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Assessment of Climatic Change Impacts on Coastal Zones in the Mediterranean. UNEP's Vulnerability Assessments Methodology and Evidence from Case Studies

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ASSESSMENT OF CLIMATIC CHANGE IMPACTS ON COASTAL ZONES IN THE MEDITERRANEAN. UNEP'S VULNERABILITY ASSESSMENTS METHODOLOGY AND EVIDENCE FROM CASE STUDIES

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1. INTRODUCTION

Realizing the potential threat of predicted climatic changes to marine and coastal systems, the then Oceans and Coastal areas Programme Activity Centre of the United Nations Environment Programme (UNEP), in cooperation with the Intergovernmental Oceanographic Commission (IOC) of UNESCO, launched, in late 1987, a systematic approach to assessing the likely impacts of climatic changes in the geographical areas covered by the UNEP-sponsored Regional seas Programme. Therefore 11 task teams had been established for regions covered by the Programme (Mediterranean, Caribbean, South Pacific, East Asian Seas, South Asian Seas, South-west Pacific, West and Central Africa, Eastern Africa, Persian/Arabian Gulf, Black Sea and Red Sea). The task of the teams was to assess the environmental, economic and social problems of coastal seas and the adjacent terrestrial areas that are likely to follow on the heels of predicted climatic changes, and to identify suitable response measures and policy options that may be adopted to mitigate or avoid the negative impacts of these changes.

During the work on the Mediterranean regional study (UNEP, 1989a) carried out between 1987 and 1989 by UNEP's Co-ordinating Unit for the Mediterranean Action Plan (MEDU), it was felt that, although the general effects might be similar throughout the Mediterranean region, considerable differences in the impact of climatic changes could be expected at different sites, and that, consequently, different response options would be required. Moreover, it became clear that, as in the case of global predictions, regional predictions may be used only for general policy guidance and that only site-specific studies could lead to practical management and policy decisions and actions of relevance to each particular location.

This is particularly true when assessing the impacts of future climatic changes given the influence of local geographic factors on rainfall and temperature patterns and microclimate, and in the case of sea level where tectonic movements, sediment compaction and extraction of oil, gas and usually water may result in local sea level changes several orders of magnitude greater than the predicted global mean sea level rise.

Therefore, in the framework of the Mediterranean regional study, six site-specific case studies were prepared during the period 1988-1989 on estuarine systems, like deltas of the rivers Ebro, Rhone, Po and Nile; Thermaikos Gulf and Ichkeul/Bizerte lakes). The final results of this work were published by Jeftic *et al.* (1992).

As a follow-up to the studies completed by 1989, a "second-generation" of five Mediterranean site-specific studies was prepared during the period 1990-1993 (Island of Rhodes (UNEP, 1994a), Kaštela Bay (UNEP, 1994b), the Syrian coast (UNEP, 1994c), the Maltese Islands (UNEP, 1994d), and the Cres-Lošinj archipelago (UNEP, 1994e), a "third-generation" of three studies was launched (Fuka-Matrouh region in Egypt, the Albanian coast, Sfax region in Tunisia) in the framework of the wider, Coastal Areas Management Programmes (CAMPs) of the UNEP-sponsored Mediterranean Action Plan. Since then, an effort is being made to include, when feasible, climatic change studies in the framework of relevant CAMPs.

This is an overall presentation compiling the results and experience gained through the Mediterranean regional study. The methodology of 14 completed first, second, and third-generation site-specific case studies in the Mediterranean region is reviewed (Jeftic et al. 1996).

2. THE CASE STUDIES

2.1 Methodology

2.1.1 First-generation case studies

In the absence of a generally accepted and tested methodology that could have been applied in a practical way to the development of the six, first-generation case studies on estuarine environments (deltas of the rivers Ebro, Rhone, Po and Nile; Thermaikos Gulf and Ichkeul/Bizerte lakes) completed by 1989, they were based on a set of general principles, assumptions and a good deal of common sense, taking into account the best available assumptions on the possible consequences of the predicted climatic changes and the evolving scenarios resulting from the work of the UNEP/WMO Intergovernmental Panel on Climate Change (IPCC).

Three of the six case studies were prepared by individual experts, one by collaboration of two experts, familiar with the study area. The remaining two studies were prepared by the UNEP staff with the assistance of 9 and 24 co-workers, respectively.

