Deliverable 6.2:
Best practices and guidelines for SIMTAP systems.

v. 30 April 2023

Table of Contents

Introduction

Aquaculture is a sector of growing economic importance in the EU. In recent years, more and more regulations and reforms are being developed under the Common Agricultural Policy with the aim of increasing fish and seafood production and safeguarding food security within the EU. At the same time, this development must be in line with the EU's sustainability and circular economy objectives. Integrated Multi-Trophic Aquaculture (IMTA) responds to these criteria and stemming from it, the SIMTAP project aims to drastically reduce production inputs and waste outputs while maximizing the total food production.

This document contains several Best Practices and Guidelines (BPG) aimed at facilitating the replicability of the IMTA systems tested during the project, referred to hereafter in the document as SIMTAP system. Best procedures on how to best design, implement and manage a SIMTAP system in a Mediterranean country will be also explored. The target audience are farmers, teachers, and students in aquaculture and agriculture, and local and regional stakeholders. This document does not claim to replace a manual of aquaculture or aquaponics, since exhaustive books have been published on this topic (e.g., Goddek et al. 2019; Hager et al., 2021; Mayoral et al., 2020; Somerville et al., 2014)[1], but to provide some specific notions, tips, and suggestions based on empirical evidence gained during the project on the SIMTAP system.

In the context of the project, two different types of SIMTAP systems have been set up and tested:

- The first is an in-land decoupled aquaponic system supplied by brackish water. Prototypes have been implemented in: i) Italy in an experimental greenhouse of the University of Pisa, Pisa; ii) Turkey at the marine unit of the Mediterranean Fisheries Research, Production and Training Institute (MEDFRI), located in Demre; iii) in Malta in an experimental greenhouse of the Agriculture and Innovation Research Hub (Ministry of Agriculture, Fishery and Animal Rights, MAFA) in Ghammieri Marsa.
- The second is instead a system of earthen ponds connected by a cascade principle and supplied directly by sea water. This system was realized in France in Bourcefranc le Chapus in the didactic-experimental aquafarm of the Lycée de la Mer et du Littoral (LML).

1

- Goddek, S., Joyce, A.; Kotzen B.; Burnell, G.M.; Burnell, G.M. Aquaponics Food Production Systems; 2019; Springer Open. ISBN 9783030159429.
- Hager, J.; Bright, L.A.; Tidwell, J.H.; Dusci, J. AQUAPONICS Production Manual: A Practical Handbook for Growers; 2021; Kentucky State University.
- Mayoral, J.; Dimitrov, I.; Yamada, S. Technical manual of aquaponics combined with open culture adapting to arid regions; 2020; Fukui Print Miyanaga; ISBN 9784990758776.
- Somerville, C.; Cohen, M.; Pantanella, E.; Stankus, A.; Lovatelli, A. Small-scale aquaponic food production; 2014; Food and Agriculture Organization of The United Nations, Rome, 2014ISBN 9789251085325.

Notwithstanding the evident differences, the two systems share the same operating principles: the association of different species of different trophic levels. In doing so, the metabolic wastes are used in a cascade production process, to produce organisms to be reused at the top of the trophic chain as fish feed and to reduce nutrient emissions into the environment. This strategy implies to develop specific technicality in the different species and above all to balance the system in environmental (e.g., temperature and salinity of the water which must be suitable for the growth of different species) and quantitative terms (e.g., by correctly sizing the different production units).

These two systems will be treated separately in the following document due to the differences in design, operations and management that characterize them. In addition to being divided by the two main SIMTAP systems, this report is also divided by topics covered. For each SIMTAP system, three macro-topics presented in as many paragraphs will be considered:

- System design and operation, concerning plant design (site selection, infrastructures, consumables) and operation (e.g., water sanitation, recirculation, analysis), the management of the individual units and their interactions (Juveniles supply/individuals/seedlings supply, monitoring of performances, correct sizing, product balance, timing of operations);
- Feeding practices, concerning feeding management (supply and/or preparation of the correct feed, its storage, and its distribution) and monitoring (analysis of feeding response, in behavioral, environmental, and productive terms);
- Cleaning and sanitation, concerning cleaning operations and sanitary procedures. It refers to the cleaning and disinfection schedule of the different plant and facility components, including notes on cleaning staff and the supply of cleaning materials; and to pest monitoring and control, involving quarantine, exclusion, and eradication measures where appropriate.

