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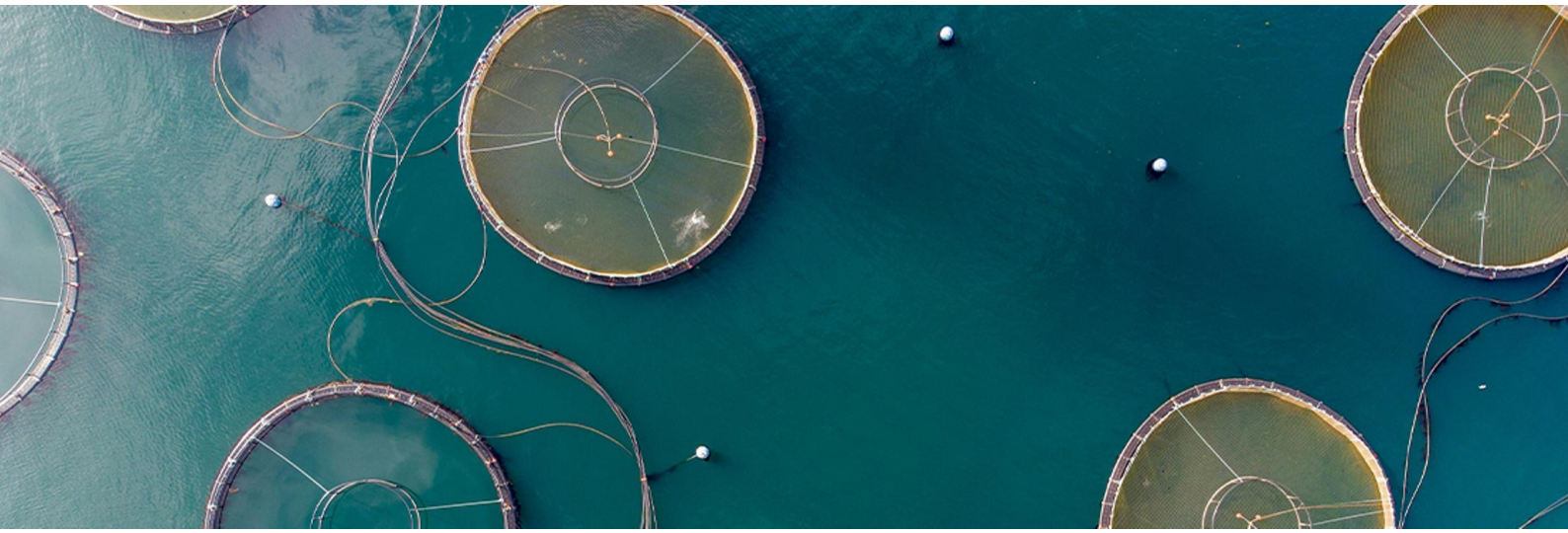

May 2026

D.3.2.2 AZA4ICE Action plan for the Thau Lagoon, France

Strategic document that outlines the key actions, stakeholders, timelines, and resources required to transition to a circular economy within the aquaculture

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

Deliverable ID

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List of Abbreviations and Definitions

AZA: *Allocated Zones for Aquaculture*, a zone dedicated to aquaculture.

AZA4ICE: *Allocated Zones for circular Aquaculture to trigger the transition to an Inclusive and Circular Economy*, a European project aimed at promoting the transition to sustainable and circular aquaculture through spatial planning and cooperation among stakeholders.

CGAAER: *General Council for Food, Agriculture, and Rural Areas*, an advisory and expert body to the Ministry of Agriculture.

CPIE Bassin de Thau : *Permanent centre for environmental initiatives in the Thau Lagoon*, an association aiming to protect and valorise the natural heritage of the zone through concertation and raising awareness.

CRCM: *Regional Shellfish Farming Committee in the mediterranean*, a trade association representing shellfish farmers along the French Mediterranean coast.

CRPMEM: *Regional Committee for Marine Fisheries and Aquaculture*, a professional organization representing fishermen and aquaculture-related activities at the regional level.

DGAMPA: *Directorate General for Maritime Affairs, Fisheries, and Aquaculture*, a department within the Ministry responsible for maritime affairs that oversees public policies related to fisheries, aquaculture, and maritime affairs.

DIRM: *Interregional Directorate for the Sea*, a government agency responsible for implementing maritime policies at the interregional level.

DPM: *Public Maritime Domain*, all maritime areas belonging to the State, including the shoreline and certain lagoons, where activities such as shellfish farming may be established.

DRAAF: *Regional Directorate for Food, Agriculture, and Forestry*, a agency of the Ministry of Agriculture responsible for implementing agricultural, food, and forestry policies at the regional level.

IMTA: *Integrated Multi-Trophic Aquaculture,* a farming system that combines multiple species from different trophic levels to optimize nutrient use and reduce environmental impacts.

IPI: *IMTA Performance Index*, Species Performance Index used to assess the technical, economic, and societal potential of a species in an aquaculture system.

LiRRIE: *Living Responsible Research and Innovation Ecosystem,* Participatory workshops bringing together researchers, professionals, and institutional stakeholders to collaboratively develop the project's strategic direction.

SCOT: *Territorial Coherence Plan*, a strategic planning document organizing land use planning and major balances of land use at the scale of a living area.

SMBT: *Thau Basin Joint Authority*, a public agency responsible for the management, planning, and coordination of territorial policies around the Thau Lagoon.

SMVM: Marine Development Plan, a planning document designed to organize the uses of the coastline and maritime areas.

SSI: *Species Suitability Index*, A sustainability index evaluating the suitability of a site's environmental conditions relative to the biological requirements of an aquaculture species.