The studies were expected to have three recognizable components:

- a general description of the environment and the environmental conditions of the study area, as well as the socio-economic structures and activities that may be affected by climatic change;

- an assessment of the likely effect of expected climatic changes on the environment, man-made structures and economic activities; and

- a summary of the major conclusions with recommendations for possible actions that may mitigate or avoid the identified potentially negative impacts, or measures that may ease adaptation to these impacts.

Data already available from various sources were used as the basis for the studies and no new research was conducted during their preparation. As background to the preparation of the studies, a bibliography containing more than 1500 references on the effects of climatic change and related topics was compiled and published (UNEP, 1989b).

In preparing the first-generation case studies it became apparent that the assessment of likely impacts was constrained by the absence of scenarios of future climates on a regional, subregional and local scale. Therefore, the Climatic Research Unit of the University of East Anglia (CRU/UEA) was commissioned by UNEP to attempt to produce a Mediterranean basin scenario and to develop scenarios of future local climate for the selected case study areas.

The scenario covering the Mediterranean basin (Palutikof *et al.*, 1992), and the more focused sub-regional and local scale scenarios, were completed only after the first-generation case studies themselves completed. Therefore, the assumptions concerning the magnitude and rate of climatic change used in the Mediterranean regional study and in the first-generation site-specific studies were those accepted at the UNEP/ICSU/WMO International Conference in Villach, 9-15 October 1985, i.e., increased temperature of 1.5-4.5°C and sea level rise of 20-140 cm before the end of the 21st century (UNEP/ICSU/WMO, 1986). For the time-horizon of the year 2025 (the time at which a greenhouse gas concentration equivalent to a doubling of pre-industrial CO_2 levels was deemed likely to have occurred), a temperature elevation of 1.5°C and sea level rise of 20 cm were assumed.

2.1.2 Second-generation case studies

Using the experience of the first-generation case studies, the preparation of five second-generation site-specific case studies (Island of Rhodes; Kaštela Bay; the Syrian coast, the Maltese islands; and the Cres-Lošinj archipelago) was initiated in 1990. The preparation of these studies was entrusted to national multidisciplinary task teams with relevant local knowledge and experience, established and guided by UNEP/MEDU, in close co-operation with the relevant national authorities. Each team was led by a national co-ordinator, and consisted of about ten national experts and a few (2-3) external members who assisted the overall work of each team.

At a preparatory meeting, each of the teams was briefed by the external members of the team on:

- IPCC's most recent scientific assessment of the anticipated magnitude and rate of global climatic and sea level change;
- the regional Mediterranean scenario of climatic change and the more specific subregional temperature, precipitation and sea level change scenarios relevant to the particular study area; and
- the main impacts that could be expected to result from climatic change. At the same meeting, the objectives and contents of the study were determined, and specific tasks assigned to each member of the team. Although individual members of each team had specific tasks assigned to them, the studies finalized by each team are the collective work of the team as a whole.

The overall objectives of the studies were identified as being:

- to identify and assess the possible implications of expected climatic change on the natural and man-made terrestrial, aquatic and marine ecosystems; population, including public health and demographic changes; land- and sea-use practices; coastal structures; and economic activities and development plans;

- to determine the areas, systems, structures and activities that appeared to be most vulnerable to the expected climatic changes; and

- to suggest policies and measures which may reduce, avoid or allow adaptation to the negative effects of the expected impact through changes in planning and management of coastal areas and resources.

These objectives were expected to be met using the presently available data and assumptions, and the best possible extrapolations from these data and assumptions. No research generating new data was carried out under the studies, although some existing data-sets were re-analysed and synthesized, to examine evidence for past trends.

Assumptions used in the studies were those accepted by the Second World Climate Conference, i.e., an increase in temperature of 2-5^{o}C, and a sea level rise of 65 $\pm$35 cm by the end of the 21st century (UNEP/WMO/ICSU, 1990), as modified by the regional and the relevant sub-regional scenarios prepared by the CRU/UEA, and the information available on local tectonic trends. The CRU/UEA scenarios for temperature and precipitation were based on the combined output of four general circulation models, statistically correlated with meteorological records from the Mediterranean basin. Although, generally, these scenarios indicate that in the Mediterranean basin the temperature change due to the greenhouse effect would be similar to the changes in global mean temperature, scenarios also show that the coastal regions, particularly in the north, are zones of very rapid transition, which emphasizes the need for the highly detailed scenarios. Regarding precipitation, scenarios indicate that it would probably increase in autumn and winter, but decrease in summer, particularly in the eastern Mediterranean.