In-land aquaponic systems

Production system design and operation

In general, the main loop of the system is: aquaculture units, deposit/filter feeder units and macro-algae/hydroponic units. The rationale behind this system is a multitrophic chain in which the fish waste feeds first the deposit and filter feeders and then the plants, while at the same time the produced deposit and filter feeders feed the fish. The choice of the farmed species is certainly a crucial point for the design of an IMTA recirculating system. There are many criteria to take into consideration, including trophic complementarity, natural geo-distribution, domestication degree, environmental requirements, feeding regime, growth performances, and market value.

All the SIMTAP systems tested during the project are based on the breeding of Gilthead Sea Bream and European Sea Bass, which had already been previously selected as the best fish for biological, zootechnical and commercial characteristics in the context of Mediterranean aquaculture.

Moreover, the choice of the production site is very important. Thanks to a participatory approach between partners and sector experts, the project has identified and prioritized the key spatial factors for the construction of an inland SIMTAP system. Some of the most important parameters to be considered are the distance from salt and fresh water sources, the electricity and road networks, fish hatcheries and plant nurseries, inhabited centers (possible market outlets), protected areas etc.

A decision support system (DDS) has been developed in a GIS Environment for the implementation of SIMTAP systems in the Mediterranean area (Del. D3.05). The DDS is implemented using a GIS-MCDA (Multi-Criteria Decision Analysis, MCDA) to identify the best locations of SIMTAP systems.

The initial aim of the project was for the SIMTAP system prototypes to operate in such a way that the aquaculture and aquaponics units were directly connected, with a continuous flow of water, in a coupled system. One of the main conclusions from the empirical experience of managing the prototype is that a decoupled system is much easier to manage. Therefore, the first recommendation is to design a similar system with the main sections decoupled. For this reason, the design of the system should be thought of as a multi-loop system that includes a recirculating aquaculture system (RAS), a section for detritivore and filter-feeder organism (DFFO) production, and a hydroponic system. These sub-systems should be temporarily linked for the recirculation of nutrients and water. Therefore, RAS and DFFO section must be equipped with all the conventional infrastructure and machinery: fish and filter feeders' tanks, water pumps, blowers, biofilter units, chiller, power units, PC-controlled monitoring units.

The hydroponic system, on the other hand, in addition to all the conventional structures and materials, must be equipped with storage tanks for the nutrient solutions, the greater capacity of which must be dedicated to the water discharged from the IMTA system. The size of these reservoirs depends on the total recirculation flow of the system and the estimated evapotranspiration and discharge rates.

It is proposed that the system must be equipped with an emergency power generator to prevent black-out, which could have serious consequences for the water conditions and consequently for the organisms bred in the system. The following figures shows the construction process of the SIMTAP plant located in Turkey, with a focus on some components.

Environmental operating parameters must focus on water resources used to supply aquaculture operations, as well as water discharge.

It is suggested that inlet water, regardless of its source, passes through a cleaning and disinfection system before entering the aquaculture plant. For this purpose, a UV disinfection system is preferable, which can also be supported by a particle filter and ozonization system depending on the inlet water quality. For example, for well water, the passage through a filtering system is almost necessary to avoid clogging issues in the system due to suspended particulate matter.

Figure 1: Construction of the greenhouse that hosted the SIMTAP system at MEDFRI *in Turkey, and its main components.*

Figure 2: Main compartments of the SIMTAP system implemented at MEDFRI *in Turkey.*

Figure 3: Filtering and treatment equipment of the SIMTAP system implemented at MEDFRI *in Turkey.*

The system should be also be fitted with a heat pump unit to deal with any extreme water temperatures that the system could face, depending on the location.

Inlet water should be analyzed for water quality and for chemistry parameters appropriate for the culture species. Sampling should be conducted periodically to evaluate seasonal fluctuations that can affect water quality. The most important parameters to be monitored, preferably daily or at least once or twice a week, are pH and the concentration of total ammonia nitrogen (TAN), nitrite, nitrate, and dissolved nitrogen. Other parameters to be evaluated, albeit less frequently, are alkalinity, hardness, and the level of hydrogen sulphide.