1. Executive Summary

This Action Plan presents France's contribution to the AZA4ICE project and proposes a roadmap to support the transition of aquaculture toward models that are more resilient to climate change, diversified, and circular. It based on scientific evidence, participatory approaches, and feedback from aquaculture professionals, researchers, local authorities, and public agencies active in the aquaculture sector in the French Mediterranean.

This document is based on the results of the project's events, known as LiRRIE (Living Responsible Research and Innovation Ecosystems), the Bluefasma self-assessment tool, and the AZA4ICE, C-AZA methodology, developed within the project. This Action Plan places particular emphasis on recommendations drawn from the LiRRIEs, involving all stakeholders in the sector (Figure 1).

Focused on the French Mediterranean context, and on the Thau Lagoon, the Action Plan emphasizes that the sector's transition goes beyond technical solutions, requiring adjustments to governance, the regulatory framework, and spatial planning. The sector's transition also involves the mobilization and cooperation of numerous key stakeholders.

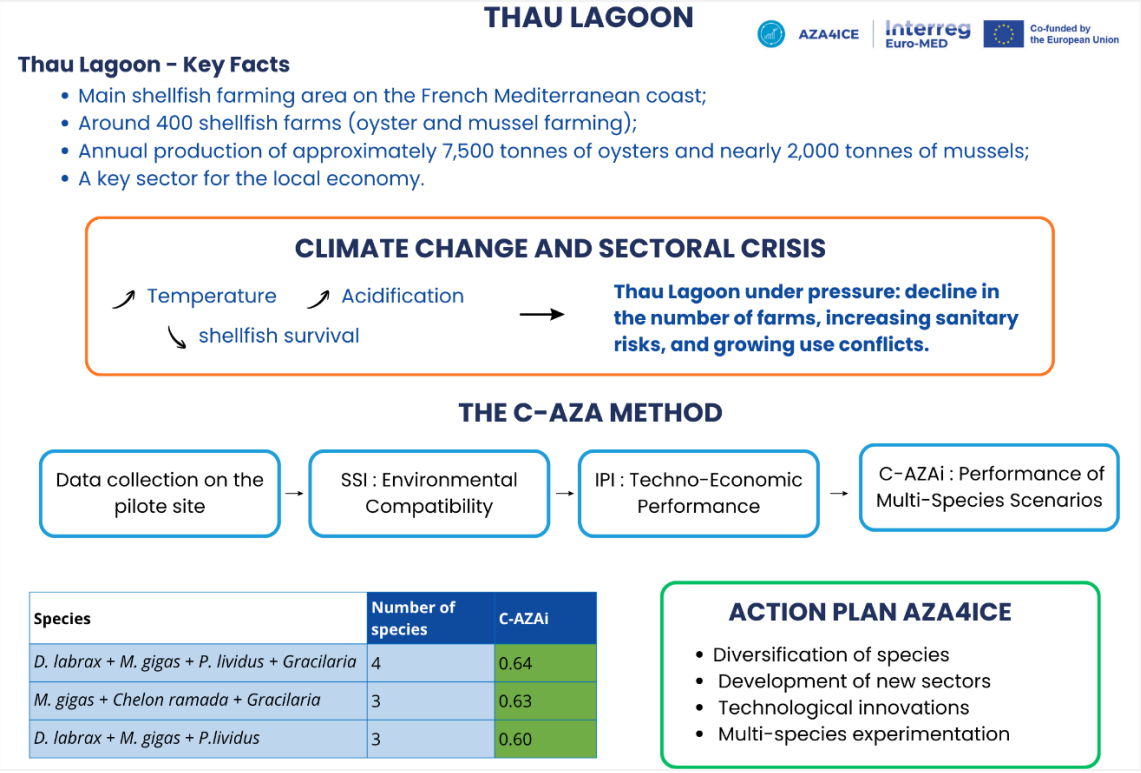

Figure 1 Summary of the AZA4ICE project at the Thau Lagoon pilot site

2. Introduction

2.1. Scope and Objectives

The implementation of the AZA4ICE project in France comes at a pivotal moment for aquaculture. Climate change is no longer a matter of theoretical projections but of observable realities that are already impacting production levels, ecosystem functioning, and thus the economic viability of aquaculture businesses.

The objective of this Action Plan is to translate this dynamic into a coherent strategic and operational framework. It aims to:

- Support the adaptation of existing aquaculture activities to climate change and the resulting environmental constraints;
- Encourage the diversification and development of circular aquaculture systems, particularly Integrated Multi-Trophic Aquaculture (IMTA);
- Provide recommendations to public authorities for adapting regulatory frameworks, spatial planning, and governance;
- Facilitate experimentation, learning, and the replication of solutions at the regional level in France.

This Action Plan aims to guide the way toward operationalization. It identifies priorities, defines responsibilities, and proposes conditions for implementation. It was developed with stakeholders from the pilot site through various AZA4ICE (also known as LIRRIE) events, Figure 2.

