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Integrate Aquaculture:
an eco-innovative solution to foster
sustainability in the Atlantic Area

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WP4: UNDERSTANDING IMTA BEST-PRACTICES IN ATLANTIC AREA

ACTION 5: A Case Study to determine bottlenecks of commercially establishing an IMTA in earthen ponds in South Atlantic area

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CONTENTS

1 Description

A Case Study to determine bottlenecks of commercially establishing an IMTA in earthen ponds in the South Atlantic area is one of the deliverables of Action 5: *Pilot action 3; test and develop an IMTA eco-friendly standard model for land base semi-extensive aquaculture industry*, and one of the actions of WP4*: Understanding IMTA best-practices in Atlantic Area*. This report presents two studies to determine bottlenecks of commercially establishing a marine integrated multitrophic aquaculture (IMTA) of fish, oysters and macroalgae in earthen ponds, in the Portuguese South-Atlantic area.

1.1 Introduction

The most widely used aquaculture fish farming regime in the south coast of Portugal is production in earthen ponds. These earthen ponds are generally old saltern ponds that have been adapted for aquaculture. The production density normally practiced is relatively low (<1 to 3 $kg.m^{-3}$) and, given the energy and feed costs, as well as predation losses, disease and constant theft, yield is extremely low. Added to this, the selling price has to compete with imported fish placed on the market at much lower prices; the final profitability is almost nil.

For these reasons there has been a progressive abandonment of aquaculture production sites with a consequent degradation of the wetlands that are generally located in ecologically sensitive areas, such as the Natura 2000 network.

However, these sites may give rise to a commercial investment by the aquaculture industry provided that dual purpose wetlands are created incorporating both conservation activities and eco-friendly aquaculture. Extensive and semi-intensive aquaculture production in an integrated multitrophic system, which is a system balanced with positive results in environmental bioremediation and economic stability (better product, lower cost, product diversification and risk reduction) may be one solution. IMTA is the combined cultivation of animals that need food from external origins with organisms that extract organic and inorganic matter from the rearing environment creating a balanced production system. These dual-purpose wetlands can be implemented to expand the area available for aquaculture.

The IMTA approach combines organisms with different trophic levels to promote a more efficient usage of the marine resources. The earthen pond culture by itself consists of a multitrophic farming technique where, for instance, fish, polychaetes, bivalves, other invertebrates, seaweeds, and plankton can coexist, extending from the water column to the sediment. The knowledge behind the IMTA farming techniques relies on understanding the roles of each organisms and how to implement them. Fish are usually the main product of these farms due to their higher commercial value. Nevertheless, they excrete organic and inorganic metabolites that combined with uneaten feed provide a nourishing formula for extractive organisms. Within the group of extractive organisms, we found organic and inorganic extractive organisms (*e.g.* oysters and seaweeds). These extractive organisms transform organic and inorganic carbon into biomass whilst they mitigate the effects of particulate and dissolved nutrients produced by the fish. Therefore, the IMTA concept provides an ecosystem service while new yields are generated from a single resource, namely wastewater or effluent.

IMTA system is encouraged by major policies in the EU (EU Blue Growth Strategy, Atlantic Action Plan, RIS3) but there are still many challenges that need to be resolved to be fully implemented in the Atlantic Area. One of the challenges pointed out by the industry is the overcoming of legal and administrative procedures necessary to start an IMTA production. To verify the bottlenecks found by the industry in the implementation of an IMTA endeavour this deliverable describes the steps followed by a prospective farmer who wants to diversify the profits of old salterns by using an unexploited section of the saltern to establish an IMTA production. This was the MadeInSea case.

Another challenge was related to the production of macroalgae as a biofilter to decrease the impact (eutrophication) of the effluents and at the same time to increase profitability. Seaweed farming is mostly situated in coastal lagoons and offshore in extensive (open) regimes, usually using long-line systems. Overall, seaweed farming represents over 27% of the worldwide aquaculture production, and over 90% of total production resides in Asia, mostly in China and Indonesia (FAO 2018). Europe, accounts only for 0.75% of the total production, with a remarkable 270 thousand tonnes, being produced in Norway, France, and Ireland. Seaweed biomass can have several origins, ranging from beach cast, wild harvest, open cultures (Seaweed Energy Solution, Norway) and closed cultures (tank culture, *e.g.* Algaplus, Portugal).

