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Research, part of a Special Feature on A Systems Approach for Sustainable Development in Coastal Zones

Aspects of Mussel-Farming Activity in Chalastra, Thermaikos Gulf, Greece: An Effort to Untie a Management Gordian Knot

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ABSTRACT. Small-scale mussel farming in the coastal area of Chalastra (Thermaikos Gulf, Greece) has faced major problems during the last decade due to environmental limitations and to institutional constraints imposed by the absence of local planning and development policies. The aim of our work was to demonstrate crucial aspects of implementing the Systems Approach Framework (SAF) in the area, and more specifically to explain: (a) the key parts of a bioeconomic model that constitutes the basis of a draft management tool, (b) the results of several investigative scenarios examined through the management tool, and (c) the stakeholders' feedback through the participative procedures. The goal was to evaluate the effects of the SAF implementation on the communication between scientists, policy makers, and local stakeholders. The scenarios refer to alternative farming techniques and different environmental conditions, and examine the effects of institutional deficiencies in qualitative and quantitative ways, regarding the sustainability of the activity. The selection of the scenarios was directed from the need to provide a dialogue platform between the conflicting stakeholders. The results clearly demonstrate the effects of mussel-farming techniques on mussel production, as well as the impacts of environmental conditions, human decisions, and institutional choices on the regional (and individual) economic welfare. In the bottom line, the value of the SAF is demonstrated through the apprehension of the policy issue, its impacts, and the alternative management perspectives, as well as through the establishment of a multidimensional collaboration group for the area, which is essential for the further development of the management tool and the implementation of an integrated management policy.

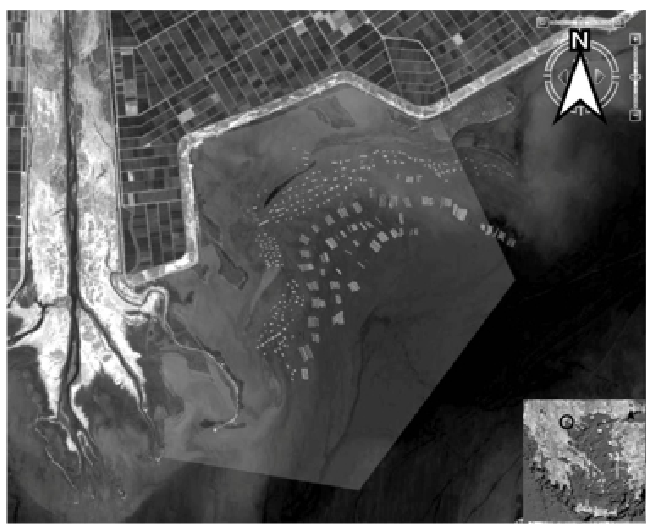
Key Words: *integrated management; integrated modeling; mussel farming; stakeholder involvement; Systems Approach Framework (SAF) implementation*

INTRODUCTION

Mollusc culture, specifically the cultivation of suspension-feeding bivalves, is a developing activity worldwide (Duarte et al. 2008), because it does not require external inputs and it can have positive environmental impacts on the coastal system by contributing to the removal of nutrients from the water (Newell 2004). However, integrated coastal management of bivalve farming areas can prove complicated, especially when, along with the associated environmental and socioeconomic problems, there is insufficient institutional regulation.

During the last decade the most important mussel-farming area in Greece, i.e., Chalastra, in the gulf of Thermaikos, is facing severe problems due to decreasing levels of production and mussel quality, and due to the insufficient regulation of the activity. This has resulted in significant socioeconomic pressures and stakeholder conflicts.

Fig. 1. The mussel-farming area of Chalastra in the Thermaikos Gulf (from Google Earth).



Chalastra's coastal zone

The coastal area of Chalastra (Fig. 1) is located along the northwest side of the inner gulf of Thermaikos (Greece), 20 km northwest of Thessaloniki, at the delta of the rivers Axios, Loudias, and Aliakmon. Chalastra area is protected by the

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Ramsar Convention as part of the delta. It is small relative to the gulf, occupying only 1.35 km^2, with a maximum depth of 24 m. The coast is bordered by an irrigated area with a drainage system discharging into the gulf. The outfall of Thessaloniki's Waste Water Treatment Plant (WWTP) is located 4.8 km northeast of the site, while there are also some small-scale industrial activity, mainly food processing units, in the broader area (Karageorgis et al. 2005).

The main marine activity in Chalastra is intensive mussel farming of the Mediterranean mussel *Mytilus galloprovincialis*. Thirty percent of Greece's mussels are farmed in Chalastra, making it the country's largest mussel-production area. Mussel farming in the reference area is mainly a small-scale, family-based activity, providing employment for a significant part of the local population, both directly and through the associated processing industry. There are approximately 250 registered mussel farmers and 14 processing units in the area, while the number of seasonal workers cannot be accurately defined. Two cultivation systems are used: a) long-line cultivation is used in 55 farms, each occupying approximately 10,000 m^2, at depths ranging from 6 to 22 m, and b) pole cultivation, used in 150 to 200 farms, each occupying 500 m^2, at depths of 2 to 5 m. The pole cultivation system serves mainly to support the long-line system.

Operational framework of mussel farming

The development of mussel farming in Chalastra was initiated in the early 1980s. The activity proved to be successful due to the short production cycle of 9 months and the high-quality product in terms of weight and condition index (Moriki 2007). Hence, local investment ensued, resulting in a doubling of the number of units by the 1990s. Initially, there was a preliminary effort to regulate the activity but it proved unsuccessful. In Table 1 a brief timeline of the institutional events that have taken place during the last 20 years is presented, aiming to provide an overview of the operational framework of the activity. Bureaucracy creates severe impediments, with legal gaps, authority overlaps, and lack of effective control being sustained by the many (14) implicated public bodies. Due to the several institutional delays and failures, currently more than half (55%) of the long-line units and all the pole units are operating under expired licenses. As a conclusion, the owners, deprived of the right to renew them, are subject to prosecution, resulting in both private (higher production cost) and social costs (explotation property rights would otherwise be used as local community contributory benefit). The unsolved regulatory issues have led to fines, legal and labor insecurity, black markets, oligopsony, and stagnant profits during the last decade.

Under these conditions, mussel farmers tried to maximize their profits by intensifying the cultivation techniques, neglecting the available spacing guidelines. The result was the opposite of their aim. Although the number of cultivated mussels increased, the quality decreased, resulting in an approximately 20% production decline during the last 10 years. Due to the decline in quality, the selling price of the product has remained stagnant, despite increase of costs due to inflation. At the same time the occurrence of harmful algal blooms (HABs) became more frequent, causing significant selling restrictions throughout the year.

Table 1. Institutional event timeline.

