique nécessite une action coordonnée entre une diversité d'acteurs. Pour ce faire, l'un des principaux atouts de la démarche AZA4ICE en France réside dans la mobilisation active et le dialogue entre différents acteurs, identifiés et associées tout au long du projet et des événements participatifs.

Ces acteurs comprennent notamment :

- Les professionnels de l'aquaculture, incluant les conchyliculteurs, et porteurs de projets émergents, qui contribuent par :
 - Le partage de savoir-faire et de retours d'expérience de terrain ;
 - L'identification des contraintes, risques et opportunités pratiques sur la production ;
 - La mise à l'épreuve et l'adaptation de nouveaux modèles de production en conditions réelles.

- Les organismes scientifiques et de recherche, en particulier l'IFREMER et les équipes associées, qui jouent un rôle central dans :
 - La production de connaissances scientifiques sur le fonctionnement des écosystèmes, l'impact du changement climatique et les impacts de l'aquaculture sur le milieu ;
 - L'accompagnement dans l'expérimentation, du suivi et de l'évaluation de systèmes aquacoles innovants et circulaires.

- Les autorités publiques et administratives, à différents niveaux de gouvernance, incluant :
 - Les administrations nationales, en charge des politiques des pêches et de l'aquaculture (par ex. DGAMPA) ;



- Les services déconcentrés de l'État aux niveaux régional et interrégional (par ex. DIRM, DRAAF) ;
- Les collectivités territoriales impliquées dans le développement économique, la planification spatiale et la gestion environnementale. Ces acteurs sont essentiels pour assurer la cohérence réglementaire, l'intégration des résultats d'AZA4ICE dans les outils de planification et le soutien à des démarches expérimentales et adaptatives.
- Les organisations professionnelles représentatives, notamment le Comité Régional de la Conchyliculture Méditerranée (CRCM) et le Comité Régional des Pêches Maritimes et des Élevages Marins d'Occitanie (CRPMEM Occitanie), qui :
 - Représentent les intérêts collectifs des professionnels ;
 - Assurent un rôle d'interface entre les producteurs, la recherche et les autorités publiques ;
 - Soutiennent des actions structurantes, des projets collectifs et des stratégies de développement de filière.
- Les structures d'appui et autres parties prenantes, telles que les centres techniques, pôles d'innovation, agences de développement et organismes de formation. Cela inclut en particulier le CEPRALMAR, centre technique spécialisé en aquaculture méditerranéenne, qui joue un rôle clé dans :
 - La recherche appliquée et l'appui technique aux producteurs ;
 - La conception et la mise en œuvre de projets pilotes et expérimentaux (par ex. coculture algues-coquillages) ;
 - Le transfert de connaissances, la formation et le renforcement des capacités des professionnels ;
 - La facilitation du dialogue entre professionnels, scientifiques et autorités publiques.
- Les consommateurs et la société civile, qui, bien qu'ils ne soient pas au cœur des objectifs techniques et de planification d'AZA4ICE, jouent un rôle stratégique dans la durabilité à long terme de l'aquaculture.



Les attentes en matière de qualité des produits, de performance environnementale, de traçabilité et d'ancrage territorial influencent la dynamique des marchés et l'acceptabilité sociale.

AZA4ICE vise à mettre en place un cadre commun pour organiser cette coopération, en facilitant le dialogue et aligner les actions aux différents niveaux de gouvernance. Le Plan d'Action met l'accent sur la co-construction et la responsabilité partagée, considérant que des solutions efficaces et durables émergent de l'interaction entre expertise scientifique, savoir-faire professionnel, politiques publiques et compréhension sociétale.

4. Besoins, enjeux et opportunités régionaux

4.1. *Situation actuelle de l'aquaculture dans la lagune de Thau*

Le secteur la conchyliculture à Thau traverse actuellement une situation critique. Le bassin subit une accumulation de pressions économiques, démographiques, environnementales et sanitaires.

Sur le plan économique, les coûts de production ont fortement augmenté ces dernières années, notamment sous l'effet des prix de l'énergie, du coût du travail sans croissance significative du chiffre d'affaires. Les prix de vente sont stables, parfois en baisse, ce qui soulève de fortes inquiétudes quant à la viabilité économique à long terme des exploitations.

Depuis 2018, environ 20 % des entreprises aquacoles ont disparu de la lagune de Thau, notamment en raison du vieillissement des exploitants, le nombre d'exploitations conchylicoles sur la lagune est estimé autour de 400 entreprises. D'un point de vue démographique, le secteur vieillit rapidement, avec une majorité de professionnels âgés de plus de 50 ans, ce qui souligne l'urgence du renouvellement générationnel et de l'amélioration de l'attractivité des métiers de l'aquaculture.

Sur le plan environnemental, la lagune de Thau constitue l'un des socio-écosystèmes les plus fragiles de la région. Quinze zones de rejet ou exutoires ont été recensées autour du bassin versant de la lagune de Thau. Les préoccupations relatives à la qualité de l'eau et à la résilience des



écosystèmes sont au cœur des discussions. Plusieurs professionnels soulignent l'importance de la productivité primaire du milieu, notamment dans les zones de mer ouverte, qui conditionne le potentiel de développement de nouvelles productions filtrantes. Cette question doit être intégrée dans les réflexions de planification et dans les scénarios de diversification. Les pressions sanitaires et zoo-sanitaires s'intensifient depuis une dizaine d'années. Ces pressions entraînent des suspensions de production avec des épisodes de mortalité et une incertitude importante pour les producteurs.

4.2. *Besoin de diversification et de transformation systémique*

La conchyliculture est une activité agricole à part entière, mais elle demeure l'un des systèmes de production les moins diversifiés. La diversification ne doit pas être comprise comme une simple addition de nouvelles espèces, mais comme une réorganisation systémique des modèles de production. L'AMTI vise à rendre le système circulaire, c'est à dire optimiser l'utilisation des ressources, réduire les rejets et les impacts environnementaux et accroître la résilience.

L'aquaculture circulaire et les approches en AMTI offrent des leviers concrets pour engager cette transformation. En associant des espèces aux fonctions trophiques complémentaires, ces systèmes permettent également de diversifier les sources de revenus. La diversification pourrait permettre la réduction de la vulnérabilité aux risques sanitaires.

La diversification constitue également un levier majeur pour le renouvellement générationnel. L'innovation, l'expérimentation et l'émergence de nouveaux modèles productifs peuvent redonner du sens et des perspectives aux métiers de l'aquaculture, et attirer de nouveaux profils, notamment plus jeunes.

4.3. *Principaux défis et opportunités*

Un défi central réside dans le décalage entre l'urgence économique des exploitations et le temps nécessaire à la recherche, à l'expérimentation et à la consolidation réglementaire. L'acceptabilité sociale et professionnelle constitue un autre enjeu, nécessitant dialogue, coopération entre les



différents acteurs et démonstration concrète des bénéfices à travers des projets pilotes et des preuves de concept.

Le cadre réglementaire demeure un frein important, en particulier pour l'algoculture, où des incertitudes persistent. Dans le même temps, l'approche de AZA4ICE, par la méthode C-AZA, offre des opportunités significatives en réduisant les délais de développement, en apportant un appui scientifique robuste et en accélérant le passage du concept à l'expérimentation.

4.4. Gestion du risque

La question de la prise de risque a été soulevée par les professionnels lors des échanges. Le développement de nouveaux systèmes de production (nouvelles espèces, co-cultures, innovations techniques) implique des incertitudes techniques, économiques et environnementales.

Dans ce contexte, il apparaît nécessaire de clarifier qui porte et assume ces risques : producteurs, autorités publiques, projets expérimentaux ou dispositifs de financement.

Plusieurs acteurs ont également souligné que les entreprises de la filière disposent aujourd'hui de moyens financiers limités, ce qui réduit leur capacité à investir dans des démarches de recherche et développement. Le développement de nouveaux modèles aquacoles nécessite donc des mécanismes d'accompagnement et de financement adaptés, afin de soutenir les phases d'expérimentation et de limiter le risque pour les producteurs.

5. Cadre juridique, réglementaire et d'autorisation

L'aquaculture en France est encadrée par un ensemble de réglementations européennes, nationales et locales visant à concilier développement économique, protection de l'environnement et gestion de l'espace maritime. La création ou l'extension d'une activité aquacole nécessite plusieurs autorisations administratives concernant diverses réglementations françaises : la réglementation environnementale, les documents relatifs à la planification spatiale, la réglementation sanitaire et la réglementation foncière.

Selon le rapport CGAAER ¹« Développement de la filière piscicole », la multiplicité des autorisations et la durée d'instruction des dossiers



constituent un frein important au développement de la filière. Dans plusieurs pays européens, ces procédures sont simplifiées via des guichets uniques, une solution également recommandée pour la France.

L'aquaculture est fortement encadrée par la réglementation environnementale. Elle exige des évaluations avant toutes mises en place d'exploitation. L'évaluation est cadrée par une étude d'impact environnementale, une évaluation Natura 2000 ainsi que l'analyse des rejets (azote, phosphore) dans le milieu de l'activité. Certains critères comme la taille du projet concerné mais également de la sensibilité du milieu sont des éléments essentiels pour ces études. Cependant en France, les seuils déclenchant ces évaluations peuvent être plus stricts que dans certains pays européens, ce qui peut créer un désavantage compétitif.

En effet les activités aquacoles doivent respecter des règles rentrées en vigueur, telles que la directive cadre sur l'eau, les réglementations Natura 2000 ainsi que les règles de qualité des eaux lagunaires.

Aujourd'hui, des documents tel que le SCOT et le volet littoral du SMVN ont des sections mettant en avant une volonté de protection du milieu marin tout en donnant la priorité aux activités de pêche et de cultures marines. Ils imposent également une gestion stricte de l'urbanisation et de la qualité de l'eau.

Occupant une concession ou une occupation du domaine public maritime (DPM), la filière de l'aquaculture est concernée par les documents relatifs à la planification spatiale maritime. Le concept de zones allouées à l'aquaculture (AZA) consiste à identifier des zones marines où l'aquaculture est prioritaire par rapport aux autres usages (tourisme, navigation, etc.). Cette approche vise à anticiper et organiser le développement de l'aquaculture à l'échelle territoriale. Cette planification vise donc à réduire les conflits d'usage, faciliter l'installation de nouvelles fermes et sécuriser les investissements et la pérennité des activités aquacoles.

Dans le bassin de Thau, cette planification s'inscrit dans un cadre territorial déjà structuré. Elle est notamment encadrée par des outils tels que le SCOT mené par le SMT et les documents d'urbanisme locaux, qui organisent les usages du territoire et du plan d'eau. Ces outils contribuent à la protection

¹ Développement de la filière piscicole, 2022. CGAAER- Rapport n°014044-01



des milieux naturels et à la cohérence de l'aménagement du territoire. Toutefois, ils peuvent également être perçus par certains acteurs comme des contraintes pour l'expérimentation de nouveaux modèles aquacoles.

L'accès au foncier constitue également un enjeu majeur pour le secteur. Dans les zones lagunaires comme Thau, les espaces conchylicoles sont protégés par des documents d'urbanisme. Cependant comme annoncée précédemment, la baisse d'exploitations est remarquée. L'évolution de ces documents est nécessaire pour réduire la pression foncière permettre aux activités de s'installer la diversification des productions, la co-culture et le développement de nouveaux modèles aquacoles.

La filière de l'aquaculture est soumise à des règles sanitaires strictes. Les principales obligations concernent la surveillance des maladies, la traçabilité des produits, et les contrôles vétérinaires nécessaires. Ces règles sont essentielles car certaines maladies virales peuvent affecter la production.

Les exploitations, sur la zone de la lagune de Thau, peuvent obtenir un statut sanitaire indemne, ce qui facilite les exportations mais peut limiter certaines importations d'animaux vivants. Cependant, il a été souligné la difficulté d'obtenir des réponses réglementaires claires pour certains projets innovants. Par exemple, des interrogations subsistent concernant l'approvisionnement de bassins de stabulation en eau de forage ou en eau traitée, ce qui illustre le besoin d'un dialogue renforcé entre professionnels et autorités compétentes.

Pour résumer un certain nombre de freins réglementaires sont identifiés. Plusieurs obstacles au développement de l'aquaculture sont régulièrement cités :

- Complexité administrative,
- Délais longs pour les autorisations,
- Contraintes environnementales strictes,
- Concurrence d'usage du littoral,
- Manque de planification spatiale.

Ces éléments expliquent en partie la stagnation de la production aquacole française malgré une demande mondiale en forte croissance.



6. État actuel des entreprises aquacoles

6.1. État de la conchyliculture

La conchyliculture demeure le pilier de l'aquaculture méditerranéenne française et constitue le cœur de l'activité économique des lagunes côtières telles que la lagune de Thau. Très ancré dans les territoires, sur le plan économique mais également culturel, la lagune connaît néanmoins une transition majeure sous l'effet de facteurs environnementaux, sanitaires, économiques et démographiques.

La production d'**huître creuse (*Crassostrea gigas*)** reste dominante et globalement compatible avec les conditions lagunaires. Toutefois, les professionnels observent une variabilité concernant les taux croissance, les taux de survie et la qualité des produits. Les vagues de chaleur estivales, les épisodes d'hypoxie et les dégradations ponctuelles de la qualité de l'eau affectent de plus en plus les cycles de production. Ces évolutions imposent une adaptation des pratiques à travers l'innovation technique, le suivi environnemental renforcé et la gestion adaptative indispensables pour sécuriser la production.

La production de **moule méditerranéenne (*Mytilus galloprovincialis*)** en lagune, n'est plus considérée comme viable à moyen et long terme dans la lagune de Thau. Les projections scientifiques et les résultats expérimentaux convergent vers un risque élevé de mortalité estivale à partir de 2050, principalement en lien avec l'augmentation des températures et l'acidification dû au changement climatique. Les observations de terrain confirment déjà cette vulnérabilité. En conséquence, les acteurs soutiennent largement la relocalisation de la production de moules en mer, dans des environnements plus stables, ce qui implique la structuration d'une nouvelle filière collective « moules en mer ».

L'**huître plate européenne (*Ostrea edulis*)** est perçue comme une espèce stratégique de diversification, de restauration patrimoniale ainsi que de valeur écologique. Son redéploiement constitue une opportunité de long terme pour réduire la dépendance à une seule espèce tout en renforçant les services écosystémiques. Néanmoins, des verrous techniques et organisationnels persistent, notamment en matière d'écloserie, de nurserie, de gestion sanitaire et de performances d'élevage. Le renforcement des capacités locales d'écloserie, de pré-grossissement et de nurserie est identifié comme un prérequis essentiel pour assurer la pérennité de la



production de l'huitre plate européenne.

6.2. État de la pisciculture

La pisciculture n'est actuellement pas pratiquée sur la lagune de Thau, principalement en raison de la sensibilité environnementale, des contraintes spatiales et des limites réglementaires propres aux systèmes lagunaires confinés. La seule infrastructure liée au poisson à proximité immédiate est une éclosérie terrestre en système de recirculation (RAS), fonctionnant indépendamment de la production lagunaire.

À l'échelle régionale, la pisciculture demeure toutefois une composante pertinente de l'aquaculture méditerranéenne française. L'élevage en mer est présent à travers des sites de production en mer méditerranée française, notamment au large de Marseille dans les Bouches-du-Rhône, dans la baie du Lazaret dans le Var, aux abords de Cannes dans les Alpes-Maritimes, ainsi qu'en Haute-Corse et Corse-du-Sud. Les professionnels de la Baie du Lazaret ont exprimé un intérêt pour des stratégies de diversification et de co-cultures potentielles entre pisciculture, conchyliculture et espèces extractives.

6.3. Vers une diversification aquacole ?

La diversification est apparue comme l'un des leviers majeurs pour renforcer la résilience et la capacité d'adaptation des systèmes aquacoles en Méditerranée française. Elle est largement perçue comme une nécessité, face à la vulnérabilité croissante des modèles de production à une espèce, aux chocs climatiques, sanitaires et économiques.

À ce stade, la diversification s'opère principalement à travers des initiatives expérimentales et pilotes, ciblant des espèces et des systèmes favorables à des modèles circulaires ou écosystémiques. La production de macroalgues figure parmi les pistes les plus prometteuses. Bien que les volumes restent limités, les algues sont reconnues pour leur rôle potentiel dans l'absorption des nutriments, la bioremédiation et la coculture avec les coquillages.

Sur la lagune de Thau, le projet COCOALG porté par le CEPRALMAR vise à évaluer la faisabilité technique, environnementale et opérationnelle de la coculture algues-coquillages, en produisant des références essentielles pour un déploiement futur.

Les holothuries, et en particulier *Holothuria tubulosa*, ont également été



identifiées comme une voie de diversification à plus long terme. Leur rôle détritovre représente un caractère intéressant pour les systèmes circulaires. De plus ils contribuent à la qualité des sédiments tout en ouvrant l'accès à des marchés de niche à forte valeur ajoutée. Ce potentiel est exploré dans le cadre du projet HOLOPROD, porté par un acteur industriel, autour du développement d'écloseries, d'essais de grossissement et de l'évaluation de la viabilité économique.

La plupart des systèmes de diversification sont observables sous la forme d'initiatives expérimentales et pilotes. Cela dit, les discussions ont également mis en avant une volonté des aquaculteurs à travers des initiatives personnelles. Des professionnels, sensibilisés à la diversification et à l'AMTI, mettent en place des systèmes de coculture dans leurs fermes aquacoles. Certains on émit un souhait de s'orienter vers la diversification pour la pérennité de la filière.

La diversification est conçue comme un processus de transition progressive, et non comme une substitution rapide des activités existantes. Elle nécessite du temps, de l'expérimentation, un accompagnement technique et une clarification réglementaire. Les outils d'aide à la décision tels que C-AZA jouent un rôle clé pour réduire l'incertitude, en identifiant les combinaisons d'espèces et les configurations spatiales les plus pertinentes, facilitant ainsi des décisions d'investissement et des politiques publiques éclairées.

6.4. Principaux défis et réponses proposées

L'analyse de l'état actuel des entreprises aquacoles met en évidence des défis structurels et transversaux aux espèces, aux systèmes de production et aux territoires. Ces défis sont généralement étroitement liés et appellent des réponses coordonnées et multi-niveaux, plutôt que des mesures isolées.

Tableau 1: Les principaux défis sur la lagune de Thau, réponses et impacts associés

Principaux défis	Réponses prioritaires	Impacts attendus
Vulnérabilité climatique des systèmes lagunaires.	Relocalisation en mer, adaptation des calendriers, anticipation des événements extrêmes.	Réduction des mortalités, meilleure stabilité de production.



Dépendance aux modèles monospécifiques-	Diversification progressive, AMTI, intégration multiespèces.	Réduction des risques économiques et biologiques, résilience accrue.
Incertitude et manque de références pour les espèces émergentes.	Pilote C-AZA et expérimentations, recherche appliquée et appui technique.	Accélération des apprentissages, sécurisation des investissements, émergence de nouvelles filières.
Pressions environnementales et fragilité des écosystèmes.	Intégration d'espèces extractives (algues, détritivores), pratiques circulaires.	Amélioration de la qualité de l'eau, services écosystémiques, acceptabilité sociale.
Vieillesse de la profession et faible attractivité.	Outils collectifs, innovation, diversification, amélioration des conditions de travail, intégrations de formations	Attractivité renforcée, renouvellement générationnel.
Rigidité et complexité réglementaires.	Utilisation des résultats AZA4ICE et C-AZA dans la planification et l'instruction-	Cohérence des politiques, déploiement plus rapide et sécurisé des projets.

Cette synthèse souligne que les réponses doivent être combinées au sein d'une trajectoire de transition cohérente, articulant solutions techniques, adaptations de gouvernance et stratégies territoriales.

7. Vision

La vision partagée issue des ateliers LiRRIEs reconnaît le changement climatique comme une contrainte importante et irréversible pour l'aquaculture méditerranéenne. Plutôt que de chercher à préserver à tout prix les modèles existants, les acteurs convergent vers la nécessité de repenser les systèmes de production, l'organisation spatiale et les cadres de



gouvernance.

L'innovation est identifiée comme un levier clé de cette transition, notamment à travers le suivi environnemental, la modélisation, l'automatisation et l'amélioration des pratiques d'élevage. Toutefois, les échanges ont mis en évidence qu'un élément central de la vision repose sur le développement de modèles aquacoles écosystémiques et circulaires, incluant l'AMTI. Ces approches visent à restaurer les interactions fonctionnelles entre les espèces, à réduire les rejets, à optimiser l'utilisation des ressources et à renforcer les services écosystémiques. Les solutions low-tech et inspirées du fonctionnement naturel des écosystèmes sont perçues comme complémentaires de l'innovation technologique, en particulier dans les milieux lagunaires fragiles.

La diversification occupe une place stratégique dans cette vision. Elle permet de réduire la vulnérabilité aux chocs climatiques et sanitaires, tout en créant de nouvelles opportunités économiques. Elle constitue également un levier majeur pour améliorer l'attractivité du secteur et une opportunité pour soutenir le renouvellement générationnel.

Enfin, l'importance d'une planification spatiale et d'une gouvernance agile appuyées par des outils tels que C-AZA est à souligner. À l'horizon 2035–2040, l'aquaculture méditerranéenne française ambitionne d'évoluer vers des systèmes diversifiés, résilients face au changement climatique et circulaires, fortement ancrés dans les territoires, socialement acceptés et reconnus comme des contributeurs positifs au fonctionnement des écosystèmes et aux systèmes alimentaires locaux.

8. Potentiel des résultats C-AZA

La méthodologie C-AZA vise à identifier les opportunités de développement d'une aquaculture circulaire en combinant plusieurs niveaux d'analyse : la compatibilité environnementale des espèces, leur performance technique et socio-économique, et enfin les scénarios d'association d'espèces dans des systèmes de production intégrés. Cette approche permet d'orienter les choix de diversification et d'innovation pour les territoires aquacoles.



8.1. Indice de durabilité du Site (SSI)

L'indice de durabilité (SSI : Site Suitability Index), mesure l'adéquation entre les conditions environnementales d'un site et les exigences physiologiques d'une espèce. Cet indice est calculé à partir de plusieurs paramètres environnementaux tels que la température, l'oxygène dissous, la turbidité, la salinité et la disponibilité trophique (chlorophylle-a). Les données environnementales sont comparées aux seuils critiques et aux plages optimales de tolérance des espèces afin de produire un score mensuel de compatibilité. Le score varie généralement entre 0 et 1 (*tableau 2*) : plus la valeur est élevée, plus les conditions sont favorables au développement de l'espèce.

Tableau 2 : SSI (Site Suitability Index) pour les espèces sélectionnées

Nom scientifique des espèces	Nom vernaculaire	SSI
<i>Sparus aurata</i>	Dorade	0.62
<i>D. labrax</i>	Bar	0.67
<i>M. galloprovincialis</i>	Moule	0.42
<i>M. gigas</i>	Huitre creuse	0.64
<i>Ostrea edulis</i>	Huitre plate	0.42
<i>R. decussatus</i>	Palourde	0.67
<i>H. tubulosa</i>	Concombre de mer	0.52
<i>Chelon (Liza) ramada</i>	Mulet	0.81
<i>P. lividus</i>	Oursin	0.52
<i>Gracilaria sp.</i>	Gracilaire	0.32
<i>Porphyra sp.</i>	Nori	0.46

Concernant la lagune de Thau, le mulet a obtenu le SSI le plus élevé, suivi du bar, de la palourde, puis de l'huitre creuse.



L'interprétation de ces résultats montre que ces espèces présentent une compatibilité environnementale globalement favorable, mais avec des variations saisonnières importantes. Par exemple, les conditions de température et d'oxygène sont particulièrement favorables durant les mois printaniers et estivaux, tandis que certains paramètres comme la salinité ou la disponibilité trophique peuvent devenir limitants à certaines périodes de l'année. Cette variabilité souligne l'importance de prendre en compte la dynamique saisonnière des conditions environnementales dans la planification aquacole.

Le SSI constitue donc un premier filtre permettant d'identifier les espèces potentiellement adaptées au site étudié.

8.2. Indice de Performance des Espèces (IPI)

L'indice de performance des espèces (IPI : Innovation Performance Index), évalue la pertinence du développement d'une espèce au regard de critères techniques, économiques et sociétaux (tableau 3).

Cet indice repose sur plusieurs catégories de critères pondérés :

- L'aire de distribution et l'existence d'une aquaculture déjà développée,
- Le niveau de domestication et les connaissances sur le cycle de vie,
- Les exigences alimentaires et le modèle de production,
- Les performances de croissance et de survie,
- La valeur de marché et les opportunités de valorisation,
- L'acceptabilité sociétale et l'opinion des consommateurs.

Chaque critère est associé à un poids et à un score, permettant de calculer un score global IPI pour chaque espèce (tableau 3)

Tableau 3 : IPI pour les espèces sélectionnées

Nom scientifique des espèces	Nom vernaculaire	IPI
<i>Sparus aurata</i>	Dorade	0.65
<i>Dicentrarchus labrax</i>	Bar	0.65
<i>Mytilus galloprovincialis</i>	Moule	0.79



<i>Magallana gigas</i>	Huitre creuse	0.77
<i>Ostrea edulis</i>	Huitre plate	0.69
<i>Ruditapes decussatus</i>	Palourde EU	0.46
<i>Holothuria tubulosa</i>	Concombre de mer	0.36
<i>Chelon (Liza) ramada</i>	Mulet	0.51
<i>Paracentrotus lividus</i>	Oursin violet	0.44
<i>Gracilaria sp.</i>	Gracilaire	0.73
<i>Porphyra sp.</i>	Nori	0.62

Le tableau ci-dessus synthétise ces différentes dimensions et met en évidence les espèces présentant le meilleur potentiel de développement dans un contexte donné : la moule, l’huitre creuse puis la gracilaire. Ces espèces obtiennent un score élevé grâce à une bonne connaissance de leur cycle de production, une forte acceptabilité sur le marché et une disponibilité sécurisée du naissain.

L’interprétation de cet indice permet ainsi de dépasser la seule compatibilité environnementale pour intégrer les conditions réelles de mise en œuvre technique et économique de nouvelles productions. Les résultats montrent que certaines espèces présentent un potentiel intéressant mais nécessitent encore des travaux de recherche ou de structuration de filière pour lever certains verrous techniques ou sociétaux.

8.3. Scénarios d’association d’espèces dans les C-AZA

La troisième étape de la modélisation C-AZA consiste à analyser des scénarios d’association d’espèces, afin d’identifier des systèmes de production multi trophiques susceptibles d’améliorer la circularité des activités aquacoles (tableau 4).

Dans l’étude menée pour la lagune de Thau, 11 espèces ont été analysées, appartenant à différents niveaux trophiques : espèces nourries (poissons), filtreurs (mollusques), détritivores et producteurs primaires (algues).

Les résultats sont présentés dans le tableau 4 indiquant un indice



d'association (IS), qui mesure la cohérence écologique et fonctionnelle des combinaisons de deux, trois ou quatre espèces.

Tableau 4 : Indice C-AZA des scénarios propices à une aquaculture circulaire

Scénario		Nombre d'espèces	C-AZA
1	<i>D. labrax + M. gigas + H. tubulosa + Gracilaria / Pyropia</i>	4	0.59
2a	<i>D. labrax + M. gigas + H. tubulosa</i>	3	0.55
2b	<i>D. labrax + M. gigas + P. lividus</i>	3	0.60
3	<i>D. labrax + M. gigas + P. lividus + Gracilaria</i>	4	0.64
4	<i>M. gigas + H. tubulosa + Gracilaria</i>	3	0.57
5	<i>M. gigas + P. lividus + Gracilaria</i>	3	0.51
6	<i>M. gigas + Chelon ramada + Gracilaria</i>	3	0.63
7	<i>M. gigas + Gracilaria</i>	2	0.50

Certains scénarios obtiennent des scores particulièrement élevés, notamment ceux associant :

- Des mollusques filtreurs comme *Magallana gigas*,
- Des poissons comme *Sparus aurata* ou *Dicentrarchus labrax*,
- Des espèces extractives telles que les algues (*Gracilaria sp.*),
- Des détritivores comme le concombre de mer (*Holothuria tubulosa*).

