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Integration of Mathematical Modeling and Multicriteria Methods in Assessing Environmental Change in Developing Areas: A Case Study of a Coastal System

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ABSTRACT

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An integrated methodology, based on the combination of a marine water quality model and multicriteria analysis, is proposed as a new tool for addressing economic and environmental issues for coastal areas. The model consists of three interacting components (terrestrial, hydrodynamic and biological submodels), which are used to evaluate the likely environmental impact of various economic development scenarios. Multicriteria Analysis combines the model outputs with socioeconomic values for the coast and through assignment of different weights/priorities by the user provides a ranking system for these scenarios. The Gulf of Gera, Island of Lesvos, Greece, a semi-enclosed and shallow system surrounded by a cultivated and inhabited watershed, was used as a case study for this method. Four scenarios concerning the development of tourism, the construction of agricultural greenhouses, the cultivation of woody plant species and the development of animal husbandry were tested against the present condition of the watershed (which is primarily dominated by olive oil production). The trade-off between increased profits and environmental impacts for these development scenarios was illustrated using Cluster and Principal Component Analysis. The results of these analyses showed that tourism and animal husbandry balance profits and environmental degradation most effectively and represent the most favorable future development strategies for the study area. The present approach can be used as a supportive tool for policy-planners and decision-makers to quantify interrelated socio-economic and environmental issues for the sustainable development of coastal areas.

ADDITIONAL INDEX WORDS: *Multicriteria analysis, coastal management, integrated analysis, Mediterranean Sea, mathematical modeling.*

INTRODUCTION

Many coastal areas are experiencing increasing environmental pressures from a variety of activities such as urbanization, industrialization and tourism development. Various factors control these activities, so that changes in demographic, industrial, social and technological patterns result in unexpected economic and environmental repercussions often leading to a need to revaluate coastal management strategies (LIPIATOU and CORNAERT, 1999). A common problem for the development of ecologically sustainable policies is the conflict between environmental and resource management priorities. The interwined aspects of coastal zone sustainability call for a new methodological framework, which could form the basis for balanced environmental management (GOLDIN and WINTERS, 1995). This need elucidates a gap between experimental work and decision-making, because of the incompatibility of methods for policy analysis (CARRARO and SINISCALCO, 1995; TURNER, 1999). The transfer of knowledge from scientists to decision-makers, industries and politicians is an important challenge for our society (THIEL, 1999).

The complex nature of dynamic ecological and economic processes has been supported by integrated models, which are a powerful method to analyze and to evaluate changes in the environment caused by human activities such as the consumption and production of goods and services, recreation or environmental protection measures (COLLADOS and DUANE, 1999). The effectiveness and the popularity of monodisciplinary models, based on either economic factors or ecological principles, are higher than multidisciplinary models (SMITHERS and SMIT, 1997). However, multicriteria choice methods, which assign scores to multiple objectives of a complex problem and classify the objectives in a ranked list, should be considered as another potentially powerful tool for policy analysis (MUNDA *et al.*, 1994; MARTINEZ-ALIER *et al.*, 1998). Multicriteria methods can consider a variety of factors simultaneously while incorporating information expressed in metric and non-metric form and attach different weight preferences to the variables (NIJKAMP *et al.*, 1990).

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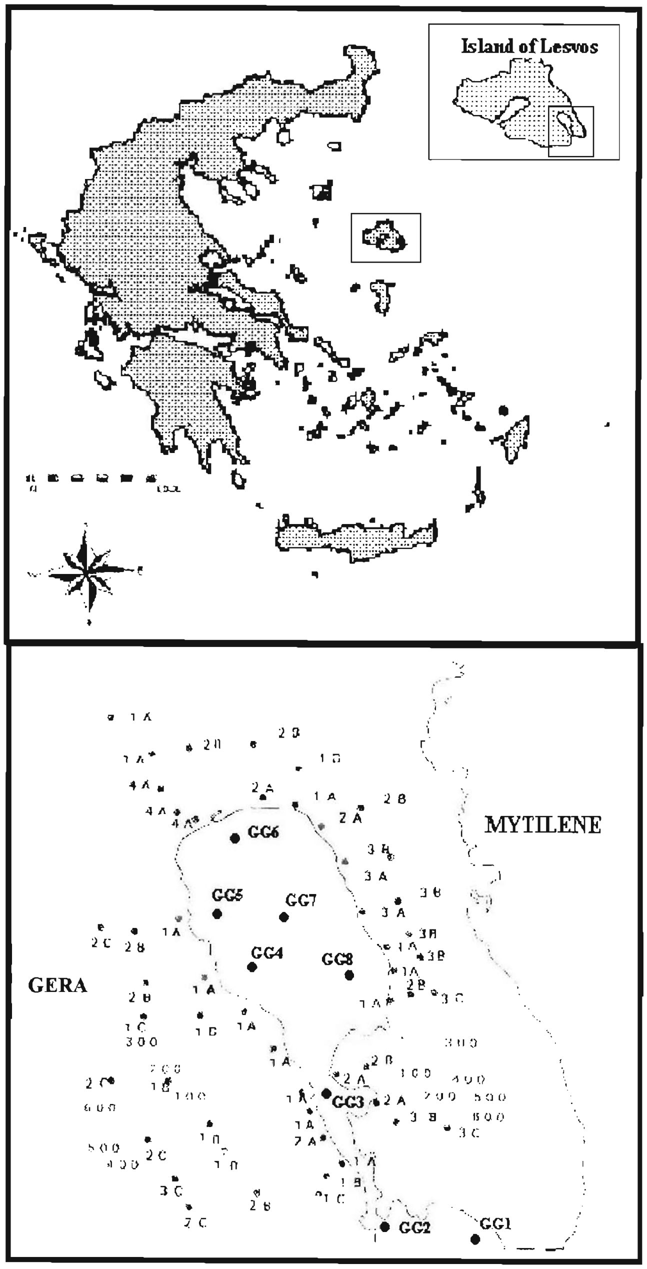

Figure 1. The study area, the gulf of Gera, Island of Lesvos, Greece. The sampling sites of the marine (GG1–GG8) and the terrestrial ecosystem. (Land cover categories are: 1, cultivated olive groves; 2, abandoned olive groves; 3, maquis; and 4, wetlands. Letters A, B, and C correspond to the altitudes of <150 m, 150–300 m and >300 m, respectively.)

In the present study, an integrated methodology is developed to obtain a coherent analytical framework allowing economic goals to be directly compared with environmental objectives. A mathematical model was used to assess alternative scenarios for coastal zone development. The model structure emphasized the linkage between terrestrial and aquatic processes to objectively evaluate the effects of hypothetical changes in land use on water quality. A case study was carried out in a semi-enclosed marine ecosystem in Greece, surrounded by an agricultural and moderately developed watershed. The environmental effects of four scenarios concerning the development of tourism, the construction of agricultural greenhouses, the cultivation of woody plant species and animal husbandry were tested with the model. Multicriteria analysis was used as a way to combine model outputs with the socio-economic values of these scenarios to provide a ranking system based on appraisal scores.

