Simulator Software for Marine Fish Farms Sustainability

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Abstract: - One of the main costs of the marine fish farms is the extruded feed. This paper discusses many issues given when fish, mussels, oysters or other shellfish are fed and their relation with the sustainability. There are several simulator software for fish growth and there are several published models for sustainability, but, as far as we know, there are very few simulator software for marine fish farms sustainability in existence. First, we will introduce other simulators published by other authors. We have observed that many of them just solve some of the issues, but not all. Authors will propose a simulator based on underwater wireless sensors that will solve issues aforementioned giving sustainability for marine farms. Because sensors are not wired, they could be deployed widely without cable limitations. The simulator permits to design scalable systems. It will be useful when there are many fish cages, allowing low cost maintenance. Our proposal takes into account many simulation models and methods in existence for sustainability in marine fish farms and we have introduced in it the possibility of choosing the method for modeling.

Key-Words: - Software Simulator, Simulation, Sustainability, Marine Fish Farms.

1 Introduction

Marine fish farms are responsible for growing and harvesting fish, mussels, oysters or other shellfish in specially prepared areas. They are also used for international investments in fish farming. There are several types of cages for marine farms: Open net pens or offshore floating marine fish cages (the most common in the Mediterranean zone) and the spar cages, with Single or Several points Mooring [1]. There are also some known works that predict the best places where the cages should be placed (taking into account the tidal flow of the sea or even its temperature [2]).

It is needed some criteria and specific guidelines to evaluate the repercussion of the aquiculture in the environment [3]. The conference reports given in the international conference that was held in Sidi Fredj, Argel, in June 25-27, 2005 [4], traced some recommendations for the sustainability aquiculture. The sustainability makes the aquiculture acceptable ecologically, socially fair and financially viable [5]. Actually, there are many strategies for the sustainability development such as the one proposed by the European commission [6], but the environment protection is where our efforts must be focused to achieve its full sustainability.

Spanish law is very hard when someone is trying to acquire the acceptance to set up a marine fish farm. The authorization and its concession are given after a favourable environmental impact study in the place where it is proposed to be placed. Moreover, marine fish farms managers are urged to have an annual tracking about the activity of some environmental parameters of the water column in several depths and of the sea bed [7, 8]. These parameters have to be taken to the water (Temperature, pH, Salinity, Phosphates, Nitrates, etc.) and to the sediments (Organic Carbon, Soluble Nitrogen, Shanon diversity index, Margalef index, etc.). These parameters have been defined in the Technical Report sent by J. C Macias et al to "mispeces.com" [9]. They also proposed to model the impact given by the marine installations and propose to define the main environmental indicators that affect them.

The rest of the paper is structured as follows. Section 2 formulates the problem we have seen about the sustainability in marine fish farms. Section 3 describes some related works. Our proposal and its advantages compared with other works are explained in Section 4. Finally, section 5 gives the conclusions and future works.

2 Problem Formulation

Our research is focused on these aspects related with the ecology and with the environment. So, our main goals are the following ones:

- To protect the environment. We have to diminish the dumpings and their impact because many of them have high grade of nitrate, and to avoid the effects of the eutrofisation. We have to study the effect in the fisheries when fishes have been growth in a fish farm. We have to find solutions to the predation of the aquatic production by the wild protected species. We must develop systems to reduce the impact in the natural environment of the rogue fishes, transgenic fishes and the foreign fishes.

- To make aquiculture sustainable. The feed for the fishes in marine farms is an extruded feed or pellet that is presented in a granulated from. Its raw material comes from the natural medium. There are different types of processes for the feed to produce high biomass or product concentrations [10]. The cost of the feed production should be taken into account because it is getting harder to supply the alimentary demands of the aquatic sector.
- We have also to take into account the detritus and the fecal pellets of every one of the aquiculture cage. Those excrements together with the wasted feed because it is not eaten form a pollution zone at the bed of the cage. The size of the pollution zone is related to the type of the material of the bottom (mud, sand, etc.) and to the distance between the fish cage and the bottom (the lower distance, the higher surface of pollution).