In preparing the studies, increased air and sea-surface temperatures, and changes in local climate and weather (patterns of rainfall and winds in time and space; geographic distribution, intensity and frequency of storms) were taken into account as first-order impacts resulting from climatic changes. Consideration was also given to second-order impacts, such as changes in: relative humidity, runoff and river flow rates; soil conditions, coastal biome distribution, coastal currents, wave regimes and sea water stratification and mixing; location and/or persistence of oceanic frontal systems; salinity and coastal water chemistry; patterns of coastal flooding and other episodic events; and human health and comfort.

Special consideration was given to the potential social and economic impacts of:

- changes in precipitation and temperature patterns modifying relative humidity and altering evapotranspiration rates, and thus likely to affect: the hydrological cycle and local water balance; animal distribution and abundance, including pests and disease vectors; productivity of natural and agricultural systems; soil decomposition processes and fertility; human drinking water supplies; freshwater management practices; and coastal marine ecosystems, fisheries productivity and mariculture through changes in salinity and mixing of coastal waters; and

- changes in sea level, which may lead to: increased frequency and intensity of flooding, as well as increased inland extent of flooding; rearrangement of coastal unconsolidated sediments and soils; increased soil salinity in areas previously unaffected; changed wave climates; accelerated dune and beach erosion; upward and landward retreat of the boundary between freshwater and brackish waters; greater upstream intrusion of saltwater wedges; shifts in bank and wetland vegetation; changes in the physical location of the terrestrial-aquatic boundary, changes in coastal water clarity, coastal water circulation patterns and in sediment sink volumes; modification of offshore bottom profiles; changes in Marin and coastal terrestrial productivity; and alterations in sediment and nutrient flux rates, with consequent changes in marine primary production.

UNEP's guidance and co-ordination ensured that the structure and contents of the studies were harmonized in order to facilitate the comparison of the findings on a Mediterranean scale.

The main findings, conclusions and recommendations of the case studies were presented and reviewed by a meeting of experts (Malta, September 1992) drawn from all five task teams (UNEP, 1992). The meeting proved to be very useful in providing the opportunity for a strong interaction between the task teams and for the comparison of their results. This led to a more balanced assessment of the relative significance of the impacts identified in the individual studies. As a consequence of this interaction, a number of conclusions and recommendations contained in the individual studies were revised or presented in a new, more sharply focused context, thus making them more useful for policy makers and managers.

2.1.3 Third-generation case studies

The third-generation case studies (the Fuka-Matrouh region in Egypt, the Albanian coast and the Sfax region in Tunisia) follow the methodology adopted and used for the preparation of the second-generation studies. The only changes were:

- that of setting the years 2030 and 2100 as the time horizons for the assessment of the impacts;

- that the studies were prepared in the wider framework of CAMPs for management and planning of land-use and the use of resources in the same geographic areas/sites in the conditions of climatic change; and

- the use of assumptions as presented in 1992 to IPCC (IPCC, 1992), i.e. a global temperature elevation of 0.3°C per decade, scenarios of elevated global temperatures of 0.9°C and 2.5°C were adopted for the year 2030 and 2100, respectively, as modified by the relevant subregional or local-scale scenarios prepared by the CRU/UEA; a global sea level rise of 16 cm by 2030 and 48 cm by 2100 was assumed on the basis of Wigley and Raper's analysis (Wigley and Raper, 1992), as modified by the available information on local tectonic trends, land movements and past trends in relative sea level.

- The objectives of the studies were broadened by the addition of three specific items:

- to formulate recommendations for planning and management of coastal areas and resources, as well as for the planning and design of major infrastructures and other systems;

- to provide an input into other projects and developments relevant to the subject of the study; and

- to provide useful information for policy and decision makers, managers, economists, and the general public.

3. COMPARATIVE ANALYSIS OF THE MAIN FINDINGS

3.1 Potential impacts of expected climatic changes on natural systems and socio-economic activities

Table 1 summarizes the major potential impacts of climatic changes identified in the case studies analysed in this paper.

Not surprisingly, increased erosion of unstable or presently threatened parts of the coastline, inundation of coastal flatlands, loss of wetlands, and salinization of lagoons and coastal lakes, were singled out as the most probable negative consequences of climatic changes common to the four studied deltaic regions and the Thermaikos Gulf. A combined impact of relative sea level rise, decreased water and sediment flows, and the likely increased frequency and intensity of storms and waves were perceived as the principal factors contributing to these effects.