Ces associations illustrent le potentiel de systèmes d'aquaculture multi trophique intégrée (IMTA) capables de valoriser les flux de nutriments et de réduire les impacts environnementaux des élevages.



La méthode C-AZA révèle un scénario prometteur avec un haut score de 0,64 pour la combinaison de 4 espèces : *D. labrax* + *M. gigas* + *P. lividus* + *Gracilaria* (Scénario 3 dans le tableau 4) Toutefois, les résultats soulignent également certaines limites, notamment liées aux conditions environnementales locales dans la lagune de Thau (par exemple la salinité, la quantité de producteurs primaire) et au niveau actuel de connaissance sur certaines espèces. Les travaux futurs devront donc approfondir ces aspects afin de consolider les scénarios les plus prometteurs.

8.4. Conclusion

Les résultats de la modélisation C-AZA mettent en évidence le potentiel de diversification et d'intégration de nouvelles espèces dans les systèmes aquacoles méditerranéens. L'approche combinant compatibilité environnementale, performance technique et scénarios multi trophiques constitue un outil d'aide à la décision pour orienter le développement de l'aquaculture vers des modèles plus durables et circulaires.

La transition vers des modèles aquacoles circulaires devra également intégrer la dimension saisonnière des systèmes de production méditerranéens. Certaines espèces ou associations multi trophiques peuvent être plus adaptées à des périodes spécifiques de l'année, ce qui ouvre la voie à des modèles de production saisonniers ou alternés, permettant d'optimiser l'utilisation des ressources environnementales tout en renforçant la résilience des exploitations.

9. Actions proposées

9.1. Actions et interventions clés

La diversification des espèces dans la lagune de Thau constitue un levier majeur pour améliorer la durabilité du secteur aquacole. Elle repose sur l'identification de nouvelles espèces à fort potentiel écologique et économique, à l'aide de la méthode innovante C-AZA du projet. Ces approches visent à restaurer les interactions fonctionnelles entre les espèces, à réduire les rejets, à optimiser l'utilisation des ressources et à renforcer les services écosystémiques.

Le développement de l'AMTI, en particulier les systèmes incluant des algues, doit être encouragé dans l'avenir de l'aquaculture. Les visions des scientifiques et des aquaculteurs affirment les impacts positifs de ces



pratiques.

Les scientifiques proposent également des scénarios d'adaptation face au changement climatique, en plus de la diversification et de l'AMTI. Ces adaptations incluent la relocalisation de certaines activités aquacoles en mer, notamment les moules qui sont moins résilientes dans la lagune de Thau. L'eau de mer offre aux cultures des conditions plus favorables, comme la température et l'acidité du milieu.

La coopérative des conchyliculteurs méditerranéens vise à favoriser les productions en conchyliculture. Selon eux, un élément clé pour sécuriser la production régionale est de développer une filière structurée qui repose sur la mutualisation des infrastructures et le transfert de compétences.

En réponse au vieillissement de la filière, le CRCM a engagé en 2021 un contrat de développement de la filière conchylicole en Méditerranée. La première phase (2021–2024) a porté sur la stabilisation et l'adaptation, tandis que la seconde phase (2024–2029), désormais étendue à la région Sud PACA, vise à accompagner des transformations structurelles plus profondes.

Les formations sont également des éléments clés à valoriser au sein d'une filière en pleine évolution. Dans un processus de transition, le secteur doit se munir de dispositifs permettant le transfert de données, de connaissances et de compétences. Ces éléments clés sont également des leviers pour permettre aux innovations, comme la méthode C-AZA, d'être transmis.

Le secteur doit également saisir de nouvelles opportunités commerciales, et favoriser les circuits courts, pour valoriser les produits durables en mettant en avant leurs qualités ainsi que leurs origines locales. Pour cela la création d'un label certifiant l'origine des produits pour mieux informer les consommateurs est une piste d'action. Déjà envisagée, sa mise en place se heurte à des difficultés. Saisir ces opportunités permettrait de s'orienter vers des plans économiques plus rentables et viables à long terme.

L'émergence de nouvelles pratiques aquacoles nécessitera une évolution des cadres réglementaires et juridique. Ce cadre est généralement qualifié de complexe et multi-niveaux par les acteurs de la filière freinant le développement de projet.

Les documents de planification territoriale sont également concernés et devront être adaptés. Sur la lagune de Thau, le Schéma de Cohérence Territorial, est un document d'urbanisme qui fixe une stratégie et un cadre pour l'aménagement et le développement du territoire. Le SCOT vise à concilier l'ensemble des activités du territoire, notamment le



développement de l'aquaculture occupant une place de plus en plus importante.

Une politique publique forte et adaptée est nécessaire pour accompagner l'évolution du secteur aquacole et sécuriser l'accès aux zones de production, en cohérence notamment avec les objectifs du Comité Régional de la Conchyliculture de Méditerranée (CRCM).

L'accès au financement constitue un autre élément clé pour soutenir le développement de l'aquaculture. Les structures d'accompagnement jouent un rôle essentiel pour informer, guider et accompagner les porteurs de projets et les entreprises aquacoles dans l'identification et l'accès aux financements.

Enfin, la coopération entre l'ensemble des acteurs de la filière, les scientifiques, les professionnels et les autorités publiques est essentielle au développement d'une aquaculture durable. Elle favorise la recherche, le transfert de connaissances et le développement de solutions innovantes adaptées aux enjeux environnementaux et économiques de la lagune. Cette coopération doit s'appuyer sur des échanges réguliers et des espaces de concertation afin de soutenir la prise de décision, en tenant compte des attentes de l'ensemble des acteurs du secteur.

9.2. Acteurs responsables

La mise en œuvre d'actions en faveur d'une aquaculture durable dans la lagune de Thau nécessite une coopération étroite entre l'ensemble des parties prenantes.

Les entreprises aquacoles sont les acteurs opérationnels. Elles mettent en œuvre les projets, testent et développent des pratiques innovantes et durables, et assurent la promotion de leurs activités et de leurs produits.

Les organismes scientifiques, comme l'Ifremer, participent aux expérimentations sur la diversification des cultures ou des élevages voir à la domestication de nouvelles espèces, à l'élaboration de scénarios d'adaptation dans la lagune de Thau et au soutien à l'innovation, en lien étroit avec les professionnels.

Les centres techniques tels que le Cedralmar sont dédiés à la mutualisation d'équipements et à la recherche appliquée. Ils accompagnent la validation de procédés techniques par des essais, prototypes et expertises et sont des



interfaces entre la recherche, l'industrie et les institutions.

Les formateurs sont des éléments moteurs dans la transition vers une filière structurée et durable. Les formations sont des leviers stratégiques pour assurer la maîtrise des nouvelles techniques et des bonnes pratiques en aquaculture.

Les organisations professionnelles, telles que le CRCM et les coopératives conchylicoles méditerranéennes, assurent la structuration du secteur et la mutualisation des ressources. Elles contribuent à la coordination des acteurs, à l'accompagnement des entreprises et au renforcement des modèles économiques.

Les structures de l'accompagnement sont également des structures clés. Le SMBT, CPIE et les pôles de compétitivité, notamment le Pôle Mer Méditerranée, jouent un rôle essentiel dans l'accompagnement au montage de projet et l'accès aux financements régionaux, nationaux et européens.

Les autorités publiques garantissent le cadre réglementaire des activités aquacoles et la sécurité sanitaire des productions. À l'échelle locale, les collectivités territoriales, notamment à travers le SCOT du bassin de Thau piloté par le SMBT. LE SMBT pilote et évalue les politiques publiques afin d'engager le bassin de Thau dans une dynamique de transition écologique et favoriser sa résilience. En s'appuyant sur l'animation territoriale et la concertation des acteurs locaux, il met à profit une expertise reconnue en gestion intégrée et en ingénierie environnementale. Les collectivités territoriales jouent un rôle central dans l'intégration des activités aquacoles au sein de l'écosystème du Thau, notamment les régions Occitanie et Sud Provence-Alpes-Côte d'Azur (PACA).

9.3. Calendrier

A court terme, les priorités portent sur l'adaptation du cadre réglementaire du secteur aquacole, qui se réalisera en deux temps, en termes de production et de vente. L'objectif est de réduire les freins à la mise en place des nouvelles pratiques sur la lagune de de Thau. Cette étape est essentielle pour favoriser le développement et l'utilisation de solutions innovantes, tout en assurant les recherches dans le secteur et à l'acquisition de connaissances, notamment sur l'AMTI et la diversification des espèces.

À moyen et long terme, l'objectif est de faire évoluer les projets pilotes vers



des applications opérationnelles et des projets concrets de diversification des espèces. Pour cela, une mutualisation de la filière, notamment des structures, des équipements et des connaissances, sera nécessaire et devra être anticipé. L'objectif est de structurer la filière de l'aquaculture pour assurer les productions et leurs commercialisations.

À long terme, l'ambition est d'améliorer significativement la résilience économique du secteur aquacole tout en réduisant son impact environnemental (tableau 5).

Tableau 5: Calendrier prévisionnel des actions proposées

Court terme	Moyen terme	Long terme
<ul style="list-style-type: none"> -Adaptation du cadre réglementaire (Production et vente). -Adaptation des documents de planification. 	<ul style="list-style-type: none"> -Applications opérationnelles des projets pilotes. -Mutualisation des équipements, des structures et des connaissances pour la structuration de la filière. -Adaptation du cadre réglementaire (Production et vente). -Adaptation des documents de planification. 	<ul style="list-style-type: none"> -Implémentation des systèmes AMTI. -Implémentation des formations adaptées pour la transition de la filière. -Résilience économique des entreprises, réduction de l'impact environnemental à travers la circularité des systèmes et meilleure utilisation des ressources.

9.4. Aspects financiers et sources de financement

Plusieurs dispositifs de financement sont mobilisables pour soutenir le développement d'une aquaculture durable, à différentes échelles.

Les régions Occitanie et Sud PACA proposent des aides financières locales pour soutenir les projets aquacoles portés par les acteurs territoriaux. À l'échelle nationale, des appels à projets permettent de mobiliser des ressources via le FEAMPA (Fonds Européen pour les Affaires Maritimes, la Pêche et l'Aquaculture), notamment à travers le DLAL FEAMPA et le GALPA de Thau, qui apportent un soutien spécifique au développement local mené par les acteurs de la pêche et de l'aquaculture.



Enfin, les programmes européens, tels qu'Horizon Europe (appels à projet du Cluster 6 – Alimentation, bioéconomie, ressources naturelles, agriculture et environnement) et le Conseil Européen de l'Innovation (EIC), constituent des leviers majeurs pour le financement de projets innovants dans le domaine de l'aquaculture durable.

10. Suivi et évaluation

Le suivi repose sur des indicateurs environnementaux, économiques et sociaux. L'objectif est de proposer des critères d'évaluation qui permettent de suivre une transition efficace (tableau 6).

Tableau c: Suivi et évaluation de la filière de l'aquaculture sur le bassin de Thau

Dimension	Ce qui est évalué	Exemples d'indicateurs
Environnement	<ul style="list-style-type: none"> - Diversification de l'aquaculture. - Résilience des espèces au changement climatique. - Exploitation intégrant l'AMTI. - Réduction de l'impact environnemental. 	Qualité de l'eau et des sédiments, la biodiversité, taux de mortalité des espèces, nombre d'AMTI mise en place, espèces extractives.
Économie	<ul style="list-style-type: none"> - Viabilité des entreprises. - Diversification des revenus. - Meilleure utilisation des ressources. 	Nombre d'entreprises, création de nouvelles exploitations, production, chiffre d'affaires, emploi, diversification des productions.
Social	<ul style="list-style-type: none"> - Attractivité de la filière. - Renouvellement générationnel. - Mise en place de circuit court. - Centre de formation. 	Âge des exploitants, nombre d'installations, acceptation sociale (consommation des produits), mise en place de formations



11. Conclusion

Ce Plan d'Action s'inscrit dans une transition de l'aquaculture méditerranéenne française plus durable et circulaire, en particulier sur le territoire de la lagune de Thau. Face aux effets du changement climatique, à la fragilisation des écosystèmes et aux tensions économiques et démographiques du secteur, la filière doit opter pour une évolution.

Ce Plan d'Action fournit un cadre cohérent pour accompagner cette transition. Il constitue ainsi un document opérationnel basé sur l'état actuel de l'aquaculture et sur le retour des acteurs de la filière en Méditerranée française.

La transition vers des modèles plus résilients, circulaires et diversifiés représente une nécessité. Elle repose sur plusieurs piliers complémentaires : la diversification des espèces, le développement de l'Aquaculture Multi-Trophique Intégrée, l'intégration de nouvelles espèces, la relocalisation stratégique de certaines productions en mer, ainsi que l'appui à l'innovation technologique. Les résultats de la méthodologie C-AZA mettent en avant des opportunités de diversification et de systèmes circulaires.

Cependant, la réussite de cette transition ne dépend pas uniquement des solutions techniques. Elle suppose une gouvernance coordonnée, une évolution des cadres réglementaires réduisant les freins, un accompagnement financier adapté et un renforcement continu des compétences professionnelles. La coopération entre scientifiques, producteurs, centres techniques, organisations professionnelles et autorités publiques apparaît comme la condition essentielle pour aller vers une aquaculture durable.



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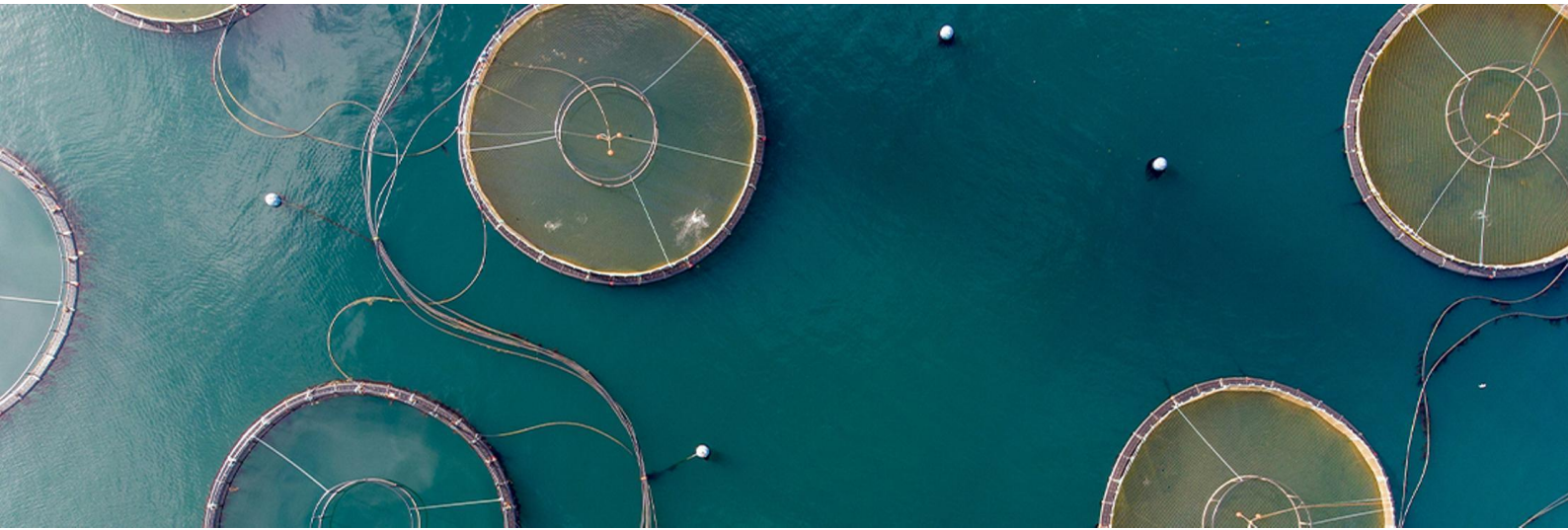


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Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Varna Bay, Bulgaria

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Abbreviations

AZA	Allocated Zone for Aquaculture
C-AZA	Circular Allocated Zone for Aquaculture
C-AZAi	C-AZA Index
GES	Good Environmental Status
HAPO	Hellenic Aquaculture Producers Organisation
IMTA	Integrated Multi-Trophic Aquaculture
LIRRIE	Living Responsible Research & Innovation Ecosystems
NECCA	Natural Environment and Climate Change Agency
SAC	Special Area of Conservation
SiSI	Site Suitability Index
SPA	Special Protection Area



1. Executive Summary

The **Action Plan for Bulgaria** has been developed within the framework of the project “*Allocated Zones for circular Aquaculture to trigger the transition to an Inclusive and Circular Economy in aquaculture sector fostering new business opportunities and eco-consciousness society*” (AZA4ICE). Its purpose is to support the sustainable development of marine aquaculture through the application of the Allocated Zones for Circular Aquaculture (C-AZA) methodology. The plan focuses on realistic and implementable steps that build upon existing aquaculture activities rather than proposing large-scale expansion or the creation of new zones disconnected from current practice.

The analysis of the current situation shows that marine aquaculture in Bulgaria operates under conditions of limited marine space, strong competition with other maritime uses, and a complex regulatory framework, while at the same time demonstrating clear potential for diversification and the adoption of circular and multi-trophic production models. Results from BLUEfasma Circularity self-assessment tool and consultations within the LiRRIE group confirm a high level of investment readiness, provided that greater spatial and regulatory predictability is ensured.

The application of the C-AZA methodology in Bulgaria was carried out in areas with already established aquaculture activities, enabling both verification of the methodology and identification of opportunities to upgrade existing businesses. The results indicate that multi-trophic aquaculture is assessed as suitable (good), though not universally optimal, while Recirculating Aquaculture Systems (RAS) show high potential at appropriate coastal locations. Diversification beyond mussel farming — including oysters and combined systems with finfish (e.g., seabass) — is realistic under certain conditions.

The Action Plan proposes a set of priority measures aimed at:

- improving existing marine aquaculture through the C-AZA approach;
- piloting Integrated Multi-Trophic Aquaculture (IMTA) systems;
- developing land-based RAS units for specific species (e.g., turbot);
- better coordination between C-AZA and the Maritime Spatial Plan;
- strengthening capacity-building and stakeholder dialogue.



The Action Plan is a practical tool that can be used in consultations, pilot initiatives, and future planning processes. It is fully aligned with the National and European strategic frameworks for aquaculture development.

2. Introduction

The Action Plan has been developed within the framework of the Interreg Euro-Med project “*Allocated Zones for Circular Aquaculture to trigger the transition to an Inclusive and Circular Economy in the aquaculture sector fostering new business opportunities and eco-consciousness society (AZA4ICE)*”. The Plan aims to support the implementation of the Circular Aquaculture Zones (C-AZA) approach in Bulgaria, with a focus on marine aquaculture along the Bulgarian Black Sea coast. The document serves as an operational framework designed to translate the overarching transnational strategy of the AZA4ICE project into the specific national and regional context.

The geographical scope of the Action Plan covers the territorial waters of the Republic of Bulgaria, with particular attention to the pilot areas analysed within the project (the area north of Varna Bay), without limiting the applicability of the proposed measures to other suitable coastal zones.

The main objectives of the Action Plan are to:

- identify the key challenges, needs, and opportunities for **the development of circular marine aquaculture** in Bulgaria;
- integrate the results from the stakeholder engagement process (LiRRIE forum), **the regulatory analysis**, and the assessment of circular business models among aquaculture operators;
- propose concrete actions and measures aimed at **implementing the C-AZA methodology**;
- support dialogue and coordination among public authorities, businesses, research organisations, and other stakeholders.

Aquaculture sector in Bulgaria

The development of aquaculture in Bulgaria is closely linked to the country’s long-term economic and institutional transformations. The sector experienced strong growth during the period 1960–1990, when production was based on large pond systems, targeted public investments, and stable domestic demand.



This upward trend reached its peak in the 1980s, with Bulgaria recording its highest historical aquaculture output in 1984 — **14,571 tonnes** (FAO data). The subsequent political and economic changes of the late 1980s and early 1990s led to a sharp decline in the sector, driven by lack of financing, fragmentation of production structures, and deteriorating management of existing infrastructure. Since the late 1990s, the Bulgarian aquaculture sector has entered a period of partial recovery and structural transformation. After 2000, moderate growth is observed, reaching between **14,000 and 16,000 tonnes** in the period 2015–2019, followed by a new decline in recent years.

As of 2023, total aquaculture production is estimated at **approximately 10,000–11,000 tonnes**, comprising a variety of freshwater and marine species. The species composition has shifted over time, with rainbow trout becoming the dominant species and accounting for a significant share of production, alongside traditional carp species. Bulgaria is also characterized by the presence of marine aquaculture, primarily through the cultivation of the Black mussel (*Mytilus galloprovincialis*), which in recent years represents around one-seventh of total production but remains highly sensitive to environmental conditions and market dynamics. This long-term trajectory reflects both the structural constraints of the sector and the development opportunities arising from European policies and financial instruments supporting sustainable and circular aquaculture.

Freshwater production is relatively more diversified and stable, whereas marine aquaculture in Bulgaria remains highly concentrated, primarily around the cultivation of the Black mussel (*Mytilus galloprovincialis*) along the Bulgarian Black Sea coast. Such single-species production ensures economic viability but simultaneously limits opportunities for diversification, benefit, and broader adoption of innovative and circular production systems.

The Bulgarian Black Sea coast is characterised by a limited number of naturally sheltered marine areas and by competition among various maritime and coastal activities, including tourism, maritime transport, fisheries, military zones, and nature conservation. This places marine aquaculture in a context of heightened spatial and environmental sensitivity and underscores the need for more targeted and coordinated spatial planning.

At the national level, the development of the sector is framed by the Multiannual National Strategic Plan for Aquaculture, as well as by the



relevant European policies related to the Blue Economy, the Green Deal, and the transition to a circular economy.

Nevertheless, the practical implementation of circular approaches in marine aquaculture remains limited, with businesses and institutions often facing regulatory, spatial, and investment uncertainties.

Within the AZA4ICE project, the application of the Living Responsible Research Innovation Ecosystems (LiRRIE) methodology enabled the establishment of a structured dialogue process among science, industry, public authorities, and other stakeholders. This process highlighted the need for an integrated approach that combines spatial planning, environmental requirements, and economic sustainability.

In this context, the Circular Aquaculture Zones (C-AZA) methodology is considered a practical tool to support the development of marine aquaculture in Bulgaria. It aims to promote more efficient use of marine space, reduce conflicts between different maritime activities, and create favourable conditions for the adoption of circular and multi-trophic aquaculture production models.

3. Role and Responsibilities of Key Stakeholders

The implementation of the Circular Aquaculture Zones (C-AZA) methodology in Bulgaria requires coordinated participation from a wide range of public institutions, regulatory authorities, research organisations, business operators, and other stakeholders. These actors hold direct or indirect responsibilities related to the management, control, and planning of the use of marine and coastal space.

The aquaculture sector is closely linked to policies on land use, maritime spatial planning, environmental protection, food safety, and regional development. For this reason, clear distinction of roles and effective inter-institutional coordination are critical prerequisites for the successful application of the C-AZA approach.

Organisation	Main role and responsibilities
Ministry of Agriculture and Food (MAF)	Development and implementation of national aquaculture policy; management of the Maritime, Fisheries and Aquaculture Programme as an EU financial instrument; strategic planning and coordination with European policies.



Executive Agency for Fisheries and Aquaculture (EAFA)	Registration, licensing, and control of aquaculture activities; enforcement of the regulatory framework; monitoring and reporting of production.
Bulgarian Food Safety Agency (BFSA)	Control of food safety and animal health; approval and supervision of aquaculture facilities; veterinary and sanitary requirements.
Ministry of Environment and Water (MEW)	Policies and regulations in the field of environmental protection; Environmental Impact Assessment (EIA) and Appropriate Assessment procedures; implementation of EU environmental legislation.
Environment Executive Agency (EEA)	National environmental monitoring; collection and analysis of data on the status of waters and the marine environment; information support for planning and regulatory control.
Regional Inspectorates for Environment and Water (RIEW)	Territorial enforcement of environmental legislation; participation in EIA procedures and oversight of activities at the local level.
Basin Directorates	Water management at river basin level; permitting regimes for water abstraction and discharge; control of water quantity and quality, including in coastal areas.
Ministry of Regional Development and Public Works (MRDPW)	Development and coordination of the Maritime Spatial Plan of the Republic of Bulgaria 2021–2035; integration of sectoral interests, including aquaculture, into spatial planning.
Aquaculture operators and business	Implementation of production activities; investments in infrastructure and technology; application of circular and multi-trophic models; participation in pilot initiatives.
Institute of Fisheries and Aquaculture	Scientific research and development; development and testing of technologies; expert support for policies and projects.
Institute of Fish Resources	Research on marine ecosystems and resources; scientific support for spatial analysis, monitoring, and sustainable management of marine aquaculture.



Non-governmental organization (NGOs) and Fisheries Local Action Groups (FLAGs)	Representation of local and sectoral interests; support for local development; participation in consultations and community engagement.
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4. Key Challenges and Opportunities for Development

This section summarises the main issues, challenges, and development opportunities for marine aquaculture in Bulgaria, identified during expert meetings held under the AZA4ICE project. The analysis is based on expert discussions and consultations with stakeholders from the public sector, industry, academia, and non-governmental organisations. It reflects the real constraints and potential for applying the **C-AZA methodology** under Bulgarian conditions.

4.1 Main challenges

A key challenge is the need for better coordinated spatial planning for marine aquaculture. The absence of clearly defined and pre-agreed zones for aquaculture development creates uncertainty for investors and increases the risk of conflicts with other maritime activities.

Additionally, stakeholders emphasise the need for greater regulatory clarity and predictability, particularly regarding permitting procedures and their timelines, environmental assessments, and the interaction between different competent authorities. This is especially important for new or innovative production models, including multi-trophic and circular aquaculture.

From the perspective of both industry and the scientific community, there is also a recognised need to strengthen capacity and technical expertise related to the implementation of circular models, environmental risk management, and adaptation to climate change.

4.2 Key challenges

The development of marine aquaculture in Bulgaria faces a combination of spatial, environmental, regulatory, and economic challenges.

Among the main spatial challenges are:



- a limited number of suitable and naturally sheltered marine areas;
- competition with tourism, shipping, commercial fisheries, defence activities, and other maritime uses;
- insufficiently detailed spatial analyses tailored to the needs of the sector.

