MODELLING THE EFFECTS OF ANTHROPOGENIC ACTIVITIES AND CLIMATE CHANGE ON A SMALL CATCHMENT IN AN AEGEAN ISLAND

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Abstract

A watershed model, including a runoff and an erosion component, was applied to a small watershed in the Eastern Mediterranean. The catchment is drained by ephemeral rivers flowing into the gulf of Kalloni, Island of Lesvos in the Aegean sea. The model estimates the daily nutrient loading of the receiving water body, taking into account both the environmental (geomorphology, land uses) and the socioeconomic (population, tourist activities, animal farming, industry) characteristics of the watershed. The model, which is forced by the daily rainfall height, was run for one typical year and calibrated using field data, collected along the route of the main rivers draining the catchment. The contribution of the various loading sources was estimated by the model, emphasizing on the importance of the anthropogenic activities for nutrient loading of coastal ecosystems and therefore, for the development of eutrophication episodes. An analysis of available meteorological data was also performed in order to assess the effects of global change on the frequency and intensity of rainfall events and possible scenarios were formulated. These scenarios were simulated and their effects on runoff and erosion were estimated.

Key words: Watershed modelling; Anthropogenic activities; Climate change; Eastern Mediterranean

1. Introduction

Human activities often induce unpredictable and not easily controllable changes in the hydrological regime and the nutrient budget of river basins (Kuusemets and Mander 2001). These activities include agriculture and fertilization, dispersion of untreated sewerage, animal farming and industrial by-products. According to the source and the transport route that the resulting pollutants follow to reach the receiving water bodies, two kinds of sources can be distinguished, the point and non-point. Point sources can be monitored at their point of origin and therefore their management is relatively easy, whereas non-point sources are rather diffused and uncontrollable (Arhonditsis *et al.* 2002a). The nutrients resulting from both types of sources enrich the receiving water bodies and eutrophication phenomena are often observed, especially in enclosed bays, gulfs or lagoons. Therefore, the monitoring and control of the various sources of nutrients is of primary importance for managers and decision makers in the framework of Integrated Coastal Zone Management (Kontogianni *et al.* 2006).

Small Eastern Mediterranean watersheds undergo rapid hydrological cycles characterized by a rather short rainfall period during winter and a dry summer. The rivers draining these basins are ephemeral flowing mainly from November to mid-April (Arhonditsis *et al.* 2002b). The foreseen climate change is expected to strongly affect the water budget of these small watersheds influencing runoff, erosion, nutrient transport, as well as the groundwater reservoirs. In order to assess these changes in the framework of policy making, possible scenarios are formulated and watershed models are used to test the scenarios in a quantitative manner (Komatsu *et al.* 2007, Lin *et al.* 2007, Wu *et al.* 2007).

In the present work, a time series of rainfall data for a small Mediterranean island is analyzed. Possible trends due to the climate change are assessed and two scenarios are formulated representing the recently observed trends and the reference condition. The two scenarios are simulated using a runoff and a soil erosion model for a small catchment in the study area and a comparative analysis is performed for the amounts of runoff, nutrient leaching and soil eroded, between the two scenarios.

2. Methodology

2.1 The study area

The gulf of Kalloni is a shallow semi-enclosed water body (mean depth of about 11 m), located in the island of Lesvos, Greece in Eastern Mediterranean (Figure 1). It is connected to the open sea through a narrow, shallow and long channel (Spatharis *et al.* 2007a). The climate of the island is typical Mediterranean characterized by a hot-dry summer from May to September and mild-rainy winter for the rest of the year. The surrounding watershed of 413 Km^2 is covered, according to the CORINE database, mainly by grasslands

(26%), coniferous forests (22%), horticulture (18%), olive groves (16%), maquis (2%) and urban areas (0.3%) (Figure 1). Application of fertilizers is usually carried out from December to February, coinciding with the period of high precipitation. Therefore a considerable amount of inorganic nitrogen and phosphorus is leached and ends up into the gulf during the winter period through the network of intermittent rivers. Other sources of nutrient enrichment include the untreated domestic sewage of the towns and villages of the area, farming and industrial by-products, mainly from the elaboration of olive oil. The gulf of Kalloni and the surrounding area are considered as an important habitat for biodiversity since a large part is covered by estuaries, small rivers, streams, salt works, pine forests and reed thickets. For this reason, the area is included in the NATURA 2000 network as one of the "special areas for nature conservation".