Salinization of aquifers due to sea level rise was identified as potentially the most important impact of climatic changes common to all studied islands, Kaštela Bay, Sfax, Albania and the Syrian coast. Due to hydrological processes occurring at a distance from the coast reducing recharge to important water bodies such as lake Vrana, salinization may not be restricted to coastal aquifers. Reduced ground water recharge to this lake may enhance saline water penetration.

Superimposed on these widespread effects would be the specific impacts on: agriculture and fisheries (e.g. in the deltas of Ebro, Nile and Rhone); coastal infrastructures and harbour installations; functioning of gravitational sewerage systems of settlements barely above the present mean sea level (e.g. Split) coastal defence systems (deltas of the Po and Nile, Thermaikos Gulf); and monuments of historic and artistic importance (e.g. Venice, Rhodes and Osor on Cres).

Table 1 *Major potential impacts identified in the studies*

Delta of Ebro Spain	Increased coastal erosion; reshaping of coastline; loss and flooding of wetlands; reduced fisheries yield
Delta of Rhone France	Erosion of unstable or threatened parts of coastline; reduction of wetlands and agricultural land; increased impact of waves; increased salinization of coastal lakes; destabilization of dunes; intensified tourism
Delta of Po Italy	Increased flooding and high-water events; increased coastal erosion; retreat of dunes; damage to coastal infrastructure; salinization of soils; alteration to seasonal water discharge regimes; reduced near-shore water mixing and primary production; increased bottom water anoxia
Delta of Nile Egypt	Increased coastal erosion; overtopping of coastal defenses and increased flooding; damage to port and city infrastructure; retreat of barrier dunes; decreased soil moisture; increased soil and lagoon water salinity; decreased fisheries production
Ichkeul-Bizerte Tunisia	Increased evapotranspiration leading to decreased soil moisture, reduced lakes fertility and enhanced salinity; increased salinity of the lakes and shift to marine fish fauna; reduced extent of wetlands and loss of waterfowl habitat
Thermaikos Gulf Greece	Inundation of coastal lowlands; saline water penetration in rivers; drowning of marshland; increased sea water stratification and bottom anoxia; decreased river runoff; salinization of ground water; decreased soil fertility; damage to coastal protective structures; extension of tourist season
Island of Rhodes Greece	Increased coastal erosion; salinization of aquifers; increased soil erosion
Maltese Islands Malta	Salinization of aquifers; increased soil erosion; loss of freshwater habitats; increased risk for human health, livestock and crops from pathogens and pests
Kaštela Bay Croatia	Inundation of Pantana spring and Zrnovica estuary; increased salinization of estuaries and groundwater; negative impact on coastal services and infrastructure; accelerated deterioration of historic buildings; increase in domestic, industrial and agricultural cultural water requirements
Syrian coast Syria	Increased soil erosion; modification of vegetation cover due to increased aridity; increased salinization of aquifers; erosion of beaches and damage to coastal structures and human settlements due to exceptional storm surges
Cres-Lošinj	Increased salinization of lake Vrana; extension of tourist season; Croatia increased risk from forest fires
Albanian coast	Salinization of coastal aquifers and shortage of adequate quality of drinking water; soil erosion (physical); extension of summer drought; extension of tourist season
Fuka-Matrouh Egypt	Increased evapotranspiration and decreased rainfall; extension of summer aridity; increased coastal erosion; flooding in eastern part; decreased soil fertility
Sfax coastal area Tunisia	Salinization of ground water; increased rainfall; possible flooding

Increased soil erosion and the concomitant decrease in soil fertility would be aggravated in a number of areas (islands of Rhodes and Malta, Fuka-Matrouh, Thermaikos Gulf, Syrian coast). Hazards from forest fires, already a major problem in some areas (island of Rhodes, Cres-Lošinj archipelago), would increase considerably with the predicted increase in the aridity of these areas. The expected increase in the intensity and frequency of episodic events, such as extended droughts and temperature extremes, would affect agriculture, particularly in regions presently stressed by such events (e.g. the delta of Rhone).

The Ichkeul-Bizerte lakes would share many of the problems identified in the deltaic areas, and would experience a considerable shift from their present fresh- and brackish-water to marine flora and fauna. Similar shifts could be expected in deltaic areas with large coastal lagoons and lakes (e.g. lake Manzala in the delta of Nile). These shifts, combined with the potential reduction in the area of wetlands, would significantly affect migratory birds, many of which depend on the availability of suitable Mediterranean habitats for over-wintering and transit areas during their north-south migrations.