Table 1. *Summary statistics of nitrate, nitrite, ammonia, phosphate, silicate, organic nitrogen in μg-at/l, chlorophyll a in μg/lt and total bacterial number in 10^3 cells/ml, in the gulf of Gera, from June 1996 to October 1997.*

Parameter	Range	Mean Value	Standard Deviation
Nitrate	0.09–2.57	0.55	0.37
Nitrite	0.01–0.56	0.10	0.07
Ammonia	0.05–6.62	0.91	0.98
Phosphate	0.02–0.85	0.19	0.12
Silicate	3.09–10.17	7.59	1.15
Organic Nitrogen	0.17–27.99	7.93	4.06
Chlorophyll *a*	0.03–3.07	0.98	0.59
Total bacterial number	331–1145	655	162

METHODOLOGY

The Study Area

The Environment

This study was carried out in the Gulf of Gera located within the Island of Lesvos, Greece. The Gulf of Gera is a semi-enclosed marine ecosystem with a mean depth of 10 m and a total volume of 9×10^8 m^3 (Figure 1). The surrounding 194-km^2 watershed is dominated by olive cultivation and is inhabited by 7064 people according to a 1991 census. Non-point sources nutrient fluxes from agricultural run-off are substantial, especially during the winter period when their contributions vary between 40 to 60% of the total inorganic nitrogen (*i.e.* the limiting nutrient) loading to this ecosystem (ARHONDITSIS *et al.*, 2000a). The most important point discharges in the water body under consideration are untreated domestic wastewater and effluent from local industrial activities, especially olive oil-processing by-products. Summary statistics of the chemical and biological information collected from eight sampling sites in the study area (Figure 1), are presented in Table 1. These mean values are characteristic of a mesotrophic environment with eutrophic trends according to a eutrophication classification system for the Aegean Sea (IGNATIADES *et al.*, 1992; KITSIOU and KARYDIS, 1998).

The terrestrial ecosystem is characterized by a near monoculture of olive trees, located mainly on terraced hillslopes. There is a trend in the Aegean archipelago for this agriculture type to be combined or replaced by animal husbandry (especially sheep and goats) to provide increased incomes for the local farmers (MARGARIS, 1992). The exposure of these areas to free grazing affects the secondary plant species succession, reduces species diversity and leads to progressive land degradation. The damaged vegetative cover intensifies soil erosion and soil-water loss, reduces groundwater level, increases nutrient fluxes, decreases productive capability and ultimately results in an ecosystem which is unable to regenerate (GIOURGA *et al.*, 1998). It is therefore clear that both the terrestrial and marine ecosystems encounter disturbances that constitute severe long-term threats to the ecological stability of the region.

The Economy

Olive cultivation was a traditional monoculture that sustained the local economy to a large extent. However, during the recent decades, the proliferation of competitive substitute products for olive oil, *i.e.* seed-oils, resulted in an economic decline followed by a mass emigration of the inhabitants to continental Greece and abroad (MARGARIS, 1992). The size of an average farm is approximately 2.3 ha, with 2 ha being olive groves. The cost of agricultural products is high and the prospects for mechanization are limited due to the mountainous terrain and the small size of the farms. Furthermore, the implementation of modern techniques, such as irrigation, pruning, optimal application of fertilizers and hand or chemical thinning of olive groves are the exception rather than the rule in this area. This fact is attributed mostly to lack of knowledge by the local farmers, to limited advice by the Department of Agriculture and to the low price of olive oil, which makes increased production unprofitable (LOUMOU *et al.*, 2000). The Gross Margin per holding—the Gross Value Product minus the Variable Expenses—is estimated at 2200 $US according to the average annual production during 1984–1994. In most cases the gross margin covers 25% of the average annual household expenditure, estimated at 9000 $U.S., while in special occasions of high annual yield this proportion doubles (LOUMOU *et al.*, 2000). Consequently, serious underemployment characterizes the agricultural sector, which cannot ensure an income sufficient to cover the needs of a family. Tourism is less developed in this area, despite its positive economic impacts, compared with other areas of the island due to substantial employment in a local tannery. A small increase in tourism occurred after the late 1980's, when this factory suspended its operation. Thus, the local farmers supplement their income mostly as construction workers and as livestock breeders. The livestock of the area numbers about 5500 sheep and goats.

In the present study, alternative managerial schemes are tested to increase the per capita income and to secure economic and ecological sustainability. Data on the socio-economic system have been obtained through the Prefecture of Lesvos, the corresponding DEPARTMENT OF AGRICULTURE (1994) and the NATIONAL TOURISM ORGANIZATION (1993). Values for the socioeconomic criteria were based partially on relevant studies of these Departments, using questionnaires that took into account various characteristics of the local population (*i.e.* age, education level, sex, annual income), and partially on the authors' own judgment resulting from personal communications with the mayor of Gera and other local authorities.

Development of Scenarios

In general terms, no feasible scenarios—especially for short time scales of interest—could be developed by ignoring the existing infrastructure, tradition and the natural resources of the area (NIJKAMP and VREEKER, 2000). This implies that olive cultivation and pluriactivity are integral parts in strategic action plans focused on the economic welfare. The first proposal is a partial shift from olive oil to edible olive production. This shift matches well-documented trends in domestic and foreign markets. This shift would result in an increase in the net domestic product, since the higher costs and demands for labor and natural resources are greatly exceeded by the higher product values. Moreover, the improvement in olive oil quality combined with appropriate marketing could also result in increased unit profits. The environmental risk is slightly larger than for the present situation due to increased application of fertilizers, insecticides, organic substances used for the chemical thinning of the olive trees and greater irrigation demand. All these changes concerning the cultivation of olive groves and reorganization of whole agricultural production, would be combined with the following scenarios that tend to improve employment and provide supplementary incomes for the local population.

Scenario 1. (Emphasis on cattle breeding) The first scenario is the development of the livestock breeding, which would entail a tripling of the present average number of animals per farm. The animal husbandry will mostly be cattle, sheep, goats and pigs, which will be fed with fodder and farm-produce by-products, whereas free grazing will be kept at very low levels. Moreover, special emphasis should be given to the breeding of poultry, another profitable sector that is underdeveloped in the region. This scheme proposes a mild turn in the local economy, which means rapid accommodation of the local labor to changes of production and moderate investments in infrastructure and technical knowledge. The most significant drawback of this plan is the additional environmental pressure due to the animal manure and farm waste, which is a potential threat to both seawater and groundwater quality (VALIELA *et al.*, 1997). Furthermore, there is a possibility that the coexistence of competitive producers on the same or neighboring islands targeting the same markets, could compromise the economic benefits of this scenario.

Scenario 2. (Cultivation of woody plant species) An alternative plan that is also focused on the development of the primary sector is the cultivation of woody plant species that prosper in a wide range of soil types, temperature and moisture such as almond, fig and pomegranate trees. These crops' demands for fertilizers and labor do not exceed the requirements of olive groves. The scenario exploits the mountainous zones of the watershed, where abandoned olive groves abound and severe problems of erosion and soil degradation exist (ARROYO *et al.*, 1994). This cultivation is familiar to the local farmers and easy to implement and will sustain soil cohesiveness and productivity of the terrestrial ecosystem. However, the fact that these trees enter into production five years after planting and the implicit long-term yield of the additional profits constitute an undesirable prospect for the local habitats; furthermore, the expected increase in the per capita income will not be large.

Scenario 3. (Construction of greenhouses) This scenario is the construction of greenhouses on abandoned olive groves having a slope of less than 15%. This proposal emphasizes the cultivation of crops such as tomato, cucumber, pumpkin, melon, okra, and aubergine in order to satisfy the needs of Lesvos as well as neighboring islands such as Limnos and Chios, where these types of crops do not currently exist. This plan would result in an increase in the net domestic product, since the higher production costs and higher demands for employment will result in higher values per unit product. However, there are some shortcomings due to i) the lack of technical knowledge by the local farmers, and ii) some unsuccessful past experiences, with the production of flowers, which have made the local population hesitant to pursue related enterprises. The environmental threat is due to increased consumption of natural resources (water), the application of fertilizers, herbicides, fungicides and soil disinfectants such as the methyl bromide (SHORTLE and DUNN, 1991). However, the cost of greenhouse-construction is covered to a large extent (≈50%) by European Union subsidies.