Early 1980s	• Initial development of the mussel-farming activity in the area of Chalastra. • Local authorities' initiative for the regulation of the activity. • The act is not promoted because the central government demands that any regulation should comprehend the activity at a national level. The necessary management studies for that are not available at the time. • The property rights for the activity are controlled from the regional authority, with the contribution of 13 other public authorities and in the absence of the aforementioned management regulation. The operation licenses are valid for 10 years and can be renewed after that time.
Late 1980s to early 1990s	• Local community requests the expansion of mussel activity in the area. • The activity is recognized as compatible with the Ramsar convection. This action promotes development of mussel farming and of supportive structures (small piers for the water vessels, wooden houses for equipment and processing activities). • The number of operation licenses for the activity in the area is doubled. In order to maximize their profit, the mussel farmers are using excessive cultivation techniques, but because a management regulation is still missing the authorities are unable to address this problem. • The activity is further developed in other areas of the Thermaikos Gulf.
Late 1990s early 2000s	• The legal framework for the regulation of the productive activities (in which mussel farming belongs) in "organized areas" is released. • The first scientific study in the mussel-farming areas of Chalastra and Loudias is implemented by the National Center of Marine Research. • Two management studies for the establishment of the Organized Area of Aquaculture Development (OAAD) of the Thermaikos Gulf are implemented. Local administration requests for approval from the authorities regulating the activity in the area, and from the central government (Ministry for the Environment, Physical Planning and Public Works). • The regional authority, awaiting for the OAAD approval, is turning down all the requests for renewal of the expired operation licenses for the mussel farms of Chalastra. • The operational licenses are gradually expiring. Local authorities agree to overlook this situation until it is regulated by the OAAD. The units with expired operational licenses continue to operate, but they are subject to fines.

(con'd)

During 2000s	• The OAAD approval is delayed because of excessive bureaucracy. • The mussel farmers that now lack operational licenses ask for a solution. A social conflict is created because the mussel farmers with valid operational licenses demand to be the only ones that can exploit the area. Mussel production is declining, enhancing the social conflict.
05/2011	• The OAAD approval is still delayed. • The structure of municipal, prefectural, and regional governance is changed, creating confusion regarding the new authorities of each public body. • The Framework for the “Rural Design and Sustainable Development for Aquaculture” is open for public deliberation. This framework is covering, among others, certain parameters of the OAAD's operation.

Seeking sustainability

Although mussel-farming activity in the area has been the subject of several studies during the last decade (Anagnostou 2001, Pagou et al. 2001, Papathanassiou et al. 2007, Moriki 2007), all of them were environmentally orientated, mainly targeting a monitoring effort.

Yet the situation connected to the aforementioned operational framework creates important socioeconomic pressures and uncertainty for the mussel farmers, thus compromising the sustainability of small-scale mussel-farming activity, and highlighting it as a key policy issue for the area. In an effort to (a) improve communication between scientists, policy makers, and local stakeholders, and (b) investigate the potentials of the activity, the SAF was implemented as a means of promoting sustainable integrated management (Hopkins et al. 2011a). As a part of this approach the stakeholders of the area were asked to participate in a multiscaled deliberation process. A bioeconomic model was developed and used in order to investigate quantitatively and qualitatively the outcomes of various stakeholder-oriented, management scenarios.

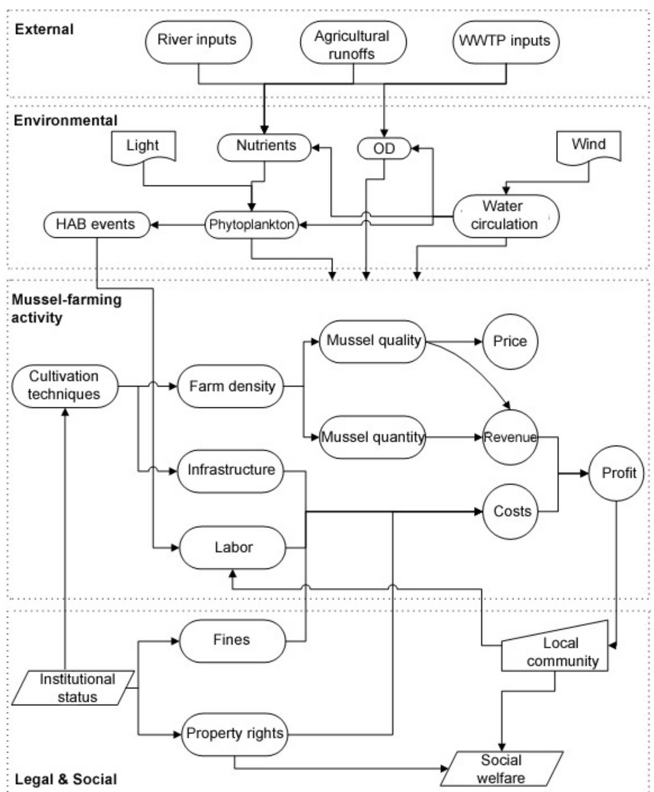
Creating a management tool

The modelling part of the Systems Approach Framework (SAF) implementation was limited by a severe lack of reliable data. This was true not only concerning the environmental data (river and waste water treatment plant discharges, organic material time-series, mussel-growth parameters and production) but also for the socioeconomic data, mainly because of the institutional particularities of the activity. Therefore, the challenge was to use the limited data to best represent the function of the farming system and to provide a tool capable of investigating alternatives that would support sustainable management.

The scope of the modelling approach, and the way the information was communicated to the stakeholders, are the answers to this challenge. An exploratory analysis was conducted concerning the system, transferring information and knowledge amongst stakeholders, in the framework of a participatory management procedure. The emphasis was not placed on predicting future states or simulating reality exactly, but on observing possible developments and detecting behavior patterns (Brugnach et al. 2008). It should be noted that this work is not meant to provide a complete integrated modeling assessment, but to show how such a process might be initiated and evaluated through a case study approach.

The formation of a conceptual diagram of the system (Fig. 2) was required in order to identify the components and linkages important for the scenarios to be addressed, and to communicate the structure of the management tool to the stakeholders.

