Contract nº INCO-CT-2005-015105

AQUAS

WATER QUALITY AND SUSTAINABLE AQUACULTURE: LINKS AND IMPLICATIONS

Specific Support Action

Integrating and strengthening the European Research Area

FINAL ACTIVITY REPORT

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Version 1.0

Section 1. Project execution

1.1. Objectives and state-of-the-art

The general objective of this project is to gain "structured" knowledge related to the interrelations between aquaculture activities and water quality, which in the future could be used for the design of a set of innovative policies for a more sustainable development and management of aquaculture facilities. This is to be done by studying two coastal/estuarine zones, in which aquaculture activity is already significant, developing a conceptual framework for water quality in these areas. The selected study sites (Mediterranean Coast in Spain and Patos Lagoon in Brazil) are representative of a variety of European and Latin American coastal environments, and have been chosen because there is enough knowledge (including field observations) to develop the proposed approach.

The general aim of this project is divided into specific objectives:

- To establish a conceptual framework for the studied areas.
- To structure the existing knowledge and advance the state-of-the-art concerning the relationship between aquaculture activities and water quality.
- To collect, structure and further exploit existing water quality and nutrient flux data from previous projects in two selected core study sites.
- To perform an initial analysis of the effects of aquaculture on local water quality and the effects of water quality on aquaculture, for the selected study sites.
- To assess the carrying capacity of the studied systems in terms of concentration levels (patterns) and gradients under average and selected critical conditions.
- To start considering alternative aquaculture management practices within the context of sustainable and integrated coastal zone management.
- To start developing a list of possible predictors and data necessary to conduct an adequate assessment of water quality conditions.
- To begin creating the base from which to derive a set of guidelines for sustainable aquaculture in partially limited waterbodies.

The main contribution to the state-of-the-art arising from this Specific Support Action is the definition of a conceptual framework for the nutrient, pollutant and farm wastes, identifying source - sink - resuspension processes in coastal/estuarine systems, leading to quantitative estimations of the nutrient input from aquaculture into the environment. Additional contributions expected from this project are:

- General evaluation of the effects that natural forcing terms have on the carrying capacity of the coastal/estuarine systems.
- Overall assessment of the carrying capacity for different nutrients/pollutants in coastal/estuarine systems under different climatic and management conditions.
- The proposed conceptual dilution framework, the hybrid approach (observations plus simulations) and the use of the natural forcing mechanisms to enhance the system carrying capacity.
- Overall assessment of the implications of these physical and biochemical processes on natural functions and social/economic uses of the coastal/estuarine systems.

- Development of alternative management criteria to better structure aquaculture development.
- Preliminary identification and assessment of alternative management practices oriented to the improvement of coastal water management, in order to allow a more efficient development in socially, economically and ecologically admissible terms.

1.2. Contractors

The only contractor involved in the project is the **Centro Internacional de Investigación de los Recursos Costeros (CIIRC)** from Spain. Nevertheless, in order to achieve the objectives of the project, three other institutions participate in the project as subcontractors:

- **Fundaçao de Apoio à Universidade de Rio Grande (FAURG)** from Brazil.
- **Instituto de Ingeniería del Agua y Medio Ambiente de la Universidad Politécnica de Valencia (UPV)** from Spain.
- **Universidad Autónoma de Baja California (UABC)** from México.

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1.3. Work performed and main achievements

The work performed started with the compilation of information from previous projects related to both case studies: Valencia Coast in Spain and Patos Lagoon in Brazil. On the other hand, data were also collected on one complementary site: San Quintin Bay (Mexico), which is dedicated to oyster culture.

A description of aquaculture facilities in the three sites was also carried out. In Valencia Coast (figure 1) they consist in farms with cages dedicated to intensive culture of gilthead seabream and sea-bass (figure 2). Although there are 15 farms in this area, only 4 (Crimar, Cultipeix, Acuimed and Gramasa) were analyzed (those with more available data).

The data collected in this area include:

- Water samples: Salinity, temperature, pH, turbidity, suspended solids, nutrients, chlorophyll a, bacteria and phytoplankton.

- Sediment samples: organic matter, dissolved oxygen, total nitrogen and total phosphorus.
- Meteo/oceanographic data: waves, winds and currents.
- Socio-economic data.

Figure 1. Location of the study area in the Spanish Mediterranean Coast.

Figure 2. Fish cages in Valencia Coast

In Patos Lagoon (figure 3) aquaculture activities are focused on the semi-intensive cultivation (densities between 20 and 30 individuals/m^2) of *Farfantepenaus paulensis* shrimp in enclosures (figure 4), because they require little financial investment and management is made easier. These enclosures are mainly located in Justino Bay and Mangueira Bay. In this case, the compiled data were:

- Hydrographical data: river discharge, salinity, temperature and current velocity and direction.
- Water samples: water temperature, conductivity, salinity, pH, turbidity, chlorophyll a, nutrients, dissolved oxygen, BOD_5 and bacteria.
- Sediment samples: trace metal concentrations.
- Socio-economic data.