2.2 Data used

Data analysis was based on meteorological data collected at the meteorological station of the Mytilini airport (39^{o} 04' N, 26^{o} 36' A) by the National Hellenic Meteorological Society. Information was also used from the statistical analysis of historical data for the island of Lesvos (1936-1942, 1952-1975), carried out by Houtjeos (1981). Finally, the calibration of the watershed models was based on field data (concentrations of dissolved inorganic nitrogen and phosphorus) collected during 2004-2005 at the outlets of the major rivers draining the watershed of the gulf of Kalloni (Spatharis 2007).

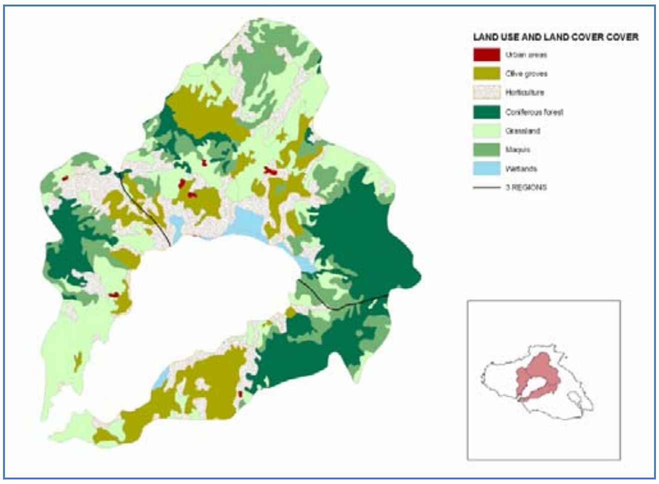

Figure 1. The watershed of the Kalloni gulf in the Island of Lesvos including land use information according to the CORINE classification.

2.3 The models applied

Two models were applied to describe runoff and erosion processes. The runoff model estimates the nutrient and organic matter leached from the watershed, from both non-point and other sources (Tamvaki and Tsirtsis 2005). Surface runoff was estimated according to the Curve Number Equation (Haith and Tubbs 1981) based on the land uses. The three parts of the Kalloni watershed (eastern, western and northern) were divided into fundamental cells, each one of them considered homogenous according to its main characteristics (slope, land use, hydrological conditions, agricultural practices). The amounts of nutrients (nitrate, ammonium, phosphate) transported to the gulf due to surface runoff were determined using a special function, belonging to the category of 'loading functions'. The concentrations of nutrients required to apply the loading functions were determined by field experiments. The loading from other sources was also estimated, including sewerage, by-products of livestock breeding and industrial activities (olive-oil refineries). Transfer coefficients from the literature were used to estimate loading from each type of source and a retention factor was further applied to consider decomposition processes occurring along the route connecting the source to the sea. These retention factors were calibrated using field data, collected during 2004-2005 at the outlets of the major rivers draining the watershed.

The model describing the erosion processes is based on the Universal Soil Loss Equation (USLE) which calculates the amount of eroded material according to the rainfall, soil type, slope, land use and agricultural practices (Renard *et al.* 1997). For the application of the model, the Kalloni watershed was divided to fundamental cells considered homogenous for their main characteristics, mentioned before. Methodological details about the model application and calibration have been given in a previous paper (Arhonditsis *et al.* 2002a).

3. Results

The mean number of rainy days per month during the time periods of 1936-1975 and 2000-2008 for the island of Lesvos is shown in Figure 2. A reduction is observed throughout the year after 2000 (about 2 days per month), however it was not found statistically significant.

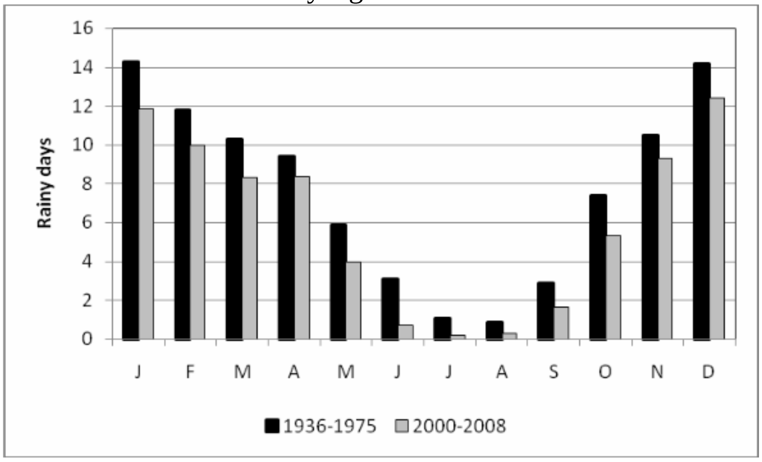

Figure 2. Mean number of rainy days per month for the time periods of 1936-1975 and 2000-2008 for the island of Lesvos.

