REGIONAL SEAS

UNITED NATIONS ENVIRONMENT PROGRAMME

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Implications of expected climate changes in the Mediterranean region: an overview

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PREFACE

In spite of uncertainties surrounding the predicted climate changes, greenhouse gases seem to have accumulated in the atmosphere to such a level that the changes may have started already and their continuation may now be inevitable.

The environmental problems associated with the potential impact of expected climate changes may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future. Therefore, in line with the Decision of the Fourteenth Session of the UNEP Governing Council on "Global climate change"[1/], the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of UNEP launched and supported a number of activities designed to assess the potential impact of climate changes and to assist the Governments in idendification and implementation of suitable response measures which may mitigate the negative consequences of the impact.

In 1987, Task Teams on Implications of Climate Change were established for six regions covered by the UNEP Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas and South-East Pacific).

The initial objective of the Task Teams was to prepare regional overviews and site specific case studies on the possible impact of predicted climate changes on the ecological systems, as well as on the socio-economic structures and activities of their respective regions. The overviews and case studies were expected:

- to examine the possible effects of the sea level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);
- to examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;
- to examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and
- to determine areas or systems which appear to be most vulnerable to the above changes.

The regional studies were intended to cover the marine environment and adjacent coastal areas influenced by or influencing the marine environment.

The regional studies prepared by the Task Teams were planned to be presented to the intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in development of policy options and response measures suitable for their region.

The site specific case studies developed by the Task Teams were planned to be presented to national seminars.

Once the initial objective of the Task Teams (impact studies) is achieved, they concentrate on providing assistance to national authorities in defining specific policy options and suitable response measures.

1/ UNEP/GC/DEC/14/20; see annex to this document.

The initial objectives of the Mediterranean, Caribbean and the South Pacific Task Teams have been completed and were reviewed by a meeting of the representatives of the Task Teams (Split, 3-8 October 1988)[2]. The work of the other three Task Teams is expected to be completed in 6-8 months. The establishment of two additional Task Teams (for the West and Central African region and for the Eastern African region) is in process.

The drafts of the regional studies (overviews) of the Task Teams were already considered by meetings convened under the Mediterranean, Caribbean, South Pacific, South-East Pacific and East Asian Seas Action Plans.

One site specific case study (Delta of Nile) was presented at a national seminar (December 1988). Two additional seminars are planned for mid-1989 (Delta of Po and Thermaikos Gulf).

A special intergovernmental meeting will be convened in mid-1989 in Marshall islands for the 19 island States of the South Pacific to consider their policy options, suitable response mechanisms and additional site specific case studies to be developed.

A detailed case study on the Maldives was prepared with assistance of the South Pacific and the Mediterranean Task Teams and will probably lead to a large-scale country project.

The development of climate scenarios for the Mediterranean region has been initiated. They are planned to be completed in 1990 and to be used in connection with the revision of the Mediterranean regional study.

On a global scale a review on the interaction of the oceans with greenhouse gases and atmospheric aerosols was published[3] on the basis of the work carried out by a working group of GESAMP, and a bibliography on effects of climate change and related topics was prepared by the Mediterranean Task Team.

This publication was prepared by Messrs G. Sestini[4], L. Jeftic[5] and J.D. Milliman[6] on the basis of the work carried out by the UNEP Task Team on Implications of Climate Change in the Mediterranean region working under the co-ordination of Mr. L. Jeftic. The numerous case studies resulting from the activities of the Task Team are being prepared for publication in a separate volume.

2/ UNEP(OCA)/WG.2/25.

3/ UNEP Regional Seas Reports and Studies No. 94, UNEP 1988.

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1. INTRODUCTION

The greenhouse effect is Man's most pressing environmental problem, one which presents major scientific challenges across a wide range of disciplines. Changes in global climate between now and the middle of the 21st century are likely to be dominated by the influence of global warming due to increasing concentrations of carbon dioxide and other gases in the atmosphere. These greenhouse gases individually and collectively change the radiative balance of the atmosphere, trapping more heat near the Earth's suface and causing a rise in global-mean surface air temperature and as a consequence substantial global warming is virtually certain.