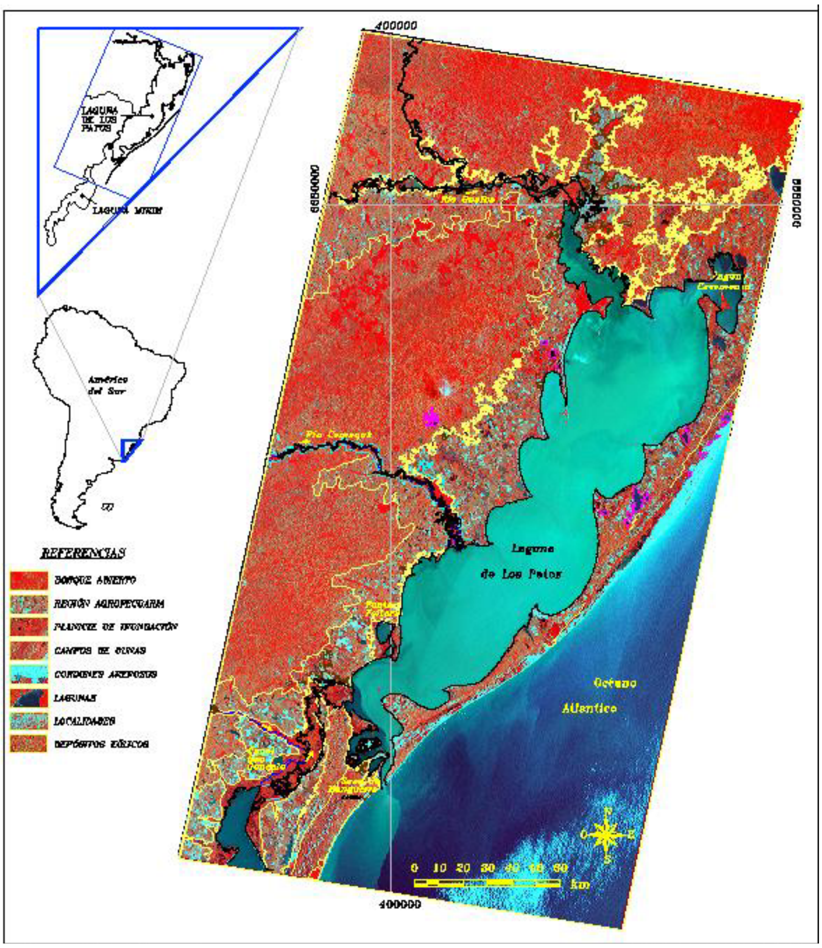

Figure 3. Location of Patos lagoon in Brazil.

On the other hand, data were collected on one complementary site: San Quintin Bay (figure 5) in Baja California, Mexico, where cultures of the Pacific oyster *Crassostera gigas* are carried out by 21 companies, occupying 9,000 racks (figure 6) in 730 ha in the west arm of the Bay, known as Falsa Bay. The commercial production is about 900 T/year.

Moreover, hydrodynamic and water quality numerical simulations were carried out in both main areas (Valencia Coast and Patos lagoon). From the combined analysis of data and simulations, circulation patterns in both areas were determined.

Figure 4. Shrimp enclosures in Patos Lagoon

Figure 5. San Quintin Bay, B.C. (Mexico)

Figure 6. Oyster culture in San Quintin Bay

Moreover, hydrodynamic and water quality numerical simulations were carried out in both main areas. From the combined analysis of data and simulations, natural forcing terms and circulation patterns in both areas were determined. Thus, the overall analyses of the wind field (at meso-scale) in Valencia Coast showed that it is highly variable (at a time scale of hours to days) and presents a seasonal behavior. Nevertheless, the main wind components occur as daily breezes, where the land-coming winds are mainly from W, NNW and NW while the sea-coming winds are mainly from ESE, E and SE (figure 7). These last winds are more intense, with greater velocities (up to 8 m/s, while land-coming winds have velocities lower than 3 m/s). It is important to point out that geomorphologic features can affect the wind field, which may be locally deflected.

On the other hand, hydrodynamic field in this area is very complex and must be explained in a 3D approach, since an “area” (2DH) or a “profile” (2DV) approach seem to be insufficient. However, the salinity gradients on the surface watershed show that the surface circulation and the wind field are correlated. It is interesting to note that, despite the variability and complexity of the hydrodynamic field at local time scale (hours to days), the overall analysis of the measurements (at meso-scale) indicate that, the main currents components are following the isobaths at which the currentmeters were moored (see figure 8). Therefore, the lack of cross-shore velocity components of the wind-induced circulation strengthens the topography influence on the nearshore circulation pattern.

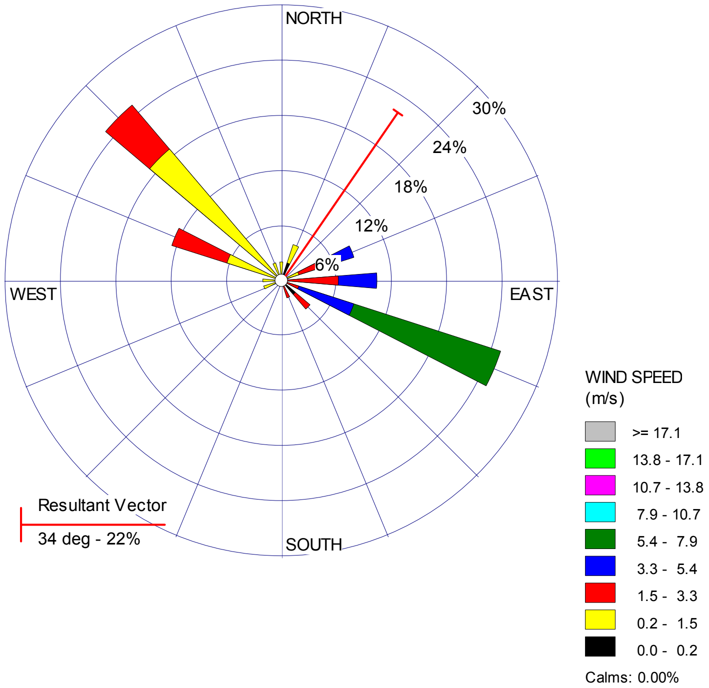

Figure 7. Wind field measured in Valencia Coast.

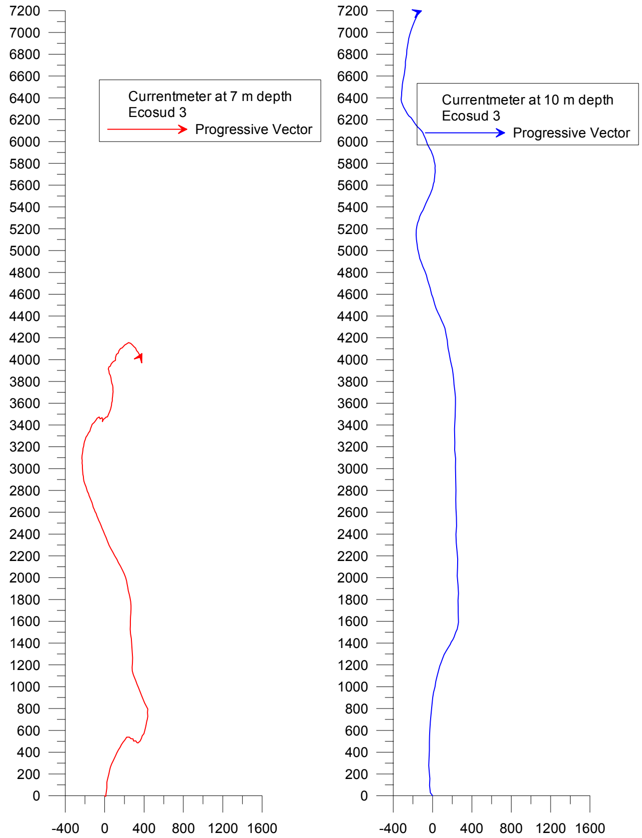

Figure 8. Progressive vectors of 2 currentmeters measuring in Valencia Coast. These vectors indicate water particle paths, which follow the orientation of isobaths.

