Documentation Report for Appraisal Step

AS DocRpt-7.4.16 – Thermaikos Gulf

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WT 5.1 ESE COMPONENTS

5.1a Preparation of the ESE Models for Coupling to Simulation Model (SimMod)

1. *Data Input and Process*

A number of changes were made to the ESE components of the model presented for System Formulation as at that point the models were incomplete and with important structure failures and gaps. The SSA team managed to obtain extra data for the area, provided from the Department of Fisheries and Aquaculture of the Alexandrian Technological Institution of Thessaloniki from a previous study at the mussel farming area of Chalastra. The revised tables for data inputs and process are documented in tables 5.1a-f.

Complementary you can also see the document "Thermaikos AS Report 7.4.16 v.5" that is providing an overview of the model.

Ecological Component:

As the Policy Issue in the area of Chalastra is the "Sustainable management of the mussel farming activity", a great deal of concern from both the stakeholders and the scientific team was placed in the cultivation process and the way this was described in the model. A series of changes took place in the model, most basic of them being the "separation" of the mussel growth sub-model into two distinct parts: one simulating the net growth of mussels using a straightforward ecological approach taking under account the grazing of mussels on the major available food sources, i.e. phytoplankton and Total Organic Carbon, and a second one simulating the influence of the farming activity (placing of farms, farm density and characteristics) in the productivity of the farm. There changes happened mostly after the provision of the aforementioned sets of data.

During the simulation efforts of the FS the scientific team faced a problem concerning how to simulate the circulation results it the general area around the mussel farming area and also inside it. Finally, auxiliary data of water current velocities from an existing, validated 3D circulation model running for the greater area of Thermaikos gulf were used in order to build an advection sub-model that is used to determine the concentration of substance entering the mussel farming compartment from the neighbor compartments, based on the assumption that the advected quantity of substance is a function of the flow between the compartments and the variation of the concentration of the substance. Using salinity as the advected variable, the validity of the component was verified and an exchange coefficient between the upper and lower layer of the mussel farming area was calculated. Additionally, in order to describe the influence of the existence of the whole farming are in the circulation of water inside it, the scientific team created a "circulation pattern coefficient" matrix, based on the results of 2D circulation model in the farming area and wind data for the area of interest. These components were not constructed during the formulation step. More details can be found to the process tables 5.1.d-f and also to the AS short report.

The ecological approach that was designed in the formulation step was altered significantly. The level of complexity of the system and the limited data resources would lead in uncertain assumptions and parameterizations, so a more simple approach than the first was applied, based mostly in the combinational use of the advection component described above and parameterizations of the available data. More details can be found to tables 5.1.d-f and also to the AS short report.

The stakeholders are aware of these simplifications and agreed that the formulation of the model should be adapted to the current data availability, but also it should be structured in a way that it can easily be upgraded if new data sets and information become available.

Economical Component

The economical component was altered almost completely, or to be stated more accurately it was developed in a way that was considered better in terms of "serving" the policy issue and the formation of scenarios. The production functions that were presented in the formulation step were kept outside EXTEND. Substitutionally a Cost – Benefit analysis of the individual mussel farm was developed in the EXTEND model, in a form of a multiple choice panel, affected from environmental, social and technical characteristics. Due to absolute lack of economical data, a questionnaire survey was undertaken from the scientific team of AUTH, to determine a range of values for the basic categories of costs in the area and also for the farming techniques followed from the farmers. The Cost – Benefit sub-model is connected to the environmental component through the farm's annual production and it is incorporating the number of days with occurrence of Harmful Algal Blooms, an environmental parameter that nevertheless can not be predicted and it is affecting the activity mostly economically[1]. Finally the model is calculating the profit of the individual farm, being at the same time a platform for the testing of multiple scenarios. More details can be found to tables 5.1.d-f and also to the AS short report.

Social Component

During the formulation step the scientific team realized that although there is a lot of social information available for the area of Chalastra, it is not in a form that can be utilized in a simulation model, and thus the model was lacking a social component. This was altered in a small scale by using the social part of the model mostly as a switch (on/off) and an aggregator. Thereby, the social component is incorporating the major scenario formatted within the model in the form of the basic management and policy choice: *no institutional management* (present situation, illegal activity, excessive cultivation techniques, etc) or *institutional management* (law enforcement, management of the area according to the existing regulations, etc). At the same time, the amount of money that is entering the local community deriving from the activity is estimated, both as a household income and also as retributive benefit, in order to identify the welfare of the community under several scenarios. The narrow simulation effort is accompanied by a social analysis that is trying to incorporate the available information. More details can be found to tables 5.1.d-f and also to the AS short report.

2. Document of the data used for each of the ESE Hindcast runs.

Verifications were run for an annual period (2004-2005) where there were available data for that. The ecological sub – models "advection of substance", "phytoplankton biomass" and "mussel production" were optimized against observed data (see data inputs in table). Unfortunately there were insufficient observation data points to be used for further hindcast checks.

The economical variables could not be the subject of a hindcast run, as the only data available were those collected for the development of the model. Nevertheless, the

[1] As noted during the DS, the occurrence of HAB's is not affecting the quality or health of mussels, but can affect humans that consume the mussels, thus when blooms occur the mussel farming area remains closed and depended to the time of occurrence, costs a lot of extra effort for the maintenance of the production.

development was based in realistic and well balanced assumptions so the final results are also moving inside an area of values that are corresponding to reality.

For more information please refer to the table 5.1.g at the end of this report.

3. Submit Generic model building blocks.
4. Please, submit your ESE models to the WP5 directory on the ftp server.

The AUTH team is currently in discussion with WP8 in deciding which blocks are most suitable for the model building block library. The proposed blocks to be submitted to the model library are listed in table 5.1h at the end of the document.

5. A brief technical explanation

The policy issue selected during the initial phase of the project from the scientific team and the stakeholders is the examination of the management of mussel culture activity in the area of Chalastra, Thermaikos gulf.

The quality and quantity of the mussel production is affected most significantly from the availability of food and from the cultivation techniques used in the area. The last decade certain changes, regarding both the environmental and social aspects of the system, influenced majorly the mussel farming activity creating pressure on the environment and the local population. The operation of the WWTP of Thessaloniki altered the nutrient balance in Thermaikos gulf. At the same time, due to institutional and management mistakes and failures, 60% of the owners of long-line mussel farms are at the moment operating illegally without activity permission. At least half of the illegal farms were placed in the area without any authorization or rural plan. All of the raft mussel farms that are auxiliary to the long-line systems are operating illegally. The activity is under no official institutional control having as a consequence illegal and extreme mussel farming techniques, in order to maximize production and profit: increasing the size of the farm, reducing the distances between the cultivation ropes, etc. As a result of all these above, the Chalastra's mussel quality and production is declining.

The purpose of the model is to investigate how the production is affected under different environmental conditions and cultivation techniques. Various scenarios can be investigated including changes in: the farm characteristics; the legality status of the farm; the amount of invested capital in the activity; the irrigational inputs, the number of Harmful Algal Bloom occurrence; the number of the farms in the area; the institutional management status of the whole area. At the same time, in a more theoretical level, extreme scenarios can be applied investigating what would happen if there was a major alteration in the advected quantities of substances in the mussel compartment.

The output of the ecological component describes the quality-quantity of the mussel production. The output of the economical component is representing the Cost – Benefit analysis of an individual mussel farm and thus the viability of the activity under certain conditions. Finally the social component is has two outputs: (1) an estimation of the social welfare of the community because of the money entering the community through the activity and (2) an estimation of the social benefit because of the retributive benefits of the activity. The economic impacts of the various scenarios will be analyzed regarding costs of implementation against real and non-market benefits during the Output step.

5.1b Results of the ESE Interpretive Analyses

1. A*dditional data*

In order to develop the economic component of the model the scientific team of AUTH performed a survey to a sample population of the mussel farmers of Chalastra in order to acquire data concerning several cost categories and also implemented farming techniques. Also, as mentioned earlier, the Department of Fisheries and Aquaculture kindly offered data concerning several variables, most important of whom being the data of mussel production in different cultivation sub-areas. More details can be found to tables 5.1.d-f and also to the AS short report.

WT 5.2 SYSTEM SIMULATIONS

5. 2a The Simulation Model (SimMod) Construction

5.2a.1 Model Setup

For the calibration and verification of the descriptive model data sets were used collected during the period 2004-2005. The main drivers for the system are meteorological and ecological data: water current velocities; nitrate phytoplankton and TOC concentrations, solar irradiance, water temperature, wind direction and velocity. Additional key drivers are the mussel farming techniques. When not available in that form the original data sets were converted into daily values for each variable. Unknown parameters were evaluated using literature and the software's optimizer block. The values were optimized against the observed data for "advection sub-model" (using salinity, a conservative variable), for phytoplankton concentration (phytoplanktonic carbon) and mussel production (kg of mussels per m of cultivated sock). However the set of observed values was not large enough to separate into two sets, using one for parameterization and the other for validation, so the same set of observations was used for both processes. As mentioned already it is not possible to run a hindcast run for the socio-economic component as there are no available data and the formulation is based in logical financial calculations.