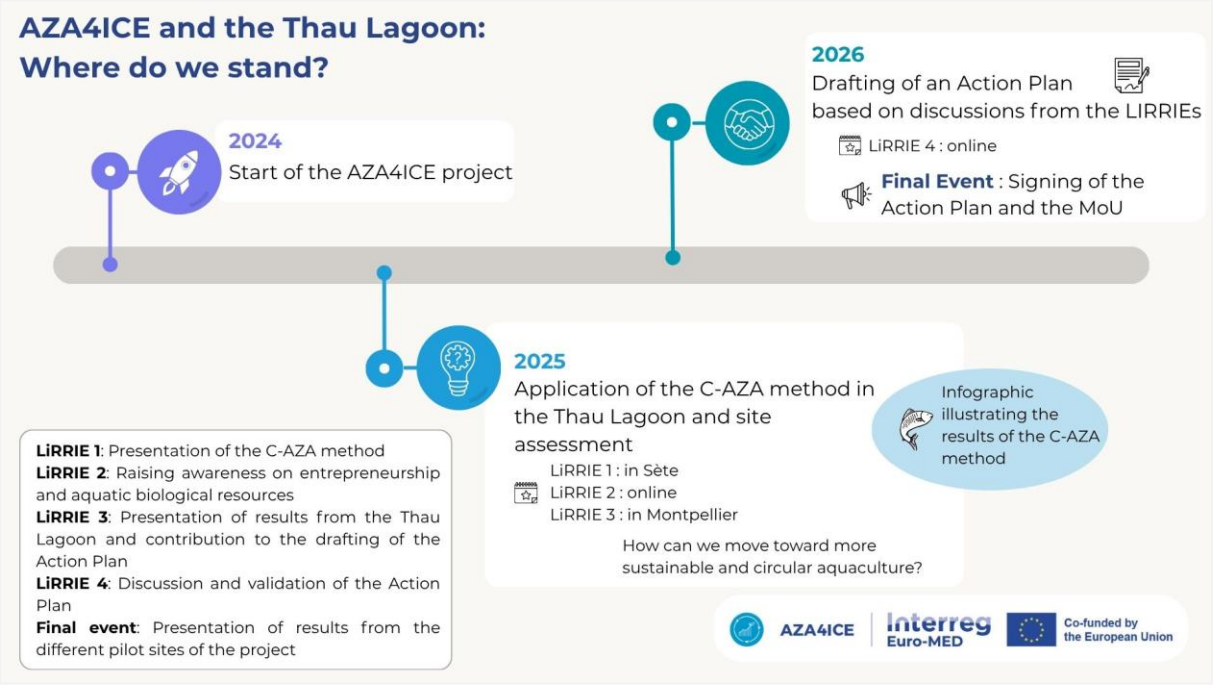

Figure 2: Summary of AZA4ICE initiatives at the Thau pilot site

2.2. Context

The French aquaculture sector is characterized by a diversity of production systems, including shellfish farming, inland aquaculture, and marine fish farming. In 2023, France produced and sold 146 thousand tonnes of shellfish products. Shellfish farming is mainly dominated by oysters, followed by mussels. It is followed by fish farming, with a total production and sales volume of 39 thousand tonnes. This includes primarily inland aquaculture, particularly salmon farming, as well as marine fish farming.

In the Mediterranean, aquaculture is an established but relatively limited sector. Environmental constraints, strong competition for coastal space, and regulatory complexity have historically hindered its development. Production is largely dominated by shellfish farming, especially oysters and mussels, concentrated in coastal lagoons such as the Thau Lagoon (Hérault, France). This lagoon is essential for the sector in the Mediterranean, as it is one of the largest Mediterranean lagoons, covering an area of approximately 75 km^2 and producing 90% of the Mediterranean's oysters.

3. Roles and Responsibilities of Key Stakeholders

The transition toward a circular and resilient aquaculture sector, capable of addressing climate change, requires coordinated action among a wide range of stakeholders. One of the main strengths of the AZA4ICE approach in France lies in the active engagement and dialogue between these stakeholders, who have been identified and involved throughout the project and its participatory events.

These stakeholders include:

- Aquaculture professionals, including shellfish farmers and emerging project developers, who contribute through:
  - Sharing know-how and field-based experience;
  - Identifying practical constraints, risks, and opportunities related to production;
  - Testing and adapting new production models under real conditions.

- Scientific and research organizations, particularly IFREMER and associated teams, which play a central role in:
  - Producing scientific knowledge on ecosystem functioning, climate change impacts, and the effects of aquaculture on the environment;
  - Supporting the experimentation, monitoring, and evaluation of innovative and circular aquaculture systems.

- Public and administrative authorities, at different governance levels, including:

  - National administrations responsible for fisheries and aquaculture policies (e.g. DGAMPA);
  - Decentralized state services at regional and interregional levels (e.g. DIRM, DRAAF);
  - Local authorities involved in economic development, spatial planning, and environmental management. These actors are essential to ensure regulatory consistency, integrate AZA4ICE results into planning tools, and support experimental and adaptive approaches.

- Representative professional organizations, notably the Regional Shellfish Farming Committee for the Mediterranean (CRCM) and the Regional Committee for Maritime Fisheries and Marine Farming of Occitanie (CRPMEM Occitanie), which:

  - Represent the collective interests of professionals;
  - Act as an interface between producers, research bodies, and public authorities;
  - Support structuring actions, collective projects, and sector development strategies.

- Support structures and other stakeholders, such as technical centers, innovation hubs, development agencies, and training organizations. This notably includes CEPRALMAR, a technical center specializing in Mediterranean aquaculture, which plays a key role in:

  - Applied research and technical support to producers;
  - Designing and implementing pilot and experimental projects (e.g. algae–shellfish co-culture);
  - Knowledge transfer, training, and capacity building for professionals;
  - Facilitating dialogue between professionals, scientists, and public authorities.

- Consumers and civil society, who, although not at the core of AZA4ICE's technical and planning objectives, play a strategic role in the long-term sustainability of aquaculture. Expectations regarding product quality, environmental performance, traceability, and territorial anchoring influence market dynamics and social acceptance.

AZA4ICE aims to establish a common framework to organize this cooperation by facilitating dialogue and aligning actions across different governance levels. The Action Plan emphasizes co-construction and shared responsibility, recognizing that effective and sustainable solutions emerge from the interaction between scientific expertise, professional know-how, public policies, and societal understanding.