Summarizing, to feed the fishes in marine fish farms have many costs for the marine farmers. First, because extruded feed throws to the cage in the water and it is difficult to know exactly how much is needed, so many of it is wasted. Second, because there could be floating extruded feed and semi-sinking extruded feed. And third, because when the fishes don't eat all extruded feed that is threw, the floor of the sea gets dirty [11, 12] (not only due to the feed, but also because of fish excrements). So, there is a deposition of particulate organic waste from those marine fish farm cages on to sea-bed sediments that can cause major changes to the benthic ecosystem, so it is needed a system to clean it (many countries have a law to avoid this type of pollution). This wastage must be also distinguished of the sea pollution [13].

Many benefits will be obtained by a fish farmer company, and their developer, if they have a simulator that considers all these parameters and factors. Results obtained by the simulator could be analysed by the manager to improve their marine fish farm. It could be also used not only for a better implementation but to troubleshoot the implemented deployment when the real system is simulated.

3 Related Works

Because of the concern of these issues, some people have been working on developing applications to model some of these parameters.

On one hand, there are several individual works modelling the deposition and biological effects of waste solids from marine cage farms. But all of them are focused on the modelling of some specific issues related with marine fish farm, not on the simulation of the sustainability related with them.

One of these applications is DEPOMOD [14]. Its goal is to enable better predictive capability of the impact from large marine cage fish farms on the benthos. DEPOMOD predicts the solids accumulation on the seabed arising from a fish farm and associated changes in the benthic faunal community. It could be used for assessing the potential impact of a farm throughout a growing cycle, or if the biomass consent is increased.

Another application presented by O. M. Pérez et al., in [15] uses GIS (Geographical Information Systems), combined with a spreadsheet, as a Tool to Aid Modelling of Particulate Waste Distribution at Marine Fish Cage Sites. The tool uses known distribution algorithms but also incorporates functions to calculate feed loading for all the cages within a pontoon independently. It also simulates post-depositional distribution of the carbon and uses approximate estimates of feed and faecal waste derived from dietary considerations (mass balance model) and separate, unique settling velocities for waste feed and faecal particles. The model performance has been validated using measured levels of sediment carbon, and they showed a significant correlation between predicted and real sediment loading. Later, R.A. Corner et al. presented in [16] an integrated model of GIS with feed loss. GIS system is also used for many Marine Environmental Information Systems [17].

Last simulation model, that has been developed and published, is the simulation model of sustainability of coastal communities [18]. This model was developed to simulate biological interactions related to traditional fishing, aquaculture, the physical marine environment and coastal labour market interactions and the regulatory environment.

Aquaculture production was described by a standard Cobb–Douglas production function. It has been calibrated using published information on fish farms, fishing, fished stocks and labour activity. It can simulate traditional fishing, aquaculture, other employment, and the unemployed labour using the appropriate regulations of biomass, fish production and employment suggested.

None of these simulators have its main purpose on the sustainability in the fish farm. Because of the lack of software applications in this area, some projects have been started by several research centers to tackle this issue. Some of the main ones are:

- AQCESS [19]: Aquaculture and Coastal, Economic and Social Sustainability.
- BIOFAQs [20] Biofiltration and Aquaculture: an Evaluation of Substrate Deployment Performance with Mariculture Developments.
- ECASA [21]: Ecosystem approach for sustainable Aquaculture.
- ICES [22]: Working Group on Environmental Interactions of Mariculture.
- MERAMED [23]: Development of monitoring guidelines and modelling tools for environmental effects from Mediterranean aquaculture.
- MEDVEG [24]: Effects of nutrient release from Mediterranean fish farms on benthic vegetation in coastal ecosystems.

4 Our Proposal

First, let's see what is needed to have in a simulator for sustainability in marine fish farms.

1. To simulate all issues aforementioned in section 2, several types of measurements must be taken or must be modelled:
   - Physic-Chemical characterization of the water: Water Temperature, Dissolved oxygen (dO_2), pH, Salinity, Conductivity, Ammonium, A Chlorophyll, Total Organic Carbon (TOC), Phosphates, Total Phosphorus (TP), Nitrates, Nitrites, Total nitrogen and Solids suspension.
   - Physic-Chemical characterization of the sediments: TOC, soluble phosphorus, soluble total nitrogen and redox potential.
   - Granulometric composition of the sediments: Grain-size composition and sedimentologic characterization.
   - Description of the benthonic communities in the medium: Shanon diversity index, index of fairness, Margalef´s diversity index (Species richness).
2. It has to allow to model the design and planning of the system of underwater sensors [25][26] to take accurate measurements, so it should be kept in mind several factors:
   - The number of sensors
   - The distribution of sensors
   - Sensors coverage
   - Where are they placed
   - Periodicity taking samples

   These factors are not fixed because they depend on the number of cages, their size and the environment where they are placed.
3. The Simulator must also permit to take into account many factors given by the environment and the marine fish farm characteristics:
   - Where the marine fish farm is placed: depth, distance from the coast.
   - Environmental characteristics of the place.
   - Occupied/cultivated surface.
   - Production system.
   - Produced biomass.
   - Generated waste materials.