Not all the impacts of predicted climatic changes were considered as necessarily harmful. Tourism was singled out in several studies (e.g. the delta of the Rhone, Albania, islands of Rhodes and Malta, Cres-Lošinj archipelago) as one sector of the economy that may potentially benefit from climatic changes, mainly due to the extended duration of the tourist season. Agriculture and aquaculture, aided by modern agricultural techniques, genetic engineering, introduction of new species and cultivation of better varieties of traditionally used species, were also seen as potential beneficiaries of climatic changes in certain areas (the delta of Ebro, Cres-Lošinj archipelago).

Realizing that during the time horizons adopted for the studies, the main driving forces shaping the economies and social changes of the study areas will be only very marginally related to climatic changes, no serious attempt was made in any of the studies to assess the economic or social costs and benefits that may be associated with the impact of climatic changes.

As a consequence of the high uncertainty surrounding the scenarios used in the preparation of the studies, the assessment of impacts in the first-generation studies and, to a lesser extent, also in the second-generation studies, is largely qualitative. For instance, a rise in sea level would undoubtedly enhance coastal erosion but the magnitude of this erosion is difficult to evaluate without precise figures for the rates of change at a local scale. Despite such uncertainty, the case studies clearly indicate that the overriding feature of future impacts of climatic changes will be an exacerbation of existing environmental problems. It was also recognized that these impacts, particularly in the short-term, will be only of minor significance when compared with the impacts caused by non-climate related factors, such as: inadequate freshwater management regimes, and poor land use planning and management, coastal and soil erosion.

3.2 Actions suggested to avoid, mitigate and adapt to the predicted impacts

Table 2 clearly indicates that the first-generation case studies produced recommendations of little value to policy and decision makers since they emphasize the nature and extent of the inadequacies of existing databases, without clearly articulating what the longer term value of such data might be for planning and management of coastal areas under conditions of future climatic change and sea level rise. One study (Ichkeul-Bizerte lakes, Tunisia) made no recommendations or suggestions for response measures whilst the remaining five emphasized the need for better models, improved monitoring, information and databases, risk assessment and response scenario building.

Table 2 Major potential response measures identified in the studies

Delta of Ebro Spain	Basic research on hydrology; detailed mapping and risk assessment; study of coastal processes; establishment of long-term data series; assessment of possible changes in insect pest populations; redefine the Ebro management unit; re-evaluate the existing delta development plans in the light of findings of the case study
Delta of Rhone France	Improved documentation of recent environmental trends; mapping of areas at risk; identification of natural indicators of vulnerability and plants suitable to counter erosion; modelling biological system response under differing environmental conditions
Delta of Po Italy	Creation of information systems; monitoring and modelling of trends; analysis of future trends and preparation of scenarios
Delta of Nile Egypt	Elaborate scenarios of future environmental and socio-economic conditions; establish database for future planning purposes
Thermaikos Gulf Greece	Monitoring of long-term trends; mapping of high-risk areas; readjustment of present flood defenses; possible damming of Thessaloniki Bay and engineering control of water level
Island of Rhodes Greece	Coastal zone management (land use, set-back zones) and readjustment coastal building standards; water resources management and exploration for additional water resources; reforestation; study of the consequences of the changes to tourist season and services in relation to the island economy and population
Maltese Islands Malta	Local and national development plans to take into consideration the possible impact of climatic change; assessment in detail of the: impact of sea (level rise and the local climatic changes on the local aquifers; prevention of soil erosion by maintenance of existing dry stone walls and terrace systems and by planting of trees; assessment of vulnerability of humans, livestock and crops to future increase in pests and pathogens
Kaštela Bay Croatia	Taking into account the findings of the study in ongoing and future construction projects in the region; re-evaluation of existing land-use plans and zoning policies for buildings; revision of major policies and programmes of flood-hazard mitigation measures
Syrian coast Syria	Integrated coastal zone management and planning, which should include development of water management plans, solution to problems of soil and coastal erosion and increased salinization, monitoring programmes and establishment of a data bank on natural and cultivated vegetation
Cres-Lošinj Croatia	Trapping and storage of peak flow of karstic rivers over the Kvarner mainland; artificial recharge of the karstic underground aquifers during the prolonged summer dry season; elevation of coastal defence structures in order to protect valuable existing buildings and structures; periodic revision of physical and urban development plans; assessment of the requirement of the extended tourist season in the light of demand for additional space and services; application of suitable protective measures against forest fires
Albanian coast	Integrated planning of the coastal area; Development of a strategy for the prevention of climatic impacts including a monitoring system and local inventories of impacts
Fuka-Matrouh Egypt	Installation of coastal protection measures in critical areas. Promotion of drought-tolerant vegetation; Fresh water management;
Sfax Tunisia	Preparation of climatic atlas; collection of relevant quality data; management of water resources; Prohibition of agriculture development;