An important conclusion of field observations (supported by numerical simulations, e.g. figure 9) is that, at meso-scale, while the wind has a strong daily breeze behavior, the current field shows a strong "boundary condition" influence by the shoreline.

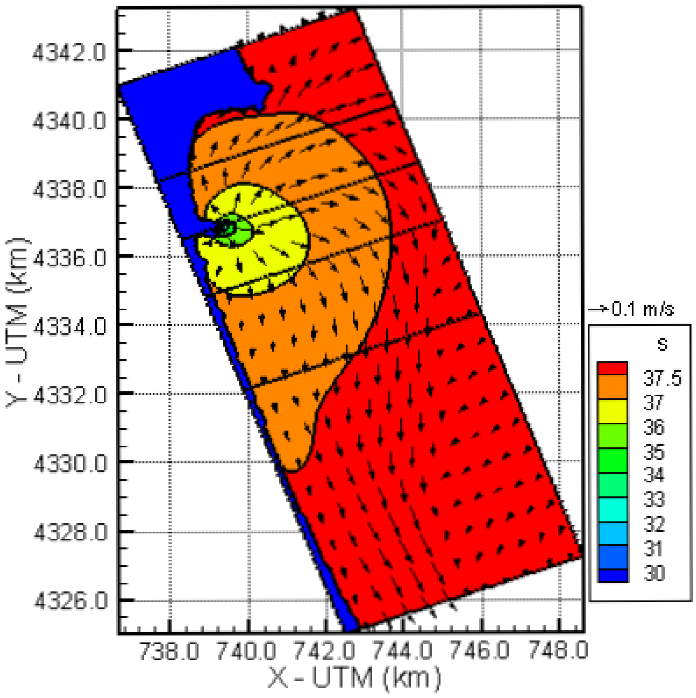

Figure 9. Numerical simulation of hydrodynamic pattern in Valencia Coast, showing how currents follow the coast.

In Valencia Coast, maximum tidal ranges are of about 30 cm. Moreover large storm waves are scarce due to the protection offered by Balearic Islands and river discharges are also limited since large rivers are not present in the area and waters are intensely used for irrigation. For these reasons wind is the main hydrodynamic driver in this area, although orography and geomorphology can locally affect the wind field, generating non-homogeneous conditions (figure 9).

Concerning Valencia Coast, one of the main sources of nutrients and pollutants are the rivers (e.g. Jucar) discharging in the area and the coastal lagoons (e.g. la Albufera) with open mouths to the sea. These waters have high nutrient concentrations due to the intensive agricultural exploitation of the river drainage basin, with the subsequent return of waters "enriched" with pesticides and fertilizers and to the discharge of partially treated domestic and industrial wastewater from upstream towns. Another major source of nutrients and especially pollutants in this area are the marine outfalls of coastal towns, which discharge, in general, relatively close to the shoreline both treated and untreated waters.

Besides other secondary sources (illegal spills of wastewater or irrigation flows from ditches) that can introduce little amounts of nutrients and pollutants to the coastal systems, another source of these substances in Valencia coastal area are the wastes from aquaculture. The two main sources of wastes generated by fish farms are the excess of food supplied that is not consumed and fish excretions. The main near-field impacts are on the benthos below the cages.

Collected data allowed analyzing the environmental impact of fish cages. Almost all the cages are dedicated to the culture of the gilthead seabream (*Sparus Aurata*) and sea-bass (*Dicentrarchus labrax*). Figure 10 shows the great amount of food that is wasted during the feeding of fishes, while figure 11 allows seeing the impact of this wasted food on the sea bottom.

Figure 10. Food being wasted during feeding.

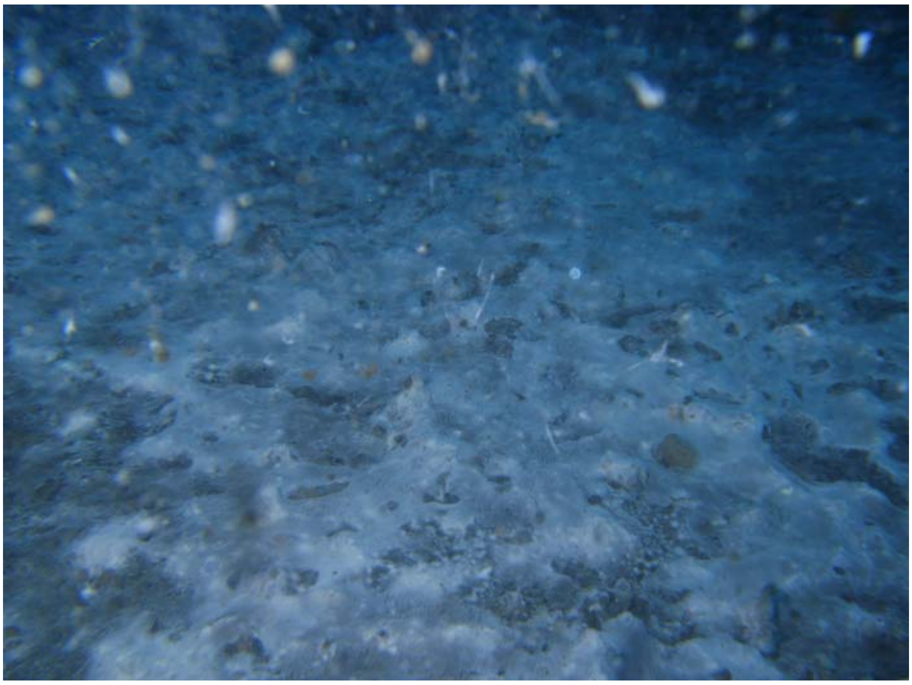

Figure 11. Impact of wasted food on sea bottom.