It must be considered that the outlet water deriving from the system (the portion that is not recirculated) must be treated like normal industrial wastewater before being released into the environment, therefore referring to the relevant national legislation. The use of marine aquaculture and aquaponics wastewater for crop irrigation water is not possible given the high salinity and could be used almost exclusively after dilution, which depends on the availability of freshwater in the location. Even in this case, however, a specific authorization would be needed for which again reference should be made to the relevant national legislation.

As regards the halophyte unit, experiments carried out during the project showed that there are no contraindications to using Deep Water Culture (DWC) without substrate media as a cultivation method. In particular, the water depth of the tested tanks was 20-30 cm. From an environmental point of view this is certainly an added value of the system because no herbicide is applied to treat possible weeds nor insecticide for soil insects, which would be necessary in soil-bound crop in greenhouse or in open field. Apart from this, as far as pest control in general is concerned, there are no differences compared to common hydroponic culture management protocols, for example possible interventions concerning infections of the epigeal plant parts.

Maintaining optimum air temperature and humidity ranges for the crops grown in greenhouses in a Mediterranean environment is certainly an issue to be considered at the design stage. The SIMTAP system in Malta, for example, has been subject to extreme summer heatwaves with maxium temperature inside the greenhouse up to 55°C and the temperature of the recirculating water to 33°C. This can have serious consequences for both the people working in these structures and the species being grown. Exhaust fans, shading nets and water recirculation chillers can overcome the heat problem.

Since the system is based on principles of sustainable production, attention must also be paid to energy consumption. The optimal system should be developed based on daylight only, exploiting different crops in succession to ensure that this unit is operational throughout the year rather than resorting to artificial lighting. In fact, the experimental tests carried out on aquaponics have never foreseen the support of artificial lighting.

Regarding the Italian context, some conclusions drawn from the aquaponic tests carried out are:

- The productivity of both sea beet (*Beta vulgaris* subsp. *maritima*), a facultative halophyte, and the Swiss chard (*Beta vulgaris* var. *cycla*), a salt-tolerant glycophyte, generally decrease with increasing water salinity.
- The productivity of the glasswort (*Salicornia europea*), an obligate halophyte (or eu-halohyte) was significantly greater in saline water than in non-saline water; the optimal salinity level was between 10 and 20 g/L, although satisfactory production was obtained at higher salinity levels, to 30-35 g/L.
- The best crop rotation is the alternation of *Beta spp.* in autumn-winter and *Salicornia europea* in spring-summer.
- In any case, crop plants need an adaptation period before transplanting in the SIMTAP system. This adaptation can be readily achieved by exposing the seedings to a progressive salinization of the nutrient solution in the nursery unit; one or two weeks are necessary in fall-winter and spring-summer, respectively.

During the project, a production simulation tool called SIMULSIMTAP was developed which allows to estimate the possible succession of different crops and their coupling with fish production. This allows to design potential SIMTAP systems in different locations. The inputs required by the tool for running are environmental parameters of the plant location site, characteristics of the farmed species (both plants and fish) and the main plant and operating parameters of the system. This also allows long-term production planning, verifying the balance between source and sink of the various nutrients, with a particular focus on nitrogen, an element whose balance is a priority in the system.

As far as fish rearing is concerned, a recommendation that emerged from the experimental tests carried out is to always start the rearing cycle with juvenile fish rather than using adult fish, since the latter suffer much more from transport and adaptation. In fact, when adult fish were introduced, high mortality was also observed at this stage, whereas very little mortality of juvenile was observed and no other problems were observed once they were grown.

In the SIMTAP system built in Italy and in Turkey, there have been difficulties in rearing DFFO and obtaining a consistent production over time and, above all, in quantities sufficient to make the system completely feed self-sufficient. There is still much to be learned about the behavior of polychaetes and especially of bivalve species when introduced into such a system, and the project certainly leaves room for improvement in this respect. For these reasons, the conclusion is that when designing a IMTA system where such organisms are desired, it is recommended that the system be equipped with mechanical filtration systems, even if they are to be used only occasionally.

A weak point of the tested system certainly emerged to be the measurement of water quality in real time, and possibly automatically. This would be fundamental above all for the parameters related to the content of inorganic nitrogen, which strictly influences the growth conditions of the fish and can cause toxicity beyond certain thresholds. Currently, colorimetric methods developed for water sample (e.g. Merck quick test) with high salinity can be successfully used for frequent (weekly or biweekly) manual monitoring. Therefore, in such a system, the solution so far is only to implement periodic water sampling and chemical laboratory analyzes. In any case, in this regard, a positive note was that the fish proved to be very resistant to even high concentrations of nitrogen compounds (up to 5 mg/L of TAN and 300-400 mg/l of nitrate) and phosphorus in the water.

