

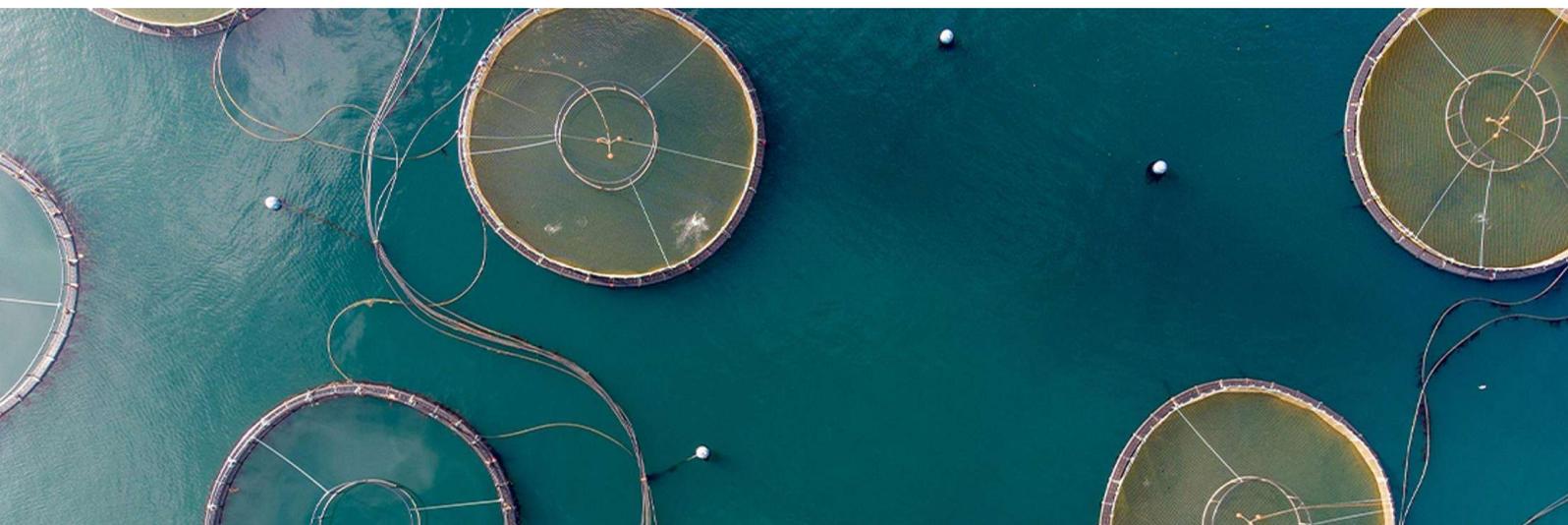


AZA4ICE

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Month 2025

AZA4ICE ACTION PLANS

AZA4ICE Action Plan for implementing circular
aquaculture practices in pilot project Krka River
estuary

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Deliverable ID

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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.