5.2a.2 Link ESE Components

The ecological component is linked to the economical component through the "*mussel production*" variable. The "mussel farm area" sub-component of the model is separated into four sub-areas of mussel farming and a reference area[2]. Each sub-area is represented in the model from a "*mussel farm model*" incorporating both the ecological and the economical part of the individual farm. In the ecological part the annual production of the farm and correspondingly the area is calculated and transferred to the economical part were the annual revenue is calculated. The two components are also reacting through the "farm characteristics" that are determined in the ecological component, as they affect the production in multiple ways, but are also important input information for the calculation of costs and revenue. The connections are not visible in the model, as both EXTEND databases and "throw & catch" blocks are being used to make the model look more neat and easy to present and understand.

The economical component is connected to the social component through two variables: (1) the profit of the mussel farm that is used to calculate an estimation of the amount of money entering the local community, i.e. a rough estimation of the local welfare and (2) the legality costs, that when deriving from a legal mussel farming establishment are driven back to local municipality as retributive benefits.

The social component is incorporating a major scenario switch on/off, as mentioned earlier. The institutional status of the area is "reacting" with the ecological and economical component, altering the farm characteristics, the number of the farms in the area (ecological component) and the legal status of the mussel farm (economical component).

Special note must be given to the internal feedback loop in the ecological component: the mussels are feeding on phytoplankton thus the mussels biomass growth is one the major variables influencing the phytoplankton biomass in the area.

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[2] In reality there are not any mussel farms placed in that particular area, but as there were available data for the major mussel food sources, the scientific team decided to run a comparison simulation, in order to demonstrate the influence of several parameters in the mussel growth.

Approximations involved:

- the model assumes that the total of the mussel production of each farm is sold and calculates the revenue based straightforwardly, using a constant sell price, this being a generalized truth,
- in reality, at the present state, most of the 55 long-line mussel farms have different characteristics, but as having 55 sub-models working in EXTEND would make the simulation very slow, the area is separated into four sub-areas, assuming that in every one of them the farming characteristics and the legality status are the same,
- as it is not possible to ecologically predict HAB's occurrence and duration and they are not causing quality reduction to the mussels, the events are treated as economical parameters: assuming that 30 days of HAB's occurrence annually is considered normal for the area, the approximation made states that for every extra 15 days of HAB's occurrence a certain amount of labor has to be invested in order to maintain the production.

5.2a.3 Run & Test Simulation Model

1. *Final Inputs, processes or major modifications.*

Changes to the inputs and processes are described in section 5.1a.1 and are documented in tables 5.1a-f at the end of this document.

2. Noteworthy problems and how they were resolved.

The concentration of Total Organic Carbon is not simulated by the model because of lack of important data for the formulation of the component. The limited available data from the stations Mi and DA3 were used for a parameterization, i.e. an adaption of the data to a trigonometric, time related equations (please refer to the AS short report for more information). The same technique was used for the parameterization of the concentration of inorganic nitrogen in the neighbor compartments, in order to redeem the model from input data tables and to be able to manipulate easier these data for uses in several scenarios.

5.2a.4 Hindcast with Policy Issue

Ecological component

The model is descriptive. There were not enough data qualitatively and quantitatively to support hindcast. The limitation of this fact was discussed thoroughly between the scientific team and the PG, and it was decided that the model will be used as a guide to the dynamics of the system and as a tool in order to demonstrate the potential of the SAF and of Integrated Coastal Zone Management.

The main goal of the ecological component of the model, with respect to the Policy Issue, is to simulate the mussel growth in the long – line cultivation system that is mainly used in the area, in order to identify the importance of several aspects and techniques to the yearly production. Most importantly for the policy issue and the scenarios, the model is trying to simulate the mussel production of an individual mussel farm and aggregate the result of the farming area. The simulation of the production is affected from i) the availability of food (phytoplankton & TOC), ii) the individual mussel farm characteristics, iii) the placing of the farm in the area and iv) the environmental conditions (temperature, wind, etc).

The advection component was verified using salinity data of the period 2004-2005. The model produces values which are visibly verifiable similar to the observed data. Figures 1 and 2 shows the observed values of salinity in the mussel compartment compared to the values produced by the model.

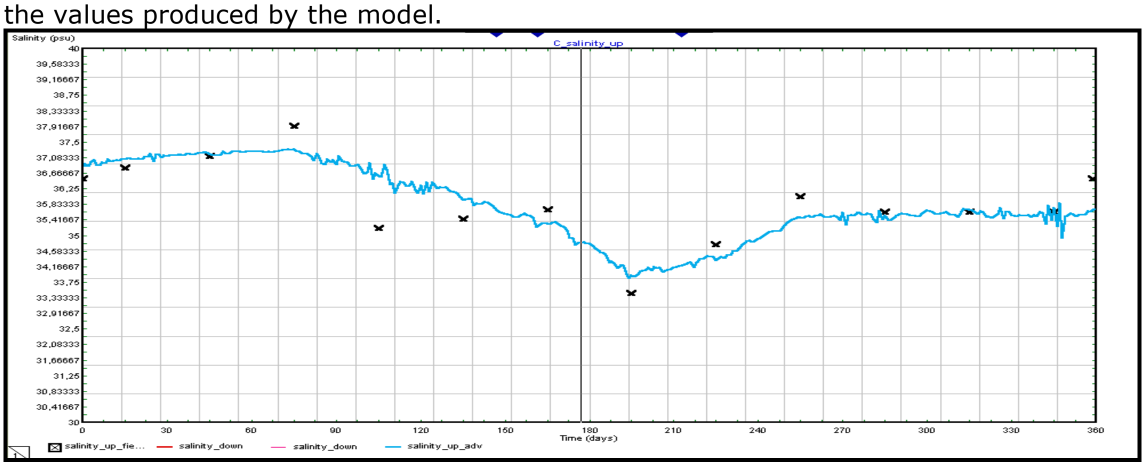

Figure 1: Upper sea layer salinity as a result of the yearly "salinity advection" component run – validation against observed data.

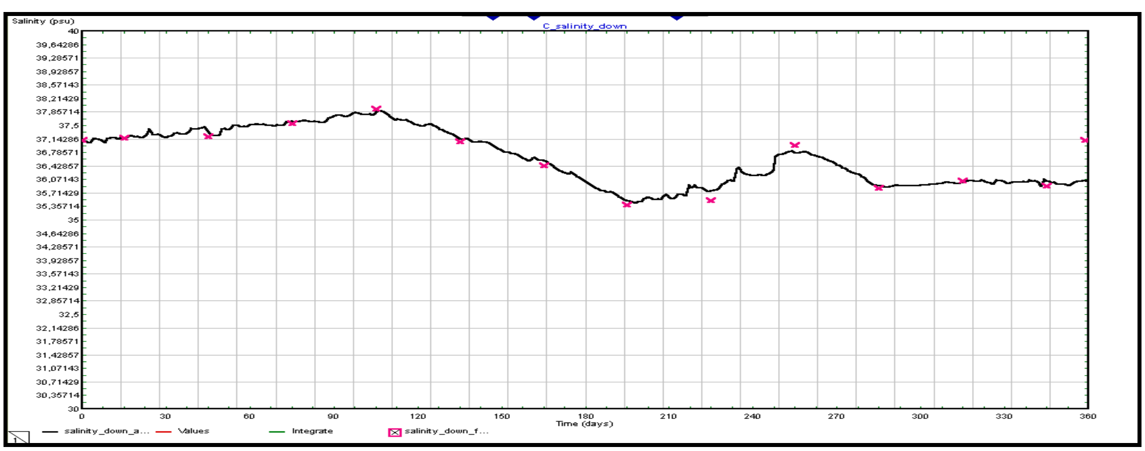

Figure 2: Lower sea layer salinity as a result of the yearly "salinity advection" component run – calibration against field data.

The model produces results of very satisfying accuracy, leading to the conclusion that can be safely used to determine the amount of both inorganic nitrogen and phytoplankton advected from the neighbor compartments to the mussel compartment, although similar validations of the advection component can not be ran as both substances are not conservative parameters and their concentration it the water is influenced by other means also.

An example of the phytoplankton sub-model, calculating the phytoplankton biomass taking under account the advection from neighbor compartments and the primary production created in the mussel compartment, for the upper layer is presented in figure 3. The model produces results within the correct order of magnitude, but however is also visible that the model does not include some of the detail, as it is obvious that in certain days the model overestimates the value of the concentration of phytoplanktonic C in the mussel compartment. This is probably caused by certain limitations in the design of the model, as the design neglects other possible sinks of phytoplankton, except natural mortality and (when present) mussel consumption. Yet, as it was reviled during the sensitivity analysis contacted for the mussel growth equation, this will not influence importantly the dynamics of the system.