As far as manpower is concerned, it must be kept in mind that for a SIMTAP sysmte not only agricultural workers are needed for cleaning, harvesting and other ordinary activites, but also highly specialized manpower for water quality monitoring and maintenance of electric and hydraulic devices.

The fish tanks should be covered with nets to prevent accidental fish escape. This behavior was observed sporadically as the project progressed. This was probably due to the occasional low oxygen concentration in the water, also related to fish stocking density, or in case of overflows. To better control dissolved oxygen concentrations, liquid oxygen supply can be implemented, while in the SIMTAP experimental prototypes blowers or agitators were used for this purpose. However, liquid oxygen is expensive and, more importantly, highly flammable and therefore requires careful handling and a specially equipped distribution system. During the design of a possible SIMTAP system, therefore, all these trade-offs must be considered.

In Italy and Malta, the system has shown, progressively with the growth of the fish, a poor clarity of the water, both with the control diets and with the alternative ones (see as an example Figure 4). This is a standard condition for in-land aquaculture farms, although it must be considered that it makes visual inspections of the tanks more complex.

Figure 4: SIMTAP system in operation at University of Pisa in Italy; focus on fish rearing tanks, where the lack of clarity of the water can be noticed.

Feeding practices

In conventional aquaculture systems, a certain amount of biomass produced requires feed consumption, during the entire production cycle, from one and a half to three times higher. It follows that if the feed comes from cultivated products and/or wild fish stocks, the consumption of biotic and abiotic resources necessary for their production is huge. Fishmeal and fish oil are two of the main ingredients of marine feed due to their excellent nutritional characteristics. However, these two ingredients also represent an important bottleneck to the development of sustainable aquaculture systems. While aquaculture is experiencing a constantly growing trend on the world scene, there is an increasing need to develop alternative feeding strategies to those currently in use.

The use of DFFO obtained from IMTA could help feed manufacturer to produce high quality fish diets reducing the dependence on marine and plant-based ingredients and additives. However, the complete exploitation of these organisms in the aquaculture industry is still far to be achieved. The most important bottlenecks are i) the scarce information about their application in fish nutrition, ii) the intensification of their production, iii) the competition with human consumption, and iiii) legislative boundaries, at least in the EU. To our knowledge there are few experimental trials conducted using these species as feed ingredient. Previous research experiences in this direction are also very limited.

On the one hand, the project has shown that sea bream and sea bass respond very well when fed with freshly distributed DFFO (polychaetes and bivalves) and, from the trials carried out in Italy, the production performances obtained were generally comparable to those obtained with the commercial control feed. At the same time, if the performances obtained with commercial diets want to be completely equaled, it is essential to provide, alongside fresh extractive organisms, a mineral mix to balance the vitamin and mineral needs. On the other hand, a consideration that emerged during the project is that, even with a well-optimized production process and favorable legislation, the main economic driver for bivalves from IMTA could be food production, while use as a feed ingredient could be limited to food industry rejects.

Finally, it is important to remember that the feed used plays a key role both in the environmental, economic, but also social (e.g., local supply fostering local development or not) sustainability aspects of aquaculture systems. From an environmental point of view, management of the nitrogen in the system is crucial. The protein content of the feed influences the nitrogen emissions of the fish metabolism. On the one hand, as mentioned previously, this is important because it affects production and the fish/plant ratio, but if in excess, it risks determining toxicity for the fish themselves.

Cleaning and sanitation

In the experimental systems tested, both macroalgae and filter feeders were cultivated in cubic tanks. These were found to be unsuitable due to cleaning difficulties. It is recommended that instead of a series of cubic tanks, raceway structures be used to produce macroalgae and deposit filter feeders, as these are much more hydrodynamic and easier to maintain. In addition, a bottom drain valve should be installed in all holding tanks/structures to allow for a more efficient and effective cleaning methodology.