In contrast, the second and third-generation studies generated more concrete proposals for response measures, including the need for changes to codes and standards such as those covering construction and engineering works, and the need to take the identified potential impacts into consideration in the future planning and management plans for coastal areas and resources.

The difference in perspective between the recommendations of the first- and second/third-generation studies reflects, at least in part, the nature of the experts involved in completing the site-specific studies. The first-generation studies were completed on the whole by natural scientists, concerned more with the theoretical basis for impact assessment and the uncertainties surrounding their predictions of future impact, rather than with the day-to-day realities facing coastal zone managers. Managers must respond to the exigencies of present problems and require a clear statement of likely changes and the levels of uncertainty associated with quantitative estimates of change, if they are to assess adequately the comparative costs and benefits of alternative courses of action. By including 'end-users' in the task teams assembled for the second-generation of case studies, the management perspective was incorporated from the outset and hence the recommendations for response measures include many actions that could be immediately acted upon by the responsible authorities and institutions.

4. CONCLUSIONS

Although future global mean temperature can be predicted using global circulation models (GCMs) with a reasonable degree of certainty, local temperature change is more difficult to predict given the strong influence of physical and biological features such as topography, wind, precipitation and vegetation cover. The forecasts of future precipitation on local and sub-regional scales developed for various climate scenarios by the CRU/UEA have significantly higher degrees of uncertainty than do those for temperature. Nevertheless, it is clear from these models and forecasts that significant regional and local variations in extent and magnitude of changes will occur in the Mediterranean basin. Even where the extent of future climatic changes are similar, the nature of the impacts may differ significantly. Reducing rainfall in Malta by 10% would have far greater impacts on the natural environment and human drinking water supply than reducing rainfall by a comparable amount in the Cres-Lošinj archipelago, for example. Similarly, predicted sea level rise will have more significant impacts in low-lying deltas such as those of the Po, Rhone, Ebro and Nile, than in the relatively steep rocky shorelines of Malta, the Cres-Lošinj archipelago, Kaštela Bay and the Syrian coast. The analysis of the 14 Mediterranean case studies amply demonstrates that the impacts will be highly site-specific, and therefore effective adaptation to these impacts should be also eminently site-specific.

For annual mean temperature, the greatest sensitivity to greenhouse warming was shown for the mainland areas to the north-east, and in the south-west. Temperature increases lower than the global mean temperature change were indicated over the islands and southern coast of the Mediterranean Sea. It is important to note that the Mediterranean coast was generally shown to be a zone of rapid transition, emphasizing the need for the detailed scenarios as a basis for the CAMPs. The scenarios for precipitation are much more difficult to evaluate since the confidence that can be placed in sub-grid-scale scenarios of precipitation is low. Areas of increase for annual precipitation are shown to lie mainly over the northern part of the study area, and over the central Mediterranean between Italy and Tunisia.

Potential evapotranspiration is likely to increase throughout the Mediterranean. Coupled with increases in temperature this would lead to an increase in land degradation, deterioration of water resources and, in the long run, may affect agricultural production and practices, as well as natural vegetation and aquatic ecosystems. Exceptional events of drought or rainfall and floods, marine storms, tidal surges, and enhanced coastal water stratification and eutrophication could increase in frequency.

At the level of the case study sites, the smallest annual temperature change is indicated for Sfax and Fuka-Matrouh (0.7-0.8°C by 2030; 2.0-2.3°C by 2100) whilst the greatest annual warming may occur over Cres-Lošinj Islands (1.8-2.0°C by 2030; 3.5-3.9°C by 2100). In the case of precipitation, the scenarios suggest an increase in the annual total for Rhodes, Kaštela Bay and Sfax and a reduction in the case of Fuka-Matrouh and the Syrian coastal region. In the case of Malta and Cres-Lošinj, the scenarios suggest little change. Since summer precipitation is negligible over much of the Mediterranean basin, changes in the annual total are less significant than changes between autumn and winter, and for all case study areas, with the exception for Malta, scenarios indicate an increase in precipitation during the winter. A decrease in summer precipitation, whilst it has little impact on the annual total, may nevertheless have significant effects on plant growth through extension of the summer period of water stress.