The environmental challenges include:

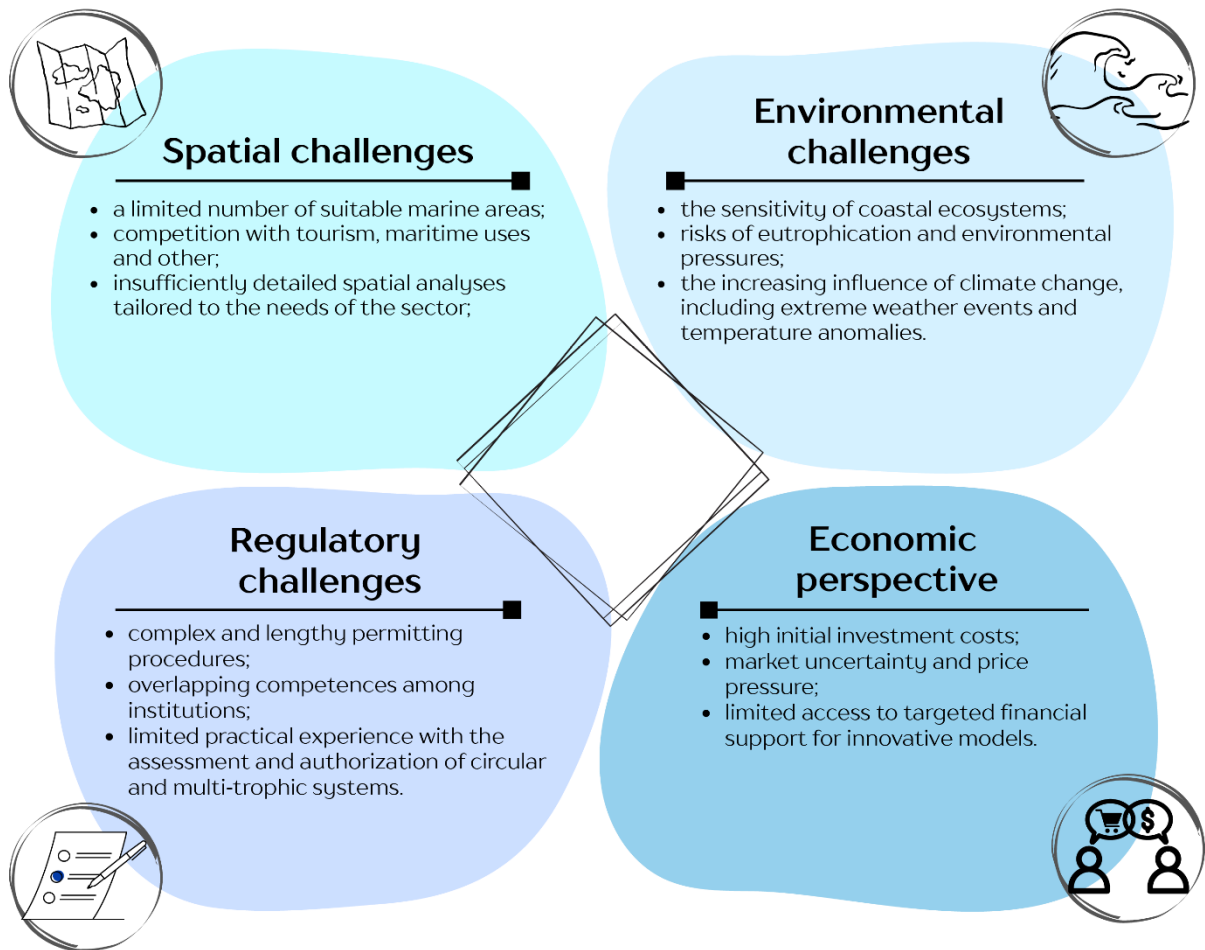
- the sensitivity of coastal ecosystems;
- risks of eutrophication and localised environmental pressures;
- the increasing influence of climate change, including extreme weather events and temperature anomalies.

The regulatory and administrative challenges are reflected in:

- complex and lengthy permitting procedures;
- overlapping competences among institutions;
- limited practical experience with the assessment and authorisation of circular and multi-trophic systems.

From an economic perspective, businesses highlight:

- high initial investment costs;
- market uncertainty and price pressure (lack of competitiveness);
- limited access to targeted financial support for innovative models.



4.3 Opportunities for Development

There are significant opportunities for the development of marine aquaculture in Bulgaria, particularly in the context of the circular economy.

One of the key opportunities is the application of the C-AZA methodology as a tool for planning and coordination, which can reduce conflicts between different maritime activities and create a more favourable investment environment.

Additional opportunities include:

- development of Integrated Multi-Trophic Aquaculture (IMTA) systems combining species from different trophic levels;
- increasing added value through species diversification;
- leveraging national scientific and research capacity to test and adapt innovative solutions;



- better utilisation of European policies and financial instruments supporting sustainable and circular models.



Collaboration between the public sector, industry, and the scientific community, supported by consultative mechanisms such as the **Living Responsible Research and Innovation Ecosystem (LiRRIE)** — is considered a key factor for transforming these opportunities into practical and implementable solutions.

5. Regulatory Framework

This section presents an extended analysis of the current legal, regulatory, and administrative framework governing the aquaculture sector in Bulgaria, with a particular focus on marine aquaculture. The analysis is based on the results of the regulatory review carried out under the AZA4ICE project, as well as on expert discussions within the LiRRIE working group.

The purpose of this section is not only to summarise the applicable laws, regulations, and EU acts, but also to outline the practical implications of their implementation, the main regulatory challenges, and the opportunities for improving predictability and coordination through the application of the C-AZA approach.



5.1 Characteristics of the Regulatory Framework

The regulation of the aquaculture sector in Bulgaria is carried out through a multi-level and sectorally fragmented legal system, comprising national legislation, secondary regulations, and applicable European Union directives and regulations. Marine aquaculture simultaneously falls under the scope of policies and regimes related to:

- agriculture, fisheries, and aquaculture;
- environmental protection and biodiversity conservation;
- water management;
- maritime spatial planning;
- food safety and veterinary control.

As a result of this complexity, numerous competent authorities are involved in management, permitting, control, and monitoring processes, including the Ministry of Agriculture and Food, the Executive Agency for Fisheries and Aquaculture, the Ministry of Environment and Water and its regional structures (Regional Inspectorates of Environment and Water, River Basin Directorates), as well as the Bulgarian Food Safety Agency (BFSA).

Although the mandates of individual institutions are clearly defined, the lack of an integrated and coordinated approach often leads to complicated and long procedures, particularly in the case of marine aquaculture.

5.2 Key Sectoral Legislation and Regulatory Regime

Fisheries and Aquaculture Act (FAA)

The Fisheries and Aquaculture Act is the primary legislative act regulating the breeding and rearing of fish and other aquatic organisms. The Act provides the legal definition of “aquaculture” and establishes registration regimes, administered by the Executive Agency for Fisheries and Aquaculture (EAFA):

- persons engaged in the breeding and rearing of fish and other aquatic organisms;
- the production of carriers of genetic material from hydrobionts.

When technical installations are placed in the waters of the Black Sea, registration is carried out following additional approvals, where applicable. The FAA also requires the maintenance of specialised registers and the submission of a technological description and production flow scheme.



Water Act (WA)

The Water Act introduces permitting regimes for the use of water bodies for aquaculture and related activities, administered by the River Basin Directorates. These regimes are directly linked to:

- conditions for water use and/or wastewater discharge;
- compliance with the environmental objectives for water bodies;
- requirements for preventing negative and cumulative impacts.

The WA is really important for marine aquaculture, as its requirements are often applied jointly with environmental procedures under the Environmental Protection Act (EPA) and the Biodiversity Act (BDA).

Veterinary Medical Activity Act (VMAA)

The VMAA regulates the registration of livestock establishments under Article 137 and introduces veterinary and biosecurity requirements, as well as hygiene standards for aquaculture production facilities. The competent authority is the **Bulgarian Food Safety Agency (BFSA)**. The requirements under this Act are essential for ensuring animal health status and the safety of aquaculture products.

5.3 Secondary Legislation and Practical Implementation

The practical requirements for aquaculture activities are specified in secondary legislation, including:

- **Ordinance No. 37 of 10 November 2008 on the use of state-owned reservoirs for fisheries purposes and the rules for commercial and recreational fishing and aquaculture in state-owned water bodies under Article 3(1) of the Fisheries and Aquaculture Act** – regulates the rules for conducting aquaculture in state-owned water bodies, including the Black Sea.
- **Ordinance No. 7 of 21 November 2019 on maintaining the registers under Article 16(1) of the Fisheries and Aquaculture Act** – sets out the procedures for maintaining the registers under the FAA.
- **Ordinance No. 18 of 4 November 2016 on the content of the technological description and the technological production**



- scheme for aquaculture** – defines the requirements for the technological description and production scheme.
- **Ordinance No. 4 of 20 October 2000 on the quality of waters for fish farming and for the cultivation of shellfish** – establishes water quality requirements for fish farming and shellfish cultivation, directly relevant to mussels and oysters.
 - **Ordinance on the conditions and procedures for Environmental Impact Assessment (EIA), adopted under the Environmental Protection Act** – regulates the conditions and procedures for conducting Environmental Impact Assessments, including screening rules, reporting requirements, and annexes.
 - **Ordinance on the conditions and procedures for Appropriate Assessment of plans, programmes, projects, and investment proposals for compatibility with the conservation objectives of protected areas (Article 31 of the Biodiversity Act, Natura 2000)** – regulates the Appropriate Assessment under Article 31 for Natura 2000 compatibility.
 - **Ordinance No. 44 of 20 April 2006 on veterinary requirements for livestock establishments** and **Ordinance No. 36 of 23 March 2006 on specific requirements for the production, transport, and placing on the market of raw materials and foods of animal origin** – regulate veterinary and hygiene requirements for establishments and products of animal origin.

This set of secondary legislation provides detailed regulation but also increases administrative complexity, particularly when several regimes must be applied simultaneously.

5.4 EU directives with direct impact on marine aquaculture

Water Framework Directive (2000/60/EC)

The Water Framework Directive establishes the objectives for achieving and maintaining “good ecological status” of water bodies. In Bulgaria, the directive is integrated into the national legislative framework through the Water Act and implemented through the River Basin Management Plans. For marine aquaculture, the Directive is relevant in terms of the permissible scale and intensity of activities and the assessment of cumulative impacts.



Habitats and Birds Directives (Natura 2000)

The Habitats Directive and Birds Directive, transposed through the Biodiversity Act, are of key importance for marine aquaculture, as a significant share of Bulgaria's coastal and marine areas falls within Natura 2000 sites. Investment proposals are subject to Appropriate Assessment, which often represents a major source of uncertainty and delays, including for innovative or circular production models.

5.5 Key Regulatory Challenges

With regard to the regulatory framework, the analysis and the work of the LiRRIE group identify the following key challenges:

- fragmentation of the legislative and institutional framework;
- sequential and lengthy procedures with limited predictability;
- absence of certain secondary legislation foreseen in primary laws;
- insufficiently specific guidance for circular and multi-trophic systems;
- limited link between spatial planning and permitting regimes.

These factors do not constitute insuperable barriers, but they require targeted coordination and planning solutions.

5.6 Role of the Circular Aquaculture Zones (C-AZA) Methodology

The C-AZA methodology does not replace existing legal regimes, but it can function as a preparatory and coordination tool that:

- supports preliminary assessment of spatial and environmental suitability;
- reduces the risk of substantial revisions during EIA and Appropriate Assessment procedures;
- facilitates coordination between institutions through a shared analytical basis;
- assists in selecting realistic technologies and species adapted to local conditions.

In this way, C-AZA contributes to more predictable and efficient implementation of investments in marine aquaculture, fully aligned with the national and European legal framework.



6. Circular Aquaculture in Bulgaria

This section summarises the current state of the aquaculture sector in Bulgaria in terms of its readiness and capacity to apply the principles of the circular economy. The analysis forms on the results of the **BLUEFasma self-assessment tool** (<http://BLUEFasma.upatras.gr/>) applied within the AZA4ICE project, as well as on expert discussions with sector representatives.

6.1 Circular Economy in Aquaculture

The assessment results show that the aquaculture sector in Bulgaria is at a relatively low level of actual implementation of circular practices, despite the reported high interest and readiness to invest. In most cases, businesses apply basic environmental measures related to resource efficiency and compliance with regulatory requirements, but lack systematically developed circular models that reduce material and/or energy consumption.

This characteristic is particularly evident in marine aquaculture, where production is concentrated on a limited number of species and technologies, and opportunities for diversification and integration with other activities remain underdeveloped.

6.2 Main Limitations Identified by Business Operators

Several groups of constraints have been identified that hinder the wider application of circular approaches in aquaculture:

- Structural and spatial constraints, including the absence of pre-planned and pre-agreed zones for aquaculture development and limited opportunities for expansion or combination of activities;
- Regulatory uncertainty, related to permitting procedures for new or innovative production models, including multi-trophic systems;
- Investment barriers, including high initial capital costs and limited access to targeted financial instruments for innovative (circular) solutions;
- Insufficient technical and managerial capacity, particularly regarding the design, operation, and monitoring of more complex circular systems.



6.3 Readiness for Change and Investment in the Sector

Despite the identified constraints, the results of BLUEFasma clearly indicate a high level of readiness to invest in circular economy practices. A significant share of surveyed enterprises expressed interest in:

- implementing more efficient technologies;
- combining different types of production;
- participating in pilot projects and demonstration initiatives;
- collaborating with research organisations and public institutions.

This gap between strong motivation and limited practical implementation highlights the need for a supportive environment that includes clear spatial planning, coordinated regulatory procedures, and targeted capacity-building measures.

6.4 Importance of the Circular Aquaculture Zones (C-AZA) Methodology

The identified state of the sector confirms that the C-AZA approach has the potential to act as a catalyst for the transition to circular models by:

- reducing spatial and regulatory uncertainty;
- creating conditions for combining different activities and species;
- facilitating access to financing and public support;
- stimulating cooperation between industry, science, and public institutions.

Thus, the results of the BLUEFasma tool represent an important starting point for formulating targeted actions and measures within this Action Plan.

7. Vision

The vision for the development of the marine aquaculture in Bulgaria, formulated within the LiRRIE forum, is oriented towards a gradual but purposeful transition from limited and sector-isolated production practices to a sustainable, spatially planned, and circular-oriented development model.

At the core of this vision lies the understanding that marine aquaculture in Bulgaria should not expand rapidly in terms of production capacity, but should instead improve the quality, sustainability, and added value of existing and future activities. This requires a combination of spatial



planning, regulatory predictability, scientific support, and active engagement of the business sector.

The development of the sector can be supported and guided through the following key directions:

7.1 Strategic Positioning of Marine Aquaculture

Marine aquaculture should be clearly recognised and integrated as a legitimate maritime activity within the framework of maritime spatial planning. This includes:

- identifying and pre-agreeing suitable zones for aquaculture development;
- reducing conflicts with other activities through spatial zoning;
- creating greater investment predictability.

Allocated Zones for Aquaculture (AZA) should be compatible with and potentially integrated into the **Maritime Spatial Plan of the Republic of Bulgaria 2021–2035 (MSP)**, serving as an operational tool for implementing spatial priorities in the aquaculture sector.

While the MSP defines the strategic framework and the balance among different maritime activities, AZA provides a more detailed regulatory and management framework for specific aquaculture activities, including monitoring conditions, spatial allocation, and technological requirements.

The **C-AZA methodology** is viewed as the instrument through which this vision can be operationalised, linking strategic planning with concrete production models.

7.2 Diversification and Transition to Circular and Multi-Trophic Models

The development of marine aquaculture in Bulgaria should be based on diversification of species and production systems, building upon the existing experience with mussel cultivation. The vision includes:

- promoting Integrated Multi-Trophic Aquaculture (IMTA) systems;
- combining different trophic levels to improve resource efficiency;



- gradually introducing circular solutions adapted to local environmental conditions.

This approach is viewed not only as an ecological necessity but also as an opportunity to enhance the economic resilience and added value of the sector.

7.3 Improving the Regulatory Framework

The development vision clearly emphasises that the sector requires a more predictable and coordinated regulatory environment that:

- facilitates the implementation of innovative production models;
- streamlines and coordinates administrative procedures;
- provides clear guidance for the assessment and authorisation of circular and multi-trophic systems, as well as adequate timelines for implementation.

This does not imply lowering environmental standards, but rather improving institutional coordination and sector-level planning.

7.4 Role of Science, Innovation, and Capacity Building

Research and scientific organisations are seen as key partners in implementing the vision through:

- scientific support for spatial analysis and the selection of suitable zones;
- adaptation and testing of technologies under real conditions;
- training and capacity building for operators and public administration.

The vision proposes close cooperation between science and industry, including through pilot projects and demonstration activities that should stimulate the development of the aquaculture sector.

7.5 Social Acceptability and Cross-Sector Dialogue

The development of marine aquaculture should be socially acceptable and aligned with the interests of other maritime sectors, including tourism,



transport, and defence. The work of LiRRIE demonstrates that timely dialogue and transparency are essential for:

- reducing public tension;
- building trust among different users of the marine space;
- ensuring the sustainable integration of aquaculture into coastal regions.

8. Significance of Allocated Circular Aquaculture Zones

The application of the Circular Aquaculture Zones (C-AZA) methodology within the AZA4ICE project in Bulgaria has a distinctly practical character, as the analyses were carried out in areas with already established aquaculture activities. This allows for simultaneous verification of the methodology under real conditions and assessment of the potential for upgrading, modernisation, and diversification of existing businesses, rather than planning entirely new zones. Such an approach is particularly suitable for the Bulgarian context, where marine aquaculture is spatially constrained and strongly dependent on the local hydrodynamic and ecological characteristics of the coastline.

The results of applying C-AZA in zones with active aquaculture farms show that the methodology reflects the real constraints and opportunities of the marine environment. In cases where production activities already exist, the methodology confirms the suitability of the zones for certain species and technologies and identifies opportunities for improving the spatial organisation of installations.

Moreover, it outlines the potential for introducing more complex, circular, and integrated production models with higher added value. This provides grounds for considering C-AZA not only as a tool for planning new investments but also as a supportive instrument for the development and modernisation of existing aquaculture farms.

Regarding Integrated Multi-Trophic Aquaculture (IMTA), the analyses show that such systems are assessed as applicable and environmentally justified, but not as a universally optimal solution for all evaluated zones. The effectiveness of IMTA models depends significantly on local hydrodynamic conditions, ecological capacity, and the spatial configuration of the coastline. In this sense, multi-trophic systems emerge as a realistic but



gradually implementable option that should be adapted to the specific characteristics of each zone rather than applied identically.

The analyses also show that Recirculating Aquaculture Systems (RAS) achieve strong scores in terms of circularity, impact control, and production efficiency, but their potential is highly dependent on spatial conditions. In the Bulgarian context, RAS systems are most suitable as land-based facilities located near the sea or in constrained coastal environments that provide access to seawater and infrastructure. The lack of large, naturally sheltered coastal systems along the Bulgarian Black Sea coast limits the potential for large-scale offshore RAS development, but with careful site selection, RAS remains an important component of the sector's future development.

From a species-specific perspective, the C-AZA results clearly confirm that the Black mussel (*Mytilus galloprovincialis*) remains the most suitable and stable species for open-sea aquaculture in Bulgaria. In addition, the analyses identify further potential for oyster cultivation, which shows favourable results in some of the evaluated zones. Within circular and multi-trophic models, combinations of mussels, oysters, and fish (e.g., sea bass) emerge as a promising opportunity, provided they are carefully adapted to local ecological and spatial constraints.

Regarding turbot (*Scophthalmus maximus*), the results indicate that open-sea aquaculture for this species is difficult to realise under Bulgarian conditions due to the hydrodynamic characteristics of the coastline, exposure of sites to waves and storms, and the species' specific biological requirements. In this context, turbot aquaculture should be directed primarily towards land-based recirculating systems located near the sea, which provide a more controlled environment and higher production security.

Overall, the results of applying the methodology show that it is applicable and appropriate for Bulgarian conditions, but requires a territorially differentiated approach, realistic expectations regarding the technologies used, and a focus on species and technological upgrading rather than rapid expansion of production volumes. This approach provides a solid foundation for formulating concrete, feasible, and prioritised actions aimed at the sustainable development of marine aquaculture in Bulgaria.



9. Programme of measures

Nº	Measure	Scope and contents	Lead Responsible Institution	Supporting stakeholders	Time horizon	Funding resources
1	Application of the C-AZA methodology as a tool for upgrading existing marine aquaculture	Use of C-AZA results to analyse and optimise already active aquaculture zones (e.g., restructuring, diversification opportunities, spatial arrangement of installations).	Ministry of Agriculture and Food; Executive Agency for Fisheries and Aquaculture	Aquaculture operators; Institute of Fish Resources; NGOs	Short-term (< 3 years)	National funds; Maritime, Fisheries and Aquaculture Programme (MFAP); limited private investments
2	Pilot introduction of Integrated Multi-Trophic Aquaculture (IMTA)	Pilot-scale implementation of IMTA (mussels–oysters; mussels–fish such as sea bass) in zones with established aquaculture and proven ecological potential.	Aquaculture operators	Institute of Fisheries and Aquaculture; Institute of Fish Resources; Fisheries Local Action Groups (FLAGS)	Short-term (< 3 years)	MFAP; pilot projects; research and demonstration budgets
3	Pilot introduction of land-based Recirculating Aquaculture Systems (RAS) in suitable zones	Support for land-based RAS facilities near the sea as an alternative to open-sea farms for sensitive species (e.g., turbot).	Aquaculture operators	Ministry of Environment and Water; research organisations	Medium-term (3–5 years)	Private investments; MFAP; other EU instruments



4	Coordination between C-AZA and the Maritime Spatial Plan	Using the C-AZA results as an analytical basis for updating and implementing the Maritime Spatial Plan, with the aim of more clearly positioning aquaculture.	Ministry of regional development and works	Ministry of Environment and Water; research organisations	Medium-term (3–5 years)	Public investments; MFAP; other EU instruments
5	Capacity building and stakeholder dialogue	Trainings, workshops, and consultations with businesses, local communities, and other maritime sectors (tourism, shipping), focused on circular aquaculture.	Institute of Fish Resources; Fisheries Local Action Groups (FLAGs)	Ministry of Agriculture and Food; business sector; NGOs	Ongoing	MFAP; small project budgets; own resources



10. Monitoring and Evaluation

The monitoring and evaluation of the implementation of this Action Plan aim to track the progress of the proposed measures and enable timely adjustments when necessary. The approach is oriented towards realistic and easily measurable indicators that reflect both the process and the achieved results.

10.1 Success indicators

Progress in implementing the Action Plan can be monitored through the following groups of indicators:

- **Process indicators**

- number of zones where the C-AZA approach has been applied or updated;
- number of coordination meetings and stakeholder consultations conducted;
- number of pilot initiatives or demonstration activities;
- number of capacity-building events (trainings, workshops, information sessions).

- **Output indicators**

- implemented or tested multi-trophic systems;
- new or modernised aquaculture installations, including land-based RAS facilities;
- improved institutional coordination in planning and permitting processes.

- **Qualitative Indicators**

- increased predictability of procedures for businesses;
- strengthened dialogue between the aquaculture sector and other maritime activities;
- enhanced trust and public acceptance of marine aquaculture.



10.2 Follow-up and adaptation

Monitoring of implementation should be carried out periodically, with a focus on practical results and emerging challenges. When necessary, the Action Plan may be updated or supplemented, taking into account:

- new data and analyses;
- results from pilot activities;
- changes in the regulatory framework.

11. Conclusions and Recommendations

This Action Plan aims to support the targeted and sustainable development of marine aquaculture in Bulgaria, with emphasis on applying circular economy principles, introducing innovations, and developing integrated production models. The analysis of the sectoral context, the regulatory framework, and the outcomes of the LiRRIE process shows that the sector has realistic development opportunities, which should be realised primarily through upgrading and modernising existing activities rather than through uncontrolled spatial expansion.

The application of the C-AZA methodology in areas with already established aquaculture activities creates conditions for practical testing and refinement of the approach, as well as for identifying concrete opportunities for diversification, integration of different trophic levels, and optimisation of the spatial arrangement of installations. The results indicate that multi-trophic systems (IMTA) represent a promising development direction, although applicable under clearly defined ecological and technological conditions, while recirculating aquaculture systems (RAS) demonstrate strong innovation potential at suitable coastal and land-based locations. In addition, diversification beyond traditional mussel farming — including oysters and combined systems with fish — emerges as a realistic and economically justified opportunity in certain zones.



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In this context, the C-AZA methodology is established not as an alternative, but as a supporting and enhancing tool within the existing regulatory and institutional framework. Through preliminary spatial and environmental analysis, the approach contributes to better investment planning, reduced potential conflicts, and improved coordination among competent authorities, thereby creating more favourable conditions for the development of circular, innovative, and integrated marine aquaculture in Bulgaria.



ANNEXES

Annex 1 - Key Legislative Acts, Competent Authorities and Practical Implications for Marine Aquaculture

Law / Directive	Competent Authority	Practical Implications for Marine Aquaculture
Fisheries and Aquaculture Act (FAA)	Ministry of Agriculture and Food; Executive Agency for Fisheries and Aquaculture (EAFA)	Defines the legal right to conduct aquaculture activities; introduces registration regimes for facilities and operators; requires technological descriptions and maintenance of registers.
Ordinance No. 37/2008	EAFA	Regulates the conditions for conducting aquaculture in state-owned water bodies, including the Black Sea; sets rules for the use of marine space.
Water Act (WA)	Ministry of Environment and Water; River Basin Directorates	Introduces permitting regimes for water abstraction and discharge; sets conditions related to water quantity, quality, and cumulative impacts.
Water Framework Directive (2000/60/EC)	Ministry of Environment and Water; River Basin Directorates	Requires compatibility of activities with the objectives for “good ecological status”; influences permissible production intensity and scale.
Environmental Protection Act (EPA)	Ministry of Environment and Water; Regional Inspectorates of Environment and Water (RIEW)	Regulates Environmental Impact Assessment (EIA) procedures for investment proposals; may extend timelines when additional assessments are required.



Biodiversity Act (BDA)	Ministry of Environment and Water; RIEW	Introduces Appropriate Assessment for Natura 2000 compatibility, a key factor in marine and coastal areas with high conservation value.
Habitats and Birds Directives (Natura 2000)	Ministry of Environment and Water; RIEW	Restrict or guide the siting of aquaculture installations; require proof of no significant adverse impact.
Veterinary Medical Activity Act (VMAA)	Bulgarian Food Safety Agency (BFSA)	Registration of livestock establishments; requirements for biosecurity, animal health status, and disease control.
Ordinance No. 44/2006 and Ordinance No. 36/2006	BFSA	Define veterinary and hygiene requirements for aquaculture facilities and products.
Ordinance No. 4/2000 (Water Quality)	Ministry of Environment and Water	Sets minimum water quality requirements for marine and coastal waters used for mussel and shellfish cultivation.
Maritime Spatial Plan of the Republic of Bulgaria (2021–2035)	Ministry of Regional Development and Public Works	Provides the strategic framework for the spatial allocation of aquaculture; influences activity admissibility and spatial conflict management.
Regulation (EU) 2021/1139 (EMFAF / PMDR)	Ministry of Agriculture and Food (Managing Authority)	Provides financial instruments for investments, modernisation, and innovation; does not replace regulatory regimes but supports sustainable



ANNEX 2 – Alignment with the Multiannual National Strategic Plan for Aquaculture in Bulgaria 2021–2027

This Action Plan for Bulgaria has been developed in full alignment with the objectives and priorities of the **Multiannual National Strategic Plan for Aquaculture (MNSPA)**. The national plan defines the strategic framework for sector development, while the AZA4ICE Action Plan provides practical tools and pilot approaches that support the implementation of these objectives, particularly in the field of marine aquaculture.

Alignment with Key Priorities

1. Simplification of Administrative Procedures

The MNSPA identifies administrative burden and lengthy procedures as key challenges for sector development. The AZA4ICE Action Plan does not propose changes to the regulatory framework but contributes by:

- conducting preliminary spatial and environmental assessments of potential zones;
- identifying constraints and sensitive areas at an early stage;
- supporting institutional coordination already during the planning phase.

2. Coordinated Spatial Planning

The MNSPA emphasises the need to define aquaculture zones in the marine area and integrate them into maritime spatial planning. The C-AZA methodology directly addresses this priority by providing:

- an analytical basis for identifying and comparing suitable zones;
- a tool for reducing spatial conflicts;
- a link between strategic planning and concrete investment intentions.

3. Enhancing Competitiveness and Sustainable Growth

The AZA4ICE Action Plan reinforces the strategic objective of the MNSPA for sustainable growth by focusing on:

- diversification of production;
- application of circular and multi-trophic models;



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- technological solutions with lower environmental risk.