Some recommendations are derived to moderate and monitor the protozoa population, along with the continuous UV-disinfection:

- use of disposable gloves and accurate hand washing when operations require to plunge hands in the recirculating water.
- at the start of a new plantation, or each time fish or other organisms are introduced for the start of a new cycle, detailed monitoring of the microbial population through laboratory analysis should be carried out every two weeks. When this stabilizes, routine analysis could be performed every two months.

Still related to the introduction of new fish into the system, quarantine is suggested in case other batches of fish are being farmed in the system. In this case, the newly introduced fish should remain separated from the rest of the system in non-recirculating water tanks for a few weeks (2 to 4) with daily discharge of 10-20% of the water volume.

As regards the introduction of mollusks, it is important to ask the supplier that they are washed and rinsed thoroughly before being transported to the plant.

In general, prophylaxis is very important: the right precautions must be taken to prevent the entry of pathogens. General recommendations in this regard are disinfecting shoes before entering the plant facilities and avoiding wearing clothing that has previously been worn during visits to other aquaculture facilities.

At the same time, it must be acknowledged that the exposure of a similar system to pathogens is very limited compared to offshore systems and earthen ponds. In addition, the system is very little stressed by predators and escapes.

Before any new production cycle, the whole system should cleaned and disinfected using bleach 10% sodium hypochlorite bleach (1 L/m^3).

Connected earthen ponds

Production system design and operation

The system tested in France was designed to be self-sufficient at a territorial level rather than at the farm level. The system is in Charente-Maritime, a department on the southwest coast of France. It is an area with a coast highly suited to the production of mussels and oysters, and an inland area suited to the cultivation of arable crops.

The system developed in France follows the general concept of an extensive fish farming system, based on a continuous flow rate that allow a constant water renewal of the ponds.

First, regarding site selection for such a system, slope, soil composition and depth are determining factors. Ponds are designed to retain water, so unless expensive linings are used, the clay composition of the soil should be at least 20 percent to ensure water retention. Also, soils with a pH of 6-8.5 are ideally best and require minimal treatment. Soils with high organic matter content should be avoided because they can create high oxygen demands and release nitrogenous compounds that are toxic to aquatic organisms.

Proper height and width of levees are important to accommodate the required production and harvesting equipment. Ponds should be of adequate depth to maintain seasonal water quality parameters and thermal stability. Shallow ponds (less than 1 m) lend themselves more to operations carried out manually. Greater depths allow instead to possibly intervene with small boats; therefore, this is a parameter to be considered very carefully when thinking of designing a similar system. A gentle slope is suggested for pond levees to reduce erosion and facilitate harvesting operations. It is also advisable to leave the ponds slightly emptied compared to the maximum water capacity, to absorb any episodes of heavy rain. On the other hand, if the pond system is designed with surface water basin as water source, it must be designed considering historical data on the impacts of possible droughts.

A general layout of the system implemented at LML in France is shown in Figure 5. The inlet water is fed directly from the ocean into a water channel when there is high tide. A gate allows to control the water draft from the ocean, and its depth in the channel and consequently in the whole system. At low tide, the gate keeps the water in the system, which is separated from the ocean during this time. Once the water has been drawn from the inlet water channel, it is recirculated in the cascade system made of five earthen ponds: an airlift pump in fact ensures that the water arrives in the pond intended for fish farming (Pond 7 in the figure) from which it passes through all other ponds. Each pond (except the one with macroalgae) is also equipped with an extra-blower to ensure the minimum concentration of oxygen required, especially during summer. The water exchange takes place at high tide, when an extension pipe is mounted (arrow with white shadow in the figure) which connects the entire flow with a last pond destined to grow macroalgae, from which the water then escapes. This is the only outlet flow of the entire system. The indicators used to manage the water exchange in the system are salinity, water depth (e.g., to compensate for evaporation) and oxygen concentration.