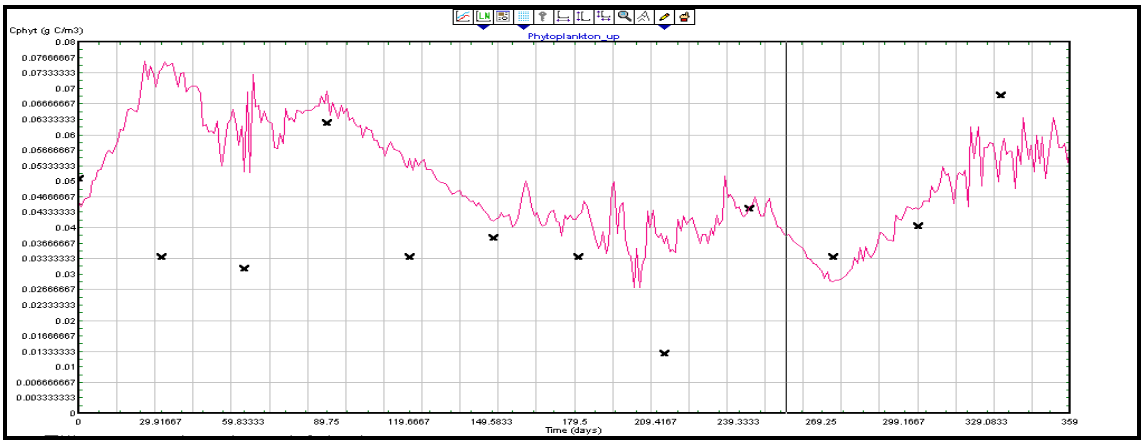

Figure 3: Primary production and advected phytoplankton available for mussel consumption.

An example of the mussel growth sub-model, taking under account the cultivation techniques, is demonstrated in figure 4. The model produces satisfactory results compared to observation data of mussels, collected from the mussel farm placed in the station M1. The mussel model is taking under account all the basic parameters influencing mussel growth in a farm.

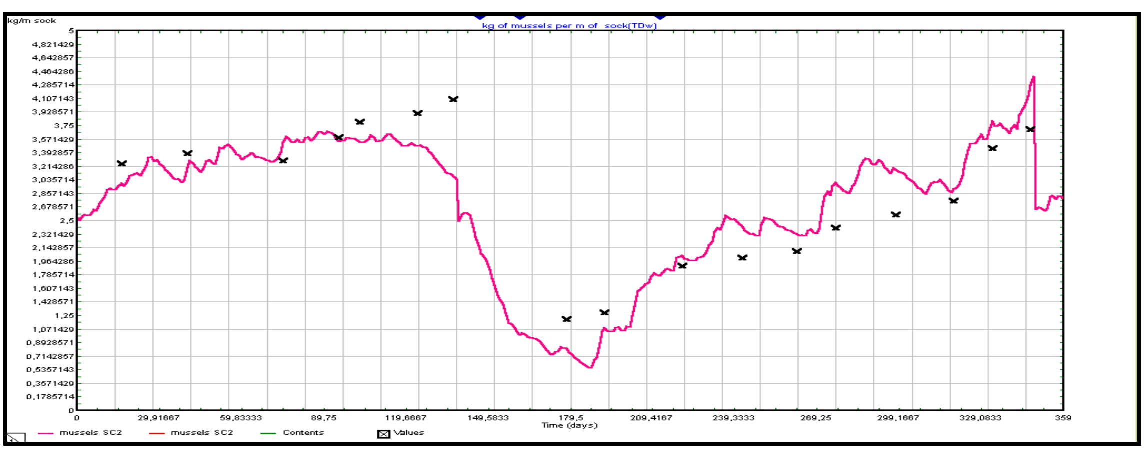

Figure 4: Simulation of the mussel SC2 production in a standard farm, kg of dry C per meter of cultivated sock and field observations from station M1.

Economic and social components

As described earlier in this document hindcasting or verifying procedures were not contacted for the economic and social parts of the model as either the formulation of the models or the availability of data allow it. Both the assumptions and the results of the models are verified through the data collected from the questionnaire survey.

The results of the overall sensitivity analysis of the model will be analytically presented during the preparations for the scientific article.

5.2b Results of the Simulation Model Runs

5.2b.1 Edit final Scenarios

The basic scenarios under consultation with the PG are:

1. Evaluation of the impact of the modification of agricultural inputs, quantitatively and qualitatively, to the mussel production of the area. Is this impact important? What will be the economic impact regarding costs and benefits?
2. Evaluation of the impact of different management practices, concerning the individual farm and the whole farming area, to the mussel production of the area. Is this impact important? What will be the economic impact regarding costs and benefits?[3]

1. *Submit any technical information* that describes the scenario.

Most of the changing variables, parameters and information in the model are controlled via pop-up menus, where the user can see the choices and decide the combination of management options. Each combination of management options in the model can be described as a scenario, but presented above there are the two basic scenarios investigated by the simulation model and presented in this report.

The first scenario is demonstrating the influence of the alteration of agricultural inputs in the mussel farming area. The agricultural inputs are taken under account in the calculation of the concentration of inorganic nitrogen, in the advection block. The scenario is based in a double assumption: (1) that the quantity of the agricultural inputs is altered, i.e. if the area is expanded and more water is used and then discharged in the water compartment of the mussel farming area and (2) the quality of the agricultural inputs is altered, i.e. the agricultures decide to use more or less nitrogenous fertilizer. The scenario is controlled by pop-ups that are altering the quantity and the quality of the agricultural inputs in the "inorganic nitrogen advection block". These variables are representing the *Irrigational scenario variables*.

The second scenario provides a very wide range of different management variables and options, but for organizational and interpretational reasons it is divided into two major policy options, controlled from the "social component" of the model, via the "institutional – not institutional management" option provided. This option is controlling certain parameters connected to the mussel farm, both ecological and economical, as the farming characteristics and the legal status of the farm.

In summary, the choice variables and parameters used for the scenario analysis can be divided into the following sections:

[3] There is third basic scenario that at the moment is under implementation, concerning the opportunity benefits of the existence of the mussel farming activity in the area. There are certain issues to be addressed before the scientific team is able to contact this investigation, but efforts are made towards this direction.

Environmental drivers (ecological component):
Irrigational: (1) quantity of inputs, (2) quality of inputs,
External: alteration in the greater area of Thermaikos gulf, i.e. qualitative alteration of the inputs from the neighbor compartments.

Technical drivers (ecological & economical component):
Cultivation line number
Distance between the lines
Distance between the socks
Sock length

Socio-economic drivers (economical & social component):
Automation equipment investment
Days of Harmful Algal Bloom occurrence
Legal status
Institutional status

2. *Significant changes* to the Simulation Model (scenario versions).

The model is formulated and structured in that way, so that there are not any significant changes made, during the different scenarios implementation. Changes made consist in altering different variables, parameters or information inputs.

5.2b.2 Input data for Scenarios

The input data (changing variables, parameters and information) for each scenario are documented in table 5.1i at the end of the current document. There are no additional input data sets used in the scenario analysis. Where necessary certain inputs (agricultural inputs, compartment substance concentrations, and phytoplankton and TOC concentrations) were altered by multiplying by a factor, between 0.5 and 2. This kind of analysis certainly involves approximations and gaps and for a more precise analysis, the model should be expanded to include more detail. This will be achieved during System Output.

5.2b.3 Conduct and evaluate Scenario Runs

Scenario 1: Alteration of agricultural inputs qualitatively and quantitatively.

Five runs were conducted related to this scenario. The data input were altered as follows: (1) Current agricultural inputs, (2) Double agricultural inputs with the current inorganic nitrogen concentration, (3)Half agricultural inputs with the current inorganic nitrogen concentration, (4) Current quantity with double concentration of inorganic nitrogen, (5) Current quantity with half concentration of inorganic nitrogen. Finally the influence of these alterations to the phytoplanktonic biomass available for mussel consumption was investigated, as it is presented in Figure 5. It is obvious that the influence is not significant. More details in the interpretation section above.

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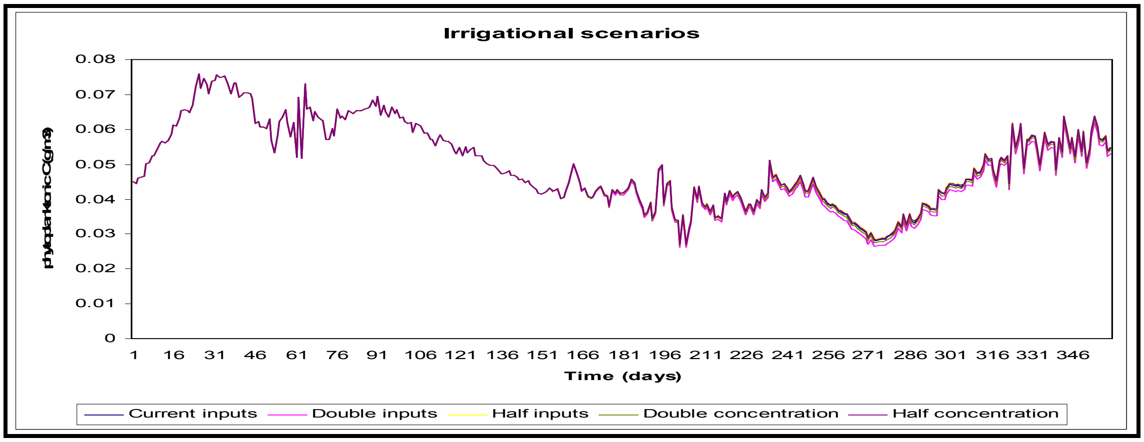

Figure 5: The influence of the alteration of agricultural inputs in the phytoplanktonic biomass available for mussel consumption.

Scenario 2: (Basic) Comparable investigation between the present state (random) and the state under the implementation of institutional management.

