# SESAME

Southern European Seas: Assessing and Modelling Ecosystem changes

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# Publishable Final Activity Report

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Project coordinator name: **Dr Evangelos Papathanassiou**
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**Publishable final activity report**

SESAME is an Integrated Project (IP) under the EU's 6th Framework Programme. The project involved almost four hundred scientists from 59 research institutes in 24 countries, collecting data on every aspect of the Mediterranean and Black Sea ecosystems on a scale that was never attempted before. The project was designed to study the past, present and future environmental changes in the Southern European Seas (SES) ecosystems, as well as the effect of these changes on fundamental goods (tourism, fisheries) and services (mitigation of climate through carbon sequestration and ecosystem stability through conservation of biodiversity) provided by the ecosystems.

The project's innovative character is reflected in the close merging of economic and natural sciences in order to study the changes in a time period ranging from 50 years ago to the next 50 years to come, by connecting ecological models with climatic and socio-economic scenarios.

The scientific objectives of SESAME were:

1.  To assess changes in the SES ecosystems over the last 50 years.

2.  To assess the current status of the SES ecosystems through analysis of existing and newly collected data at basin scale as well as through model simulations.

3.  To predict changes in the SES ecosystems, using existing and new observations at a regional and basin scale, in order to construct scenarios of the ecosystem responses to likely changes in climate and anthropogenic forcings during the next five decades.

4.  To assess and predict changes in the ability of the SES ecosystems to provide goods and services. Ecosystem variability has affected, *inter alia,* specific goods and services with potentially high societal importance (goods: tourism and fisheries - services: ecosystem stability through conservation of biodiversity, and mitigation of climate change through carbon sequestration in deep waters and sediments.

In order to accomplish the scientific objectives, a lot of effort was put into the collection of existing data as well as on the actual assessment of changes in the two basins. In addition, the current status and prediction of possible changes was mainly based on data and information from previous as well as new oceanographic cruises. Modelling work was completed through both regional and basin-wide modeling at hindcasting and predicting levels, while the connection of higher trophic levels with low trophic levels was also successfully achieved during the project.

<u>Assessment of changes in the SES ecosystems over the last 50 years</u>

The assessment of changes in the SES ecosystem functioning during the last 50 years, in response to natural changes and anthropogenic forcing was based on historical data and numerical models. The regions of interest were the key areas defined in the frame of the project as regions of socio-economic interest. Finally, integration among modellers and socio-economists assisted in providing the project with answers to the specific objectives, particularly the ability of ecosystems to provide goods and services and address the issues in an integrated manner which was the project's overall aim.

Partners involved: HCMR, CNRS (LOV, CEFREM, LOB, LMGEM, LOBB, LA, Paris), SIO-RAS, IMS-METU, CSIC (IMEDEA, ICMAN, CEAB, ICM), CoNISMa (UniBo, DiSTeBA), AEGEAN, IO–BAS, IOLR, CNR (IBF, IAMC, ISAC, ISMAR, IRSA), GeoEcoMar, IBSS, IOF, MHI, NIMRD, NIB, NIOF, SSC-RAS, SZN, UNITIBLISI, UB, UoC, UoM, UNIVPM, ULCO, UoP, USOFIA, IMS-METU, ULg-MARE, ICBM, EC-DG JRC, MHI, OGS.

Data mining from published databases, grey literature, reports and observations, unpublished existing datasets as well as data from re-treatment of historical samples, with emphasis on time series and regime shifts, was completed during the first two years of the project. The analysis of historical data showed that several components of the SES ecosystems have changed during the last 50 years. Changes were not identical in both basins, nor attributed to the same drivers.

Temperature, salinity, oxygen and nutrient analyses in the NW Mediterranean Sea have demonstrated that one of the most important features is a marked seasonality. The analysis of oxygen and nutrient trends in the E. Mediterranean confirmed the general depletion of nutrients compared with other parts of the world ocean, as well as their west to east decrease in concentrations along the two basins. It appears that the principal reason of this scarcity relates to the Eastern Mediterranean hydrology and circulation as a concentration basin. Nutrient fluxes in the Mediterranean Sea have been confirmed. The possible impact of the Eastern Mediterranean Transient (EMT) on the nutrient concentrations and transfer among the two basins has been recently analyzed, leading to the conclusion that there is an increased transport of nutrients from the eastern to the western basin. However, due to the density of the carrying water, the nutrients were transported to layers deeper than the intermediate layer. The East-West gradient in nitrate concentration displayed a sharp discontinuity at the Straits of Sicily, while silicate distributions appear to be more homogeneous.

The role of dissolved organic carbon in carbon export had been demonstrated in the past. Climate change can strongly affect the amount of dissolved organic carbon exported at depth, for example simply by changing the amount of dense waters formed, an event already manifested during the EMT. Moreover, an increase in temperature may also affect dissolved organic carbon mineralization rates, which are significantly higher in the Mediterranean Sea than in the open ocean. The physically induced downward export of the surface production can be "size fractionated" and contributes to the heterogeneous particulate spatial distribution of the Large Particulate Matter (LPM). The mesoscale physical structures may enhance the biological production by about one order of magnitude and induce a spatially heterogeneous distribution of LPM. Accordingly, the highest LPM values were found in the Strait of Gibraltar and the lowest in the open Ligurian Sea. In the western Mediterranean basin, the cross-slope transport suggests that the sedimentation rates are high near the slope while the export rates to the open sea are fairly low. Changes in the meso-scale structures in response to water mass circulation modifications, due to climate change, may greatly affect the carbon sequestration process. Data of the Underwater Vision Profiler allowed the construction of a database on particle size distributions from 1254 profiles, for a range of seasons and locations all over the world. About 700 of these profiles are found in the Mediterranean Sea.

Using a model conjointly with chl-a satellite data, it appears that the carbon consumption and sequestration in the Mediterranean Sea has increased in the surface layer during the period 1998-2001 compared to 1979-1983. This is due to 1) increased primary production, 2) a decrease in the deep carbon injection due to the declining mixing events. Consequently, the Mediterranean Sea has shifted from a source of $CO_2$ (for the atmosphere) in the years of 1979-1983, to a sink during 1998-2001, while the deep export of carbon has increased. Model simulations in the Gulf of Lions confirm that the reduction of vertical mixing during 1990-2001 compared to 1976-1989 substantially reduces the vertical export to depths. It also shows that the interannual variability of this vertical export is strongly linked to the variability of convection ('convective years' as opposed to 'weakly convective years').

In the Black Sea, the climatic conditions and their variability are the principal factors that define the hydrological structure and dynamics of the waters; the latter, in turn, determine the

hydrochemical structure and the distribution and quantitative characteristics of plankton and nekton species in the Black Sea's pelagic zone. Among the entire set of the climate-forming factors, two meteorological factors -air temperature and wind- are the most important ones regarding the hydrological regime. After 1970, large nutrient inputs from the major rivers have modified the upper layer ecosystem of the entire Black Sea. Changes in the suboxic boundary towards the surface also altered the related chemical properties. Before 1970, the nitrate maximum was formed at greater depths and the nitrate gradient vanished at the anoxic boundary. Comparison of the annual chemical fluxes in the Dardanelles reveals that the inputs from the Marmara Sea to the Mediterranean are at least 4-5 times higher than the exports from the system via the strait undercurrent, thus indicating a net mass transfer from the Black Sea to the Mediterranean via the Turkish Strait System. The Black Sea inputs, comparable with those of riverine and atmospheric origins, are expected to contribute to the net production and thus to the nutrient balance in the Aegean basin of the eastern Mediterranean.

Furthermore, work on phytoplankton biodiversity in the NW Mediterranean Sea has resulted in the creation of an inventory on phytoplankton biodiversity, in biomass estimation and pigment analyses from which the chlorophyll vertical profiles were associated with three pigment-based size classes (micro-, nano-, and pico-phytoplankton). A database comprising HPLC-analysed pigment profiles and derived pigment indices from 1991 to 2007, from the western and eastern Mediterranean, was created and inserted in the SESAME database. The trends of nutrients and phytoplankton community evolutions have been defined from three time-series stations on the French Mediterranean coast. The concluding analysis showed a recent trend of diversity loss in close correlation to climate change. The phytoplankton biomass variability seems to be linked to two distinct interannual signals: (1) to the modified surface circulation pattern consisting of a northward shift and intensity increase of the Algerian current, and simultaneously, to the reduced cyclonic circulation in the entire western basin; and (2) to the surface heat content anomalies during 1998-1999 (unusually cold winter) and 2003 (summer heat wave). Additionally, eutrophication and its consequences at different levels of ecosystem structure was studied in the Adriatic Sea for the last 30 years, thereby emphasizing the prediction that the Adriatic Sea should be anticipating large shifts in ecosystem structure and functioning. Further research in the Black Sea revealed that during the 1980s a total of 31 monospecific blooms occurred in the area, whereas, during the 1990s, along with the reduction of frequency and duration of phytoplankton outbursts, the blooms were mainly composed of several co-occurring species.

Up to 45 zooplankton datasets for the Black Sea were inserted into the SESAME database, providing information on mesozooplankton biomass, total abundance, groups, and species composition and abundance. Similarly, for the Mediterranean Sea, 33 datasets were provided, concerning species composition, abundance and biomass. Analysis of temporal and spatial data on zooplankton biodiversity revealed that the interannual variability is different among the studied sites, probably due to the influence of local drivers. For a uniform data analysis, statistical software for time series treatment for biologists was compiled and presented during the first SESAME summer school held in Varna, Bulgaria. Based on this software, comparative analysis of six Mediterranean zooplankton time-series, including environmental parameters, was performed. Mediterranean mesozooplankton time series (1957- 2006) from six coastal stations in the Balearic, Ligurian, Tyrrhenian, North and Middle Adriatic and Aegean Sea were analyzed and compared. The analysis focused on fluctuations of major zooplankton taxonomic groups and their relation with environmental and climatic variability. Intra-station analyses showed (1) coherent multi-taxa trends off the coastal village of Villefranche-sur-mer, that diverge from the previous results found at species level; (2) co-variation of zooplankton and water masses as a consequence of the boundary hydrographic regime in the middle western Mediterranean, in

Baleares; (3) decrease in trophic status and abundance of some taxonomic groups off Naples; (4) increase of zooplankton abundance and decrease in chlorophyll possibly caused by reduction of anthropogenic nutrient input, increase of microbial components, and more efficient grazing control on phytoplankton, off the coast of Athens. At basin scale, the analysis of temperature revealed significant positive correlations between Villefranche, Trieste and Naples regarding the annual and/or winter average, as well as synchronous abrupt cooling and warming events centred around 1987 at the same three sites. Pooling the data submitted in the SESAME data base, the spatial differentiation of total abundance and biomass in the Mediterranean Sea, was characterized by a west-east decrease of values (same as for chl-a). In the Black Sea, the analysis of a single time series data set collected at an offshore station off Bulgaria during the summers of 1967-2005, revealed the evolution of the community composition from the warm mid-1960s-early 1970s, to the cold mid-1980s and 1990s and then back to the warm late 1990s and the first decade of 21$^{st}$ century. The comparison of data collected in the summers of 1988, 1989 and 1999, has singled out the summer of 1989, mostly due to the impact of the invader's *Mnemiopsis leidyi* high abundance on mesozooplankton. Data collected in the southern Black Sea (1991-95) showed that mesozooplankton abundance and biomass were generally higher in the south-western part and close to the Bosphorus strait. Finally, the spatial distribution of the scyphomedusae and the ctenophores seemed to be related to the water circulation, while the interannual variability of their populations were probably controlled by food availability and physical factors.

