FOAM, THE NEW BENTHIC DEGRADATION MODEL AND ITS CALIBRATION IN MEDITERRANEAN CONDITION: AN APPLICATION TO A FISH FARM

P. De Gaetano *, P. Vassallo, A.M. Doglioli, M.G. Magaldi
* Department of Physics, University of Genoa
degaetano@fisica.unige.it

EGU - Vienna, April 2009

slide 1 - TITLE

Good morning everybody. My name is Patrizia De Gaetano and I'm a PhD student in Geophysics at the Genoa University.
Today, I am going to present to you an interesting application of my studies in dispersion and degradation of the organic matter in the sea: the impact on the environment due to the aquaculture activity.

slide 2 - Aquaculture application

In fact, the aquaculture is the food production activity with the most rapid growth in the world, the latest data of FAO say that the 47 % of the consumed fish comes from farm, and in particular marine fish farm in intensive system.
For this reason, the attention to the possible impact on the surrounding environment due to the aquaculture activities increases.
In particular, the particulate waste, uneaten feed and faeces released by the cages, are the main cause of environmental impacts because the they increase the organic load of (on) the benthic environment and might determine changes in the community structure and functions and in the biodiversity of the benthic assemblages.

slide 3 - MAIN QUESTION

For these reasons, it's necessary to develop predictive tools able to assess whether or not, the establishment of a new farm or the permission for an increase in production of an already existing one, can result in a potential impact on the surrounding environment.
The numerical models can represent the right tools because they can be used to perform environmental impact predictions and to test different scenarios.
The modelling framework that we improved is able to evaluate and assess the impact due to a marine fish farm because it considers the benthic response to the organic load and not only the dispersion of the waste.

slide 4 - MODELLING FRAMEWORK

The modelling framework is composed by

- the hydrodynamic model, POM a coastal circulation model developed by the Princeton University;
- the dispersion model LAMP3D developed by Andrea Doglioli in 2000;
- and the benthic degradation module FOAM.

  Now, I will give you a brief description of the dispersion and degradation models.

slide 5 - LAMP3D

Lamp3D is a single particle lagrangian model.
In this kind of model, the dispersion phenomenon is reproduced by imaginary numerical particles and we can assign different characteristics at each particles, as a pollutant concentration and a settling velocity.
At each time step, the particle position is calculated on the basis of the flow velocity, computed by the hydrodynamic model POM, and a random jump representing the turbulence diffusion.
Then, the outputs are the 3D velocity field and the concentration in the water column.

slide 6 - FOAM

The FOAM module is based on the ideas expressed in the work of FW in 1997. They proposed an index of impact based on the ratio between the quantity of oxygen supply and the quantity of oxygen demanded by the sediment.
The oxygen supply is a function of the near bottom flow velocities and the oxygen demand is a function of the carbon flux to the benthos and it's strongly related to the rate of microbial metabolism.
These two variables are calculated by the dispersion model LAMP.

slide 7 - FOAM 2

Based on I parameter, FOAM identifies three levels of sediment stress:

- if I is more than 1 the oxygen supply is greaten than the demand and therefore the impact is minimal.
- When I is about 1 the impact is moderate
- while if I is less than 1 the sediment exhibits the azoic sediment endpoint and the stress results high.

On the basis of the calculated stress level, three different mineralization rates are taken into account and they are used by FOAM to compute the organic carbon concentration remaining on the seabed after the degradation.

slide 8 - FOAM 3

But the oxygen demand, representing the benthic metabolism, and the mineralization rates are computed by FW for a salmon fish farm in Atlantic condition. We want to apply the model to the Mediterranean fish farms so we want to measure these parameters in Mediterranean conditions.

slide 9 - Oxygen Demand

For these reason, the two sampling campaigns are performed in July and October 2006 in a typical Mediterranean fish farm, in witch the benthic data cover a large range of organic loads and microbial activity.
Sediment samples are collected in sediment traps and cores and the background sedimentation, benthic oxygen respiration and CO2 production are measured.
Considering the measurements of oxygen consumption and the organic carbon flux to the sediment, we obtained two different relationship one for the data measured in July and an other for the data measured in October.

slide 10 - Oxygen Demand 2

In fact in the Mediterranean condition, the relationship between the oxygen demand and the carbon flux to the sediment depend on the season and so on the water temperature contrary to what found by FW97 for the Atlantic conditions (gray line).