Tables 1 and 2 present the changing technical drivers and the results regarding the individual, area and total profit on both scenarios. Figures 6 and 7 present graphically the simulation of production in the four mussel farming areas, demonstrating clearly the high significance of the mussel farming techniques in the production.

Table 1: Present state parameters, as stated in the scenario and estimation of the individual and total profit from the model.

Present state	**area 1**	**area 2**	**area 3**	**area 4**
status	illegal	legal	illegal	illegal
no of lines	14	12	16	12
line distance (m)	9	10	8	5
sock distance (m)	0.6	0.4	0.4	0.8
sock length (m)	3.25	3	3.5	3.25
no of farms	13	18	12	12
individual profit (€)	41925.55455	42919.8824	40353.558	48339.6453
area profit (€)	545032.2092	772557.8831	484242.69	580075.7436
total profit (€)	2381908.53			

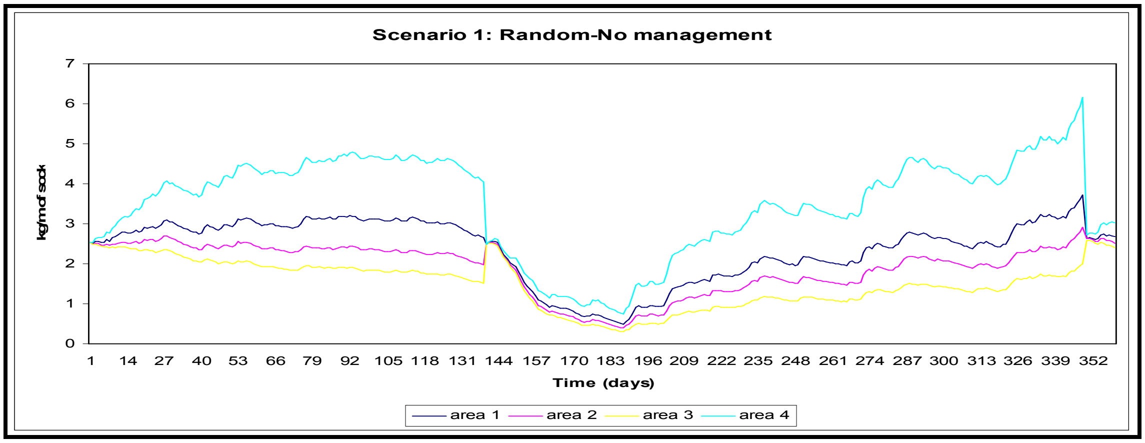

Figure 6: The estimated course of the mussel production (kg/m of sock – dry weight) in the four mussel farming areas at the present state scenario.

Table 2: Institutional management parameters, as stated in the scenario estimation of the individual and total profit from the model.

Institutional management	**area 1**	**area 2**	**area 3**	**area 4**
status	legal	legal	legal	legal
no of lines	10	10	10	10
line distance (m)	10	10	10	10
sock distance (m)	0.6	0.6	0.6	0.6
sock length (m)	3	3	3	3
no of farms	13	18	12	12
individual profit (€)	47479.7	45587.4	41815.9	50803.0
area profit (€)	617235.9	820573.7	501790.8	609635.6
total profit (€)	2549236.0			

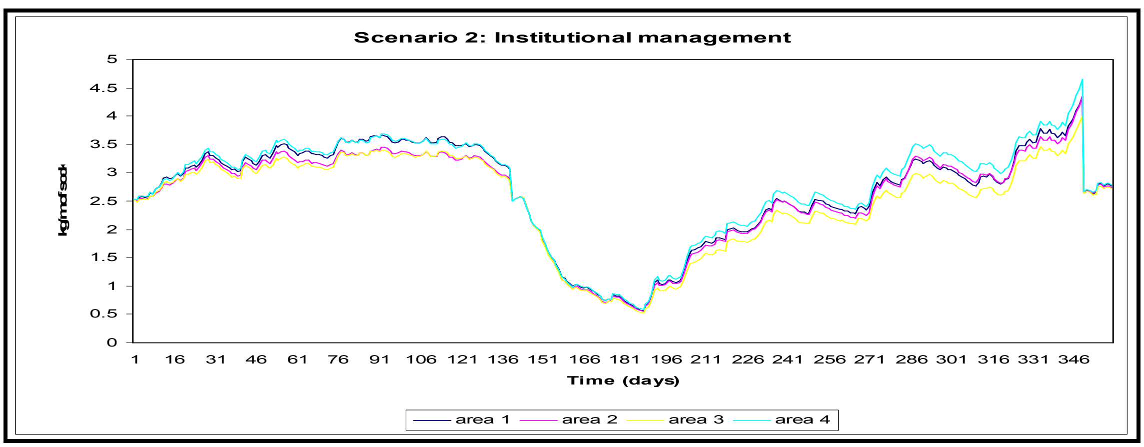

Figure 7: The estimated course of the mussel production (kg/m of sock – dry weight) in the four mussel farming areas at the institutional management scenario.

There is wide range of scenarios that can be implemented concerning changes in the drivers as mentioned earlier. For the time being those are the results to be presented.

More information and analysis of other scenarios will take place during the activities and reporting of the Output step, including the preparations for the scientific paper.

WT 5.3 OUTPUT PREPARATIONS

5.3a Complete Interpretive Analyses

5.3a.1 Describe and Interpret Scenario Results

Please refer to the Scientific Report

5.3a.2 Complete Collateral Analyses

Please refer to the Scientific Report and *WT5.1b.*

5.3a.3 Draft Conclusions of Simulation Analysis

Please refer to the Scientific Report.

5.3b Generate Scientific Products

Note some of these will be documented and archived during the Output Step.

5.3b.1 Interactive versions of Simulation Model

The model is constantly redesigned in order to increase the usability for the stakeholders. In order to decrease complexity of the appearance of the model most the connections between the components are made using Extend databases and "throw-catch" blocks. Screen captures and examples are shown in Appendix 1.

Following the SSA12 – Barcelona example, the modeler is planning to put the various management options and scenario choices in visible points and create the possibility to open and close the relative graphs by choice. There is also a plan for the design of generic blocks in two forms, one for the specific case of SSA 16 and one more easily applicable as it would be straiten from all the connections via databases. These actions will take place during the Output step and the

5.3b.2 DST requirements and other visualizations

The Policy Issue in the area of Chalastra is not really implying very much conflict between activities, but there are certainly conflicts inside the community of the mussel-farmers and misunderstanding issues with the public services. The scientific team is preparing the scenarios under consideration for the DST and the deliberations but alternative advice of how to implement the DST without the use of electronic means will be particularly useful as putting the stakeholders in front of a computer is not regarded as a viable choice.

5.3b.3 Discussion with Output Step regarding SSA needs

SSA 16 hasn't received specific recommendations for the implementation of the Output step in Chalastra, but in general the team will try to follow and include the useful advice given in the WP6 documents.

5.3c.3 Maintain Contact with Participant Group

The Policy Group of SSA 16 is majorly consisting of mussel farmers, some residents of the area of Chalastra and a representative of a public body (Authority for the Management of the protected area of Axios – Loudias – Aliakmon estuaries) with not direct authorization in the mussel farming area. Although the directly implicated public bodies were interviewed twice during the Design Step of the project and asked to participate to the PG, there were certain hesitations and no participation at last.

In the most recent PG five people attended: four mussel farmers, including the president of one of the two existing working associations and the public body representative. We will put effort in raising the number of the participants during the Output step, when we will officially present the results of this effort. Recently an other public body, the Authority for Management of Thermaikos gulf, has shown risen interest for the results of the efforts made until now and promised to participate actively to the actions planed during the Output step.

References

Arhonditsis G., Tsirtsis G., Angelidis M.O., Karydis M., (2000). "Quantification of the effects of non-point nutrient sources to coastal marine eutrophication: application to a semi-enclosed gulf in the Mediterranean Sea". Ecological Modelling, 129, pp.209-227.

Chapelle A., Ménesguen A., Deslous-Paoli JM., Souchu Ph., Mazouni N., Vaquer A., Millet B., (1999). "Modelling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters farming and inputs from the watershed". Ecological Modelling, 127, pp.161-181.

Kourafalou, V.H., Tsiaras K., 2007, "A nested circulation model for the North Aegean Sea", Ocean Science, 3, pp.1-16.

Moriki A., Galinou-Mitsoudi S., Petridis D., Kosti D., Savvidis Y., Dimitriadis X., Koutitas Ch., (2008). "Environmental impacts of intensive mussel culture in the coastal waters of the gulf of Thessaloniki (N. Greece)". Fresenius Environmental Bulletin, 17, No 11b.

National Center of Marine Research, (2001).). Scientific report on the management of mussel production zones in Thessaloniki and Thermaikos gulfs (in Greek).

Savvidis Y., Antoniou A., Dimitriadis X., Moriki A., Galinou-Mitsoudi S., Alvanou L., Petridis D. and Koutitas Ch. (2007) "Hydrodynamics in a mussel culture area in Thermaikos" Gulf' Proc.8th Int. Conf. on Mediterranean Coastal Environment, (E.Ozhan editor), Alexandria Egypt, 2007, Vol. 2, pp.1263-1274.