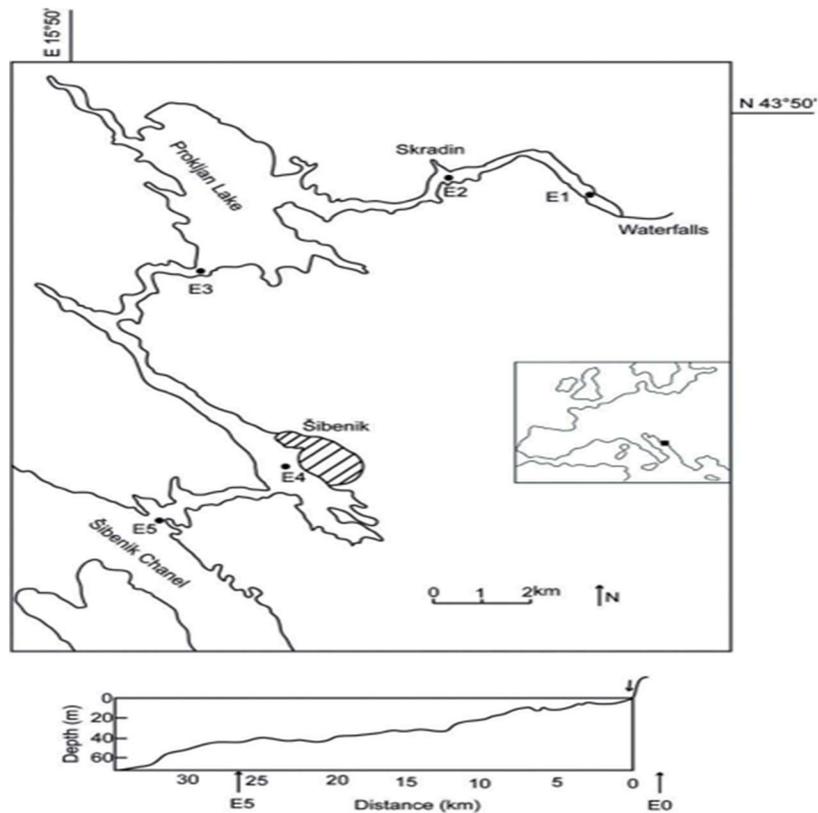


Figure 1. The provision of the Krka estuary from Skradinski buk to the fortress of St. Ante (Vilicic et al., 1989.)

1.2 Context

The pilot project area of Krka is located entirely within the administrative part of the city of Sibenik and extends through the areas of the settlements of Raslina, Zaton and Sibenik, 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*).

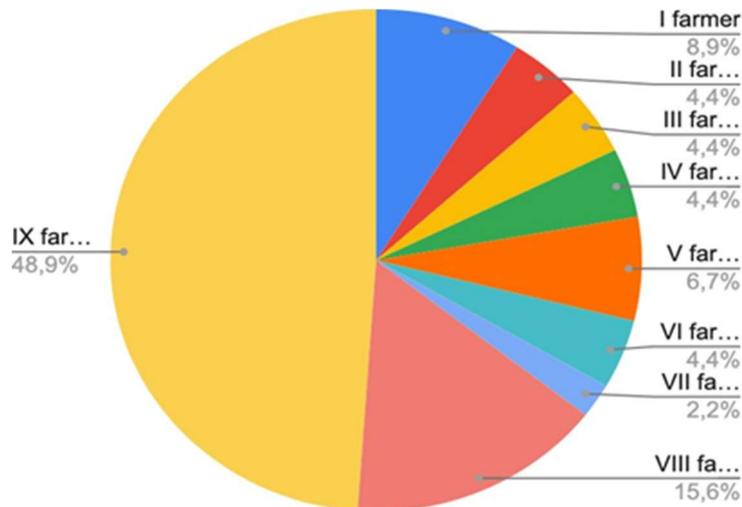


Figure 2. Size of farming areas in Krka River estuary (Zaninovic, 2022.)