By 2025, the warming commitment lies in the range 0.5-3.2°C (Villach, 1985) (Bolin et al., 1986). Even the low end of this range will mean significant changes in regional climate. When coupled with possible increased frequency of extreme events, the impacts could be considerable, far exceeding anything previously experienced by mankind. Moreover, in consequence of the melting of mountain glaciers, of polar ice sheets and of the thermal expansion of the oceans, global sea level is expected to rise.

Many important economic and social decisions being made today (such as water resources management, coastal engineering projects, urban, communications and energy planning, nature conservation) are based on the assumption that past climatic data provide a reliable guide to the future. This is no longer a safe assumption. Climatic changes must be taken in consideration in view of the current population explosion, increasing use of coastal areas (tourism, agriculture, fishing, harbours, industries), and the limited resources of the Mediterranean countries, especially in regard to water, good soil and fisheries.

The environmental problems associated with the potential impact of expected climatic changes may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future. Therefore, in six regions covered by the UNEP Regional Seas Programme (Mediterranean, Caribbean, South Pacific, South Asian Seas, South-East Pacific and East Asian Seas), Task Teams have been established and charged with the preparation of studies on the possible impact of climatic changes on the ecological systems as well as on the socio-economic structures and activities.

The intended objectives of the studies were:

(a) to examine the possible effects of the sea level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);

(b) to examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;

(c) to examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and

(d) to determine areas or systems which appear to be most vulnerable to the above changes.

The regional studies were intended to cover the marine environment and adjacent coastal areas influenced by or influencing the marine environment. The studies were expected to be based on:

(a) the best available existing knowledge and insight into the problems relevant to the subject of the study;

(b) assumptions 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 (for the purpose of these studies temperature elevation of 1.5°C and sea level rise of 20 cm by the year 2025 were accepted, with the understanding that these estimates may have to be revised on the basis of new scientific evidence); and

(c) several detailed case studies, which would constitute the substantive annexes of the studies.

This paper reviews the results of the studies prepared by the Mediterranean Task Team, that were presented at a Joint Meeting of the Task Team on Implications of Climatic Changes in the Mediterranean and the Co-ordinators of Task Teams for the Caribbean, South-East Pacific, South Pacific, East Asian Seas and South Asian Seas Regions organized in Split (3-8 October 1988) by the Co-ordinating Unit for the Mediterranean Action Plan in co-operation with the Oceans and Coastal Areas Programme Activity Centre of UNEP (UNEP, 1988).

2. PHYSICAL ASPECTS

2.1. Geography

The Mediterranean Sea lies between Europe, Asia and Africa. It extends about 4000 km from Gibraltar to Syria; the maximum distance in the north-south direction (from France to Algeria) being about 900 km. Excluding the Black Sea, it covers about 2.5 million km^2, with an average depth of about 1.5 km, a maximum depth of 5000 m and a volume of 3.7 million km^3 (Fig. 1).

The Mediterranean Sea is connected with the Atlantic by the Strait of Gibraltar (15 km wide, 290 m deep), with the Sea of Marmara by the Dardanelles (4 km wide, 55 m deep) and with the Red Sea by the Suez canal (120 m wide, 12 m deep). The Sicilian Channel (110 km wide, 350 m deep) separates the Western from Eastern basin. In the Western Mediterranean (about 0.85 million km^2) are found the Alboran Sea, the Algero-Provençal basin, the Ligurian Sea and the Tyrrhenian Sea. In the Eastern Mediterranean (about 1.65 million km^2) are the Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levant Basin.

