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access 2sea

AQUACULTURE PILOT PROJECTS IN THE ATLANTIC AREA REGION

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PILOT ACTION 2. AQUACULTURE ACTIVITIES INSTALLATION

CEEI Bahía de Cádiz – Centro Europeo de Empresas e Innovación
WestBIC
ciimar – Centro Interdisciplinar de Investigação Marinha e Ambiental
Technopole Quimper-Cornouaille
Investir en Finistère
ctaqua – Centro Tecnológico de la Acuicultura
UAlg
Údarás na Gaeltachta
CSAR – Swansea University Prifysgol Abertawe

TABLE OF CONTENT

OVERVIEW 1
1. INTRODUCTION 2
2. PILOT DESIGN 4
3. PILOT IMPLEMENTATION 6
4. PILOT ASSESSMENT 11
5. PILOT TRANSFERABILITY 11
6. RESULT DESCRIPTION 11
7. INDICATORS 22
7.1 SME's involved 22

OVERVIEW

Aquaculture innovation has a key role to play in the success of blue growth and sustainability, contributing to competitiveness, resource efficiency, job creation, as well as protecting and providing services to marine and coastal ecosystems. The aquaculture industry is looking for alternatives that promote economically profitable farming with a very low environmental footprint, committed to animal welfare and nutritional quality of the product. Access2Sea project is compromised with these targets and besides is improving accessibility to the marine space, supporting SME to boost business models and elaborating innovative tools or methodologies.

Access2Sea's project count on four areas of intervention to boost aquaculture SME's: **Social Acceptance**, **Spatial Planning**, **sustainable Business Models** and, in parallel, **Pilot Projects** developed with the purpose of materialising the results obtained throughout the project execution.

Pilots projects have been developed to answer to the key fields of the project: (1) **Improve the social acceptance of those activities**; (2) **Support the sustainable aquaculture activities** (new and existing) **and spatial planning**; (3) **Take advantage of business opportunities detected**.

Each pilot action carried out during the project execution were previously framed in these three main objectives: Pilot action 1, New aquaculture sites, satisfied the necessities observed in (2). **Pilot action 2, aquaculture activities installation**, was framed as part of (3) in addition to Pilot action 5, Feed intake simulation model. Pilot action 3, sustainable aquaculture, and Pilot action 4, social acceptance activities, were developed in the context of (1).

PILOT ACTION 2: AQUACULTURE ACTIVITIES INSTALLATION

1. INTRODUCTION

Extensive aquaculture in protected areas is a business based on reducing environmental degradation to the minimum possible, using the available resources without modifying the food chain of ecosystem or compromising the welfare of the cultivated species. However, this business model may be affected be seasonal production and lack of rentability. In order to support the aquaculture model and enhancing resources optimization, complementary culturing activities may be carried out. Particularly, fostering species diversification in terms of cultivation and production as well as testing new installations and methodologies.

Macroalgae play a key role in the transition of sustainable aquaculture. Currently, it is an essential link in the novel concept of Integrated Multi-trophic Aquaculture (IMTA) besides the increasing uses that are being investigated for commercial purposes. The use of macroalgae has expanded globally due to the possibilities in the development of pharmaceuticals, pigments, dyes, bioactive components, cosmetics, fertilizers, antiviral agents or hydrocolloids (Pereira et al., 2004; Indy et al., 2014). Some examples of specific uses include culture in integrated multi-trophic systems with fish and mollusks (Neori et al., 1996), biomitigation to remove nutrients from effluents from aquaculture (Hernández et al., 2005) or bioadsorption of toxic heavy metals in wastewater (Davis et al., 2003) and, of course, for food purposes (APROMAR, 2021).

The nutritional value of macroalgae is largely explained by their composition in soluble fibre, proteins, mineral salts and trace elements, all of which are beneficial to human health, and also by their content in vitamins and antioxidant substances such as vitamin C, E, carotenes and polyphenols. They are low in calories, composed mainly of essential polyunsaturated fatty acids of the omega 3 and omega 6 series. However, seaweed industry is still developing in many European countries and more research is needed in cultivation techniques.

The sum of these aspects has boosted their harvesting, commercialization and, since 2016, also their cultivation on the South Atlantic coast (AGAPA, 2021). This region is a huge area of earthen ponds, main and secondary sea channels and natural marshes that offers a unique landscape of great ecological and cultural value as a result of its transformation for salt and food industry since centuries. The permanence of inundate areas along with marshes of tidal influence created an interesting ecosystem with high biological richness as well as high biomass productivity.

Macroalgae cultivation in earthen ponds is an opportunity to promote the protection of natural areas by using their resources in a sustainable, profitable and integrated way. Its productivity is defined by environmental conditions and species selected for cultivation.

Regarding previous studies with the collaboration of local enterprises of this region, a series of criteria for the choice of species to be included in production was stablished, such as:

- Natural occurrence in the area
- Possibility of obtaining high biomass, which implies high rates of cell division and ease of reaching and maintaining high culture densities.
- Easy to obtain at low cost, without the need for considerable investment.
- Resistance to fluctuating environmental variations during growth.
- Species for human consumption, with sufficient nutritional and gastronomic value to constitute a source of income.

Based on these requirements, CTAQUA has proposed several species considering the natural populations of greatest commercial interest in the study area and the previous knowledge obtained after the implementation of the INTEGRATE and AQUA&AMBI projects. Specifically, four species of green algae were selected: *Codium tomentosum, Codium decorticatum*; and three species of red algae: *Gracilaria gracilis, Gracilariopsis longissima* and *Chondracanthus teedei.*

The introduction of macroalgae culture should be carried out taking into account the conditions of the estuaries, such as water flow depending on the production phase, coinciding with the environmental factors that produce the most optimal and efficient growth of the species. Hence, to test the introduction of innovation in a novel area, diverse actions were developed and implemented in a local aquaculture SME to increase its profitability and transfer the knowledge to the rest of enterprises interested.

IMPLEMENTATION SUMMARY

The Centro Tecnológico de la Acuicultura de Andalucía (CTAQUA) together with Centro Europeo de Empresas e Innovación (CEEI) were cooperating to support the transition toward sustainable aquaculture by assessing both the technical and business model of a company, Tsiane acuicultura multitrofica S.L.U. in order to optimize yields and reduce costs. The first step was the evaluation of their production techniques, cultivated species and business model (available on the website). After analyzing the business production and the detection of some opportunities of improvement, different trials were developed at Tsiane and in lab conditions using CTAQUA's facilities in order to improve and implement new cultivation and farming techniques. Particularly, *Codium* cultivation (*Codium decorticatum* and *Codium tomentosum*) from protoplasts in lab conditions and feasibility studies of three red algae species (*Gracilaria gracilis, Gracilariopsis longissima* and *Chondracanthus teedei)* in earthern ponds.

In terms of commercialization, to satisfy a market that goes beyond seaweed as a fresh product requiring rapid distribution and consumption, the need for processing macroalgae to be able to distribute it dried has been identified. Therefore, a prototype seaweed drying facility was improved to optimize its use in terms of the time required for drying, increasing the production of seaweed ready for packaging. This processing plant deliver high value-added end products with excellent market potential in the Added Value Marine Resource Supply Chain.Lastly, a low energy modular cultivation system for macroalgae was designed as a previous step towards its materialization and first exercise to identify efficiency and biological requirements.

A final report to compile all the results and consider the semi-industrial scale application of these pilot actions at Tsiane was carried out. In this way, the enterprise will be able to transmit short-term objectives and contribute to the best advice and preliminary search for cultivation methods alternatives that could be implemented in the company to increase its profits and make the most of the available space.