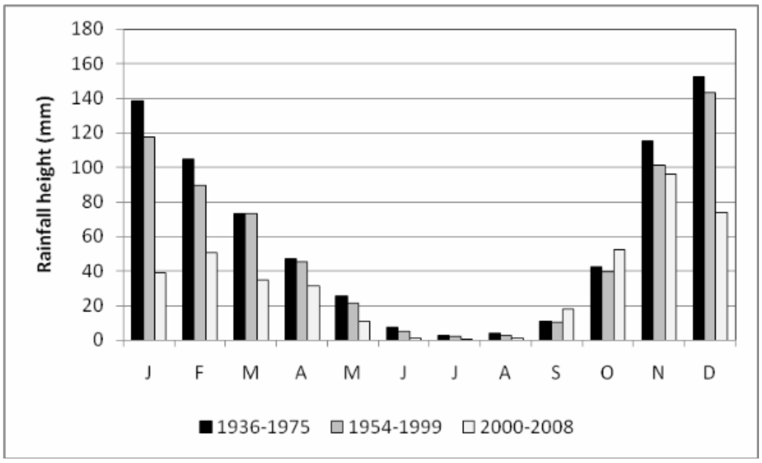

Figure 3. Mean rainfall height per month for the time periods of 1936-1975, 1954-1999 and 2000-2008 for the island of Lesvos.

The mean monthly rainfall height has shown a decreasing trend after 2000 throughout the year (Figure 3). This trend was further tested statistically and it was found significant for all months ($p<0.01$), except for November. The mean annual rainfall height (calculated using the monthly means) has almost halved after 2000 compared to the mean of 1954-1999.

The effects of this decrease on runoff, nutrient leaching and erosion were estimated by applying a runoff and an erosion model, calibrated using field data collected during 2004-2005. The goodness-of-fit of the runoff model to the field data after the calibration process for dissolved inorganic nitrogen and phosphorus, is shown in Figure 4. The agreement between model and field data is very good. The peak in nutrient leaching was observed during February, coinciding with the peak in rainfall height during the winter of 2004-2005.

The calibrated models were further used to test two scenarios for climate change based on the trends observed in the island of Lesvos after 2000. The first scenario (S1) is based on the mean monthly rainfall heights observed during 1954-1999 and is used to describe the reference condition. The second is based on the mean monthly rainfall heights observed after 2000 and describes the current trend, expressing a dry condition. A typical year was run for each scenario and results were obtained on a daily basis.

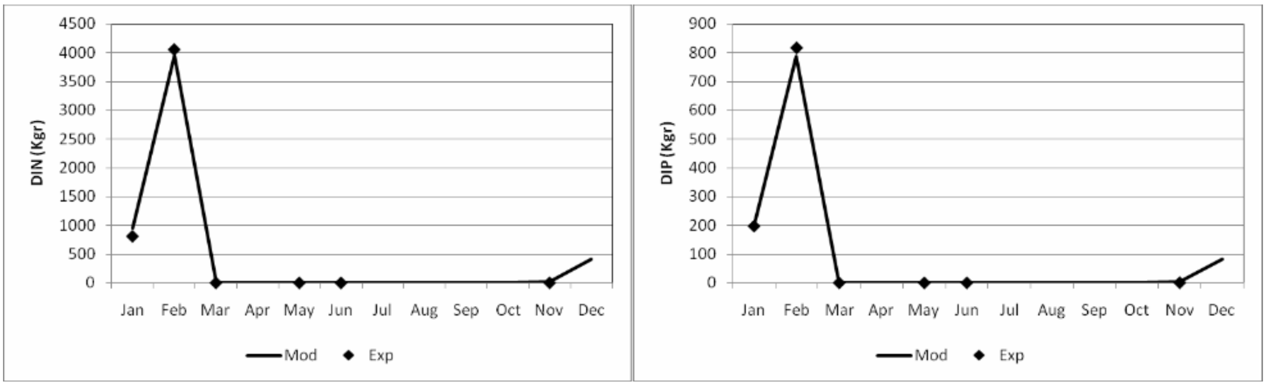

Figure 4. Goodness-of-fit of the the model output to field data collected during 2004-2005, for the loadings of Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphorus (DIP) in Kgr/month.