Scenario 4. (Development of tourism) The natural environment of the area, the high quality of swimming beaches, the mild climate, the local mineral springs and the presence of historic and cultural sites can facilitate tourism development. According to this scenario, the farmers will provide tourism services and supply rental rooms and furnished apartments. The perspective is that the area could host about 15.000 tourists from June to September, which is a doubling of the current number. Furthermore, the peak of the agricultural activities during winter and spring does not coincide with the peak summer tourism season. Consumption of local agricultural products by tourists would be a further incentive for the improvement of their quality leading to new trends and products in the primary sector (WUNDER, 2000). Additional advantages for tourism development are the good telecommunication and transportation infrastructure, accessibility to the local airport and recreation areas. On the other hand, there are some substantial problems with this scenario such as deficiencies in the existing infrastructure, since the region is totally underdeveloped for tourism. Moreover, the lack of adaptability and special skills by the local inhabitants to cope with tourism may add to this problem. Finally, the cost of this scenario is rather high, but this would be moderated by the subsidies from the European Union, which would cover 50–75% of total investments.

The Mathematical Model

The simulation of marine ecosystem functions was done using an integrated modeling approach, that consisted of three interacting components, i) the terrestrial, ii) the hydrodynamic and iii) the biological submodels (ARHONDITSIS *et al.*, 2000a). The flow diagram of the model is shown in Figure 2. The experimental procedure and the statistical analysis of the data revealed that the effects of the stratification were insignificant and the seawater column was characterized by a vertical homogeneity (ARHONDITSIS, 1998). Therefore, it was assumed that the 2-D perception of the system would sufficiently describe the dynamics of the system.

The Terrestrial Submodel

The terrestrial non-point fluxes of nutrients and organic carbon, concerning both the present condition and the hypothetical scenarios, were estimated by using a modification of the loading function approach (HAITH and TUBBS, 1981). The concept of the model assumes that non-point nutrient loading is the product of interactions between the topography, hydrology, plant cover and agricultural practices of the catchment area. The agricultural land surrounding the water body was divided into unit source areas, using a 0.25 × 0.25 km grid, the contribution of each grid-cell being independent to the total nutrient export from the watershed. Figure 1 presents the dense sampling network used for the study of spatial and temporal distribution of nutrient concentrations and their variability among the various land-cover categories (ARHONDITSIS *et al.*, 2000b). Furthermore, the discrimination of the cell-characteristics such as soil, crop, management and topographic properties was done using GIS (Arc/Info, Environmental System Research Institute, Inc.) and Landsat Thematic Mapper (TM) images, using unsupervised and supervised classification (HATZOPOULOS *et al.*, 1992). The evaluation of the scenarios was obtained by replacing the current with the proposed land uses in the appropriate cells (Table 2), and further applying the loading functions. The nutrient fluxes from sewerage, the local industrial activity, and atmospheric wet and dry deposition were also incorporated in the model by using theoretical coefficients in combination with experimental observations for the study area (MARCHETTI and VERNA, 1992; WERNER and WODSAK, 1994; MEDINETS, 1996; HERUT *et al.*, 1999). The terrestrial submodel was run with a time step of one day and the nutrient and organic carbon loading to the marine ecosystem were estimated on a daily basis. These loadings were used as an input for the biological submodel describing the flow of energy through the microbial components of the marine ecosystem.

The Hydrodynamic Submodel

The Princeton Ocean Model, a free surface and sigma coordinate model, was applied to simulate the hydrodynamic regime of the study area (MELLOR, 1996). The 2-D mode of the model was deemed sufficient due to the similarity between the circulation pattern of the upper and bottom layers (ARHONDITSIS, 1998). In this case, a rectangular grid was used with cell dimensions of 330 × 330 m and the boundary conditions between the study area and the open sea, were specified by the calculation of tidal forces. It was assumed that the resultant tidal forces, can be considered as the sum of a number of simple harmonic constituents, each one reflecting the motions of sun and moon and having its own characteristic period, phase and amplitude. Wind stresses have been also taken into account using Wilson's equation (WEIYAN, 1992). The hydrodynamic submodel outputs, which was run with a time step of one day, were used as inputs for

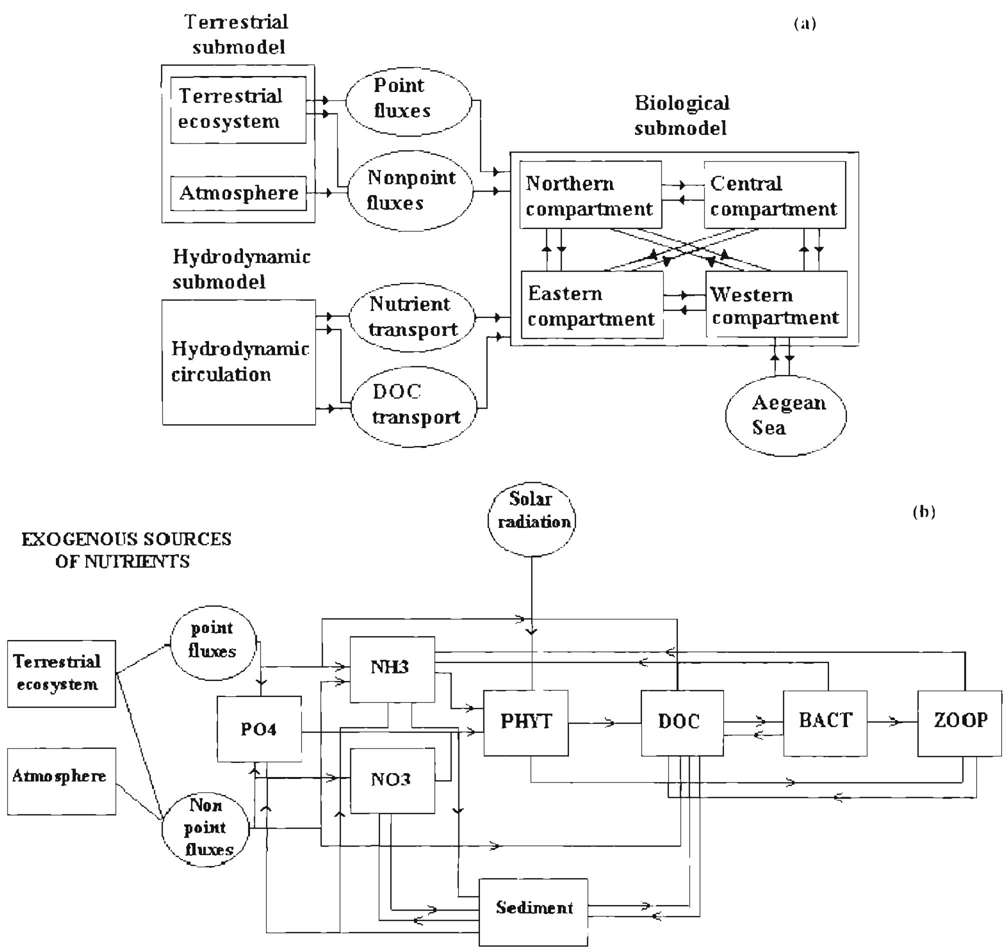

Figure 2. a) The flow diagram of the model: the terrestrial submodel estimating the input of nutrients and organic carbon from point and non-point sources, the hydrodynamic submodel quantifying the transport of nutrients and organic carbon and the biological submodel consisting of four spatial compartments and interacting with the open sea. b) The flow diagram of the biological submodel (PHYT, BACT and ZOOP, the phytoplanktonic, bacterial and zooplanktonic biomasses, respectively).

the eutrophication submodel in order to estimate the nutrient and organic carbon transport due to the seawater circulation.