The length of the Mediterranean coastline is about 46,000 km of which 19,000 km is the coastline of the Mediterranean islands (Fig. 2). The Mediterranean Sea is bordered by eighteen countries (Fig. 3): Spain, France, Monaco, Italy, Yugoslavia, Albania, Greece, Turkey, Cyprus, Syria, Lebanon, Israel, Egypt, Libya, Malta, Tunisia, Algeria and Morocco. Coastlines of individual countries range from 15,000 km (Greece) to 5 km (Monaco).

Although few in number, major Mediterranean rivers (Ebro, Rhône, Po, Vardar, Ceyhan and Nile) inject large volume of sediment into the system (Fig. 4). On the other hand, much of the coast is drained by short mountainous rivers that individually drain small areas on a highly seasonal basis. Collectively these may transport more sediment to the basin, but certainly less water.

Although alluvial and coastal plains are few and not extensive, most have demographic and economic importance. Besides settlements involving millions of people, vital agriculture and fishing resources, as well as industrial, commercial and communication centers, and the increased recreational use of beaches, most areas still contain partly to little modified natural ecosystems of irreplaceable value. Because of their ecological fragility, related to the land-sea transition, and their economic importance, these coastal lowlands are the most vulnerable to climatic changes involving hydrology, ecosystems, and a rise of sea level.

2.2. Geology

The Mediterranean Sea lies in a trapped basin within a collision zone between the African and Eurasian continents, one of the most geologically complex areas of the world. The opening of the southern Atlantic Ocean, in Early Cretaceous (120 mill. years ago) changed the original opening trend of the Tethys from divergence to convergence. Africa started to rotate northwards and to become closer to Eurasia; this evolution resulted in the Alpine orogeny during the Late Cretaceaous and the Tertiary, which destroyed most of the original Tethys ocean. Following the climax of this orogeny, the basic configuration of the Mediterranean Sea was created about 40 million years ago.

The Eastern Mediterranean basins have long been in existence and influenced by compressional forces. The active subduction of the Hellenic Trench witnesses the final stage of the disappearance of the Tethyan ocean floor beneath the European Plate. Old oceanic curst is considered to exist in the Levantine Sea, though the African continental crust probably extends as far as the Mediterranean Ridge.

In contrast, the Western Mediterranean basins were created more recently by extensional rifting during the Cenozoic with the alpine orogenic belts as back-arc basins. The oldest basin is the Balearic Sea, dating back to latest Oligocene or earliest Miocene (20-30 million years ago), the Tyrrhenian and the Aegean basins are younger, being developed in the Pliocene and Pleistocene. Some of the mountains were separated from the mainland and now constitute large islands (Corsica, Sardinia, Sicily, the Balearic islands); others, like the Aegean islands, by more recent sinking.

In some areas, these geological movements have resulted in volcanic activity, some still current today (Etna, Stromboli, Vesuvius). Seismic activity is continuous in southern Italy, the Balkans, and the Anatolian Plateau. Many parts of the region are subject to seismic hazards with disastrous consequences for human life and society.

2.3. Climate

Climatically, the Mediterranean is transitional and characterized by its winter-dominated rainfall, dry summers and profusion of microclimates due to the alternating mountains and inland seas (Figs. 5 and 6). There is a temperate, damp climate in the north and a hot arid climate in the south. Orographic rains on the European coasts (up to 2500 mm/yr) contrast markedly with minimal annual rainfalls in the southern regions of less than 100 mm. The winter rains frequently come in the form of violent downpours which are important agents in soil erosion. The summer drought lasts four months on the average, with sometimes - though rarely - a little rain in June along the European coasts. In the warmest months, evaporation is usually higher than in the adjoining desert areas to the south and east. In winter it is less than half the summer figure.

The strong summer-winter rainfall contrast that characterizes Mediterranean climate is associated with a well pronounced seasonal cycle in almost all climate variables. July, August and September are characterised by warm, dry conditions associated with a strong high pressure ridge which pushes eastwards from the Azores subtropical high over the Mediterranean. In mid-October the rainy season begins. Winter is characterized by cyclonic disturbances and low mean pressure in the Mediterranean, with higher pressure to the east associated with the Siberian high. In March, April and May, as the main features of the upper air flow begin to move northward, the rainy season continues. By May, the polar front and associated strong upper-air westerly flow is sufficiently far north that its influence is removed. Precipitation, although mainly associated with cyclonic disturbances that originate in the Mediterranean Basin, is strongly influenced by local orographic effects.