The temporal change of runoff from the watershed of the Kalloni gulf according to the two scenarios is shown in Figure 5. The annual amount of runoff is decreased from 6696800 to 1128000 m^3. This decrease is mainly observed during winter and spring (from December to May), whereas for autumn and early winter (October and November) remarkable changes were not found.

The nutrient loading of the Kalloni gulf estimated by the runoff model is shown in Figures 6 and 7. Dissolved inorganic nitrogen loading is reduced from 9541 to 8833 Kgr per year and dissolved inorganic phosphorus from 2096 to 1305 Kgr per year. This reduction is observed mainly in winter (January) and early spring (March) when the maximum runoff is taking place. However in autumn and early winter (September to November), an increase is predicted in the loading, of both nitrogen and phosphorus.

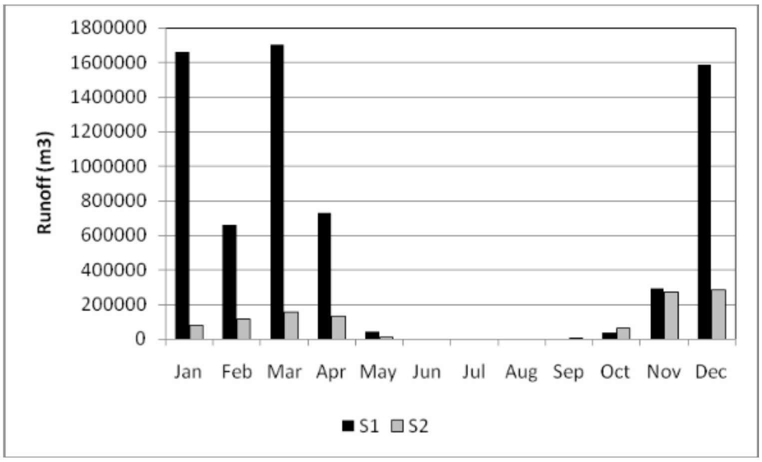

Figure 5. Temporal change of the amount of runoff from the watershed of the gulf of Kalloni according to the two scenarios S1, the reference and S2, the dry scenario.

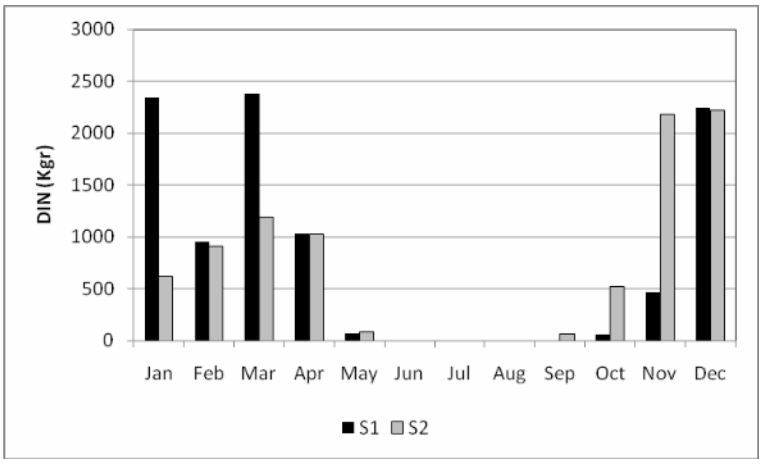

Figure 6. Dissolved Inorganic Nitrogen (DIN) loading to the Kalloni gulf according to the two scenarios S1 and S2.

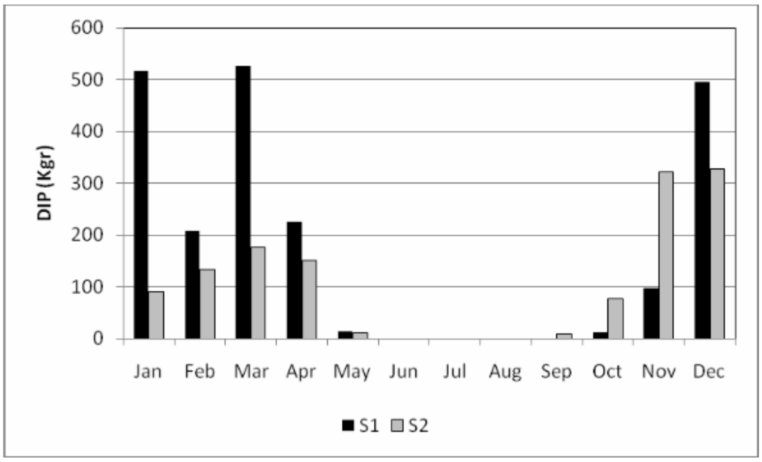

Figure 7. Dissolved Inorganic Phosphorus (DIP) loading to the Kalloni gulf according to the two scenarios S1 and S2.