The Biological Submodel

This component consisted of four spatial compartments shown in Figure 2a, the northern, the western, the eastern and the central compartment in relation to the morphological and demographic characteristics of the surrounding watershed. A fifth spatial compartment, characterizing the oligotrophic waters of the Aegean Sea, has been used for the definition of the boundary conditions (ARHONDITSIS *et al.*, 2000a). The nitrogen and phosphorus exchange at the seawater-sediment interface were also incorporated in the model using existing empirical formulations (JACOBSEN and JORGENSEN, 1975; KAMP-NIELSEN, 1975). The energy flow through the microbial food web was described by seven state variables associated with the first stages of the eutrophication process: the phytoplanktonic (PHYT), zooplanktonic (ZOOP) and bacterial (BACT) biomasses, nitrate (NO_3), ammonia (NH_3), phosphate (PO_4) and dissolved organic carbon (DOC) concentrations (Figure 2b). The seven differential equations describing temporal variation for the state variables are reported in Table 3. Two physical factors were taken into account for the development of the model, the solar irradiance and the nutrient/organic carbon exchanges among the spatial compartments due to advective and diffusive transport. Phytoplanktonic growth depends on light (φ_{LT}), nitrogen (φ_{NA}) and phosphorus (φ_P) availability and on the maximum specific growth rate (Pro). On the other hand, phytoplanktonic losses are assumed to be due to exudation (γ), zooplankton grazing (G_p) and mortality (m_p), which is transformed into DOC (m_{dp}), ammonia (m_{ap}) and phosphorus (m_{pp}) fractions. According to this model, bacterial growth depends on the availability of dissolved organic nitrogenous compounds (U_1) and ammonia (U_2), whereas exudation (e_b), mortality (m_b) and zooplankton grazing (G_b) are the most important bacterial loss factors. The zooplankton growth is based on consumption of phytoplankton and bacteria. The grazing

Table 2. *Land cover categories in the catchment area of Gera, concerning the present condition and the four alternative management practices of the watershed.*

Land Cover	Present Condition Area (km²)	Emphasis on Cattle-Breeding	Cultivation of Woody Species	Construction of Greenhouses	Development of Tourism
Olive groves					
Cultivated[a]	75.71 (39.02%)	93.04 (47.95%)	74.47 (38.38%)	73.95 (38.11%)	75.71 (39.02%)
Abandoned	40.78 (21.02%)	30.40 (15.67%)	27.43 (14.14%)	17.66 (9.11%)	32.60 (16.82%)
Urban areas[b]	8.37 (4.33%)	8.37 (4.33%)	8.37 (4.33%)	8.37 (4.33%)	16.55 (8.53%)
Maquis	62.42 (32.17%)	55.47 (28.59%)	41.66 (21.47%)	58.93 (30.37%)	62.42 (32.17%)
Wetlands	6.73 (3.46%)	6.73 (3.46%)	6.73 (3.46%)	6.73 (3.46%)	6.73 (3.46%)
Woody species			35.35 (18.22%)		
Greenhouse cultivations				28.37 (14.62%)	
Total			194.01		

[a] Includes areas with a coexisting animal husbandry of the domestic type.
[b] Includes touristic areas with hotels, rented rooms, etc.

rates G_p and G_b are multiplied by the coefficients as_p and as_b, which reflect the equivalent assimilation efficiencies. Zooplankton biomass losses are due to excretion (e_z) and mortality (m_z) including the grazing by higher predators in the trophic chain. Moreover, the products of the zooplankton metabolism were assumed to constitute indirect sources of ammonia (e_{az}, m_{az}) and dissolved organic carbon (e_{dz}, m_{dz}). The equations and the parameters expressing the phytoplanktonic and bacterial uptake and the zooplankton grazing rates are described in Table 4. The chlorophyll a content of the phytoplanktonic cells was converted to carbon assuming a C/chlα ratio of 50, whereas the dissolved organic carbon concentration is computed from the dissolved organic nitrogen data available, using a C:N ratio of 5.6 (REDFIELD *et al.*, 1963; FASHAM *et al.*, 1990). The set of ordinary differential equations defining the biological and chemical processes in the four compartments of the biological submodel was integrated with a fourth-order Runge-Kutta algorithm. The simulation was run with a time step of one day until the achievement of a steady-state annual cycle, whereas the calibration of the model was based on the "controlled random search" method. The model is not very sensitive to initial conditions and it took 3 years to achieve a steady state. Finally, the extent to which uncertainties in the values of parameters influence the equilibrium values of the state variables examined using a sensitivity analysis.

Table 3. *The seven differential equations describing the temporal variations of the state variables*[a].

$$dPHYT/dt = (Pro \times \phi_{NA} \times \phi_{LT} \times \phi_P \times (1 - \gamma) - m_p - k_{WS}) \times PHYT - G_p \pm PHYT_{comp}$$
$$dBACT/dt = (U_1 + U_2 - m_b - e_b - k_{WS}) \times BACT - G_b \pm BACT_{comp}$$
$$dZOOP/dt = as_p \times G_p + as_b \times G_b - (e_z + m_z) \times ZOOP \pm ZOOP_{comp}$$
$$dDOC/dt = (Pro \times \phi_{AN} \times \phi_{LT} \times \phi_P \times \gamma + m_{dp}) \times PHYT + (m_{db} - U_1) \times BACT + (e_{dz} + m_{dz}) \times ZOOP + DOC_{sed} + DOC_{point} + DOC_{npoint} + DOC_{atm} \pm DOC_{comp}$$
$$dNH3/dt = -(a_{n,p}{}^{b} \times \phi_N - m_{ap}) \times PHYT + (m_{ab} + e_b - U_2) \times BACT + (e_{az} + m_{az}) \times ZOOP + NH3_{sed} + ND3_{point} + NH3_{npoint} + NH3_{atm} \pm NH3_{comp}$$
$$dNO3/dt = -a_{n,p} \times \phi_N \times PHYT + NO3_{sed} + NO3_{point} + NO3_{npoint} + NO3_{atm} \pm NO3_{comp}$$
$$dPO4/dt = -(a_{pop}{}^{b} \times \phi_P - m_{pp}) \times PHYT + PO4_{sed} + PO4_{point} + PO4_{npoint} + PO4_{atm} \pm PO4_{comp}$$

[a] The subscripts *sed, point, npoint, atm*, indicate the fluxes from the sediment, the point, non-point terrestrial sources and the atmosphere, respectively. The subscript *comp* indicates the transport processes among the spatial compartments of the study area. The differential equations of the western compartment include an additional term describing the interactions of the compartment with the open sea.
[b] $a_{n,p}$ = Pro × 0.071393/C : N ratio for phytoplankton, expressing the conversion ratio of inorganic nitrogen to phytoplanktonic biomass. a_{pop} = Pro × 0.032258/C : P ratio for phytoplankton, expressing the conversion ratio of inorganic phosphorus to phytoplanktonic biomass.

The two-sided Kolmogorov-Smirnov test has shown good fit between experimental and simulated data over the six internal stations (Table 5). Moreover, the parameter values and further details about this model construction are reported elsewhere (ARHONDITSIS *et al.*, 2000a). The well-documented efficiency of the model to quantify the dynamics of inorganic nutrients-phytoplankton-bacteria-zooplankton and organic carbon relationships supports the view that it is a reliable methodological tool for the assessment to coastal marine eutrophication. This inference was supported by the results of the sensitivity analysis indicating that the model reacts with stability to the uncertainties of the model parameters; and although its ecological structure is highly aggregated, a significant increase in the number of biotic compartments *i.e.* discrimination of phytoplankton or zooplankton taxonomic subclasses, is unlikely to improve our understanding of interconnected terrestrial and marine processes (ARHONDITSIS *et al.*, 2000a). Thus, this integrated modeling approach should be considered a realistic reproduction of the dynamics of the coastal marine ecosystem and can be used for an objective testing of alternative scenarios.