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

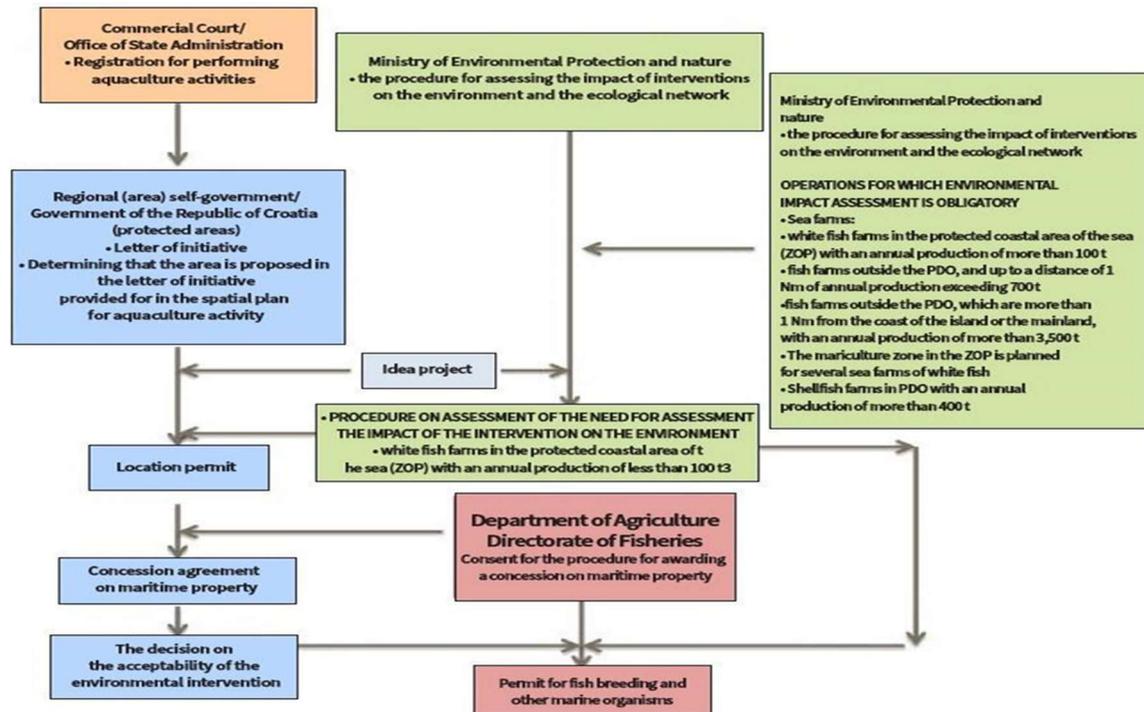


Figure 4. Procedure for issuing an aquaculture license (Directorate of fisheries, 2014.)

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 Sibenik-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

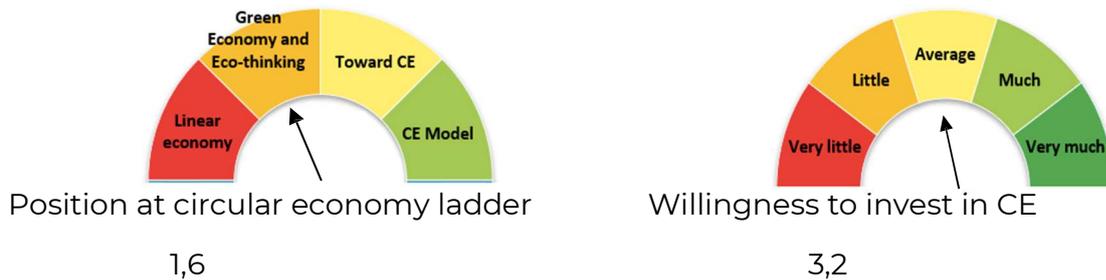


Figure 5. The average score of circular economy readiness and willingness of the companies in Sibenik-Knin County

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.