The relative contribution of non-point and other sources of nutrients (nitrogen and phosphorus) ending up into the Kalloni gulf from the surrounding watershed through runoff, is shown in Figure 8. Non-point sources refer to soil leaching, whereas other sources include untreated sewage, animal farming and industrial (oil refineries) by-products. The relative contribution of other sources is increased for the S2, compared to the S1 scenario, for both inorganic nitrogen and phosphorus. This increase in the relative contribution of other sources is due to the corresponding decrease in absolute values of the contribution of non-point sources, caused by the low annual rainfall height described in the S2 scenario.

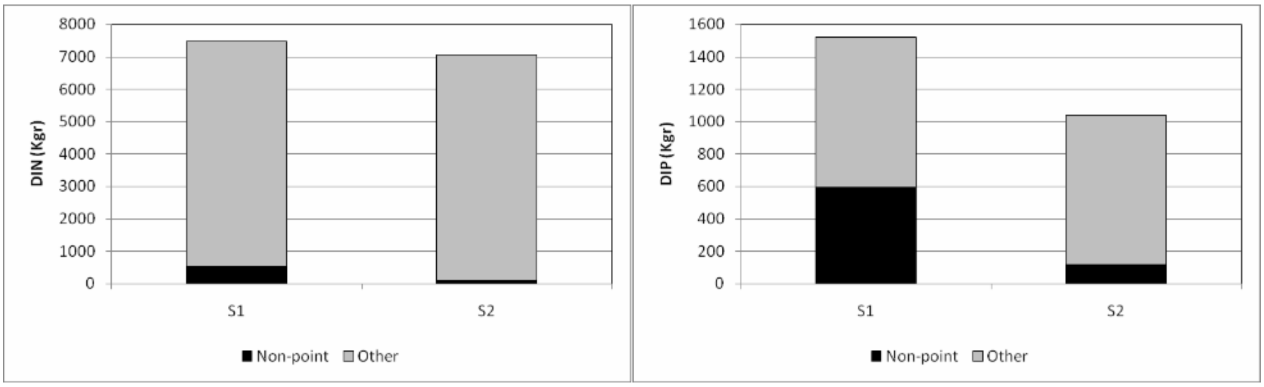

Figure 8. Contribution of non-point and other sources to the loading of the Kalloni gulf with DIN and DIP according to the two scenarios S1 and S2.

The contribution of other sources of inorganic nutrients (untreated sewage, animal farming and oil-refineries by-products), is shown in Figure 9. According to the model, the main source of nutrients is animal farming by-products, contributing by 63% and 70% for inorganic nitrogen and phosphorus, respectively. Untreated domestic sewerage is also an important source (36% for DIN and 29% for DIP), whereas the by-products of oil-refineries have a minimal effect.

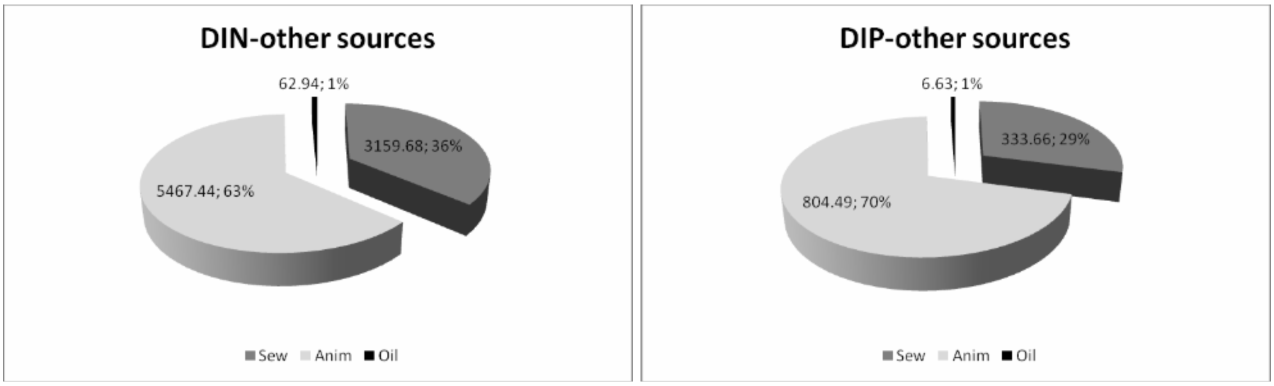

Figure 9. Contribution of other sources of nutrients (DIN and DIP) to the loading of the Kalloni gulf.