The analysis of data collected close to 4 fish farms in the Valencia Coast showed that chlorophyll *a* concentrations were between 40% and 140% higher than at a zone taken as reference. Figure 11 shows the temporary variation of concentrations. There, the coincidence of several peaks can be observed, suggesting that these concentrations follow temporary patterns related with aquaculture productive processes. Nevertheless, the dispersion of nutrient results (figure 12) suggests that the distribution of nutrient clouds arising from the farms is strongly influenced by local hydrodynamics.

On the other hand, significative changes in the phytoplanktonic biomass and in the population composition in the near field of marine fish farms off the coast of Valencia were detected. The effects observed are larger percentages of chlorophyceae and chryptophyceae, and lower values for the picocianobacteria/euchariot ratio and percentage of prymnesiales.

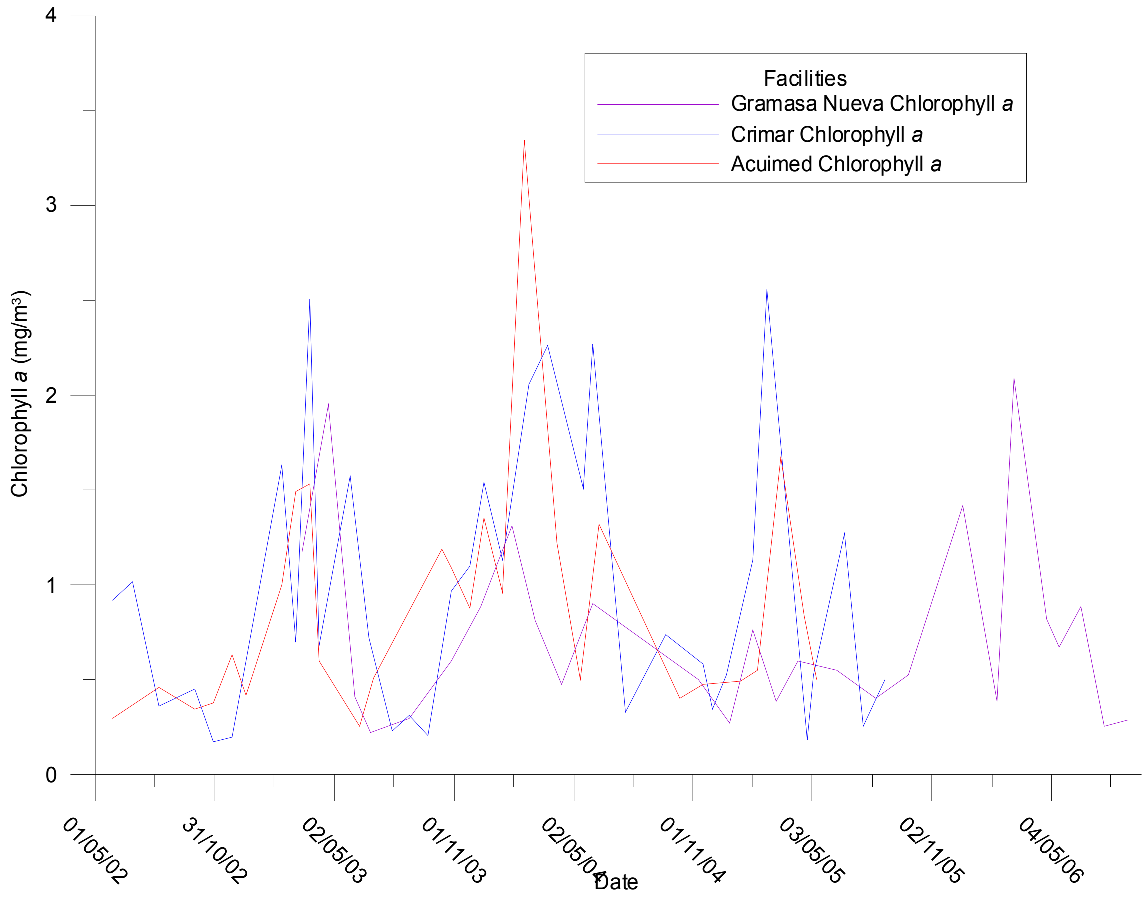

Figure 11. Time series of chlorophyll *a* concentrations in different farms.