Synergy Between the AZA4ICE Action Plan and the MNSPA 2021–2027

The main added value of AZA4ICE is that it transforms the strategic objectives of the national plan into practical, spatially specific solutions that can be used by institutions, businesses, and the scientific community. In this sense, the Action Plan can be regarded as a pilot and complementary instrument that supports the implementation and future updating of the MNSPA.



ANNEX 3 – Recommendations for Improving the Regulatory Framework in Support of Innovative and Circular Aquaculture

The development of the aquaculture sector in Bulgaria is linked to the objectives of sustainable production, reducing pressure on water bodies, efficient resource use, and minimising conflicts with other users of water bodies and the marine area. In this context, innovative production approaches such as Allocated Zones for Aquaculture (AZA), Integrated Multi-Trophic Aquaculture (IMTA) and Recirculating Aquaculture Systems (RAS) are key instruments for modernisation, investment predictability, and improved environmental management.

The following recommendations aim at minimal but strategically important adjustments to the existing regulatory framework, complemented by a new specialised ordinance regulating AZA/IMTA/RAS in a way that allows subsequent technical “upgrading” (criteria, monitoring, procedures) without requiring major legislative amendments.

1. Identified Gaps in the Existing Framework

1.1. Lack of unified terminology and recognisable regimes for innovation

The current framework (Fisheries and Aquaculture Act, Water Act and secondary legislation) does not explicitly introduce concepts or mechanisms about:

- Allocated Zones for Aquaculture (AZA) as a priority tool for spatial planning/management of aquaculture areas;
- Integrated Multi-Trophic Aquaculture (IMTA) as a production model with ecological benefits and requirements for specific monitoring;
- Recirculating Aquaculture Systems (RAS) as a technological approach with a distinct water-use profile and controlled discharges (RAS is mentioned technically in Ordinance No. 18/2016, but is not systematically embedded in the overall regime and is not used as a policy instrument).

1.2. “Zones” exist only fragmentarily, without a specific management framework (especially in the marine area)

Ordinance No. 37/2008 contains provisions on “aquaculture zones”, but these relate mainly to the placement of installations, marking, and restrictions, without:



- a clearly defined concept for designation/modification/management of zones as a sectoral policy tool;
- a minimum set of monitoring requirements and environmental measures by system type (particularly for IMTA);
- clear integration with other regimes and plans (including Water Act, Environmental Protection Act, Biodiversity Act, and sectoral plans).

11.3. The Water Act treats “aquaculture” as a single category, without differentiating between systems

The permitting regime under the Water Act includes “aquaculture and related activities”, but lacks a principle stating that permit conditions should reflect the nature of the system, its ecological effect, and its interaction with the water body — particularly important for marine systems, IMTA, and RAS with water abstraction/discharge.

11.4. Lack of an investment-oriented approach/mechanism

When the regulatory framework does not clearly define how zones are determined, what the requirements for innovative systems are, and how their environmental effects are assessed, this results in:

- administrative uncertainty and reduced investment interest;
- limited ability of public authorities to guide investments towards suitable locations and technologies.

2. Motives for the Proposed Changes

2.1. Sustainable development and improved environmental management

IMTA and RAS can reduce ecosystem pressure through better utilisation of nutrients (IMTA) and limited water exchange/controlled discharges (RAS). To realise this potential, clearly defined minimum requirements are needed for technological descriptions, monitoring, and risk management.

2.2. Reducing conflicts and increasing predictability for businesses through AZA

AZA as a spatial planning tool enables:

- prioritisation of aquaculture in specific parts of water bodies/marine areas;



- reduction of conflicts with other users;
- faster, more predictable, and more transparent investment procedures.

2.3. Alignment with European priorities and improved absorption of funding

Introducing terminology and definitions related to AZA/IMTA/RAS supports:

- preparation of funding proposals and justification of projects as “sustainable/innovative”;
- prioritisation of measures for competitiveness, environmental protection, monitoring, and digitalisation.

Practically, this increases the sector’s “readiness” to utilise European funds (e.g., the European Maritime, Fisheries and Aquaculture Fund – EMFAF, as well as complementary opportunities under innovation, environment, and regional development programmes), as the regulatory framework will provide clear eligibility rules, criteria, and management requirements.

3. Proposed Changes

3.1. Minimal Amendments to the Fisheries and Aquaculture Act (FAA)

(A) Introduction of definitions in the Supplementary Provisions

- “Allocated Zone for Aquaculture (AZA)”
- “Integrated Multi-Trophic Aquaculture (IMTA)”
- “Recirculating Aquaculture System (RAS)”

(B) Expansion of Article 25, paragraph 5

In addition to production limits, the provision should also include:

- designation/modification/management of AZA;
- minimum content of monitoring plans and environmental measures, including for IMTA.

(C) New articles (e.g., Articles 25d and 25e)

- framework for determining AZA based on criteria (ecological capacity, compatibility with regimes, safety, planning instruments);



- possibility for IMTA within AZA and requirement for technological description + monitoring.

3.2. Amendment to the Water Act (WA)

Amendment to Article 46, paragraph 1, item 2, to emphasise the principle:

“... and when determining the conditions of the permit, the nature of the production system, its ecological effect, and its interaction with the water body shall be taken into account.”

This creates a legal basis for the competent authority to tailor permit conditions according to the different impact profiles (cages, IMTA, RAS).

3.3. Secondary Legislation

(A) Ordinance No. 37/2008 – adjustment/coordination

- terminological shift from “aquaculture zones” to “Allocated Zones for Aquaculture (AZA)” if such a definition is adopted in the FAA;
- references to the new specialised ordinance (see section 3.4) instead of overloading Ordinance 37 with complex new regimes.

(B) Ordinance No. 18/2016 – technical supplement for IMTA (without duplicating definitions)

- addition of minimum requirements for technological description/layout for IMTA (components, spatial arrangement, material flows, monitoring);
- indicator specifying whether the facility is located within an AZA (designation/administrative act).

3.4. Proposal for a New Ordinance on AZA/IMTA/RAS

A new ordinance is proposed (based on the expanded Article 25, paragraph 5 of the FAA), regulating:

1. **Designation and modification of AZA** – criteria, procedures, transparency, register/map;



2. **Management of AZA** – rules for installation placement, rotation/relocation, buffer zones (where applicable), coordination with other users;
3. **Minimum monitoring and environmental measures** – basic package + additional requirements by system type;
4. **IMTA** – minimum content of monitoring plans/programmes, control points and indicators, risk-management measures;
5. **RAS** – principles for water use and controlled discharge, minimum requirements for wastewater management plans (aligned with the Water Act and Environmental Protection Act).

4. Enabling Conditions for Funding and Investment Support

The proposed amendments have a direct enabling and stimulating effect because:

AZA reduces transaction costs and investor risk by providing clearer locations and conditions.

IMTA and RAS become formally recognised regulatory categories, which facilitates:

- directing public support towards systems with positive environmental effects;
- developing priority measures and selection criteria under financial instruments;
- justifying investments in innovation, green transition, monitoring, and digitalisation.

In practical terms, this supports project preparation and absorption of funding from European instruments such as **EMFAF** (and complementary innovation/environment programmes), as the regulatory framework would provide clear definitions, procedures, and requirements for control and accountability.

The aquaculture sector needs clear definitions, predictable rules, and methods for introducing innovations, without overburdening legislation with excessive detail at the level of primary law. The proposed approach — minimal



amendments to the **Fisheries and Aquaculture Act** and the **Water Act**, combined with a proposal for a **new ordinance on AZA/IMTA/RAS** — enables:

- introduction of key concepts and principles;
- creation of a flexible framework for technical development (criteria/monitoring/procedures) through secondary legislation;
- improved spatial planning and reduced conflicts;
- opportunities to attract funding and stimulate innovative practices.



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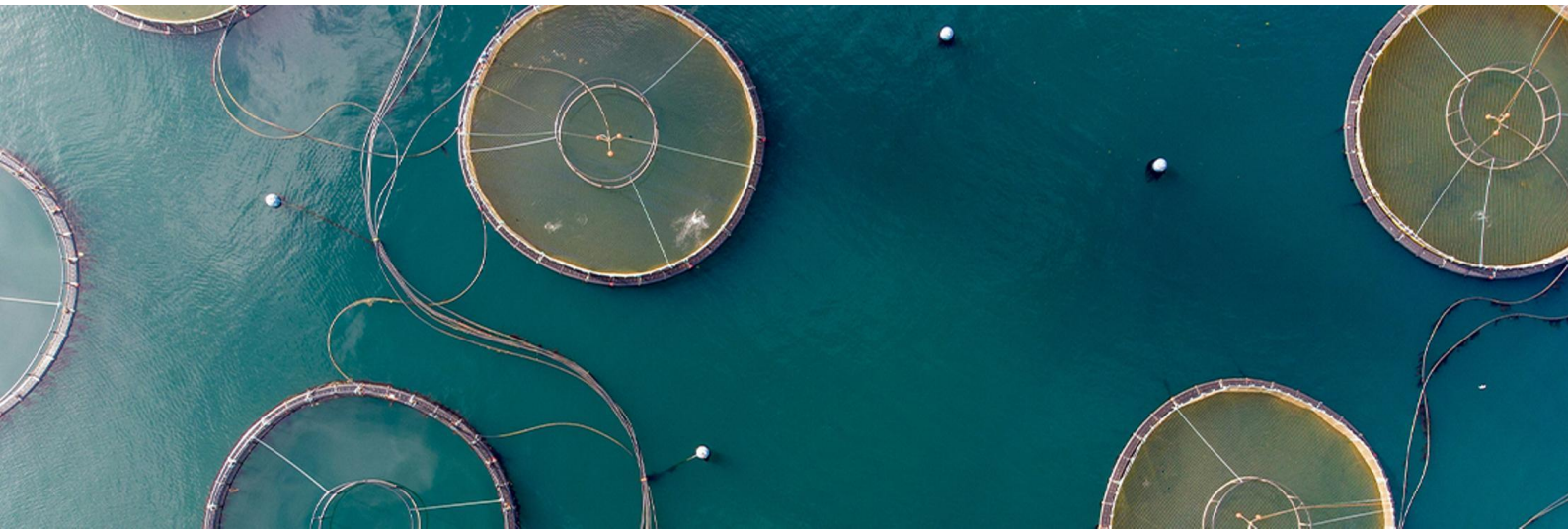


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March 2026

Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Šasko Lake, Montenegro

<https://aza4ice.interreg-euro-med.eu>



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Abbreviations

Abbreviation	Meaning
AZA	Allocated Zone for Aquaculture
C-AZA	Circular Allocated Zone for Aquaculture
AZA4ICE	Allocated Zones for Circular Economy in Aquaculture
IMTA	Integrated Multi-Trophic Aquaculture
ICE	Inclusive and Circular Economy
LiRRIE	Living Responsible Research and Innovation Ecosystem
CE	Circular Economy
SSI	Species Sustainability Index
SiSI	Site Sustainability Index
IPI	Integrated Performance Index
IS	Integrated Sustainability Index
ICI	IMTA Circularity Index
EPA	Environmental Protection Agency (Montenegro)
IMBK	Institute of Marine Biology Kotor, University of Montenegro
SME	Small and Medium-sized Enterprise
NGO	Non-Governmental Organization
EU	European Union
EIA	Environmental Impact Assessment
CFP	Common Fisheries Policy
WFD	Water Framework Directive
MSFD	Marine Strategy Framework Directive
FAO	Food and Agriculture Organization
UNDP	United Nations Development Programme
IPARD	Instrument for Pre-Accession Assistance for Rural Development
EBRD	European Bank for Reconstruction and Development
R&I	Research and Innovation
PoC	Proof of Concept
MoU	Memorandum of Understanding
HCMR	Hellenic Center for Marine Research



Executive Summary

This Action Plan sets out a **realistic, evidence-based, and co-constructed roadmap** for the introduction of circular aquaculture at **Šasko jezero**, one of Montenegro's most ecologically sensitive freshwater ecosystems. Developed within the **AZA4ICE project** and grounded in the **LiRRIE co-decided vision**, the Plan translates scientific assessment results and stakeholder priorities into a coherent set of **low-risk, low-impact, and implementable actions** for the transition towards an Inclusive and Circular Economy in aquaculture.

The strong consensus expressed during the 4th LiRRIE consultation (average score 9.8/10) confirms that stakeholders support a development pathway in which economic opportunities at Šasko Lake are pursued only in parallel with strict environmental safeguards, precautionary pilot implementation, and continuous ecological monitoring.

The Plan is underpinned by the **C-AZA assessment**, which confirms that Šasko jezero is **environmentally acceptable for carefully managed circular aquaculture** (final C-AZA index = **0.633**), provided that strict safeguards, adaptive management, and precautionary scaling are applied. The assessment identifies a **freshwater IMTA model** based on *Cyprinus carpio* (fed species) and *Phragmites australis* (inorganic extractive species) as technically and environmentally suitable, achieving a strong **Integrated Sustainability Index (IS = 0.737)**. While the **IMTA Circularity Index (ICI = 0.44)** indicates moderate circularity performance, it also highlights clear opportunities for improvement through targeted interventions.

Complementing the environmental analysis, the **BLUEfasma circularity baseline** reveals a territorial profile characterised by **low circularity readiness (average 1.7)** but **high willingness to invest (average 3.8)** among local operators. This readiness-willingness gap confirms that transition potential exists, but that implementation must be preceded by **capacity building, regulatory clarification, and practical demonstration**, particularly for small-scale fishermen who face the greatest constraints.

In response, and following an extensive **LiRRIE co-construction process**, the Action Plan proposes six mutually reinforcing actions, designed to be **financially realistic, socially acceptable, and ecologically safe**:

1. **Capacity Building Programme for Local Fishermen and SMEs**, prioritising financial literacy, funding readiness, licensing guidance, and hands-on IMTA operation, complemented by digital, market, and eco-certification skills;
2. **Establishment of a small-scale, modular IMTA demonstration pilot**, implemented as a proof-of-concept and learning tool under strict environmental safeguards and transparent monitoring;
3. **Community-based circularity initiatives**, focused on low-investment, visible practices such as waste separation points, reusable gear, clean-up actions, and educational eco-trails;
4. **Environmental monitoring and safeguards**, ensuring continuous assessment of water quality, ecosystem response, and compliance with precautionary thresholds;
5. **Business support and funding mobilisation**, assisting local actors in accessing national grants, IPARD III, Interreg, and complementary financing instruments;



6. **An inclusive governance and coordination platform**, aligned with the LiRRIE model and built around a focused governance triangle comprising the Municipality of Ulcinj, organised fishermen, and the Directorate for Fisheries.

Stakeholder feedback clearly prioritised **national and EU funding instruments** as the backbone of implementation, with IPARD III and Interreg programmes identified as key enablers. The Plan therefore adopts a **phased financing approach**, centred on low-cost, high-impact actions and external funding leverage, complemented by selective private co-financing and preferential credit lines where appropriate.

To ensure accountability and adaptability, the Action Plan includes a **robust Monitoring and Evaluation framework**, with clearly defined indicators covering environmental performance, IMTA technical operation, governance effectiveness, and community and business uptake. A **realistic 24-month implementation horizon** is proposed, allowing sufficient time for learning, adjustment, and evidence-based decision-making.

Through the integration of **scientific evidence, stakeholder co-decision, and circular economy principles**, Šasko jezero is positioned to become **Montenegro's first demonstration site for circular freshwater aquaculture**. The Action Plan establishes a solid foundation for replication in other inland waters, while safeguarding ecological integrity and strengthening local livelihoods. It represents a concrete step towards embedding circularity, inclusiveness, and innovation in Montenegro's aquaculture governance and practice.



Introduction

The transition toward sustainable and circular aquaculture in Montenegro requires a coordinated, science-based, and inclusive approach that respects the ecological sensitivity of aquatic ecosystems while supporting local economic development. Šasko jezero, as one of Montenegro's most unique freshwater ecosystems, represents an ideal testing ground for implementing innovative circular aquaculture practices in line with the AZA4ICE methodology. Through the collaborative work of the LiRRIE (Living Responsible Research and Innovation Ecosystem) in Montenegro, local stakeholders have jointly defined a vision for transforming the lake into a national model of eco-conscious aquaculture, grounded in shared governance, scientific evidence, and genuine community engagement.

This Action Plan provides a structured roadmap to operationalize that vision. It builds upon the detailed C-AZA assessment carried out for Šasko jezero, which confirmed that the lake is environmentally acceptable for aquaculture under carefully controlled, circular, and low-impact conditions. Combined with the results of the BLUEfasma circularity baseline assessment—which revealed low readiness but high willingness among local operators, the Action Plan proposes realistic, small-scale, and adaptable interventions that match the region's socio-economic and environmental context.

Scope and Objectives

Scope

This Action Plan focuses exclusively on the development of **circular, low-impact freshwater aquaculture** at Šasko jezero, using the AZA4ICE methodology as the guiding framework. It concentrates on actions that are:

- **Environmentally feasible**, based on the C-AZA results specific to Šasko jezero.
- **Socially inclusive**, aligned with the LiRRIE co-created vision and stakeholder needs.
- **Economically realistic**, given local constraints, capacities, and investment potential.
- **Scalable and transferable**, allowing replication in other Montenegrin lakes or inland waters.

The plan covers a 24-month period and focuses on interventions that can be realistically implemented with available local resources and external funding support.

Objectives

The Action Plan aims to achieve the following:

1. **Introduce and test a circular aquaculture model**—specifically a freshwater IMTA system—tailored to Šasko jezero's conditions.
2. **Strengthen local capacity** among fishermen, SMEs, and community actors to adopt circular practices and improve their technical readiness.



3. **Enhance environmental protection** through structured monitoring and nature-based aquaculture design.
4. **Establish an inclusive governance mechanism** that ensures coordinated decision-making, transparency, and multi-stakeholder participation.
5. **Support economic diversification and new opportunities** through circular business models, waste valorization, and sustainable branding.
6. **Create a replicable model** that can inform national policies and future circular aquaculture developments in Montenegro.

These objectives collectively support Montenegro's transition toward a resource-efficient, climate-resilient, and innovation-driven blue economy.

Context

Šasko jezero is a shallow, ecologically sensitive freshwater lake located near Ulcinj, connected to the Bojana/Buna River system and surrounded by wetlands of high biodiversity. Its ecological characteristics—fluctuating water levels, moderate nutrient load, limited depth, and rich bird habitats—demand a cautious, scientifically guided approach to any form of aquaculture.

The **C-AZA assessment** carried out in 2024–2025 confirmed the lake's suitability for small-scale circular aquaculture, with a final C-AZA index of **0.633**, marking it as “acceptable” but requiring strict environmental safeguards. The analysis identified **common carp** (*Cyprinus carpio*) and **common reed** (*Phragmites australis*) as the most suitable species for a freshwater IMTA model that supports nutrient recycling and ecological balance.

Parallel to this, the **BLUEfasma circularity assessment** revealed that most local businesses and fishermen operate with **low circularity readiness** but demonstrate **high willingness to invest**—a critical foundation for transition. This indicates strong openness to innovation, provided that appropriate training, technical support, and funding pathways are made available.

Guided by these findings, the **LiRRIE stakeholder process** co-decided a shared vision for Šasko jezero: a future in which aquaculture development is environmentally responsible, socially inclusive, technologically innovative, and rooted in circular economy principles. This participatory foundation ensures that the Action Plan reflects real local needs, community expectations, and institutional priorities.

Together, these elements create a unique opportunity for Montenegro to introduce a **model circular aquaculture zone** at Šasko jezero, demonstrating how ecological protection, community participation, and economic innovation can be integrated into a single, coherent development approach.



Roles and Responsibilities of Key Actors

The transition of Šasko jezero toward a sustainable and circular aquaculture model depends on the active participation, coordination, and shared responsibility of a diverse set of regional actors. In line with the LiRRIE Co-decided Vision Statement, the governance of this transition is conceived as **inclusive, collaborative, and innovation-driven**, ensuring that no stakeholder group is left behind. The ecosystem of actors engaged in the development and future implementation of the AZA4ICE Action Plan spans government institutions, scientific bodies, private sector operators, civil society organizations, and local communities—all connected through the participatory framework established by the LiRRIE methodology.

In this context, the **public sector** plays a central guiding role by providing strategic direction, regulatory clarity, and institutional support required for establishing circular aquaculture zones (C-AZA). National ministries and specialized agencies ensure that the ecological integrity of Šasko jezero is preserved, that licensing and monitoring follow transparent procedures, and that policy frameworks support the adoption of innovative IMTA and circular production models. Their role is essential in aligning the Action Plan with Montenegro's broader priorities in environmental protection, circular economy, and sustainable rural development.

The **scientific and research institutions**, particularly the University of Montenegro, Faculty of Science, act as knowledge anchors for the region. They guide the interpretation of environmental data, validate the C-AZA results, design monitoring systems, and support evidence-based decision-making. Their responsibilities extend to providing technical expertise, building local capacity through training, and supporting adaptive management of aquaculture activities based on continuous scientific assessment. Through their involvement, innovation becomes embedded in the region's transition pathway.

The **private sector**, comprising fish processors, aquaculture practitioners, and small-scale fishermen, represents the operational core of circular aquaculture development. Although the circularity baseline assessment shows that readiness for circularity remains low, willingness to invest is high positioning these actors as key drivers once the enabling conditions are in place. Their responsibilities include adopting improved practices, engaging in capacity-building activities, participating in demonstration pilots, and contributing to business symbiosis models such as waste valorization and local supply chain strengthening. Their active involvement is fundamental to transforming Šasko jezero into a living example of circular production.

The **local community and civil society organizations** contribute critical social and environmental knowledge. Their role is to ensure that aquaculture development respects cultural identity, local heritage, and the traditional use of natural resources. They support the co-creation of solutions that balance livelihoods with environmental stewardship, voice community concerns, and facilitate public awareness on circular economy principles and sustainable consumer behavior. Their participation reinforces the inclusive nature of LiRRIE and enhances societal acceptance of new aquaculture models.

Finally, the LiRRIE structure itself serves as the **coordination mechanism** connecting these actors. Through iterative co-creation, shared vision development, and structured dialogue, LiRRIE ensures that roles and responsibilities are not only defined but are collectively understood and continuously refined. This participatory



governance model enables transparent decision-making, builds trust, strengthens regional ownership of the Action Plan, and ensures that capacity-building efforts reach all stakeholder groups.

Taken together, the roles of public institutions, scientific bodies, private operators, civil society, and local communities form the foundation of a **multi-level, inclusive governance system** for Šasko jezero. Their coordinated responsibilities are essential for translating the region's shared vision into a practical, innovative, and circular aquaculture model—setting a strong example for Montenegro and the wider Euro-Mediterranean region.

Regional Needs, Challenges and Opportunities

This chapter is written specifically for the **Šasko jezero pilot area**. It synthesizes three inputs:

1. **C-AZA results for Šasko jezero** (final C-AZA index = 0.633 → Acceptable but low).
2. **LiRRIE Co-decided Vision Statement** (inclusive governance, innovation, circularity, capacity building).
3. **Circularity baseline (D2.2.1)** for businesses in Montenegro (low readiness, high willingness).

The Šasko jezero region presents a unique combination of ecological sensitivity, socio-economic pressures, and emerging opportunities for sustainable and circular aquaculture development. The results of the C-AZA assessment, the co-created LiRRIE vision, and the circularity baseline of local blue-economy stakeholders demonstrate that while the region is at an early stage of transition, it possesses a strong foundation of willingness, local engagement, and ecological potential to become a national model for inclusive and circular aquaculture.

Regional Needs

Need for Environmentally Compatible Aquaculture Models

The C-AZA results for Šasko jezero demonstrate that the lake is **environmentally acceptable for aquaculture**, but positioned **at the lower end of the “acceptable” range** (C-AZA index = 0.633). This indicates a need for:

- **Low-impact models** such as freshwater IMTA using *Cyprinus carpio* and *Phragmites australis*, which showed acceptable species sustainability scores.
- **Strict environmental monitoring**, especially for shallow lake dynamics, nutrient concentrations, and seasonal fluctuations.
- **Adaptive management**, ensuring aquaculture development does not compromise water quality or biodiversity.

Need for Clear Governance and Coordinated Decision-Making

The LiRRIE vision highlights the need for **collaborative, transparent governance**, given that Šasko jezero falls within a complex institutional landscape (local communities, municipality of Ulcinj, environmental agencies, fishery authorities, cross-border ecological connectivity with Bojana/Buna River).



Regional needs include:

- Coordination between environment, aquaculture, water management and protected area institutions.
- Clear guidance for introducing circular aquaculture in an ecologically sensitive area.
- A governance mechanism that integrates **5-helix stakeholders** (public sector, industry, academia, civil society, environment).

Need for Strengthening Local Skills and Technical Capacity

The BLUEfasma assessment shows:

- **Low circularity readiness** among businesses (avg. 1.7).
- **Very low readiness among fishermen** (1.1–1.8).
- **High willingness to invest**, particularly among processors and several fishermen (up to 4.7).

This signals a need for:

- Training on IMTA, circular practices, water-quality management and business innovation.
- Demonstration pilots in Šasko jezero to show viable circular models.
- Continuous capacity-building to bridge the gap between motivation and implementation.

Regional Challenges

Environmental Sensitivity of Šasko jezero

Šasko jezero is a shallow, vulnerable freshwater ecosystem with fluctuating hydrological conditions and direct ecological links to Bojana River and nearby wetlands.

Key challenges include:

- Rapid ecological response to nutrient inputs.
- Limited depth (2–3 m) affecting species suitability and sediment interactions.
- High conservation value and presence of protected bird species.
- Potential conflicts between aquaculture and ecosystem integrity.

The C-AZA results confirm that aquaculture is possible, but must be small-scale, controlled, and circular.

Weak Circular Economy Integration in Current Businesses

The circularity baseline identifies:

- Fragmented or minimal CE practices.
- Limited waste valorization infrastructure.
- Low awareness among small-scale fishermen of circular business models.
- Insufficient technical and financial tools to adopt CE technology.



This creates risks for implementing advanced circular models without targeted support.

Regulatory and Licensing Complexity

While Montenegro has a robust legal framework, it is not optimized for:

- **IMTA systems,**
- **Freshwater circular models,**
- **Species combinations involving aquatic plants,**
- **Micro-scale aquaculture in protected landscapes.**

Operators face administrative burdens, uncertainty in permit pathways, and limited technical guidance from authorities. This complexity may hinder the establishment of C-AZA zones unless procedures are clarified and supported.

Socio-economic Vulnerability

The region around Šasko jezero relies on:

- Small-scale fishing,
- Seasonal tourism,
- Low-intensity agriculture.

Aquaculture must therefore integrate with existing livelihoods, avoiding competition for space, resources, or ecological functions. This requires careful spatial planning and community involvement.

Opportunities

Strong Stakeholder Motivation

Despite low readiness, stakeholders demonstrate **high willingness to invest** (average 3.8), especially:

- Fish processors (e.g. MM Ribarstvo, Montefish),
- Motivated fishermen (e.g., Leona & Aleksa with willingness 4.7),
- Local micro-businesses seeking diversification.

This presents a major opportunity to catalyze quick wins through:

- Pilot IMTA setups,
- Business symbiosis (processors–fishermen),
- Waste reduction and valorization schemes.

Potential to Position Šasko jezero as a National Model

The LiRRIE vision sets a clear ambition: **Šasko jezero as a reference site for circular aquaculture and inclusive governance in Montenegro.**

This aligns with regional priorities such as:

- Sustainable use of inland waters,
- Diversification of rural economies,



- Green transition and circularity targets,
- Demonstration models under the Euro-MED Programme.

The C-AZA results confirm that the lake offers **sufficient environmental sustainability** to support such a flagship initiative.

Integrating Circular Aquaculture with Tourism and Local Economy

Potential opportunities include:

- Eco-labelled carp production from circular IMTA systems,
- Local branding (e.g. “Šasko jezero – circular & sustainable”),
- Educational tours and nature–aquaculture interpretation trails,
- Synergies with gastronomy and agro-tourism.