A database with information on fish stock and biodiversity was also created. In the North Eastern Mediterranean, the fishing fleet experienced a rapid increase since the 1980s, in all aspects, including number, size and engine power. The sharp decline in the Catch Per Unit Effort (CPUE) recorded in the spring of 1989 is itself clear evidence that the stocks responded negatively to the increase in the fishing fleet. This statement is based on a fisheries survey carried out at the end of the fishing season and just before spawning takes place. It is obvious, then, that in that period the stocks were at their minimum size and this may help to explain the low CPUE value. On the other hand, this does not justify the sudden increase in the non-commercial, non-teleost species in the catch. A similar pattern has also been observed in other regions, where non-target, non-teleosts increase as a consequence of over-fishing. The second notable change in the fish community is the increase of the small pelagics, which may indicate an ecosystem shift towards smaller pelagic species. The increased fisheries pressure on the piscivorous species decreased the predation control over the small pelagics. Consequently, a zoobenthivore-dominant system turned into the favour of the planktivores. Conversely, a general decreasing trend has been observed in large pelagic fish landings in the last 100 years, at least for the majority of the analysed traditional traps, thus probably indicating heavy overfishing of this resource. Another significant change in the eastern Mediterranean is the regression of the Lessepsian species. The very high percentages of Lessepsian fishes found in 1983 and 1984 have remarkably decreased. In conclusion, the eastern part of the basin was, and is still, under the heavy pressure of Lessepsian species, fishing pressure and eutrophication. It is, therefore, subjected to severe and continuous changes. Finally, the lack of *Posidonia oceanica* meadows, which have a significant impact on the ecosystem maturity and therefore in increasing the resilience to external impacts, plays an important role in fish community instability.

An ecosystem model is used as a tool to quantify the historical impact of fishery and environmental factors on fisheries resources. The tool is tested in two selected areas of the Mediterranean Sea: the north-central Adriatic Sea and the north Catalan sea. In both sites, it was found that: fishing efforts have increased from the 1970s to the 1990s, and will most likely continue to increase through the 2000s; there was a decrease of biomass with time, mainly

observed in commercial species; trophic interactions explain most of the variability: 55-72% for the Catalan and 84 % for the Adriatic, while fishing activity explains 20% (Catalan) and a small percentage in the Adriatic, whereas environmental variables (nutrients, phytoplankton anomaly, SST) explain the remaining part. In the Alboran Sea, literature data indicated that the post-larval phases of anchovy use the Bay of Malaga as a nursery area, and thus physical/biological phenomena affecting this (and close by) area are likely to shape the survival of the species. Physical factors themselves explain, by retention mechanisms, the existence of an (average) nursery area in Malaga Bay. The long term analysis of fisheries data showed how circulation pattern and temperature are key factors which explain the present location of the small pelagic fishery in the North Alboran Sea, and show how human pressures may not be the key top-down driver in the fate of this fishery, as long as the fishing effort does not increase.

A key marine habitat in the Mediterranean Sea with major importance for carbon sequestration is *Posidonia oceanica* meadows. The magnitude and the rates of change (i.e. expanding, declining, and steady-state) of extension and abundance that *P. oceanica* meadows have experienced during the last 50 years in the Mediterranean basin have been assessed from a large review of published data,. The results demonstrated an overall tendency towards declining of the extension and shoot density of *P. oceanica* meadows during the last 50 years. In addition, available estimates indicate that between 13% and 50% of seagrass extension of *P. oceanica* in the Mediterranean basin may have already been lost, and that shoot density in the remaining areas in the whole Mediterranean basin has been decreasing. The loss of *P. oceanica* meadows in the Mediterranean during the last 50 years may have led to a substantial (between 11% and 52%) reduction in the capacity of the key coastal ecosystems to sequester carbon and hence that of the entire Mediterranean Sea. The major causes of *P. oceanica* loss are disturbances acting at local scale, but recently, global disturbances as well, such as climate change and spreading of invasive exotic species, are also seriously threatening *Posidonia* meadows in the Mediterranean. These findings urgently call for the implementation of management measures aiming at mitigating coastal deterioration by combining local and global actions.

Since the 1970s, the Black Sea ecosystem has also experienced various anthropogenic impacts such as eutrophication, heavy fishing and non-native ctenophores' invasion. For this reason, several different approaches were used to explain and assess the complex ecosystem responses to the regime shifts, while the results showed that anchovy and other small pelagic fish stock decreased since late 1990s.

Studies were conducted to define and identify vulnerable habitats in the Mediterranean basin; they have revealed that the shift of the Mediterranean from a temperate to a tropical affinity is leading to modifications that are in accordance with a foolproof hypothesis linking biodiversity to ecosystem functioning. In the Aegean Sea, combined satellite and field data showed that the surface waters have become warmer by approximately 1.5°C from 1985 to 2005, and the trend showed that this increase would, most likely continue. A study on the elevated temperature and the Lessepsian species verified that whenever there was a warm 'pulse' resulting in a temperature increase, the number of non-indigenous species also increased. These findings may indicate a regular connection of temperature and advancement of Lessepsian species to the north, indicating therefore an example of alteration in the marine ecosystem of the Eastern Mediterranean due to elevated temperatures.

Maps of habitat types, including description of community types that can be found at each physical habitat (including pelagic habitats), a master list of species for each type and description of distribution of alien biota, have been produced. The analyses suggested that the main shift in the SES is the establishment of alien species almost throughout the basin (with their adverse

impact) with a great prevalence of species of warm water affinity. On the other hand, cold water species are probably in distress, especially in the coldest parts of the basin probably due to global warming.

Significant research advancements were accomplished regarding the reconstruction of the spatial and temporal variability of river freshwater and nutrient inputs since the early 1960s. Data compilation indicates that Mediterranean rivers suffer from a significant reduction in freshwater discharge, contrary to rivers of the Black Sea, which do not have clear discharge trends, reflecting recent climate change and also dam construction. A similar decrease can also be expected for the fluxes of dissolved silica, in contrast with the fluxes of nitrogen and phosphorus in the Mediterranean and Black Sea rivers, which were strongly enhanced by anthropogenic sources. With respect to the marine primary production that can be supported by the riverine nutrient inputs, Mediterranean and the Black Sea rivers appear to be mostly phosphorus limited during the study period. Their anthropogenic nutrient enrichment could only have had a fertilizing effect before the general decline of the phosphorus loads. Additionally, when considering silica as a limiting element, which is the case for siliceous primary producers such as diatoms, silica limitation may have become a widespread phenomenon in the Mediterranean rivers since the early 1980s. For the Black Sea rivers, this process had already started during the late 1960s. Gross primary production sustained by rivers represents only less than 2% of the gross production in the Mediterranean, and less than 5% in the Black Sea. Possible ecological impacts of the changing river inputs should therefore be visible only in productive coastal areas, such as the Gulf of Lions, where gross primary production sustained by rivers can reach more than two thirds of the primary production. Reported ecosystem changes both in the Adriatic and the Black Seas are concomitant with major changes in the reconstructed river inputs.

Historical literature from the Black Sea ecosystem has been reviewed and re-evaluated using contemporary techniques in order to extend our baseline backwards in time towards the beginning of the 20th century, enabling reference levels for system state indicators to be established. As key benthic indicator for conditions on the north-western shelf of the Black Sea the macrophyte Phyllophora (*P. crispa, P. truncata*) has been selected, which is a keystone red alga. Work to date has involved accessing early surveys for this species and compiling a database of records for re-analysis.

Although model development was not included in SESAME's objectives *per se*, in some cases/areas, the 3D models used for the long term assessment have been extended firstly by adding the representation of specific processes in relation to the objectives of the project. Long time series (~1950-2000) of river discharges (waters and nutrients) have been estimated in order to force the 3D numerical models. These data involves the discharges of fresh water, inorganic nitrate and phosphorus, silicate, dissolved inorganic carbon and sediments. Atmospheric forcings have been provided from the ERA-40 ECMWF data at a resolution of 1.1 ° for the period 1960-2000. Historical data collected during the first years of the project was effectively used in model validation and calibration. Furthermore, basin scale models of the Mediterranean and Black Sea have been integrated during 3-4 decades and long-time trends have been analysed. Regional models have simulated several time slices of 3-5 years. These time slices correspond to the CZCS and SeaWiFs period, the present situation and in some cases (the Black Sea) the pristine situation (1960s). Time slices are also identified based on the long term simulations performed with the hydrodynamical model which allow for identifying specific variations in hydrodynamical conditions that may induce modifications of ecosystem functioning (e.g. vertical mixing, deep convection, stratification, cooling, heat waves). The results from the modelling activities for the different time slices were compared and differences were explained mainly in

terms of variations in atmospheric forcings and river inputs. Emphasis was given on the variations of physical conditions, primary production, export production and nutrients content. Using a set of 1D models forced by satellite observations, carbon sequestration of the Mediterranean Sea has been assessed and compared during the CZCS and SeaWiFs periods. Time series data of anchovies and sardines in the Alboran Sea were analysed in connection with environmental variables. The evolution of the status of *Posidonia oceanica* meadows during these last decades has been assessed and the causes responsible for potential changes have been identified. A model of sediment transport has been run in the Black Sea at basin scale, in order to obtain a better representation of water transparency strongly impacted by the re-suspension of sediments on the Black Sea shelf. Finally, diagnostics were defined in order to compare model outputs during different periods and areas.

For the long term assessment using numerical models, basin scale models performed long term simulations over several decades. The Mediterranean model run for ~40 years (1958-2001) for the ocean physics while the fully coupled simulations with the biogeochemical model were limited to the years 1990-2004. A particular focus was placed on the influence of the Eastern Mediterranean Transient (EMT) event (early 1990s), particularly on the physics and biogeochemistry. It appears that, due to enhanced nutrient inputs in the euphotic layer, the EMT stimulated the primary and bacterial production in the eastern Levantine, the Aegean, the north-eastern Ionian and partly the eastern Adriatic. Since 1995-96, the overturning circulation returned to extend to the entire eastern Mediterranean basin. During the period 1999-2004, model results showed that the interannual variations of large scale averages of the Net Primary Production (NPP) are low compared to the seasonal variability. Spatial averages over selected regions show a clear east-west gradient in trophic properties. The impact of atmospheric and terrestrial inputs on the annual budget of the integrated NPP is in the range of 3-5 $gC.m^{-2}.y^{-1}$.