2. PILOT DESIGN

The main objective of the pilot project was to provide local SMEs with the necessary technology and advice to improve its profitability, through a diversification proposal to include macroalgae culture, technical and commercial alternatives, analysis of its business model and cultivation techniques.

The principal tasks of this pilot action were proposed technical improvement in macroalgae cultivation indoors (lab conditions) and outdoors (earthen ponds), designing low energy system and acquiring knowledge on drying process to increase productivity and sustainability.

Cultivation area

Macroalgae culture has been carried out in estuaries located between the Talanquera and Aguila canals in the Bay of Cadiz Natural Park (36°28'50 "N 6°09'41 "W), from May 2021 to May 2022. These estuaries are currently exploited by the company Tsiane S.L. for traditional extensive aquaculture.

Fig.1. Location of cultivation area in the earth ponds of the Bay of Cadiz.

<u>Cultivation design</u>

The pilot action was designed to test the viability of macroalgae production of different species *Codium tomentosum, Codium decorticatum, Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei*) during 2 consecutive years (2021 and 2022) between Marchand June. These months were selected due to environmental conditions and the suitability in the Tsiane production cycle, as during this period of the year the sluices are partly open, allowing a water flow but at the same time maintaining sufficient water level in the ponds for seaweed cultivation.

Three trials of the pilot actions with *G.gracilis, G.longissima* and *C.tedeei* have been tested with different durations, 2, 4 and 8 weeks. *Codium decorticatum and tomentosum* experiments had two phases, the first one of 2 months in CTAQUA's facilities and 45 days at the earthen ponds.

The culture method used was longlines attached in PVC framed structure, although with different seeding methods. For *Codium* species, the method chosen was seeding of protoplast on ropes, whereas for the three red seaweeds, polypropylene ropes were seeded with vegetative thalli.

To determine cultivation viability and growth estimation, the daily growth rate (for *Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei*) was measured through collecting weight of initial and final fresh weight; and the number of thalli obtained per metre of rope (for *Codium tomentosum* and *Codium decorticatum*).

$$RGR = \frac{ln(WWf/WWi)}{nº\ days}\ x\ 100$$

RGR: Relative Growth Rate, (% day-1)

WWi: Initial wet weight, g

WWf: final fresh weight, g

During the course of the pilot experiment, the condition of the structure, both the raft and the culture ropes, was checked every two weeks and surrounding algae that had attached themselves to the raft, especially to the culture ropes, were removed. Environmental parameters, such as water temperature, were monitored every 2 hours throughout the experiment using temperature sensors (Thermochron iButton from Maxime Integrated) placed at the culture point. Light intensity data were obtained daily from Instituto Andaluz de Investigación y formación Agraria, Pesquera, Alimentaria y de la Producción ecológica.

Seaweed dryer experimental design

The pilot action was designed to optimize its use in terms of the time required for drying, increasing knowledge about how the external temperature and humidity may interfere in the drying process of *Ulva spp.* The main aim was to obtain a biomass with an internal water content (Moisture content) between 10-20%, which considered a requirement to maintain product stability to secure seaweed food safety (Forster & Radulovich, 2015).

Three trials with were carried out during five days under different environmental conditions, but with the same biomass density, in order to test the variation:

- in moisture content (%) of *Ulva* in the dryer prototype (differentiating between trays).
- in moisture content of *Ulva* as a function of meteorological conditions.
- in proximal composition of *Ulva* with respect to drying time.
- in proximal composition of *Ulva* with respect to drying time and the place it occupies in the dryer (tray-position).

For the determination of Moisture Content (MC) of the seaweeds, initial moisture content of the raw seaweed sample and the final moisture content (wet basis) of the dried seaweeds sample was done through the oven-drying method. The samples were placed in the oven at a constant temperature of 105˚C during 24h (methods selected through previous trials results).

$$MC_{wb} = \frac{W_o - W_f}{W_o} x100$$

MCwb = Moisture content wet basis, %

Wo = weight of the sample before drying, g

Wf = weight of the sample after drying, g

Biomass samples were collected three times a day in order to analyze moisture content (n=72) and proximal composition (n= 36). External and internal temperature and humidity of the processing plant was monitored during all the experiment using the ElitechLog 6.4.1 data logger.

3. PILOT IMPLEMENTATION

Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei were collected in estuarine areas near by the cultivation point with the exception of *Codium tomentosum, Codium decorticatum* which were collected close to the cultivation site, but located in a rocky intertidal in the Bay of Cadiz. The macroalgae were transported in cold, humid and dark conditions. In the laboratory they were kept in culture tanks for 72 hours before being seeded and carried to the cultivation area in earth ponds. According to the species of seaweed to be cultivated, a type of substrate with its particular planting option was selected.

<u>Raft in earthen ponds</u>

Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei were seeded in different ways according to the type of substrate to be tested and placed on a float in order to be able to maintain the cultures always at the same depth regardless of the tides, PVC rectangular structures (1.3 m x 2.2 m) were used. The different substrates with the algae seeded on them were placed from one side to the other by means of hooks fixed to the structure, 18 cm apart and arranged parallel to the main flow. The float shall be suspended at a depth of 20 cm from buoys placed with ropes of the same length at each corner of PVC structure. To achieve neutral floatability some weights were necessary, therefore, 15 kg cement blocks anchored to the bottom were added, also attached to the corners of the structure by 2.5 m ropes (Fig. 2).

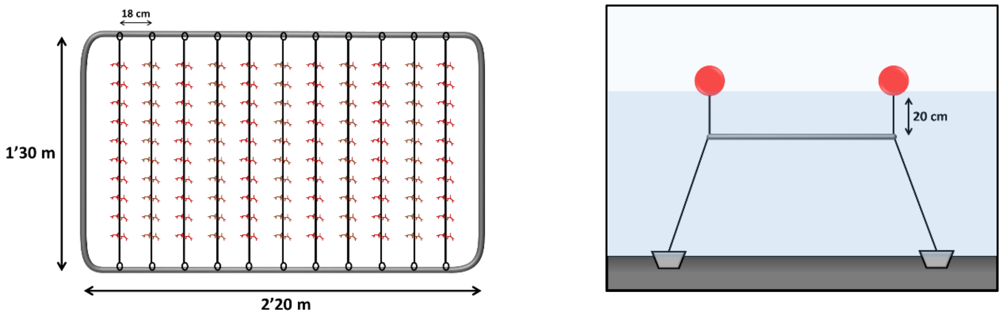


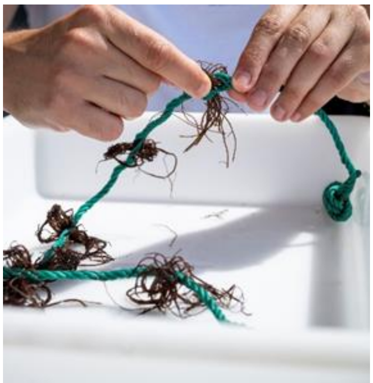
Fig. 2. Float with ropes for seaweed cultivation (left). Front view of float placed in the estuary, with its anchors and buoys (right).

Materials used:

- PVC for the raft structure
- Polypropylene ropes
- Plastic carabiners
- Rope to attach the raft to the weights and buoys
- 4 weights (15 kg each)
- 8 buoys (2 in each corner of the raft)

Fig. 3. Float with ropes for seaweed cultivation in place

Gracilaria gracilis, Gracilariopsis longissima and *Chondracanthus teedei* were seeded from thallus fragments of circa 10 cm, inserted in 5 mm polypropylene ropes by specie attached at the float. The weight of these fragments corresponded to the initial fresh weight of the culture.



Three culture ropes were set up for each species as replicates. The fragments were placed on the ropes in the laboratory three hours before they were placed in culture. The seeded ropes were taken to the estuary in cold and dark, and once there, they were placed in the rafts and arranged in the culture area.