Circular aquaculture could enhance the local value chain and diversify income sources.

Strengthening Scientific and Institutional Roles

With the University of Montenegro actively involved, the region gains:

- Strong scientific monitoring capacity,
- Support for data-driven management,
- Opportunities to test innovative methods (e.g., nutrient–plant interactions, freshwater IMTA performance).

This creates a unique research–practice–policy interface.

Summary

The region’s baseline can be summarized as follows:

- **Environmental potential:** acceptable but sensitive → requires careful management
- **Business baseline:** low readiness but high willingness → ideal for targeted support
- **Governance:** strong need for coordination and inclusive decision-making
- **Opportunity:** high motivation, scientific support and policy alignment create a realistic pathway to making Šasko jezero a **national reference for circular aquaculture**

These insights directly inform the proposed actions in the Montenegro Action Plan and form the basis for designing a realistic, community-supported, environmentally responsible transition pathway.

Current legal/regulatory/licensing framework

Montenegro’s aquaculture sector operates under a **centralized and comprehensive legal framework** that regulates freshwater aquaculture, marine aquaculture (mariculture), fisheries management, environmental protection, water



use, food safety, and animal health. Together, these laws form the institutional basis for planning, licensing, operation, and monitoring of aquaculture activities across the country.

This overview is fully based on the detailed analysis presented in **D2.3.1 – Review on aquaculture legal/regulatory framework and licensing processes.**

Core National Legislation for Aquaculture

Aquaculture in Montenegro is primarily governed by two sectoral laws:

1. **Law on Freshwater Fisheries and Aquaculture.** – Regulates inland aquaculture activities, including the use of freshwater bodies, licensing, farming practices, fish health, and construction requirements for freshwater facilities.
2. **Law on Marine Fisheries and Mariculture.** – Governs marine farming activities, spatial planning for mariculture zones, licensing, environmental obligations and operational standards for marine aquaculture.

These laws are supported by a wider legal ecosystem that covers issues essential for aquaculture operation:

- **Law on Food Safety**
- **Law on Animal Health and Welfare**
- **Law on Environmental Impact Assessment**
- **Law on Nature Protection / Biodiversity**
- **Water Management Law**
- Numerous **by-laws and ordinances** specifying technical and operational requirements.

Collectively, this framework ensures that aquaculture activities respect environmental limits, food safety standards, and public health requirements.

Institutional Setup

Aquaculture governance in Montenegro involves **several specialized institutions**, each with a distinct mandate:

- **Ministry of Agriculture, Forestry and Water Management.** – Principal policy-maker for fisheries and aquaculture; responsible for strategic planning and regulatory oversight.
- **Ministry of Agriculture, Forestry and Water Management, Directorate for Fisheries.** – Executes fisheries and aquaculture policy, including licensing, monitoring of production, resource management and implementing national strategies.
- **Environmental Protection Agency (EPA).** – Oversees environmental impact assessments, water quality protection and monitoring of ecological impacts of aquaculture operations.
- **Veterinary and Phytosanitary Directorate.** – Ensures compliance with animal health, disease control and food safety standards in aquaculture.
- **University of Montenegro, Faculty of Science.** – Provides scientific research, monitoring data, environmental studies and technical expertise.



- **Statistical Office of Montenegro (MONSTAT).** – Responsible for official data collection on aquaculture and fisheries production.

This coordinated institutional setup supports sustainable development while ensuring alignment with EU aquaculture and environmental directives.

Licensing Requirements and Procedures

Montenegro maintains a **centralized licensing system**, but procedures for aquaculture development remain **complex and involve several authorities**, depending on the farming environment (freshwater vs. marine). Licensing typically requires:

- **Site approval** from relevant authorities
- **Environmental Impact Assessment (EIA)** for most aquaculture activities
- **Water rights permits** (water use, discharge)
- **Veterinary approval** for species health and biosecurity
- **Construction permits** (for freshwater installations)
- **Concession/licence for marine space use** (for mariculture)

Although the framework is clear, the **number of required permits and institutionally fragmented workflow** makes licensing time-consuming and administratively demanding. As noted in D2.3.1, Montenegro shares common European challenges such as multi-agency involvement, overlaps between environmental and fisheries legislation and significant documentation requirements.

Regulatory Context for Innovative Systems (IMTA / RAS / circular aquaculture)

Montenegro has **no dedicated legal framework for IMTA, RAS or circular aquaculture**, but these systems are implicitly regulated through general aquaculture laws, environmental laws and water management regulations.

Key constraints include:

- **Absence of specific criteria for assessing IMTA connectivity and circularity**
- Licensing procedures designed for traditional single-species farms
- High compliance requirements for environmental protection in sensitive ecosystems
- Limited technical guidance for regulators on evaluating innovative models
- Regulatory ambiguity for new species (e.g., algae, halophytes), similar to other Euro-MED countries

Nevertheless, Montenegro's policy alignment with **EU circular economy principles** and **ecosystem-based management** provides a foundation for incorporating C-AZA results and IMTA models into future licensing reforms.

Alignment with International and EU Frameworks

Montenegro's legal and regulatory system is strongly shaped by:



- **EU Common Fisheries Policy (CFP)**
- **EU environmental acquis** (Water Framework Directive, Habitats Directive, Marine Strategy Framework Directive)
- **FAO Code of Conduct for Responsible Fisheries**
- Regional cooperation platforms (GFCM guidelines and Adriatic-AION frameworks)

This alignment ensures that aquaculture development—particularly in sensitive inland ecosystems like **Šasko jezero**—is subject to high sustainability, monitoring and conservation standards.

Key Challenges Identified

Based on the review, Montenegro faces several legal and regulatory barriers:

- **Complex and lengthy licensing procedures** involving multiple institutions
- **High administrative burden** for small operators
- **Strict environmental requirements** limiting the flexibility of site selection
- **Lack of specific regulations for innovative IMTA/RAS systems**
- **Limited technical capacity and scientific guidelines** for evaluating circular systems
- **Unclear pathways for introducing novel species** such as algae

These challenges are important considerations when defining C-AZA Action Plan interventions for Šasko jezero.

Implications for Šasko jezero C-AZA Action Plan

Considering Šasko jezero's sensitive ecological status, shallow hydrology and cross-border relevance, the regulatory framework implies:

- Mandatory EIAs for any aquaculture intervention
- Strict water quality and biodiversity protection requirements
- Potential regulatory gaps for IMTA/circular models incorporating freshwater macrophytes
- The necessity for coordinated licensing across environmental, water and fisheries administrations
- High need for **clarified guidelines, capacity building, and streamlined procedures** for implementing the C-AZA model
-

Current status of aquaculture businesses

The current state of aquaculture and fisheries-related businesses in Montenegro reveals a sector that is still predominantly positioned within a **linear economic model**, with only limited and fragmented application of circular economy (CE) principles. The results of the BLUEfasma Circularity Self-Assessment Tool, implemented with nine representative stakeholders—including fish farms, processors, brands, and small-scale fishermen—provide the first structured



baseline for assessing circularity readiness and investment motivation in Montenegro's blue economy.

This overview is fully based on the detailed findings of **D2.2.1 – Identifying the Circularity Baseline with the BLUEfasma Circularity Self-Assessment Tool in Montenegro**.

Circularity Readiness: Early-stage and Fragmented (Average: 1.7)

Readiness scores in Montenegro range from **1.1 to 2.3**, with a territorial average of **1.7**, corresponding to an **early stage of CE adoption**. This means:

- Circular practices exist but are **not systematic nor embedded** in business models.
- Stakeholders demonstrate **eco-awareness**, yet CE actions remain isolated (e.g., selective waste handling, energy-saving measures, sporadic reuse practices).
- **Companies** (fish processors and brands) tend to show **higher readiness** (1.8–2.3), reflecting better infrastructure, organizational maturity, and capacity to introduce CE measures.
- **Small-scale fishermen** have the **lowest readiness levels** (1.1–1.8), indicating reliance on traditional, linear practices with minimal application of circularity principles.

Zeta Fish (2.3) and Pescatore (2.0) represent the most advanced profiles, while Joško Fish (1.1) and Ruždi Kashodza (1.2) illustrate the lowest CE maturity in the territory.

Overall, the data confirms that CE is **not yet structurally integrated** across Montenegrin aquaculture-related operations, especially among micro-operators.

Willingness to Invest: Moderate to High (Average: 3.8)

In contrast to low readiness, willingness to invest in CE solutions ranges from **2.4 to 4.7**, with an average of **3.8**—indicating **strong motivation for transition**.

- Medium-sized companies (e.g., Montefish 4.5; MM Ribarstvo 4.6) exhibit **very high willingness**, signaling preparedness for technology upgrades, renewable energy use, valorization of fish by-products, and improved waste management.
- Among fishermen, willingness varies widely: some (Leona & Aleksa: 4.7) show exceptional investment interest, while others (Ruždi Kashodza: 2.4) remain cautious due to limited resources and perceived risks.

The gap between low readiness and high willingness demonstrates a **latent transition potential**—businesses are motivated but require technological, financial, and training support to turn willingness into real implementation.

Differences Between Industry Segments

Fish Processing & Branding Companies

Examples: Zeta Fish, MM Ribarstvo, Montefish, Pescatore

- Better organizational structure and financial capacity



- Existing CE actions (eco-packaging, energy efficiency, selective waste handling)
- Best positioned for rapid transition once targeted support is introduced
- Higher potential for **circular innovations** such as by-product valorization and material recovery

Small-Scale Fishermen

Examples: Ivan Saveljić, Joško Fish, Ruždi Kashodza

- Lowest readiness (1.1–1.8)
- Limited financial capacity, low-to-moderate willingness
- Require **awareness building**, small-scale pilots, and low-cost CE interventions (gear reuse, fuel savings, waste minimization)
- Represent the segment with the slowest natural transition speed unless strongly supported

Mariculture SME

Example: Pescatore d.o.o.

- Positioned between the two groups
- Solid readiness (2.0) and moderate willingness (3.7)
- Suitable for circular demonstration projects (e.g., mussel shell valorization, renewable energy)

Generalized Territorial Circularity Level: “Low Readiness / High Willingness”

At the territory level, Montenegro exhibits:

- **Low readiness (1.7 average):** Circular economy still at the stage of **eco-thinking**; CE practices are scattered and non-systemic.
- **High willingness (3.8 average):** Stakeholders—especially companies—are motivated to improve competitiveness, reduce costs, and adopt green solutions.

This combination signals a **strong but untapped potential**: with targeted interventions, Montenegro could move quickly from isolated CE actions to structured circularity adoption.

Key Challenges Identified

The assessment highlights several challenges affecting aquaculture businesses:

- Lack of **technical knowledge** and CE-specific skills
- Limited **financial resources**, especially among fishermen
- Dependence on traditional practices and linear supply chains
- Absence of **infrastructure for by-product valorization** (e.g., fish waste reuse)
- Low awareness of **CE market benefits**
- No established business symbiosis networks



- Limited access to **renewable energy technologies** and water/heat recovery systems

These gaps align with the national trend of early-stage CE adoption.

Opportunities for Circular Transition

Stakeholders express strong interest in adopting CE principles, particularly in:

- Renewable energy integration
- Waste minimization and by-product recovery
- Improved packaging and reduction of plastics
- Fuel-efficiency improvements
- Business symbiosis with other fisheries/aquaculture operators
- Eco-certification and branding for competitive advantage

The combination of **motivation, sectoral awareness, and baseline CE actions already in place** positions Montenegro as a strong candidate for rapid progress—especially with the introduction of C-AZA zones, IMTA-based models, and the LiRRIE participatory mechanism.

Overall Assessment

Montenegro's aquaculture businesses present a **mixed but promising profile**:

- **Circularity readiness is low** → systemic CE integration has not yet occurred.
- **Willingness to invest is high** → stakeholders are motivated and open to change.
- **Companies lead**, while **fishermen lag behind** and need stronger support.
- The sector is at a **turning point**, where targeted actions can unlock rapid transition.

These findings provide a solid foundation for designing the AZA4ICE Action Plan interventions, particularly those linked to stakeholder capacity-building, technological pilots, and the implementation of the C-AZA model in Šasko jezero.

Vision

The vision for Šasko jezero under the AZA4ICE project is to establish the lake as a **national model of sustainable, inclusive, and circular aquaculture**, where ecological integrity, community well-being, and economic development coexist in a balanced and mutually reinforcing way. Through strong local governance, multi-actor cooperation, and the adoption of innovative circular solutions, Šasko jezero aims to become a reference point in Montenegro and the wider Euro-Mediterranean region for responsible and forward-looking aquaculture practices.

This vision is grounded in the co-decided outcomes of the LiRRIE process, which brought together local stakeholders, institutions, civil society, academia, industry representatives, and environmental actors. Their shared aspiration is to transform Šasko jezero into a **thriving Living Responsible Research and Innovation Ecosystem**, where decisions are made collectively, capacities are strengthened



continuously, and actions are shaped by evidence, local knowledge, and cross-sectoral collaboration.

At the core of the vision is the commitment to **inclusive governance**. The future of aquaculture at Šasko jezero must be built on open dialogue, transparent planning, and genuine engagement of all stakeholders—ensuring that community members, fishermen, local authorities, environmental organizations, and businesses have an active voice in shaping development pathways. This inclusive model is designed to ensure that no actor is marginalized and that the benefits of circular aquaculture are equitably distributed.

The vision also places strong emphasis on **capacity-building** as a driver of transformation. Given the region's current early stage of circularity adoption, targeted training, knowledge transfer, and hands-on demonstration activities are essential for empowering local operators. By elevating technical skills, managerial knowledge, and environmental awareness, Šasko jezero can progressively build a strong local foundation capable of implementing and sustaining circular aquaculture models.

Innovation is another defining element of the vision. The region aims to embrace new circular technologies and practices—including integrated multi-trophic aquaculture (IMTA), nature-based solutions, waste valorization pathways, and low-impact production models adapted to the ecological characteristics of the lake. Innovation in Šasko jezero is understood not only as technological advancement but also as a cultural shift toward smarter resource use, reduced waste, regenerative practices, and symbiosis with natural processes.

Finally, the vision commits to the advancement of a **circular economy** that strengthens environmental stewardship while generating new economic opportunities. Aquaculture development in Šasko jezero should contribute to ecosystem protection, improve water quality through nature-based processes, reduce resource consumption, and create value-added business models that rely on reuse, recovery, and symbiotic exchanges within the local economy. This transition also supports the diversification of income sources for local fishermen, micro-enterprises, and food producers, contributing to the social and economic vitality of the wider Ulcinj region.

In summary, the vision for Šasko jezero is to become a **holistic, resilient, and inclusive circular aquaculture landscape**, where responsible governance, empowered local actors, innovative practices, and strong environmental protection work together to create long-term prosperity. Guided by the LiRRIE principles and sustained through collaborative action, Šasko jezero aims to stand as a flagship example of how circular economy approaches can transform inland aquatic ecosystems in Montenegro.

Potential of the C-AZA results

The C-AZA assessment for Šasko jezero provides a foundational scientific and technical basis for introducing circular aquaculture in this ecologically sensitive freshwater system. With a final **C-AZA index of 0.633**, Šasko jezero is classified as **“acceptable”** for circular aquaculture development, though positioned at the lower end of the acceptability range. This result indicates that aquaculture is feasible, but must be designed carefully, at appropriate scale, and aligned with environmental constraints. Despite these limitations, the C-AZA results reveal



significant potential for implementing innovative circular models that enhance environmental quality, support local livelihoods, and reinforce sustainable governance.

Environmentally Suitable Conditions for Low-Impact Circular Aquaculture

The overall Site Sustainability Index (SiSI) values—covering water quality, trophic conditions, lake use, surrounding land use, and risk assessment—demonstrate that Šasko jezero possesses baseline environmental conditions compatible with aquaculture. The site's **SiSI score (~0.8)** indicates:

- Sufficient water quality for freshwater culture species
- Stable physicochemical conditions across monitoring months
- A manageable risk level for both semi-extensive and intensive models
- Compatibility with low-impact aquaculture zones

The lake's shallow depth and dynamic hydrology create natural limitations, but they also reinforce the potential for **circular, nature-based practices** that work with the ecosystem rather than against it.

IMTA Potential Based on Species Sustainability Results

The Species Sustainability Index (SSI) and Performance Index (IPI) highlight a **high feasibility** for a freshwater IMTA model built on two selected organisms:

- **Fed species:** *Cyprinus carpio* (common carp)
 - High SSI = 0.83
 - High IPI = 0.760
 - Well-adapted to local conditions
- **Inorganic extractive species:** *Phragmites australis*
 - SSI = 0.61
 - IPI = 0.746
 - Strong capacity for nutrient uptake and phytoremediation

Together, these species create a **synergistic freshwater IMTA system** where carp growth is supported while *Phragmites* contributes to nutrient regulation and environmental recovery.

The resulting **Integrated Sustainability Index (IS) = 0.737** confirms the suitability of this combined model.

This makes Šasko jezero one of the first potential demonstration sites in Montenegro for **IMTA in inland waters**, expanding circular aquaculture beyond its traditional marine focus.

Circularity Potential Highlighted by the ICI Circularity Index

The IMTA Circularity Index (ICI) score of **0.44**—moderate in the project's rating system—indicates substantial room for circular improvement, but also reveals meaningful opportunities, including:

- Reduction of organic residues through species complementarity



- Use of emergent macrophytes for nutrient extraction and biomass utilization
- Potential to repurpose Phragmites biomass (e.g., composting, craft materials, bio-based packaging)
- Application of sediment and water regeneration concepts
- Integration of waste-minimizing practices in carp production

While the ICI is not high, it provides a **clear roadmap** for improving circularity performance through targeted actions.

Alignment with Local Vision and Socio-Economic Needs

The LiRRIE vision emphasizes sustainable development, inclusive governance, innovation, and eco-conscious economic opportunities.

The C-AZA results directly support this direction:

- They offer **scientific justification** for introducing new business opportunities in inland aquaculture.
- They provide a **precautionary yet positive** framework for local stakeholders who expressed high willingness to invest in circular practices.
- They allow Montenegro to develop a **freshwater demonstration site** that can serve the entire region.

For the local fishing community and small businesses—currently operating with low circularity readiness—the C-AZA results show that small-scale circular aquaculture can complement existing activities, enhance income stability, and bring added value through eco-certification and local branding.

Foundation for Policy Innovation and Improved Governance

The structured C-AZA assessment offers Montenegro a valuable tool for:

- Introducing science-based criteria into aquaculture licensing
- Supporting integration of circular practices into regulatory frameworks
- Enhancing cross-sector coordination among environment, water management, and fisheries authorities
- Defining zones for low-impact aquaculture within sensitive ecosystems

Šasko jezero can thus become the **pilot case** for improved national procedures on C-AZA implementation, supporting Montenegro's transition toward a greener, more circular, EU-aligned aquaculture governance model.

Potential for Demonstration, Replication, and Education

Given its ecological distinctiveness, Šasko jezero is uniquely positioned to host:

- **Demonstration IMTA units** for training fishermen, SMEs, students, and policymakers
- **Cross-border knowledge exchange** (particularly with Albania's Buna/Bojana system)



- **Public awareness activities** on circularity, ecosystem-based management, and sustainable freshwater use
- **Applied research** on nutrient flows, macrophyte use, and lake restoration models

By establishing a visible reference site, Montenegro can influence broader regional practices and increase its leadership in the Euro-MED circular aquaculture landscape.

Summary

The C-AZA results reveal significant potential for Šasko jezero to become a **safe, scientifically supported, and circular inland aquaculture zone**, with the ability to:

- Support low-impact freshwater IMTA
- Enhance water and sediment quality
- Create new business opportunities for local operators
- Serve as a pilot for circular innovation in Montenegro
- Strengthen governance and multi-stakeholder cooperation
- Demonstrate the value of circular economy in rural lake ecosystems

These findings form a key pillar of the Action Plan and will guide the design of targeted interventions, training activities, governance improvements, and pilot actions for Šasko jezero.

Proposed Actions

Proposed actions are aligned with **C-AZA results**, **LiRRIE vision**, and **local constraints** (sensitive ecosystem, low readiness, high willingness, limited financial capacity, regulatory complexity).

The actions are **practical, small-scale, low-risk, implementable within 24 months**, and designed to build readiness before scaling.

Key Actions and Interventions

Action 1 – Capacity Building Programme for Local Fishermen and SMEs

Objective

Strengthen the **technical, regulatory, financial, and business capacities** of local fishermen and SMEs, addressing currently **low readiness levels (average 1.7)** and enabling effective participation in circular aquaculture initiatives at Šasko Lake.

Rationale

Stakeholder feedback confirms high willingness to engage (average 3.8), while clearly identifying capacity gaps as the main barrier to implementation. Results from the 4th LiRRIE consultation further confirm that stakeholders prioritise **practical IMTA training as the most important capacity-building need**, followed by **circular business models and guidance on licensing procedures**. Additional training priorities include **eco-certification, financial literacy and grant**



applications, and digital sales and marketing, reflecting the need for a balanced set of technical, regulatory, business, and market-oriented skills.

These findings emphasise the importance of a **hands-on and practice-oriented training programme**, ensuring that local actors acquire the competences necessary to implement circular aquaculture solutions while maintaining environmental safeguards and economic viability.

Interventions

The capacity building programme will be designed as a **demand-driven and sequenced set of interventions**, directly supporting the implementation of the IMTA demonstration pilot and the broader transition towards circular aquaculture at Šasko Lake. Based on stakeholder consultation results, priority will be given to **practical technical skills, circular business understanding, and regulatory clarity**, identified as the key constraints to adoption.

Core interventions will include:

1. Practical IMTA Training (highest stakeholder priority)

Hands-on training on Integrated Multi-Trophic Aquaculture systems, including:

- design and operational principles of freshwater IMTA systems,
- practical operation and maintenance of IMTA units,
- feeding practices and system management under lake conditions,
- environmental monitoring and application of ecological safeguards.

2. Circular Business Models and Resource Efficiency

Training on circular economy approaches relevant to aquaculture, including:

- waste minimisation and resource optimisation,
- integration of circular practices into aquaculture value chains,
- practical examples of circular aquaculture business models adapted to the Montenegrin context.

3. Licensing and Regulatory Procedures

Guidance on administrative and regulatory requirements for freshwater aquaculture:

- permitting pathways and institutional responsibilities,
- compliance requirements for aquaculture operations,
- clarification of administrative procedures and timelines to reduce regulatory uncertainty.

4. Eco-certification and Sustainability Standards

Training on environmental certification schemes and sustainability standards, covering:

- procedures and requirements for eco-certification,
- benefits of certification for market positioning,
- links between environmental monitoring and certification credibility.

5. Financial Literacy and Access to Funding

Capacity building focused on financial planning and access to funding opportunities, including:

- overview of national and EU funding instruments,
- preparation of funding applications,
- basic financial planning and investment considerations for circular aquaculture initiatives.



6. Digital Sales, Marketing and Market Access

Training aimed at improving market reach and product visibility, including:

- use of digital platforms and online sales channels,
- social media marketing strategies for small-scale producers,
- branding and product differentiation emphasising sustainability, circularity, and local origin.

Expected Impact

- Improved operational and financial readiness of local fishermen and SMEs to engage in circular aquaculture;
- Reduced regulatory and administrative barriers through increased understanding of licensing processes;
- Strengthened link between technical innovation, economic viability, and market access;
- Creation of a local skills base capable of supporting long-term, scalable circular aquaculture operations at Šasko Lake.

Action 2 – Establish a Pilot Freshwater IMTA Demonstration Unit at Šasko Jezero

Objective

Demonstrate a **small-scale, precautionary, and environmentally safeguarded circular aquaculture model** at Šasko Lake, integrating *Cyprinus carpio* and *Phragmites australis*, in line with validated C-AZA results and stakeholder expectations.

Rationale

The C-AZA assessment confirms that the proposed IMTA model is **environmentally acceptable and suitable for lake conditions** (Integrated Sustainability Index – IS = 0.737). Stakeholder co-decision strongly supports implementation of the pilot **provided that strict environmental protection measures, continuous monitoring, and adaptive management are ensured**, positioning the pilot as a learning and trust-building instrument rather than a production-driven intervention.

Interventions

- **Design and installation of a small, modular IMTA pilot unit**, ensuring:
 - minimal visual impact,
 - full reversibility and removability,
 - non-invasive anchoring and operation.
- **Semi-extensive rearing of carp (*Cyprinus carpio*)** in floating enclosures, combined with **strategically positioned *Phragmites australis* zones** to support nutrient uptake and circular nutrient flows.
- **Implementation of strict environmental safeguards**, including predefined thresholds, contingency measures, and adaptive management protocols.
- **Regular (monthly) environmental monitoring**, focusing on water quality parameters and ecosystem response, aligned with C-AZA indicators.
- **Transparent communication of results**, through periodic reporting and presentation to stakeholders and the wider public, ensuring accessibility and trust.



Expected Impact

- **Validated proof-of-concept** for circular freshwater aquaculture under sensitive lake conditions;
- Increased **stakeholder trust and social acceptance** through precautionary implementation and transparency;
- Practical **validation and refinement of C-AZA recommendations**;
- Strengthened local capacities and evidence base for potential future scaling, subject to evaluation results.

Action 3 – Community-Based Circularity Initiatives (Low-Investment Interventions)

Objective

Enable local fishermen, small operators, and the wider community to **adopt simple, low-cost circular practices** that deliver immediate environmental benefits, strengthen community ownership, and build momentum for broader circular economy transition at Šasko Lake.

Rationale

Stakeholder feedback confirms that **simple, visible, and low-investment interventions** are the most appropriate entry point for circularity at community level, particularly given the **low readiness levels of fishermen (1.1–1.8)** and their limited financial and technical resources. Participants prioritised actions that combine **practical environmental improvements with strong community engagement and awareness-raising potential**, favouring tangible measures over purely informational campaigns.

Interventions

Core low-investment interventions will focus on practices that can be **implemented rapidly using existing local capacities**:

- **Establishment of waste separation and collection points** at landing sites and key locations around the lake, directly addressing waste reduction and resource efficiency;
- **Introduction and promotion of reusable fishing gear**, including simple net-repair and reuse schemes, to reduce waste generation and operational costs;
- **Community-based clean-up actions**, organised periodically and involving fishermen, local residents, schools, and NGOs, strengthening shared responsibility and visible environmental improvement;
- **Educational eco-trails and visitor-oriented initiatives**, linking circular practices with environmental education and sustainable tourism around Šasko Lake.

Complementary low-budget actions, identified through stakeholder feedback, will further reinforce education, collaboration, and reuse:

- **Regular (e.g. monthly) clean-up campaigns** organised jointly with schools, local NGOs, and community groups;
- **Educational presentations and workshops in schools**, focusing on circular economy principles, waste reduction, and the ecological value of Šasko Lake;



- **Creative reuse of old fishing materials** (e.g. nets, hooks, and equipment) for the production of souvenirs or educational items, combining waste reduction with small-scale local economic opportunities;
- **Recycling of collected waste in cooperation with the local community**, accompanied by public communication and promotion of results to increase visibility and motivation;
- **Structured partnerships with schools and NGOs** for the organisation of joint, periodic activities related to waste collection, awareness raising, and promotion of circular aquaculture practices.

Interventions related to **water inflow management** and broader **plastic reduction campaigns** will be considered selectively, recognising their environmental relevance while acknowledging the need for additional coordination or complementary practical measures.

Expected Impact

- Rapid, visible improvements in environmental conditions through **low-cost, practical circular actions**;
- Strengthened **community ownership and participation** in lake management;
- Increased awareness and behavioural change through education and repeated engagement;
- Creation of a supportive social environment for scaling up circular aquaculture initiatives in subsequent phases.