The CRU/UEA scenarios represent a considerably improved basis on which to assess the future impacts of climatic change, when compared with the low spatial resolution associated with scenarios constructed directly from GCM output. However, it must be recognized that the uncertainties associated with the resultant scenarios in precipitation are much greater than those associated with the temperature scenarios. Assessing second-order impacts, such as changes in vegetation distribution patterns, evapotranspiration and soil fertility, is further constrained by the fact that the parameters modelled on global, regional and sub-regional scales, whilst they may serve as crude indicators of the direction of change in biological communities, are generally not the key variables determining biotic distribution patterns. Factors such as the length of the growing season, frost occurrence and length of drought periods are generally more significant determinants and reliable indicators of species distribution, reproduction and survival than mean annual temperature or total annual precipitation.

By developing seasonal scenarios for the case study areas, the CRU/UEA has potentially addressed this issue, but even so the climate data required to quantify future biological changes adequately are far from complete. Work on improving the precision of area/site specific scenarios should continue as one of the fundamental pre-requisites for reducing the uncertainties associated with impact assessment. At the same time, work is required in developing scenarios for those climate variables that are considered of critical importance in determining the distribution and abundance of biota and hence, the overall productivity of natural and anthropogenically managed systems.

The physical impact of sea level rise on the Mediterranean lowland, coasts can be predicted, even modelled quantitatively on the basis of the presently available data and information on morphology, hydrodynamics, sediment budgets, land subsidence and the effects of artificial structures. Equally, the impacts of altered rainfall distribution on surface and ground-water could be modelled quantitatively, and the effects of increased air temperatures and changed soil-water parameters on biological systems can be estimated, at least qualitatively, thus providing some idea of impacts on agriculture and fisheries. What is much more difficult to estimate, however, is the impact of these physical and biological changes on the future socio-economic framework of these threatened lowlands, and the future anthropogenic impacts on the environment.

Unfortunately, there are no universally applicable methodologies for the assessment of the risks and benefits that may be associated with climatic changes, and for the determination of the most vulnerable sites, systems or processes. A good deal of common sense, inspired insight, and intellectual intuition, are still among the best, and indeed the only, tools available to scientists, managers and policy-makers.

In spite of the shortcomings in the present approaches to the assessment of climatic change impacts, and the inherent uncertainties underlying the assumptions on which such assessments are based, certain generalized conclusions and recommendations can be drawn from the completed Mediterranean case studies reviewed here.

In the next few decades, the impacts of non-climatic factors, such as population dynamics and present development plans, on the natural, social and economic systems of the Mediterranean, will most probably far exceed the direct impacts of climatic changes. Nevertheless, longer-term changes in climate may contribute quite significantly, particularly along the southern shores of the Mediterranean and at some vulnerable sites elsewhere, to the vulnerability of coastal communities to adverse environmental conditions and impair the sustainable development of coastal areas. The sectors of the economy most likely to be affected may well be tourism and agriculture. Traditional fisheries are already overexploiting the productive capacity of the Mediterranean Sea, and climatic change will probably add little to this stress. Aquaculture may benefit from future environmental changes. Coastal wetlands and low-lying areas, and deltas, may suffer, with consequent effects on agriculture and migratory birds.

The marine and coastal terrestrial environment of the Mediterranean is strongly influenced by climate-driven events and processes, frequently originating at a considerable distance from the site of impact. Examples of such teleconnections include: exchange of water masses through the Straits of Gibraltar; the hydrology of the North Adriatic drainage basin; the structure and movement of Levantine water masses; and the cyclogenesis of the Mediterranean basin.

Expected climatic changes will affect: surface and groundwater flows and river regimes; the availability of surface and ground-water; the incidence of floods and the amounts of sediment and nutrient transported and delivered to the sea; the movement of marine water masses (waves, currents, tides), especially the direction and intensity of storms and of extreme high and low water limits (tidal ranges); natural ecosystems, through increased temperature and its effects on water and soil qualities; and human use of the coastal lowland regions (0-5 m) as a consequence of sea level rise and altered conditions for agriculture, fishing, industry, tourism and environmental quality.