Table 4. *The equations and the parameters expressing the phytoplantonic and bacterial uptake and the zooplankton grazing rates.*

Process	Expression	Parameters
	Phytoplankton	
Light limitation	$\varphi_{LT} = \ln\{(1 + I/I_k)/[1 + I \cdot \exp(-k \cdot z)/I_k]\}/(k \cdot z)$	I_k: the half saturation light intensity k: the maximum depth z: the light extinction coefficient
Nitrogen limitation	$\varphi_{NA} = \varphi_N + \varphi_A = \frac{NO_3 \cdot \exp(-\psi \cdot NH_3)}{NO_3 + NH} + \frac{NH_3}{NH_3 + AH}$	NH: the half saturation constants for nitrate AH: the half saturation constants for ammonia ψ: the strength of the ammonium inhibition on nitrate uptake
Phosphorus limitation	$\varphi_P = \frac{PO_4}{PO_4 + PH}$	PH: the half saturation constants for phosphate
	Bacteria	
Nitrogenous substrate	$S = \min(NH_3, \nu \cdot DON)$	ν: the ratio of bacterial ammonium uptake to DON uptake
DON uptake	$U_1 = \frac{a_{BD} \times DON}{DH + S + DON}$	a_{BD}: the maximum bacterial uptake rate
Ammonium uptake	$U_2 = \frac{a_{BD} \times S}{DH + S + DON}$	DH: the half-saturation constant for bacterial uptake
	Zooplankton	
Grazing rate on phytoplankton	$G_p = g \cdot ZOOP \cdot \frac{p_1 \cdot PHYT}{K_z + F}$ $p_1 = \frac{PHYT}{PHYT + BACT}$	g: the maximum specific growth rate
Grazing rate on bacteria	$G_b = g \cdot ZOOP \cdot \frac{p_2 \cdot BACT}{K_z + F}$ $p_2 = \frac{BACT}{PHYT + BACT}$	K_z: the half-saturation constant for zooplankton grazing

Multivariate Methods

Multicriteria Analysis: The Evamix Approach

The Evamix approach represents a simple method by which multicriteria mixed data sets of both metric and non-metric form are condensed in a straightforward manner. Furthermore, an additional advantage of this method is that it allows for different priorities amongst the criteria; a useful property since quite frequently some criteria are more important than others, reflecting the different needs and objectives of societies (NIJKAMP, 1989).

The starting point of the Evamix approach is an impact matrix E with elements e_{ij}, where i $(i = 1, \ldots, I)$ in the present work represents a scenario and j $(1, \ldots, J)$ an evaluation criterion. The set of criteria can be divided into two subsets: one subset includes criteria quantified on an ordinal scaling, and one subset with criteria assessed on a cardinal (metric) scale. These subsets are denoted as O and C, where

$$O = \{j \mid j \text{ takes ordinal values}\} \quad \text{and} \tag{1}$$

$$C = \{j \mid j \text{ takes cardinal values}\} \tag{2}$$

The differences between the scenarios are expressed by means of two dominance measures: a dominance score $\alpha_{ii'}$ for the ordinal criteria and a dominance score $a_{ii'}$ for the cardinal criteria. These scores represent the degree to which scenario i dominates the scenario i′, and they are expressed by the following formulas:

$$\alpha_{ii'} = \left[\sum_{j \in O} \{w_j \operatorname{sgn}(e_{ij} - e_{i'j})\}^c\right]^{1/c}, \qquad c = 1, 3, 5, \ldots \tag{3}$$

where

Table 5. *Model calibration: Results of the Two-Sided Kolmogorov-Smirnov Goodness-of-Fit test between experimental and simulated values of the state-variables, at the six internal stations of the gulf.*

State-variables	Stations					
	GG3	GG4	GG5	GG6	GG7	GG8
Phytoplanktonic biomass	0.311*	0.187*	0.225*	0.203*	0.235*	0.202*
Bacterial biomass	0.356*	0.210*	0.329*	0.259*	0.390*	0.324*
Zooplanktonic biomass	0.315*	0.194*	0.385*	0.215*	0.381*	0.191*
Nitrate concentration	0.220*	0.212*	0.334*	0.233*	0.114*	0.256*
Ammonia concentration	0.352*	0.535	0.532	0.463*	0.225*	0.518
Phopshate concentration	0.525	0.452*	0.238*	0.295*	0.231*	0.495
DOC concentration	0.312*	0.302*	0.293*	0.154*	0.212*	0.132*

* Good accordance between simulated and experimental data at the 0.05 level of significance.

$$\text{sgn}(e_{ij} - e_{i'j}) = \begin{cases} +1 & \text{if } e_{ij} > e_{i'j} \\ 0 & \text{if } e_{ij} = e_{i'j} \\ -1 & \text{if } e_{ij} < e_{i'j} \end{cases} \quad (4)$$

$$a_{ii'} = \left[\sum_{j \in C} \{w_j|e_{ij} - e_{i'j}|\}^c\right]^{1/c} \quad (5)$$

e_{ij} represents the score of scenario i and criterion j and w_j the weight attached to criterion j. The symbol c denotes an arbitrary scaling parameter, for which any positive odd value may be chosen, whereas even values are not allowed since this would distort the various signs. The larger c is, the less influence the differences between the alternatives based on minor criteria will have on the value of the dominance measures. The scores employed in the quantitative criteria have to be standardized ($0 \leq e_{ij} \leq 1$) (NIJKAMP *et al.*, 1990). Furthermore, the rankings e_{ij} of both the qualitative and quantitative criteria should have the same direction, *i.e.* a higher score implies a better result. Since $\alpha_{ii'}$ and $a_{ii'}$ will have different measurement units, a standardization into the same units is necessary, because otherwise comparison can not be made between the outcomes of these two expressions. In the present work, the standardized dominance measures were obtained by the subtractive shifted interval technique, based on the following formulas:

$$\delta_{ii'} = \left[\frac{\alpha_{ii'} - \alpha}{\alpha' - \alpha}\right] - 0.5 \qquad d_{ii'} = \left[\frac{a_{ii'} - a}{a' - a}\right] - 0.5 \quad \text{and} \quad (6)$$

$$w_o = \sum_{j \in O} w_j \qquad w_c = \sum_{j \in C} w_j \quad (7)$$

where α and a are the lowest qualitative and quantitative dominance score of any pair of alternative scenarios (i, i′), α' and a' are the highest qualitative and quantitative dominance score of any pair of alternative scenarios (i, i′), w_o and w_c are the total weights of the qualitative and quantitative criterion sets *O* and *C*. Thus, the overall dominance measure $m_{ii'}$ for each pair of alternative scenarios (i, i′) is:

$$m_{ii'} = w_o\delta_{ii'} + w_c d_{ii'} \quad (8)$$

This measure reflects the degree to which the scenario i dominates scenario i′ for a given set of criteria and criterion weights. The final ranking of the scenarios is based on the determination of the appraisal score s_i for each scenario. By assuming that the mean of the appraisal scores s_i is zero, the following expression can be obtained:

$$s_i = \frac{1}{I}\sum_{i'} m_{ii'} \quad (9)$$

The higher the score for s_i the better scenario i will be for the given weight set w_j.

Classification

Numerical classification (cluster analysis) was performed based on the Euclidean distances among the criteria scores j and k of each of the i scenarios:

$$ED_{jk} = \sum_{i=1}^{5} (\chi_{ij} - \chi_{ik})^2 \quad (10)$$

Table 6. *Summary statistics of nitrate, ammonia, phosphate, organic nitrogen and chlorophyll a* describing the hypothetical properties of the gulf of Gera, as a consequence of the four scenarios.

Variables	Scenario 1[b]	Scenario 2[b]	Scenario 3[b]	Scenario 4[b]
Nitrate (μg-at/l)				
MAV[a]	0.72	0.54	0.62	0.60
SD[a]	0.46	0.31	0.38	0.37
Ammonia (μg-at/l)				
MAV	1.01	0.90	0.95	0.97
SD	1.02	0.88	0.97	0.99
Phosphate (μg-at/l)				
MAV	0.27	0.20	0.22	0.26
SD	0.13	0.11	013	0.14
Org. Nitrogen (μg-at/l)				
MAV	8.23	7.89	8.05	8.07
SD	4.23	4.01	4.12	4.15
chl a (μg/l)				
MAV	1.12	0.96	1.05	1.07
SD	0.65	0.55	0.62	0.63

[a] MAV: mean annual values; SD: standard deviation.
[b] Results from the simulation model.