Action 4 – Environmental Monitoring & Safeguards Implementation

Objective

Ensure the lake remains within safe ecological thresholds while supporting aquaculture.

Rationale

Šasko jezero is shallow, sensitive, and must be monitored carefully.

Interventions

- Continue water-quality sampling (temperature, pH, oxygen, nutrients, turbidity).
- Set up a simple indicator dashboard for local stakeholders.
- Establish precautionary thresholds for IMTA scaling.
- Annual ecological impact report shared with municipality and public.

Expected impact

Safeguards that ensure ecological protection and regulatory compliance.

Action 5 – Business Support & Funding Mobilization for Circular Aquaculture

Objective

Help local businesses access funding and reduce financial barriers.



Rationale

High willingness exists but financial resources are limited.

Interventions

- Advisory support for grant applications (national schemes, PRS funds, Euro-MED, IPARD III).
- Development of micro-grant schemes for fishermen (small equipment, waste-handling tools).
- Explore circular business opportunities for Phragmites biomass (composting, crafts, eco-products).

Expected impact

Greater investment in circularity, improved financial sustainability of local operators.

Action 6 – Governance and Coordination Platform for Šasko Jezero

Objective

Implement inclusive governance aligned with the LiRRIE co-decided vision.

Rationale

Licensing complexity and overlapping mandates require structured coordination.

Interventions

- Establish a local coordination group (environment, fisheries, water, municipality, IMBK, civil society, fishermen).
- Quarterly coordination meetings.
- Joint review of monitoring data and adaptive management decisions.
- Preparation of guidelines for small-scale circular aquaculture licensing.

Expected impact

Improved coordination, reduced administrative barriers, increased trust, and better policy alignment.

Responsible Actors

Actor	Role
Municipality of Ulcinj (Opština Ulcinj)	Lead local coordination role; alignment of actions with local development policies and spatial planning; facilitation of cooperation among local stakeholders; primary interface with the local community.
Local Fishermen's Associations / Local Fishermen and SMEs	Core operational actors; representation of local knowledge and livelihoods; participation in pilot activities, capacity building, and community-based circularity initiatives; feedback on feasibility and impacts.
Ministry of Agriculture, Forestry and Water	Strategic oversight and sectoral authority; guidance on licensing and permitting; alignment



Management / Directorate for Fisheries	with national fisheries and aquaculture policies; institutional support for implementation.
University of Montenegro	Scientific and technical support role; design support for the IMTA pilot; environmental monitoring; applied research; contribution to training activities and evidence-based reporting.
Chamber of Economy of Montenegro	Business and capacity-building support; advisory services related to business development, access to finance, and market readiness for circular aquaculture initiatives.
Environmental Protection Agency (EPA)	Advisory and supervisory role; review of environmental safeguards; oversight of monitoring results; contribution to environmental impact assessment and compliance, without a central decision-making role.
Civil Society Organisations and Local Associations	Supporting and engagement role; participation in awareness-raising actions, community initiatives, and feedback processes; contribution to social acceptance and outreach activities.
LiRRIE Forum Montenegro	Coordination and dialogue mechanism; platform for co-decision, information exchange, and continuous stakeholder engagement, without adding an additional governance layer.

Governance approach:

In line with stakeholder feedback, governance of Šasko Lake will be based on a **shared but focused multi-actor model**, where **local public authorities and organised user groups (municipality and fishermen)** take the lead, forming the **core governance triangle together with the Directorate for Fisheries**. Other actors contribute in **clearly defined supporting or advisory roles**, ensuring legitimacy, practicality, and sustainability, while avoiding unnecessary complexity.

Targeted involvement of **state-level institutions** remains possible where strategic alignment or institutional backing is required, without expanding the stakeholder structure beyond what is necessary for effective decision-making and coordination.

Timeline (Realistic 24-Month Horizon)

Period	Actions
Months 1-3	Establish coordination group; finalize IMTA pilot design; begin training programme.
Months 4-6	Install IMTA pilot; launch community circularity initiatives; initiate monitoring framework.
Months 7-12	Full operation of IMTA pilot; monthly monitoring; ongoing training; licensing guidance.
Months 13-18	Adjustment of pilot based on data; small-scale circularity upgrades; business support actions.



Period	Actions
Months 19–24	Evaluation of IMTA pilot; scaling recommendations; final capacity-building workshops; funding applications.

Timeline is intentionally conservative to reflect ecosystem sensitivity and administrative complexity.

Financial Aspects and Funding Resources

Estimated Budget Ranges

(Indicative; assumes small-scale pilot and capacity-building focus)

- IMTA pilot setup: **€15,000–€25,000** (modular, low-impact system)
- Monitoring equipment & sampling: **€3,000–€5,000**
- Capacity-building programme: **€5,000–€10,000**
- Circularity initiatives (gear, materials): **€2,000–€4,000**
- Coordination & training events: **€3,000–€6,000**

Total indicative budget for 24 months: **€28,000–€50,000** (Realistic for Montenegro; scalable if external funds secured)

Potential Funding Sources

National Funding Sources (Primary)

- **Ministry of Agriculture, Forestry and Water Management** – national grant schemes supporting fisheries and aquaculture development, identified by stakeholders as the **most trusted and preferred funding source**;
- **Directorate for Fisheries** – operational and targeted support measures aligned with sectoral priorities and licensing frameworks;
- **Municipality of Ulcinj** – limited co-financing from environmental protection and local development budgets, primarily to support coordination, awareness activities, and low-cost community actions.

EU and International Funding Sources (Primary and Secondary)

- **IPARD III** – prioritised by stakeholders as a key instrument for aquaculture-related investments, equipment upgrades, and small-scale processing improvements;
- **Interreg programmes (Euro-MED / IPA)** – support for pilot actions, capacity building, cross-border exchange, and innovation-oriented activities;
- **EU Blue Economy and Circular Economy funding instruments** (e.g. DG MARE, selected Horizon Europe small-scale calls) – targeted support for demonstration, innovation, and knowledge transfer;
- **International donors and financial institutions** (e.g. EBRD, UNDP Montenegro) – complementary funding for business support, sustainability measures, and technical assistance.



Private and Complementary Sources

- **Targeted co-financing by motivated SMEs** (e.g. MM Ribarstvo, Montefish, Zeta Fish), primarily in-kind or as co-investment linked to pilot implementation;
- **CSR initiatives of local companies**, supporting specific awareness or environmental actions rather than core investments.

Additional Financial Instruments (Complementary)

- **Commercial bank loans**, as potential sources of investment financing for aquaculture infrastructure, equipment, and operational scaling;
- **Preferential credit lines**, particularly through a **development bank**, offering more favourable conditions (lower interest rates, grace periods, longer repayment terms) for sustainable and circular aquaculture projects.

Financial Realism and Phasing

In line with stakeholder feedback collected during the 4th LiRRIE consultation, implementation of the Action Plan will follow a phased financing approach primarily anchored in **grant-based national and EU funding instruments**. Stakeholder responses indicate that **IPARD III is perceived as the most realistic and accessible financing mechanism**, receiving the strongest support among respondents. This is followed by **national grant schemes and Interreg/IPA programmes**, which are also considered relevant sources for supporting pilot activities, capacity building, and innovation-oriented actions.

Consequently, priority will be given to aligning key interventions—particularly the IMTA demonstration pilot and capacity-building programme—with **IPARD III priorities related to sustainable aquaculture development, rural diversification, and environmentally responsible production systems**. At the same time, national support programmes and cross-border cooperation funds will be explored to complement these investments and support preparatory, training, and demonstration activities.

Given the limited financial capacity of local public budgets and SMEs, the Action Plan prioritises **low-cost, high-impact actions in the initial phase**, while external funding instruments are leveraged to enable scaling and long-term sustainability. Private co-financing and lending instruments may be considered at later stages where appropriate, although stakeholder feedback suggests that such mechanisms are currently perceived as secondary compared to grant-based funding sources.

Monitoring and Evaluation

The Monitoring and Evaluation framework ensures that all proposed actions for Šasko jezero are implemented responsibly, achieve tangible results, and remain aligned with ecological safeguards and stakeholder expectations. Monitoring will focus on simple, measurable indicators, while evaluation will rely on continuous feedback, adaptive management, and transparent communication among key actors.



Success Indicators

Success indicators are defined across four dimensions that reflect the priorities of the Action Plan: environment, technology, governance, and community/business adoption. They correspond directly to the proposed actions.

Environmental Performance Indicators

(Linked to Actions 2 & 4)

- **Water quality remains within acceptable thresholds** for pH, oxygen, conductivity, nutrients, turbidity.
- **No negative ecological impact detected** from the IMTA pilot.
- **Phragmites shows measurable nutrient uptake** (biomass increase, nutrient reduction in surrounding water).
- **Stable ecological conditions** sustained for at least 12 consecutive months of IMTA operation.

IMTA Technical Performance Indicators

(Linked to Action 2)

- **IMTA pilot fully installed and operational** by Month 6.
- **Survival and growth of *Cyprinus carpio*** maintained at expected levels for semi-extensive culture.
- **Regular weekly/bi-weekly monitoring conducted** (health, FCR, feeding, biomass).
- **Circularity demonstrated** through nutrient flow between fed species (carp) and extractive species (Phragmites).

Governance and Coordination Indicators

(Linked to Action 6)

- **Local coordination platform established** and operational by Month 3.
- **Minimum of 4–6 multistakeholder coordination meetings held** within the project period.
- **Stakeholder participation consistently includes all helix groups** (public sector, academia, businesses, civil society, environmental actors).
- **Draft guidelines produced** for small-scale circular aquaculture licensing.

Community, Business, and Circularity Adoption Indicators

(Linked to Actions 1, 3 & 5)

- **At least 20 local stakeholders trained** through capacity-building programmes.
- **At least 3 circular practices adopted** (e.g., reusable gear, waste sorting, bycatch management).
- **One or more micro-circular initiatives launched** (e.g., Phragmites biomass use).



- **A minimum of 3 funding applications prepared** with support from the Chamber of Economy.
- **Private sector co-investment of at least €10,000** mobilized.

Follow-up and Adjustment

Follow-up mechanisms will ensure that implementation remains aligned with environmental restrictions, stakeholder needs, and practical constraints. Adjustments will be made based on monitoring data, participation feedback, and ecological safety requirements.

Quarterly Review Mechanism

- All key actors meet every 3 months to review environmental data, IMTA performance, business uptake, and governance issues.
- Issues or deviations are identified early and corrective measures are proposed.
- Meeting summaries are shared with all LiRRIE members to guarantee transparency.

Adaptive Environmental Management

If environmental thresholds are exceeded (e.g., nutrients, oxygen, turbidity):

- **Immediate action:** reduce feeding, adjust biomass levels, or temporary suspension of IMTA operations.
- **Short-term response:** increase monitoring frequency, conduct targeted ecological assessments.
- **Long-term adjustment:** modify IMTA design, reduce stocking density, or introduce additional extractive components.

Capacity-Building Adjustment

If readiness among fishermen/SMEs remains low:

- Increase practical demonstrations and on-site training.
- Simplify training materials and offer individualized support.
- Add new topics (financial literacy, basic monitoring techniques, waste minimization).

Governance Adjustment

If coordination barriers persist:

- Expand platform membership to include missing actors.
- Introduce thematic working groups (licensing, environment, business).
- Strengthen involvement of municipality and local associations.

Financial Adjustment

If financial resources fall short:



- Re-prioritize low-cost, high-impact actions.
- Increase support for external funding applications.
- Explore public–private partnerships or micro-grants from local businesses.

Final Evaluation (Month 24)

By the end of the project, a final evaluation will:

- Assess overall ecological compatibility of IMTA.
- Measure adoption of circular practices.
- Determine readiness for scaling operations.
- Provide recommendations for long-term C-AZA implementation in Šasko jezero and replication in other Montenegrin inland waters.

Conclusion

Summary

This Action Plan provides a realistic, evidence-based, and inclusive roadmap for introducing circular aquaculture at **Šasko jezero**, fully aligned with the AZA4ICE methodology, the LiRRIE co-decided vision, and the local socio-economic context. The C-AZA assessment confirms that Šasko jezero is **environmentally acceptable** for carefully controlled, low-impact aquaculture, with strong potential for implementing a **freshwater IMTA model** based on *Cyprinus carpio* and *Phragmites australis*. Complementing this, the BLUEfasma circularity baseline highlights a regional profile characterized by **low readiness but high willingness**, signaling a strong desire for innovation once technical and financial support is provided.

The proposed actions—ranging from pilot installation and environmental monitoring to capacity-building, community engagement, governance strengthening, and financial mobilization—are designed to be **realistic, low-cost, and scalable** within Montenegro's current capabilities. They aim to ensure ecological protection, empower local stakeholders, enable circularity adoption, and establish Šasko jezero as a **national demonstration site** for sustainable freshwater aquaculture.

Through strengthened cooperation among public authorities, scientific institutions, fishermen, SMEs, civil society, and the local community, Šasko jezero can become a leading example of **how circular economy principles can be implemented in sensitive inland ecosystems** in Montenegro.

Next Steps

To operationalize this Action Plan, the following next steps are recommended:

1. Formal Endorsement and Coordination Setup (Months 1–2)

- Confirm institutional endorsement of the Action Plan by the Ministry, EPA, IMBK, and Municipality of Ulcinj.
- Establish the **local coordination platform** and define clear roles and communication channels.



2. Preparation and Installation of the IMTA Pilot (Months 2–6)

- Finalize technical design and site selection within Šasko jezero.
- Acquire low-impact equipment and install the IMTA unit.
- Launch environmental baseline measurements.

3. Initiate Capacity-Building and Community Interventions (Months 2–12)

- Deliver practical training for fishermen and SMEs.
- Begin community-based circularity initiatives and awareness activities.
- Support circular micro-initiatives using Phragmites or other low-cost resources.

4. Launch Continuous Monitoring (Months 3–24)

- Conduct structured monitoring of water quality, IMTA performance, and circularity adoption.
- Review monitoring results quarterly; apply adaptive management.

5. Mobilize Financing (Ongoing)

- Support SMEs and fishermen in preparing funding applications to national and EU programmes.
- Explore co-investment opportunities from private operators.
- Identify long-term financing for IMTA scaling if results are positive.

6. Mid-Term Review and Adjustment (Month 12)

- Assess initial environmental and technical performance.
- Adjust IMTA operation, governance mechanisms, and training programmes as needed.

7. Final Evaluation and Future Planning (Month 24)

- Evaluate environmental safety, socio-economic impacts, and circularity adoption.
- Decide whether to **scale, replicate, or institutionalize** C-AZA-based circular aquaculture in Montenegro's inland waters.
- Prepare recommendations for policy refinement and long-term governance.

With coordinated action, strong stakeholder engagement, and careful environmental stewardship, Šasko jezero can become a pioneering example of circular aquaculture in Montenegro—demonstrating how ecological protection and economic opportunity can be mutually reinforcing within a sensitive freshwater ecosystem.



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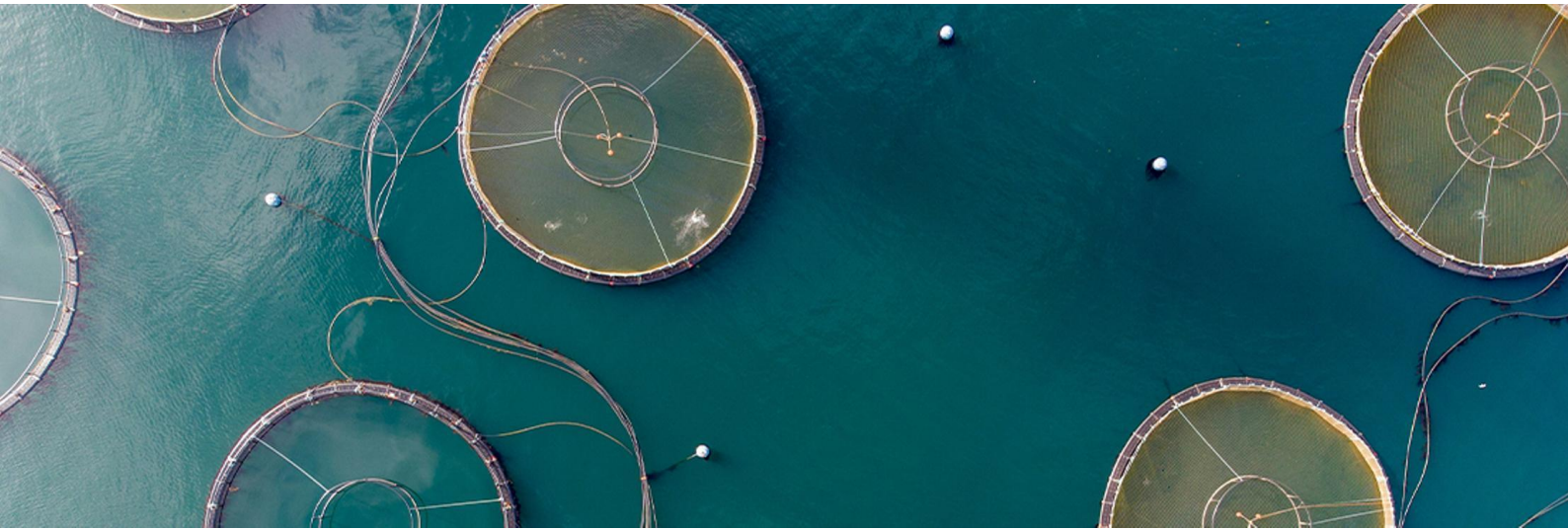


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April 2026

Output 3.1 AZA4ICE Action Plans for the transition to an Inclusive and Circular Economy in aquaculture sector

AZA4ICE Action Plan for Palaio Lagoon Lefkada, Greece

<https://aza4ice.interreg-euro-med.eu>



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Abbreviations

AZA	Allocated Zone for Aquaculture
C-AZA	Circular Allocated Zone for Aquaculture
C-AZAI	C-AZA Index
GES	Good Environmental Status
HAPO	Hellenic Aquaculture Producers Organisation
IMTA	Integrated Multi-Trophic Aquaculture
LiRRIE	Living Responsible Research & Innovation Ecosystems
NECCA	Natural Environment and Climate Change Agency
SAC	Special Area of Conservation
SiSI	Site Suitability Index
SPA	Special Protection Area



1. Executive Summary

This Action Plan has been developed within the framework of the AZA4ICE project to support the sustainable development of aquaculture in the Lefkada lagoon system through the adoption of circular aquaculture principles. The plan builds upon the results generated by the AZA4ICE methodology application, which integrates environmental suitability analysis, species selection and circular production assessment to identify opportunities for the implementation of circular aquaculture systems.

The Lefkada lagoon represents a characteristic Mediterranean coastal ecosystem where traditional lagoon aquaculture practices coexist with valuable wetland habitats and a range of coastal economic activities. Historically, aquaculture production in the lagoon has been based on extensive systems that rely on natural fish migration and low-intensity harvesting techniques. These systems are functionally closer to fisheries than to conventional aquaculture, as they depend on natural ecological processes and passive fish capture dynamics rather than controlled production conditions. This characteristic represents both a constraint and an opportunity for the development of circular aquaculture approaches adapted to lagoon environments. While these traditional practices generally maintain a low environmental impact, they also present limitations in terms of production diversification, economic resilience and resource efficiency. The AZA4ICE analysis indicated that the Lefkada lagoon presents a moderate but promising suitability for the development of circular aquaculture systems. In particular, the integration of different trophic levels within aquaculture production, through IMTA approaches, offers opportunities to enhance nutrient recycling, improve ecosystem functioning and diversify aquaculture production.

The Action Plan therefore proposes a strategic framework aimed at supporting the gradual transition towards circular aquaculture practices adapted to lagoon environments. The proposed approach combines environmental monitoring, technical innovation, stakeholder engagement and institutional coordination. Key actions include strengthening environmental monitoring programmes to better understand lagoon ecological dynamics, promoting knowledge transfer and capacity building among aquaculture operators, and exploring the feasibility of pilot IMTA systems combining fed species with extractive organisms, in particular oysters and halophytic plants. These initiatives are designed to test circular production concepts while maintaining compatibility with the ecological characteristics of the lagoon ecosystem.

Governance and stakeholder participation represent another central component of the Action Plan. The implementation of circular aquaculture practices requires effective collaboration among regional and local authorities, research institutions, aquaculture operators and civil society organisations. The LiRRIE participatory



framework developed within the AZA4ICE project provides a platform to facilitate dialogue among these actors and support shared decision-making processes.

The monitoring and evaluation framework proposed in this Action Plan will allow the assessment of environmental, technical, economic and social aspects of circular aquaculture implementation. Through a combination of environmental indicators, operational performance metrics and stakeholder engagement indicators, the monitoring system will support adaptive management and ensure that aquaculture development remains aligned with sustainability objectives.

Overall, the Action Plan provides a roadmap for exploring innovative aquaculture practices in the Lefkada lagoon while preserving the ecological integrity and cultural heritage of this coastal environment. The proposed actions aim to strengthen the long-term sustainability and resilience of lagoon-based aquaculture systems and contribute to broader regional efforts to promote circular and environmentally responsible aquaculture development in the Mediterranean.



2. Introduction

Scope and Objectives

This Action Plan aims to support the sustainable development of aquaculture in the Lefkada lagoon system through the application of the Circular Allocated Zones for Aquaculture (C-AZA) framework developed within the AZA4ICE project. The document translates the technical assessments, spatial analyses and stakeholder engagement activities carried out during the project into a structured set of strategic orientations and operational recommendations designed to facilitate the gradual implementation of circular aquaculture approaches in the pilot area.

The Plan is intended to bridge scientific knowledge, policy frameworks and practical aquaculture management by providing a coherent pathway for integrating circular economy principles into lagoon-based aquaculture systems. Particular attention is given to ensuring that production activities remain compatible with the ecological characteristics of the lagoon ecosystem while at the same time strengthening the socio-economic viability of the sector. More specifically, the Action Plan seeks to promote the integration of circular economy principles into aquaculture development strategies, encouraging production models that minimise waste, enhance resource efficiency and promote nutrient recycling within the ecosystem. In this context, Integrated Multi-Trophic Aquaculture (IMTA) systems represent a promising approach capable of combining fed and extractive species in order to optimise nutrient flows and improve environmental performance.

Another important objective of the Plan is to strengthen coordination among the different actors involved in aquaculture governance and management. Public authorities, research institutions, aquaculture operators and civil society organisations all play complementary roles in shaping the development of the sector. Improved coordination among these actors is essential to ensure coherent decision-making processes, transparent governance mechanisms and effective implementation of sustainable aquaculture strategies.

The Action Plan also emphasises the importance of improving environmental monitoring and data availability in order to support evidence-based planning and adaptive management. Reliable information on water quality conditions, ecosystem dynamics and species performance is fundamental for ensuring that aquaculture development remains compatible with environmental protection objectives.

Finally, the document seeks to facilitate knowledge transfer and capacity building among stakeholders involved in lagoon aquaculture. By strengthening technical knowledge, promoting the exchange of experiences and encouraging participatory governance processes, the Plan aims to create favourable conditions



for the progressive adoption of circular aquaculture practices within the Lefkada lagoon system.

Overall, this Action Plan is intended to serve as a strategic reference for local authorities, aquaculture operators, research institutions and other stakeholders engaged in the management and development of aquaculture activities in the Lefkada lagoon. By combining scientific evidence, stakeholder perspectives and practical recommendations, the document contributes to the long-term sustainability and resilience of lagoon-based aquaculture systems.

Context

Aquaculture plays an increasingly important role in supporting food security, economic development and coastal livelihoods across the Mediterranean region. As demand for aquatic products continues to grow, the sector is expected to expand further in the coming decades. However, the development of aquaculture activities must be carefully managed to ensure that production systems remain compatible with environmental protection objectives, biodiversity conservation and the sustainable use of coastal resources. In this context, circular aquaculture approaches have emerged as an innovative pathway for reconciling production objectives with environmental sustainability. By promoting nutrient recycling, ecosystem integration and efficient resource use, circular aquaculture systems seek to minimise environmental impacts while improving the overall resilience and productivity of aquaculture operations.

The AZA4ICE project contributes to this broader policy and scientific context by developing a methodological framework for identifying Circular Allocated Zones for Aquaculture (C-AZA). This framework builds upon the concept of Allocated Zones for Aquaculture (AZA), which has been widely promoted as a spatial planning tool for supporting sustainable aquaculture development. The AZA4ICE methodology extends this concept by integrating circular economy principles, ecosystem-based management approaches and participatory governance mechanisms. The methodological framework developed within AZA4ICE combines environmental suitability analysis, species compatibility modelling, circularity assessment and stakeholder participation in order to identify areas where aquaculture activities can be developed or strengthened in an environmentally responsible and socially acceptable manner. Through the integration of spatial analysis and participatory processes, the methodology supports evidence-based decision-making and encourages collaborative planning among stakeholders.

The Lefkada lagoon system was selected as one of the pilot sites for testing this methodology due to its ecological importance, the presence of long-established lagoon aquaculture practices and the potential for exploring innovative circular aquaculture approaches adapted to coastal wetland environments. The Lefkada pilot site is located within the Lefkada lagoon complex, a coastal wetland system situated on the north-eastern side of Lefkada Island in the Ionian Sea in western



Greece, close to the city of Lefkada. The lagoon complex consists of two hydrologically connected water bodies, namely the Paleo Lagoon and the Avlémonas Lagoon. The AZA4ICE pilot case focuses specifically on the Paleo Lagoon, where the aquaculture activities addressed in this Action Plan are currently located. The Lefkada lagoon complex forms part of a wider coastal wetland system of considerable ecological value. The area is included in the Natura 2000 network, being designated both as a Special Area of Conservation (SAC) and a Special Protection Area (SPA) and is also recognised as a Ramsar wetland of international importance. These conservation designations highlight the ecological significance of the lagoon and underline the need for careful management to ensure compatibility between economic activities and environmental protection objectives. The lagoon's fish community includes species typical of brackish environments, including grey mullet (*Mugil cephalus*), European eel (*Anguilla anguilla*), gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*).

Human use of the lagoon has historically been closely linked to its natural resources and cultural heritage. The area has long supported artisanal fishing activities based on traditional lagoon management practices. In particular, the Paleo Lagoon hosts a traditional fish-trap system locally known as *ivari*, which has been operating since the mid-1980s. This system represents a form of extensive lagoon aquaculture based on fixed structures that guide naturally migrating fish into trapping enclosures. Production includes species typical of lagoon environments as well as high-value products such as bottarga, produced from processed fish roe. Although historically managed by a larger number of operators, the workforce involved in the system has gradually declined over time due to demographic changes and institutional constraints. Nevertheless, the lagoon continues to support a low-intensity and environmentally compatible aquaculture management regime in which fish harvesting relies on fixed fish-trap installations positioned at strategic points of water exchange between the lagoon and the canal.

Aquaculture practices in lagoon environments such as Lefkada present specific characteristics that distinguish them from conventional aquaculture systems. In these transitional ecosystems, production is strongly dependent on natural processes and follows extensive management approaches, making it more closely comparable to fisheries than to intensive aquaculture. Lagoon aquaculture relies on the natural productivity of the ecosystem and on traditional management practices, often involving passive capture systems rather than controlled farming conditions. This distinction is particularly relevant in the Greek context, where lagoon-based production systems have historically developed within a fisheries management framework. As a result, they are governed by regulatory, ecological and socio-economic dynamics that differ significantly from those of marine aquaculture. In contrast, marine aquaculture represents the main component of intensive production in Greece. This is especially evident in the Ionian Sea, where environmental conditions are highly favourable, including deep waters, the presence of naturally sheltered areas and limited exposure to strong winds. These conditions support the development of offshore and coastal aquaculture systems



characterised by higher levels of technological input and production intensity.