All these parameters and factors are essential to design an optimum simulator for sustainability in marine fish farms. Just some of them are used in the simulators aforementioned in the previous section. None of the systems in existence considers all of them, just few.

On the other hand, some equations have to be taken into account in order to model the fish farm sustainability. We have studied many works where the expressions used to model a particular parameter are different. This section also shows the models introduced in our proposal

4.1 Simulator diagram

To clarify all parameters that the simulator is going to take into account and where the sensors are going to be placed in the simulator, figure 1 shows them in a sea environment. There are also several modules associated to input data used for modeling such as the amount of input feed, the size of the fish farm cage, distance between cages, environmental characteristics of the place, sensors coverage and so on.

4.2 Bed shear stress

We have shown two models in this case.

Ian G. Droppo et al. in [10], computed the bed shear stress (τ_c) as it is shown in equation 1.

$$\tau_c = 0.1\cdot(0.164\cdot L_s)^2 \qquad (1)$$

Where L_s is the cover speed. τ_c is given in Pa and L_s is given in revolutions per minute.

While U. Neumeier et al. in [11] have computed it using the Quadratic Stress Law as is shown in equation 2.

$$\tau_c = \rho\cdot C_D\cdot U^2 \qquad (2)$$

Where ρ is the water density, C_D is the drag coefficient and U is the time-averaged velocity. C. E. L. Thompson et al. in [27] defined C_D value of 0.02 for the flume used in Messina. Using a seawater density of $1.03x10^3$ (kg/m^3), we can see their difference graphically in figure 2.