The two scenarios (S1, the reference and S2, the dry scenario) were also simulated for soil erosion in the Kalloni watershed (Figure 10). The decrease in the annual rainfall height described by the S2 scenario has a direct effect on soil erosion resulting to a remarkable decrease (from 42 to 26 tons of soil erosion per year) compared to the reference condition. This decrease is mainly predicted for winter and spring (December to May), whereas for autumn a slight increase is foreseen.

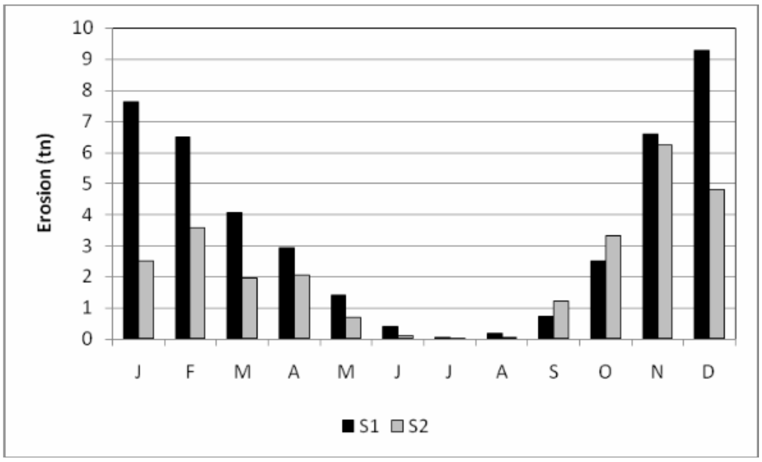

Figure 10. Temporal change of soil erosion at the watershed of the gulf of Kalloni according to the two scenarios S1 and S2.

4. Discussion and conclusions

Recent changes in the climatic conditions are expected to affect the hydrological budget and the nutrient balance of watersheds worldwide. These effects may be more pronounced in small arid Eastern Mediterranean watersheds undergoing rapid hydrological cycles. According to the analysis carried out on available meteorological data for a small island in the Aegean, a reduction in the mean annual rainfall height is observed after 2000, supporting a dry future condition, even though the number of rainy days has not changed significantly. This decrease in rainfall and a corresponding increase in air temperature have already been reported or predicted for other Mediterranean regions (Diodato and Bellocchi 2007, Yano *et al.* 2007, Sanchez-Lorenzo *et al.* 2007).

The reduction in the mean rainfall height is mainly observed during winter and spring resulting to a significant decrease in the amount of runoff and soil erosion, and consequently in the amounts of nutrients in the dissolved and particulate forms enriching the coastal system. The decrease in runoff will possibly affect the water and nutrient budgets of the receiving water body and therefore ecosystem functioning. Phytoplankton bloom events and increased productivity are often observed in enclosed bays in Eastern Mediterranean during winter, possibly driven by the massive input of nutrients from the surrounding land (Arhonditsis *et al.* 2002b, Spatharis *et al.* 2007b). These blooms are characterised by the proliferation of one or two species (sometimes toxic or potentially toxic) and by low diversity. However the increased primary productivity often supports secondary productivity and therefore fish and shellfish production, as it is the case in the Kalloni gulf. Moreover, the decrease of particulate material entering the sea will probably affect the balance between beach formation and erosion and consequently the economic value of coastline for tourism exploitation.

In conclusion, a significant change in the meteorological conditions seems that has started during the last decade in the Aegean, Eastern Mediterranean, characterised by a decrease in rainfall height. The direct effect of this change in small watersheds is the decrease of the amounts of runoff, soil erosion and nutrients entering the coastal marine ecosystem, resulting to alterations in ecosystem functioning. Indirect effects are also expected related mainly to resource exploitation, including fish and shellfish production and tourism. Therefore climate change and its effects must form a major component in the procedure of scenario development in the framework of Integrated Coastal Zone Management, especially in small arid catchments in Eastern Mediterranean.

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