The Black Sea model at basin scale was run from 1971 to 2001. The sea surface temperature (SST) provided a clear indication of changing surface waters in the Black Sea during three decades with a negative trend during 1971-1993 and a positive trend of about 2°C from 1993 to 2001. These changes in SST influenced the thickness of the CIL (Cold Intermediate waters), the oxygen and sulfide pool. The years after 1987 (*Mnemiopsis* invasion into the Black Sea) constituted the new phase of the Black Sea ecosystem transformation. Seasonal cycles of the main ecosystem compartments were changed, while both the nutrient budget and the primary production changed.

Regional models have been run for selected time slices of about 5 years. In the Aegean Sea, the occurrence of regime shifts has been investigated using 50 years of simulations, with the use of a coupled model. Statistical analysis of time series of SST and chlorophyll has been performed. No clear regime shift has been identified in the Aegean Sea, at least not at the proposed date for a Mediterranean regime shift at the end of the 1980s. This must not be an inconsistency, as nearly all parameters considered arise from the western Mediterranean and the Adriatic Sea and not from the Aegean Sea, which is known to have different dynamics than the rest of the Mediterranean Sea. The most important change in the northern Aegean Sea hydrodynamic variability is related to the Eastern Mediterranean Transient (EMT). Another important change is the gradually increasing trend *circa* 1998, identified in both model and satellite SST variability (~0.76°C difference between pre and post-1998 periods for AVHRR). In the late 1990s, as phosphate load was significantly decreased, river-influenced areas shifted from silicate limitation to phosphate limitation and this led to a reduction of primary production in the coastal area by ~20%. Primary production in the open sea is related to variability of the thermohaline circulation and of the north-south exchanges.

In the Gulf of Lions, long term simulations (1976-2005) showed that the plankton biomass and composition is strongly governed by the interannual and decadal variability of vertical convection. Model results showed the occurrence of a strong interannual and decadal variability in the intensity of vertical convection: a 'convective period' occurred in the 1980s and was followed by a 'less convective period' in the 1990s. This decrease in mixing at the end of the 80s led to a substantial decrease in the pool of nutrients in the surface layer (0-100m), a shift to small size phytoplankton and an increase in zooplankton abundance.

In other places, such as the Alboran Sea, simulations showed that the surface waters became warmer by approximately 0.5°C from 1981 to 2000, whereas the salinity decreased in the eastern basin. The SST cycle was attenuated, with the 1996-2000 period simulation presenting a milder winter and reduced mixing. The general circulation in the Alboran Sea showed important variability: with either a double anticyclonic gyre system or a single anticyclonic gyre system associated with stronger coastal currents. Modification of the northern branch of the anticyclonic gyre has an impact on the upwelling close to the Malaga coast which is a nursery area for fisheries (mainly anchovies and sardines). The productivity of the Alboran Sea ecosystem has increased since 1981 due to a stronger upwelling, thus reinforcing the upwelling productivity.

In the eastern Black Sea, a clear interannual variability of the winter and summer SST, as well as variability of the temperature of the cold intermediate layer has been simulated in response to atmospheric oscillations of the NAO. In the beginning of 80's the phytoplankton concentrations have been kept in a relatively low level, then they increased from 1986 to 1987 and decreased again reaching, in 1991, levels similar to those of the beginning of 80's. A jump of the phytoplankton biomass is simulated in 1992-1994 associated with the temperature variability and then, a negative trend of the mean phytoplankton concentration occurred for the period from 1994 to 2000. During the warm 2001-2002 period the phytoplankton concentration was again high. The mesozooplankton biomass follows the variability of the phytoplankton but is also affected by temperature and *Mnemiopsis* development.

On the Black Sea northwestern shelf an automatic regionalization procedure (SOM) has shown that the simulated chlorophyll values present a north-south gradient with a higher value in the north while the seasonality pattern presents a west-east gradient with a spring bloom in the west and a summer bloom in the eastern part. The interannual variations of the seasonal cycle of phyto- and zooplankton groups, as well as of gelatinous and bacteria groups, were described for the period 1985-1998. It was shown that the interannual variability of primary production on the shelf is not easily explainable based, for example, on river discharge only, but the supply of nutrients by sediments, *in situ* remineralization and deep sea inputs seemed to be important, especially in the summer. The interannual variability of the spring bloom does not necessarily correlate with the ones of the summer blooms. The balance of shelf waters in nitrogen is governed by river inputs, denitrification in the sediments and export at the shelf break. This export is strongly conditioned by the inclusion of sediment re-suspension through bottom stress caused by waves and bottom currents. Re-suspension is absolutely necessary for a significant export of nitrogen to the deep sea. However, even with this process the export at the shelf break has been found insufficient to balance the important loss of nitrogen in the deep sea by denitrification (e.g. anamox, heterotrophic denitrification, nitrate reduction for oxidation reaction in the suboxic layer). This suggests that atmospheric inputs of nitrogen are as important as dinitrogen fixation. The analysis of oxygen concentration on the bottom of the shelf showed that hypoxic events could occur especially in summer in two regions: the northern shelf and the area in front of Crimea. The first region of hypoxia is related to intense oxygen consumption within the sediments, while in the second zone, low oxygen content is a consequence of strong POC

accumulation and consequent bacterial oxygen consumption in the water column. The analysis of the interannual variability of hypoxic events has shown that hypoxic events are not a direct consequence of primary production for the same year but, due to the memory of stocked sediments, favorable conditions (high bottom temperature) can trigger an increased remineralization process and subsequent intense oxygen consumption.

Regarding the carbon sequestration in the Mediterranean Sea at basin scale, the assessment of the evolution of the air-sea $CO_2$ fluxes between the CZCS period (1979-1983) and the SeaWiFS period (1998-2001) showed that the Mediterranean Sea has become significantly more biologically productive (by about $15 gC.m^{-2}.y^{-1}$) and more active for carbon sequestration (by about $7 gC.m^{-2}.y^{-1}$). The global increase of atmospheric $pCO_2$ (by 30 µatm between the two periods) has been suggested to be the main reason for such a basin scale trend by shifting the Mediterranean carbonate system from a source (by about $1.5\ 10^{12} molC.y^{-1}$) to a sink situation (by about $-0.2\ 10^{12} molC.y^{-1}$).

## Assessment of the current status of the SES: coupled experimental and modelling approach

A major task in SESAME was the assessment of the current physical, chemical and biological state of SES based on new information gathered through regional and basin-scale cruises. Open sea, shelf and straits cruises were designed and executed, where intensive studies of key processes in key areas were performed. New information collected in these studies allowed for the concurrent synoptic coverage of the two Seas that enabled the identification and understanding of key mechanisms sustaining the past and present states of the ecosystem, and subsequently, led to the assessment of the current status of the SES. The results also form the information baseline for the validation of the ecosystem and climate models while supplying information to socio-economic evaluations.

Partners involved: CNRS-LOV, CNRS-LOBB, CNRS-CFFREM, CNRS-Paris, CSIC, UB, UoP, ULg-MARE, ULCO, CoNISMa, CNR-ISMAR, CNR-IAMC, CNR-ISAC, CNR-IBF, INSTM, ENEA, OGS, SZN, CNR-IRSA, ISPRA, HCMR, AEGEAN, UoC, IMS-METU, IOLR, CNSM, IO-BAS, SIO-RAS, NIMRD, GeoEcoMar, SSC RAS, MHI.

The experimental work in SESAME involved basin-wide synoptic data collection on transects that fully covered the Mediterranean and Black Seas, as well as sub-basin scale work on (i) the eastern and western shelf regions of the Black Sea and the Mediterranean basins, and (ii) the Gibraltar, Sicily Straits and the Turkish Straits System to study inter-basin exchange. The aim was to acquire new physical and biogeochemical data extending the existing records of continuous measurements in order to define the basic characteristics of these systems, analyse their contemporary states and evaluate patterns of temporal changes.

The innovative basin scale experimental design was based on two sets of multidisciplinary open-sea cruises carried out simultaneously across the Mediterranean and Black Sea in spring (March-April) and autumn (September-October) 2008, involving nine (9) major oceanographic and marine institutes and their research vessels. This particular research effort also benefited from the analysis of samples obtained from concurrent deployment of long-term instrumented mooring arrays in the deep north-western Mediterranean, south Ionian Sea and in the south-western Black Sea. In addition, more than 30 regional cruises have been conducted either as existing or newly designed cruises, in order to collect data that would allow for a better interpretation of the current ecosystem status and would provide an opportunity to calibrate the models.

Laboratory and field experiments were also completed in order to determine life cycle and vital rates of target species required by the pelagic ecosystem models. Much of the effort was devoted to analysing ecosystems, detecting seasonality and characterising each region with respect to

physical and biochemical mechanisms sustaining them and the interactions within the pelagic food web (phytoplankton, bacteria, nano-flagellates, micro and meso-zooplankton). Efforts were also made to determine air-sea $CO_2$ exchange, organic carbon fluxes (production, degradation and export) and inputs of nitrogen and phosphorus from the atmosphere.

A common sampling strategy has been elaborated. Commonly accepted methods and protocols for sampling and analyses have been defined and methodologies and protocols have been standardised prior to the cruises. In order to satisfy the intercalibration needs of such diverse scientific sampling, a visit to two common stations, as well as a specially-designed workshop, were both deemed necessary actions. Furthermore, intercomparison of the mesozooplankton data was performed during a specifically designed cruise in the Black Sea, where samples were collected using the nets that had been used by the different partners for the collection of both historical and new data. The results of this exercise showed statistical significant differences among nets and the ratios of the abundance values issued from different sampling nets were used for the comparison of zooplankton distribution between the Black and the Mediterranean Sea.

The collected data sets were processed, intercalibrated, analysed and finally inserted into the SESAME database.

Based on the results from the open sea cruises, SESAME identified monitoring stations in the spirit of the World Ocean Circulation Experiment (WOCE). Based on firmly set criteria, experts' opinions and SESAME information, seven stations are selected to represent, in addition to national monitoring activities, the network of stations that could cover changes in the future. These stations will add the information to the existing structures already in place. Five stations are proposed for the Mediterranean Sea and two for the Black Sea (eastern and western cyclones), which have already been passed on to stakeholder organisations, like CIESM. The five stations in the Mediterranean Sea have been adopted by CIESM's MED-Go-SHIP initiative.

Most importantly, this new information collected in these studies allowed the identification and understanding of key mechanisms sustaining the past and present states of the ecosystem and led to the assessment of the current status of the SES.

Key findings are summarised below, firstly on a geographical basis (western Mediterranean, Sicily Strait, Ionian Sea, Levantine basin, Aegean Sea, Turkish Straits System and Black Sea), and secondly on the integrated assessment of key parameters spreading across regions.