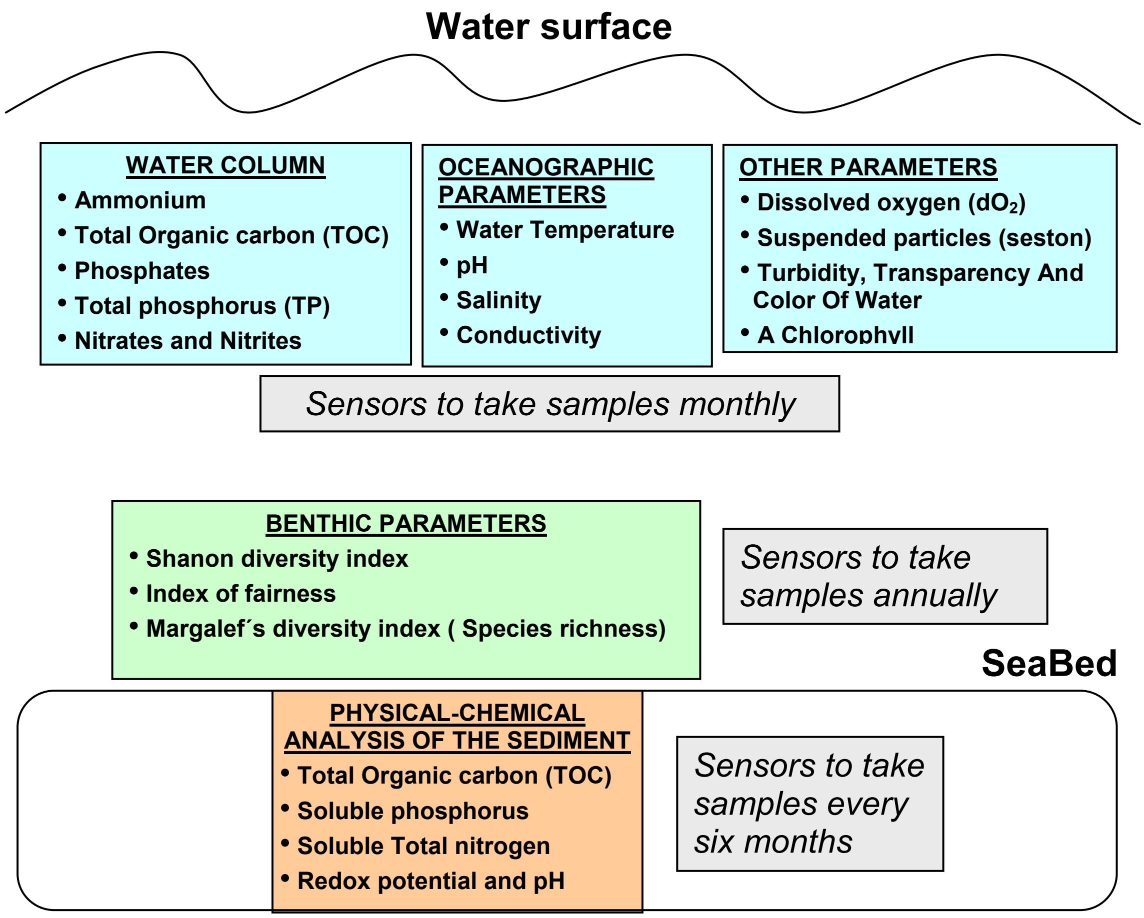

Figure 1. Shows the modules of the proposed simulator.

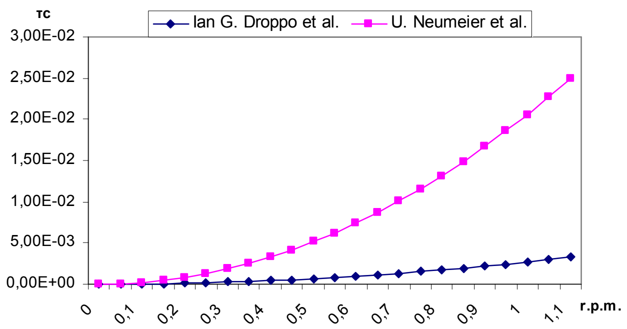

Figure 2. Difference between two bed shear stress models.

On the other hand, some considerations must be taken into account: The daily rate of feed consumption varies with the composition of the feed, the weight of the fish and the water temperature. Moreover, the time required by the fish to reach a particular weight varies with temperature [28].

4.3 Wastage rates and feed consumption

In order to model the wastage rates of fish feed and faecal material, we can choose between several types of expressions. The first one was given empirically by Liao and Mayo [29].

Equation 3 represents the relationship between feeding rates and suspended solids production for trout between 10 and 15 °C and a maximum stocking density of 28.4 kg m^{-3}.

$$SS = (0.52)\cdot F \tag{3}$$

Where SS is suspended solids production (kg SS (100 kg fish)$^{-1}$ day^{-1}) and F is the feeding rate (kg food (100 kg fish)$^{-1}$ day^{-1}).

The second one is the one presented by C. J. Cromey et al. in their simulator DEPOMOD [14]. They state that the food consumption is given by equation 4.

$$F_c = F\cdot(1 - F_w)\cdot(1 - F_{wasted}) \tag{4}$$

Where F_c (kg/day/cage) is the rate of food consumption according to the feed input (F), the water content of the food (F_w) and the proportion of food wasted (F_{wasted}).

4.4 Fish growth relationships

There are many expressions related with fish grow. In reference [30], Bergheim et al. defined their model (called BTM model). This model gives the relationship between suspended dry matter loadings and feed conversion ratios (FCR: weight of feed given per weight gain of fish) in a land-based tank production system. The relationship was developed for salmon from 30 g to 2 kg in size between 4 and 15 °C. The formula used for this model is given in expression 5.

$$SDM = 0.20 \cdot (10^{(0.49) \cdot FCR}) \quad (5)$$

Where SDM is the suspended dry matter loading (g (kg fish)$^{-1}$ day^{-1}), and FCR is feed conversion ratio (kg dry feed/kg fish weight gain).