4. Regional Needs, Challenges, and Opportunities

4.1. Current Situation of Aquaculture in the Thau Lagoon

The shellfish farming sector in the Thau Lagoon is currently facing a critical situation. The area is experiencing a combination of economic, demographic, environmental, and health-related pressures.

From an economic perspective, production costs have risen sharply in recent years, particularly due to energy prices and labor costs, without any significant increase in revenue. Selling prices remain stable, and in some cases are declining, raising serious concerns about the long-term economic viability of farms.

Since 2018, around 20% of aquaculture businesses have disappeared from the Thau Lagoon, notably due to the aging of farmers. The number of shellfish farms in the lagoon is estimated at around 400. Demographically, the sector is aging rapidly, with a majority of professionals over 50 years old, highlighting the urgent need for generational renewal and improved attractiveness of aquaculture professions.

From an environmental perspective, the Thau Lagoon is one of the most fragile socio-ecosystems in the region. Fifteen discharge points or outlets have been identified around its watershed. Concerns about water quality and ecosystem resilience are central to current discussions.

Several professionals emphasize the importance of the lagoon's primary productivity, particularly in open-water areas, which determines the potential for developing new filter-feeding productions. This issue must be integrated into planning processes and diversification scenarios.

Health and zoo sanitary pressures have intensified over the past decade. These pressures lead to production suspensions, mortality events, and significant uncertainty for producers.

4.2. Need for Diversification and Systemic Transformation

Shellfish farming is a full-fledged agricultural activity, yet it remains one of the least diversified production systems. Diversification should not be understood as simply adding new species, but rather as a systemic reorganization of production models. Integrated Multi-Trophic Aquaculture (IMTA) aims to make the system circular, meaning optimizing resource use, reducing waste and environmental impacts, and increasing resilience.

Circular aquaculture and IMTA approaches offer concrete levers to drive this transformation. By combining species with complementary trophic functions, these systems also help diversify income sources. Diversification could reduce vulnerability to sanitary risks.

Diversification is also a major lever for generational renewal. Innovation,

experimentation, and the emergence of new production models can bring renewed meaning and perspectives to aquaculture professions and attract new profiles, particularly younger generations.

4.3. Main Challenges and Opportunities

A central challenge lies in the gap between the economic urgency faced by farms and the time required for research, experimentation, and regulatory consolidation. Social and professional acceptability is another key issue, requiring dialogue, cooperation among stakeholders, and clear demonstration of benefits through pilot projects and proof of concept.

The regulatory framework remains a significant barrier, particularly for seaweed farming, where uncertainties persist. At the same time, the AZA4ICE approach, through the C-AZA method, offers significant opportunities by reducing development timelines, providing robust scientific support, and accelerating the transition from concept to experimentation.

4.4. Risk Management

The issue of risk-taking was raised by professionals during discussions. The development of new production systems (new species, co-cultures, technical innovations) involves technical, economic, and environmental uncertainties.

In this context, it is necessary to clarify who bears and assumes these risks: producers, public authorities, experimental projects, or funding mechanisms.

Several stakeholders also highlighted that companies in the sector currently have limited financial resources, which reduces their capacity to invest in research and development. The development of new aquaculture models therefore requires appropriate support and funding mechanisms to sustain experimentation phases and limit risks for producers.

5. Legal, Regulatory, and Permitting Framework

Aquaculture in France is governed by a set of European, national, and local regulations aimed at balancing economic development, environmental protection, and maritime spatial management. The creation or expansion of an aquaculture activity requires several administrative authorizations under various French regulatory frameworks, including environmental regulations, spatial planning documents, sanitary regulations, and land-use regulations.

According to the CGAAER report *"Development of the Fish Farming Sector"* (2022), the multiplicity of permits and the length of administrative procedures are major

barriers to the development of the sector. In several European countries, these procedures are simplified through one-stop shops, a solution also recommended for France.

Aquaculture is strictly regulated by environmental legislation, which requires assessments prior to the establishment of any operation. These include environmental impact assessments, Natura 2000 assessments, and analyses of discharges (nitrogen, phosphorus) into the environment. Criteria such as project size and environmental sensitivity are key factors in these studies. However, in France, the thresholds triggering these assessments may be stricter than in some other European countries, potentially creating a competitive disadvantage.

Aquaculture activities must comply with existing regulations such as the Water Framework Directive, Natura 2000 regulations, and lagoon water quality standards.

Today, planning documents such as the SCOT and the coastal component of the Marine Development Plan (SMVM) include provisions aimed at protecting the marine environment while prioritizing fishing and marine farming activities. They also impose strict controls on urban development and water quality.

As aquaculture operates under concessions or occupancy rights within the Public Maritime Domain (DPM), it is directly concerned by maritime spatial planning documents. The concept of Allocated Zones for Aquaculture (AZA) consists of identifying marine areas where aquaculture is prioritized over other uses (tourism, navigation, etc.). This approach aims to anticipate and organize aquaculture development at the territorial level, reduce use conflicts, facilitate the establishment of new farms, and secure investments and the long-term viability of aquaculture activities.

In the Thau Lagoon, this planning is part of an already structured territorial framework. It is notably guided by tools such as the SCOT led by the SMBT and local urban planning documents, which regulate land and water use. These tools contribute to environmental protection and spatial coherence. However, they may also be perceived by some stakeholders as constraints on the experimentation of new aquaculture models.

Access to land (and water space) is also a major issue for the sector. In lagoon areas such as Thau, shellfish farming zones are protected by planning documents. However, as previously mentioned, a decline in the number of farms has been observed. Updating these documents is therefore necessary to reduce land pressure, support the establishment of new activities, enable production diversification, co-culture, and the development of new aquaculture models.

The aquaculture sector is subject to strict sanitary regulations. Key obligations include disease monitoring, product traceability, and required veterinary controls. These rules are essential, as certain viral diseases can significantly impact production.