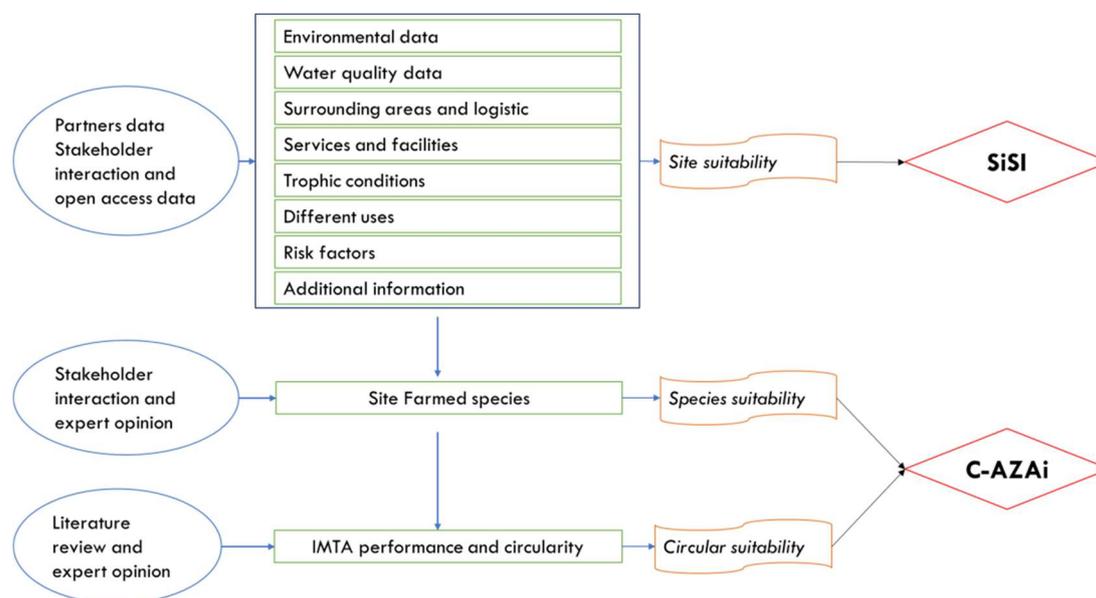


Figure 6. Methodological framework for AZA4ICE methodology implementation

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	Establishing in-house facilities	Retaining added



Integration	for processing, filleting , and direct sales channels.	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 (2033– 2036)	Market price analysis of "Eco-Brand" products compared to standard products on the EU market.	If the market does not pay a premium price, we redefine the marketing strategy or change the final product (e.g. more pharmaceutical raw materials).



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 Center).	Fully operational (serving min. 5-10 small growers)	Hub annual business report
	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 Sibenik-Knin County in a qualitative way.

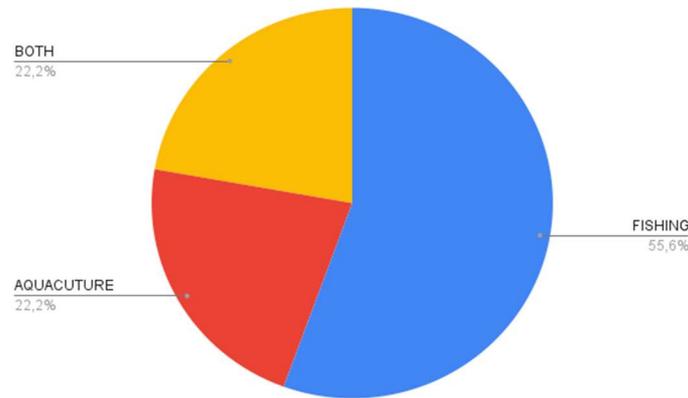


Figure 7. Status of interviewed shareholders

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.

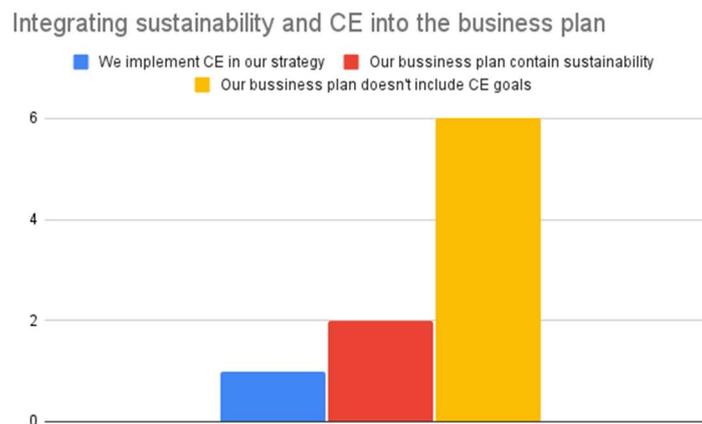


Figure 8. Integrating sustainability and CE into business plan

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).