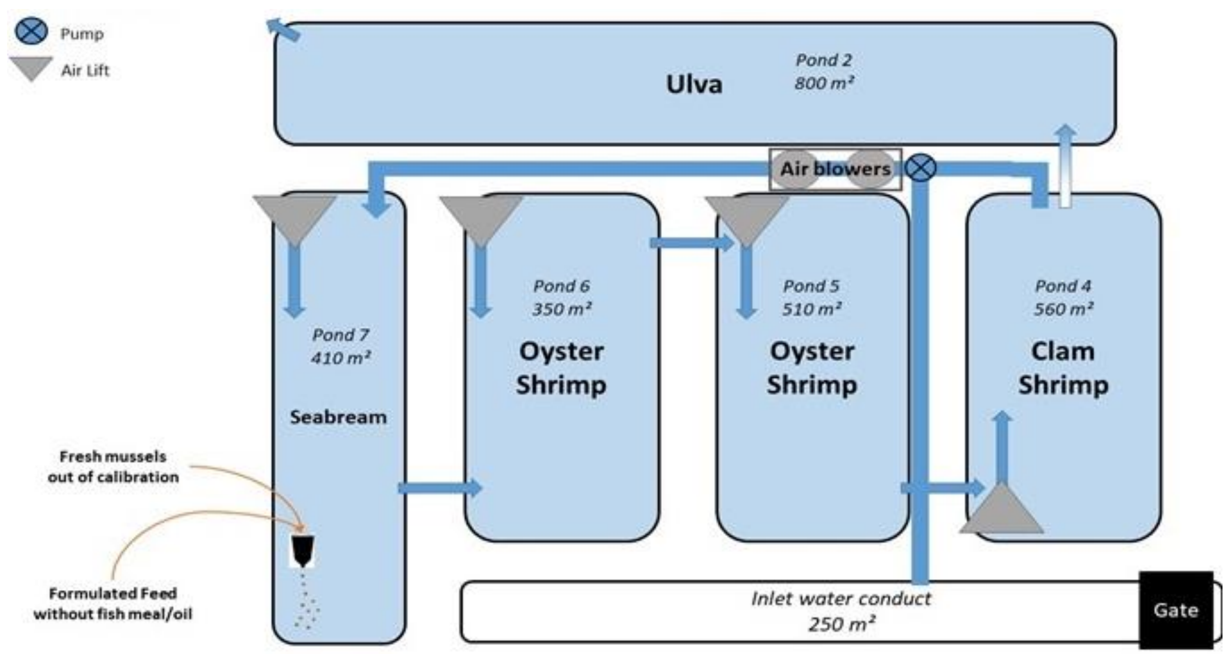

Figure 5: Experimental design of the SIMTAP system implemented at LML in France.

In the first recirculation pond, gilthead seabream (*Sparus aurata*) is stocked at a low density of about 3 fish/m^2. Oyster (*Crassostrea gigas*) and clam (*Ruditapes decussatus*), filter feeders of economic interest able to eat suspended organic matter released by fish, are stocked in the following ponds at a density of 2 oysters/m^2 and 30 clams/m^2. The three ponds stocking oysters and clams also host shrimps (*Penaeus japonicus*) at a 2.5 shrimps/m^2 stocking density, inserted at mean weight of 0.5 g during the post-larvae developmental stage. Stored shrimp is ideal for this system because, in addition to its market value, it releases nutrients available for phytoplankton growth in the water column through its burrowing activity in the sediment. The phytoplankton in turn is a feed source for the filter feeders. The system is designed to be operational from mid-spring to approximately mid-autumn (Figures 6 and 7).

The main complication for the production system is related to the implementation of the different species, based on their specificity, and thus the organization of the start-up of the system (dry period, temperature, and filtration of water for shrimps, nets on wet mud for clams). This difficulty is aggravated by the fact that, for most species (oysters, clams, shrimps), the supply comes from extensive farms and therefore has an uncertain and variable delivery date. In addition, the water supply must take account of the tides. An improvement in management would be the possibility of temporarily storing the species in dedicated structures according to their arrival date, so that when they are fully available, they can be introduced into the system according to the planned sequence. An alternative strategy, albeit more complex and later to implement, would be to introduce a collateral system for the domestic production of juvenile mussels and shrimps.

.

Figure 6: Detail of fish capture at LML.

Figure 7: View of one of the SIMTAP system ponds during system downtime at LML.

Another point concerns the management of the water cycle and the need to ensure a sufficient supply of oxygen for the sea bream. In this regard, there were initial concerns about the ability of sea bream to tolerate very low dissolved oxygen levels, depending on the time of day (i.e., phytoplankton photosynthesis). However, sea breams shown to survive at oxygen levels considered lethal (<3 ppm), which in any case should be avoided and therefore air-lift systems have been installed to deal with potential crises. It is recommended that sea bream be stocked in good conditions well before the critical periods (late summer) so that they can adapt before the period of high heat.