(Moreover the data measured by FW cover a higher range of values than the Mediterranean case, both for the carbon flux to the sediment and for the oxygen request. This could be due to several factor including the smaller size of the Mediterranean fish farm, the new generation of the feed employed and also the salmon are in need of more feed than the Sea Bream and Sea Bass.)

slide 11 - Benthic state

Moreover, we divided the measured data of O_2 consumption and CO_2 production on the basis of the three sediment stress level for each season and we computed the mineralization rates as the mean value of the inorganic carbon production rates for each sediment state and for each season.

slide 12 - Benthic state 2

The mineralization rates obtained for warm season are higher than the ones for cold season, (because in the warm season a greater microbial ability to degrade the organic load is observed) and in general in Mediterranean conditions, the mineralization rates resulted higher than in Atlantic ones (with the exception of October moderate stress level that showed a lower ability to degrade the organic load). In the highlight of the obtained results, we decide to test the two extreme cases, the warm and the cold season. Indeed we performed two sets of simulations considering the Mediterranean parameterization and we compared the results with the ones in De Gaetano et al., 2008 obtained considering the Atlantic parameterization.

slide 13/14 - AQUA fish farm

We considered an offshore fish farm located in the Ligurian Sea, in the waters in front of Lavagna.
The farm is composed of 8 floating cages, located at about 1.5 Km from the coast and the bottom depth is about forty m.
The productive target is 200 tons per year.
The reared species are the sea bream and the sea bass, the typical species reared in Mediterranean sea.

slide 15 - Settling velocity

The settling velocity values of the waste represent key parameters for aquaculture waste dispersion models. For this reason we used the values specifically targeting Mediterranean fish and their feed that two recent works have been measured.
Vassalo et al. in 2006 measured the settling velocities of the feed particles usually utilized in the Mediterranean fish farm and Magill et al in the same year, measured the settling velocities of their faecal waste.
We can note that the settling velocity of the particles depends on the dimension of the feed, the size of the fish and the species rearing.
The single arrow represents the slowest sinking particle, the double arrow the quickest one.

slide 16 - Model set up

The new simulations are performed considering:

- different waste typology, feed and faeces

- different setting velocity, the slowest and the fastest particles both for feed and for faeces
- different conditions of feed release, in continuous mode as the fish self-serviced or supplied manually by an operator twice in a day.

The results are presented in relation to:

- the extension of the area that the waste produce on the bottom,
- the organic carbon accumulation on the sea bed and
- the values of the benthic parameter I, representing the sediment stress conditions,

Moreover, we compare the results with the ones obtained considering De Gaetano et al. setup in witch we utilized the Atlantic mineralization rates, in order to evaluate the difference.

slide 17 - Impacted area

The impacted area represents the extension of the sea floor in witch there are still present particles after the degradation action. In this figure, I report the time series of the impacted area extension for the different experiments. The colors represent the two different settling velocities: the black line represents the impacted area of the slowly sinking particles, the red line the quickly sinking ones.

slide 18 - Impacted area 2

In general, for the feacal pellets the impacted area is smaller than for uneaten feed.
Moreover for feed, the slowly sinking particles are dispersed on a large area than the quickly sinking ones while for the faeces is the opposite. Considering the feed waste, both slowly and quickly sinking particles released in periodical mode are dispersed on a larger area than in the continuous case and the greatest impacted area is due to the slowly sinking feed in periodical released.

slide 19 - Impacted Area 3

Comparing the results of the simulated impacted area for the different scenarios, the relative difference between the impacted area extension in the six experiments remain the same considering the Atlantic and Mediterranean parameterizations:

- The impacted area associated to the faeces is negligible compared to the uneaten feed.
- the slowly sinking feed particles are dispersed in a larger area than the quickly sinking ones.
- the feed released in periodical mode are more dispersed than in continuously released.