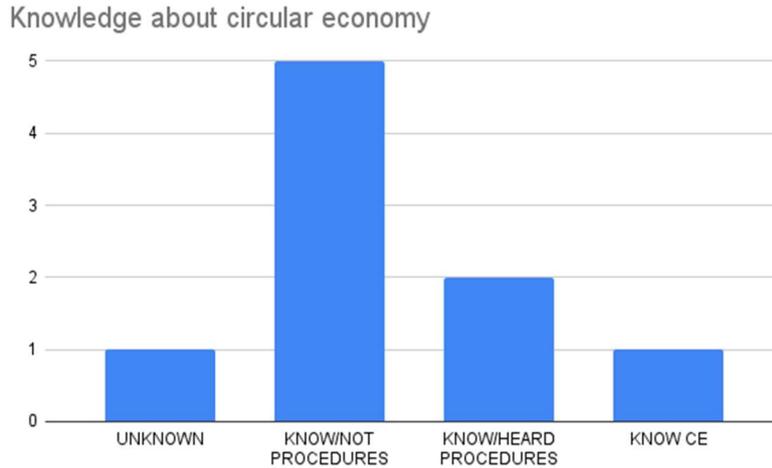


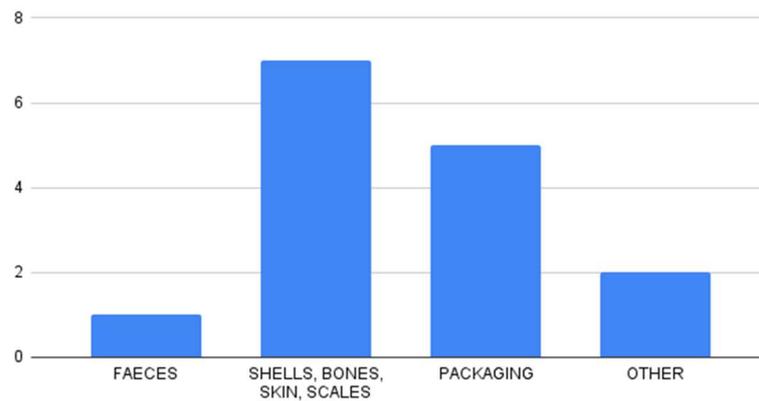
Figure 9. Knowledge about circular economy

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).

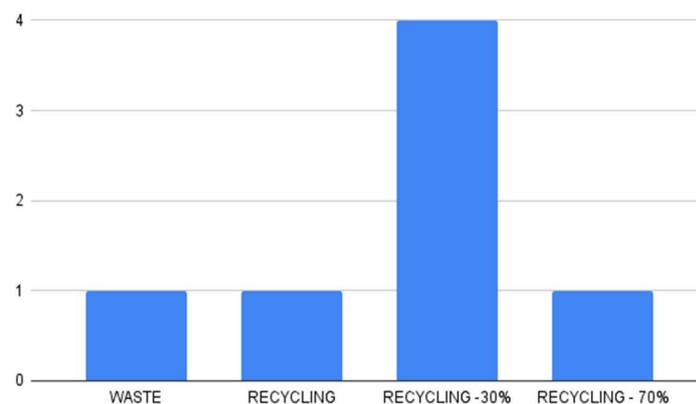


Figure 10. Type of packaging used to store goods

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).

Waste produced by companies**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.*).

Disposal of discarded nets and ropes**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 Sibenik-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 Sibenik-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 was 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:

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

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:

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

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

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

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 weighed 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
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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 stela 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</i>	Temp (°C)	12	20-25	30		TRY



tubulosa	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>Ulva intestinalis</i>, <i>U. lattucae</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
	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: *Dicentrarchus labrax*

- 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	0.6	0.15	0.3



		product			
		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	0.08
		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
	<i>Holothuria tubulosa</i>	Distribution range and facilities (criterion 1)	Biogeography in the MED/Black Sea	0.4	0.1
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
<i>Ulva sp.</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	0.12
	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



Tables and figures

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