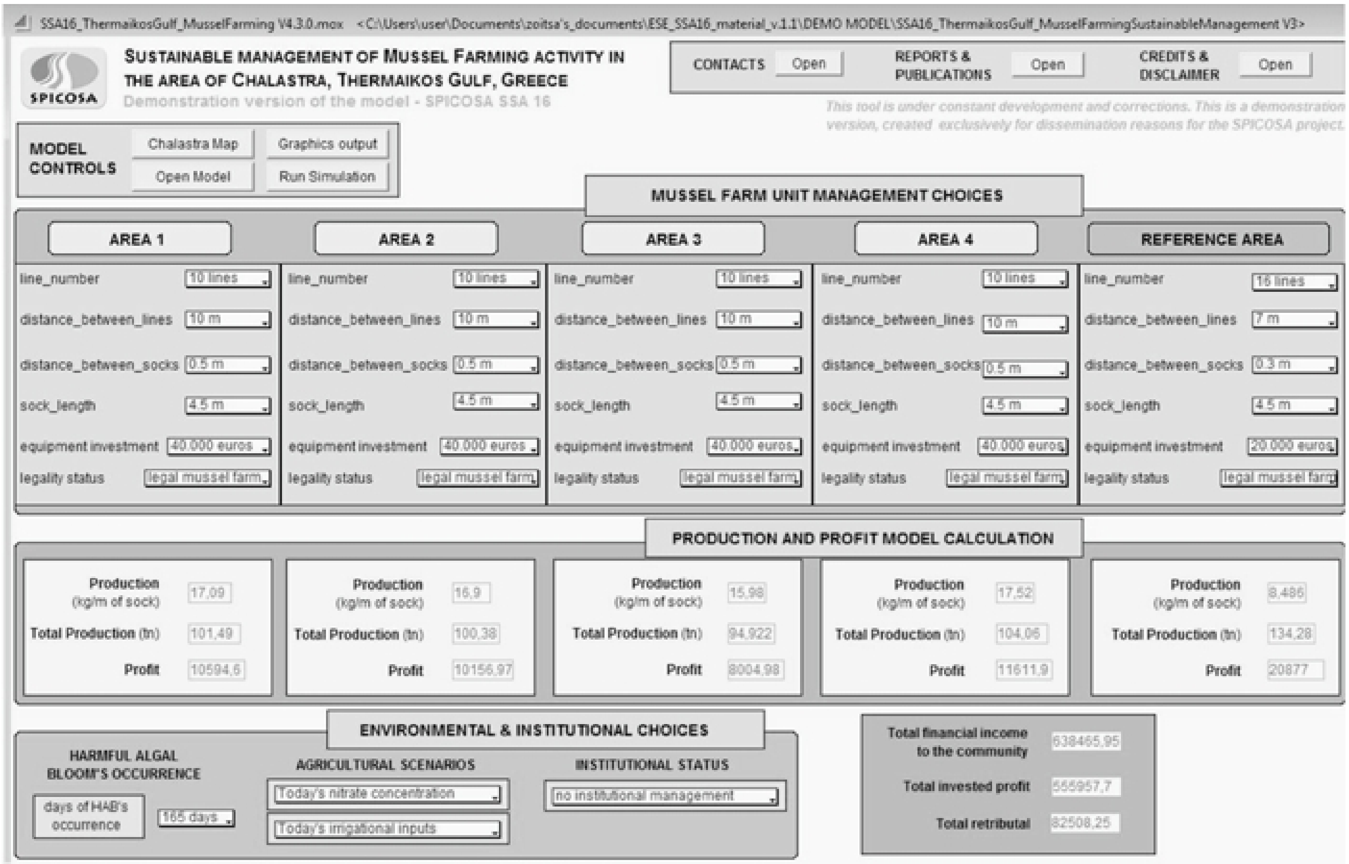
Fig. 2. Conceptual diagram of the system.



The overall management tool consists of the following coupled parts:

1. A circulation component, describing the exchange of water and substances between the mussel-farming area and the surrounding sea.

Fig. 3. Layout of the current version of the management tool.



2. A biological component, describing the dynamics of phytoplankton biomass in the mussel-farming area.
3. A component simulating mussel growth in the long-line farm.
4. An economic component, conducting a financial analysis of the long-line mussel farm.
5. A component examining indicators of social welfare connected to mussel farming.

The components of the ecological and economic dimensions of mussel farming are analytically described below due to their critical role in the implementation.

The management tool is served by auxiliary models and databases that provide necessary external inputs (e.g., wind direction and velocity, agricultural inputs, water velocity data, organic matter, etc.). It is designed to provide the user with a number of choices, regarding overall farming activity (e.g., alternative techniques, harmful algal bloom duration, capital invested, legality of the establishment, etc.). The layout of the management tool is presented in Fig. 3. The current version is available at http://dataportals.pangaea.de/spicosa/SPICOSA_model_library.html.

METHODS

Stakeholder involvement

In order to gather information on stakeholders' views about the key issues of mussel-farming activity, a number of individual interviews were conducted. The heads of the public offices responsible for the mussel-farming activity were interviewed regarding their opinion and their intention to participate in the implementation. The same procedure was followed for the representatives of the mussel-farmers' associations.

During these interviews qualitative information was gathered about the activity, the operational framework, and the interconnections between the various groups of stakeholders in the area. It was soon realized that gathering stakeholders in a joint meeting would be ineffective before any quantitative information became available. Thus it was decided that during the exercise stakeholder involvement would be kept on a private level in order to avoid conflicts. The joint meeting was postponed for future stages of the SAF implementation.

After completing the first round of private interviews, an institutional map was created. The map included information about the different categories of stakeholders, such as their

Table 2. Ecological model state variables, forcings, parameters, and functional relationships.

State Variables	**Functional Relationships**
Mussels: total tissue [kg of dry weight per meter of cultivated sock]	*dMussels/dt=(NetGrowth*DenCoeff*PatternCoeff-Losses)*Mussels* [1]
Forcings	*OD=POC-PHYT* [2]
T_w: water temperature [°C]	$F=p_1$*PHYT+p_2*OD [3]
POC: Particulate Organic Carbon [gC/m^3]	p_1=PHYT/(PHYT+OD) [4]
PHYT: Phytoplanktonic carbon concentration [gC/m^3]	p_2=OD/(PHYT+OD) [5]
OD: Organic Detritus [gCm^3]	
Parameters	*NetGrowth=*as_{PHYT}*{a_M*[p_1*PHYT/(k_M+F)]+as_{DT}*[p_2*OD/(k_M+F)]} [6]
as_{PHYT}: mussels assimilation efficiency of phytoplankton [-]	
as_{DT}: mussels assimilation efficiency of DT [-]	*Losses*= e_M+m_M [7]
a_M: maximum specific mussel growth rate [day^{-1}]	where m_M=f(T_w) as
k_M: half saturation constant for mussel filtration [g/m^3]	
filt_rate: average filtration rate of mussels [m^3/sec/g]	if T_w<25° C then the mortality rate m_M =0.02*a_M.
line_no the number of lines in the specific mussel farm establishment [-]	if 25° C<T_w<26° C then the mortality rate is m_M=0.25* a_M. [8] if T_w>26° C then the mortality rate is m_M=0.5* a_M.
line_length: the length of the average cultivation line [m]	
SC1: mussels of length <2cm	*DenCoeff=*U_{mean}/$U_{required}$ [9]
SC2: mussels of length >2cm	$U_{required}$=filt_rate*line_no*mussels/line_lenght [10]
socksSC1: socks occupied by mussels of size class 1 [-]	*mussels=musSC1*socksSC1*(1/3)+musSC2*socksSC2*(2/3)* [11]
socksSC2: socks occupied by mussels of size class 2 [-]	
musSC1: dry weight of mussels of size class 1 [g/m of sock]	
musSC2: dry weight of mussels of size class 2 [g/m of sock]	
e_M: excretion rate of mussels [day^{-1}]	
m_M: mortality rate of mussels [day^{-1}]	
WD: Wind direction [°]	*PatternCoeff=f(WD)* [12]

authority over the mussel-farming activity, the linkages between stakeholder groups, the possession of data of interest for the analysis, and the willingness to participate in a joint stakeholder meeting concerning the sustainability of mussel farming. This knowledge was then utilized for organizing a second round of individual interviews aimed at gathering the available data, informing the stakeholders about the goals of the SAF implementation and recording their reactions, identifying those willing to actively participate, and recording the scenarios that stakeholders were interested in, regarding the sustainability of the small-scale mussel-farming activity.

Mussel-farm component

The formulation of the model component describing mussel growth under the local cultivation conditions is of crucial importance for the SAF implementation. Mussel growth is usually simulated by bioenergetic approaches (Gangnery et al. 2004, Brigolin 2007, Brigolin et al. 2009), but this would require data that are currently unavailable for the study area. To confront the limitations, a case-specific ecological approach was used. Mussel growth depends on the availability of food, the environmental conditions, and the farming techniques expressed through the farm characteristics. The mussel-growth component of the model represents one mussel farm. The farming area is separated spatially into four subcompartments in order to investigate the influence of placing due to circulation patterns. Different, virtually independent, farm components are developed for each area. Phytoplankton and organic detritus (OD) availability are calculated for the whole area through auxiliary components of the model. The model describes the two annual production cycles occurring in Chalastra for *Mytilus galloprovincialis* (Moriki 2007), and it calculates the mussel biomass in dry weight of carbon per meter of cultivated sock.