After finishing the experiment, 30g of biomass of *G. gracilis, G. longissima* and *C. teedei* (n=9) were collected to observe the quality of this biomass. For this purpose, proximate composition and heavy metal content (cadmium, mercury and lead) were analyzed in an external lab.

Fig. 4. Seeding method for seaweed cultivation

Indoor cultivation; Protoplast seeding culture in laboratory conditions

C. tomentosum and *C. decorticatum* trials were carried out according to the methodology used by Hwang et al. (2007). The preliminary steps of cell fixation were placed on cultivation strings. The strings used were 5 cm wide strips (AlgaeRibbon from AlgaeTex) and also on three biodegradable strings of 2 mm diameter, and one of 1 mm diameter in collaboration with the BIOGEARS project (EMFF-01-2018 Blue Labs), led by AZTI. and then wound onto 5 mm braided polypropylene strings.

There were some previous steps before seeding. Firstly, the algae were examined to detect epiphytes and remove it. After cleaning, each species of Codium were blended with autoclaved seawater, and then poured into a tray. Culture strings were introduced for 2 hours in the tray for facilitating *Codium* cells **(Fig.5** attachment at 17ºC and light conditions of 98 µmol/photons m*s-2.

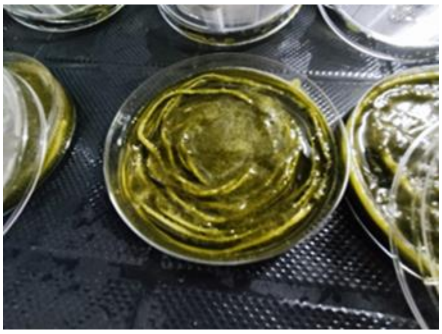
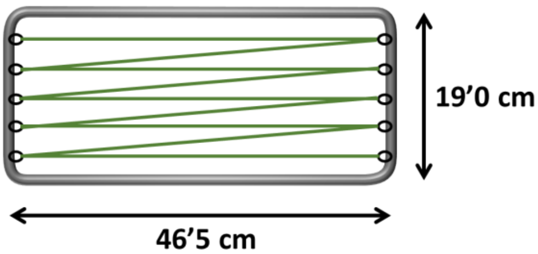


Fig. 5. First phase of *Codium* cultivation from protoplast

They are then transferred to 20 L aquaria for 60 days, placing these coiled ropes in small rectangular PVC structures (46.5 cm x 19.0 cm) (Fig. 6). These aquaria will be maintained at a temperature of 18 °C and irradiance of approximately 900 µmol m-2 s-1. Subsequently, the ropes shall be removed from the structure, braided into the main rope and the ropes shall be transported and placed in the culture tanks. The culture shall be maintained until the required size is reached and the existing biomass harvested. The initial fresh weight of the culture in this case corresponds to the difference between the unplanted tape/rope and itself with the cells attached.



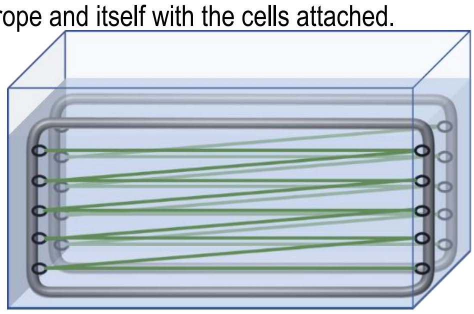


Fig. 6. Top view of structure with ropes in place and measurements (left). Front view of structures placed in 20-litre-aquarium (right).

Eight 50 cm PVC frames were designing to contain the seeding of Codium cells in a 400L tank with constate aeration and 20% of water exchange per week. These tanks were placed outdoors as a previous step towards earther pond cultivation.

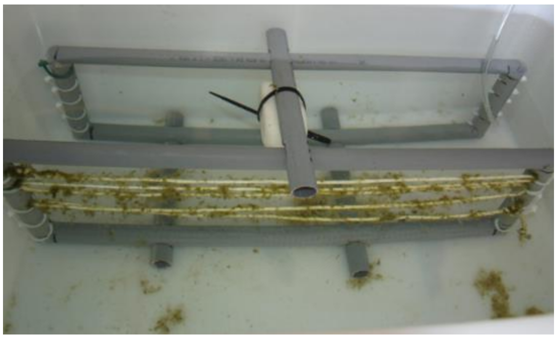


Fig. 7. Third step in Codium cultivation where structures are placed outdoors in 400L tanks

<u>Macroalgal dryer improvement</u>

For the development of extensive aquaculture in estuary areas, the autonomy of instrumentation is crucial. Therefore, to include seaweed culture in a company a necesity that appear is how to process this product. The first prototype of a macroalgal dryer which use solar energy was designed in the framework of BIOSEA project but to optimise its efficiency with Access2sea project, CTAQUA has worked on the introduction of some technical and metholodogical improvements.

As part of the structural upgrade the door and lockers were modified to avoid heat loss.In addition to increase the biomass capacity, internal frame was reinforced. Lastly, in order to allow air circulation and facilitates biomass collection, a new base was installed. The design also considered the dryer capacity to accommodate drying the seaweeds placed inside the chamber.

Internal water content is one of the main components of food and also a factor directly related to product life. This Moisture content (MC) contributes significantly to food preservation and security as high values may decline its quality and jeopardizing its safety. Comparing with a cereal, for example, it contains about 15% moisture and below *circa* 13% moisture products are safe from different organisms that could grow (Bradford et al., 2020).

Fig.8. Macroalgal dryer that contents 9 kg of *Ulva spp.* sorted out in 3 shelves.

However, because seaweeds contain an average of about 85% water and it is considered seaweed equivalency in terms of dry product (average 20% moisture), which is how most seaweed is already processed and sold after harvesting (Forster & Radulovich, 2015).

Attending to this requirement, the main objective of the experiment was obtaining a biomass with an internal water content (MC) between 10-20% as maintaining stable product (Forster & Radulovich, 2015). Hence, in terms of methodological improvements, three trials were carried out during five days each to optimise the time required on the dryer process according to environmental conditions such us external temperature and humidity. Moisture content (%) was monitored three time at day (9.00, 12.00, 18.00 h) every day. The experimental period was extended during August 2022. Biomass of *Ulva spp*. used for each experiment were 9 kg, divided in three shelves of the dryer chamber. The biomass samples (n=72) collected for measuring moisture content were measured using the oven dry method (105 ºC , 24 h). Proximal composition samples (n= 36) were daily obtained in the first experiment and each two days in the second and third ones.

Fig. 9. *Ulva* samples extracted from dryer trials in a commercial oven to calculate measure moisture content (left) and post storage in a desiccator silica gel until being weighted

Land-based low energy cultivation system

Biological requirement for efficient cultivation purposes were identified. Hence, the components that should be included in the recirculating aquaculture system for macroalgae. Due to the interest in designing an autonomous system that do not demand extra energy, solar panels and batteries were included as power source.

The location and height of key components may signify a big variation in energy consumption in water pumping, so these are aspects to address carefully. It was essential to consider the necessary design adjustments to obtain the highest energy efficiency in the pumping system.

The main components are:

- 1 1500 litres tank (sump)
- 6 culture tanks for macroalgae of 200 litres each
- Pump 1 (for adjustable flow)
- Pump 2. External aeration
- 1 solar panel
- 1 battery
- Valves to regulate flow
- Piping system
- 1 mechanical filter for water inlet to the pump
- 1 mechanical filter for algae outflow before it is recirculated to the sump
- 1 ultraviolet system to disinfect the incoming water from the environment

A feasibility study of the outline to size the solar panel, battery and pumps to four water renewals per day of each tank according to the energy requirements of the system was performance. In addition to a preliminary estimation of required energy

4. PILOT ASSESSMENT

Regarding the objectives for new aquaculture installations the tasks to develop where defined before previous assessment of the business model and technical bottlenecks of the SME supported, considering the transferability to the aquaculture activities placed in a natural asset. Another evaluation was carried out to assure the feasibility of the actions tested, and therefore, stablish advice and analyses the risks to short and medium term for the business.