Tables 5.1.a-c Input data and information of the ESE components

Table 5.1a: Input data and information of the Ecological component – advection of substance

Ecological component – advection of substance					
Name	**In Model**	**Units**	**Block No**	**Source**	**Data analysis**
Water flow Q(i)	Water flow between neighbor compartments and mussel farming area for a typical year, used on the advection block to run the process.	m^3/day	Extend DB	3D circulation model for Thermaikos Gulf (Kourafalou & Tsiaras, 2007). Use of typical year	Model results converted into daily values
Salinity (S)	Neighbor compartments – Mussel compartment Calibration – validation of the advection component	psu		Aristotle University of Thessaloniki	Statistical (mean month values)
Inorganic Nitrogen (InN)	Neighbor compartments – Mussel compartment Calculation of the InN advected and the InN available for phytoplanktonic growth on the mussel compartment.	mg/m^3		HCMR	Statistical (mean month values) + parameterization using trigonometric equations
Phytoplanktonic C (Phyt) or Chl-a	Neighbor compartments – Mussel compartment – Mussel farming sub-areas Calculation of the phytoplanktonic biomass available for mussel consumption	g/m^3		HCMR Alexandrian Technological Institution of Thessaloniki, Department of Fisheries and Aquaculture	Statistical (mean month values)
Solar Irradiance (I)	Used to calculate the limitation of phytoplanktonic growth because of light.	MJ/m^2/day.		Aristotle University of Thessaloniki	Mean annual measurements for the last decade, provided in Watt/m^2, converted into MJ/m^2/day.
Compartment volumes	Used to the advection component	m^3	Extend DB		
Agricultural water inputs	Used as inputs to the advection component	m^3		Aristotle University of Thessaloniki – Department of Agronomics	Monthly estimations of a mean concentration of InN based on an agronomic study contacted in the area.

Table 5.1b: Input data and information of the Ecological component – mussel farm area

Ecological component – mussel farm and area					
Name	**In Model**	**Units**	**Block No**	**Source**	**Data analysis**
Mean water velocity (u_mean)	Mean water velocity in the mussel farming compartment, used on the calculation of the density inhibition coefficient	m/sec	Extend DB	3D circulation model for Thermaikos Gulf (Kourafalou & Tsiaras, 2007). Use of typical year	Statistical analysis of the model results
Total Organic Carbon (TOC)	Mussel compartment, inside and outside the farming area	g/m^3		HCMR Alexandrian Technological Institution of Thessaloniki, Department of Fisheries and Aquaculture	Statistical (mean month values) + parameterization using trigonometric equations
Sea Temperature (T)	Sea temperature affecting mussel mortality	º C		Aristotle University of Thessaloniki	Statistical (mean month values) + parameterization using trigonometric equations

Table 5.1c: Input data and information of the Economical component – Cost Benefit analysis

Economical component – cost benefit analysis					
Name	**In Model**	**Units**	**Block No**	**Source**	**Data analysis**
Mean invested capital per cultivation line	Calculation of establishment depreciation cost	€	Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical
Mean consumable material cost per cultivation line	Calculation of operational cost	€	Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical
Mean effort man-days required from farmer per cultivation line	Calculation of gasoline cost	€	Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical
Mean effort man-days required from workers per cultivation line	Calculation of labor cost	€	Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical
Mean extra effort required for every 15 days of HAB's occurrence	Calculation of extra labor costs	€	Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical
Information concerning salaries, automation equipment, price of gasoline, price of mussels, etc	Cost and Benefit analysis of the individual mussel farm		Extend DB	Questionnaire survey contacted by AUTH scientific team	Statistical

Tables 5.1. d-f Key processes described in the ESE components

Process name	**Phytoplankton Light Limitation**
Function in model	Calculating the limitation produced because of light intensity on the phytoplanktonic growth.
Variables IN	Light irradiance in the surface of the water body (Watt/m^2), concentration of Chl-a (mg/m^3).
Information IN	Maximum depth of the water compartment - body (m).
Variables OUT	The coefficient representing the light limitation no the phytoplanktonic growth (dimensionless).
Formulation	fL=ln((1+Irradiance/Ik)/(1+Irradiance*(e^(-k*z))/Ik))/(k*z) where: Irradiance: is the surface irradiance (MJ/m^2 per day), Ik: is the half saturation light intensity for phytoplanktonic growth (MJ/m^2 per day) z: is the maximum depth of the area (m) k: is the light extinction coefficient (m^{-1}), that is related to chlorophyll concentration with the equation k=kw+kc*C, kw: is the extinction of water without chlorophyll(m^{-1}), kc:is a coefficient for light attenuation due to chlorophyll (m^3/mg per m)
Reference	Taylor & Joint, 1990. Arhonditsis et al. 2000.
Validation data	Not validated – no data available, only margins for the coefficient values. However this equation has been used successfully in other Greek study areas, with similar irradiance and chl-a measurement and produces similar results inside the aforementioned margins.
Extend block(s)number	(4136) (13) in the model
Comments	The block is candidate for a generic use. A dialog box is used in order to choose and change crucial parameter values.

Process name	**Advection of substance**
Function in model	It is designed to calculate the advection of substance in the two layers of the mussel farming water compartment, using the concentration of the substance and the current velocity in three neighbor compartments and any external water inputs to the compartment such as agricultural inputs.
Variables IN	Mean daily current velocities at the three inter-surfaces between the mussel and the neighbor compartments (m/sec). These data are provided from an existing circulation model running on the greater area of Thermaikos gulf. Concentration of substance in the neighbor compartments. Units are of choice per m^3 and are usually depended on the substance.
Information IN	Volume of the upper and the lower layer of the mussel farming compartment. Exchange coefficient between the upper and the lower compartment (after optimization of the modulus by using salinity, a conservative variable, as the advected substance).
Variables OUT	Concentration of substance in the mussel farming compartment (upper and lower level). Units of choice per m^3, mostly depended on the advected variable.
Formulation	dC=Total_Flux/Volume -exch_coeff*(C-C_down); where: C is the concentration of the substance, Total_Flux is the sum of the calculated fluxes from the other compartments and alternative sources, Volume is the volume of the compartment, exch_coeff is the coefficient determining the exchange between the upper and the lower layer of the compartments.
Reference	Sub-model created for use with this model, using basic information of the system and data from existing, validated circulation model of the area.
Validation data	Annual salinity data (2004-2005) were used for the validation of the model and the calibration of the exchange coefficient between the upper and the lower compartment, that was then used as standard to the advection equation.
Extend block(s)number	(4126)(3)- Inorganic Nitrogen advection, (4287)(0) – Phytoplankton advection.
Comments	Although this block is designed and documented in a generic form it is rather unlikely to be used in another case without major changes, as the number of the neighbor compartments or the external inputs. This design is case specific and it is advisable to be used as a guide and not as generic block, if needed in similar cases.

Process name	**Calculation of Inorganic Nitrogen biologically consumed in the mussel farming compartment**
Function in model	It is designed to calculate the Inorganic Nitrogen that is used for the biological procedures, mosti important of whom is phytoplanktonic growth in the mussel compartment. The calculation is based in the calculation of the advected InN from the neighbor compartments and the measurements of InN in the mussel compartment, as the data available were inadequate for the formulation of an ecological function. The calculated concentration is used to feed the phytoplanktonic growth equation.
Variables IN	Mean daily current velocities as stated in the advection process above. Concentrations of Inorganic Nitrogen in the neighbor compartments and the mussel farming compartment, substituted by trigonometric equations (validated using field data of the period 2004-2005) (mg/m^3).
Information IN	Volume of the upper and the lower layer of the mussel farming compartment (m^3). Exchange coefficient between the upper and the lower compartment (dimensionless). Amount of Inorganic Nitrogen sinking in the bottom (%).
Variables OUT	Concentration of Inorganic Nitrogen consumed for phytoplankton growth (g/m^3).
Formulation	InN consumed = InN advected – InN mussels where InN consumed is the concentration consumed for phytoplanktonic growth, InN advected is the concentration entering the mussel area from the neighbor compartment, InN mussel is the trigonometric equation substituting the remaining concentration in the mussel compartment.
Reference	Sub-model created for use with this model, using generic well-founded approximations.
Validation data	Not validated. However, the sub-model is feeding the primary production and the calculation of the total concentration of phytoplankton in the mussel compartment, producing results validated against field data.
Extend block(s)number	(4126)(3) Inorganic N advection, (4134)(11) calculation of the biologically consumed InN, (4181)(127) calculation of the fragment used for phytoplankton growth

Process name	**Phytoplankton growth**
Function in model	The block is calculating the net phytoplanktonic growth and mortality and then is using them to calculate the actual phytoplanktonic concentration developed from primary production.
Variables IN	Temperature of the water body (ºC), the Inorganic Nitrogen concentration available for phytoplanktonic growth (g/m^3), the limitation of phytoplanktonic growth because of the light irradiance (dimensionless)
Information IN	Maximum growth rate of phytoplankton (aPHYT, d^{-1}), fraction of C to N (C/N, dimensionless), half saturation constant for inorganic nitrogen phytoplanktonic uptake (ksp_InN, dimensionless), temperature coefficient (kT, $^oC^{-1}$) and the maximum mortality rate of phytoplankton (mort, d^{-1}).
Variables OUT	Concentration of phytoplanktonic biomass (g/m^3).
Formulation	phyto_growth=aPHYT*INlim*fL*fT where: INlim = InN_C/(InN_C+ksp_InN) where InN_C=InN*(C/N) fL is the light limitation on phytoplankton (Hblock "phytoplankton light limitation"), fT=e^(kT*Twater), phytmort=mort*fT dphyt/dt=phyto_growth-phytmort
Reference	A.Chapelle et al, 1999. G.Arhonditsis, et al, 2000.
Validation data	Not validated. However, the sub-model is feeding the calculation of the total concentration of phytoplankton in the mussel compartment, producing results validated against field data.
Extend block(s)number	(4146)(23)