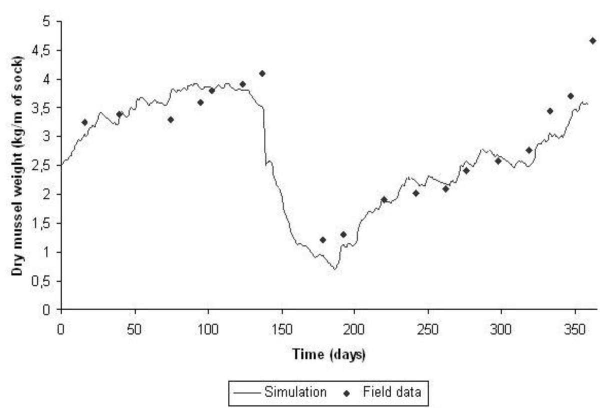
The mussel-growth equation ([1] in Table 2) connects growth to food consumption. It uses the logic of models developed for other species (Fasman et al. 1990, Arhonditsis et al. 2000). The growth of mussels depends on filtering phytoplankton (PHYT) and organic detritus (OD). It is assumed that the mussels' filtering capacity changes as a function of the relative proportion of the concentration of the two food sources ([3], [4], and [5] in Table 2). The filtration levels of mussels on phytoplankton and organic detritus, combined with the coefficients representing the different assimilation efficiencies of the food sources, gives the net growth of mussels ([6] in Table 2). Loss of mussel biomass is due to excretions and natural mortality ([7] in Table 2; the latter is below 2% of the total stock (Camacho et al. 1995). The effect of high water temperature on mussel mortality rate is expressed using a temperature-related equation ([8] in Table 2). The mussels are separated into two size classes, which differ in growth and loss rates (Table 2).

As mentioned above, the effect of the chosen farm characteristics in the productivity of the farms emerges as one of the key points regarding the area's issues. Excessive practices increase the density of the farm, by adding a larger number of cultivated individuals. A farm-density coefficient was introduced to the model in order to express this influence. Mussels are passive filter-feeding organisms, pumping water with a rate related to water velocity. A minimum water velocity is required for the water mass to be renewed inside the farm, so that mussels can be fed adequately. The required water velocity is calculated by taking into account the quantity of mussels per meter of cultivated sock, the farm's characteristics, and a mean filtration rate of the average mussel (Brigolin et al. 2009). The farm-density coefficient ([9] in Table 2) is expressed through the fraction of the mean water velocity, calculated by a hydrodynamic model running for the area (Kourafalou and Tsiaras 2007) to the minimum required velocity for the quantity of mussels cultivated in the farm ([10] in Table 2). The model allows the user to specify the technical characteristics of the mussel farm, i.e., the number of long-lines, the distance between long-lines, the distance between socks in which the mussels are placed, and the length of these socks. For simplicity reasons, it was assumed that the characteristics chosen are the same for all the farms of each subcompartment. It was also assumed that the number of individual mussels per meter of sock was constant (Table 2).

It was also important to take into account the effects of the farms on the inhibition of water movement in the area. The results of previous studies regarding the influence of mussel farms on the hydrodynamic circulation of Chalastra (Krestenitis 2003, Galinou-Mitsoudi et al. 2006, Savvidis et al. 2007, Galinou-Mitsoudi et al. 2009) were used to create an empirical coefficient describing the inhibition of water movement caused by the farms under different wind conditions. The mean velocity results (Savvidis et al. 2007) for each subcompartment were compared to the average water velocity in the area when the influence of the farms was not taken into account (Kourafalou and Tsiaras 2007). Thus an area-specific, flow-pattern coefficient was introduced, i.e., a different coefficient for each of the four subcompartments (related to the major wind directions), which describes the advantages of the farms exposed to the oncoming flow as compared to the farms on the other side of the area which received water already stripped of particulate matter and of lower velocity. This approach provides a generic representation of the farms' influence on water circulation, but is limited because it is not able to investigate farm-placing alternatives.

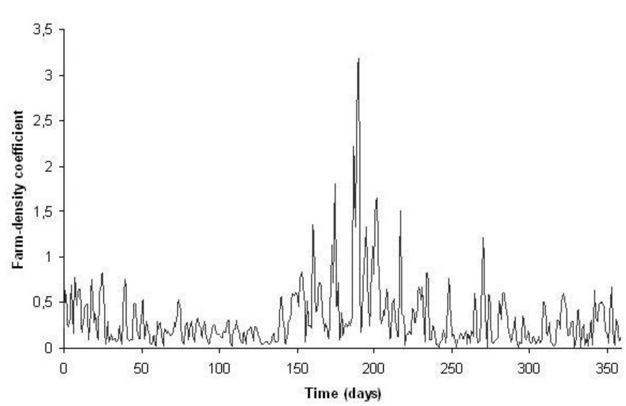
Table 2 presents the basic variables, parameters, and functional relationships of the ecological component of the mussel-farm model. The maximum growth rates of the two size classes of mussels were estimated from available data (Moriki 2007). The assimilation efficiency of mussels on phytoplankton and organic detritus was derived from Chapelle et al. (2000). The model was calibrated for the parameter k_M, which is the half saturation constant for mussel growth. The results of dry mussel weight per meter of sock show a good fit to the experimental data (Fig. 4). The drop in mussel biomass corresponds to the harvesting of the mussels at the time they reach marketable weight. The result of the ecological mussel component represents the net weight of mussel production and is transferred to the economic part of the model, in order to assist further analysis.

Fig. 4. Mussel component calibration: observed and simulated dry weight.



The farm-density coefficient ([9] and [10] in Table 2) is an index of how well the mussels are fed, thus determining their growth and quality in terms of individual mussel weight. Fig. 5 shows the average daily variation of this coefficient under the current, excessive cultivation characteristics. The results demonstrate that the value of the coefficient is usually <1, showing inadequate feeding of the mussels in the average farm. The value of the coefficient increases only during the harvesting and seeding period, which is when the density of organisms in the water is lower than usual.

Fig. 5. Daily variation of the farm-density coefficient.



Economic component

The economic model component aims at demonstrating the feasibility of quantifying economic links between mussel-farming activity and operational and environmental conditions. For this reason a financial analysis was conducted to estimate profitability, and thus economic sustainability, of mussel farming activity under different technical, legal, or environmental conditions. The analysis was formulated at the scale of an individual farm, in order to compare different farming conditions between the areas, and thus explore a variety of management options. The basic inputs of the economic model are the annual net mussel production of each farm and the farm characteristics, as determined in the ecological model component.

Table 3. Values and definitions of the financial parameters used in the economic component: the values and approximations made were based on the interview survey implemented in Chalastra.