Both reports are deliverables available at Access2Sea website

5. PILOT TRANSFERABILITY

During project execution, Access2Sea website and social networks have had a key role in the dissemination of actions, methods and results, above all in the middle of the health crisis of 2020. However, CTAQUA has worked at the extensive creation of communication material such as project leaflets, WP7 leaflets, three different infographics, newsletters and Layman's reports. These contents have been physically distributed in:

- The LFC Tourism and aquaculture Alliance for Sustainability (25 attendees)
- Stand at the National Aquaculture Conference in Cádiz (Spain)
- Stand at the 9th Atlantic Stakeholder Platform Conference, celebrated in Spain
- Presentation of pilot actions outcomes and tools designed at the Access2Sea final event, Cadiz (Spain).

LFCs are essential for the transference of knowledge and the detection of issues which a SME may be facing. In addition to provide an atmosphere to generate a discussion and be able to obtain a framework of possible solutions.

CTAQUA as an innovation center in charge of the transition of knowledge to the business designed each activity carried out for the Pilot action 2 considering transferability. Most of the experimental trials have been placed in the supported enterprise to facilitate the upscaling and detect the associated bottlenecks.

6. RESULT DESCRIPTION

Preliminary results showed the system and cultivation methodology functions well for three species. Pilot tests at Tsiane's facilities have shown that *Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei* presented a growth rate between 1 and 3.7% per day during experimental time (Trial 1 between April and May 2021 and trial 2 from March to May 2022.). Thus, corroborating the suitability of this productive activity to be carried out in marshes.

The growth rate differed according to the study species: *G. gracilis* showed a rate of 1.53 ± 1.13 % in the first trial and 1.4 ± 0.28 % in the second, similar results were obtained for *G. longissima* during experiment 1, 1.22± 1.25 % and higher values for the second, 2.61 ± 0.31 % (Fig. 10). However, the growth data for *C.teedei* have been higher than for the previously described species with values of 3.17 ± 0.23% in the first trial and 3.18 ± 0.54% in the second one

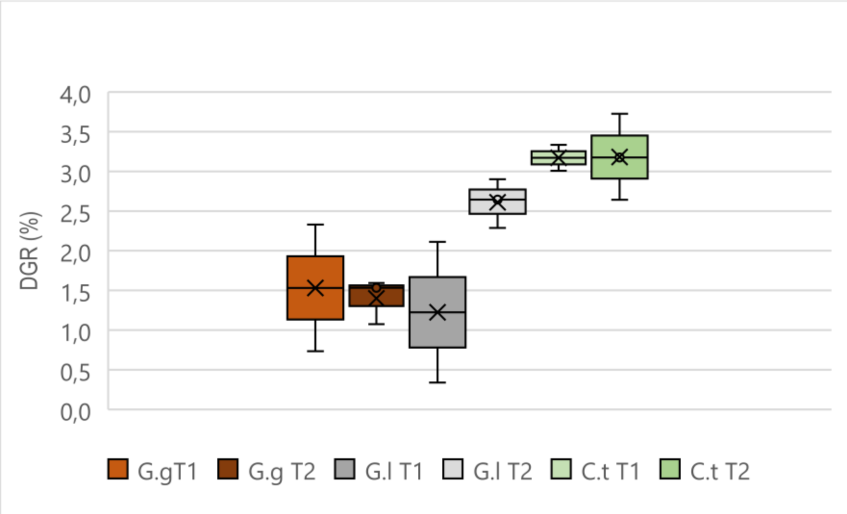


Fig. 10. Daily growth rate, DGR, (%) of the three species: *Gracilaria gracilis,*(G.g) *Gracilariopsis longissima (G.l) and Chondracanthus teedei (C.t)* by year. Trial 1 (T1) was carried out between April and May 2021 and trial 2 (T2) from March to May 2022.

The successful survival and growth of these macroalgae was also a consequence of the cultivation system selected for the study area. The installation worked correctly, maintaining the desired buoyancy of the raft and managing to keep the depth of the culture constant, which directly affects the light intensity received due to the turbidity of the water in the study area. It also avoided the dehydration of the macroalgae being cultivated by remaining submerged at all times (Fig. 11).

The methodology tested for macroalgae cultivation in the earthen ponds has been successful for the species *Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei* and the season studied. The installation used could be substituted by longlines distributed perpendicularly along the channel, held by sticks at the edge.

Fig. 11. Seeding cultivation raft placed in earthern ponds

Proximal composition results of total sugar, total protein, ash, salt and crude fibre are presented in Fig. 12. *Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei* showed protein values of 3.25 ± 0.64 gWW/100g, 2.05 ± 0.35 and 2.65 ± 0:92, respectively, being *G.gracilis* the one with the highest protein content.. Macroalgae cultivated were not nutrient limited and values obtained have been high considering other food products such as vegetables such us lettuce 1,5 g FW/100g, canons 0,9 or spinaches 1,3 (Valdivia and Almanza, 2016).

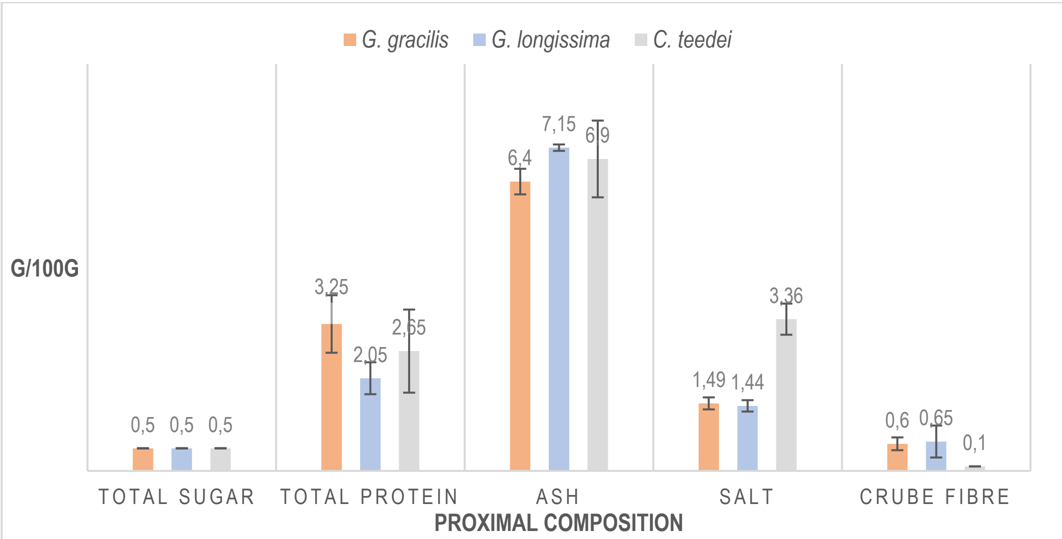


Fig.12. Proximal composition results of total sugar, total protein, ash, salt and crude fibre of *G.gracilis (orange), G.longissima (blue), C.teedei (gray)*

Heavy metal analysis including lead, mercury and cadmium were carried out in the biomass harvested to assure that the cultivation area was appropriated and biomass quality above food safe limits (Table 1). All the seaweed cultivated measures were found under Pb < 5.0 mg/kg, Cd < 0.5 mg/kg, and Hg < 0.1 mg/kg (Mabeau & Fleurence, 1993). Results of mercury and cadmium were even under detection level.