Process name	**Calculation of phytoplankton biomass available for mussel consumption**
Function in model	It is designed to calculate the phytoplanktonic biomass available for mussel growth by taking under account the quantity advected from the neighbor compartments and the quantity produced through primary production in the mussel farming compartment.
Variables IN	Mean daily current velocities as stated in the advection process above. Concentrations of phytoplanktonic biomass in the neighbor compartments and the mussel farming compartment, calculated using the primary production equation described above (validated using field data of the period 2004-2005) (g/m^3).
Information IN	Volume of the upper and the lower layer of the mussel farming compartment (m^3). Exchange coefficient between the upper and the lower compartment (dimensionless). Amount of phytoplanktonic biomass sinking in the bottom (%).
Variables OUT	Total concentration of phytoplanktonic biomass available for mussel consumption
Formulation	Phyto_available=Phyto_advected+Primary_production-Phyto_sink
Reference	Created for use with this model using logical assumptions.
Validation data	Annual phytoplankton biomass data (2004-2005) were used for the validation of the model.
Extend block(s)number	(3462)(75)

Process name	**Farm density inhibition coefficient**
Function in model	It is designed to calculate a coefficient describing the inhibition of the water movement inside the mussel farm, by comparing the mean water velocity in the area (provided by the circulation model used for the advection component also) to the required water velocity that the number of the mussels in the farm need in order to be fed properly. In reality it is a ratio between the real velocity in the area and the required velocity in order the water to be renewed at least ones during the day, allowing the mussels to have access to "new" food sources. If the ratio is >1, then the water in the farm is renewed more than once, providing the mussels with water enhanced with food (phytoplankton and TOC). If the ratio is <1 then the water velocity is inadequate to cover the mussel farm needs and the growth is inhibited. Increased mussel farm density, increases the need for higher velocities in order for the mussels to be fed properly.
Variables IN	Mean daily water velocity in the area (m/sec), mussel dry biomass (kg/m of sock)
Information IN	Mussel farm characteristics: length of production line (m), length of cultivation sock (m), number of production lines, distance between production lines (m), distance between cultivation socks of SC1 and SC2 (m). Number of mussel farming area. Institutional status (scenario switch on/off, influencing the farm characteristics). Mussel filtration rate (m^3/sec/gr).
Variables OUT	Density coefficient (dimensionless).
Formulation	den_coeff_0=u_mean/(filtration_rate*((musselsSC1*1000*socks_sc1)*0.33+(musselsSC2*1000*socks)*0.66)*line_number/ line_length);
Reference	Created for use with this model using realistic assumptions.
Validation data	Not validated.
Extend block(s)number	(928)(98), (557)(90), (1699)(90), (2878)(90), (3057)(90)
Comments	If the mean velocity in the area exceeds a threshold value (here 2,00 m/sec) the coefficient takes zero values, as the mussels are closing up in high velocities in order to protect them selves. The block is candidate for a generic use.

Process name	**Net mussel growth and loss rates**
Function in model	It is designed to calculate the net growth rate and the rate of losses of mussels in a selected size class, in relation to the concentrations of phytoplankton and Total Organic Carbon, temperature and the correlated to the size class parameters of growth.
Variables IN	Available concentration of phytoplankton biomass (g C/m3), Available concentration of Total Organic Carbon (g C/m3) Water temperature in the sub-area (ºC)
Information IN	Maximum growth rate of mussels corresponding SC (day^{-1}), excretion rate of mussels corresponding SC (day^{-1}), half saturation constant for mussel grazing (gr/m^3).
Variables OUT	Net growth rate of the selected mussel SC (days^{-1}), Rate of losses of the selected mussel's size class (days^{-1}).
Formulation	net growth=aphyt*(aMUSSELS*((p1*PHYT)/(kz+F)))+apoc*(aMUSSELS*((p2*b*TOC)/(kz+F))), where F=p1*PHYT+p2*b*TOC, p1=PHYT/(PHYT+b*TOC) p2=TOC/(PHYT+b*TOC) kz: the half saturation constant for mussel grazing aphyt and apoc: assimilation efficiencies of mussels for phytoplankton and TOC respectively aMUSSELS: maximum specific growth rate of mussels losses= mortality +excretion rate mortality=f(temperature) excretion rate=constant parameter
Reference	The block is designed for use with this model, but the ecological approach followed was based in the dynamics of one used for zooplankton grazing, by Arhonditsis et al., 1999.
Validation data	Not validated at this point. The net growth and loss rates calculated in this process block were used further in the calculation of the mussel growth in the farm and the mussel production was then validated against field data.
Extend block(s)number	(940)(110), (436)(113), (682)(100), (686)(103), (1709)(100), (1712)(103), (2388)(100), (2391)(103), (3067)(100), (3070)(103)
Comments	The block is candidate for a generic use.

Process name	**Mussel growth in the farm**
Function in model	It is designed to calculate the mussel growth in the individual mussel farm taking under account the net growth rate and the rate of losses of mussels in the selected size class calculated as described above, the placing of the farm in the farming area via the circulation pattern and the density inhibition coefficient.
Variables IN	Net mussel growth rate (day^{-1}), Net mussel loss rate (day^{-1})
Information IN	Mussel farming sub-area, circulation pattern, density inhibition coefficient (dimensionless), break and harvest time.
Variables OUT	Mussel growth (production) of corresponding size class (kg of dry weight/m of cultivated sock).
Formulation	dMussel_SC_growth/dt =[(net_growth*den_coeff*pattern_coeff)-losses]*mussels_SC where net_growth: the net growth rate of corresponding mussel SC den_coeff: the density inhibition coefficient pattern_coeff: the coefficient determined by the circulation pattern in the area and the placing of the mussel farm, losses: the net loss rate of the corresponding mussel SC.
Reference	The equation is designed for use with this model. It is following the basic principals of ecological growth.
Validation data	Data of mussel growth collected from sampling stations inside the farming area (2005-2006) were used for the validation of the model. The same data were used to calculate the maximum growth rates of mussels.
Extend block(s)number	Too many blocks implicated. Please refer to the ESE model for more detail.

Process name	**Mussel filtration on phytoplankton + calculation of mussel biomass in the area**
Function in model	It is designed to use the results of the mussel growth in the farm component in order to estimate the mean value of mussel biomass in the area and the influence of the mussel grazing to phytoplankton.
Variables IN	Mussel biomass (SC1 and SC2, kg/m of cultivated sock)
Information IN	Farming characteristics, number of mussel farms in the area.
Variables OUT	The estimated mean value of dry mussel biomass per m^3 in the mussel farming area.
Formulation	bio = (musselsSC1*socks_sc1*0.33+musselsSC2*socks*0.66)*1000*line_number*sock_length where: sock_sc1: the number of socks occupying SC1 mussels socks: the number of socks occupying SC2 mussels line_number: the number of cultivation lines sock_length: the length of cultivation socks phyto_filtr=bio*filtration rate
Reference	The equation is designed for use with this model.
Validation data	Not validated. This is estimation in order to help identify the influence of the mussel biomass in the phytoplanktonic biomass.
Extend block(s)number	(3624)(187), (4453)(249), (3661)(227), (3713)(228) and (4302)(15)
Comments	There are problems with the function of this equation in the model, trying to be resolved.

Process name	**Mussel farm Revenue and Profit**
Function in model	It is designed to calculate the revenue of the farmer from the mussel farm, using the annual production, the farm characteristics and the mean selling value. Finally, in association with the MF Total Costs equation described below, the total profit of the mussel farm is calculated.
Variables IN	Annual mussel production (kg of wet weight / m of cultivated bunch)
Information IN	Farm characteristics (scenario and choice depended), mussel value
Variables OUT	Total annual revenue.
Formulation	An_Rev= price *production*m of sock*n of sock per line*n of line. An_Profit=An_Rev-Costs
Reference	The equation is designed for use with this model.
Validation data	Not validated, as there are no available data. The results are within the range of the data collected through the survey
Extend block(s)number	(128)(220), (1407)(198), (2089)(198), (2768)(198), (3447)(198)

Process name	**Mussel farm Total Cost**
Function in model	It is designed to calculate the total costs of a mussel farm establishment taking under account all the major categories of potential cost as: establishment depreciation, equipment depreciation, operational costs, gasoline costs, labor costs (including potential extra work) and legality costs.
Variables IN	None. The development of the model is based in financial and technical information that are kept constant annually.
Information IN	Institutional status of the area and Farm number both are influencing the number of lines in a mussel farm. Investment on automation equipment (boat). Number of Harmful Algal Bloom occurrence in the area (scenario choice). Legal status of the farm. Initial capital invested per line. Operational cost per line. Annual man-days required per line. Labor price. Gasoline value.
Variables OUT	Total costs of the mussel farm (euro/day and euro/year).