In the western Mediterranean, activities concentrated on the shelf-open sea interactions, river-ocean carbon transfer, as well as automated particulate observations and glider operations. The analyses of particulates suggested the mixed layer sources of biogenic particles, which were also higher in the western part of the basin, and related to seasonal patterns. It was shown that flash floods from small rivers have a distinctive role on deposition and export patterns over the shelf, and a mesocosm experiment characterized the productivity of river waters, e.g. of Rhone river, with respect to salinity and nutrient ratios. Glider sections and altimetry reconstruction of fields across the Almeria-Oran front in the Alboran Sea provided a first-time detailed synoptic view of the vertical motions and mixing characteristics of a sharp front and its evolution over time, and provided insights into how this modifies and interacts with the western Mediterranean ecosystem.

Continued monitoring of the Sicily Strait with multiple instrument deployments and cruise data provided fine details to complement long-term observations. While surface currents were highly variable, deeper currents represented a steady flow from the eastern to the western Mediterranean basin. Long-term observations confirmed the outflow of the Eastern Mediterranean Transient (EMT) through the Sicily Strait, and also showed two main pulses of saline intermediate and

deep water formed in the EMT process flowing out of the eastern basin: one immediately after the formation event in 1992, and another one developing after 2006, due to replacement motions of the deep water masses, with near-surface inputs of lower salinity Atlantic Water intensifying between those events, thereby having important consequences for both the western and the eastern basins.

In the Ionian Sea it became evident that the main water masses distribution and pathways were significantly influenced by sub-basin and mesoscale dynamics. The overall north Ionian Gyre anticyclonic circulation is in agreement with the present action of the Adriatic-Ionian bi-modal oscillating system mechanism (BiOS). The diversion of part of the Atlantic Water (AW) into the Ionian basin, together with a prospective salinity increase in the Levantine basin, might be gradually creating the favourable preconditioning for a possible switch of the dense water formation site from the Adriatic to the Aegean, an event which already occurred in the 1990s.

Furthermore, in areas such as the Levantine Basin, one of the most intensive river-shelf-deep ocean interactions appeared to occur in the Cilician Basin area. The fresh water inflow in the wide shelf region interacts with the eddies and meandering currents of the Asia Minor current and gets dispersed, while differences between the eutrophically inclined inner shelf waters, the oligotrophic deep waters and the large scale Rhodes gyre, all create sharp contrasts and characteristic eco-regions (niches). Additionally, dense water formation evidenced in the Gulf of İskenderun in winter contributes to the export and replacement processes in the manner of a shelf pump.

In the Aegean Sea, the research activities resulted in details of development of its water masses in the deep northern, central and southern basins, and the detailed structure of this complex ecosystem in terms of different species groups. Moreover, it also established some of the vital rates needed in ecosystem models. In the northern Aegean in particular, the work carried out helped to detect the effects of the outflow from the Turkish Straits. The complex stratified flows in the Turkish Straits System and hydraulic controls were verified, whereas their effects on the plankton and bacterial productivity of the system were quantified through collaborative studies. It was found that the Marmara Sea has its own production response although it remains highly influenced by the Black Sea; the highest chlorophyll, phytoplankton, bacterial, particulate organic matter concentrations occur at the Turkish Straits System, in sharp contrast to the neighboring seas.

In the Black Sea, continued monitoring provided details of long-term changes in the ecosystem as well as the seasonal variability characteristics. Following major changes in the 1990s, there seems to be a recovery of the Black Sea ecosystem, to a relatively stable present state. In addition, another important observation in the Black Sea was that the average water temperature in the upper 100m layer in April and September 2008 was higher than the historical values. This corresponds well with the warming of the regional climate during the past 15 years. Considerable spatial variability (that exceeds the observed one in previous studies) of temperature and salinity vertical distributions in the permanent pycnocline have been conditioned by complicated dynamics of the Rim current and the mesoscale eddies. The winter of 2007-2008 was rather cold leading to the partial renovation of the Cold Intermediate Layer (CIL, T<8°C) waters. The analysis of the thermohaline anomalies in the CIL during spring revealed the formation of more cold and dense water in the western and eastern sub-gyres. On the other hand, during summer, the thermohaline anomalies in the CIL showed a longer lifetime in the central part of the basin, where mixing processes are weaker than in the Rim current zone.

It was found that in April, the Black Sea circulation pattern retained certain features of the Rim current winter intensification. The cyclonic alongshore current was quasi-permanent and the

mesoscale eddy dynamics were not as intensive as in September-October, when eddies defined the circulation pattern. Moreover, the impact of the large anticyclonic eddy on ventilation of the NW shelf waters and the shelf-deep sea exchange was studied. It was eventually revealed that the eddy moved along the shelf break and repeatedly interacted with the shelf edge front, causing its disturbances and formation of the cross-shelf jets and the chl-a rich filaments spiralling around the eddy. The total shelf-deep sea water transport was equivalent to 40% of the overall volume of the shelf water.

During the summer seasons of 2007-2010, the wind vorticity over the western Black Sea was predominantly anticyclonic, which was rather unusual. As a result, the desalinated water rich in chl-a and nutrients was blocked near the northern part of the Black Sea coast, while this was probably the main reason behind the blue-green algae bloom in 2009-2010.

In parallel with the experiments carried out and interpreted in each region, efforts were made to obtain integrated assessments spreading across regions, in order to determine relative magnitude, roles and structure of selected species or processes which would then allow for overall and comparative assessments.

One such case was the basin-wide evaluation of the nutrient fluxes, where the integration aspect had been missing, and overall data availability did not have an interdisciplinary orientation. From SESAME's work it became evident that, by far, the greatest exchange rates of water in the Mediterranean system occurs at the Strait of Gibraltar, where the inflowing nutrient depleted Atlantic water and the outflowing nutrient enriched Mediterranean deep water, mainly accounting for the oligotrophic character of the Mediterranean Sea. According to this compilation, the water fluxes at Gibraltar create a nutrient imbalance that varies between 72-209 Gmol/yr for N, 98-167 Gmol/yr for Si, and 1.2-7.8 Gmol/yr for P. These budgets were then compared to the Atmospheric and Terrestrial nutrient Inputs (ATI) and to the exchange with the Black Sea. Although the latter is a considerable freshwater source for the Mediterranean (comparable to the sum of all Mediterranean rivers), it seems almost negligible in terms of the nutrient exchanges. For nitrogen and phosphorus, the ATI match fairly well the nutrient imbalances even for the upper limits. However, for silicon, the ATI are far too low to compensate the imbalance even for the lower limits. Most of the ATI estimates, however, refer only to inorganic nutrient forms and neglect organic forms which in the case of silicon are negligible.

A west-to-east decreasing gradient was observed in phytoplankton biomass and activity, coupled with an increasing depth of the Deep Chlorophyll Maximum (DCM). An increasing prevalence of smaller size fractions occurred with autotrophic prokaryotes becoming increasingly important in the east. The seasonal cycle of phytoplankton is close to a sub-tropical regime. Productivity measurements in the eastern basin showed prevalence of heterotrophy in the oligotrophic environment, with high respiration rates. An analysis of the SeaWiFS time series has also highlighted a robust pattern in spatial distribution of the time of chlorophyll maxima in the climatological year. This strong phenological signal was interpreted as a consequence not only of differences in abiotic forcing, but also as reflecting different community structures and functioning.

A noteworthy finding in SESAME is the relevant role of diatoms even in the eastern Mediterranean at the horizon of the Deep Chlorophyll Maximum (DCM), especially as the presence of diatoms at the DCM had already been highlighted in the western basin. This suggests that diatoms may play a more important role than previously thought, which may be hampered by the observed slight decrease of silicon inputs into the basin, which should become stronger in the next decades because of the anticipated increased precipitations and water use on land. Small

size fractions of plankton are important in the eastern basin, but they do not contribute to nitrogen inputs, as coexist with larger eukaryotes and possibly rely on the organic forms of nitrogen and phosphorus. The latter acts as a temporary storage for the episodic inputs from the atmosphere thus smoothing the downward variability.

The phytoplankton community of the north-western Black Sea was characterized by the higher species diversity and richness compared to the north-eastern Black Sea (120 against 70 species). In both regions, phytoplankton abundance and biomass decreased in the offshore direction, with more pronounced coastal maxima in spring. Dinoflagellates and diatoms dominated the community biomass, the former in spring, and the latter in autumn. In both regions, chl-*a* concentration decreased from the coast to the centre of the Black sea. In spring, chl-*a* concentration in the north-western shelf zone was 1.5 times higher that over the north-eastern shelf. In autumn, chl-*a* concentrations were quite similar in both regions. The rates of primary production in the western shelf were 2-3 times higher compared to those in the eastern part. Finally, in both regions, the productivity decreased towards the open sea, similar to the phytoplankton biomass (chl-*a*), reaching the range of oligotrophy - mesotrophy.

The coordinated cruises carried out in 2008 represent the most recent and largest zooplankton surveys conducted in open epipelagic waters of the Mediterranean basins in the last decades and, for the first time, a parallel and intercalibrated investigation in the Mediterranean and Black Sea. Bulk and structural parameters of mesozooplankton were analyzed to compare regional and seasonal features of communities in different hydrological and trophic conditions. In spring, the distribution of epipelagic mesozooplankton highlights a notable spatial heterogeneity with spots of high standing stock concentrated in regions of high phytoplankton production, like the north-western basin, or in areas having pelagic and neritic characters, like the North Aegean Sea. It appears that in autumn, zooplankton was much less abundant but more homogeneously distributed among different basins. The west-east decreasing pattern of standing stock reported by previous studies was not visible in spring or autumn. The vertical gradient observed in zooplankton distribution closely reflects the availability of potential food, mainly represented by phyto- and microzooplankton that are concentrated in the upper water column. This typical vertical pattern was already reported for the Mediterranean Sea by previous studies. A significant regional differentiation was recorded in zooplankton communities and in the west-east distribution of some species. Some regional differences recorded in group or species distribution can be considered as characteristic features of the Mediterranean zooplankton.

Regarding the different areas of the Black Sea, the quasi-synoptic surveys revealed high resemblance in the total zooplankton biomass. In spring, biomass was two to four times higher than in autumn. Abundance and biomass were higher in the regions close to the continental slope than in the open sea, which is in accordance with previously reported results. The mass development of the heterotrophic dinoflagellate *Noctiluca scintillans* was found only in the north-western and western basin. However, the significant mesoscale heterogeneity of its distribution does not allow considering this 'bloom' as typical for the western parts of the sea. A few years ago, the highest concentration of this species was reported in the north-eastern Black Sea. The vertical distribution of zooplankton biomass was typical for the Black Sea. In both seasons, zooplankton performed diel vertical migration ascending to the upper layers at night and aggregating in the layer below oxycline in the daytime. The obtained data on abundance, biomass and species composition confirmed recently obtained results that the Black Sea zooplankton community has recovered after the collapse of the 90s. Both quantitative and qualitative parameters have reached the values observed in the 80s before the non-indigenous ctenophore invasion.