Table 1. Heavy metal results of lead, mercury and cadmium for *Gracilaria gracilis, Gracilariopsis longissima and Chondracanthus teedei,* including safety limits for the food industry (Mabeau & Fleurence, 1993).

Species	**Lead** (mg/kg)	**Mercury** (mg/kg)	**Cadmium** (mg/kg)
G. gracilis	0,23±0,16	<0,02	<0,01
G. longissima	0,11	<0,02	<0,01
C. teedei	0,375 ± 0,36	<0,02	<0,01
Safe limit	<5	<0,1	<0,5

Indoor cultivation: *Codium sp.* trials

Some evidences of *Codium* cells attached to seeding string were observed between the day 1 and day 15 for both species. The method for determining the number of thalli obtained per meter of rope was measured. This primary phase is the more decisive in cell fixation, however, after this period microalgae, brown seaweeds and bacteria colonized the strings and presence of *Codium* was reduced. Fig 13 showed cell attachment at the five different substrate day 15, whereas day 50 all strings were colonized by other organisms and there was no presence of *Codium* cells. There were not found any difference between substrate, as at the first stage all the substrate seemed show signs of *Codium* but this presence was decreasing in the 4 ropes and ribbon. Feasibility of Codium cultivation in earthen pond was not possible to test as previous steps in seeding cultivation were not successful. Therefore, further research needs to be developed with different and controlled environmental conditions in order to avoid bacteria and algae proliferation and maintain *Codium* cultivation.

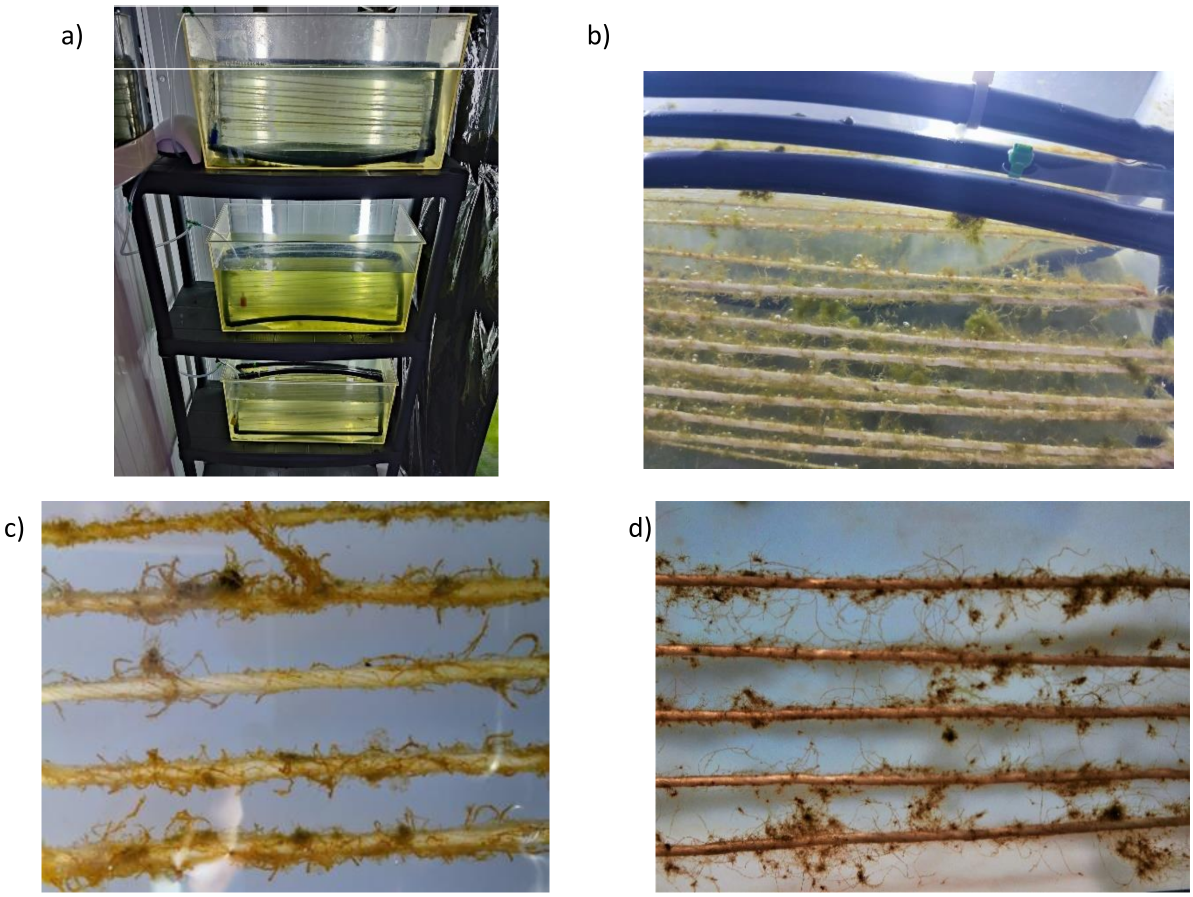


Fig. 13. Codium cultivation trial monitoring during 50 days: a) first day-*Codium* culture b) Day 15 c) Day 30 d) Day 50.

Macroalgal dryer

The main objective of this dryer is to reduce internal water content of the biomass to 10-20%; a MC < 20% is considered sufficient for maintaining biomass composition stable (Forster & Radulovich, 2015). To achieve this target several modifications were done in the prototype design.

The technological improvements consisted of the structure reconditioning to avoid heat loss; redistribution of trays to reach a higher degree of drying in the last section located close to the ground; and replacing the metal holderers for a wooden skeleton upon which the trays are placed (Fig. 14). This modification brings robustness to the structure, besides allowing for an increase in its maximum biomass capacity and facilitating easier handling.

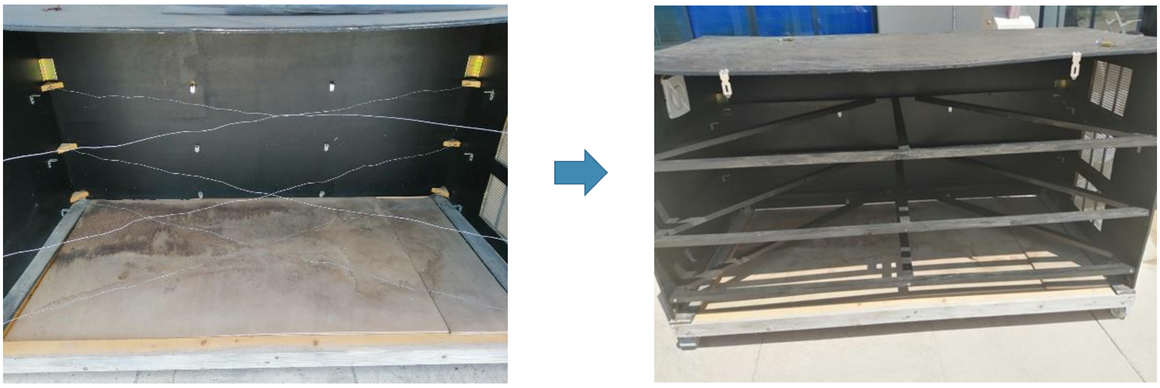


Fig. 14. Macroalgal dryer internal structure before (left) and after the technical improvements (right).

In terms of methodological improvements, three trials were carried out during five days each to optimise the time required on the drying process according to environmental conditions such us external temperature and relative humidity.