Financial parameters	Value	Units
Initial capital	900	€/line
Establishment lifetime	10	years
Daily use of automation equipment (water vessel)	8	hours
Water vessel lifetime	20,000	hours in use
Operational cost	300	€/line
Optimum man-days	20	days/line
Legal labor	35	€/day
Illegal labor	25	€/day
Optimum farmer man-days	20	days/line
Average mussel selling price	0.40	€/kg
Mussel selling price +25%	0.50	€/kg
Perquisite of licensed establishments	1500	€/year
Port authority fines to establishments having expired licenses	10,000	€/fine
Inflation rate	0.03	-
Rate of work attenuation because of automation equipment	0% for minimum investment +5% for every €20,000 of investment	% of work attenuation days
Extra worker man-days because of harmful algal bloom events	0 for 30 days of harmful algal bloom occurrence +2 days for every extra 15 days of harmful algal bloom occurrence	days/line
Extra farmer man-days because of harmful algal bloom events	0 for 30 days of harmful algal bloom occurrence +1 day for every extra 15 days of harmful algal bloom occurrence	days/line

The outputs of the economic component are the costs, revenues, and profits of the mussel farms. Furthermore, the total profit of the mussel-farming activity is estimated by aggregating results from all the farms. This value is used as an indicator of local community welfare. The data used in order to formulate the economic component were mainly provided by the mussel farmers of Chalastra, during their interviews, as well as from relevant literature (Moriki et al. 2008, Anagnostou 2001). Table 3 shows the financial parameters used in this model.

The farmers' revenues are a straightforward result of the total production of the mussel farm. These revenues are calculated by multiplying the annual production of each farm with the current selling price of mussels. This estimation is accurate because the mussel farmers in Chalastra usually sell the total of their production in foreign markets each year. A potential increase in the selling price of mussels was further examined in cases where the improvement of mussel quality was evident, i.e., when the individual mussel weight was more than 10 g, a weight that was average for the area 10 years ago.

The costs of mussel-farming activity include infrastructure and water vessel depreciation, operational and labor costs, gasoline usage for water vessels, and costs related to the aforementioned regulative deficiencies. In Table 4 the cost categories used in the analysis are analytically presented.

As already noted, the occurrence of harmful algal blooms is fast becoming one of the most important problems for the mussel farmers of Chalastra (Pagou 2005). Their occurrence cannot be simulated environmentally, because it is random and not connected to specific parameters, and there is no evidence that harmful algal blooms affect mussel health or growth. However, during harmful algal bloom events the veterinarian authority prohibits harvesting of mussels for time periods that may vary from one month to more than six months (Karageorgis et al. 2005). Although there are no production losses, maintaining the mussels in a good state requires extra labor, which increases the annual labor costs. Hence, harmful algal bloom occurrence is used as an exogenous economic parameter in the model.

Table 4. Descriptions and definitions of the cost categories used to define the total costs of a mussel farm establishment.

Cost category	Formulation relationship
Farm establishment depreciation (ropes, nets, etc.)	Based on the initial investment cost (per cultivation line) and on the assumption of a common life span for all assets. =[cost of fixed asset (initial investment)] / [life span (years)]
Automation equipment (water vessel) depreciation	Estimated using the activity level (average hours that the vessel is being used per day) and the total lifetime hours of the vessel. = [automation investment*hours used per day] / [total lifetime hours]
Standard operational costs	Calculated per cultivation line, based on the annual amount of money spent for basic consumable materials. =[average operational costs per line] * [number of lines in each farm]

(con'd)

Standard labor costs	Calculated from the average man-days required per cultivation line for optimum productivity. The man-days required per line are negatively connected to the total investment on automation equipment, as a bigger vessel is contributing to labor attenuation. =[optimum man-days per line] * [average wage in the area]
Extra labor costs	Determined from the average man-days required per line for retaining optimum productivity under harmful algal bloom restrictions (extra man-days per line). =[extra man-days per line] * [average wage in the area]
Gasoline costs	Based on the assumption that gasoline consumption is positively connected to higher automation investments (bigger water vessels). It depends on the current gasoline prices, as well as on the frequency of using the water vessel. The number of days the water vessel is used is a function of the number of cultivation lines and of the frequency and duration of the harmful algal bloom's occurrence. = [gallons needed per working day]*[number of working days]
Legality costs	Licensed establishments pay an annual perquisite of €1500/year. Establishments with expired licenses pay on average a fine equal to €10,000/year.

RESULTS

Institutional map and stakeholder involvement

The institutional stakeholder map created during the SAF application is presented in Fig. 6.

Through the initial stakeholder involvement a set of scenarios (Table 5) was isolated in order to be further investigated through the management tool and to be discussed during the stakeholder meetings.

Table 5. Investigated scenarios.

1. Unit level management
Exploration of different layouts in an individual long-line mussel farm in order to determine the effect of farming characteristics on productivity.
2. Area level management
Exploration of different layouts in the whole long-line mussel-farming area in order to determine the effect of farming characteristics on the area productivity.
3. Legal framework and social prosperity
Exploration of the effect of institutional status alterations on the economic robustness and on the contributory benefits to the local community.
4. Environmental constraints and mussel-farm unit economy
Exploration of the effects of the duration of harmful algal blooms on the economics of the mussel farm.

During the SAF implementation, a small group of stakeholders, mainly mussel farmers, was kept informed of developments whereas most of the public authorities' representatives expressed interest in having only the final results and were unwilling to participate in intermediate deliberations. Towards the end of the SAF implementation, two joint stakeholder meetings were organized, where the major actors at the local, regional, and national levels participated. The first meeting was structured around the presentation of the management tool, the scenarios, and the perspectives of the analysis, in order to establish a deliberation procedure. The second meeting focused on building trust between the different stakeholder groups and on organizing a noninstitutional core group of specialists and major representatives willing to frequently communicate and share information.

Investigation of scenarios

The first scenario (Table 6), which is hypothetical, is an introduction to the logic of the management tool and the dynamics of alternative farming techniques. It refers to the hypothetical situation of a single farm in the area, with no inhibition of the water circulation due to other farms (flow-pattern coefficient = 1). The objective of this scenario is to examine the influence of individual farming techniques on the farm's productivity. It was assumed that the farm covered approximately 10,000 m^2, and that the length of each cultivation line was 100 m. The first four rows of Table 6 demonstrate the alternative farming characteristics examined in each case, while the following three rows illustrate the corresponding results regarding the quality and quantity of production.

Table 6. Effects of individual farm characteristics on farm productivity.

Farm management	Case 1	Case 2	Case 3	Case 4
Number of lines	10	12	14	16
Line distance (m)	10	9	8	7
Sock distance (m)	0.6	0.5	0.4	0.3
Sock length (m)	3.0	3.5	4.0	4.5
Mussel wet weight (kg/m of sock/y)	23.2	16.8	12.1	8.5
Average ind. mussel weight (g)	15.5	11.2	8.1	5.6
Total production (tn)	76.1	93.4	112.3	134.3

The second scenario (Table 7) introduces the idea of mussel-farming area management, concerning cultivation techniques. Three cases were examined: Case A was a random case close to the present state of the farming area, Case B was an excessive case (more intensive farming techniques), and Case C followed the available regulation for mussel farming. It was assumed that each farm covered approximately 10,000 m^2, and that the length of each cultivation line was 100 m. Regarding the economic analysis, an initial average investment for automation equipment equal to €40,000 was assumed. The institutional status, as well as the harmful algal bloom duration influence on the costs was neglected. For comparison reasons, the sock length in each area was kept constant. The first five

Fig. 6. Map of institutional stakeholders for mussel-farming activity in Chalastra.