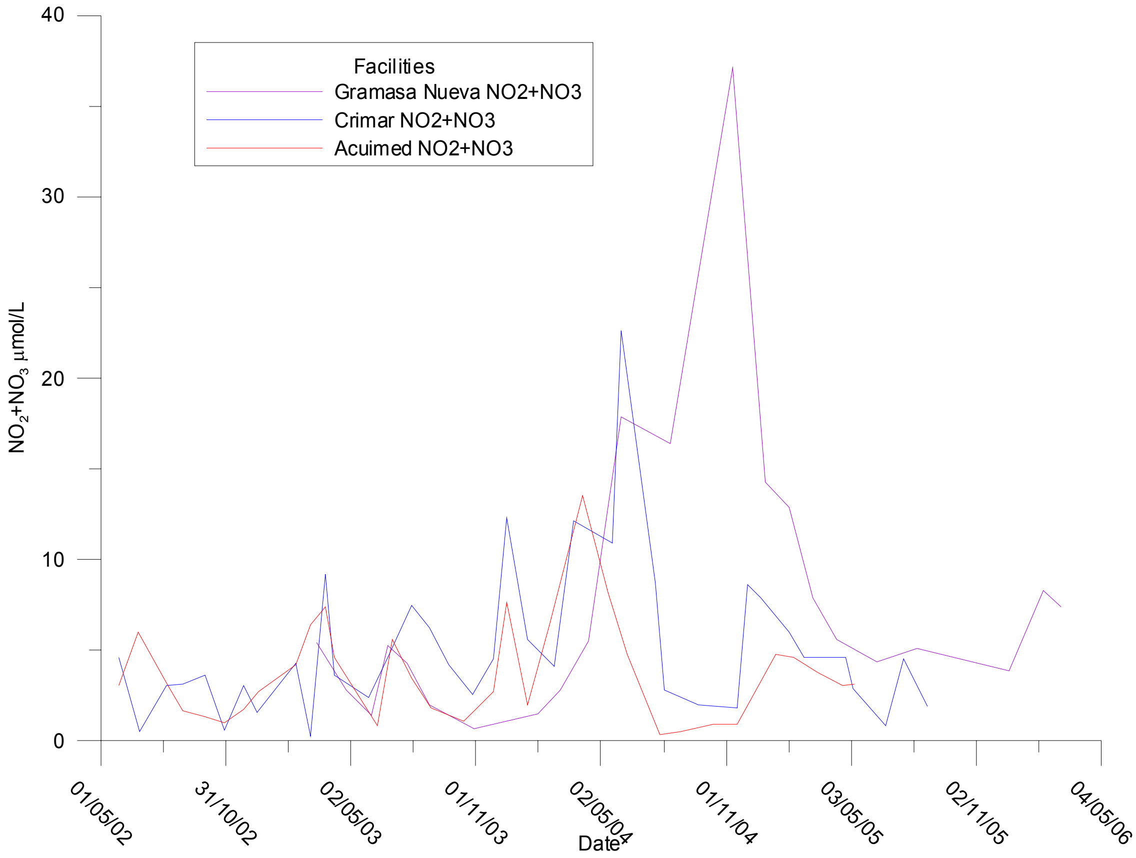

Figure 12. Time series of nitrite + nitrate concentrations in different farms.

The evaluation of the carrying capacity in open aquatic ecosystems (like Valencia coast) subjected to multiple sources of nutrients and pollutants is a difficult task due to the changing conditions in both hydrodynamics and water quality.

Below aquaculture facilities from the Valencia coast, many times (about an average of 32% for chlorophyll *a* and an average of 58% for Total Phosphorus) the limit concentrations fixed by EU were exceeded. This indicates that water quality in the area located below the cages is significatively affected by them. Nevertheless, to conclude that the carrying capacity of these ecosystems is exceeded, measurements at a certain distance from the farms are necessary.

Finally, a preliminary set of sustainable management criteria were defined for Valencia Coast in order to develop a sustainable aquaculture of fish cages.

- Aquaculture is an increasing activity in Valencia Coast, with a number of facilities, which are being monitorized in the frame of Environmental Surveillance Programs (ESPs). These ESPs must continue to guarantee the assessment of farm environmental impacts.
- There is a lack of harmonization among ESPs, since the measured parameters are not the same in different farms. A process of harmonization must be implemented.
- Most of the indicators controlled and measured in the ESPs are useless. There is a lack of definition of the most suitable indicators in order to establish potential

environmental impacts at medium and long term. An effort must be made to define more representative and suitable parameters.

- Most of the aquaculture farms in Valencia coast are well located, in zones with high dilution. As a consequence, no great impacts are foreseen, except in the areas located below the cages, which must be monitorized to control potential impacts.
- The production in Valencia coast is intensive with high fish densities (up to 90 fishes/m^3). This facilitates the transmission of diseases and the use of substances (e.g. antibiotics) which can harm other species of the ecosystems where facilities are located. Moreover, some organisms (e.g. bacteria) can develop resistance to antibiotics, being a potential source of diseases. The use of these substances must be limited to the amount strictly necessary.
- Some pollutants are not measured in the ESPs (e.g. antibiotics, substances antifouling, etc.). They must be controlled, in particular how much time they persist in the environment.
- About 20% of the supplied food is lost, settling directly on the bottom. Aquaculture producers must optimize nourishment minimizing losses of food.
- There is not homogeneous legislation at a regional level. This also should be harmonized.
- The determination of long term effects on the environment requires constant monitoring and additional research. This is a job to be performed altogether by authorities, companies and scientists.

Concerning Patos lagoon, hydrodynamic patterns in the area of Saco the Mangueira, which is the one dedicated to shrimp culture, were also established through field measurements and numerical simulations (figures 13 and 14). Thus, Patos lagoon is wind forced rather than tidal driven, since astronomical tides are of reduced importance (the mean and maximum amplitude values are 0.5 and 1.2 m). Fluvial discharge may also generate seasonal pressure gradients contributing to lagoon subtidal circulation. According to this, the dynamics of the lower estuary is controlled by the non-local wind effect, which indicates the importance of remote forcing on the dynamics of Saco da Mangueira. During periods of low intensity winds, however, the local wind effect may become important inside the embayment. Thus, the response to the local wind action over the area is instantaneous and very important for the internal circulation of the area. This internal circulation is responsible for the transport of water from one end of the embayment to the other, as well as controlling oxygenation and resuspension of sediment and nutrients according to the wind direction. The combined action of this internal circulation with the exchanges between Saco da Mangueira and the main access channel prevent the occurrence of anoxic conditions.

To study the environmental impact of shrimp cages in Saco de Mangueira, a biweekly monitoring was done in the surroundings of the region of the open cages, during the period of cultivation of summer and fall of 2006. The purpose of monitoring was to characterize the abundance, the composition of the community and the nutritional status of the underwater vegetation in the region of the cages in order to diagnose about the possible effects of the cultivations on the ecology of these communities.

The monitoring of the biomass of seagrasses was done weekly (during the cultivation period) and biweekly (after the cultivation period) from January to July 2006 in the surroundings of the cages of shrimp. The percentages of covering and abundance of seagrass were estimated in 4 points located in adjacent and distant areas (300-500 m) to the open cages. The parameters of water temperature, salinity, transparency and level were daily sampled. Samples of water were collected and filtered for analysis and determination of the concentrations of nitrite (NH_2), nitrate (NH_3), ammonium (NH_4), phosphates (PO_4) and suspended solid material.