The hierarchical sorting strategy for the development of dendrograms was the group average sorting. This method joins two groups of samples together at the average level of similarity between all members of one group and all members of the other (PIELOU, 1984). All values have been standardized prior to the analysis, a necessary procedure for multivariate methods, so as to permit the comparison of variables with different dimensions (SNEATH and SOCAL, 1973).

Principal Component Analysis

Principal Component Analysis (PCA) is a well-known and popular statistical method that looks for a few linear combinations, which can be used to summarize the data, losing in the process as little information as possible. This attempt to reduce dimensionality can be described as "parsimonious summarization" of the data (MARDIA *et al.,* 1997). In the present work, the Principal Components were the characteristic eigenvalues of the Covariance Matrix, of the original variables.

RESULTS

Summary statistics of the chemical and biological parameters describing the hypothetical (simulated) properties of the Gulf of Gera, as a consequence of the application of the four scenarios to the model, are reported in Table 6. It can be seen that animal husbandry resulted in the highest concentrations of inorganic nutrients, organic nitrogen and chlorophyll a, followed by the agricultural greenhouse scenario. The tourism development scenario had intermediate influences, while the "cultivation of woody plant species" scenario resulted in similar marine ecosystem properties compared to the present condition. Standard deviations were relatively small and covaried with mean values.

The model suggests that the circulation pattern of the Gulf of Gera and especially exchanges with the Aegean Sea are

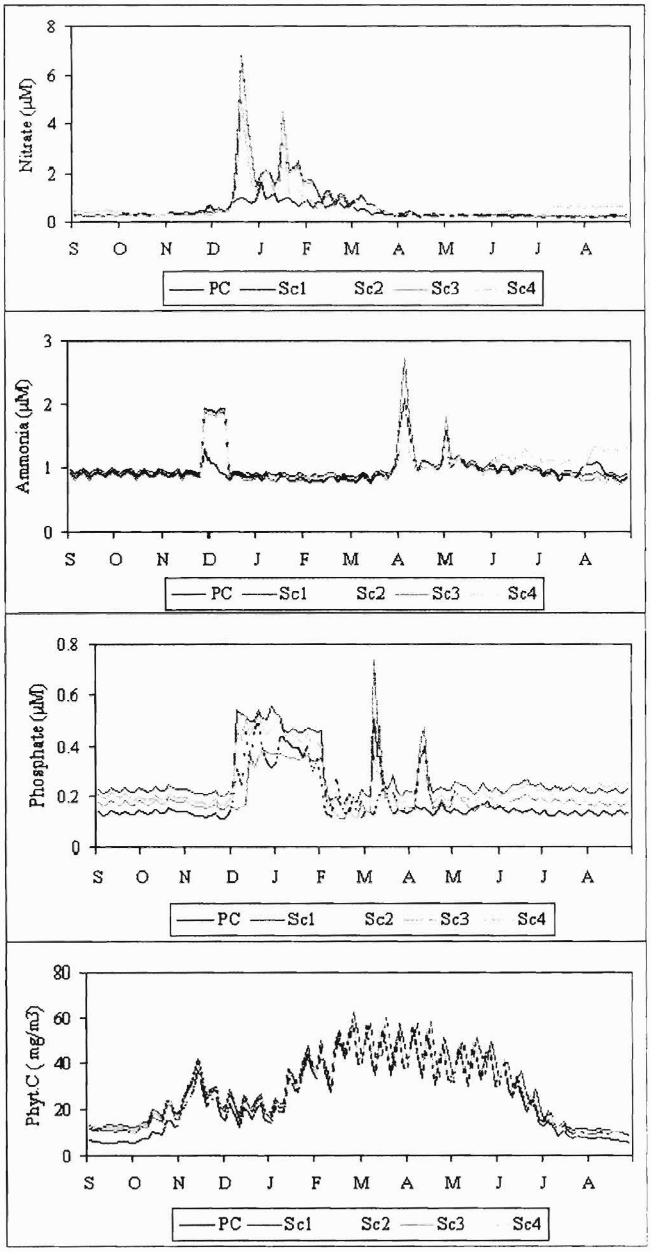

Figure 3. Simulation results of (a) nitrate, (b) ammonia, (c) phosphate concentrations and (d) phytoplanktonic biomass in the western compartment of the study area, according to the present condition (PC) of the gulf of Gera and the four alternative scenarios (Sc1–Sc4).

important factors for the functioning of the marine ecosystem and for the temporal variability of the various chemical and biological state variables (ARHONDITSIS *et al.*, 2000a). The simulated annual cycles of four state variables of the model in the western compartment, under the four proposed management practices of the watershed in comparison with the present condition, are shown in Figure 3. Similar results were observed for all of the spatial compartments of the model. The presentation of this particular site was due to its complicated dynamics, since it is influenced by both exogenous point and non-point nutrient loading and by interactions with the open sea. During the winter period, the ambient temperature and the inflows of the colder runoff make this shallow gulf denser than the external system. This regime in combination with the semi-enclosed character of the gulf limit the exchange oligotrophic waters from the Aegean Sea. In this period, exogenous non-point nutrients accumulate in the seawater body and the predicted nutrient concentrations had several peaks resulting from event-based nutrient fluxes from the terrestrial ecosystem. The animal husbandry and the greenhouse cultivation scenarios were characterized by high concentrations of nitrate (5.0–7.0 μM), ammonia (1.5–2.0 μM) and organic nitrogen (12–14 μM) with threefold or fourfold increases over present concentrations. However, these nutrient pulses did not always result in similar increases in algal biomass, which was mostly limited by physical factors such as light intensity and temperature (ARHONDITSIS *et al.*, 2000a). The autotrophic microorganisms therefore, did not utilize a major fraction of the nutrient stock and the ecosystem is protected from serious phytoplanktonic blooms (< 80 mg C/m^3) during the winter period. The predicted high nutrient concentrations and the moderate responses by the primary producers, during the winter period, confirmed this conceptual scheme. This situation is reversed gradually until the summer, when significant inflows of the oligotrophic waters of the Aegean Sea have a nutrient dilution effect. During the summer, excessive nutrient loads are flushed out of the Gulf of Gera and seawater is renewed on average every ten days, especially under favorable physical conditions (spring tides, north winds). This results in low nutrient concentrations during the summer period when light and temperature do not limit algal growth and blooms are most likely.

The values of fifteen criteria, describing the present condition and the potential environmental and socio-economic conditions of the Gulf of Gera after implementation of the four alternative scenarios, are presented in Table 7. Nutrients and chl α values are numerical, but have been given an opposite sign in order to conform to the idea of "the greater the value, the more favored the criterion". The rest of the variables are expressed on an ordinal scale—which is extensively used in environmental policy analysis (NIJKAMP *et al.*, 1990)—from 0 to 4 with 0 representing the least favorable condition. It was considered that the ordinal ranking of these criteria would be more appropriate and reliable than assignment of literature based values expressed on the cardinal scale, since the study dealt with the relative rather than the quantitative differences for the scenarios. The criterion "labor requirements" refers to the desire to decrease local unemployment. The present management of the area gave the most unfavorable result for this criterion. The criterion "viability of the scenario" characterizes the coexistence of competitive producers in neighboring places and the perspectives of the consumption demands *i.e.* "the products of the scenarios correspond to a temporary or to a well-established habit of the consumers (an index of stability and security of the scenario)?" and "how easily the producers can adjust in an alternative future consumption trends?" The "easiness of implementation" contains some basic ideas such as i) the differ-

Table 7. *The values of the fifteen criteria, describing the present condition and the potential environmental and socioeconomic aspects of the gulf of Gera, after the implementation of the four alternative scenarios.*