Formulation	The establishment depreciation is calculated assuming a life of 30 years. The initial capital spend per line is used.
	yearly_depreciation=capital*line_number/years;
	depreciation_es=yearly_depreciation/365;
	The operational cost per line is calculated based in the annual amount of money spend for operation of the line (basically consumable material).
	operational= line_cost*line_number;
	The days of use of the automation equipment is calculated based on the assumptions that the boats are operated from the farmer exclusively and that the size of the boat (related to the money spend to buy it) is altering the required working effort both for the farmer and the workers.
	automation_days=((farmer_days+extra_days)-farmer_days*rate)*line_number;
	The gasoline costs are being calculated using the assumption that a bigger boat consumes more

	gasoline, the current gasoline value and the number of days that the boats are used.
	gasoline_costs= lit_per_day*automation_days*gasoline_value/365;
	The automation equipment depreciation in a daily bases is calculated using the average hours a boat is being used per day (here we estimate that the average value is 8 hours/day) and the total lifetime hours of a boat (here we estimate an average of 20.000 hours).
	depreciation_eq=(capital_auto*8)/20000;
	The calculation of the standard labor costs are based on the optimum values per production line.
	labor_costs=man_days*labor*line_number/365;
	The calculation of the extra labor costs are also based on the optimum values per production line
	extra_labor=worker_extra*labor*line_number/365;
	The estimation of the (daily and annually) total costs
	total_costs=depreciation_es+depreciation_eq+operational+labor+extra_labor+gasoline_costs+legal_costs;

Reference	The block is designed for use with this model, using logical economical and financial assumptions and based on data collected during the questionnaire survey implemented from the AUTH.
Validation data	Not validated, as there are no available data. The results are within the range of the data collected through the survey.
Extend block(s)number	(2220)(202)
Comments	The block is candidate for generic use. The block used in the model of SSA 16 is documented in a generic way, but nevertheless designed to cover our special scenario needs. A highly generic format will be also developed and delivered to WP8.

Tables 5.1g Verification data for testing the simulation model

Parameter	mathematical abbreviation	Data type (P = Parameter, C = Constant,	Units	Spatial resolution	time step	Extend data source (X = Excel; E = Extend database	Excel file name + location, or Extend DB nr and Table nr	Source	Name + path of corresponding MOX/LIX file
Salinity	Salt	Variable	psu	Compartment level	Daily	E lookup table	(322)(323)	AUTH, Sc. Civil Engineering, Dep. Hydraulics and Environmental Techniques	-
Phytoplanktonic C concentration	Phyt	Variable	g/m^3	Compartment level	Daily	E lookup table	(2543)(101)	HCMR and Alexandrian Technological Institution, Dep. Fisheries & Aquacultures	-
Mussel biomass	Mussels_SCi	Variable	kg of mussels (dry weight)/m of cultivated sock	Farm level – farming area level	Daily	E lookup table	(3763)(228)	Alexandrian Technological Institution, Dep. Fisheries & Aquacultures	-

Tables 5.1h MODEL BUILDING BLOCKS

[1] Sublibrary type = 1 (Ecology), 2 (Economic), 3 (Physical), 4 (Social), 5 (Tools), 6 (PCraster)

Block Name	Purpose	Block Type (H block or ModL)	Sublibrary type [1]	in connectors	out connectors
Phytoplankton light limitation	Calculating the limitation produced because of light intensity on the phytoplanktonic growth	H block	1	Light irradiance in the surface of the water body (Watt/m^2), concentration of Chl-a (mg/m^3).	The coefficient representing the light limitation no the phytoplanktonic growth (dimensionless).
Mussel farm density inhibition coefficient	Calculating a coefficient describing the inhibition of the water movement inside the mussel farm	H block	5	Mean daily water velocity in the area (m/sec), mussel dry biomass (kg/m of sock)	Density coefficient (dimensionless).
Net mussel growth and loss rate	Calculating the net growth rate and the rate of losses of mussels in a selected size class	H block	1	Concentration of phytoplankton biomass (g C/m3). Concentration of Total Organic Carbon (g C/m3). Water temperature in the area (ºC).	Net growth rate of the selected mussel SC ($days^{-1}$). Rate of losses of the selected mussel's size class ($days^{-1}$).
Mussel farm Total Costs	Calculating the total costs of a mussel farm establishment taking under account all the major categories of potential cost	H block	2	Farm's technical characteristics	Total costs of the mussel farm (euro/day and euro/year).
Mussel Farm characteristics	Choice panel for the mussel farms characteristics	H block	5	Farm's number or other identification	None. The block is a choice panel and is creating a DB with the farm characteristics of every farm.

Tables 5.1i Input data for scenarios

Table 5.1.i.1: Input data for ecological drivers

Variable	Name	Value
Irrigational water	Present Irrigational inputs Half Irrigational inputs Double Irrigational inputs	1.0 x agronomic water inflow data 0.5 x agronomic water inflow data 2.0 x agronomic water inflow data
Irrigational water concentration in InN	Present Irrigational inputs Half Irrigational inputs Double Irrigational inputs	1.0 x agronomic water InN concentration data 0.5 x agronomic water InN concentration data 2.0 x agronomic water InN concentration data
Alteration of InN inputs from neighbor compartments	Present input values Half input values Double input values	1.0 x InN concentration data 0.5 x InN concentration data 2.0 x InN concentration data
Alteration of TOC concentration in the mussel compartmetn	Present values Half values Double values	1.0 x TOC concentration data 0.5 x TOC concentration data 2.0 x TOC concentration data

Table 5.1.i.1: Input data for ecological drivers

Variable	Name	Value
Cultivation line number	10 lines 12 lines 14 lines 16 lines 18 lines	10 lines (institutional management scenario) 12 lines 14 lines 16 lines 18 lines
Distance between the lines	5 m 6m 7m 8m 9m 10m	5 m 6m 7m 8m 9m 10m (institutional management scenario)
Distance between the socks	0.4 m 0.5 m 0.6 m 0.8 m 1.0 m	0.4 m 0.5 m (institutional management scenario) 0.6 m 0.8 m 1.0 m
Sock length	2.50 m 2.75 m 3.00 m 3.25 m 3.50 m	2.50 m 2.75 m 3.00 m (institutional management scenario) 3.25 m 3.50 m

Table 5.1.i.c: Input data for socio-economic drivers

Variable	Name	Value
Amount of money spend for boats	Automation equipment investment	20.000,00 40.000,00 60.000,00 80.000,00 100.000,00 120.000,00
Number of days (annually) with occurrence of HAB's	Days of HAB's occurrence	30 days 30+15 days, until 180 days (disaster scenario)
Legal status	Legal mussel farm Illegal mussel farm	5.000,00 rent (institutional management scenario) 10.000,00 fine

Appendix 1: Screen captures of the model – Ideas for the stakeholder version

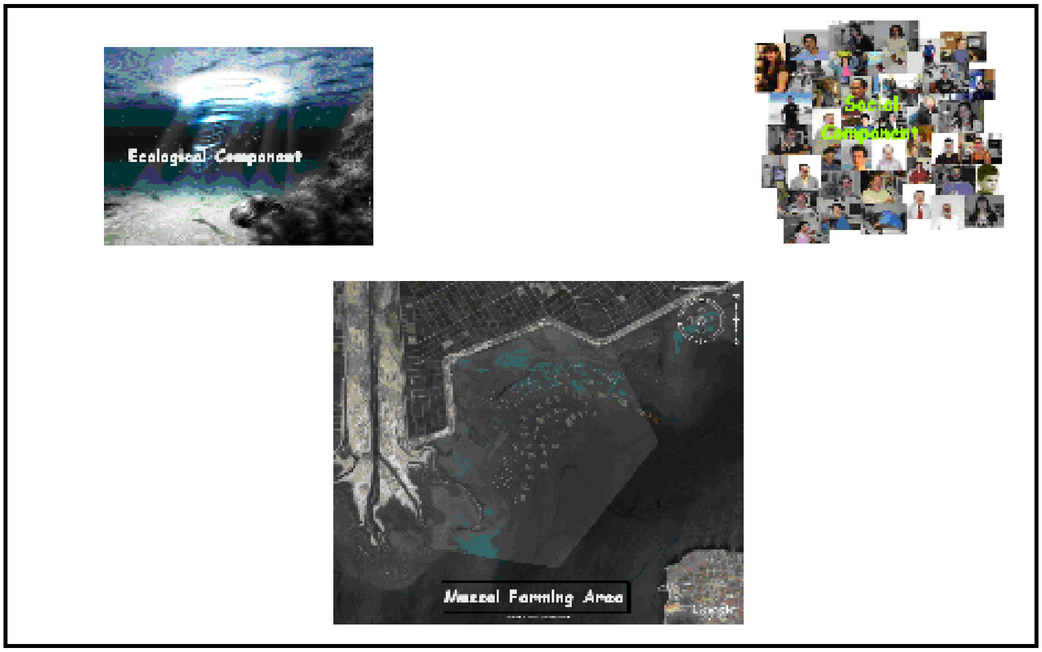

Figure 8: Screen caption of the higher level of the ESE model.