The main seaweeds of interest that are currently farmed worldwide are *Saccharinaa japonica*, *Undaria pinnatifida*, *Kappaphycus alvarezii*, *Eucheuma spinosum*, *Gracilaria* sp., *Porphyra* sp, *Ulva* sp. and *Codium* sp. Each one of these species has already been through years of research, which ensures confidence to farmers, biologists, and possible stakeholders. Despite the bibliography, it is necessary to set up field experiments to assay the environmental conditions that the seaweed will have to endure. The experience from the recently launched Ulva production at the Piscicultura Vale da Lama (PVL) constitutes the PVL case.

2 Legal and Administrative bottlenecks: The MadeInSea case

MadeInSea (MIS) is a small and medium-sized enterprise (SME), that was founded in 2018 aiming to develop high-quality marine products based on innovation and sustainable use of the Ocean. MIS owns a 17-hectare lot of saltmarsh and traditional saltpans integrated in a national protected area and close to the Reserva Natural do Sapal de Castro Marim e Vila Real de Sto. António, on the margin of the Guadiana estuary, at Vila Real de Santo António, in Algarve Region, Portugal (Fig. 1).

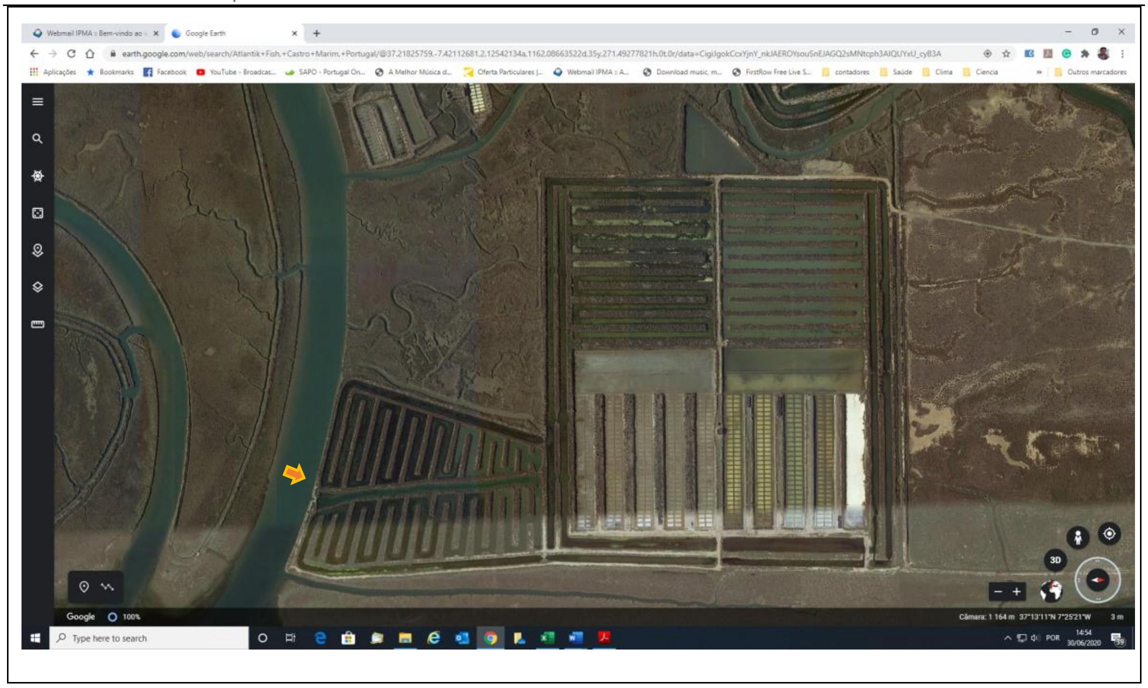

Fig. 1 – Aerial view of the MadeInSea salterns. The area to be adapted for IMTA production is the “serpentine” channels surrounding the main channel next to the water inlet (yellow arrow).