Regarding the particulate organic carbon, it was shown that the greatest inputs occurred in fresh water influenced zones of the Adriatic, north Aegean, Black Sea and the Turkish Straits System, with a high contrast to open sea areas. More specifically, dissolved organic carbon was strongly affected by stratification and mesoscale processes, with relative increase in recently ventilated deep waters. Horizontal maps of particulate organic carbon (POC), particulate phosphorus (PP) and particulate nitrogen (PN) allowed for the recognition of the high abundance of the particulate biogenic elements in the Black Sea, in comparison to all Mediterranean regional seas. They also revealed the existing spatial heterogeneity in the intermediate layers of different sub-basins. Among the Mediterranean regional seas, the highest POC concentrations were found in the upper layers of Northern and Central Adriatic Sea and Northern and Central Aegean. Additionally, maxima were reached in the Northern Adriatic during autumn after the fertilization due to riverine discharges of nutrients. In the Black Sea, POC concentrations were higher in the north western part during summer, while high POC concentrations were also found in the upper layer (0-25 m) of the Marmara Sea, both in winter and summer seasons. The highest PP concentrations are characteristic of the most productive seas under direct riverine influence: the Northern Adriatic, the Marmara Sea and the Black Sea. In the open waters of all the different regional seas, the exponential decreases of POC and PP are evident in both seasons. The photic upper layer was enriched in particulate matter and presented higher variability among stations. Moreover, areas under direct riverine influence (N&C Adriatic, Marmara Sea, Black Sea) presented higher concentrations and greater variability. More particularly, PP had a vertical distribution similar to that of POC with a relative stronger decrease with increasing depth. Finally, concerning the deeper layers, the Western Mediterranean Deep Waters (WMDW) and Eastern Mediterranean Deep Waters (EMDW) have the lowest POC, PN and PP concentrations. The lowest concentrations were found in the EMDW of the Ionian Sea and Ierapetra gyre.

Overall, the basin-wide compilation of past data and new measurements showed that in spring, all the SES regions were sinks for atmospheric $CO_2$. On the contrary, in autumn, the more open SES areas were sources of $CO_2$ (Alboran, Levantine, Cilician & Aegean), whereas the more coastal SES areas remained sinks (Adriatic, Marmara, Black Sea), while it was only in the Black Sea that the $CO_2$ sink increased in autumn.

Lastly, specific research efforts also focused on the analysis and data interpretation of samples obtained from the long-term instrumented mooring arrays in the deep north-western Mediterranean, south Ionian Sea and in the south-western Black Sea. These moorings, equipped with sediment traps and current-meters at different depths, allow for the exploration of particulate carbon cycling at large scale in order to better understand the biogeochemical cycles in the SES basins. By combining data of organic carbon (OC), primary production obtained from satellite imagery, algorithm-generated OC fluxes in the water column, and OC fluxes measured at the two sediment trap-levels, it becomes feasible to construct the budget of OC in the three SES basins. Fluxes from the upper traps best represent primary fluxes, while new production is equivalent to the OC escaping from the photic layer. The calculation of the expected fluxes of OC at 100 m depth gave new production values of 63.88, 31.26 and 93.34 mg OC $m^{-2}$ $d^{-1}$ at the western and eastern Mediterranean and the Black sea, respectively.

## Assessment of the future SES ecosystem changes

SESAME's activities regarding the prediction of ecosystem changes in the future focused on the following objectives: to simulate, explore and assess the variations in the SES marine ecosystem structure and functioning that would occur in the $21^{st}$ century under consensus scenarios of (global) change in the physical and biogeochemical forcing functions of the SES; to assess the changes against the current state of the SES ecosystem, at both the basin and the regional scale;

to explore the impact of socio-economic alternative development paths on the SES ecosystem; and to contribute to the evaluation of the changes in the SES ecosystem's ability to provide services.

Partners involved: CNRS, CoNISMa, CSIC, DMG-SU, HCMR, ICBM, IMS-METU, INGV, MHI, ULg-MARE and OGS.

"Exploring and Assessing" the potential future patterns require almost exclusively the use of modelling tools forced by forcing functions representing the future state of the system. It should be stressed that the achievement of the objectives listed above was not intended to be a "forecasting" exercise (a truly impossible task), but rather a scientific exercise in testing hypotheses of changes in the SES ecosystem dynamics, occurring under consensus scenario, at the best of the current (state of the art) modelling capabilities. In addition, such modelling-based assessment effort requires a tight and well coordinated interaction and synergy with the SESAME activities devoted to the observational reconstruction and modelling hindcast of the SES ecosystem dynamics. This was achieved for the modelling part by ensuring that the majority of the modelling team active in modelling hindcast were also active in modelling 'forecast'. This ensured the acquisition, for the modelling projections into the 21$^{st}$ century SES, of a set of numerical models calibrated and validated in hindcast work, against the 20$^{th}$ century dynamics and, constrained by the observational evidence provided by experimentalists.

In this context, SESAME addressed its activities towards the assessment of the potential changes in the SES ecosystem induced by climate variability (natural and man induced) and anthropogenic pressure variability. The emphasis on changes induced by anthropogenic pressure established a straightforward and two-way connection with the SESAME socio-economic team, as they provided the general characteristic scenarios of future alternative development paths in the socio economic dynamics, which were then translated into anthropogenic pressure on the SES and then quantified by modellers to provide a set of forcing functions usable by numerical models.

Having established the general framework and the connections/interactions with the rest of the SESAME project, the general approach was defined so as to: (1) address the (natural and man-induced) climate variability impact on SES through long term, basin scale (Mediterranean and Black Sea) simulations; and (2) address the anthropogenic pressures (Alboran Sea, Gulf of Lions, northern Aegean, eastern and western Black Sea) simulations.

In addition to the aforementioned modelling activities, specific actions were also dedicated to develop process studies on specific components of the Biota (*Posidonia Oceanica* meadows, anchovies). Such specific modelling activities also addressed the potential changes in response to climatic and man-induced pressures.

Changes were evaluated against the following time horizons: a) 2030-2050 for the regional modelling studies addressing anthropogenic pressure; and b) 2080-2100 for the basin scale modelling addressing climate variability.

The first step was then to provide all the modelling teams with adequate, and coherent forcing function sets.

Moreover, and with respect to climatic variability, the atmospheric forcing function data necessary to run the models were obtained from a climate simulation carried out at a global scale in the context of the EU-funded Project ENSEMBLES. This project attempted to hindcast the 20$^{th}$ century climate dynamics and projected these dynamics into the 21$^{st}$ century, by adopting the IPCC A1b scenario of $CO_2$ emission into the atmosphere, thereby defining the potential climatic change arising from anthropogenic activities.

On the contrary, the definition of the anthropogenic pressure on the SES ecosystem was more demanding. Among the many manifestations of the man-induced pressures, SESAME addressed the input of nutrients into the coastal sea via river transport. Since the transport of water and nutrients to the sea by the river system is depending on climatic processes, the projection into 21$^{st}$ century was achieved by implementing, over the SES watershed, a hydrological model forced by the very same forcing function data that constituted the forcing for the numerical models, thereby ensuring coherence among the modelling efforts. With this formulation, climate remains the only driver and anthropogenic effects have not been accounted for. In order to include these, the group of socio-economists defined 3 different socio-economic scenarios evolved from the Millennium ecosystem assessment scenarios. These are: the Business As Usual (BAU), the Policy Targeted (PT) and the Deep Blue (DB) scenario. The general characteristics of the three scenarios were then quantified in order to define parameters for the hydrological model that define the socio-economical changes, pertinent to each scenario that can affect the river nutrient transport. Essentially, the same model was also hindcast, for the 20$^{th}$ century river runoff and nutrient input into the SES.

Subsequently, the hydrological model in its final configuration included both the climatic and anthropogenic pressure effects on the processes determining the land based input of nutrients to the sea via river transport.

The final set of forcing function data (climate and anthropogenic pressure related data) were then handed over to the SESAME modelling teams.

Modelling results of the SES basin and regional scale coupled ecosystem dynamics provided a first and preliminary assessment of the change potentially affecting the SES dynamics in the 21$^{st}$ century, assuming specific scenarios of climatic change and anthropogenic pressures. In general, these results indicate that both the climatic and the land based 21$^{st}$ century forcing do not seem to produce very large changes in the SES ecosystem dynamics despite the warming process of the surface water and the increased stability of the water column. More specifically, the somehow surprising result was that the regional scale ecosystem dynamics turned out to be insensitive (or minimally sensitive) to variations in the land based, riverine nutrient input, as defined in the specific SESAME scenarios.

The different structure and the different assumptions underlying the numerical models employed in SESAME still prevent a totally coherent assessment of the possible changes occurring in the SES in the 21$^{st}$ century, but from the description of the results and in particular from the comparison of the twin simulations carried out with forcing pertinent to the 20$^{th}$ and 21$^{st}$ century, some general hypotheses on the nature and the characteristics of the potential changes may be drawn. For example, one of these hypotheses may be that the 'greenhouse' warming of the atmosphere, a process already (apparently) in action in the last quarter of the 20$^{th}$ century continues and, with respect to the SES translates, in a progressive warming of the SES waters. Additionally, it may be the case that the temporal and spatial pattern of this progressive warming might have important consequences on the biogeographical and biodiversity structure of the SES. The results of the Mediterranean Sea model, indicate that the progressive warming evolves with a northward shift of the surface isotherm, potentially paving the way for meridionalization processes (ingression of warm water species). Similarly, it may be hypothesized that the 21$^{st}$ century will be "warmer" and the vertical structure of the water column will increase its stability. Other examples of similar, hypothetical events may be related to the warming process in principle, having an enhancing effect on the biological production pattern. On the other hand, the increased stability of the water column might have a contrasting effect on production patterns:

the longer permanence of the mixed layer in the euphotic zone is a positive effect, but the reduced nutrient supply from the deeper ocean has a negative effect.

Furthermore, the 21st century Mediterranean thermohaline circulation seems to slow down with respect to current conditions, in particular the deep circulation and so the deep Mediterranean parts seem to be more 'stagnant'. In the Black Sea, ecosystem dynamics (basin and regional scale) indicate that there is a reaction of the biota to the climatic variability. More specifically, for the 21st century basin, the regional scale models describe a phytoplankton seasonal cycle characterized by an earlier spring bloom timing.

The hypothesis that simulation carried out at the regional scale using the three SESAME-devised scenarios for the river nutrient load, gave, almost ubiquitously, a surprising result, as the regional basin subject to the simulation efforts are apparently insensitive (or minimally sensitive) to the scenario dependent land based nutrient input.