Most depressions originate within the Basin. There are four regions of cyclogenesis. The main region lies in the western Mediterranean, producing "Gulf of Genoa" depressions which only occasionally move far enough eastward to affect the Eastern Basin. Central and Eastern Basin depressions tend to move to the northeast or east where futher intensification may occur. Eastern Basin depressions, especially when undergoing subsequent interaction with polar continental air from the Iranian plateau, may bring rain to a wide area, from Egypt to Iraq.

Annual surface winds in the Mediterranean are generally from the north and west. The combination of dry winds and sunny days, which occurs as often as 250 times a year, produces a strong evaporating influence over the entire surface of the Mediterranean that conteracts the effects of precipitation and runoff (Miller, 1983). The complex topography behind the shores of the Western Mediterranean, constitutes barriers against air currents and openings or gaps between mountains that impose prevailing wind directions. Departure from geostrophic wind is usually less than 45° (about 20 or 30°) over flat and smooth terrain, but in narrow mountain gaps, the angle may reach 90°, that is, the air may fall down the fall-line, almost like water would do. So, an ageostrophic flow can pass freely and at a considerable velocity into the Mediterranean Basin through the gaps, some below 1000 m elevation. These wind systems were well known and named by fishermen and people in general many centuries ago (Mistral, Bora, etc.). If the air flow along the pressure gradients in the lower and middle troposphere is strong enough to force the flow over the mountains rather than around them, strong and gusty winds on the lee side will result (Föhn winds).

3. THE SEA

3.1. Circulation

The surface waters in the Mediterranean mostly enter from the Atlantic Ocean and migrate towards the east with many eddies. The annual thermal changes of surface waters control the surface density and the basic characteristics of the annual biocycle. The return of Mediterranean water is by way of Levantine E-W flowing Intermediate Water and Mediterranean Deep Water. Such intermediate and deep water is produced by very pronounced evaporation processes in the east which gradually increase salinities to 38-39‰. Deep sea water in the Mediterranean has a temperature between 12.5° and 13.5°C in the west and between 13.5° and 15°C in the east.

The estimated turnover time for Mediterranean waters is 80 years. The basic nature of the Mediterranean circulation system contains components of strong vertical convection which produce vertical recycling of nutrients and other dissolved substances (Miller, 1983). When winter storms lower surface temperatures in the western Mediterranean to 12°C, deep convection can take place; in the Algero-Provençal basin it has been traced to the depth of 2,000 m.

Characterized by very weak tides, the Mediterranean is often considered a tideless sea. This however gives a wrong impression since although the tidal elevations are small, the energy of the tides is not (Hopkins, 1985).

Sea level in the Mediterranean is lower than in the Atlantic, progressively decreasing from Gibraltar towards the North Aegean, with maximum differences of about 80 cm (Miller, 1983).

3.2. Water balance

The Mediterranean Sea has a deficient hydrological balance, with loss through evaporation exceeding the input of water through run-off and precipitation. This deficiency is mainly compensated by the influx of Atlantic surface waters through the Strait of Gibraltar and (to a lesser extent) of Black Sea waters through Dardanelles, 40,000 and 6,000 m^3sec^{-1}. respectively. To maintain the salt balance, deep water outflow across the Strait of Gibraltar has about 3‰ salinity higher than inflowing surface waters.

The river run-off in the Mediterranean is estimated at about 15,000 m^3s^{-1} of which 92% flows from the northern shore and the rest of draining from the southern shore. The Northwest Mediterranean and the Adriatic Sea receive about 70% of the total Mediterranean river water input. Prior to the damming of the Nile river, however, fresh water input from Egypt averaged 3,000 m^3sec^{-1}.