Farms in the Thau Lagoon area may obtain disease-free sanitary status, which facilitates exports but may limit certain imports of live animals. However, difficulties

in obtaining clear regulatory guidance for some innovative projects have been highlighted. For example, uncertainties remain regarding the use of groundwater or treated water to supply holding tanks, illustrating the need for stronger dialogue between professionals and competent authorities.

In summary, several regulatory barriers have been identified. The main obstacles to aquaculture development include:

- Administrative complexity;
- Lengthy permitting procedures;
- Strict environmental constraints;
- Competition for coastal space;
- Lack of effective spatial planning.

These factors partly explain the stagnation of French aquaculture production despite strong global demand.

6. Current State of Aquaculture Farming

6.1. State of Shellfish Farming

Shellfish farming remains the cornerstone of French Mediterranean aquaculture and the core economic activity of coastal lagoons such as the Thau Lagoon. Deeply rooted in the territory, both economically and culturally, the lagoon is nevertheless undergoing a major transition driven by environmental, sanitary, economic, and demographic factors.

The production of **Pacific oysters** (***Crassostrea gigas***) remains dominant and generally suited to lagoon conditions. However, professionals are observing increasing variability in growth rates, survival rates, and product quality. Summer heatwaves, hypoxia events, and occasional water quality degradation are increasingly affecting production cycles. These changes require adaptation of practices through technical innovation, enhanced environmental monitoring, and adaptive management to secure production.

Mediterranean mussel (***Mytilus galloprovincialis***) production in the lagoon is no longer considered viable in the medium to long term in the Thau Lagoon. Scientific projections and experimental results indicate a high risk of summer mortality by 2050, mainly linked to rising temperatures and acidification due to climate change. Field observations already confirm this vulnerability. As a result, stakeholders largely support relocating mussel production offshore, in more stable environments, which implies structuring a new collective “offshore mussel” sector.

The **European flat oyster** (***Ostrea edulis***) is seen as a strategic species for diversification, heritage restoration, and ecological value. Its redeployment represents a long-term opportunity to reduce dependence on a single species while enhancing ecosystem services. However, technical and organizational

barriers remain, particularly in hatchery production, nursery phases, sanitary management, and farming performance. Strengthening local hatchery, pre-growing, and nursery capacities is identified as a key prerequisite to ensure the sustainability of European flat oyster production.

6.2. State of Fish Farming

Fish farming is currently not practiced in the Thau Lagoon, mainly due to environmental sensitivity, spatial constraints, and regulatory limitations specific to confined lagoon systems. The only fish-related infrastructure nearby is a land-based hatchery operating under a Recirculating Aquaculture System (RAS), functioning independently from lagoon production.

At the regional scale, however, fish farming remains a relevant component of French Mediterranean aquaculture. Offshore farming is present through production sites in the French Mediterranean Sea, notably off Marseille (Bouches-du-Rhône), in the Bay of Lazaret (Var), near Cannes (Alpes-Maritimes), as well as in Haute-Corse and Corse-du-Sud. Professionals from the Bay of Lazaret have expressed interest in diversification strategies and potential co-culture systems combining fish farming, shellfish farming, and extractive species.

6.3. Toward Aquaculture Diversification?

Diversification has emerged as one of the main levers to strengthen the resilience and adaptive capacity of aquaculture systems in the French Mediterranean. It is widely seen as a necessity in response to the growing vulnerability of single-species production models to climatic, sanitary, and economic shocks.

At this stage, diversification is mainly taking place through experimental and pilot initiatives, targeting species and systems suited to circular or ecosystem-based models. Macroalgae production is among the most promising avenues. Although production volumes remain limited, seaweeds are recognized for their potential role in nutrient uptake, bioremediation, and co-culture with shellfish.

In the Thau Lagoon, the COCOALG project led by CEPRALMAR aims to assess the technical, environmental, and operational feasibility of algae–shellfish co-culture, providing essential references for future deployment.

Sea cucumbers, particularly *Holothuria tubulosa*, have also been identified as a longer-term diversification pathway. Their detritivore role makes them particularly interesting for circular systems. They contribute to sediment quality while opening access to niche, high-value markets. This potential is being explored through the HOLOPROD project, led by an industrial stakeholder, focusing on hatchery development, grow-out trials, and economic viability assessment.

Most diversification systems are currently at the experimental or pilot stage. However, discussions have also highlighted a growing willingness among aquaculture professionals to engage in diversification through individual initiatives. Some, already aware of diversification and IMTA approaches, are implementing co-culture systems on their farms. Others have expressed a desire to move in this direction to ensure the long-term sustainability of the sector.

Diversification is seen as a gradual transition process rather than a rapid replacement of existing activities. It requires time, experimentation, technical support, and regulatory clarification. Decision-support tools such as C-AZA play a key role in reducing uncertainty by identifying the most relevant species combinations and spatial configurations, thereby facilitating informed investment decisions and public policies.

6.4. Main Challenges and Proposed Responses

The analysis of the current state of aquaculture enterprises highlights structural and cross-cutting challenges affecting species, production systems, and territories. These challenges are closely interconnected and require coordinated, multi-level responses rather than isolated measures.