The company initiated its activity producing marine salt and *fleur de sel* catering to the organic food market and is currently preparing the development of a second business area centred in the production of algal polysaccharides for the biotechnology market.

The strategy of the company is based on the sustainable use of marine resources and the company is committed to adopt sustainable business models. With this scope, MIS decided to take a circular economy approach, planning to extract these biopolymers from macroalgae produced in conjunction with fish and molluscs within an IMTA system

In order to install their unit in a set of pre-existent earthen ponds on the same site, MIS established a technical and scientific partnership with IPMA-EPPO, looking forward to transferring the technology developed by the research unit team over the past 8 years.

Regarding the IMTA system *per se*, besides the expertise of the IPMA's research team, reference technical and scientific literature has been fundamental to plan and design the most suitable technical solution.

Nevertheless, MIS has been facing some hurdles throughout the planning and pre-implementation phase of said system. One of these hurdles has been the **difficulty to prepare a sound long-term business model**. IMTA is a relatively novel concept and there are still very few companies taking this approach. Much of the information available comes from technical and scientific literature about pilot-based studies that have been generally focused in the technical and biological aspects of the systems. There is, however, still room to improve the knowledge concerning economic and business implications, namely insofar as metrics assumptions are concerned. **Insufficient economic metrics preclude the presentation of a robust and bankable long-term business plan**, despite the shareholders contribution to the investment plan.

The implementation of areas for aquaculture needs to be created in an integrated framework with the management of the coastal zone. These areas need to be selected based on both environmental and institutional issues, that is, they must consider the environmental needs of aquaculture, its potential environmental impacts, the users and uses of the coastal and marine systems, as well as the immaterial values of coastal waters and marine areas in such a way that any request for a license for aquaculture production is situated in an appropriate location. After that it is necessary to select the target species and identify others that will be used as extractive species to recognize their productive and/or commercial use.

Another important bottleneck is the **actual regulatory framework**. For valid aquaculture permits there is no restriction to start an IMTA in Portugal. New projects follow the licencing procedure of Law Decree DL40/2017, regardless of whether they are IMTA or conventional aquaculture. The managing entity is Direção Geral dos Recursos Naturais (DGRM) that will ask for technical reports from other government entities: Environment

(APA), Harbours (Docapesca), Aquaculture (IPMA), Marine Safety (AMN), Food Safety (DGAV) and Nature Conservation (ICNF). These are binding reports and therefore their agreement is of upmost importance. Only after the general agreement, DGRM will grant the Permit for Aquaculture Activity (TAA). The challenge lies in the project design in view of the different concerns that each entity evaluates. The process of obtaining a TAA can last between 1 and 3 months, depending on the technical report's timely deliberation.

Since MIS' site is located in a protected area, the use and occupation of the land is regulated by specific directives and regulations approved for the occupation and use of this part of the territory, named in Portuguese as "**Plano de Ordenamento**", enforced by the Nature Conservation authority.

As it happens in most protected areas in Portugal, this regulation was created nearly 15 years ago, when IMTA was still a concept unknown for most people. At the time, the paradigm for aquaculture fundamentally concerned monoculture and intensive units.

Consequently, this regulatory local framework does not encourage the development of new aquaculture sites, reflecting the criticism and disapproval of aquaculture, mainly based on assumed inevitable environmental impacts (contamination, nutrient loading, spreading of diseases, etc.). Even though IMTA is a much more sustainable approach with demonstrated positive results, both economically and environmentally, this fact is still not duly appreciated in the regulatory framework. **It is essential to update this framework, to include sustainability and circular economy principles** as a key requisite to regulate human activities.

Although it is possible to install the IMTA unit itself, there are many limitations imposed on adjacent land use. One of the main obstacles is the challenging and sometimes insurmountable **restriction imposed on the installation of basic and essential infrastructure** (to implement this or any other sustainable economic activity), such as access, offices, warehouses, or laboratories.

The company submitted a project to the Nature Conservation authority and received a favourable opinion, subject to terms and conditions for its implementation with a view to complying with the existing restrictive rules. Presently, MIS maintains its interest in developing and implementing the project, working on a different and creative new version of project.