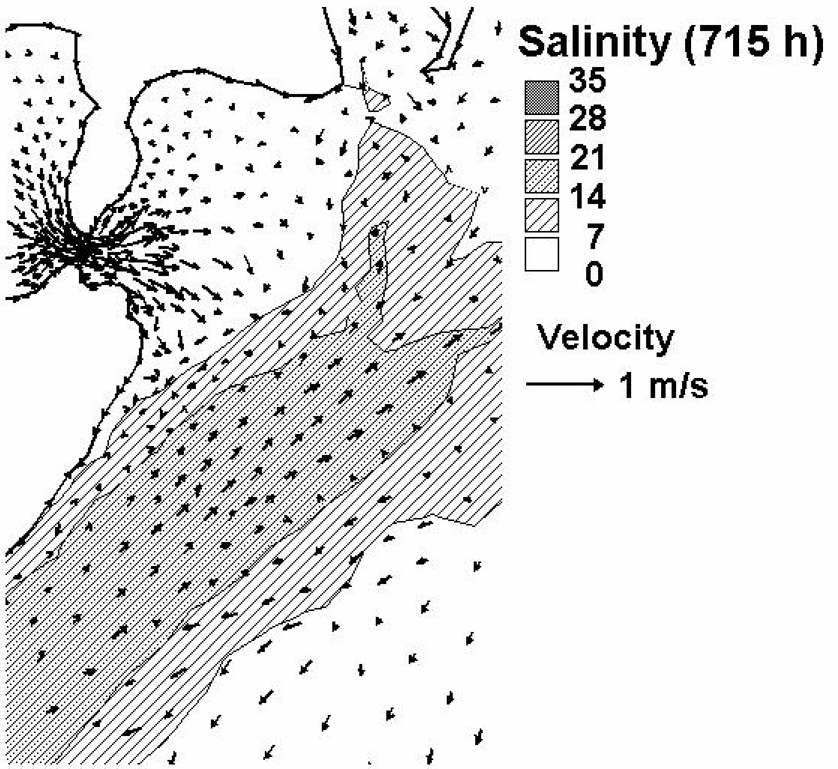

Figure 13. Numerical simulation of hydrodynamic pattern in Saco de Mangueira, with horizontal distribution of salinity at the surface and velocity vectors

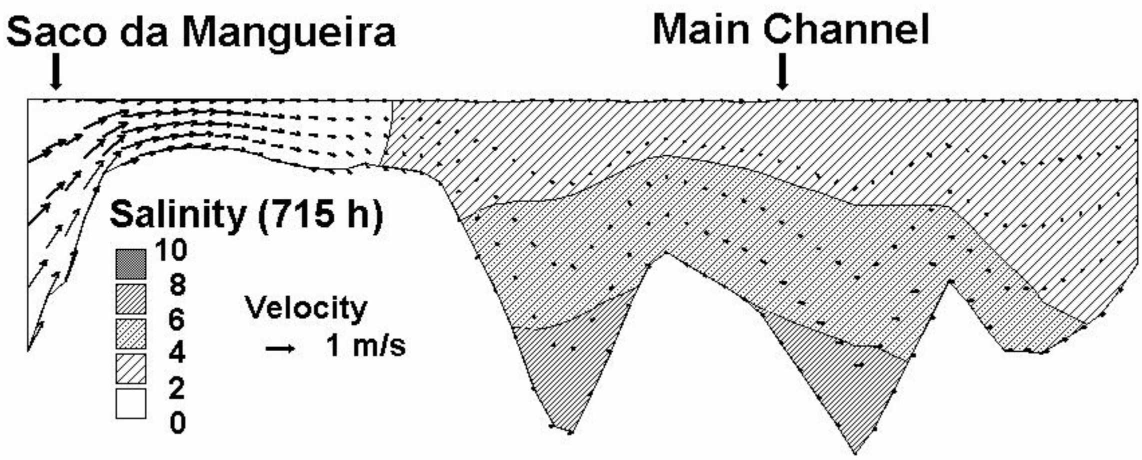

Figure 14. Vertical cross section at the entrance of the embayment showing the salinity distribution and velocity vectors

The greater abundance and percentage of covering of seagrass occurred in January and February (figure 15). This was due to high values of temperature, salinity and low hydrodynamics. From March, with the increase of flow of fresh water, there was a significant reduction of biomass, being this specially composed of drifting seagrass retained along the cultivation structures.

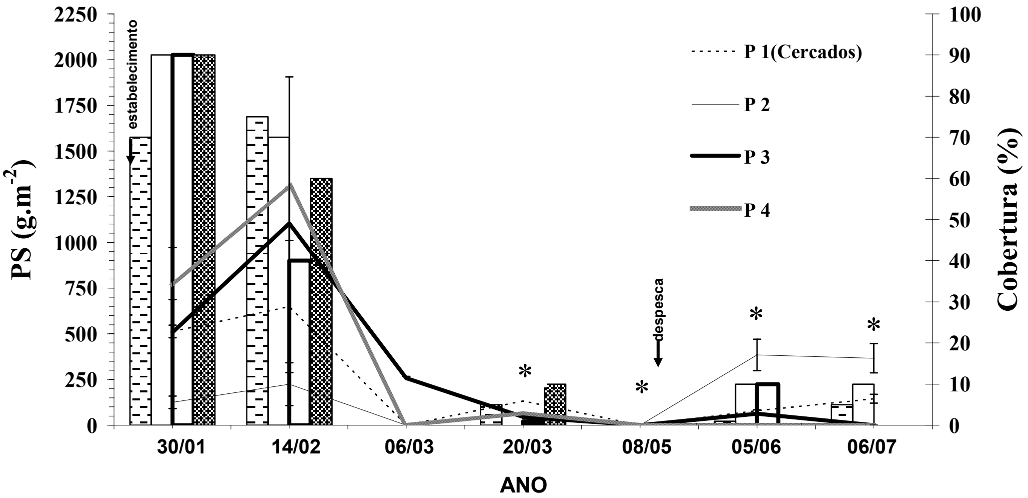

Figure 15. Variation of biomass of sea-grass during the sampling period. Arrows indicate installation dates and harvesting of the cages.

The concentrations of nutrients found for the period of February to March 2006 presented a great variation especially due to the high hydrodynamics of the place sampled. In general, the values found are according the intervals of values found for non-polluted estuaries.

According to these results, the region of the cages is susceptible to the development of blooming of opportunistic seagrasses, which settle under adequate conditions of high temperature, salinity, low hydrodynamics and sufficient input of nutrients. Such conditions are normally typical in the summer, concomitant with the period of cultivation of the shrimp. The settling and the permanence of these vegetated bottoms in the estuary are controlled by physical-chemical parameters and hydrologic factors which intensely vary in time and in space. Moreover, the species of dominant seagrass present high index of nutrient uptake in the water column followed by rapid increments of biomass.

In Patos lagoon, there are different sources of pollution since it is exposed to significant anthropogenic effects from a local port (the second major port of Brazil) and both industrial (oil refinery and terminal, fertilizer-producing plants, fishery industries) and dwelling areas of the Rio Grande city. The major sewage effluent of Rio Grande City (185,000 inhabitants) is disposed untreated in the estuary. Several other smaller effluents (industrial, domestic, fluvial and rain runoff) can be found, spilling different types of pollutants inside the lagoon, in shallow marginal bays along the area.