Table 1: Main challenges in the Thau Lagoon, responses, and associated impacts

Main Challenges	Priority Responses	Expected Impacts
Climate vulnerability of lagoon systems	Relocation offshore, adaptation of production calendars, anticipation of extreme events	Reduced mortality, improved production stability

Dependence on monospecific models	Progressive diversification, IMTA, multi-species integration	Reduced economic and biological risks, increased resilience
Uncertainty and lack of references for emerging species	C-AZA pilot projects and experimental trials, applied research and technical support	Accelerated learning, secured investments, emergence of new value chains
Environmental pressures and ecosystem fragility	Integration of extractive species (algae, detritivores), circular practices	Improved water quality, ecosystem services, greater social acceptance
Ageing workforce and low attractiveness of the sector	Collective tools, innovation, diversification, improved working conditions, integration of training	Increased attractiveness, generational renewal
Regulatory rigidity and complexity	Use of AZA4ICE and C-AZA results in planning and permitting processes	Greater policy coherence, faster and more secure project deployment

This synthesis highlights that responses must be combined within a coherent transition pathway, integrating technical solutions, governance adaptations, and territorial strategies.

7. Vision

The shared vision emerging from the LiRRIEs workshops recognizes climate change as a major and irreversible constraint for Mediterranean aquaculture. Rather than striving to preserve existing models at all costs, stakeholders converge on the need to rethink production systems, spatial organization, and governance frameworks.

Innovation is identified as a key driver of this transition, particularly through environmental monitoring, modeling, automation, and improved farming practices. However, discussions highlighted that a central element of this vision lies in the development of ecosystem-based and circular aquaculture models, including IMTA. These approaches aim to restore functional interactions between species, reduce waste, optimize resource use, and enhance ecosystem services. Low-tech solutions inspired by the natural functioning of ecosystems are seen as complementary to technological innovation, especially in fragile lagoon environments.

Diversification plays a strategic role in this vision. It helps reduce vulnerability to climate and health-related shocks, while creating new economic opportunities. It also represents a major lever to improve the attractiveness of the sector and an opportunity to support generational renewal.

Finally, the importance of spatial planning and agile governance supported by tools such as C-AZA should be emphasized. By 2035–2040, French Mediterranean aquaculture aims to evolve towards diversified, climate-resilient, and circular systems, strongly rooted in local territories, socially accepted, and recognized as positive contributors to ecosystem functioning and local food systems.

8. Potential of C-AZA Results

The C-AZA methodology aims to identify opportunities for developing circular aquaculture by combining several levels of analysis: the environmental compatibility of species, their technical and socio-economic performance, and finally, scenarios for combining species within integrated production systems. This approach helps guide diversification and innovation choices for aquaculture territories.

8.1. Species Suitability Index (SSI)

This index will rank species based on their compatibility with the environmental conditions of the pilot site, determined by their specific tolerance ranges. Through this approach, the most suitable species for the site will be identified and subsequently tested in the next phase. Key factors such as biological tolerance to

temperature, oxygen levels, turbidity, and salinity will be evaluated, enabling the scoring of species across the three trophic levels to ensure optimal compatibility and performance. The score generally ranges from 0 to 1 (Table 2): the higher the value, the more favorable the conditions are for species development.

Table 2: SSI (Species Suitability Index) for selected species

Scientific name	Common name	SSI
Sparus aurata	Gilthead seabream	0.62
D. labrax	European seabass	0.67
M. galloprovincialis	Mussel	0.42
M. gigas	Pacific oysters	0.64
Ostrea edulis	European flat oyster	0.42
R. decussatus	Clam	0.67
H. tubulosa	Sea cucumber	0.52
Chelon (Liza) ramada	Thinlip mullet	0.81
P. lividus	Sea urchin	0.52
Gracilaria sp.	Gracilaria	0.32
Porphyra sp.	Nori	0.46

For the Thau Lagoon, the thinlip mullet achieved the highest SSI, followed by seabass, clam, and Pacific oyster.

The interpretation of these results shows that these species exhibit overall favorable environmental compatibility, although with significant seasonal variations. For example, temperature and oxygen conditions are particularly favorable during the spring and summer months, while certain parameters such as salinity or trophic availability may become limited at specific times of the year.

This variability highlights the importance of taking seasonal environmental dynamics into account in aquaculture planning.

The SSI therefore serves as an initial screening tool to identify species potentially suited to the study site.

8.2. IMTA Performance Index (IPI)

The Species Performance Index (IPI: Innovation Performance Index) assesses the relevance of developing a species based on technical, economic, and societal criteria (Table 3).

This index is based on several categories of weighted criteria:

- The distribution range and the existence of already established aquaculture;
- The level of domestication and knowledge of the life cycle;
- Feeding requirements and production model;
- Growth and survival performance;
- Market value and valorization opportunities;
- Societal acceptability and consumer perception.

Each criterion is associated with weight and score, allowing the calculation of an overall IPI score for each species (Table 3).

Table 3: IPI (IMTA Performance Index) for selected species

Scientific name	Common name	IPI
Sparus aurata	Gilthead seabream	0.65
Dicentrarchus labrax	European seabass	0.65
Mytilus galloprovincialis	Mussel	0.79
Magallana gigas	Pacific oyster	0.77
Ostrea edulis	European flat oyster	0.69
Ruditapes decussatus	European clam	0.46
Holothuria tubulosa	Sea cucumber	0.36
Chelon (Liza) ramada	Thinlip mullet	0.51

Paracentrotus lividus	Purple sea urchin	0.44
Gracilaria sp.	Gracilaria	0.73
Porphyra sp.	Nori	0.62

The table above synthesizes these different dimensions and highlights the species with the greatest development potential in a given context: Mediterranean mussel, Pacific oyster, and Gracilaria. These species achieve high scores due to a strong understanding of their production cycle, high market acceptance, and a secure supply of seed.

The interpretation of this index therefore goes beyond environmental compatibility alone by incorporating the real technical and economic conditions for implementing new production systems. The results show that some species present promising potential but still require further research or value chain structuring to overcome certain technical or societal barriers.