Within this context, the AZA4ICE project provides an important framework for exploring how traditional lagoon aquaculture systems can be strengthened and adapted to respond to contemporary environmental, economic and governance challenges. The application of the C-AZA methodology at the Lefkada pilot site aims to assess the environmental suitability of the lagoon for aquaculture activities, identify opportunities for circular production models and support participatory governance processes involving local stakeholders. Through the integration of environmental data, spatial analysis, circularity assessment, and stakeholder engagement under the LiRRIE framework, the AZA4ICE approach contributes to the development of evidence-based strategies capable of maintaining the ecological integrity of the lagoon while supporting the long-term sustainability of its traditional aquaculture practices.

3. Roles and Responsibilities of Key Actors

The development and implementation of circular aquaculture systems requires the coordinated involvement of a wide range of actors operating at different institutional, scientific and operational levels. Sustainable aquaculture governance relies not only on appropriate regulatory frameworks but also on effective collaboration among public authorities, research institutions, private operators and local communities. Each of these actors contributes specific knowledge, responsibilities and capacities that are essential for the successful implementation of circular aquaculture strategies.

Public authorities play a central role in defining the institutional and regulatory context within which aquaculture activities are developed and managed. Their responsibilities include establishing policy frameworks, issuing licences, regulating access to aquatic resources and ensuring that aquaculture operations comply with environmental protection standards. Public authorities are also responsible for spatial planning processes, environmental monitoring programmes and the coordination of sectoral policies related to fisheries, aquaculture, environmental conservation and coastal development. Through these functions, governmental institutions contribute to creating the enabling conditions necessary for the development of sustainable aquaculture systems.

Research institutes and scientific organisations provide the scientific knowledge and technical expertise required to support evidence-based decision-making. Their work contributes to improving the understanding of ecosystem dynamics, evaluating environmental carrying capacity and developing modelling tools capable of assessing species suitability and system interactions. In addition, research institutions play an important role in supporting innovation by testing new production models, evaluating environmental performance and providing technical guidance for the implementation of circular aquaculture approaches



such as IMTA systems.

Aquaculture operators represent the actors directly responsible for the implementation of production activities. Their experience and practical knowledge of local environmental conditions are fundamental for translating scientific recommendations into operational practices. The willingness of operators to adopt new technologies, diversify production systems and participate in collaborative governance processes plays a crucial role in determining the feasibility and long-term success of circular aquaculture initiatives.

Local communities and civil society organisations also contribute significantly to the governance of aquaculture activities. Their perspectives help ensure that development strategies are aligned with local social expectations, cultural values and environmental priorities. In coastal areas where multiple economic activities coexist, including tourism, fisheries and environmental conservation, community involvement is essential for maintaining social acceptance and preventing potential conflicts over resource use.

The stakeholder engagement process conducted within the AZA4ICE project highlighted the importance of maintaining open and continuous dialogue among these different actors. The LiRRIEs participatory framework developed within the project provides a platform for facilitating this dialogue, allowing stakeholders to share knowledge, discuss potential challenges and collaboratively identify solutions that support sustainable aquaculture development in the Lefkada lagoon system.

Regional and National Authorities

At the national level, aquaculture governance in Greece is primarily coordinated by the Ministry of Rural Development and Food, which holds the main responsibility for the regulation, strategic planning and development of the aquaculture sector through its Directorate of Aquaculture and Fisheries. This ministry is responsible for defining national aquaculture policies, implementing the national strategic plan for sustainable aquaculture development, and supervising licensing procedures for aquaculture establishments. In addition, it coordinates the implementation of relevant European Union policies, including the Common Fisheries Policy and funding instruments supporting the development of the blue economy. The regulatory framework for aquaculture also involves several other national ministries whose competences intersect with coastal and marine management. The Ministry of Environment and Energy plays a key role in environmental permitting procedures and spatial planning policies, particularly through the implementation of environmental impact assessment requirements and the management of protected areas. At the same time, the Ministry of Maritime Affairs and Insular Policy is involved in matters related to maritime space management, navigation safety and coastal infrastructure. These multiple administrative responsibilities reflect the inherently cross-sectoral nature of aquaculture governance in Greece, where



environmental protection, maritime management and economic development must be coordinated across different institutional domains.

At the regional level, administrative responsibilities are exercised by the Region of the Ionian Islands (Perifereia Ionion Nison), which constitutes one of the thirteen administrative regions of Greece and includes the regional units of Corfu, Lefkada, Kefalonia, Zakynthos and Ithaca. The regional administration plays an important role in implementing national policies at the territorial level, particularly with regard to regional development planning, environmental management and the coordination of sectoral activities such as fisheries, aquaculture and coastal tourism. In addition, a significant role is played by the Decentralized Administration of the Peloponnese, Western Greece, and the Ionian Islands, which operates as a deconcentrated state authority. This body is responsible for key administrative functions, including the approval of environmental terms, supervision of spatial planning instruments, and oversight of compliance with national legislation. Its role is particularly relevant in licensing procedures and environmental governance, acting as a critical link between central government and regional/local authorities. Within the region, the Regional Unit of Lefkada represents the main territorial authority responsible for local administrative coordination. Regional authorities contribute to supervising aquaculture activities through regional fisheries services, participating in environmental monitoring programmes and supporting regional development initiatives that affect coastal and lagoon ecosystems. They also act as intermediaries between national ministries, local municipalities and sectoral stakeholders, facilitating the implementation of regulatory frameworks and development strategies at the local scale.

In areas designated as environmentally protected, additional governance responsibilities are exercised by specialised environmental management bodies. In the case of the Lefkada lagoon system, conservation and environmental management tasks are coordinated by the Natural Environment and Climate Change Agency (NECCA) through its regional management units responsible for Natura 2000 sites. These bodies oversee the implementation of conservation measures, monitor ecological conditions and ensure that human activities within protected areas remain compatible with biodiversity protection objectives.

Finally, the Municipality of Lefkada plays a particularly strategic role in the governance of lagoon systems. Beyond its general responsibilities in local planning, infrastructure development and coastal management, the municipality holds a unique dual function as both owner and operator (aquaculturist) of the Lefkada lagoons. This dual role makes it a central actor in decision-making processes related to lagoon management, directly influencing both production practices and environmental stewardship. Municipal authorities are also involved in promoting local economic development strategies, supporting tourism and cultural heritage initiatives, and facilitating dialogue between local communities and sectoral stakeholders.

Through this multi-level governance structure, aquaculture management in



Lefkada involves a complex interaction between national ministries, regional administrations, decentralised state authorities, environmental management bodies and local authorities. Effective coordination among these actors is therefore essential to ensure that aquaculture development remains environmentally sustainable, socially accepted and aligned with broader coastal management objectives.

Research Institutes and Scientific Organizations

Scientific institutions play a fundamental role in supporting sustainable aquaculture development in Greece by providing the technical knowledge and analytical tools necessary for ecosystem-based management. Universities and research institutes contribute to the study of coastal ecosystems, the assessment of environmental carrying capacity and the development of innovative aquaculture production systems adapted to Mediterranean conditions. Several academic institutions have developed specialised expertise in fisheries science, aquaculture technology and marine ecology. These include departments of fisheries and aquaculture at Greek universities, as well as national research organisations that support applied research and innovation in the aquaculture sector. Through scientific projects, environmental monitoring programmes and collaborative research initiatives, these institutions generate the knowledge required to inform policy development and support evidence-based planning.

Beyond research activities, scientific organisations also play an important role in capacity building and knowledge transfer. Training programmes, technical workshops and collaborative research initiatives provide opportunities for aquaculture operators, public authorities and other stakeholders to exchange knowledge and improve their understanding of sustainable aquaculture practices. In this way, scientific institutions contribute not only to technological innovation but also to strengthening the institutional and technical capacities required for the implementation of circular aquaculture strategies.

Aquaculture Sector and Associations

Aquaculture operators represent the actors directly responsible for managing production activities within the lagoon system. In the Lefkada lagoon, aquaculture practices are closely linked to traditional lagoon fisheries that rely on extensive management systems based on fish migration and trapping techniques. These systems require detailed knowledge of lagoon hydrodynamics, seasonal ecological cycles and species behaviour, knowledge that has been accumulated over generations of local fishers. Operators manage the day-to-day functioning of aquaculture installations, maintain fishing structures and coordinate harvesting activities. Their role is therefore central in translating scientific recommendations and regulatory requirements into practical management actions. The success of circular aquaculture initiatives ultimately depends on the willingness and capacity



of operators to experiment with new production approaches, adopt monitoring practices and participate in collaborative governance processes.

At the national level, aquaculture producers are represented by sectoral organisations such as the Hellenic Aquaculture Producers Organisation (HAPO) and the Federation of Greek Maricultures, which contribute to representing the interests of producers, promoting sustainable aquaculture development and facilitating communication between the sector and public authorities. In the specific context of lagoon fisheries, cooperative structures and professional associations also play an important role in coordinating management practices and representing the interests of lagoon fishers at regional and national levels. Through these organisational structures, the aquaculture sector can actively contribute to policy dialogue, participate in research and innovation initiatives and support the dissemination of best practices related to sustainable and circular aquaculture production.

Civil Society and Local Communities

Local communities and civil society organisations play an important role in shaping the social context within which aquaculture activities develop. In coastal areas such as Lefkada, economic activities including tourism, fisheries and environmental conservation coexist within a shared coastal landscape. The perceptions and expectations of local communities therefore strongly influence the level of social acceptance associated with aquaculture development. Community involvement contributes to ensuring that aquaculture initiatives are aligned with local cultural traditions and environmental values. In the case of the Lefkada lagoon, traditional lagoon fisheries represent an important element of the area's cultural heritage, reinforcing the connection between local communities and the lagoon ecosystem. Maintaining this connection is essential for ensuring that future aquaculture development strategies remain socially supported and culturally meaningful.

Civil society organisations, environmental groups and local associations can also play an active role in raising awareness about sustainable aquaculture practices and promoting responsible management of coastal ecosystems. Through participation in consultation processes and collaborative governance platforms, these actors contribute to broadening the range of perspectives considered in decision-making processes.

Within the AZA4ICE project, the LiRRIEs participatory framework provided a structured platform for stakeholder dialogue, enabling representatives from public institutions, the aquaculture sector, research organisations and local communities to exchange views and identify common priorities. Such participatory mechanisms are essential for building trust among stakeholders and creating the social conditions necessary for the successful implementation of circular aquaculture initiatives in the Lefkada lagoon system.



4. Regional Needs, Challenges and Opportunities

The stakeholder consultation process carried out within the AZA4ICE project provided valuable insights into the current conditions, expectations and concerns of actors involved in aquaculture management in the Lefkada lagoon system. The analysis highlighted a number of priority needs, potential challenges and emerging opportunities that are relevant for the development of circular aquaculture practices in the area. The Lefkada lagoon represents a complex socio-ecological system where aquaculture activities coexist with tourism, fisheries and environmental conservation priorities. Understanding the needs and constraints of the regional context is therefore essential for identifying realistic pathways for the implementation of Allocated Zones for Circular Aquaculture (C-AZA).

Regional needs

One of the most important needs identified by stakeholders concerns the strengthening of environmental monitoring systems. Lagoon ecosystems are inherently dynamic and sensitive to environmental changes, and reliable data on water quality parameters, nutrient dynamics and ecosystem conditions are essential for ensuring the sustainable management of aquaculture activities. Improved monitoring systems would support more informed decision-making processes and help detect potential environmental pressures at an early stage. The availability of long-term datasets on water quality, nutrient loads and ecological indicators would also significantly improve the accuracy of modelling tools used for aquaculture planning and environmental suitability assessments.

Another key need relates to the development of technical knowledge and operational capacity associated with circular aquaculture approaches. While local operators possess extensive experience in traditional lagoon aquaculture practices, the implementation of integrated production systems such as IMTA requires additional technical expertise and specialised training. Capacity-building initiatives, demonstration activities and knowledge exchange programmes could therefore play an important role in facilitating the gradual adoption of circular production models adapted to lagoon environments.

Stakeholders also highlighted the importance of improving infrastructure and technical services supporting aquaculture operations. Although the current extensive aquaculture system requires relatively limited infrastructure, the diversification of production systems and the potential introduction of new species or integrated farming approaches may require additional logistical support, equipment and operational facilities. Investments in monitoring technologies, environmental sensors and improved maintenance of lagoon structures could enhance both the environmental sustainability and the operational efficiency of aquaculture activities.



Governance coordination emerged as another important area requiring further strengthening. Effective collaboration among public authorities, research institutions and aquaculture operators is essential for ensuring coherent planning processes and transparent management of aquaculture activities. Stakeholders emphasised the value of participatory governance platforms capable of facilitating communication among actors and supporting collective decision-making processes. In this context, the LiRRIEs participatory framework developed within the AZA4ICE project represents a useful platform for strengthening dialogue among stakeholders.

Finally, the need for stronger integration between aquaculture activities and broader socio-economic development strategies was also highlighted. Strengthening links between aquaculture production, local markets, tourism and regional identity could contribute to enhancing the economic resilience of lagoon-based production systems while reinforcing the cultural value associated with traditional aquaculture practices.

Environmentally Compatible Aquaculture Models

The development of aquaculture systems that remain fully compatible with the ecological characteristics of the Lefkada lagoon represents a key regional need. The lagoon forms part of a sensitive coastal wetland ecosystem, recognised for its ecological value and protected under European environmental legislation. Ensuring that aquaculture activities maintain low environmental impact and support ecosystem functioning is therefore essential. Circular aquaculture approaches, including IMTA systems, offer the potential to enhance nutrient recycling and improve ecological efficiency by integrating fed and extractive species. Further research and pilot initiatives are required to identify production models that are technically feasible and environmentally compatible with the lagoon ecosystem.

Governance and Decision-Making Coordination

Effective governance coordination is necessary to ensure that aquaculture development remains consistent with environmental protection objectives and regional planning frameworks. Aquaculture management in Greece involves multiple administrative levels, including national ministries, regional authorities and local management bodies responsible for protected areas. Improved coordination mechanisms could help streamline licensing procedures, facilitate data sharing and ensure that planning decisions are supported by scientific evidence. Strengthening multi-stakeholder dialogue platforms would also contribute to improving transparency and trust among actors involved in aquaculture management.



Strengthened Local Capacity

Developing local capacity for the management of circular aquaculture systems represents another important priority. This includes strengthening the technical skills of aquaculture operators, improving the ability of local authorities to monitor environmental conditions and supporting research institutions in conducting applied studies relevant to lagoon aquaculture systems. Training initiatives and collaborative research activities could facilitate knowledge transfer between scientific institutions and local operators, supporting the gradual transition towards more sustainable production practices.

Technological and Knowledge Needs

The implementation of circular aquaculture systems requires access to appropriate technologies and technical knowledge. Monitoring tools capable of measuring environmental parameters, modelling platforms that support species suitability assessments and operational technologies for integrated aquaculture systems are essential components for the successful implementation of circular production models. Increasing the availability of such tools and improving access to technical guidance would support both operators and public authorities in making informed management decisions.

Regulatory Alignment and Policy Support

Ensuring that regulatory frameworks support the development of circular aquaculture practices represents another important regional need. Although Greece has established national policies regulating aquaculture development, additional efforts may be required to align existing regulations with innovative production approaches such as IMTA systems. Clarifying licensing procedures, simplifying administrative processes and ensuring coherence between aquaculture regulations and environmental protection policies would contribute to creating a more predictable institutional environment for operators.

Socio-Economic Integration and Stakeholder Engagement

Strengthening the integration of aquaculture within the broader socio-economic activities of the Lefkada region is also essential. Aquaculture activities coexist with tourism, small-scale fisheries and nature conservation initiatives, and maintaining positive interactions among these sectors is fundamental for long-term sustainability. Stakeholder engagement processes that involve local communities, tourism operators and environmental organisations can help ensure that aquaculture development remains socially acceptable and contributes to the economic vitality of coastal communities.



Regional Challenges

Despite the favourable conditions for aquaculture development in the Lefkada lagoon, several challenges may influence the implementation of circular aquaculture approaches. One of the main challenges concerns the limited availability of detailed environmental and biological data required to support advanced modelling of species suitability and ecosystem interactions. Although basic environmental information is available, more comprehensive datasets would be beneficial for improving the accuracy of planning tools and supporting long-term management strategies. The technical complexity associated with circular aquaculture systems also represents a potential challenge. Integrated production models require a deeper understanding of ecological interactions between different trophic levels, as well as careful management of species combinations and environmental conditions. For many operators, the transition from traditional extensive systems to more integrated production models may therefore require additional technical guidance and practical demonstration activities. An additional challenge is linked to the hybrid nature of lagoon aquaculture systems, which are functionally closer to fisheries than to conventional aquaculture. In the Lefkada lagoon, production is largely based on extensive practices that rely on natural ecosystem productivity and fish migration dynamics, rather than controlled farming conditions. This dual character may create regulatory and management complexities, as existing aquaculture frameworks are not always fully adapted to systems that operate at the interface between fisheries and aquaculture. As a result, planning, licensing and management approaches may require further adaptation to adequately reflect the specific characteristics of lagoon-based production systems.

Infrastructure limitations may also influence the feasibility of diversifying aquaculture activities. The lagoon currently operates under a relatively low-intensity management regime, and the introduction of new production systems may require investments in equipment, monitoring technologies and logistical support. Market uncertainty related to the commercialisation of non-traditional aquaculture species represents another challenge. Although integrated aquaculture systems may generate environmental benefits and production diversification, the economic viability of such systems ultimately depends on the existence of stable markets and value chains for the products generated.

Finally, the regulatory framework governing aquaculture activities in protected wetland areas may introduce additional administrative complexity. The coexistence of environmental protection regulations and economic development objectives requires careful coordination between competent authorities to ensure that licensing procedures remain transparent and predictable for operators.



Environmental Challenges

Environmental variability represents an inherent challenge in lagoon ecosystems. Fluctuations in salinity, temperature and nutrient concentrations may influence the productivity of aquaculture systems and the ecological balance of the lagoon. Climate change may further intensify these dynamics, potentially affecting water circulation patterns, ecological interactions and the resilience of lagoon habitats.

Economic Viability Challenges

Ensuring the economic sustainability of circular aquaculture systems remains a key challenge. Although integrated production models may improve ecological performance, their financial viability depends on production efficiency, operational costs and market demand for the species produced. Developing effective marketing strategies and strengthening value chains will therefore be important elements for ensuring long-term economic viability.

Technological and Knowledge Challenges

The implementation of innovative aquaculture systems requires access to technical expertise and operational technologies that may not yet be widely available at the local level. Bridging this knowledge gap requires collaboration between research institutions, technical experts and aquaculture operators, as well as targeted training programmes capable of supporting the adoption of new practices.

Regulatory Challenges

The presence of environmental protection frameworks associated with Natura 2000 and wetland conservation policies may introduce additional regulatory requirements for aquaculture activities. While these regulations play a crucial role in safeguarding biodiversity, they may also complicate licensing procedures and require careful environmental assessments before new production systems can be implemented.

Regional Opportunities

Alongside these challenges, the Lefkada lagoon system also presents several favourable conditions that could support the development of circular aquaculture practices. The existing extensive aquaculture system is already characterised by low environmental impact and strong integration with natural ecosystem processes. This provides a solid foundation for exploring circular production approaches without fundamentally altering the traditional management structure of the lagoon. The environmental suitability analysis carried out within the AZA4ICE project indicated that the lagoon possesses environmental conditions compatible with aquaculture activities. The Site Suitability Index calculated for the pilot site



suggests a moderate level of environmental suitability, indicating that production activities can be sustained provided that appropriate environmental management practices are maintained. The modelling of IMTA systems conducted during the project also identified promising species combinations capable of enhancing nutrient recycling within the lagoon ecosystem. The potential integration of extractive species such as bivalves or halophytic plants alongside traditional fish production could contribute to improving ecological efficiency while diversifying production outputs. The fisheries-like nature of lagoon aquaculture systems also represents an opportunity to develop low-impact, ecosystem-based production models that are inherently aligned with circular aquaculture principles.

Another important opportunity lies in the strong cultural and environmental identity associated with the lagoon landscape. Traditional aquaculture practices represent an integral part of the local heritage and could be further valorised through sustainable branding initiatives, eco-tourism activities and the promotion of high-quality lagoon products linked to environmentally responsible production methods. Finally, the stakeholder engagement activities carried out within the AZA4ICE project revealed a generally positive attitude among local actors towards the exploration of circular aquaculture approaches. This level of interest and openness provides a favourable social and institutional context for future initiatives aimed at strengthening the sustainability and resilience of aquaculture in the Lefkada lagoon system.

Strong Stakeholder Motivation

The participatory activities carried out within the AZA4ICE project demonstrated a strong level of stakeholder engagement and willingness to explore innovative aquaculture solutions. Local operators, public authorities, and research institutions expressed interest in collaborative initiatives that could support the development of environmentally sustainable aquaculture practices while maintaining the cultural identity associated with traditional lagoon fisheries.

Lefkada Positioning Potential

The Lefkada lagoon system also holds potential to position itself as a regional example of environmentally responsible lagoon aquaculture. By combining traditional knowledge with scientific innovation and participatory governance approaches, the area could serve as a pilot case for the development of circular aquaculture models in Mediterranean coastal lagoons. Such positioning could attract research initiatives, funding opportunities and sustainable tourism activities linked to the promotion of environmentally friendly aquaculture practices.



5. Current Legal, Regulatory and Licensing Framework

Aquaculture activities in Greece are regulated through a combination of national legislation (Law 4282/2014 on Aquaculture Development), sectoral planning instruments, notably the Special Framework for Spatial Planning and Sustainable Development for Aquaculture (2011), and European Union directives. These measures, including the EU Strategic Guidelines for Aquaculture, are aimed at ensuring environmental protection, sustainable resource management, and the sustainable development of the sector. In addition to the aforementioned legal instruments, aquaculture activities in Greece are also subject to the provisions of Legislative Decree No. 420/1970 (Fisheries Code), particularly Article 35. This legislation remains highly relevant for activities carried out in waters rich in fish resources, including transitional environments such as lagoons. Its application is especially important in lagoon systems like Lefkada, where aquaculture practices are functionally and historically linked to fisheries activities, production systems must also comply with conservation regulations associated with protected areas and wetland ecosystems.

The regulatory framework seeks to balance economic development with the protection of sensitive coastal and marine ecosystems, particularly in areas characterised by high ecological value such as coastal lagoons and wetlands, in alignment with the Marine Strategy Framework Directive (2008/56/EC). The licensing process for aquaculture installations in Greece typically involves several administrative stages and the participation of multiple competent authorities, as mandated by the Hellenic Ministry of Rural Development and Food. Aquaculture operators are required to comply with spatial planning regulations, environmental protection legislation (Law 4014/2011 on environmental licensing), and water management policies derived from the EU Water Framework Directive (2000/60/EC). In most cases, licensing procedures include mandatory Environmental Impact Assessments (EIA), technical project evaluations, and consultations with competent environmental authorities before the authorisation of production activities, ensuring adherence to the Directive 2011/92/EU.

In lagoon environments such as the Lefkada lagoon system, aquaculture activities must also comply with conservation regulations associated with protected areas and wetland ecosystems. The lagoon is part of the wider network of coastal wetlands protected under European environmental legislation, including Natura 2000 provisions (Birds Directive 2009/147/EC and Habitats Directive 92/43/EEC), which impose specific requirements aimed at safeguarding biodiversity, habitat integrity, and ecological processes. As a result, aquaculture development in such areas must demonstrate compatibility with conservation objectives through appropriate assessments and ensure that production activities do not compromise the Good Ecological Status (GES) of the ecosystem as defined by EU environmental standards. The introduction of circular aquaculture systems, including IMTA, may require additional consideration within existing regulatory frameworks. Innovative production models that integrate multiple species or introduce new farming



components may not always be explicitly addressed by current licensing procedures defined in older national statutes. Ensuring that regulatory systems are capable of accommodating such innovations, a priority highlighted in the European Green Deal and in the Farm to Fork Strategy, while maintaining strict environmental safeguards represents an important aspect of future aquaculture governance. Compliance with these evolving standards is essential for the transition toward a circular blue economy.

National and Regional Legislation

The regulatory framework for aquaculture in Greece is primarily defined at the national level through sectoral policies and spatial planning instruments that guide the development and organisation of aquaculture activities. One of the key policy instruments is the Special Framework for Spatial Planning and Sustainable Development for Aquaculture, which establishes strategic guidelines for the spatial organisation of aquaculture activities and promotes the creation of organised aquaculture development areas. Within this framework, specific zones known as Areas for Organised Aquaculture Development (POAY) are designated to concentrate aquaculture activities and ensure coordinated environmental management. These zones aim to reduce spatial conflicts, improve monitoring and facilitate the implementation of integrated management approaches for aquaculture development.

At the regional level, administrative responsibilities related to aquaculture management are exercised by the Region of the Ionian Islands, which oversees the implementation of national policies, participates in licensing procedures and coordinates regional development strategies. Regional authorities also collaborate with national ministries responsible for fisheries, aquaculture and environmental protection to ensure compliance with regulatory requirements. Additional responsibilities related to environmental monitoring and wetland management may involve specialised environmental authorities responsible for the protection of Natura 2000 sites and coastal ecosystems. These institutions play an important role in evaluating the ecological compatibility of aquaculture activities and ensuring that environmental regulations are effectively implemented.

Regulatory Framework for Innovative Systems

While the existing regulatory framework provides general guidance for aquaculture development, innovative production systems such as IMTA may present new regulatory considerations. Integrated aquaculture models combine multiple species performing different ecological functions, which may not always fit easily within licensing categories designed for single-species production systems. For example, the integration of fed species with extractive organisms such as bivalves or halophytic plants may require the simultaneous authorisation of different types of aquaculture activities within the same production area. Similarly,



environmental monitoring requirements may need to be adapted to account for the ecological interactions between species and the overall nutrient dynamics of integrated systems. Addressing these regulatory challenges requires close collaboration between competent authorities, research institutions and aquaculture operators in order to ensure that licensing procedures remain clear, transparent and compatible with innovative aquaculture approaches.

Proposed Regulatory Solutions

In order to facilitate the implementation of circular aquaculture systems in the Lefkada lagoon, several regulatory improvements should be considered. One potential approach involves strengthening the integration between aquaculture licensing procedures and spatial planning instruments that identify suitable areas for aquaculture development. The results of the AZA4ICE analyses could support this process by providing scientific information on site suitability, species compatibility and circularity assessment. Another important step could involve the development of specific guidelines for the evaluation of integrated aquaculture systems within environmental assessment procedures. Such guidelines would help competent authorities assess the environmental performance of circular production models and ensure that licensing decisions are based on consistent evaluation criteria. Finally, improving coordination between national ministries, regional authorities and environmental management bodies could contribute to streamlining administrative procedures and reducing uncertainty for operators interested in exploring innovative aquaculture approaches.

6. Current Status of Aquaculture Enterprises

Aquaculture activities in the Lefkada lagoon are primarily based on traditional extensive practices that have historically developed within Mediterranean lagoon ecosystems. These production systems rely largely on natural ecological processes and have been adapted over time to the environmental characteristics of shallow coastal lagoons. Traditional lagoon fisheries typically exploit natural fish migration patterns between the marine environment and the lagoon system. Fish enter the lagoon during specific periods of their life cycle and are subsequently harvested using traditional trapping systems positioned at lagoon inlets. This production model relies primarily on the natural productivity of the lagoon ecosystem. The existing production system is characterised by relatively low environmental impact and minimal infrastructure requirements. Because production relies on natural ecological processes rather than intensive farming methods, these systems are generally considered compatible with the ecological characteristics of coastal wetlands. However, production volumes remain relatively modest, and economic returns may be limited compared to more intensive aquaculture systems. For this reason, opportunities exist to enhance the productivity and resilience of the lagoon



aquaculture sector through the diversification of species and the gradual introduction of complementary production components. The integration of extractive species such as bivalves or halophytic plants could contribute to improving the ecological efficiency of the system while generating additional production outputs. Such diversification could increase economic resilience while maintaining the ecological balance of the lagoon environment.