In Patos Lagoon, the residence time depends more upon meteorological conditions (wind, rainfall, evaporation, etc.) than on tidal exchange because of the low tidal range. A residence time of one and a half year has been estimated for a mean annual freshwater discharge of 1,000 m^3/s. During high discharge, generally during winter (June - August), the entire lagoon is fresh and the calculated freshwater residence time is about 5 months.

In Mangueira Bay, although surface waters always stayed well oxygenated, there is water pollution caused by the discharge of domestic and industrial effluents, in particular close to the Rio Grande City and the industrial district. Faecal contamination seems to be permanent in the area near the city. Therefore, due to this point-source contamination that area is not adequate for fishing and aquaculture activities. Sometimes, very high concentrations of nitrogen and phosphorus have been found near fertilizing-manufacturing, soy-processing and wood-chipping plants. Nutrients in the area are increased by the use of fertilizers in the rice and soy farms located along the watershed of the lagoon. This simultaneous combination of nitrogenous and phosphatic nutrient inputs causes serious problems of artificial eutrophication and an excessive increase in vegetal biomass in Mangueira Bay. Figure 16 shows a numerical simulation of primary production in Patos Lagoon.

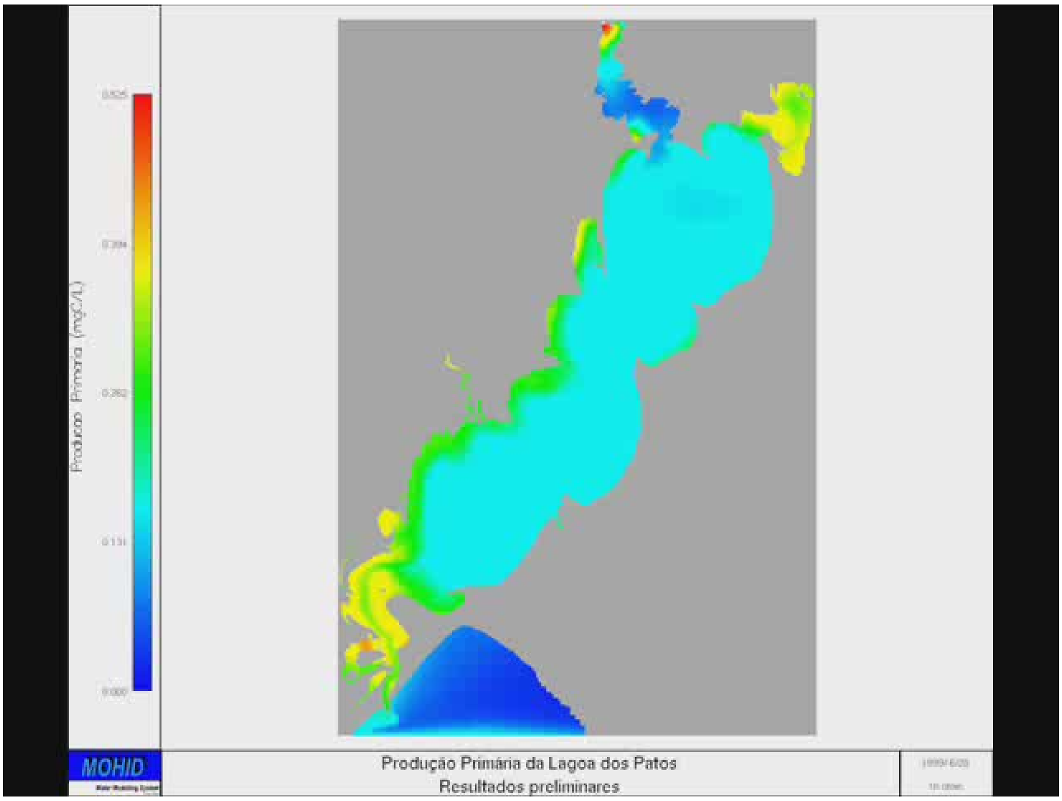

Figure 16. Numerical simulation of primary production in Patos Lagoon

The system carrying capacity was estimated for Patos Lagoon, starting from measurements carried out close to shrimp enclosures in Justino Bay. Nutrient and dissolved oxygen results indicated that the current method of shrimp cultivation in enclosures does not significantly alter water quality.

A model was developed to estimate the carrying capacity in Mangueira Bay. With a fixed limit of 0.07 mg/l of Total Nitrogen (corresponding to the usual conditions in the Bay) a maximum of 70 enclosures (with a diameter of 32 m and density of 20 individuals/m^2) could be installed in Mangueira Bay (see figure 17). This would allow keeping nutrient conditions in the Bay at a level similar to the present situation.