8.3. Species association scenarios within C-AZA

The third step of the C-AZA modelling approach consists of analyzing species association scenarios in order to identify multi-trophic production systems that can enhance the circularity of aquaculture activities (Table 4).

In the study conducted for the Thau Lagoon, 11 species were analyzed, belonging to different trophic levels: feed species (fish), filter feeders (molluscs), detritivores, and primary producers (algae).

The results are presented in Table 4, which provides an Association Index (IS) measuring the ecological and functional coherence of combinations of two, three, or four species.

Table 4: C-AZA Index for scenarios supporting circular aquaculture

Scenario		Number of species	C-AZA
1	*European seabass + Pacific oyster + sea cucumber + gracilaria / pyropia*	4	0.59
2a	*European seabass + Pacific oyster + sea cucumber*	3	0.55

2b	*Europea seabass + Pacific oyster + purple sea urchin*	3	0.60
3	*European seabass + Pacific oyster + purple sea urchin + gracilaria*	4	0.64
4	*Pacific oyster + sea cucumber + gracilaria*	3	0.57
5	*Pacific oyster + purple sea urchin + gracilaria*	3	0.51
6	*Pacific oyster + thinlip mullet + gracilaria*	3	0.63
7	*Pacific oyster + gracilaria*	2	0.50

Some scenarios achieve particularly high scores, especially those combining:

- Filter-feeding molluscs such as *Magallana gigas*;
- Fish species such as *Sparus aurata* or *Dicentrarchus labrax*;
- Extractive species such as macroalgae (*Gracilaria* sp.);
- Detritivores such as sea cucumber (*Holothuria tubulosa*).

These combinations illustrate the potential of IMTA systems capable of valorizing nutrient flows and reducing the environmental impacts of aquaculture operations.

The C-AZA method identifies a particularly promising scenario, with a high score of 0.64 for the four-species combination: *European seabass + Pacific oyster + purple sea urchin + gracilaria* (See Scenario 3 in Table 4).

However, the results also highlight certain limitations, particularly related to local environmental conditions in the Thau Lagoon (e.g. salinity, availability of primary producers) and the current level of knowledge for some species. Future work will therefore need to further investigate these aspects in order to consolidate the most promising scenarios.

8.4. Conclusion

The results of the C-AZA modelling highlight the potential for diversification and integration of new species into Mediterranean aquaculture systems. The approach, combining environmental compatibility, technical performance, and multi-trophic scenarios, provides a decision-support tool to guide the development of aquaculture towards more sustainable and circular models.

The transition towards circular aquaculture systems will also need to incorporate the seasonal dimension of Mediterranean production systems. Certain species or multi-trophic combinations may be better suited to specific periods of the year, opening the way for seasonal or alternating production models. Such approaches can optimize the use of environmental resources while strengthening the resilience of aquaculture operations.

9. Proposed Actions

9.1. Key Actions and Interventions

Species diversification in the Thau Lagoon represents a major lever for improving the sustainability of the aquaculture sector. It is based on the identification of new species with strong ecological and economic potential, using the project's innovative C-AZA method. These approaches aim to restore functional interactions between species, reduce waste output, optimize resource use, and strengthen ecosystem services.

The development of IMTA, particularly systems incorporating algae, should be encouraged as part of the future of aquaculture. Both scientific and aquaculture stakeholders highlight the positive impacts of these practices.

Scientists also propose adaptation scenarios in response to climate change, in addition to diversification and IMTA. These adaptations include the relocation of certain aquaculture activities offshore, particularly mussel farming, which is less resilient in the Thau Lagoon. Marine environments offer more favorable conditions for cultivation, such as improved temperature and acidity levels.

The Mediterranean shellfish farmers' cooperative aims to promote shellfish production. According to its members, a key factor in securing regional production is the development of a structured value chain based on shared infrastructure and the transfer of skills.

In response to the aging workforce in the sector, the Mediterranean Regional Shellfish Farming Committee (CRCM) launched a sector development contract in 2021. The first phase (2021–2024) focused on stabilization and adaptation, while the second phase (2024–2029), now extended to the South PACA region, aims to support deeper structural transformations.

Training is also a key element to strengthening within a rapidly evolving sector. As part of the transition process, the sector must establish mechanisms to ensure the transfer of data, knowledge, and skills. These elements are also essential levers to facilitate the dissemination of innovations such as the C-AZA method.

The sector must also seize new market opportunities and promote short supply chains in order to enhance the value of sustainable products by highlighting their quality and local origin. In this regard, the creation of a certification label indicating

product origin could improve consumer awareness. Although already considered, its implementation faces several challenges. Capitalizing on these opportunities would support the transition toward more profitable and long-term viable economic models.

The emergence of new aquaculture practices will require the evolution of regulatory and legal frameworks. These frameworks are often described by stakeholders as complex and multi-level, which can hinder project development.

Territorial planning documents will also need to be adapted. In the Thau Lagoon area, the SCOT is a spatial planning document that defines a strategic framework for land use and development. It aims to reconcile all territorial activities, including the growing role of aquaculture.

A strong and appropriate public policy is required to support the evolution of the aquaculture sector and to secure access to production areas, particularly in alignment with the objectives of the Mediterranean Regional Shellfish Farming Committee (CRCM).

Access to funding is another key factor in supporting aquaculture development. Support organizations play a crucial role in informing, guiding, and assisting project developers and aquaculture businesses in identifying and accessing funding opportunities.

Finally, cooperation among all stakeholders in the sector - scientists, professionals, and public authorities—is essential for the development of sustainable aquaculture. It promotes research, knowledge transfer, and the development of innovative solutions tailored to the environmental and economic challenges of the lagoon. This cooperation should be supported by regular exchanges and consultation platforms to facilitate informed decision-making, considering the expectations of all stakeholders.