Criteria	Present Condition	Emphasis on Cattle-Breeding	Cultivation of Woody Species	Construction of Greenhouses	Development of Tourism
Socioeconomic aspects					
1. Gross margin per capita	1	2	2	4	4
2. Cost of implementation	4	3	3	2	1
3. Existing infrastructure	4	3	2	1	1
4. Labour requirements	1	2	2	3	3
5. Viability of the scenario	0	2	3	2	3
6. Easiness of implementation	2	3	2	3	2
7. Related activities and consequent prospects	0	2	1	3	4
Environmental aspects					
8. Pollutants not incorporated in the model*	3	3	2	1	3
9. Preservation of terrestrial ecosystem*	0	2	4	2	1
10. Consumption of natural resources*	3	2	3	1	1
11. Nitrate (μM)	−0.55	−0.72	−0.54	−0.62	−0.60
12. Ammonia (μM)	−0.91	−1.01	−0.90	−0.95	−0.97
13. Phosphate (μM)	−0.19	−0.27	−0.20	−0.22	−0.26
14. Org. Nitrogen (μM)	−7.93	−8.23	−7.89	−8.05	−8.07
15. chl a (μg/l)	−0.98	−1.12	−0.96	−1.05	−1.07

* The values for these criteria were based on the references cited in the respective part of the text (Development and scenarios) and on the authors; own judgement.

ences between the existing technical knowledge, traditions and habits and innovative requirements, which determine the ability of the local population to deal with a new economic model, ii) the time-scale of the return, considering that a short-term return is more desirable. In this particular criterion, the present condition was attached to the ordinal number (2), which reflects the moderate easiness of introducing innovations in the area and the reluctance of the local inhabitants to drastically change their way of life (GIOURGA *et al.*, 1998). Finally, the criterion "related activities and consequent prospects" refers to services, commerce, marketing prospects and other productive activities simulated by the basic functions of the scenarios.

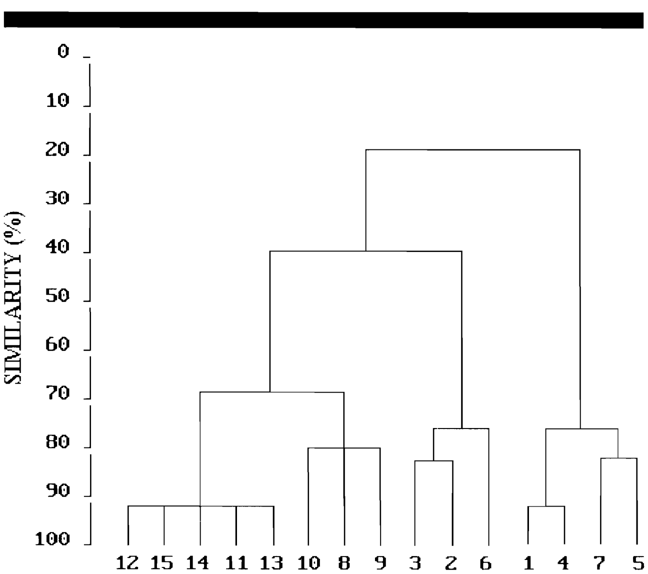

Figure 4. The classification pattern based on the euclidean distances among the 15 variables used for the evaluation of the present condition of the gulf of Gera and the four alternative scenarios. The names of the variables are given in Table 7.

The classification pattern based on the Euclidean distances amongst the 15 evaluation variables is illustrated in Figure 4. The variables that characterize the quality of the marine ecosystem appeared as an entity with 90% similarity, while their combination with the three environmental criteria (8, 9, 10) forms a rather coherent core with a mean similarity level of 70%. By contrast, the gross margin per capita (1), the labor requirement (4), the viability of the scenario (5) and the related activities and consequent prospects (7) describing the future socio-economic perspectives of the scenarios, are clumped into a single group to the right. Furthermore, a third cluster can be observed in the mid region of the dendrogram consisting of criteria 2 (cost of implementation), 3 (existing infrastructure) and 7 (easiness of implementation), that is the variables that characterize the present socio-economic properties of the study area.

The Principal Component Analysis, which provided results very similar to Cluster Analysis, divided the variables into four clusters (Figure 5). At the upper right hand side of the diagram, marine environment quality variables are clumped together. In contrast, the remaining environmental variables such as the consumption of natural resources (10), the quantities of pollutants that are not incorporated in the model (8) and the preservation of the terrestrial ecosystem by the proposed management practices (9), are scattered throughout the plot. The cluster in the upper left hand portion of the plot is similar to the above-mentioned upper right cluster of the dendrogram, concerning the future socio-economic results of the scenarios, whereas the present conditions are found at the bottom of the diagram. The two axes can be interpreted as the environmental quality (the horizontal axis) and the socio-economic values of the developmental strategies (the vertical axis).

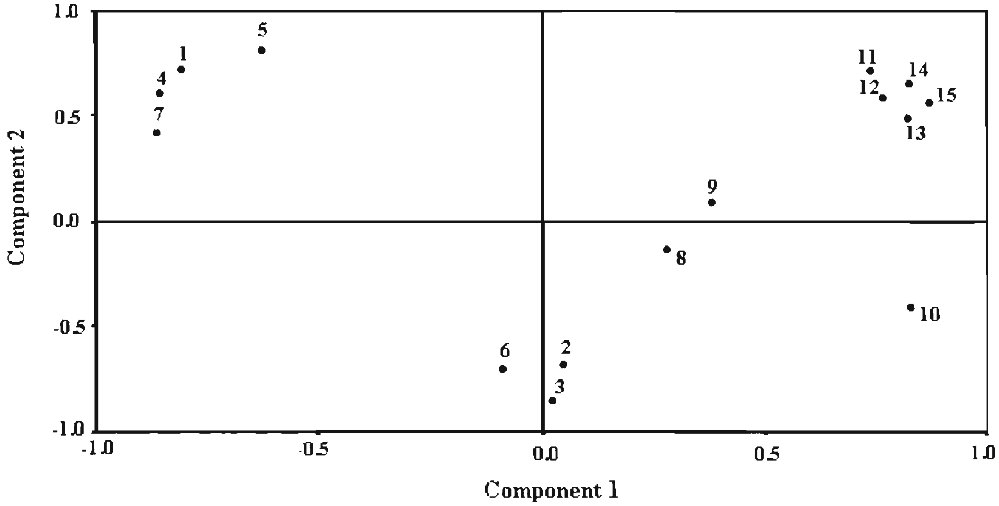

Figure 5. Representation of the variables of the system in two dimensions by Principal Component Analysis. The names of the variables are given in Table 7.

Table 8 presents the results of the multicriteria analysis, based on the Evamix approach. In Table 8(a), all criteria have been given equal priorities. Scenario 1 is classified first in the ranking list, followed by scenarios 4, 2, and 3 in descending order. This analysis suggest that a partial reorientation of olive cultivation towards production of edible olives combined with development of animal husbandry is the most favorable scenario for the region, if all variables are assumed to be of equal importance. In Table 8(b), the socio-economic outcome criteria were given priority to reveal the potential of each scenario to increase per capita income. The development of tourism is the most favorable scenario for personal income gain, followed by greenhouse agriculture cultivation and animal husbandry. In Table 8(c), priority was given to the quality of the natural environment. In this case, scenario 2 which focused on the development of the primary sector and the exploitation of the mountainous zones with the cultivation of woody plant species such as the almond, fig and pomegranate trees had the highest score. In contrast, the remaining three scenarios were ranked below the present condition, which suggests that they will lead to declines in environmental quality. This result is strong evidence of the dilemma characterizing most strategic action plans attempting to balance economic welfare and environmental protection (CANTLON and KOENIG, 1999). In Table 8(d), the priorities have been given according to the results of the multivariate methods. The criteria were distributed into three subclasses, the first containing the future prospects of the scenarios, the second containing the environmental variables and the third involving the present socio-economic status of the region. The weighing with respect to these ranking of the criteria was obtained by the expected value approach (NIJKAMP *et al.*, 1990). Furthermore, this selection of priorities more realistically reflects the needs and the aspirations of the local population (MAYOR OF GERA, *personal communication*, 1998). In this case, the ranking list is similar to the one of the equal priorities, whereas the basic difference exists in the significant increase of the appraisal score for scenario 4. Thus, an-