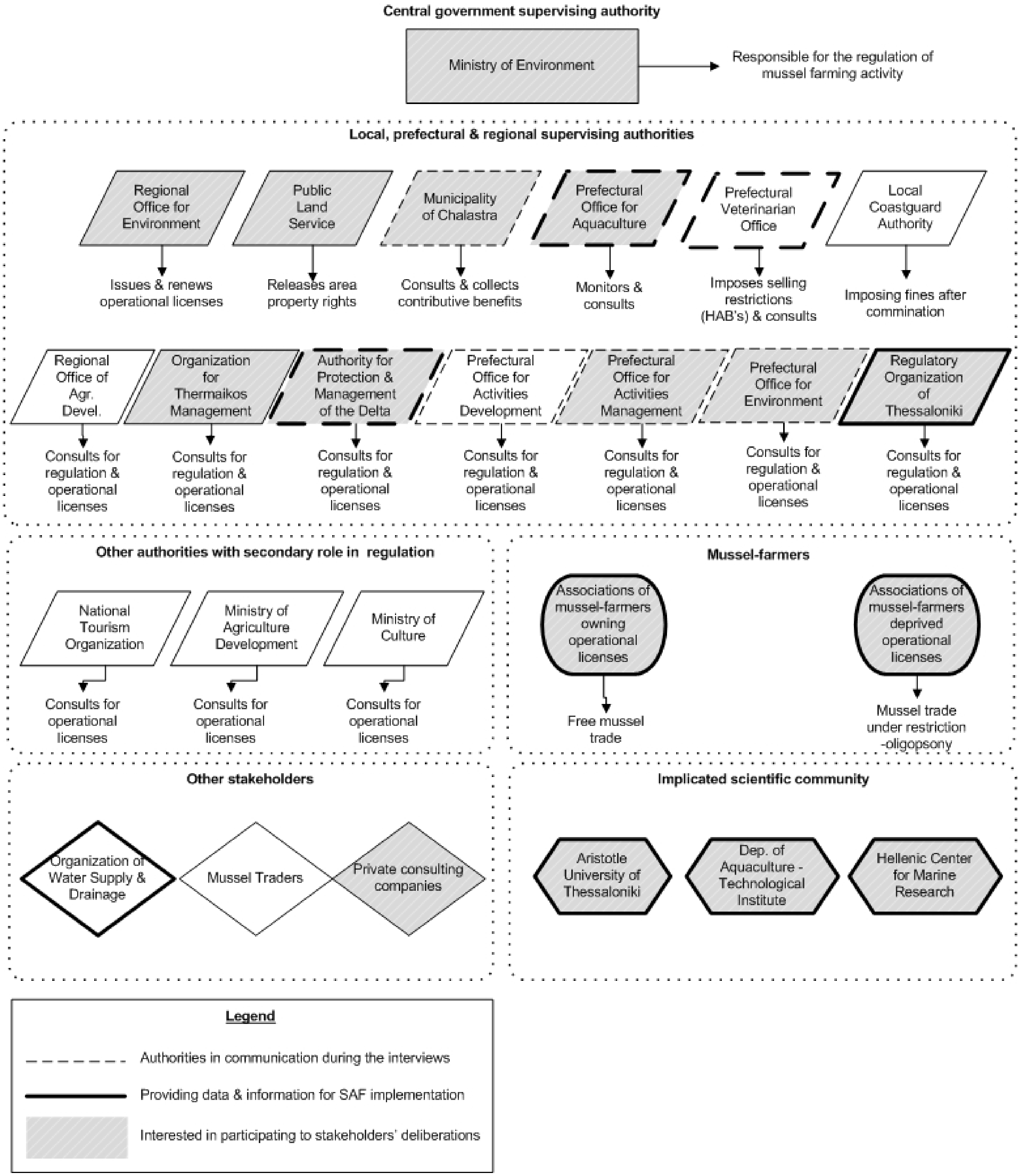


Table 7. Farming techniques examination: (A) random case, (B) excessive case, and (c) regulated case.

Area management	Sub-area 1			Sub-area 2			Sub-area 3			Sub-area 4		
Case	a	b	c	a	b	c	a	b	c	a	b	c
Number of lines	13	15	10	15	15	10	12	15	10	14	15	10
Line distance (m)	8	7	10	7	7	10	9	7	10	8	7	10
Sock distance (m)	0.4	0.4	0.5	0.6	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.5
Sock length (m)	3.0	3.0	3.0	3.5	3.5	3.5	4.0	4.0	4.0	4.5	4.5	4.5
Number of farms in the area			13			18			12			12
Mussel wet weight (kg/m of sock)	11.2	9.9	17.1	9.8	9.7	16.9	11.3	9.3	16.0	13.1	10.1	17.5
Average ind. mussel weight (g)	7.5	6.6	11.4	6.5	6.5	11.2	7.5	6.2	10.6	8.7	6.7	11.6
Total production (tn)	72.1	73.6	67.6	79.6	83.9	78.07	89.1	92.0	84.4	108.6	113.0	104.0
Costs (€)	26,284	27,001	25,209	27,001	27,001	25,209	25,925	27,001	25,209	26,643	27,001	25,209
Individual profit (€)	2,156	2,026	1,483	4,422	6,113	5,591	9,211	9,300	8,079	16,196	17,587	15,847
Individual profit (higher quality)			8,156			13,291			16,400			26,110

Total area profit (€)		
	Case a	495,026
	Case b	541,533
	Case c (normal quality)	489,541
	Case c (higher quality)	937,924

rows of Table 7 demonstrate the alternative farming characteristics for each area examined, followed by the results regarding the quality and quantity of production, as well as, the costs and profits for each farm. When the final product is of higher quality (i.e., individual mussel weight greater than 10 g), the calculation process assumes also a 25% increase on the selling price. The bottom-right of Table 7 shows the profit estimates for the entire study area in each case.

The objective of the third scenario is to evaluate the economic implications to the local community due to the lack of an active institutional regulation for the mussel-farming activity. On this account, an economic comparison was performed between two alternatives: (a) the present situation, where 55% of the long-line establishments no longer have a valid operation license, and (b) the socially desirable one, where all establishments are under a common regulating framework. In both cases it was assumed that the farms comprise 10 cultivation lines, with 10 m distance between the lines, 0.5 m distance between the socks, and 4.5 m length of each sock. An initial investment for automation equipment equal to €40,000 was assumed, along with a negligible influence of harmful algal blooms on production costs. The results are presented in Table 8.

The last scenario investigates the relation between the frequency of harmful algal blooms occurrence and the economic results on mussel farming. The farm characteristics are considered the same as in the previous scenario, while the institutional status was now neglected. For the calculation of the mean annual individual profits all the farms were taken into account. The results are presented in Table 9.

Table 8. Economic implications of institutional regulation.