It may further be assumed that regional basins seem to be more affected by the climatic variability than by the nutrient inputs, while it may be further speculated that the results of the Mediterranean Sea model indicate that the progressive warming evolves with a northward shift of the surface isotherm, potentially paving the way for meridionalization processes (ingression into the basin of warm water species).

Finally, one last assumption may be that the 21st century Mediterranean Sea thermohaline circulation seems to slow down with respect to current conditions, particularly the deep circulation.

The modelling work on specific components of the biota, allowed adding conclusions such as that the inclusion of the IBMs small pelagic fish model into regional circulation schemes run under the conditions of the IPCC climate change scenario for the Mediterranean Sea showed that, the predicted change in hydrographic structures might have a major impact in the distribution and importance of the small pelagic fish populations in the Alboran basin. Furthermore, it may be concluded that the expected 21st century dynamics of *Posidonia Oceanica* meadows in the Mediterranean for the first half of 21st century under scenarios of global change were computed. The results demonstrate that warming, even under a relatively mild scenario, will lead to the functional extinction of *Posidonia* meadows by the middle of this century (year 2047 ± 8.4), while efforts to alleviate local stresses (mostly derived from reduction of nutrient and organic inputs to coastal areas) will have a limited effect in conserving the meadows under climate change.

SESAME modellers finally advanced the integration with the socio-economists through the definition of the main diagnostics/ indicators that can be extracted from the output of the coupled numerical model in order to provide relevant environmental information for the socio-economical studies relative to the studied goods and services. The main challenge was to define indirect indicators for the provision of goods and services.


## Development of Ecosystem models to connect low and higher trophic levels

A specific objective in SESAME was to improve the conceptual and mathematical representation of higher trophic levels in Eulerian and Lagrangian approaches in order to produce tools useful to managers and decision-makers of SES goods and services connected to these levels. SESAME, therefore, developed E2E approaches through a structure of three tasks dealing with Eulerian, Lagrangian and mass-balance models, respectively. The work has been successfully completed as well as the interaction with the rest of the SESAME experimentalists, modellers and

socio-economists. An additional product of this accomplishment was not only the formal fulfilment of the duties contained in the contract but also the scientific efficiency resulting from the work performed.

Partners involved: CSIC, HCMR, CNRS, SIO-RAS, IMS-METU, ULg, CoNISMa, CNR, OGS, NIB and SZN.

SESAME succeeded in producing Eulerian-type models for components of the biota that are essential in the transfer towards higher trophic levels. This was a totally new effort for cases like anchovies, appendicularia or scyphozoa. The new models developed include an ECO3M Model for the Gulf of Lions, with a size-based approach for the zooplankton dynamics. In the same sub-basin of the Mediterranean, a physiological model with enough elements to create a functional group for the appendicularia has been completed and used to explore the complex interactions between appendicularia and ciliates in the pelagic ecosystem through a mixed laboratory - modelling approach. The module has been added to the state-of-the-art Biogeochemical Flux Model to study the appendicularians impact on phytoplankton, particle production and remineralization at the annual scale. In addition, a Eulerian Model for anchovy has been developed for the Black Sea, in order to explain the rise and fall of European anchovy landings and *Mnemiopsis leidyi* outbursts in the last decades. The nature of trophic controls during different phases of the Black Sea ecosystem have been reanalyzed in an effort to work on the abrupt transition of the north-western Black Sea shelf ecosystem from a eutrophic to an alternative pristine state. Combining this dynamics with the role of phosphate law regulations as well as Danube flow rates has allowed identifying two historical pelagic food-web regimes in the basin. The economic recession of early 90s plus the climatic and environmental regulation regime created a phosphate limitation in the basin and a collapse of the classic (phyto->zoo->fish) food-chain in the pelagic ecosystem. Instead, this limitation, apparently maintained a low-energy, inefficient food web dominated by the dinoflagellate *Noctiluca scintillans* and jellyfish, and relatively low levels of phytoplankton, bacterioplankton, mesozooplankton and fish.

An Aegean Sea model for the European anchovy in relation to the lower trophic levels was also developed, which was enabled to make, for the first time, a closing of the life cycle of the European anchovy through IBMs in a joint effort where the Lagrangian individuals were forced by physical and biological fields produced through Eulerian tools. This model was capable of reproducing several generations of anchovies with spatial and body signals coherent with observations in the North Aegean.

Moreover, a Bayesian model for anchovy was developed, in order to integrate the ecosystem approach to fisheries in a frame where the combined action of man and environment is analyzed at a decadal time scale in the Southern Iberian Peninsula. This specific model is particularly well suited for decision-making since it is based on probability calculations able to produce risk analyses of population collapses under different managing scenarios.

Lastly, for the first time, a model has been produced for the complex population dynamics of large scyphozoa in the Mediterranean and their life cycle includes, for the first time, both benthic and pelagic phases that are controlled by the physical environment. The inclusion of this physical forcing in population dynamics models has been able to explain the fluctuation of the *Cotylorhiza tuberculata* jellyfish in the Mediterranean coast. This is the first time the environmental forcing of the mechanism driving the life cycle of a jellyfish has been disentangled. Cause and effect have been resolved to seize the mechanics of climate forcing on jellyfish and to explain past fluctuations of abundance in connection with a thermally-changing Mediterranean. For other large, yet fully pelagic scyphozoa like *Pelagia noctiluca,* the life cycle

has been combined with the circulation patterns in the Adriatic Sea to explore their occurrence at the coast of this basin.

As explained above, an important part of this Eulerian work has been projected, particularly for the case of European anchovy, into Lagrangian frames. Since the start of SESAME, the partners involved in this work developed a collective strategy for generating an operative European anchovy IBM. This strategy was assisted through the implementation of a Wiki site to share know-how on the different modules (growth, feeding, respiration, etc.) assigned to each partner. The Wiki has also been the repository of the data base on European anchovy growth through otoliths and the guide for correctly interpreting the connection between them in the case of *E. encrasicolus*. The Wiki site also allowed for the creation of a hierarchical guide to implement anchovy IBMs with existing platforms to run IBMs in a user-friendly environment like Ichtyop (free software of increasing use in Lagrangian models). Some parameterizations for Ichtyop have also been provided in the process. The output of this work has been diverse, as it activated the Eulerian progress (since the metabolic equations are the same) and allowed to complete the life cycle and to reproduce the interannual dynamics of growth and biomass accumulation of this species in the Aegean in a linked Eulerian-Lagrangian configuration. In the Alborán Sea, an important validation exercise was performed. IBMs being a Lagrangian technique are not usually accompanied by validation tools of parallel Lagrangian nature. Moreover, IBMs validation is usually accomplished by comparison of observed Eulerian fields with simulated distributions of many individuals. Since IBMs reproduce individual life trajectories, new tools to validate these models through tracers of these trajectories have been developed and tested through an *ad hoc - in situ* mixed modelling Lagrangian experiment. This work was projected on modellers attempting to predict future ecosystem changes on an impressive result on the future scenario expected under IPCC conditions for the fisheries of the Alboran Sea, where recruitment problems are likely collapsing landings for the end of this century.

A more complete characterization of the fish community and its response to different IPCC scenarios was performed through mass-balance type models. A very exhaustive analysis of different managing and climatic scenarios in the Adriatic and Catalan Seas explored the wide range of expected ecosystem responses (and associated services). This work demanded the generation of new mathematical tools to transfer modifications in the lower part of the trophic food-web towards forcings able to impact on Ecopath with Ecosim, (EwE) simulations. The proper integration required a 2-way on-line coupling that is not straightforward due to differences in time, space and biological resolution. In the approach developed, the BGC and EwE models are not coupled by using the output of one model as a forcing of the second and vice versa, but the two models work separately, and the output of a model is used to constrain the trajectory of the other, as in Data Assimilation methodology. Through this new coupled approach, it was possible to perform analyses that combine fishing scenarios with the different climate scenario contemplated in SESAME, including a reference as well as the A2 and B2 from IPCC. A total of 27 fishing scenarios were performed (1 baseline, 16 management of commercial species, and 10 management by fleet), for each of the three climate scenarios, thus giving a total analysis of 81 scenarios (3 climatic x 27 fishing scenarios). The result indicates, for example under the B2 climatic scenario, that the decreased nutrient input results in an overall decrease of biomass and catches of all groups. Changes on the lower trophic levels driven by climate are much larger than any indirect top-down effect induced by fisheries. Fishing changes had in some cases the potential to counterbalance the climatic effects on the upper part of the food web. In particular, the scenarios regarding decrease on the fishing mortality of hake favored the increase in biomass of hake, whereas the increase in fishing mortality for hake produced its drastic decrease and a side negative effect on the biomass of conger eel and turbot and brill.

The overall analysis performed with this methodology has demonstrated its potential to discover unexpected changes and indirect trophic effects mediated by the food web. The largest effects are mainly top-down: the increase of biomass of groups targeted by fisheries (e.g. hake) when a fishing reduction was imposed, produced a decrease of biomass of their preys (e.g., invertebrates). Additionally, cascading effects of fishing changes mediated by the food web are evident for seabirds, which were one of the most affected groups in most of the scenarios, even if this group is not directly targeted by fisheries and is not described as an accidental catch in the model. Important bottom-up effects are also detectable, such as the decrease of nutrient inputs that produce cascading decreasing biomasses up to the food web. The results also highlighted that some biotic groups appeared to have a central role in ecosystems and that cautious management methods should be implemented in a changing-oceans context.

## Changes in the ability of the SES ecosystems to provide goods and services

The central target in SESAME's socio-economic research strategy was to assess and predict changes in the ability of the SES ecosystems to provide goods and services. The specific objectives contributing to this overall target were to: *(a)* Identify the ecosystem functions (observed and predicted from model simulations) that are pertinent to the selected goods and services as well as their changes during the last decades; *(b)* Carry out a scoping analysis to understand and evaluate key stakeholder perceptions referring to the future ability of the SES marine environments; *(c)* Develop a sound methodological approach for integrating scientific modelling and socio-economic analysis; and *(d)* Transfer and/or adapt state-of-the-art analytical and policy tools to investigate the economic welfare implications of alternative development scenarios in the SES marine ecosystems.

Partners involved: AEGEAN, HCMR, AUEB, FEEM, ECON-BOUN, IIE NASU, UHU, CSIC, UNITIBLISI, UoP and CIIM.

Research was initiated with the investigation of the complex links between ecosystem functions/services and human (direct and indirect) uses of them - as manifested in the chosen SES goods and services. Upon completion of the review on the definitions of ecological goods and services and classifications of ecological functions, participants focused on specific aspects of marine ecosystem functions. For example, an identification of the main attributes supporting fisheries was carried out on the basis of a bibliography search of the literature on studies relating ecosystem functions or attributes to fish stocks in Mediterranean and Black Seas. As a result, the most effective functions at providing biomass in the Alboran Sea and the north-western Black Sea have been evaluated: enrichment, concentration and retention processes. From a policy perspective, it is imperative to have a clear idea about the ability of marine ecosystems to absorb the stress from human appropriation activities. Therefore, the identification, use and utility of ecological thresholds in biodiversity conservation were examined. The resilience and the reversibility response, the non-linearities, as well as the uncertainty in predictions and threshold interactions are considered the main threshold attributes. Furthermore, stakeholders' information is an important factor influencing thresholds knowledge in policy making.