Table 8. *Multicriteria analysis results, according to the Evamix approach (c = 3).*

Scenarios: Short Description	Appraisal Score	Scenarios: Short Description	Appraisal Score
a) Equal priorities		c) Priority to environmental criteria	
Scenario 1: Emphasis on cattle-breeding	0.136	Scenario 2: Cultivation of woody species	0.200
Scenario 4: Development of tourism	0.059	Present condition	0.079
Scenario 2: Cultivation of woody species	−0.029	Scenario 1: Emphasis on cattle-breeding	−0.072
Scenario 3: Construction of greenhouses	−0.049	Scenario 4: Development of tourism	−0.103
Present condition	−0.117	Scenario 3: Construction of greenhouses	−0.104
b) Priority to socioeconomic criteria		d) Priorities according to the results of the multivariate methods	
Scenario 4: Development of tourism	0.089	Scenario 1: Emphasis on cattle-breeding	0.120
Scenario 3: Construction of greenhouses	0.065	Scenario 4: Development of tourism	0.100
Scenario 1: Emphasis on cattle-breeding	0.061	Scenario 2: Cultivation of woody species	0.036
Scenario 2: Cultivation of woody species	0.019	Scenario 3: Construction of greenhouses	−0.032
Present condition	−0.234	Present condition	−0.224

imal husbandry and tourism development represent the most favorable perspectives for the study area, when balancing the desire for increased profits and environmental quality. Finally, it was observed that the present condition in all cases, with only the exception of environmental quality, had the lowest score meaning that all the alternative management practices for the watershed are preferable for the improvement of the local standard of living.

DISCUSSION

Environmental policy is essentially a risk strategy, which serves to minimize the mismatch between economic development and ecological sustainability under certain future conditions. It is a multiple objective task, involving economic efficiency analysis, risk assessment and ethical judgments on the distribution of benefits and costs, both currently and with respect to future generations (JAMES *et al.*, 1989; HEDIGER, 2000). In the present study, an integrated methodology was developed which is capable of addressing policy objectives and resolving various types of coastal environmental management conflicts.

The study area was the Gulf of Gera, Island of Lesvos, Greece, a semi-enclosed and shallow ecosystem surrounded by an intensively cultivated and inhabited watershed. The local environment is faced with severe pressures due to the nutrient fluxes from agricultural runoff and point sources that cause the Gulf to have mesotrophic conditions. Moreover, the abandonment of olive groves and the adoption of free grazing threaten these areas with erosion and soil degradation. Currently, the economy is characterized by a traditional monoculture of olive groves with limited prospects for modernization, low per capita incomes and serious underemployment that have lead to mass emigration. Thus, both the environmental and socio-economic problems of the area highlight the importance of exploring alternative economic models.

Four scenarios concerning the socio-economic conditions, which take into account the existing infrastructure, institutions, traditions and natural resources of the area were considered. An additional assumption in these scenarios was equal accessibility of the local population to the benefits and costs of the investments. The basic component of all the scenarios was a partial shift in the olive cultivation towards production of edible olives, accompanied by appropriate marketing and a reorganization of the agricultural sector. Supplementary incomes and total employment were sought in i) animal husbandry; ii) cultivation of woody plant species compatible with the local environment; iii) cultivation of greenhouse vegetables; and iv) development of tourism. These scenarios were intended to keep agricultural production self-sufficient while maintaing a balance between employment and economic activities.

The alternative scenarios and consequent changes in the land use were applied to a marine water quality model, which describes the dynamics of inorganic nutrients-phytoplankton-bacteria-zooplankton and organic carbon relationships. These state-variables are appropriate for describing the quality of the marine ecosystem, since changes in their values are associated with the process of eutrophication and have been used extensively in the past for developing scoring systems that assess the environmental quality of coastal systems (KARYDIS, 1996). The use of mathematical modeling for evaluating the environmental impacts of the various scenarios was considered less susceptible to perceptual bias than other methodologies, such as adoption of an expert judgment on the environmental variables. The predictions of the model reveal only a minor increase in the mean annual values for the chemical and biological properties of the marine ecosystem relative to present conditions, although the exogenous point and non-point inflows are higher, especially under the scenarios of the animal husbandry and greenhouse vegetables. These results show the critical role of the physical forcing (*i.e.* climatic conditions) and exchanges with the Aegean Sea which flush the Gulf of Gera, preventing nutrient accumulation and serious phytoplanktonic blooms.

The simulated marine ecosystem quality data were combined with socio-cultural and economic variables for the watershed, in view of the multidisciplinary character of the developmental strategies. This mixed data set was used to assess the effectiveness of two multivariate statistical methods, cluster and principal component analysis, as methodological tools in holistic approaches of system analysis. The results showed a clear distinction between the environmental and socio-economic objectives for the study area. Furthermore, the spectrum of the economic criteria was subdivided into two additional classes with reference to their temporal response. This implies an independent interaction of the present socio-economic status of the study area and the future prospects of the scenarios with the decision-making process. Thus, future policy for the development of the region should acknowledge the necessity of linking these three components in an integrated management strategy for coastal resources.

Finally, the multicriteria analysis was used to provide a ranked classification of the proposed scenarios. Thus, multiple criteria analysis suggested that a partial shift in olive cultivation towards production of edible olives in combination with the development of animal husbandry is the best option. The familiarity of the local inhabitants with these activities and the low cost of the investment are greater than the additional environmental pressures resulting from this scenario. Moreover, emphasis in agricultural production towards increased quality of the products, a well-established demand nowadays, should be considered as an antidote to the threat of competitive producers on neighboring islands. The positions of tourism development, under the different priorities assigned during the analysis, revealed that it is a promising prospect for the area, with multiple effects on the local economy. The rational planning and application of this strategy can moderate environmental impacts, *i.e.* the current debate about the costs and the benefits of the construction of a wastewater treatment plant in the area (minimizing the point fluxes resulting from this scenario); and the erasing socio-cultural dilemmas *i.e.* the sustaining of the national character and protecting local traditions. Furthermore, the development of an agriculture sector that is focused on the cultivation of greenhouse vegetables is beneficial from an individual income gain perspective. When priority is given to the quality of the natural environment the analysis favored cultivation of woody plant species that prosper on the mountainous zones, but the minor profits and the limited prospects for a broader stimulation of the economic growth make this the least desirable scenario.

The present integrated approach has proved to be a powerful tool for exploring the existing patterns of the various components of the economic/environmental system and the analysis of complex schemes where quantitative and qualitative variables are involved. It is therefore proposed as a simple and effective methodology for objective evaluation of development scenarios, which balance economic welfare and environmental quality. Additional gains will be obtained by i) incorporating in the marine water quality model the dynamics of predators of the upper levels of the trophic chain, such as fish species of commercial interest or classical indicator organisms for water quality management, such as total and fecal coliform bacteria (CHAPRA, 1997; PEZZEY *et al.*, 2000); ii) modeling the functional properties of the terrestrial ecosystem, such as soil condition and nutrient export (VATN *et al.*, 1999; ARHONDITSIS *et al.*, 2000b). These developments will lead to a further clarification of the environmental issues and will enable the evaluation of different economic scenarios for the area, such as fish or shellfish culture. Finally, the study did not address how the multicriteria analysis could be used in decision making, who should decide on the priorities (*i.e.* what role the local population should play in the process) and how multicriteria analysis can be used as explanatory tools for local populations and arriving at consensus. These issues are likely to give in the present methodology different outcomes, motivating on-going research.

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