It can be observed in Fig. 15 a variation in values of temperature (T) and relative humidity (RH) during experiment time. This event is merely due to the conditions outside that vary at a particular time. When the temperature rises, the relative humidity falls, causing the air to become drier. Therefore, when the temperature drops, the air becomes wet, causing the relative humidity to increase. This effect was similar during the three trials in spite of environmental condition were fluctuating between them. A pattern observed is the slightly lower RH and higher temperature inside of the chamber provided by fan installation supporting the dry capacity of the structure. The Highest temperature and humidity registered inside of the dryer have been 43 ºC, and 86%, respectively.

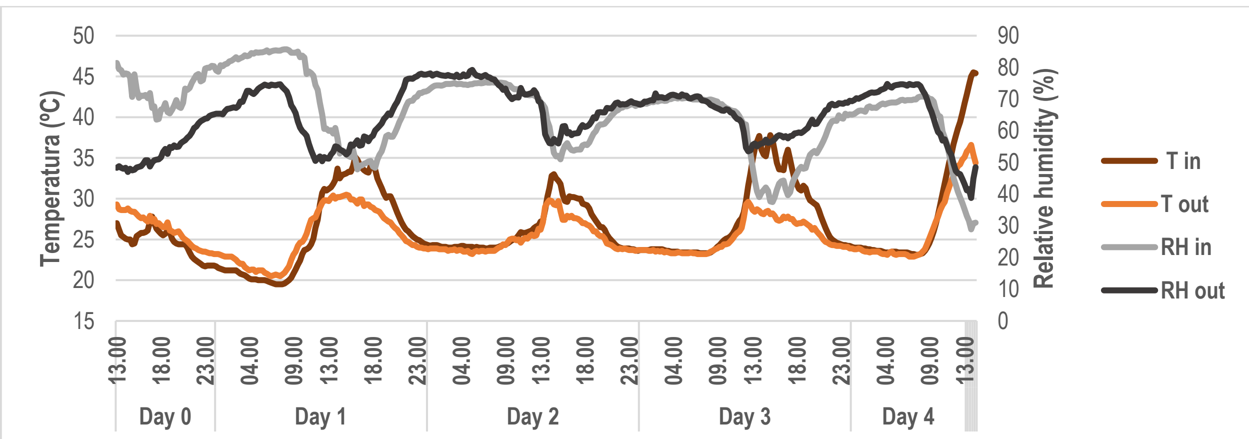


Fig. 15. Drying chamber and ambient temperature (ºC) and relative humidity (%) records during the first trial.T in: temperature inside (dark red). T out: temperature outside of the dyer or ambient temperature (orange) .RH in: relative humidity inside (light grey). RH out: Relative humidity outside of the dyer or ambient humidity (black)

Table 2. Maximum, minimum and mean values of ambient temperature (T) and relative humidity (RH) in each trial performed.

	Trial 1		**Trial 2**		**Trial 3**	
	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)
Min	20,5	38,8	19,5	20,2	20,90	57,40
Max	36,6	79,2	36,3	82,1	29,60	91,90
Mean	25,58	64,8	26,32	53,90	24,92	73,53

In each experiment showed in Fig.16, moisture content of the biomass decreased to around 60% already during Day 0, however, momentary increases were observed each morning after nocturnal temperature decreases (Fig.15). Environmental conditions were the most appropriate for an efficient biomass drying during trial 2, with lower RH and higher temperature average values. In this trial, the humidity percentage target (10-20%) was achieved in 24 hours, even reaching less than 10 % during day 2. However, in trial 1 and 3 it was fluctuating and 72 hours were required to achieve this target.

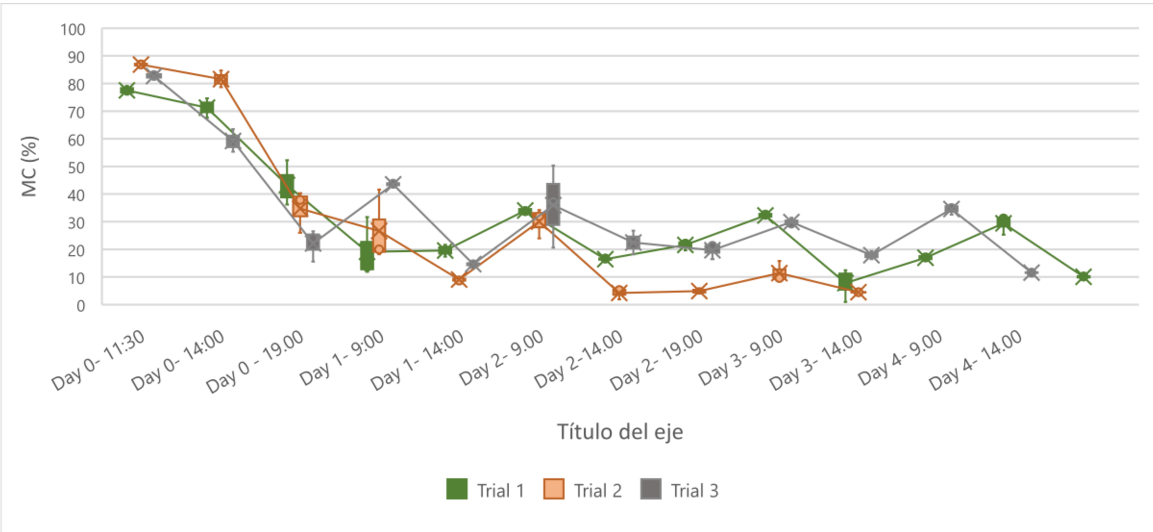


Fig. 16. Moisture content (%) of *Ulva spp*. in the dryer during 5 days in 3 different trials.

A two-way variance analysis (ANOVA) was carried out to test the differences of MC between trials and time. Significant differences of MC in Ulva spp. (p-value > 0,05) were found between trials, therefore, environmental conditions variations (T= ± 2ºC and RH=± 20%) have affected the drying process. In addition, significant differences of MC were observed between hours (p-value < 2e-16) (Table 3).

Table 3. Results of the two-way ANOVA assessing the effects of the factors "trial", "Hour", and "Day" on the Moisture content.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	2	476	238	3.603	0.031371 *
Hour	3	13173	4391	66.531	< 2e-16 ***
Trial:Hour	4	1462	366	5.540	0.000508 ***
Hour:Day	11	46695	4245	64.320	< 2e-16 ***

The dyer includes an air extractor fan located on the side panel between the top and the upper tray. Moreover, ambient humidity is generally larger (especially at night) close to the ground. Therefore, in the first trial, we also evaluated whether there was difference in drying time between trays. As can be seen in the graph comparing moisture content, indeed significant differences (two-way ANOVA, p-value= 0.0251) were observed both between trays (in particular between the upper and lower two trays) and in the interaction between tray and time (Table 3); thus, it can be concluded that it takes a shorter time to dry the biomass in the upper trays and that final moisture content is also lower in the upper tray.

Table 4. Results of the two-way ANOVA assessing the effects of the factors "tray" and "Day" on the Moisture content.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Tray	2	588	294	15.008	3.36e-05 ***
Day	4	27784	6946	354.580	< 2e-16 ***
Tray:Day	8	418	52	2.666	0.0251 *
Residuals	29	568	20		

Graphically, an increasing tendency of MC in the biomass placed on the lower tray (higher distance to the fan) may be observed regarding upper and middle tray at the same day. Hence, it was demonstrated that there is a variation in the drying effectivity according to the fan and ground proximity.