But other works relate the feed consumption with the fish growth and the size of the cage like the model presented in [31]. They defined a ratio between the amount of ingested feed and the resulting fish growth, called the theoretical feed conversion ratio (FCR_t). They observed that this ratio increases slightly with increasing fish weight. Then they defined the factual feed conversion ratio (FCR), as the ratio between the amount of feed actually given to the fish and the resulting fish growth. So the excess, (uneaten feed) is equal to $FCR-FCR_t$ times the fish growth. They calculated $FCR-FCR_t$=0.3, so the waste feed equals 0.3 kg per kg fish produced. Assuming the fish production as T_P, the emission of excess feed is $T_P \cdot (FCR-FCR_t)$ and the flux of faeces is about 0.1·TP. Taking into account the total area of the net pens as A_F, the spatial and temporal mean flux F_{feed} (g m^{-2} day^{-1}) of excess feed from the pens is given by expression 6.

$$F_{feed} = \frac{T_p}{A_F}\left(FCR - FCR_t\right) \quad (6)$$

And the Spatial and time mean flux of faeces from the pens is given by expression 7.

$$F_{faeces} = 0.1 \cdot \frac{T_p}{A_F} \quad (7)$$

Our simulator cover all types of models given by several authors and the user could choose which one to use depending on the case.

4.5 Waste distribution

One of the main issues to take into account for sustainability in marine fish farms is spread the fecal pellets and the uneaten feed. This section describes models in existence.

The excess feed and faeces from the fish are dispersed on the seabed under the cages. They are settled some distance from the farm implying an adversely impact in the coastal environment. There have been many studies about the factors influencing the sedimentation and accumulation of organic material under and near the fish cages [32][33][34], but our study is about their distribution, not about their composition.

Many factors can be taken into account to measure the waste deposition:

- The biomass of the fish
- The metabolic rates of the fish
- The settling rates of excess fish feed
- The settling rates of fecal pellets
- Feeding rates
- The amount of excess (waste) feed
- The consumption of waste feed by other species
- The rate of decay of organic particles on the bottom
- The sinking velocity of the particles
- The velocity and the direction of the current
- Depth-varying currents
- The water depth

Several works have presented computations of the dispersion of uneaten feed and faeces from fish farms using particle-tracking models [35][36]. These models are focused on spatial boundaries of sedimentation of particulate organic matter and the fish farm is assumed to produce a uniform emission of particles [37]. Other works such as the ones in [38] and [14], add other factors such as the variation in bottom topography and changes in current speed with depth. But other researchers have generally used criteria based on measurements at pre-specified "up-current" and "down-current" locations, and blanket minimum current speeds and water depths, etc. to assess the impact [39]. However, these criteria appear to have little scientific basis and do not ensure acceptable levels of excess feed and fecal matter concentrations at all sites.

In order to compare the models in existence we are going to describe them.

One of the first modeling techniques for estimating the environmental impacts of aquaculture, i.e. the dispersion of particulate matter at marine fish farm cage sites was the Gowen et al. model [32]. They constructed a model that involves simply tracking the horizontal and vertical motion of the wastes to determine where they settle. The distance dispersed is given by equation 8.

$$d = \frac{D \cdot C_v}{S} \quad (8)$$

Where D is the water depth, C_v is the velocity of the current and S is the settling velocity (of the faeces or of the feed).

Pérez et al. presented an extension of this model in [15]. They located the farm in the middle of a 500 by 500 cell array, each cell representing 1 m^2. They assumed that wastes fall more or less vertically through the cage, so the source of distribution was assumed to be from the depth corresponding to the bottom of cage. Equation 9 gives their expression for X and Y position.

$$(X,Y)=\left(\frac{d\cdot V\cdot\sin\theta}{u}+x,\frac{d\cdot V\cos\theta}{u}+y\right) \quad (9)$$

Where d is the depth under the cage, V is the mean current speed, Θ is the current direction, y is the settling velocity and (x, y) is the position of each cage. The carbon deposition co-ordinates calculated with this formula and their associated carbon values are exported to the Geographical Information Systems (GIS) software. Interpolation between values is undertaken by the GIS program to produce a complete map. The current readings, speed (V) and direction (Θ), are taken at regular intervals over a defined time period.

Cromey et al. model, also called DEPOMOD [14], allows a detailed description of the farm on a 3D grid. The dispersion model differs from the other models because the net pens (cages) are treated as the basic unit of a farm. The spatial distribution of particle sedimentation under a fish farm then becomes a function of the net pen size, the separation between pens and their configuration. The sedimentation from each of the cage is computed and these may overlap, creating various local accumulation maxima. In order to model the horizontal trajectory of a particle, they consider the current as a sum of two parts: a slowly varying component relating to tidal or wind forcing plus a more rapidly varying component relating to turbulence with a mean of zero. They define the trajectory of a particle in the horizontal plane, as it is shown in equation 10.

$$P(x,y,t+1)=P(x,y,t)+u(z,t+1)\delta t+rw_{step(x)}+v(z,t+1)\delta t+rw_{step(y)} \quad (10)$$

Where t is the time step (t), P(x, y, t) is the position of a particle, u and v (m/s) are the velocity components and $rw_{step(y)}$ is the length step in the random walk model (turbulence). $rw_{step(y)}$ is dependent on the time the particle is in the turbulent field and a dispersion coefficient.