Feeding practices

In fact, the feeding of the fish, the only species in the system fed with external inputs, was designed on a vegetable basis (formulated without fishmeal and fish oil) using locally available feedstuffs. These were then integrated with discarded fresh mussel out of calibration from local producers, distributed once a week, and, finally, also with small wild gray shrimp from the pond system itself. These were important most of all to balance the fish needs in micronutrient and fatty acids.

In fact, in the experimental carried out test, three treatments were compared, one with commercial feed, one with an experimental plant-based feed only and one with an experimental plant-based feed added with fresh mussels' flesh (shells were removed) once a week. Treatment with plant-based feed supplemented with mussels showed growing performances (particularly harvest size and FCR) and mortality very similar to the results of the commercial feed, thus showing that this "alternative" diet formulated was successful. At the same time, the composition of the body in fatty acids of fish fed with the alternative diet shows a lower content of EPA and DHA than those fed with commercial feed.

As expected, the worst performances were obtained from the exclusively plant-based feed.

The results therefore show great potential for the substitution of commercial feeds, although it should be reported that the use of mussel flesh in direct feeding requires a learning period (1 month) for sea bream. Mussels not consumed during the learning period may decompose in the tank. A resin feeder was installed in the tank to hold the whole and crushed mussels, and the uneaten mussels were emptied daily during the adaptation month.

Other complications that have arisen in relation to feeding concern:

- the impossibility of following the evolution of the real number and size of fish in coastal ponds; The calculation of the biomass is therefore based on trial weighing, which is usually not easy to carry out, and a theoretical number resulting from the stocking. It is therefore necessary to use a temperature-dependent growth model to update the fish ratio on a weekly basis;
- variations in dissolved oxygen related to the photosynthetic activity of the phytoplankton, which requires a feeding plan and a check of the oxygen level before the planned feeding to assess its feasibility.

The quantity of DFFO reared in the ponds was increased during the various trials, with good results. The fact that, even with increased quantities, the mussel filling rate was considerable, together with the high presence of phytoplankton in the tanks, suggests that there is ample room to increase the density of these organisms in the ponds.

Cleaning and sanitation

First, in a pond system it would be preferable to implement rat and bird containment systems. In fact, these, in addition to damaging production and causing stress in the fish, can act as vectors of diseases.

The system of coastal ponds with natural bottom does not require cleaning and does not allow sanitary management. The monitoring of mortality is visual and the removal of dead fish, if observed, is daily.

Conclusions

Table 1 shows a SWOT analysis of the main internal (management, technological and physical resources, manpower and organization) and external (political, economic, socio-cultural, environmental, and legal) factors that emerged during the project. In conclusion, the project has indeed highlighted the great potential of these systems, but also some management hotspots, as well as a technical-economic immaturity that currently hinders their scalability on a commercial scale.

Table 1: SWOT analysis of the tested SIMTAP systems.

Strengths	**Weaknesses**
• Reduced wastewater impact • Production diversification • Reduced need for external inputs	• Sizing of the different units • Nutrient balance between the different units • Absence of specialized market • Poor agronomic knowledge of halophytic plants • Deposit/filter feeder integration and productive performances in RAS system • Skilled manpower required
Opportunities	**Threats**
• Plant improvement and large-scale production • Revenues from halophytic species • Integration with renewable energy systems • Premium price for production	• Legal framework • Economic sustainability

The source of feed and energy is fundamental to ensuring the sustainability of processes. Given that the system requires large amounts of energy, especially in-land but also in ponds, the installation of solar panels or wind power supply systems could improve the economic feasibility of SIMTAP systems on a larger scale, and optimize their environmental performance. All the alternative diets tested during the project showed good performance. The analyzes have shown that, beyond satisfactory mortality and growth, there is still work to be done regarding the necessary supplements (minerals, etc.) to also guarantee an optimal body composition of the farmed fish.

Surely the project has paved the way for future insights into many topics that have not yet been explored in the scientific literature: the feeding of sea bream and sea bass with fresh clams and mussels; aquaponics with brackish water; the breeding of DFFO in IMTA systems. The goals of future aquaculture are clear: sustainability, resilience, and competitiveness. The SIMTAP project, showed the potential of this type of system to satisfy each of these requests thanks to:

- the reduction of nutrient discharges from the system;
- feed partial self-sufficiency of the system through the integration of the various production units.