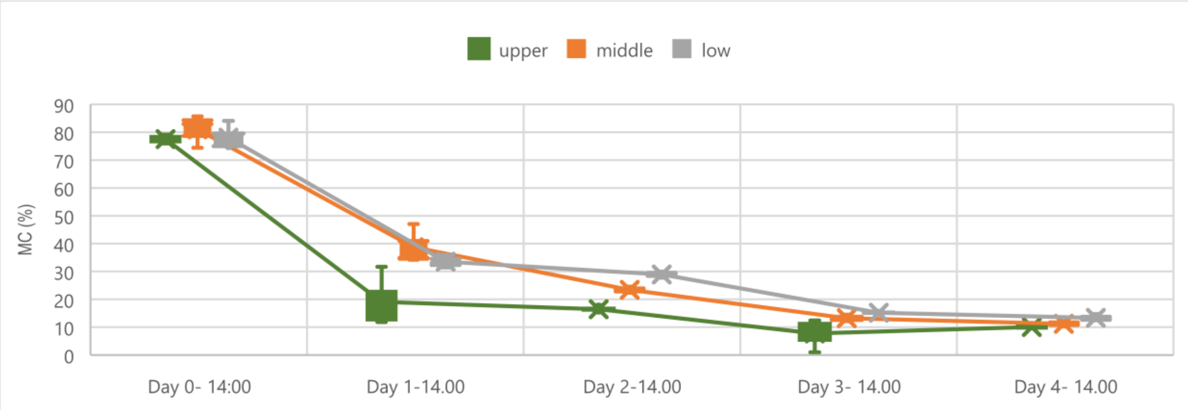


Fig.17. Moisture content (MC) of *Ulva spp*. according to fan and ground proximity during trial 1

In order to verify the stability of the biochemical composition during the drying process, proximal composition analysis was carried out on samples taken all days in trial 1, and initial and final values in trial 2 and 3. After results visualization and considering drying temperature was not higher than 40°C, it appeared the proximal composition of *Ulva* biomass remained more or less constant during the drying process. Values obtained for protein and carbohydrates for example, of *Ulva* were comparable to those of dried *Ulva* available on the market (17,8 and 42 g/100g, respectively (Porto-Muiños).

Proximal composition analysis is expressed as fresh weight, for that reason there is a significant increase in carbohydrates and protein, as if the biomass has a minor water content the proportion will be higher. Nevertheless, when corrected for moisture content, there is no difference.

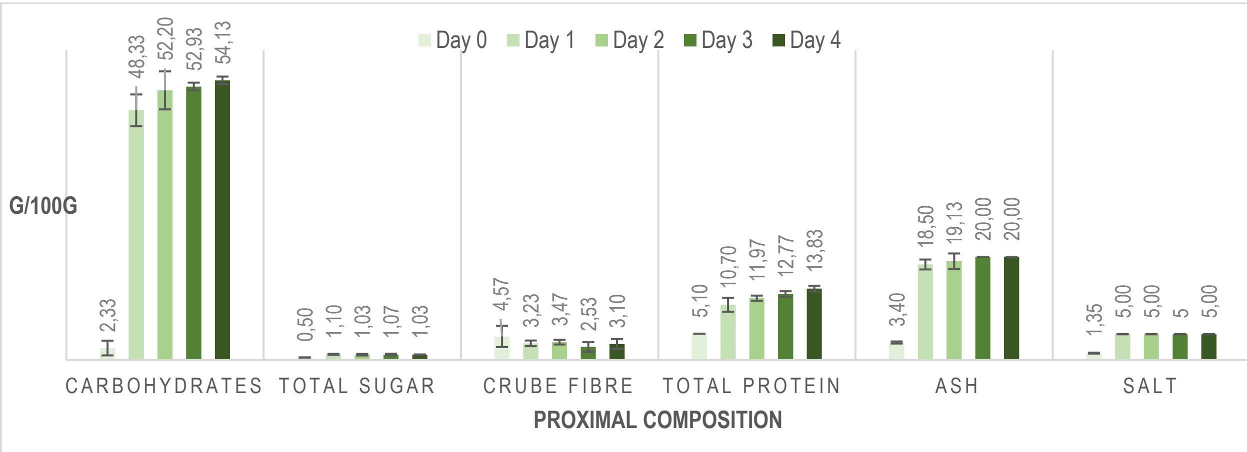


Fig. 18. Proximal composition analysis (Carbohydrates, total sugar, crude fibre, total protein, ash and salt) of trial 1 during 5 days

Summarizing, we can conclude that the solar dryer is capable of efficiently drying seaweed biomass in a relatively short drying time. As the fan is running on solar energy and no other energetic expenses are required for its operation, this prototype can be considered as profitable and can provide a positive financial impact on the investor for biomass density and season period indicated. Further improvements are recommended to prevent the absorsotion of water by the biomass during the night and to overcome the difference between drying trays.

Overall, drying at a lower temperature (< 40 °C) and lower humidity (*circa* 53%) was found to be suitable in terms of the processing cost, functional properties and preservation of the bioactive compounds in *Ulva spp.*

Fig. 19. Final state of the Macroalgal dryer

Land based efficient cultivation installation

Using the experience with on-land seaweed cultivation obtained in this and other projects, a set of requirements and conditions were laid out that formed the basis of the design of a low-energy, land-based, recirculatory macroalgae cultivation system with the help of an engineering consultancy. The lay-out of the system consists of six tanks of 600 L each and a sump of 1,500 L (Fig. 20). Assuming 4 renovations per day and constant aeration, energy requirements of such a system can be satisfied by using three solar panels of 550 Watts peak, resulting in a total of 1.65 KWP (kilowatts peak) (Fig. 21).

This study allows to test the feasibility of the system in terms of energy and foster the use of renewable enery sources taking advance of solar radiation and obtaining an autonomous cultivation facility that brings the opportunity for its application in locations not connected to the national electricity grid.

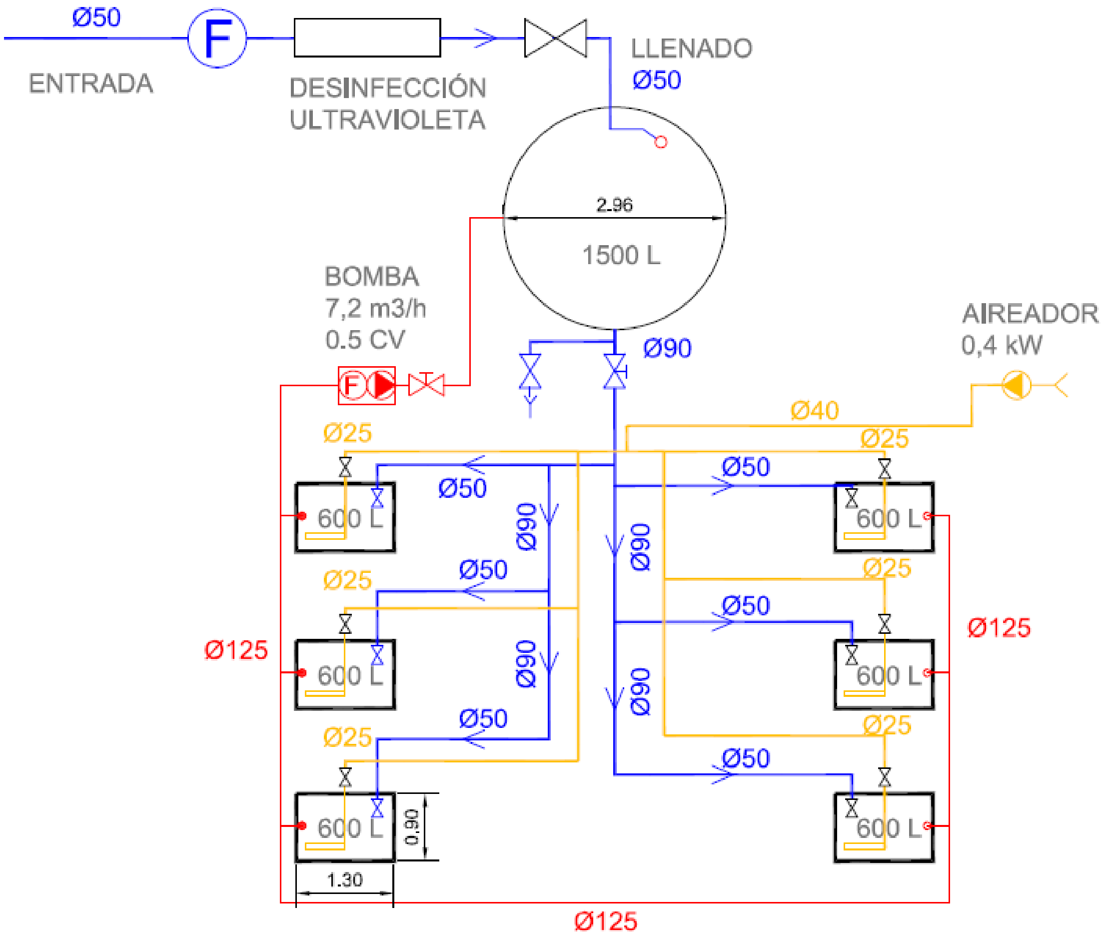


Fig. 20. Recirculating Aquaculture System (RAS) for Macroalgae: Plant distribution.