9.2. Responsible Stakeholders

The implementation of actions supporting sustainable aquaculture in the Thau Lagoon requires close cooperation among all stakeholders.

Aquaculture enterprises are operational actors. They implement projects, test and develop innovative and sustainable practices, and promote their activities and products.

Scientific organizations, such as Ifremer, contribute to experimentation on crop and livestock diversification, including the domestication of new species. They also develop adaptation scenarios for the Thau Lagoon and support innovation in close collaboration with industry professionals.

Technical centers such as Cépralmar are dedicated to the pooling of equipment and applied research. They support the validation of technical processes through

trials, prototypes, and expertise, and act as interfaces between research, industry, and public institutions.

Training providers are key drivers in the transition toward a structured and sustainable sector. Training programs are strategic levers to ensure the mastery of new techniques and best practices in aquaculture.

Professional organizations, such as the CRCM and Mediterranean shellfish cooperatives, contribute to structuring the sector and pooling resources. They play an important role in coordinating stakeholders, supporting businesses, and strengthening economic models.

Support organizations are also key actors. Structures such as SMBT, CPIE, and clusters, particularly Pôle Mer Méditerranée, play a crucial role in supporting project development and facilitating access to regional, national, and European funding.

Public authorities ensure the regulatory framework governing aquaculture activities and the sanitary safety of production. At the local level, territorial authorities, particularly through the SCOT of the Thau Basin, led by SMBT, play a central role. SMBT oversees and evaluates public policies to support the Thau Basin in its ecological transition and enhance its resilience. Through territorial coordination and stakeholder consultation, it leverages recognized expertise in integrated management and environmental engineering.

Regional and local authorities also play a central role in integrating aquaculture activities within the Thau ecosystem, particularly the Occitanie Region and the DIRM.

9.3. Timeline

In the short term, priorities focus on adapting the regulatory framework of the aquaculture sector, to be implemented in two stages, covering both production and marketing aspects. The objective is to reduce barriers to the adoption of new practices in the Thau Lagoon. This step is essential to foster the development and uptake of innovative solutions, while supporting ongoing research and knowledge acquisition in the sector, particularly in relation to IMTA and species diversification.

In the medium to long term, the objective is to scale up pilot projects into operational applications and concrete species diversification initiatives. To achieve this, greater sector-level coordination will be required, particularly through the pooling of infrastructure, equipment, and knowledge, which will need to be anticipated. The aim is to structure the aquaculture sector to ensure both production and market development.

In the long term, the ambition is to significantly enhance the economic resilience of the aquaculture sector while reducing its environmental impact (see Table 5).

Table 5: Proposed Timeline for Actions

-Adaptation of the regulatory framework (production and sales). -Adaptation of planning documents	-Operational applications of pilot projects. -Sharing of equipment, infrastructure, and expertise to build the sector. - Adaptation of the regulatory framework (production and sales). -Adaptation of planning documents.	-Implementation of AMTI systems. -Implementation of tailored training programs to support the sector's transition. -Economic resilience of businesses, reduction of environmental impact through circular systems, and more efficient use of resources.

9.4. Financial Aspects and Funding Source

Several funding mechanisms are available to support the development of sustainable aquaculture at various levels.

The Occitanie and Sud PACA regions offer local financial assistance to support aquaculture projects led by local stakeholders. At the national level, calls for projects enable the mobilization of resources through the EMFAF (European Maritime, Fisheries, and Aquaculture Fund), notably via the DLAL EMFAF and the Thau GALPA, which provide specific support for local development led by stakeholders in the fisheries and aquaculture sectors.

Finally, European programs such as Horizon Europe (mainly calls for projects under Cluster 6 - Food, Bioeconomy, Natural Resource, Agriculture, and Environment) and the European Innovation Council (EIC) serve as major drivers for funding innovative projects in the field of sustainable aquaculture.

10. Monitoring and Evaluation

Monitoring is based on environmental, economic, and social indicators. The goal is to propose evaluation criteria that enable the tracking of an effective transition (Table 6).

Table 6: Monitoring and Evaluation of the Aquaculture Sector in the Thau Basin

Dimension	What is being assessed	Examples of indicators
Environment	- Diversification of aquaculture. - Species resilience to climate change. - Farming practices incorporating AMTI. - Reduction of environmental impact.	Water and sediment quality, biodiversity, species mortality rates, number pf AMTI initiatives implemented, extractive species.
Economy	- Business viability. - Income diversification. - Better use of resources.	Number of businesses, creation of new operations, production, revenue, employment, diversification of production.
Social	- Attractiveness of the sector. - Generational renewal. - Establishment of short supply chains. - Training center.	Age of farmers, number of new farms, social acceptance (consumption of products), establishment of training programs.

11. Conclusion

This Action Plan is part of a transition toward a more sustainable and circular French Mediterranean aquaculture sector, particularly in the Thau Lagoon region. Faced with the effects of climate change, the increasing fragility of ecosystems, and the economic and demographic pressures on the sector, the industry must embrace change.

This Action Plan provides a coherent framework to support this transition. It thus serves as an operational document based on the current state of aquaculture and the feedback from industry stakeholders in the French Mediterranean region.

The transition to more resilient, circular, and diversified models is essential. It rests on several complementary pillars: species diversification, the development of Integrated Multi-Trophic Aquaculture, the integration of new species, the strategic relocation of certain production activities to the sea, and support for technological innovation. The results of the C-AZA methodology highlight opportunities for diversification and circular systems.

However, the success of this transition does not depend solely on technical solutions. It requires coordinated governance, regulatory frameworks that reduce barriers, appropriate financial support, and continuous strengthening of professional skills. Cooperation among scientists, producers, technical centers, conditions for moving toward sustainable aquaculture.

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