The effects of sea level rise are most predictable even though the extent of sea level rise is difficult to foresee. A global mean eustatic rise in sea level of about 20 cm by 2025 would not, in itself, have a significant impact in the Mediterranean, except locally. However, local sea level changes could be substantially greater than this in some areas because of natural land subsidence, that may be enhanced by excessive groundwater extraction. The negative impacts will be felt in low-lying areas, deltas and coastal cities.

Among the most likely consequences of sea level rise will be: increased direct wave impact on exposed coasts (e.g. the coastal barrier of Venice lagoon, beach resorts of the Rhone delta) and on harbour installations (e.g. Alexandria, Port Said, La Golette-Tunis); increased frequency and intensity of flooding of estuaries, canals and lagoons, with potentially serious consequences for agriculture, aquaculture, lagoonal fisheries and wildlife (e.g. the delta of the Ebro and Ichkeul/Bizerte); and worsening of existing shore erosion problems (e.g. the deltas of the Nile and Rhone).

By the middle of the next century, the impact on coastal settlements and construction (e.g. harbours, coastal roads) might be considerable in places where they are only slightly above the present mean sea level (e.g. Venice). Historic settlements and sites may require special, often quite expensive, protection measures, while the problem of other structures should be addressed through their gradual transformation or translocation.

Many unprotected shorelines and low-lying regions of the Mediterranean currently suffer from erosion and experience periodic inundation during high sea level conditions (e.g. storms). Any increase in the mean sea level, or in the frequency and intensity of episodic events affecting that level, would worsen the present situation. However the dynamic character and the long–term non-climatic coastline changes is not legislatively recognized. Usually back shore space is lacking to accommodate the retreating coastline. Only the application of highly site-specific combinations of adaptive and protective measures can mitigate or avoid the problems caused by erosion and inundation. Under the Mediterranean conditions preference should be given, whenever applicable to soft, non-engineering solutions.

Sea water intrusion into coastal aquifers will intensify with an elevation of mean sea level, and worsen the already quite widespread freshwater supply difficulties experienced in a number of locations (e.g. Malta) along the shores of the Mediterranean. The best response to the expected impact would seem to be the timely adoption of more rational freshwater management policies and measures, based on realistic analyses and projections of future freshwater demand. Such projections are dependent upon realistic scenarios of future socio-economic conditions.

Regarding sea level change, responses options can be either preventive or reactive. For example, in some instances entire economic important coasts and lagoon margins can be walled in to protect irreplaceable coastal uses and values (e.g. harbours, towns of historical-artistic value, lagoonal resources, specialized agriculture), while in others uneconomic crops could be gradually replaced with lagoons or ponds destined for aquaculture and nature reserves and to act as a buffer zone, since their inner margins can be more easily protected than the exposed coast.

Until the middle of the 2lst century, the impact on marine resources, natural vegetation and crops, is not likely to be significant, except in regions where climatic or soil conditions are already marginal, although forested areas may experience increased risk from fires. Due to changes in precipitation and temperature, gradual latitudinal and altitudinal shifts in vegetation belts may occur in some areas. The positive economic impacts and opportunities created by these shifts may be considerable, particularly if combined with modern agricultural practices (e.g. genetic engineering, introduction of species to areas where they cannot grow under present conditions).

The changes in climatic conditions are expected to have only a very limited effect on the distribution and dynamics of the Mediterranean coastal human population, which will remain strongly influenced by non-climatic factors. In areas where tourism development is at present limited by temperature conditions, an increase in temperature could lead to a gradual extension of the tourist season, with concomitant environmental problems and economic benefits.

Sectoral approaches addressing the impacts of climatic changes will not lead to their successful long-term solution. The most promising general policy option to avoid or mitigate the eventual negative impacts of expected climatic changes is the broad application of integrated coastal zone planning and management, which takes into account, among other factors, the long-term trends in climatic conditions. In this context, the long-term national socio-economic development plans will have to be re-examined in order to take into account not only the presently obvious trends and available resources, but the influence the changed climate may have on these trends and utilization of the resources.

Raising public awareness about the problems that may be associated with expected climatic changes is of great importance as it may facilitate societal decision-making and generate the necessary public support for measures and expenditures that may seem, by an uninformed public, as being unjustified.

In conclusion, the preparation of the Mediterranean climate impact studies could be considered as a very cost-effective and successful exercise through which countries and their own interdisciplinary experts, including managers, planners and policy-makers, were mobilized to consider the potential threat that climate change may pose on their environment and socio-economic development.

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