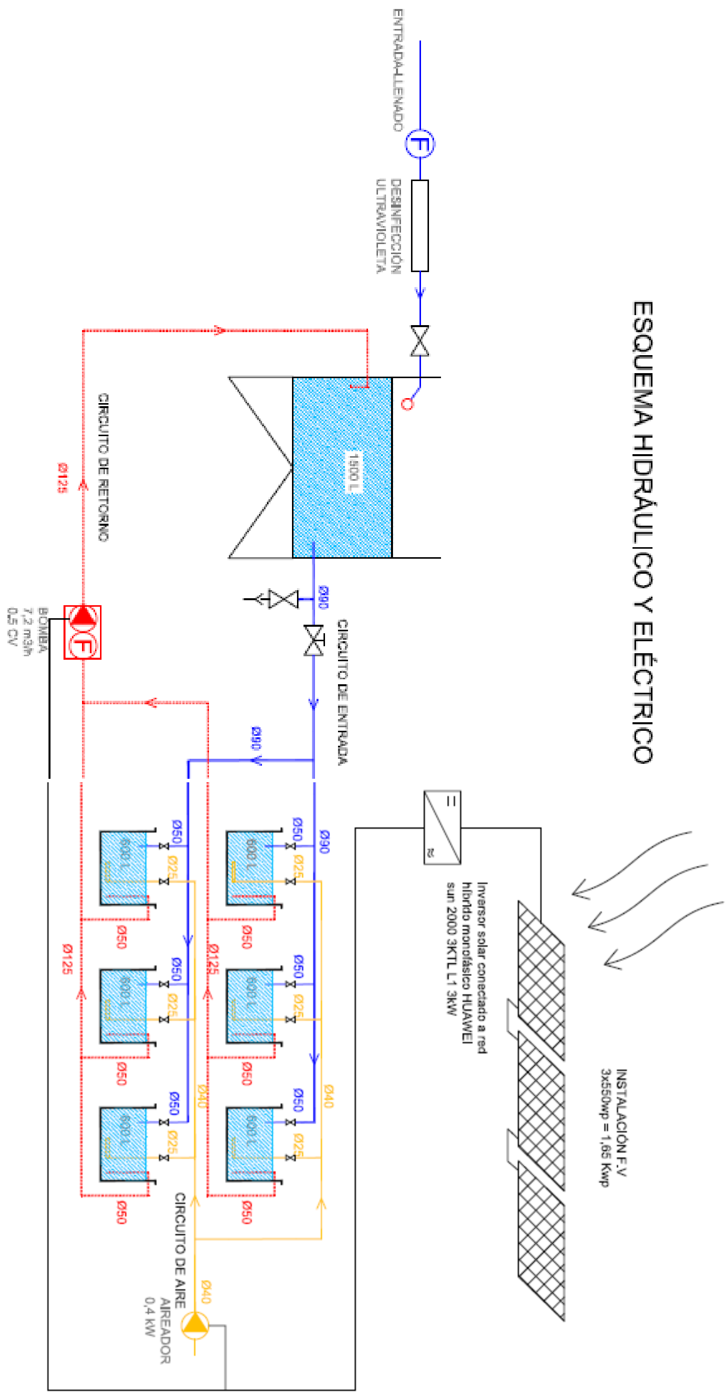


Fig. 21. Recirculating Aquaculture System (RAS) for Macroalgae: hydraulic and electric scheme

7. INDICATORS

- Number of enterprises supported to introduce new to the firm products:1
- Number of case studies and pilot actions implemented:1

7.1 SME's involved

Tsiane Acuicultura Multitrófica, is a company located in the Bahía de Cádiz Natural Park. It is dedicated to extensive aquaculture production in estuaries, specifically in a group of salt marshes with a total surface area of 679 hectares covering the municipalities of Cádiz (SPAIN).

This business is based on the foundations of a Blue Economy, reducing environmental degradation to the minimum possible, using the available resources in cascade production systems, where the waste from one product becomes raw material for the next link in the food chain.

All the experiments materialized aimed to facilitate increased commercial use of seaweed products and thanks to the evaluation of a local business, the opportunity to implement the positive results obtained. These reports are available on the ACCESS2SEA website

Audio-visual material

No

Lead Partner

CEEI Bahía de Cádiz
C/ Manantial, 13. Edificio CEEI
Polígono Ind. Las Salinas de San Jose Bajo
11500 El Puerto de Santa María (Cádiz) - Spain
Tlf: (+34) 956 860 654 / Fax: (+34) 956 860 028
E-mail: asuarez@ceeicadiz.com
Web: www.ceeicadiz.com

Partners

Centro Tecnológico de Acuicultura de Andalucía
Muelle Comercial S/N
11500 El Puerto de Santa María (Cádiz) - Spain
Tlf: (+34) 956 56 93 63
E-mail: mm.agraso@ctaqua.es
Web: www.ctaqua.es

Swansea University Centre for Sustainable Aquatic Research
Wallace Stores, Singleton Park
SA2 8PP - Swansea
Tlf: +44(0) 1792 29 53 83
E-mail: p.n.howes@swansea.ac.uk
web: www.swansea.ac.uk

Údarás na Gaeltachta
Na Forbacha, Co. Dublín. Galway
Tel: 091-503100
Fax: 091-503101
E-mail: foh@udaras.ie
web: www.udaras.ie

Innovation & Management Centre CLG T/A WESTBIC
11 Galway Technology Centre, Wellpark Road
Galway, H91 E2W5 - (Ireland)
Tlf: (+353) 86 2574978
E-mail: smccormack@westbic.ie
web: www.westbic.ie

Technopole Quimper Cornuaille
2 rue François Briant de Laubriere
29000 Quimper - Francia
Tlf: +33(0)298 100 200
E-mail: rachel.sellin@tech-quimper.fr
web: www.tech-quimper.fr

CIIMAR | Interdisciplinary Centre of Marine and Environmental Research of the University of Porto
Novo Edificio do Terminal de Cruzeiros do Porto de Leix
Avenida General Norton de Matos, S/N
4450-208 Matosinhos | Portugal |
Tlf: (+351) 223 401 852
E-mail: rodrigo.ozorio@ciimar.up.pt
web: www.ciimar.up.pt

University of Algarve
CRIA - Pavilhão B1
8005-139 Faro (Portugal)
Tlf: +351 289 800 097
E-mail: ajmarq@ualg.pt
web: www.ualg.pt

Investir en Finistere
46, quai de la Douane
CS 63825 29238, Brest cedex 2
Tlf: +33 (0)298 339 773
E-mail: a.coppens@investir29.fr
web: www.investir29.fr

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