3 Operational bottlenecks: The PVL case

The Piscicultura Vale da Lama (PVL) is an aquaculture company located in the nature reserve of Ria de Alvor, in the municipality of Lagos, Algarve, Portugal (Fig. 2). The aquaculture activity started in 1989 with the production of oysters, sea bream, sea bass and some sole with origin from the estuary itself. PVL in partnership with "Aqualvor-Actividades em Aquacultura, Lda.", produced annually about 500 tonnes, in 12.3 hectares of water surface. Currently the company's main production species are seabream (*Sparus aurata*) and seabass (*Dicentrarchus labrax*) in a semi-intensive system, with a small amount of meagre (*Argyrosomus regius*) and sole (*Solea senegalensis*) production.

Aiming to diversify and to start macroalgae production as a biofilter for the fishpond effluent, the PVL is testing different rearing system for *Ulva* spp. Nowadays, numerous farms are looking into seaweed farming as a potential biofilter and profitable product. Beyond its role as a biofilter, their natural occurrence, no need for fresh water, fast growth and interesting pool of bioactive compounds makes them a sustainable resource that matches perfectly with the mainstream blue and circular economy trends.

Seaweed production in open systems is not easy since they have different reproductive cycles (haploid (n) and diploid (2n)) that are triggered by diverse factors. One such factor can be environmental stress, which leads to a loss of productivity/biomass and in some cases total loss of biomass. **The species biology can be a bottleneck to production**.

Certain biological limitations can confine the production to a specific season of the year, geographic area, and production system.

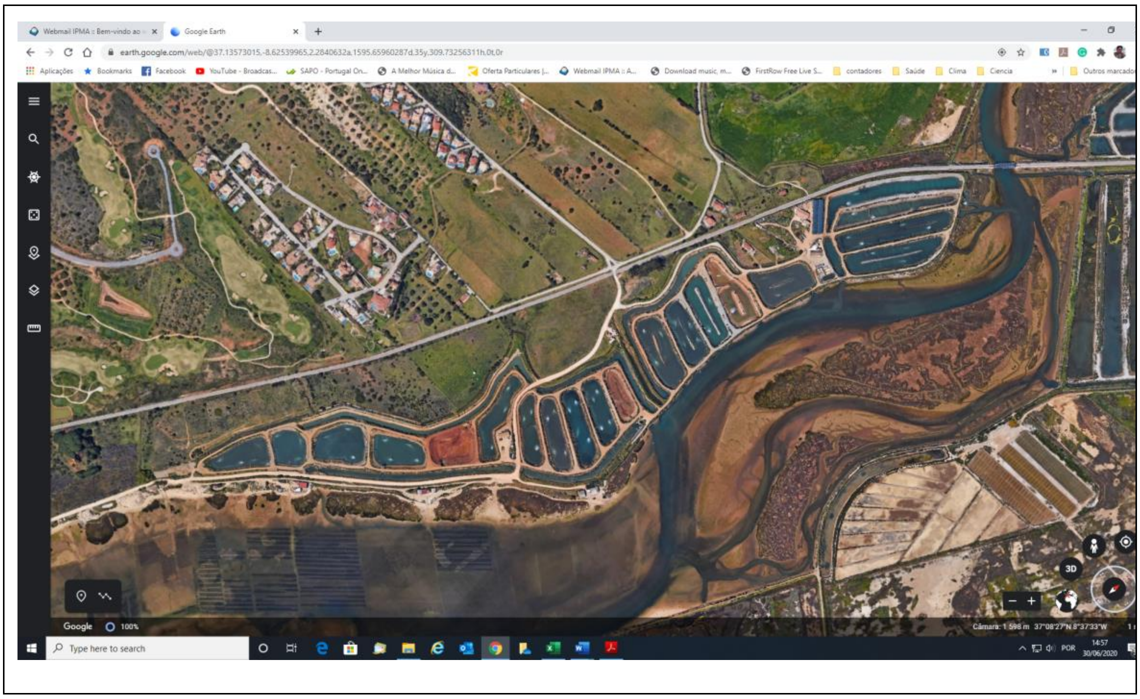

Fig. 2 – Aerial view of the Piscicultura Vale da Lama.