Institutional control	Case 1	Case 2
Institutional status	Status quo: 45% of units having valid licenses	Desirable situation: all units with valid licenses
Mean annual individual profits (nonlegal/legal) (€)	8272 / 16,125	16,425
Annual profits of the whole mussel activity (€)	643,433	903,350
Total community contributory benefits (€)	36,000	82,500
Total community foregone earnings (€)	More than 300,000	-

DISCUSSION

Management scenarios

The exploratory analysis used by the layout spacing scenarios revealed the importance of individual farming characteristics to the quantity and quality of mussel production. Thus, a longer distance between the socks on a cultivation line improves the quality of production more than other farming techniques, such as reduced number of cultivation lines or longer distance between the long-lines (Tables 6 and 7). Furthermore the elongation of socks provides a significant increase in production (Table 7). The vertical expansion of socks does not have significant effects on mussel quality, yet the effects of increasing the sock length beyond 4.5 m has to be further investigated, especially regarding the availability of mussel food at greater depths. Accordingly, the comparison between the results of Tables 6 and 7 indicates that further investigation is necessary regarding the placement of the farms in the coastal

Table 9. Economic effects of harmful algal blooms occurrence.

Environmental constraints	Optimum case	Case 1	Case 2	Case 3	Case 4
Harmful algal bloom occurrence/year	30 days	45 days	75 days	120 days	165 days
Mean annual individual profits (€)	16,425	15,723	14,319	12,214	10,108
Extra cost/farm (€)	0	702	2106	4211	6317
Profit reduction	0%	4%	13%	25%	38%

area. The effect of water movement inhibition due to the farms is reasonable, yet the objective should be the optimum placement of the farms in order to minimize it.

The multiple alternatives examined through the model, for the typical farm of 10 000 m^2 surface area, demonstrate that in terms of quantity the best results are produced from the usage of excessive cultivation techniques (Table 7, Case B). In terms of mussel quality, based on the individual weight, the excessive practices fall short compared to the regulated case (Table 7, Case C). Specifically in the regulated case the enhancement of production is approximately 42% compared to the excessive case and 32% compared to the random case. The individual farm and area profits are initially estimated using the current selling price, thus indicating that the excessive case is more profitable compared to the other two. Yet the parameter of mussel quality is one of the most important when determining the selling price. During the last decade, the reduction of quality, along with the regulating issues, have kept the selling price of mussels stagnant, against the general increased costs of labor and expendables, resulting in reduced profit. An enhancement of mussel quality, if supported from proper regulation of the activity, can correspondingly support an increase in the selling price. A 25% increase (€0.5/kg) was examined for the regulated case, demonstrating an average 42% increase of profit compared to the excessive case, and 47% compared to the random case, raising a discussion point regarding the sustainability in terms of quantity or quality of the production.

As the implementation of the SAF targets the area of Chalastra, any benefits or losses refer intentionally to local scale. Increased profits from mussel farming will have considerable effects on the local community welfare, because a significant number of families depend on the activity, and the leaking profits affect the sustainability of the local market. On the contrary the money from the penalties, when collected, is not supporting the local economy in any way. Compared to the desirable situation (Table 8) where all farms have a valid license, the status quo results in significant profit losses (due to fines), which are greater than €300 000 per year. Thus, if the institutional regulation, that is constantly delayed, is implemented, these currently foregone earnings could be invested to optimize the production and to upgrade the welfare of the local community. Specifically, the implementation of a common institutional management in the area could increase the total income by 29%, and the contributory benefits for the local community by over 56%. These estimations are considered conservative because the selling price is assumed to be equal to the current levels. The aforementioned quality improvement could lead to significantly higher profits at both individual and total area levels.

The influence of harmful algal bloom events on the economy of a standard mussel farm was also found to be significant (Table 9). It should be noted that the emphasis was given to the total annual duration of the phenomenon and not to the number of discrete events. According to the analysis, the extra costs per individual farm may reduce profits up to 38%, thus causing a significant economic impact on the mussel-farming sector. Although it is difficult to determine a way to reduce the occurrence of harmful algal bloom events in the area, the analysis demonstrates their high importance as they are considered significant occupational hazards for mussel farmers in the study area.

Institutional map and stakeholder deliberations

The institutional stakeholder map created through the SAF implementation reveals the complex operational framework of the activity. The fragmentation of authority, the bureaucracy and the lack of a local supervising public body are responsible for the delay in implementing the regulation and for the lack of substantial control, which in turn leads to excessive cultivation practices. The SAF implementation in Chalastra, though a management oriented process, aims specifically at providing understanding of the system functioning and enhancing the communication between stakeholders, in order to promote sustainability. The joint stakeholder meetings focused on these objectives by seeking: (a) to underline the lack of information, (b) to familiarize the stakeholders with the management tool and the results of the specific scenarios, and (c) to present the future potentials of this tool.

In both meetings great interest was shown in the results and in the possible uses of the information gathered. The various groups of stakeholders reacted differently to the presented scenarios and their results. Namely, the mussel farmers focused primarily on the economic impacts of the institutional failures. On the other hand, the representatives of the public bodies were interested in the results of the alternative farming techniques, asking thus for further exploration of the spatial distribution effect of the mussel farms in the area. Although recognizing the consequences of insufficient regulation, most of the authorities' representatives are passing the responsibility of solving the problem on to a higher level of authority. Nevertheless, the representative of the Ministry of Environment, which is the higher authority, claimed lack of sufficient information in order to proceed in regulation and was interested in the potentials of the management tool.

The deliberations revealed the lack of communication between the different authorities, demonstrating that certain information regarding both the area and the farming activity is not available to everyone involved in the management process, thus causing delays and misunderstandings. To alleviate this problem a group was formulated during the second meeting, comprised of several representatives who hold key positions in the managing authorities, mussel farmers, and scientists. The aim of this group is to reinforce the communication between the different managing authorities and to ensure all available information is utilized.

CONCLUSION

Although the SAF implementation in the area of Chalastra suffered from data limitations, the aspects discussed in this paper have significantly contributed to understanding the main impacts on mussel-farming activity under different operational and management decisions, as well as under different environmental conditions. Appropriate improvement of the management tool can provide further answers to management scenarios important for the development of the activity, such as the optimum number of farms on the area, the optimum placing and orientation, the evaluation of alternative cultivation systems, and the economic interconnection with relating activities. The formulation of the management tool enables these improvements.

The joint meetings achieved a solid communication between stakeholders, and a public commitment by the authorities involved in the activity, thus creating a social impact by raising the hopes for a forthcoming solution concerning the regulative issues. In the context of the SAF, the use of even a simple management tool proved useful both in quantifying aspects of the mussel-farming activity and also in providing a basis for further dialogue and investigation. In addition, the formation of the multidimensional collaboration stakeholder group was a result quite innovative for the area, particularly under the current complicated operational framework of the activity. These contributions are promoting a more sustainable approach towards the management of small-scale mussel farming in the area. At the same time they are highlighting the value of the SAF, even in cases where, although the preconditions for integrated coastal management seem to be absent, there is an urgent need for participative management initiatives.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol17/iss1/art1/responses/

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LITERATURE CITED

Anagnostou, Ch. 2001. *Management study of the mussel production zones of the Thessaloniki and Thermaikos Gulfs, final technical report* (in Greek). Ch. Anagnostou, scientific coordinator. National Center of Marine Research (NCMR) on behalf of the Prefecture of Thessaloniki.

Arhonditsis, G., G. Tsirtsis, M. O. Angelidis, and M. Karydis. 2000. Quantification of the effects of nonpoint nutrient sources to coastal marine eutrophication: applications to a semi-enclosed gulf in the Mediterranean Sea. *Ecological Modelling* 129(2-3):209-227. http://dx.doi.org/10.1016/S0304-3800(00)00239-8

Brigolin, D. 2007. Development of integrated numerical models for the sustainable management of marine aquaculture. Ph.D. thesis. University of Ca' Foscari Venice, Italy.