Circularity Readiness Profile

The analysis carried out within the AZA4ICE project suggests that the Lefkada lagoon possesses several characteristics that could support the gradual adoption of circular aquaculture practices. The existing extensive production model already operates in close interaction with natural ecosystem processes, providing a favourable foundation for the implementation of integrated aquaculture approaches. In particular, the relatively low environmental pressure associated with current practices reduces the risk of ecological imbalances and creates favourable conditions for the introduction of additional trophic components aimed at enhancing nutrient recycling. However, the transition towards circular production systems would require targeted technical support, pilot demonstrations and stakeholder engagement processes capable of supporting the gradual adoption of new practices.

7. Vision for Circular Aquaculture in Lefkada

The long-term vision for aquaculture development in the Lefkada lagoon is based on the gradual transition towards circular and ecosystem-based production systems that combine economic viability with environmental sustainability. This vision builds upon the ecological characteristics of the lagoon and the traditional knowledge associated with lagoon fisheries while introducing innovative approaches capable of enhancing resource efficiency. In this context, it is essential to recognise that aquaculture in the Lefkada lagoon operates as a fisheries-based system, relying on natural productivity, hydrodynamic processes and fish migration patterns rather than controlled farming conditions. The transition towards circular aquaculture must therefore be adapted to this specific context, avoiding the direct transfer of intensive marine aquaculture models and instead promoting solutions that are compatible with extensive, ecosystem-driven production systems. Circular aquaculture approaches aim to maximise resource efficiency by promoting nutrient recycling and integrating multiple trophic levels within aquaculture production systems. By combining species that occupy different ecological niches, circular systems can transform organic and inorganic waste into additional biomass, thereby improving overall system productivity while reducing environmental pressures. The introduction of IMTA systems could allow the combination of fed species with extractive organisms capable of utilising organic and inorganic waste. In lagoon environments, such systems may involve the integration of fish production with filter-feeding bivalves and halophytic plants



capable of absorbing dissolved nutrients. At the same time, the vision for circular aquaculture in Lefkada emphasises the importance of preserving the cultural and ecological heritage associated with traditional lagoon fisheries. Rather than replacing existing production systems, circular approaches are intended to complement and strengthen traditional practices while improving their environmental and economic sustainability. While improving their environmental and economic sustainability and maintaining the strong ecological integration that characterises lagoon-based production systems.

8. Potential of C-AZA Results

The application of the AZA4ICE methodology to the Lefkada pilot site provided valuable insights into the environmental suitability of the lagoon for circular aquaculture development. The site suitability analysis integrated environmental parameters, water use compatibility and infrastructure availability to evaluate the overall potential for aquaculture activities. The results indicated an acceptable level of suitability, suggesting that the lagoon can support sustainable aquaculture development when appropriate environmental management practices are maintained. In addition to the spatial suitability assessment, the species suitability analysis identified several candidate species that could potentially be integrated into circular aquaculture systems based on their environmental requirements and ecological functions. The modelling of IMTA configurations highlighted a promising combination involving European seabass (*Dicentrarchus labrax*), Pacific oyster (*Magallana gigas*) and halophytic plants such as *Salicornia* spp. This configuration demonstrated favourable characteristics in terms of nutrient recycling, ecological compatibility and potential economic value. In such a system, seabass would represent the fed component generating organic and inorganic nutrients, oysters would function as filter feeders capable of removing particulate organic matter from the water column, and halophytic plants would absorb dissolved nutrients, contributing to improving overall nutrient balance within the system. These results provide a strong scientific basis for exploring pilot implementation of circular aquaculture systems within the lagoon environment. Demonstration projects based on these configurations could generate valuable information on environmental performance, operational feasibility and economic viability, supporting future decisions on the potential expansion of circular aquaculture approaches in the Lefkada lagoon system.



9. Proposed Actions

Key Actions and Interventions

The proposed actions translate the results of the AZA4ICE environmental suitability assessment, species modelling analysis and stakeholder engagement process into a structured operational pathway for the development of circular aquaculture in the Lefkada lagoon system. The actions respond directly to the main needs identified during the pilot activities, including the need to strengthen technical knowledge related to circular aquaculture practices, improve environmental monitoring capacities, reinforce coordination between institutional actors and aquaculture operators, and test in practice the feasibility of circular aquaculture systems adapted to lagoon ecosystems. Particular attention is given to the ecological characteristics of the Lefkada lagoon, which represents a sensitive coastal wetland environment where aquaculture activities must remain compatible with environmental conservation objectives and with other socio-economic uses of the lagoon area. For this reason, the proposed interventions combine technical innovation, environmental safeguards and participatory governance mechanisms in order to ensure that aquaculture development remains environmentally sustainable while supporting the economic resilience of local production systems. Overall, the actions are designed to support a gradual transition from traditional extensive aquaculture practices towards more circular and ecosystem-based production models. Rather than replacing existing lagoon management systems, the proposed approach seeks to build upon the ecological characteristics of the lagoon and the existing knowledge of local operators, introducing complementary practices that enhance nutrient recycling, production diversification and environmental monitoring. In this context, it is important to recognise that lagoon aquaculture systems in Lefkada operate at the interface between fisheries and aquaculture, relying largely on natural ecosystem productivity and traditional fish capture dynamics. The proposed actions therefore adopt a context-specific approach that does not aim to impose conventional aquaculture models, but rather to adapt circular aquaculture principles to a system that is structurally closer to fisheries. This implies the development of flexible management solutions, the adaptation of regulatory and monitoring approaches, and the integration of traditional ecological knowledge with innovative circular production practices.

The proposed interventions are structured around five complementary areas of action: strengthening local technical capacity, testing integrated aquaculture systems through demonstrative pilot facilities, promoting community awareness and participation, reinforcing environmental monitoring systems, and establishing coordination mechanisms capable of supporting long-term governance of circular aquaculture initiatives. These actions are conceived to be implemented in parallel over a period of approximately twenty-four months, allowing the gradual development of pilot initiatives while simultaneously establishing the institutional and technical foundations required for the future operationalisation of C-AZA in the



Lefkada lagoon system.

Action 1: Capacity Building Program

Objective: *Strengthen local technical capacity and facilitate the adoption of circular aquaculture practices among lagoon operators and institutional stakeholders.*

The transition towards circular aquaculture practices in the Lefkada lagoon requires the strengthening of local technical capacity and institutional knowledge. During the stakeholder consultation carried out within the AZA4ICE pilot activities, several participants expressed strong interest in sustainable aquaculture approaches. However, discussions also revealed that many operators and local actors have limited technical knowledge regarding the practical implementation of IMTA systems and other circular production models. For this reason, a structured capacity-building programme is proposed in order to provide a comprehensive learning pathway combining scientific knowledge, practical guidance and peer exchange among stakeholders. The programme aims to facilitate the gradual adoption of circular aquaculture practices among lagoon operators while also improving the understanding of circular production principles among institutional stakeholders involved in aquaculture governance. Training activities will focus on the ecological functioning of circular aquaculture systems and the design and management of IMTA configurations adapted to lagoon environments. Particular attention will be given to nutrient recycling processes within aquaculture systems, species compatibility in integrated production models, water quality monitoring practices and the operational management of multi-species aquaculture systems. The programme will also explore the economic opportunities associated with production diversification, including the potential market value of extractive species such as bivalves and halophytic plants. In addition, the capacity-building activities will provide guidance on the regulatory framework governing aquaculture development and on potential funding opportunities supporting sustainable aquaculture initiatives.

The programme will target aquaculture operators active in the lagoon, technical staff from public authorities, researchers, and other stakeholders involved in lagoon management. Training will be delivered through a combination of workshops, field demonstrations and online seminars in order to facilitate knowledge exchange between scientists, practitioners and institutions.

The estimated budget for the implementation of this action ranges between €40,000 and €60,000.

Action 2: Demonstrative IMTA Facilities

Objective: *Validate the feasibility of circular aquaculture systems within the Lefkada lagoon environment.*



The establishment of a demonstrative IMTA system represents a central component of the Action Plan. The objective of this action is to validate the feasibility of circular aquaculture systems within the environmental conditions of the Lefkada lagoon while providing a practical demonstration of integrated production models. The pilot facility will integrate a fed species with extractive organisms capable of utilising organic and inorganic nutrients released during aquaculture production. Based on the modelling results generated within the AZA4ICE project, a promising configuration combines European seabass (*Dicentrarchus labrax*) with filter-feeding bivalves (*Magallana gigas*) and halophytic plants such as *Salicornia*. This trophic structure enhances nutrient recycling processes while promoting ecological integration within the lagoon ecosystem. The demonstrative system will operate at a limited experimental scale within the lagoon in order to allow careful observation of production performance, ecological interactions and operational feasibility. The pilot facility will generate valuable data on species growth performance, nutrient dynamics and system efficiency under integrated production conditions. Environmental monitoring activities will accompany the operation of the pilot system in order to assess water quality parameters, nutrient dynamics and ecological interactions between species. These monitoring activities will provide scientific evidence on the environmental performance of circular aquaculture systems within lagoon environments. In addition to its experimental function, the pilot facility will also serve as a learning platform where aquaculture operators, policy makers and researchers can observe the functioning of integrated aquaculture systems and exchange practical knowledge on circular production practices. The design of the demonstrative system will take into account the extensive and fisheries-based nature of lagoon aquaculture in Lefkada, ensuring that the pilot remains compatible with existing management practices and hydrodynamic conditions rather than introducing fully intensive production models.

The estimated investment cost for this action ranges between €120,000 and €180,000.

Action 3: Community-Based Circularity Initiatives

Objective: *Enhance social acceptance of circular aquaculture and strengthen community participation in sustainable lagoon management.*

The long-term success of circular aquaculture initiatives depends not only on technical feasibility but also on the level of social acceptance and engagement among local communities. Lagoon ecosystems are closely connected to local cultural identity and economic activities, making community participation an important component of sustainable management strategies. Building on the positive engagement observed during the stakeholder consultation process, the LiRRIE events, a series of community-based initiatives will be developed to increase awareness of circular aquaculture concepts and promote local participation in lagoon conservation efforts. These initiatives will focus on communicating the



environmental benefits associated with circular aquaculture systems, particularly their contribution to nutrient recycling, ecosystem restoration and sustainable food production. Activities may include educational workshops, public presentations, outreach initiatives involving schools and local organisations, and visits to the demonstration site. Participatory initiatives such as lagoon clean-up events or environmental awareness campaigns may also be organised in order to strengthen the relationship between aquaculture activities and environmental stewardship within the lagoon system.

The estimated budget for this action ranges between €20,000 and €30,000.

Action 4: Environmental Monitoring and Safeguards

Objective: *Ensure the ecological compatibility of aquaculture activities through structured environmental monitoring and adaptive management.*

Given the ecological sensitivity of lagoon ecosystems, environmental monitoring represents a critical component of the Action Plan. The monitoring framework is designed to ensure that aquaculture activities remain compatible with ecosystem conservation objectives and that circular aquaculture systems contribute positively to the ecological functioning of the lagoon. Monitoring activities will focus on assessing water quality conditions, nutrient dynamics and potential ecological impacts associated with aquaculture operations. Key parameters include dissolved oxygen concentrations, nutrient levels, turbidity, chlorophyll-a concentrations and sediment quality indicators, all of which are particularly relevant for the ecological functioning of lagoon environments. The monitoring programme will support adaptive management practices by providing timely information that allows adjustments to aquaculture operations if environmental thresholds are exceeded. This adaptive approach ensures that production activities remain aligned with environmental protection objectives. Monitoring approaches will also consider the specific dynamics of lagoon ecosystems, including natural variability and fish migration patterns, which are characteristic of systems operating at the interface between fisheries and aquaculture.

In addition to supporting aquaculture management, the monitoring system will contribute to improving scientific knowledge on the ecological dynamics of the Lefkada lagoon and provide useful data for future spatial planning and ecosystem-based management initiatives.

The estimated cost for monitoring activities over the implementation period ranges between €50,000 and €80,000.

Action 5: Commercial Support and Funding Mobilization

Objective: *Strengthen cooperation among institutions, aquaculture operators and local stakeholders through a structured governance mechanism.*



The successful implementation of circular aquaculture initiatives requires effective coordination among public authorities, aquaculture operators, research institutions and local stakeholders. For this reason, a structured governance mechanism will be established in order to facilitate cooperation and information exchange among the different actors involved in lagoon management. A multi-stakeholder coordination platform will be created to support dialogue and joint decision-making regarding aquaculture development in the Lefkada lagoon system. The platform will follow principles similar to the LiRRIE participatory framework applied during the AZA4ICE project and will include representatives of public authorities, aquaculture operators, research institutions and civil society organisations. Through regular meetings, the platform will provide a forum for discussing the progress of the Action Plan, sharing monitoring results, identifying emerging challenges and coordinating future initiatives supporting circular aquaculture development. The coordination platform will also contribute to identifying funding opportunities capable of supporting pilot initiatives and infrastructure investments required for circular aquaculture development. Potential funding sources include European programmes supporting sustainable aquaculture and blue economy innovation, as well as national and regional funding instruments dedicated to fisheries and coastal management.

The estimated budget for governance and coordination activities ranges between €30,000 and €50,000.

Responsible Actors

The successful implementation of the proposed actions relies on coordinated collaboration among multiple institutional and local actors. Public authorities responsible for fisheries and aquaculture management will play a central role in facilitating regulatory processes and ensuring alignment with national aquaculture policies and environmental regulations. Research institutions and universities will provide scientific and technical expertise, particularly in relation to environmental monitoring, IMTA system design and the evaluation of ecological interactions. Aquaculture operators will play a key role in implementing pilot activities and testing circular production systems within the lagoon environment. Local communities, civil society organisations and educational institutions will contribute to awareness-raising activities and community engagement initiatives supporting sustainable lagoon management.

Implementation Timeline

The implementation of the Action Plan is structured over a 24-month period organised into three main phases.



Phase 1: Preparation and Stakeholder Mobilisation (Months 1–6)

During the first phase the governance framework and coordination mechanisms will be formally established. Preparatory activities will include stakeholder meetings, the definition of cooperation agreements between participating actors and the technical planning of the demonstration pilot. Capacity-building activities will begin during this phase, while baseline environmental monitoring will be initiated in order to establish reference conditions for the lagoon ecosystem.

Phase 2: Pilot Implementation and Capacity Development (Months 7–18)

The second phase will focus on the operational implementation of the proposed actions. The IMTA demonstration pilot will be installed and progressively brought into operation. Environmental monitoring will be conducted throughout this phase to evaluate the ecological performance of the integrated system. Training activities will continue with additional technical modules and field-based learning sessions, while community engagement initiatives will promote public awareness and participation.

Phase 3: Evaluation and Knowledge Dissemination (Months 19–24)

The final phase will focus on evaluating the results of the pilot actions and identifying opportunities for further development. Monitoring results and operational experiences will be analysed to assess the feasibility and sustainability of circular aquaculture systems in the lagoon. The results will be disseminated through workshops, technical reports and stakeholder meetings in order to support the replication of successful approaches in other lagoon environments.

Financial Aspects and Funding Resources

The implementation of the proposed actions may be supported through a combination of European, national and regional funding instruments that promote sustainable aquaculture development, innovation in the blue economy and the protection of coastal ecosystems. Given the strategic importance of sustainable aquaculture within European maritime and environmental policies, several financial mechanisms may contribute to supporting the implementation of the Action Plan. At the European level, funding opportunities are available through programmes dedicated to fisheries, aquaculture and maritime development, including instruments supporting sustainable aquaculture practices, environmental innovation and the circular economy. In particular, financial support may be mobilised through initiatives promoting ecosystem-based aquaculture, climate-resilient coastal economies and sustainable food production systems. Complementary financial resources may also be accessed through research and innovation programmes focusing on marine ecosystems, sustainable aquaculture technologies and circular production models. These programmes may support both pilot initiatives and research activities aimed at improving technical



knowledge and environmental monitoring capacities. At the national and regional levels, additional funding opportunities may be available through programmes dedicated to fisheries management, coastal development and environmental protection. These instruments may support investments related to pilot infrastructure, monitoring systems, capacity-building activities and stakeholder engagement initiatives. By combining multiple funding sources, the Action Plan aims to ensure financial feasibility while facilitating the gradual development of circular aquaculture practices within the Lefkada lagoon system.

10. Monitoring and Evaluation

An effective monitoring and evaluation framework is essential to ensure that the implementation of circular aquaculture practices in the Lefkada lagoon remains aligned with environmental sustainability objectives, economic viability and social acceptance. The monitoring system proposed in this Action Plan aims to track environmental conditions, operational performance, economic outcomes and stakeholder engagement throughout the implementation process. The collected information will support adaptive management by allowing decision-makers and stakeholders to identify emerging challenges, evaluate the effectiveness of implemented actions and adjust strategies when necessary. Monitoring activities are organised around four complementary groups of indicators: environmental performance indicators, technical and operational indicators, economic and circularity indicators, and social and governance indicators. Together, these indicators provide a comprehensive overview of the ecological, economic and institutional dimensions of circular aquaculture development within the lagoon system.

Progress indicators

Environmental performance indicators

Environmental monitoring focuses on maintaining the ecological integrity of the lagoon ecosystem while evaluating the potential contribution of circular aquaculture systems to nutrient recycling and water quality improvement. Lagoon environments are particularly sensitive ecological systems where hydrodynamic conditions, nutrient cycling and biological productivity interact closely. For this reason, particular attention is given to key parameters related to water quality, trophic dynamics and ecosystem health. Monitoring these parameters allows the early detection of potential environmental pressures and ensures that aquaculture activities remain compatible with conservation objectives and ecosystem functioning.



Indicator	KPI	Measurement method	Frequency	Responsible
Water quality	Dissolved oxygen (mg/L), turbidity (NTU), temperature	In situ sensors and field measurements	Monthly	Research partners / lagoon managers
Nutrient dynamics	Nitrogen and phosphorus concentrations	Water sampling and laboratory analysis	Quarterly	Research institutions
Phytoplankton dynamics	Chlorophyll-a concentration	Laboratory analysis	Quarterly	Research partners
Ecosystem health	Biodiversity index (fish and benthic organisms)	Field surveys	Annual	Research institutions
Sediment quality	Organic matter content and contaminant levels	Sediment sampling and laboratory analysis	Annual	Accredited laboratories

These indicators allow continuous assessment of whether aquaculture activities remain environmentally sustainable and whether circular aquaculture practices contribute positively to nutrient cycling and ecosystem stability within the lagoon.

Technical and operational indicators

Technical and operational indicators are designed to assess the feasibility and effectiveness of circular aquaculture practices introduced within the Lefkada pilot site. These indicators focus on the performance of integrated aquaculture systems, the adoption of circular production practices and the operational efficiency of the proposed IMTA configurations. Monitoring these aspects helps determine whether circular aquaculture systems can be successfully implemented under the ecological and economic conditions of lagoon environments.

Indicator	KPI	Measurement method	Frequency	Responsible
Adoption of circular practices	Number of operators adopting circular aquaculture practices	Operator surveys	Annual	Project coordination
Pilot system	Production	Farm records	Annual	Operators



performance	yield of fed and extractive species (kg/year)			
Feed efficiency	Feed Conversion Ratio (FCR)	Farm records	Annual	Operators
Integration of trophic levels	Biomass ratio between fed and extractive species	Production monitoring	Annual	Research partners
Environmental monitoring tools	Number of farms using environmental monitoring technologies	Surveys	Annual	Project team

These indicators allow the evaluation of operational performance and provide useful information for assessing the scalability and long-term viability of circular aquaculture systems in the lagoon context.

Economic and circularity indicators

Economic monitoring focuses on the ability of circular aquaculture systems to generate economic value while improving resource efficiency and production diversification. Circular aquaculture aims not only to reduce environmental impacts but also to strengthen the economic resilience of aquaculture enterprises by promoting the valorisation of secondary species, improving resource use efficiency and expanding market opportunities.

Indicator	KPI	Measurement method	Frequency	Responsible
Production diversification	Number of species cultivated in integrated systems	Farm records	Annual	Operators
Circular biomass use	Share of extractive species production (%)	Production records	Annual	Operators
Economic performance	Cost per kg of biomass	Financial records	Annual	Operators



	produced			
Revenue diversification	Income generated from secondary species	Financial reports	Annual	Operators
Investment mobilisation	Funding secured for circular aquaculture initiatives (€)	Financial tracking	Annual	Project coordination

These indicators make it possible to evaluate the economic sustainability of circular aquaculture practices and their contribution to local economic development and diversification of lagoon-based production systems.

Social and governance indicators

The successful implementation of circular aquaculture depends not only on technical feasibility but also on effective governance and stakeholder participation. Social and governance indicators therefore focus on measuring the level of stakeholder engagement, knowledge transfer and institutional coordination achieved during the implementation of the Action Plan. Active involvement of aquaculture operators, local authorities, research institutions and civil society organisations is essential to ensure transparency, social acceptance and long-term sustainability of aquaculture development within the lagoon.

Indicator	KPI	Measurement method	Frequency	Responsible
Stakeholder participation	Number of participants in workshops and consultations	Attendance records	Annual	Project coordination
Capacity building	Number of trained stakeholders	Training reports	Annual	Project team
Knowledge dissemination	Number of outreach events and publications	Project reports	Annual	Project coordination
Social acceptance	Stakeholder satisfaction index	Surveys	Biennial	Project team
Institutional	Number of	Meeting	Annual	Governance



coordination	coordination meetings between stakeholders	reports		platform
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These indicators help ensure that the development of circular aquaculture remains socially supported and institutionally coordinated across different governance levels.

Monitoring review and adaptive adjustments

Monitoring results will be periodically analysed in order to support adaptive management of aquaculture activities and ensure continuous alignment with environmental, economic and social objectives. A multi-stakeholder review process will be established to evaluate monitoring outcomes and discuss potential adjustments to the implementation of the Action Plan. Regular review meetings involving public authorities, research institutions, aquaculture operators and other relevant stakeholders will provide opportunities to share monitoring results, identify potential risks and coordinate corrective actions where necessary. If environmental monitoring indicates signs of ecosystem stress, such as declining dissolved oxygen levels, excessive nutrient accumulation or changes in phytoplankton dynamics, adaptive management measures should be implemented. These can include adjustments to stocking densities, optimisation of IMTA system components or temporary modifications to production practices in order to maintain ecological balance within the lagoon system. Similarly, if monitoring results reveal limited participation in training programmes or stakeholder engagement activities, communication and outreach strategies should be revised in order to better address local needs and improve accessibility for aquaculture operators and community members.

Financial monitoring will also contribute to adaptive management. In the event of funding constraints or delays in accessing external financial resources, implementation priorities may be adjusted to focus on actions that generate the greatest environmental and social benefits with limited financial investment. At the end of the implementation period, a comprehensive evaluation should be conducted to assess the overall effectiveness of the Action Plan. This evaluation should consider the environmental performance of pilot aquaculture systems, the level of adoption of circular practices and the degree of stakeholder engagement achieved. The results will provide valuable guidance for the potential scaling-up of circular aquaculture approaches within the Lefkada lagoon system and in other Mediterranean lagoon environments with similar ecological characteristics.



11. Conclusion

This Action Plan provides a strategic framework to support the gradual development of circular aquaculture practices within the Lefkada lagoon system. Building upon the results generated through the AZA4ICE methodology, the plan identifies opportunities for enhancing the sustainability, resilience and diversification of lagoon-based aquaculture while maintaining the ecological integrity of this sensitive coastal ecosystem. Lefkada represents a distinctive aquaculture context where traditional extensive lagoon farming practices have developed over centuries in close interaction with natural ecological processes. These systems have historically maintained relatively low environmental impacts and represent an important component of the cultural and socio-economic heritage of the region. At the same time, evolving environmental challenges and economic pressures highlight the need to explore innovative approaches capable of strengthening the long-term viability of aquaculture activities. Circular aquaculture approaches offer a promising pathway for addressing these challenges by promoting more efficient use of resources, encouraging nutrient recycling and integrating multiple trophic levels within aquaculture production systems. The potential introduction of IMTA configurations adapted to lagoon conditions may contribute to improving environmental performance while creating new economic opportunities through production diversification.

The Action Plan emphasises that the transition towards circular aquaculture should occur progressively and in close alignment with the ecological characteristics of the lagoon ecosystem. Environmental monitoring, scientific research and adaptive management therefore play a fundamental role in guiding decision-making processes and ensuring that aquaculture activities remain compatible with conservation objectives. Equally important is the role of governance and stakeholder participation. Effective collaboration among public authorities, research institutions, aquaculture operators and local communities is essential for creating the institutional conditions necessary to support innovation while maintaining social acceptance and transparency in decision-making processes. Through the combination of scientific knowledge, participatory governance and pilot experimentation, the Lefkada lagoon can serve as an important case study for exploring the application of circular aquaculture principles in Mediterranean lagoon environments. The experience gained through the implementation of this Action Plan may provide valuable lessons for other coastal regions seeking to balance aquaculture development with environmental protection and sustainable resource management. In this perspective, the Lefkada pilot site represents not only an opportunity to improve local aquaculture practices but also a contribution to the broader objective of promoting circular and ecosystem-based aquaculture systems across the Mediterranean region.



Summary and Next Steps

The implementation of this Action Plan will begin with a set of priority actions aimed at strengthening the governance framework and initiating the first technical and operational activities required to support the gradual transition towards circular aquaculture practices in the Lefkada lagoon system. In the short term, initial efforts will focus on reinforcing coordination among key stakeholders, including regional and local authorities, aquaculture operators, research institutions and environmental organisations. Strengthening this coordination is essential to ensure that future aquaculture development is guided by a shared understanding of environmental conditions, socio-economic priorities and regulatory requirements. In this context, the establishment or activation of the local LiRRIE platform will play a central role in facilitating dialogue among stakeholders and providing a structured forum for discussing the implementation of circular aquaculture practices within the lagoon environment. At the same time, priority will be given to improving the environmental monitoring of lagoon conditions. The collection of additional data on water quality, nutrient dynamics and ecosystem health will contribute to refining the assessment of aquaculture carrying capacity and supporting evidence-based management decisions. Strengthened monitoring activities will also provide essential baseline information for evaluating the environmental performance of future circular aquaculture initiatives. In the following phase, capacity-building activities and technical workshops will be organised in order to support aquaculture operators in exploring the potential integration of extractive species within existing production systems. These initiatives will facilitate knowledge transfer between research institutions and aquaculture practitioners and will help identify practical solutions for implementing circular aquaculture practices adapted to lagoon conditions.

Pilot initiatives aimed at testing small-scale IMTA configurations may also be explored during this phase. Such pilot activities will focus on species combinations that are ecologically compatible with lagoon ecosystems and that present potential economic value, allowing stakeholders to evaluate the feasibility of circular production systems under real operational conditions. Over the medium term, the results generated through monitoring activities, stakeholder engagement and pilot experimentation will provide valuable evidence to guide the progressive development of circular aquaculture practices in the Lefkada lagoon. These experiences will contribute to strengthening technical knowledge, increasing stakeholder confidence and identifying potential opportunities for the gradual scaling-up of integrated aquaculture systems in suitable areas of the lagoon. In parallel, efforts will continue to facilitate access to European and national funding opportunities capable of supporting investments in sustainable aquaculture infrastructure, environmental monitoring technologies and innovation in production practices. Access to financial resources will be an important enabling factor for supporting the long-term implementation of circular aquaculture approaches.



Through these coordinated steps, the Action Plan aims to establish the conditions for a gradual and well-informed transition towards circular aquaculture in the Lefkada lagoon system. The proposed approach seeks to ensure that innovation in aquaculture development remains fully compatible with the ecological characteristics of the lagoon ecosystem while supporting the socio-economic sustainability of local aquaculture activities and coastal communities.



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