Moreover the slowly sinking feed particles released in periodical mode form a greatest impacted area in all simulated set up.

slide 20 - Impacted Area 4

Considering De Gaetano et al. setup, the impacted area for the all six simulations, is greater than this calculated with Mediterranean parameterization. Moreover considering the warm season, the impacted area results smaller than considering the cold season.

slide 21 - Bottom Organic Concentration

The organic carbon concentration, remaining on the seabed after the degradation, for the feed particles almost linearly increases with time and the maximum values are reached in the case of the quickly sinking feed particles in periodical released.
The faecal wastes are completely degraded and they doesn't contribute to the organic carbon enrichment at the bottom.

slide 22 - Concentration

As well for impacted area, the general trend of organic carbon concentration remains the same in the three setup:
the maximum value is due to the quickly sinking feed particles released in periodical mode, while the faecal waste are completely degraded.

slide 23 - Concentration 2

A general increase is observed for the cold setup simulations while we can note a general decrease in warm season respect to the Atlantic parameterization.
During the warm season in witch higher mineralization rates are observed, the organic carbon concentration is lower than in cold season.

slide 24 - Index of impact

The three different sediment stress levels are represented with three colors: blue correspond to the high stress condition, green to the moderate stress condition and orange is the no stress one. Moreover we report the bottom velocity and the organic carbon concentration.
Two interesting results are reported.
When bottom current shows an intensification the sediment is in no stress condition, while when the current is weak or it is in direction reversal, the sediment presents an high stress condition.

slide 25 - Index of impact 2

The dependence of the sediment stress level on the current intensity is also showed in this scatter diagram, in witch I report the values of the I parameter for the different experiments in the simulated time. The red color represents the I parameter values of the quickly sinking particles, while the black color represents the ones of the slowly sinking particles. The current velocity near the cages computed by the model is also reported. When the parameter I is greater than 1.5 the sediments result in the no stress condition while if I is less the 0.5 the sediments are in the high stress level.
We can note that when the current is weak, the sediment results in the high stress condition, while when the current increases, the sediment is in the no stress condition.

slide 26 - Index of impact 3

Moreover, for feed particles periodically released, the parameter I is more frequently in the high stress condition than for the other experiments, while for the faeces the sediments are always in no stress condition.

slide 27 - Index of impact 4

The occurrence of the sediment stress levels show that for all setup the faecal pellets produce always a non stress condition of sediment and the maximum occurrence of high stress is due to the feed in periodical released.
In warm season, the occurrence of moderate and high stress conditions is highest than in cold season and in De Gaetano set up while in cold season the no stress condition is the most frequent.

slide 28 - Model validation

The outputs of the model are compared with field data measured during the five campaigns performed between the 2000 and 2005, in the four station around the cages as established (istablishid) by the Regione Liguria in the procedure (prosidur) of the assessment of environmental impact.
For each stations, three samples of sediment are taken and analyzed for total carbon.

slide 29 - Model validation 2

I report the field data in the four station surrounding the fish farm (blue bar), the model outputs for the new and old setup in order to facilitate the results comparison.
The organic load in the sediment are highest in station S2 and lowest in station S4 in agreement to model outputs.
Considering the data trend, the new model set up shows a best agreement with field data than the De Gaetano setup.
The comparison between absolute values of field data and model outputs is not possible since make too strong assumptions on sediment density and sampling methodology in order to express both in the same units.

slide 30 - Conclusion

In conclusion:

- The obtained results confirm that the uneaten feed, especially released in periodical mode, is the primary cause of the ecological impact on the benthos community, causing greatest organic carbon concentration on the seabed and more frequent conditions of high stress level of sediment.

- in Mediterranean condition the benthic degradation depends on the season and in particular on the water temperature.

- This dependence influences also the impact typologies: the warm season is characterized by a more frequent occurrence of moderate and elevate organic load and by a higher degradation causing lower organic carbon concentration on the sea bed and smaller impacted area.

  Managers and policy makers may take into account these differences in planning the installation of new fish-farms or the expansion of existing ones. A balance among the organic matter spread and the occurrence of different sediment states may be accurately evaluated with the application of the model.

- Moreover, the utilize of the Mediterranean parameterization improve the prediction capability of the module.

Further investigations are necessary to systematically characterize the Mediterranean fish farms. This can be achieved applying the entire model POM-LAMP3D and FOAM to several sites.
Moreover, several sampling campaigns should be carried out in order to obtain a whole range of variations of FOAM parameters with temperature and improve the prediction capability of the model.