Brigolin, D., G. D. Maschio, F. Rampazzo, M. Giani, and R. Pastres. 2009. An individual-based population dynamic model for estimating biomass yield and nutrient fluxes through an off-shore mussel (*Mytilus galloprovincialis*) farm. *Estuarine, Coastal and Shelf Science* 82(3):365-376. http://dx.doi.org/10.1016/j.ecss.2009.01.029

Brugnach, M., C. Pahl-Wostl, K. E. Lindenschmidt, J. A. E. B. Janssen, T. Filatova, A. Mouton, G. Holtz, P. van der Keur, and N. Gaber. 2008. Complexity and uncertainty: rethinking the modelling activity. Pages 49-68 *in* A. J. Jakeman, A. A. Voinov, A. E. Rizzoli, and S. H. Chen, editors. *Environmental modelling, software and decision support: state of the art and new perspectives.* Elsevier B.V. Amsterdam, The Netherlands. http://dx.doi.org/10.1016/S1574-101X(08)00604-2

Camacho, A. P., U. Labarta, and R. Beiras. 1995. Growth of mussels (*Mytilus edulis galloprovincialis*) on cultivation rafts: influence of seed source, cultivation site and phytoplankton availability. *Aquaculture* 138(1-4):349-362. http://dx.doi.org/10.1016/0044-8486(95)01139-0

Chapelle, A., A. Mınesguen, J. Deslous-Paoli, P. Souchu, N. Mazouni, A. Vaquer, and B. Millet. 2000. Modelling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters farming and inputs from the watershed. *Ecological Modelling* 127(2-3):161-181. http://dx.doi.org/10

.1016/S0304-3800(99)00206-9

Duarte, P., U. Labarta, and J. M. Fernαndez-Reiriz 2008. Modelling local food depletion effects in mussel rafts of Galician Rias. *Aquaculture* 274(2-4):300-312.

Fasman, M. J. R., H. W. Ducklow, and S. M. McKelvie. 1990. A nitrogen—based model on plankton dynamics in the oceanic mixer layer. *Journal of Marine Research* 48:591-639.

Galinou-Mitsoudi, S., Y. Savvidis, and X. Dimitriadis. 2006. Interaction between mussel culture and hydrodynamics: a preliminary study in the gulfs of Thessaloniki and Thermaikos, Greece. *Journal of Biological Research* 6:139-145.

Galinou-Mitsoudi, S., Y. Savvidis, A. Moriki, D. Petridis, and X. Dimitriadis. 2009. Mussel production in relation to ecohydraulic conditions in the culture area of NW Thessaloniki Gulf (NW Aegean, Greece). Poster abstract presented at the European Aquaculture Society's Aquaculture Europe 09 Conference, August 15 to 19, 2009, Trondheim Norwegian University of Science and Technology, Trondheim, Norway.

Gangnery, A., C. Bacher, and D. Buestel. 2004. Application of a population dynamics model to the Mediterranean mussel, *Mytilus galloprovincialis*, reared in Thau Lagoon (France). *Aquaculture* 229(1-4):289-313. http://dx.doi.org/10.1016/S0044-8486(03)00360-0

Hopkins , T. S., D. Bailly, and J. G. Støttrup. 2011. A systems approach framework for coastal zones. Ecology and Society 16(4): 25. http://dx.doi.org/10.5751/ES-04553-160425

Karageorgis, A. P., M. S. Skourtos, V. Kapsimalis, A. D. Kontogianni, N. Th. Skoulikidis, K. Pagou, N. P. Nikolaidis, P. Drakopoulou, B. Zanou, H. Karamanos, Z. Levkov, and Ch. Anagnostou. 2005. An integrated approach to watershed management within the DPSIR framework: Axios River catchment and Thermaikos Gulf. *Regional Environmental Change* 5(2-3):138-160. http://dx.doi.org/10.1007/s10113-004-0078-7

Kourafalou, V. H., and Tsiaras K. 2007. A nested circulation model for the North Aegean Sea. *Ocean Science* 3:1-16. http://dx.doi.org/10.5194/os-3-1-2007

Krestenitis, Y. 2003. Elements of hydrodynamic circulation. Pages 11-57 *in* K. Pagou, scientific coordinator. *Monitoring of the quality of marine environment of the gulf of Thessaloniki (Thermaikos), final technical report*. National Center of Marine Research (NCMR), Athens, Greece.

Moriki, A. (scientific coordinator). 2007. *Water circulation in organized areas of aquaculture development and land-planning and environmental management interventions final technical report* (in Greek). Archimed II, Alexander Technological Educational Institute of Thessaloniki, Moudania, Greece.

Moriki, A., S. Galinou–Mitsoudi, D. Petridis, D. Kosti, Y. Savvidis, X. Dimitriadis, C. Koutitas, and L. Alvanou. 2008. Environmental impacts of intense mussel culture in the coastal waters of the Gulf of Thessaloniki (N. Greece). *Fresenius Environmental Bulletin* 17(11b):1945-1955.

Newell R. I. E. 2004. Ecosystem influence of natural and cultivated populations of suspension-feeding bivalve mollusks: a review. *Journal of Shellfish Research* 23(1):51-61

Pagou, K. 2005. Eutrophication in Hellenic coastal area. Pages 311-317 *in* E. Papathanassiou and A. Zenetos, editors. *State of the Hellenic marine environment*. Hellenic Center for Marine Research, Institute of Oceanography, Athens, Greece.

Pagou, K., E. Krasakopoulou, A. Pavlidou, G. Assimakopoulou, H. Kontoyiannis, and Ch. Anagnostou. 2001. Inner Thermaikos Gulf (NW Aegean Sea, E. Mediterranean): a preliminary approach. Pages 6-11 *in* V. Dupra et al., editors. *Coastal estuarine systems of the Mediterranean and Black Sea regions: carbon, nitrogen and phosphorous fluxes*. Reports and Studies Series No 19. Land-Ocean Interactions in the Coastal Zone (LOICZ), LOICZ International Project Office, Texel,The Netherlands.

Papathanassiou, E., K. Pagou, A. Giannakourou, E. Krasakopoulou, S. Galinou-Mitsoudi, G. Assimakopoulou, Ch. Anagnostou, I. Krestenitis, P. Drakopoulou, S. Zervoudaki, E. Strogyloudi, and A. Pavlidou. 2007. Mussel cultures and the eutrophic marine environment in Thermaikos Gulf—NW Aegean Sea, Greece. Pages 40 to 41 in *Book of Abstracts, 10th International Conference on Shellfish Restoration (ICSR) 2007, November 12-16, 2007, Vlissingen, The Netherlands*. Wagenigen Institute for Marine Resources and Ecosystem Studies (IMARES) Yerseke, Zeeland, The Netherlands.

Savvidis, Y., A. Antoniou, X. Dimitriadis, A. Moriki, S. Galinou–Mitsoudi, L. Alvanou, D. Petridis, and C. Koutitas. 2007. Hydrodynamics in a mussel culture area in Thermaikos Gulf. Pages 1263-1274 in *Proceedings of the Eighth International Conference on the Mediterranean Coastal Environment, MEDCOAST 07*. Alexandria, Egypt. Mediterranean Coastal Foundation, Dalyan, Ortaca/Mugla,Turkey.