Every production system has specific characteristics, like water source, area, colour, depth, construction material, biome, microbiome, filters, fauna, and others. Each different aspect will have influence on the biomass, changing the physiology and even morphology of the seaweed, hence the biomass quality (Machado et al. 2019, Spoerner et al., 2012). Although several papers have reported successful production of seaweeds as biofilters for fishpond effluent, when the objective is to produce bulk biomass the results are not so strait forward. A balance between the environmental parameters must be attained to achieve high yields, productivity and maintain biomass quality. **Fishpond effluents have high variability of nutrients over time**. Thus, the designed system must be flexible and consider from where to pump the water and how to maintain nourishment.

As the industry and research suggest there is a general law applied to seaweed farming: at the same time that the intensity of the production system increases so does the price and production volume whilst the variability of the seaweed biomass diminishes. Therefore, the need to develop or acquire a high-tech production system is only needed when the purpose of the produced biomass demands.

Different 'grades' of seaweed can be produced, according to the quality and consistency required by the end-product (Holdt and Kraan, 2018). If a farmer aims to maintain a high-grade seaweed with a specific set of properties, the system must provide the conditions to maintain that grade. To achieve this, it is important **to control the physical and chemical parameters of the rearing medium**. Wild harvested and open systems do not allow close control of the environmental parameters, meaning that the biomass is more exposed to the natural variability of the environment. Higher environmental control can be achieved in closed systems making them more productive but also more susceptible to human and mechanical errors.

Finally, after understanding the biology of the seaweed and establishing a production system with regular and predictable yields, one will have **to develop a harvesting and packaging and processing methodology**. Fortunately, nowadays, technologies have been developed for these purposes and some companies also provide custom-made machinery. Nevertheless, depending on the destination of the biomass, **proper logistics planning must be used to preserve the biomass and its properties** until reaching the processing plants, and or labs.

Since the start of the systems development phase at PVL, several issues were identified, although the farming conditions are ideal due to continuous nutrient supply (effluent) and area. The most predominant ones were related the **control of epiphytes**, **proper biomass nourishment and promotion of continuous growth**.

The production system is composed by six 500 L cylindrical tanks, one 1,800 L fiberglass raceway and one 15,000 L concrete tank. To nourish the macroalgae, effluent water is derived from a reservoir water tank (effluent and water from Ria de Alvor) and recently directly from a production tank.

Continuous water sampling showed a daily variability in the dissolved inorganic nutrients concentration. Hence, to achieve a balance of nutrients within the tanks several water flow versus growth experiments were performed to compensate for the diurnal variability. These parameters are highly related to the chemical composition and productivity of the biomass. At our facilities, due to limited lab equipment, the only biomass quality parameter that could be calculated was the dry weight including the organic matter. Hence, the dry weight of the sample was used as a biomass quality standard parameter.

During the first trials, once the biomass was transferred into the scaling up tanks, the thalli lost its texture, consistency, dry weight, and colour, turning from emerald green to a yellowish white in few days. Possibly, some of the culturing conditions were limiting the nutrient availability, and the environmental stress could have induced sexual reproduction, which led to an almost total biomass loss. After understanding the role of water flow and its connection to the biomass physiology, our results allowed us to scale up from the small 500 L to the 15,000 L maintaining biomass quality.

One common issue, with scaling up systems or processes, is thinking that replicating the environment will provide the same result, even though the scale is larger. **The system design is a limitation for the producer**. The right equipment must be chosen to allow a practical maintenance of the system and data record whist it provides the right conditions for biomass growth. The system must have inbuilt redundancies, and Murphy's Law ("*Anything that can go wrong will go wrong*") can help the readers to find what can go wrong while farming.

To collect high yields from these systems, it was necessary to learn how **to maintain and achieve high densities within the production tanks** (over 5 kg/m^2). Without a constant water nutrient content evaluation, it was not possible to choose efficiently the equipment that makes part of the system. Naturally, the water flow, nutrient content and uptake are related. On one hand, a farmer can use the algae system as a biofilter, decreasing the water flow and improving the biofiltration efficiency. On the other hand, depending on the system design (*e.g*. raceway), the water will be completely depleted of nutrients at the end of the tank. Thus, the biomass will be limited. One alternative is to do the opposite, and promote high water flow, increasing the nutrient availability along the tank full length, increasing growth. In this case the biomass will never be nutrient limited unless the water source does not contain enough nutrient or the equipment (*e.g.* pumps) do not provide capacity (enough water flow). Again, in semi-intensive and intensive systems turbulence is used to break stratification and increase the renewal of diffusive boundary layers between water with nutrients and algae surface. With aeration, the biomass is propelled along the water mass. Hence, the correct equipment (*e.g.* pumps, air blower, filter, harvesting gear and electric system) are a necessity for macroalgae production.