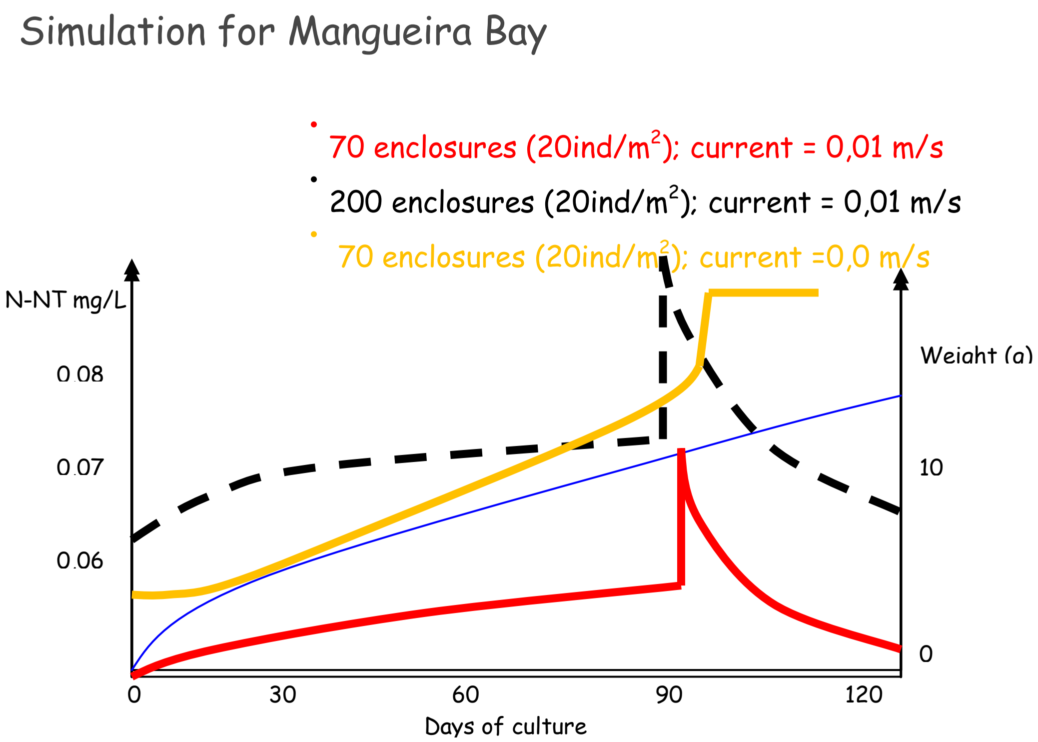

Figure 17. Estimation of the carrying capacity for Mangueira Bay.

Finally, a preliminary set of sustainable management criteria were defined for the three sites. For Patos Lagoon Estuary, in order to develop a sustainable shrimp aquaculture (SSA), the following measures were proposed:

- To use only shrimp indigenous specie (*Farfantepenaeus paulensis*) to avoid risks of impacts related to displacement of ecological niches.
- The SSA should be implemented on a familiar basis, as complementary activity to the fishery and agriculture for the rural community, and should involve the community in a participatory management.
- The SSA should avoid the use of antibiotic substances and high density storage systems.
- The SSA must protect key functional processes, as the quality and the circulation of the water, the primary productivity and the maintenance of biodiversity.
- Shallow waters of estuarine embayments are nursery areas. Their biodiversity is key for the trophic ecology of the estuary and the development of the

aquaculture must be done carefully in order to maintain it in good environmental quality.

- The installation of the structures inside the estuarine embayment should avoid the submerged prairies of *Ruppia maritima*.
- An environmental monitoring program should be implemented to control the dissolved nitrogen, organic matter and turbidity in the water column.
- In order to avoid use conflicts, and promote social and gender equity SSA should privilege the development of artisanal fishermen community and encourage the women involvement.
- The spatial planning of SSA development must consider all regulations at federal, state and local levels as the water use code (Estate Technical norm FEPAM 03/95) and the Municipal Environmental Plan.
- The SSA should take in consideration the Code of Conduct for Responsible Fisheries, articles 9 and 10 from FAO.

In the third studied site, San Quintín Bay, with an average depth of about 2 m and a single mouth, the water circulation and exchange with Pacific Ocean coastal waters is restricted. The long axis of Falsa Bay is aligned towards the mouth in the South, coinciding with the orientation of dominant westerly winds that promote upwelling. During spring and summer is normal to have the influence of the local winds which blow all day long from the northwest sharing importance with astronomical tides in the hydrodynamics of Falsa Bay. During the rest of the year, semidiurnal astronomical tides dominate the hydrodynamics, with tidal amplitude of 2.4 m during spring tides and strong ebb currents (~1 m/s) at the mouth.

San Quintín Bay is considered a well mixed system since no significant vertical gradient of dissolved properties is observed in most of the Bay. The effect of the upwelling water is the cause of temporal variability at the mouth of the bay of biological and chemical parameters, with phytoplankton chlorophyll *a* decreasing from the mouth to the inner parts of the lagoon. The system is considered net heterotrophic and produces dissolved inorganic phosphorus (DIP) acting as a source to the ocean. Concerning dissolved inorganic nitrogen (DIN), the system exports DIN to the ocean during El Niño event, whereas it imports DIN during non-El Niño years. These fluxes of DIN from the ocean to San Quintín Bay are associated with the upwelling intensity.

As most of the 28,000 inhabitants of the area live away from the shore of the bay, nutrient loads from sewage and horticulture crops with groundwater exploitation into San Quintín Bay are limited due to the relatively human isolation of the bay and to the short rain periods during winter months. Although surrounding San Quintín Bay there is a valley with significant agricultural activities (and the associate use of nematocides, herbicides, pesticides and fungicides), sedimentary concentrations of organic pollutants in San Quintín Bay are low and likely they do not affect the oyster cultures. The estimated water residence time for Falsa Bay, based on salt budgets, is 4-6 days in the spring and summer months, and 12 days during winter.

The oyster carrying capacity of Falsa Bay was estimated in 5,974 and 1,913 T for the spring and neap tides respectively, while an average value of 3,636 T was obtained for a two-week cycle. This suggests that the production potential of the culture units installed in Falsa Bay (4,300 T) is at the limit or above the limit of the carrying capacity.

In order to develop a sustainable oyster aquaculture in San Quintin Bay some problems were detected and several indicators were proposed to detect bivalve aquaculture impacts and their impacts on the environment.

The expected end results are those described in the objectives of the project. In particular, the estimation of the carrying capacity of the studied systems and the identification of alternative management criteria and practices are the main contributions from the project.

There are no exploitable results expected from the project, so there are not publishable results associated to them. The plan for using and disseminating the knowledge includes a project webpage (http://lim-ciirc.upc.es/aquas/), a project brochure, papers in scientific journals and press releases, as well as different forums to transfer project results to responsible administrations, private companies and general public.

2. Dissemination and use

2.1. Exploitable knowledge and its use

There are no exploitable results and knowledge in this project.

2.2. Dissemination of knowledge

The dissemination activities are the following:

Planned/ actual dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
Month 4 / 6	Project webpage	General public	All	10^5	CIIRC
Month 4 / 6	Project leaflet	Researchers Managers Stakeholders	Spain, Brazil, Mexico	10^3	CIIRC
Month 18 / 12	Papers in Scientific Journals	Researchers	All	10^4	All
Month 16 /	Press release	General public	Spain Mexico	10^4	UPV, UABC
Month 17 /	Focused forums	Responsible administrations	Spain Brazil Mexico	10^2	All
Month 16 /	Specialized sessions	Administrations Private companies	Spain Brazil Mexico	10^2	All
Month 18 /	Open forums	General public	Spain Brazil Mexico	10^2	All

2.3. Publishable results

There are no publishable results since there are not exploitable results.