The speed magnitude and direction of the dominant current is different for every place. It depends on the sea area, the depth. As an e. g., S. Porrello et al. measured in [40] the speed and the direction in the Western Mediterranean Sea. The study area had a homogeneous water column and a weak current speed that determined a reduction in waste dispersion from cages and an absence of waste resuspension. In addition, the short distance between the sea-cage floor and bottom of the sea (5–7 m) did not allow too waste dispersal. They took an East North East and West South West dominant direction at a depth of 26 meters. The highest speed mean values were recorded at the surface layer (about 3 meters) and gradually decreased as depth increased. The general trend was a gradual velocity increase from the bottom to the surface. There were not any clear differences between the months and the depth. They noticed that there was a strong accumulation of waste just beneath the cages with a small dispersion area. In fact, the low current acted only in a few meters of the water column. There were recorded no differences among sampling points located at a distance greater than 50 meters.

Stigebrandt et al. presented a dispersion model [41][42] that gives the mean carbon emission from the net pens. It is shown in expression 11.

$$F=0.5\cdot(F_{feed}+F_{faeces}) \quad (11)$$

Where F_{feed} and F_{faeces} are given by expressions 6 and 7 respectively. *F* is calculated in $g/m^2\cdot day$.

They calculated the sedimentation rate F(r) stating that is generally highest beneath the central parts of a net pen and decreases with the distance r from the centre. They also say that current velocities are approximately normally distributed, but the dispersion increases with the variability of the current and with the sinking time as it is shown in expression 12.

$$T=\frac{H}{w(s)} \quad (12)$$

Where, H is the distance between the bottom of the net pen and the seabed, and w is the sinking velocity of the particles. The sedimentation at distance r from the cage centre, F(r) ($g\ m^{-2}\ day^{-1}$), is related to the emission from the net pens F ($g\ m^{-2}\ day^{-1}$) through the relationship shown in expression 13.

$$F(r)=\mu(r)\cdot F \quad (13)$$

The dimensionless dispersion function *μ(r)* (also called the normalized sedimentation or loading function) has values between the range 0–1. When there is no mean current, maximum sedimentation occurs beneath the centre of a net pen (r = 0). The sedimentation rate decreases with increasing distance from the centre of the cage. The maximum loading $\mu(r)$ decreases with increasing dispersion of particles and increases with cage size.

Some measurements about the settling velocities of both uneaten feed and faeces can be read in reference [43]. They measured an uneaten feed settling velocity of 0.128 m/s and a faeces settling velocity of 0.04 m/s.

5 Conclusions

We have given the state of the art of the models in existence and simulators related with marine fish farms, but none of them have been developed from the sustainability point of view. We have seen that there are few and they are developed to solve specific issues, not the whole problem of the sustainability. It urges to the necessity of developing a complete simulator dealing with all issues of the sustainability in marine fish farms.

We propose a flexible simulator focused on the sustainability that is able to choose the model to simulate several parts such as the bed shear stress, and the waste distribution.

We can use the simulator to improve the occupation of the space given by the fish farm cages. So, it could be used for planning fish farming cages outside the coast and to systemize the study of the environmental impact and the monitoring of the measures taken to achieve a sustainability management. Using real measurements (distance from sensible species, vulnerable or protected species, depth, ocean currents and other factors), we can employ the simulator to choose the best places where the cages could be placed with the objective of diminish the negative effects to the environment.

Simulations could be used for assessing the impact of a farm throughout a growing cycle, or to measure if the biomass is increased. Prediction of the dispersion of particulates during use of in-feed medicines may also be undertaken.

These types of simulations could encourage private initiatives and develop scientific researchers about the reserve effect, the environment enrichment associated to the marine fish cages and their interaction with artificial reefs.

Now we are finishing adding models to the simulator in order to allow users which model want to use in the simulation. All these models are from water or sediments parameters, from sensors to design or plan the system or from the environment. Future works will show the differences between our simulator and from real environment measurements.

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