A comprehensive scoping and policy analysis of selected case sites in Mediterranean and Black Sea was conducted, thereby identifying major policy issues and validating the choice of fisheries, tourism, biodiversity and carbon sequestration as key (market and non market) goods and services. The analysis was based on the DPSIR framework and focused on the case study areas (Alboran Sea, Gulf of Lions, East Levantine Basin and Eastern Black Sea) exploring the selected issues by using available data in an attempt to describe the links in the cause-effect hierarchy

and, in particular, to identify the causes of ecosystem change over the past decades. It became clear from this exercise that human activities in the SES region have impacted coastal and marine ecosystems but it is also evident that there are problems with the availability of data in many areas, which undermines the understanding of the systems and consequently hinders the development of quantitative models. The lack of data availability is particularly apparent in countries outside the EU and efforts should be made to improve and coordinate data collection and accessibility throughout both regional seas.

The scoping study has also shown that the implementation of laws and regulations is often only partial, frequently because of the lack of a clear monitoring and enforcement strategy, but also because of the governments' financial and capacity constraints. The inherent complexity of marine ecological systems, which hinders full understanding and creates uncertainty regarding the effects of interventions combined with the diversity of economic, cultural and social conditions across the region, present enormous challenges for regional sea management. Finally, there is evidence that the fragmented approach to marine and coastal governance that has been the characteristic paradigm of past decades is being superseded by a more integrated, coherent and inclusive approach. Effective governance is fundamental to the protection of the ecosystems that provide the goods and services in the SES region. This fact is being increasingly recognised by supranational institutions such as the UNEP, UNDP and the EU, as well as individual states that understand the need for cooperation and consensus in maintaining marine ecosystems. The emerging EU maritime policy and the Marine Strategy Framework Directive could provide a template for the future governance of the Mediterranean and Black Seas as well as other regional seas.

Regarding the stakeholder analysis, the methodology followed is an extension of Power/Interest Matrix to include attitudes and influence. This approach classifies stakeholders in relation to the power that they hold and the extent to which they are likely to show interest in the strategies of the SESAME scenarios for future change. SESAME research has identified and categorized 217 stakeholder groups including networks in the countries of interest (28 international, 121 national and 68 local stakeholders). The application of the weighting scheme led to the identification of 22 key stakeholder groups, which were further analyzed. The final results of the categorization was concluded with the identification of the extent of stakeholder involvement; stakeholders were divided in three groups: Group 1: those who have highly positive or negative attitudes and high power (should be involved in decision making); Group 2: those who have moderately positive or negative attitudes and medium power (should be consulted); and Group 3: those who have moderately positive or negative attitudes and low power (should be informed).

The socio-economic research has quantified, in economic terms, the losses of social welfare expected from the degradation of Mediterranean and Black Sea marine ecosystem by addressing:

a) The non-market valuation of critical marine habitats, the appearance of jellyfish outbreaks and the loss of biodiversity in a choice experimental framework.

b) The total economic value of carbon sequestration in SES in a benefit transfer framework.

c) The social value of preserving fish stocks in the SES, in a market analysis framework.

The usefulness of such monetary estimates lies in their ability to signal otherwise undetected economic losses and policy failures in cases where the rate of use of global commons exceeds the sustainability threshold. Five stated preference surveys were implemented in the NW Black Sea, the Levantine Sea (SE Turkey and Cyprus), the Northern Aegean and the Gulf of Lions.

The valuation of biodiversity in the SES marine ecosystems has been approached from three different aspects (species abundance, number and distribution of invasive species, preservation of marine critical habitats) in two case sites (Levantine Sea and NW Black Sea) with the implementation of the combined Contingent Valuation Survey (CVS) and Choice Experiment (CE). Similarly, the combined CVM and CE have been applied to valuate the ecosystem functions supporting tourism (water clarity and jellyfish outbreaks in two study sites, the NW Black Sea shelf and the Gulf of Lions). Moreover, a market assessment Stochastic Frontier Analysis (SFA) of fisheries in the Alboran Sea and Northern-eastern Black Sea (Georgia) has been conducted. Finally, a basin wide benefit transfer exercise for carbon sequestration has been completed, thus estimating the costs of GHG emissions under different energy evolution paths in 2020, 2030 and 2050 based on cost-assessment for $CO_2$ and with the help of Integrated Assessment Models (IAM).

Alternative scenarios (Policy-Targeted (PT), Deep Blue (DB) and Baseline (BAU)) were constructed along two divergent themes on the premise that the extent to which the Ecosystem Approach is articulated in European integrated and cross-sectoral policy is not fully known, to cover SESAME's needs. These scenarios were then implemented at a catchment level, in order to explore future changes in land-based nutrient inputs into the SES, as well as for fisheries in close collaboration with modellers.

Finally, the scenarios along with all valuation estimates of tourism, fisheries and carbon sequestration were incorporated into the adapted regional macroeconomic model GTAP (Global Trade Assessment Project), where the welfare losses in the SES countries in the scenarios were estimated.

A choice experiment (CE) was designed and implemented to investigate tourist and local preferences for a marine rehabilitation program that would improve bathing water quality and biodiversity and reduce the risk of contracting water-related diseases in the Turkish and Ukrainian coast of the Black Sea. In the Gulf of Lions, a choice experiment was designed to value the protection of critical marine habitats and avoidance of jellyfish outbreaks. Similarly, another valuation study, aimed at valuing marine resilience as a joint outcome of preserving critical marine habitats and indigenous species, was also conducted (Levantine Sea).

The results of the choice experiment valuations were based on the conditional logit model (CLM) estimation. The CLM estimations revealed that all attributes included in the definition of the valuation scenarios are highly significant determinants of respondents' utility. The positive coefficients on the water quality, biodiversity and health risk reduction attributes indicate that these attributes contribute positively to the respondents' well-being. The Marginal WTP for an increase to the covered area of critical habitats from – 20% of current cover levels to an increase of 20% is estimated at 43.44€ (21.17). The MWTP for the decrease of marine alien species from more than 50% to 10% of total species is estimated at 93.94€ (26.72). Respondents express higher MWTP in order to avoid the expansion of alien species than the protection of critical habitats. The results could be used for the development of marine policy scenarios, in order to inform policy makers about the values of marine ecosystem services.

The valuation results of the choice experiment in the Gulf of Lions were also based on the Multinomial Logit model (MNL) with main effects of attributes only. The estimations show that the attributes of 'marine biotopes' and 'jellyfish outbreaks' are significant for respondents. The positive coefficients of attributes indicate that consumers are willing to pay to improve the situation. On the other hand, the negative coefficient of cost is consistent with economic theory. For the attribute 'important biotopes' the average WTP is estimated at 29.65€ in order to prevent 20% decrease and gain 20% of important biotopes area in 20 years compared with today's levels.

Respondents are also willing to pay an amount of 19.14€ to reduce the probability of jellyfish outbreaks from 0.9 to 0.1 for two decades.

The valuation study aimed at valuing marine resilience as a joint outcome of preserving critical marine habitats and indigenous species. Modelling of changes in 20 years was a difficult task because of the dynamics and the complexity of phenomena. Since no models were available for the quantitative projections of the impact of loss of habitats and invasive species, attributes' levels were based on experts' opinion. In this context, experts predict that in the business as usual scenario (BAU) the covered area of critical habitats will decrease approximately by 20% relative to current area, a realistic policy target (PT) scenario should focuses to a 5% increase of critical habitats cover area; while a deep blue (DB) scenario should be targeted to a 20% increase of critical habitats cover area, respectively. The amount of invasion of alien species counts less than the half of native species. The BAU scenario predicts an increase of alien species to count more than native species. The PT scenario could be targeted to a decrease alien species to current level, while a DB scenario could be targeted to decrease alien species to a number smaller than 10% of native species.

Referring to fisheries, the methodology of Stochastic Frontier Analysis (SFA) for the valuation of selected function(s) supporting fisheries in the Strait of Gibraltar, Alboran Sea and the NE Black Sea has been implemented. The main objectives were the market valuation of commercial fisheries and an insight on the potential impact of global warming on fisheries value.

A relationship between the stock and captures of a fishery, and ecosystem functions for the anchovy fishery of the Northern Alboran Sea (NAS) and the red sea bream fishery of the Strait of Gibraltar, have been established through bio-economic modelling. Additionally, for the same stock and areas, the relationship between the vessel captures and the ecosystem functions has been modelled through Stochastic Distance Function Analysis. These bio-economic models have provided empirical results supporting that the ratio of summer and winter SST has a significant influence on the evolution of the exploited stock of anchovy fishery in NAS and that the mean Spring SST lagged two periods has a significant influence on the evolution of the exploited stock of red sea bream fishery in the Strait of Gibraltar. Both models also allowed a forecast of the aggregated capture of the fleets that exploit the aforementioned fisheries. The work verified the impossibility of applying a seasonal fisheries management policy based on the quantification of the Maximum Sustainable Yield (MSY), avoiding biological overexploitation without considering the evolution of marine environment conditions. It has, thus, been concluded that an adaptive management framework that accounts for the evolution of marine environment factors is needed for both fisheries.

Referring to the valuation of carbon sequestration, the costs of GHG emissions under different energy evolution paths in 2020, 2030 and 2050 have been estimated based on cost-assessment for $CO_2$ and with the help of Integrated Assessment Models (IAM). Satellite-driven data have been translated to monetary values under the two selected approaches: with the Tavoni 20$/tonC value (the benefit of reducing emissions) and with the upper-bound CASES value of 96.1$/tonC, which tries to account for long-term benefits (here targeted at the year 2050, assuming similar carbon sequestration performances as today).

The results of the valuation of carbon sequestration showed that the Mediterranean as a whole is worth more than a billion dollars as a sink of $CO_2$ according to the SESAME measurement, whereas the range of the estimates is between 17,6 to 84,5 million Euro. The economic valuation of this ecosystem service will be heavily dependent on the modelling conditions and respective assumptions that characterize the Air-Sea $CO_2$ fluxes. A major concern about these results is that they neglect the absence of measurement of carbon fluxes for the whole year in some seas.