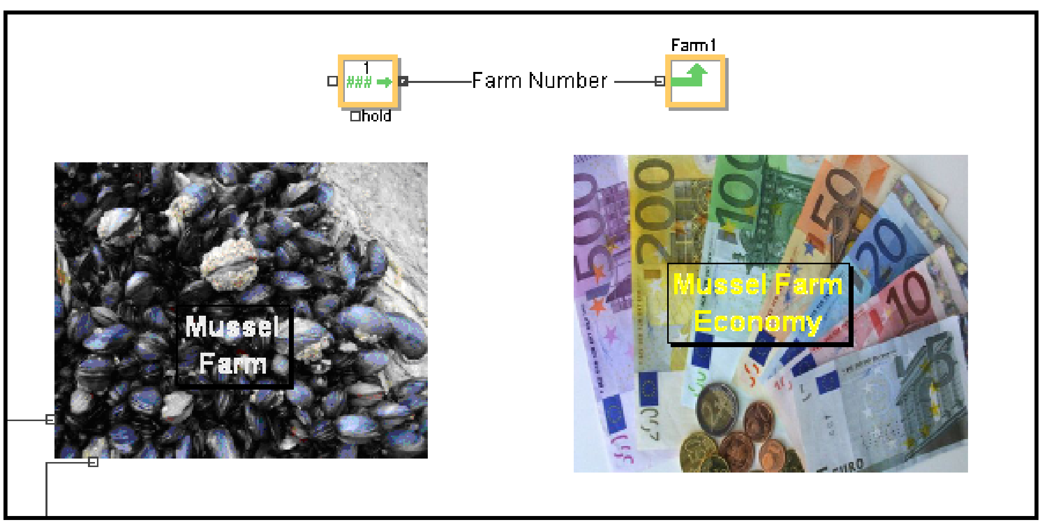

Figure 9: Screen caption of the mussel farm model incorporating both ecology and economy.

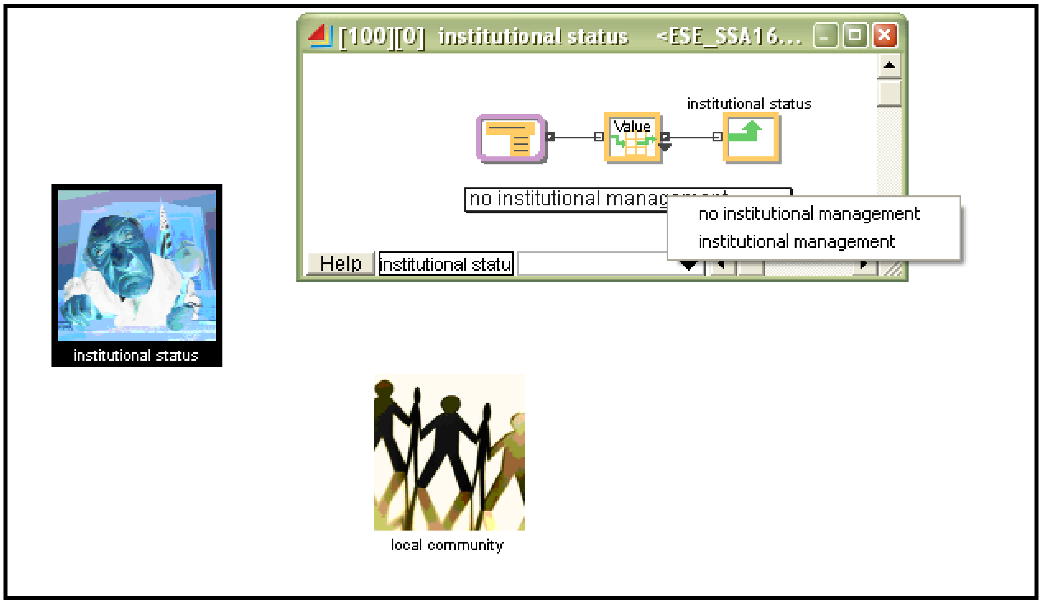

Figure 10: Screen caption of the social component of the model.

Appendix 2: Model results and parameterization

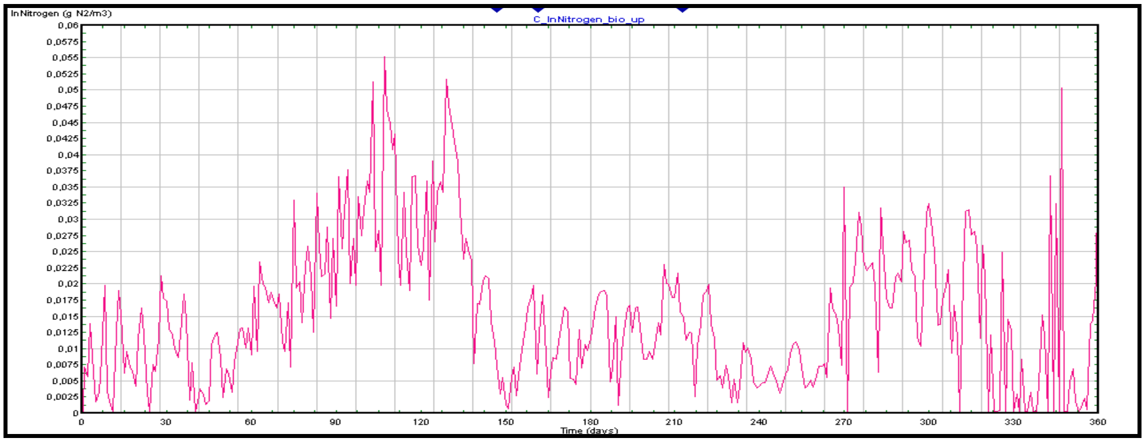

Figure 11: Simulation of the Inorganic nitrogen biologically available in the upper water layer.

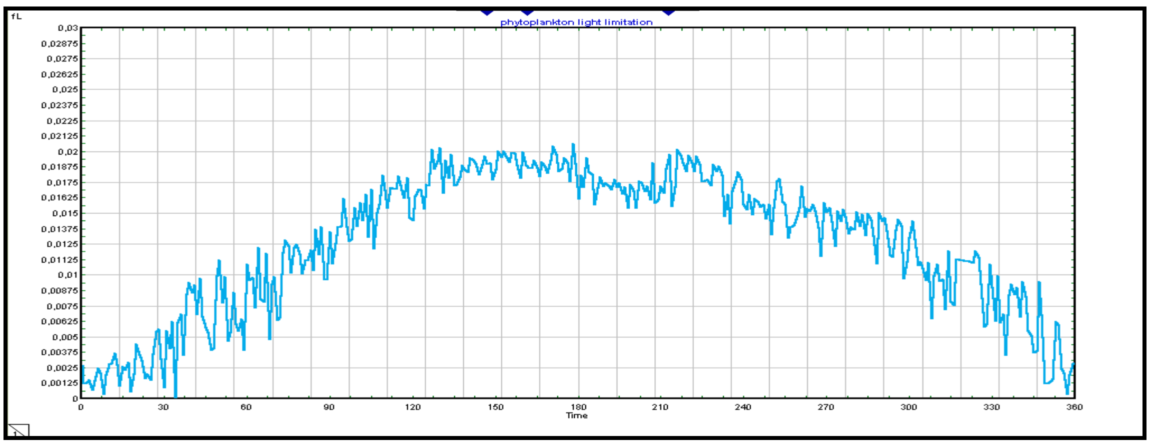

Figure 12: Phytoplankton light limitation factor.

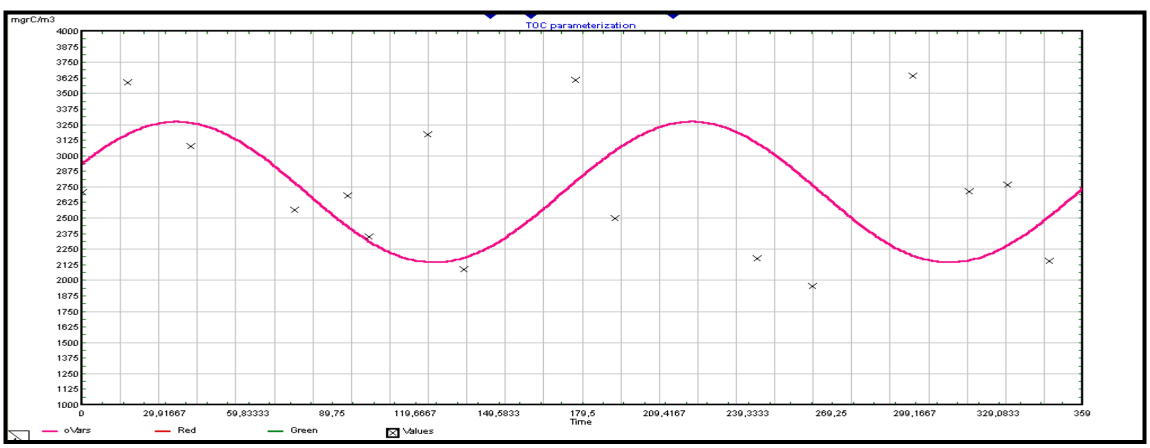

Figure 13: Total Organic Carbon mean observations for station Mi and parameterization.