Another bottleneck for seaweed farming is **epiphytes** (*e.g.* fungi, algae, plant that grows on another plant) that are not parasitic but compete directly or indirectly with the target seaweed. Epiphytes are seasonal, opportunistic, and difficult to eradicate. When handling large amounts of biomass, epiphytic treatments become limited and production can be compromised. Without a proper design, maintenance, and SOPs (System Operational Protocols) even closed systems can have clogged faucets and dirty filters that can lead to an epiphytic event. Cultures can be easily contaminated if the equipment is not pre-washed before and after its usage. Considering the usage of good aquaculture practices, human impact can be minimized. Nevertheless, natural epiphytic outbreaks will occur. During an outbreak with full system contamination a deep prophylactic treatment will be required to diminish its impact. For example, using hydrogen peroxide to cleanse the wall of the tanks, equipment, etc. Nevertheless, once dozens of kilos of algae are contaminated it will be difficult to clean all the epiphytes. However, not every epiphyte can be considered a nuisance. Some algae will grow naturally on the tanks and may not interfere with the target algae.

Not having a small lab, with isolated algae collection is a bottleneck for a successful macroalgae production. From an algal collection it is possible to stock different species and strains allowing the farmer to start from a single individual, without contamination.

In order to understand the key factors that play biofiltration, productivity, chemical composition of *Ulva* spp. and valorise this natural fish food, PVL submitted a R&D project (AVISO Nº17/SI/2019) named **Ulvalor**, that aims to study the difficulties of the production of *Ulva* spp. reared in different production systems with different water sources using fishpond effluent. This project follows under the coordination of Francisco Machado and PVL CEO António Vieira, seaweed production manager. **Ulvalor** is a co-promotion project, where PVL (promotor) teams with IPMA-DivAVB (co-promotor) and other consultants. This project aims to select the most adequate Ulva strain and production system and then characterize their performance during year-round cycles. The biomass valorisation will be also achieved through the study of Ulva bioactive compounds and chemical composition during those cycles, and through their usage as feed supplement for seabream. This project is still waiting for approval.

4 Conclusions

This report presents two studies to determine bottlenecks of commercially establishing a marine integrated multitrophic aquaculture (IMTA) in earthen ponds, in the Portuguese South-Atlantic area.

The legal and administrative bottlenecks referred to by the producer were:

1. **Preparation of a sound long-term business model**. They point out the insufficient economic metrics that preclude the presentation of a robust and bankable long-term business plan;
2. The **actual regulatory framework**. This regulatory framework does not encourage the development of new aquaculture sites, reflecting the criticism and disapproval of aquaculture, mainly based on assumed inevitable environmental impacts (contamination, nutrient loading, spreading of diseases, etc.). **It is essential to update this framework, to include sustainability and the circular economy**
3. **Limitations imposed to the land use** that restricts the installation of basic and essential infrastructures, such as access, office, warehouse, or laboratory.

The operational bottlenecks in Ulva production advanced by the producer were:

1. **Control of the physical and chemical parameters of the rearing medium**. Wild harvested and open systems do not allow close control over the environmental parameters.
2. **The system design is a limitation for the producer**. The designed system must consider from where to pump the water and how to maintain nourishment since fishpond effluents have high variability of nutrients over time.
3. **Control of epiphytes**. When handling large amounts of biomass, epiphytic treatments becomes limited and the production can be compromised therefore it is important to consider the usage of good aquaculture practices to prevent contamination.
4. **Develop a harvesting, packaging, and processing methodology** to preserve the biomass and its properties until the processing plants, and/or labs.
5. **Not having a small lab**, including an algal stock collection is a bottleneck for a successful macroalgae production.

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