The alternative scenarios were constructed along two divergent themes on the premise that the extent to which the Ecosystem Approach is articulated in European integrated and cross-sectoral policy is not fully known. These two scenarios represent the extremes of a continuum that span the range of possible futures originating from very different conceptual constructs. In doing so, it is hoped that these extreme scenarios can be used to demonstrate the alternatives in terms of the possible future for SES. The main differences between the two alternative scenarios are the global vs. localized scale that the economic and governance structures operate on and the technocratic vs. communitarianism. This leads to different futures, although both are concerned about the balance of economic, social and environmental objectives: Policy-Targeted (PT) concerns the application of formulaic EU-wide regulations and harmonization of standards across a strengthening and expanding bloc while Deep Blue (DB) is a Europe of regions. The outcomes by sector show different patterns, though with less deviation for the main sub-regions, but overall with reduced pressures compared with the Baseline (BAU) scenario.

These scenarios were implemented at a catchment level to explore future changes in land-based nutrient inputs into the SES and also for fisheries in close collaboration with modellers. Different approaches were taken for each issue but they were both consistent with the overall scenario framework developed here. A comparison of the conceptual basis underpinning the MEA and SESAME scenarios was carried out together with an investigation of the assumptions for their implementation in the global IMAGE model and how these aligned with the SESAME scenarios. Some modifications of the scenarios were necessary to render them fit for use in this project and suitable for the geo-political context of the SES. There are limitations with this approach in that there may be some degree of overestimation of the human-derived N and P component that is discharged to rivers, but overall there was good agreement with both the conceptual basis and the indicators of sectoral activities between the SESAME and MEA scenarios. On the other hand, a detailed narrative was constructed for the fisheries sector for each scenario in order to elaborate the changes to the management systems that would likely occur.

The scenarios, along with the valuation estimates of tourism, fisheries and carbon sequestration were incorporated into the adapted GTAP (Global Trade Assessment Project) regional macroeconomic model. The model has been calibrated to 2050 following the IPCC A2 scenario. The instrument for the assessment is a Computable General Equilibrium (CGE) model, tailored to the Mediterranean and Black Sea economies. The model thus allowed understanding the magnitude and the direction of both economic and environmental shocks with respect to a reference scenario on the most relevant economic variables, such as GDP, welfare, commodities demand, change in international trade and allocation of investments throughout the world.

Analysis showed that the GDP effects of changes in fish catch potential are modest. They range from a slight gain (+0.04%) for Greece to a -0.02% loss for Tunisia. However, they are more pronounced if the analysis focuses on the fishery sector production ranging from the almost -5% of Slovenia to the +3.5% of non-Mediterranean Europe. In the case of changes in ecosystem/biodiversity attractiveness, GDP changes are generally negative, but not always. The maximum loss of the -0.3% is recorded in Albania, the maximum gain, of 0.03%, in Malta. The Mediterranean area seems clearly more penalized than the Black Sea one: annualized losses range from $ 3773 to $ 6835 million in the first and from $ 259 to $ 1271 million in the latter.

Data management

Data collection, manipulation and archiving are the foundations of SESAME's data management. Data management has been one of the cross cutting themes through the project in

order to improve the data storage, access and manipulation. To this end, the appropriate tools for uniform digitisation of historical, newly observed, as well as data sets generated by mathematical models, have been developed to suit researchers' needs in close collaboration with experimentalists and modellers.

Partners involved: IOLR, HCMR, IMS-METU, IBSS, IMC, UCY, IFREMER, CLU, MHI and Uni-HB MARUM

Effective data access has been achieved through the development of SESAME-oriented multiparametric databases (CAST, SERIES, MODELS and BIOLOGY), which support web-based interface as well as standalone interface. Web-based interface includes tools for analysis of time/space data distribution (interactive map, interactive timetable) and tools for data import/export. Offline interface provides standalone utilization of databases and, in addition to tools for metadata analysis, includes tools for scientifically oriented exploration and analysis of the data: various selections, scalable quality control, gridding, visualization and statistical processing.

The SESAME Data Management website is fully operational, providing all the necessary services and facilities for data submission, access and exploitation under the SESAME Data Policy regulations and restrictions (stipulated for this reason).

To achieve these tasks, the necessary quality control structures and vocabularies as well as the relevant software have been developed or adapted to suit SESAME's needs. By doing so, SESAME Data Management succeeded in providing ready access to most of SESAME data and information to the SESAME consortium as well as to the international scientific community.

The online facilities of SESAME_CAST (which contains vertical observed profiles of physical, chemical and biological data), SESAME_SERIES (hydrophysical and hydrochemical data observed in the form of time series), SESAME_BIO (containing taxonomy-related data) and SESAME_MODEL (containing time series extracted from output of numerical simulations) databases promote interactive time-space analysis of data distribution and download selected datasets (following the regulations and restrictions of the SESAME Data Policy) in a format which is useful for further analysis by ODV or commercial packages like SURFER, GRAPHER, EXCEL and MATLAB. Publicly available data from the SESAME_CAST database can be downloaded and investigated also as standalone MEDACC database with the oceanographic interface "Hydrolog".

The Database will be the legacy of SESAME to the scientific community for its future needs. It has been decided that the database will not expire with the end of the project. SESAME will collaborate with PANGAEA so that SESAME data will be disseminated to the broader community, including the international scientific community, industry, educators, media and the public, following the rules stipulated in SESAME's Data Policy. The relevant agreement has been signed and in April 2013, this data will become available to all users. Furthermore, NOAA's National Oceanographic Data Centre - World Data Centre for Oceanography will produce a Regional Oceanographic Atlas of raw and climatic data for the Mediterranean and the Black Sea, based on the data collected and organized by SESAME.


## Capacity building, Training and Public Outreach

Beyond science, SESAME has committed to improve capacity building, training, dissemination of results and public outreach, integrated into one information platform. SESAME has successfully set in action activities fostering cooperation among Black sea and Mediterranean

scientific communities, thereby providing opportunities for mobility of researchers, training of PhD students, Graduate and Post-Graduate opportunities, organization of summer schools and additional professional training (workshops and *ad hoc* training).

During its life span, the project organised two Summer schools. The first one, on 'Statistical Analysis of Biological data and Times-Series', organized by IO-BAS, was successfully held in Varna, Bulgaria, in 2008, while the second one, on 'Coupled ecological Modelling' was held in Malta, in 2009, with the participation of 40 young scientists and PhD students from 13 countries around the Mediterranean and Black Sea regions. In the Malta Summer School, the Black Sea Commission and CIESM contributed resources for additional participants. Furthermore, 19 PhD students and a number of young researchers were supported by the Project in their participation in specially organized workshops (Training Workshop on Plankton, International Workshop on the use of Zooscan) and intercalibration exercises (Mesozooplankton Taxonomy Intercalibration Workshop, Intercalibration cruise onboard of R/V *Akademik*, Intercalibration workshop on sampling techniques and analysis of key parameters) *ad hoc* field and lab training and knowledge transfer through enhanced collaboration. The mentoring scheme for young researchers was an efficient means to promote enrolment of young scientists in the scientific community during important Scientific Conferences. Additionally, during the three SESAME Scientific Conferences, special sessions for PhD students were organized, thereby providing them with the opportunity to present their work while stimulating interactions between young scientists and fostering fruitful co-operations between the different generations of scientists. Overall, these activities contributed significantly to the strengthening of the scientific potential and capacity building, highly crucial for the research regions in question.

Regarding education, SESAME has reached out to school children and has invited them to take part in its research activities. This was thoroughly embedded in SESAME's strategy from the very beginning, and it has been accomplished through activities such as the 'participation' of schools in the 'Unluata Cruises', in March-April 2008 (either through online visits while the cruises were in progress or through visiting the vessels before departure), as well as school competitions. The School outreach program was completed during the second round of school competitions, which attracted the attention of 18 classes from 6 countries. Teaching aids, including print materials about the marine environment and climate change were prepared and made available on the website or distributed in person where possible. The competition raised the interest of schoolchildren in marine research, increased awareness on human impacts and global climatic changes on the marine environment and was perceived very positively by the teachers. The 'SESAME Club', which originated in Bulgaria through the collaboration between researchers and the Gymnasium for Natural Sciences initiated by the project, was one of the most positive and encouraging outcomes of the educational programme. Moreover, part of the Italian cruise was filmed by a professional TV crew, and the resulting documentary was shown at the 'Festival of Science' in Genoa (Italy, 2008). Even if not fully successful, some progress has been achieved through the education and dissemination activities with the help of the aquaria network. A full documentary about SESAME was shown in the Greek Television (SKAI TV) in July 2011, with subtitles, trying to capture the complexity and the results of the project to a nation-wide audience.

One of the major aims of SESAME regarding 'Dissemination and Public Outreach' was to communicate its scientific and policy aims to the stakeholders and decision makers regarding environmental and socio-economic issues. In order to accomplish this task, WP8 worked together with WP10 to organise three Stakeholder Forums, involving representatives from the political and economic sectors, environmental foundations, and non-governmental organizations,

as well as representatives from the tourism industry. The main purpose of these open forums was to introduce and inform all parties about the current environmental policies that are designed to protect the Mediterranean and the Black Seas with emphasis on the local area where the Forum was held, and to further promote the exchange of ideas and opinions on how to best protect these marine environments. The forums attracted a lot of media attention, and articles on news websites and newspapers were published, aiding further the promotion and dissemination of project results.

The Project has achieved substantial media coverage at both national and European levels, while the results have been disseminated to a large audience of end-users and the public through more than 30 events (newspaper articles, TV and radio broadcasting, media briefings and round tables, public lectures, exhibitions, and presentations). In addition, a documentary and a documentary series have been completed showcasing SESAME's activities (July 2011). A short film was produced presenting brief interviews by all WP leaders, with emphasis on the main findings, and highlights of the latest research developments. The three Newsletters produced after the first year, include research highlights, results of meetings and workshops, while they were widely distributed among partners as well as outside the project, to the wider scientific community, as well as country and regional policy officials. This also aided in raising the public awareness on important, current topics related to the SES goods and services.

Scientific achievements were widely disseminated among the scientific guild - published up to July 2011 in about 80 peer reviewed papers, reported in more than 230 conference presentations and 140 scientific forums (not including SESAME's annual Forums).

The Project's interactive website for both partners and the general public set off at the very beginning as one of central communication nodes, while it has been effectively upgraded, regularly updated and kept up to date with the latest project developments, meetings, presentations and relevant photos. During the final year, the website has been restructured as a back-office website, with plenty of storage space where presentations and photos from the SESAME Final Scientific Conference have been uploaded, and information on project developments is freely and easily accessible. The site will remain online for two years after the project's end. Since April 2010, and up until the project's end, the website counted more than 14,480 visits, while 72% of these visits were from new visitors. Overall, visitors came from 152 countries around the world, while most visits came from Greece, Italy, France and the USA respectively.

All SESAME partners have developed first-rate communication and collaboration skills, needed in order to work in a more integrated manner towards achieving the project aims and objectives, while, overall, the project was successful in establishing and stimulating effective lab and team networking for the future research and protection of SES environment.

## Dissemination and Use

Publishable results are reflected in SESAME's Publications

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