Rainfall, which accounts for an additional 30.000 m^3sec^{-1}., decreases from west to east and from north to south, varying from more than 1500 mm yr^{-1} (Alps, Pyrenees and western part of Yugoslavia) to less than 100 mm yr^{-1}. The above figures bring the total input of water into the Mediterranean to approximately 91,000 m^3s^{-1}.

The Mediterranean contributes by evaporation an estimated average of 1440 mm/year and a total of 93,000 m^3sec^{-1} to the formation of mainland fresh water, especially in its coastal zones. Most of the evaporation occurs during winter and spring, due to the prevailing strong and dry continental winds and is closely associated with the process of deep water formation. However, in fact, little is known about either evaporation or precipitation at sea.

3.3. Chemical characteristics

The most outstanding differential characteristic of the Mediterranean compared to the Atlantic is its high salinity, the result of evaporation. Of particular interest are the high oxygen concentrations, a consequence of the relatively young age of the deep water (Cruzado, 1985).

Mediterranean water has low nutrient concentrations as no deep nutrient-rich Atlantic waters enter through the Strait of Gibraltar. The only increase in nutrient concentration is from river and agricultural run-off and pollution (Miller, 1983). Phosphate values vary from 0.1 to 0.5 ug at l^{-1}, with very few definitive patterns other than higher values in deep water. The eastern Mediterranean has a smaller range of phosphate content than the western (Miller, 1983).

Because of the unique circulation patterns in the Mediterranean basin, almost any substance introduced to the surface waters will remain within the basin for at least 80 years unless it is volatile or miscible or it is sedimented out of the water column. This aspect has obvious implications when considering the impact and fate of pollutants in the basin waters.

3.4. Biological characteristics

Biological productivity in the Mediterranean is amongst the lowest in the world, the result of low nutrient content in the surface waters (see above). In the Mediterranean there is 25 mg l^{-1} of dissolved inorganic carbon, 0.5 to 1.5 mg l^{-1} of dissolved organic carbon, close to 1 mg l^{-1} of particulated suspended carbon, but only 0.1 mg l^{-1} living carbon. Much of the organic dissolved matter comes from the excretion of phytoplankton.

Maximum bioproduction occurs at about 100 m depth in summer, just at the limit where the dim light is matched by the increased concentration of nutrients. Average primary production, in the western basin, corresponds to an assimilation of 50 g C $m^{-2}yr^{-1}$ but is lower in the central areas. Primary productivity, however, can be unusually high at the mouths of rivers (due to nutrient input) and along the coasts (due to upwelling) in winter time, and in large eddies where deep water comes close to the surface. Colder years tend to be more productive, partly because mixing may reach greater depth and incorporate more nutrients, and partly because the formation of deep water may occur over a larger area.

Because of its oligothrophic character the Mediterranean Sea has a low zooplankton biomass, compared with similar Atlantic areas, but it is very rich in its variety. Its fauna is characterized by many endemic species and is considerably richer than that of the Atlantic coasts. The percentage of endemism is very high for the sessile groups such as ascidians with 50.4% (Pérès and Picard, 1964), sponges with 42.4% (Vacelet, 1981), hydroids with 27.1% (Pérès and Picard, 1964), echinoderms with 24.3% (Tortonese, 1985), decapod crustaceans with 13.2% (Pérès and Picard, 1964; Pérès, 1967) and fishes with 10.9% (Tortonese, 1985).

Profound and irreversible perturbations of the ecosystem and the biological economy of the Levantine Sea have been caused by two man-made alterations of the environment: the opening of the

Suez Canal in 1869 and the damming of the river Nile in 1965. Since the opening of the Canal, about 170 Indo-Pacific species have successfully established themselves in the eastern basin. With the lowering of the salinity barrier in the Bitter Lakes, the immigration rate appears to be increased and the area of extension of the immigrant forms now reaches up to Turkey, Cyprus and Greece (there is one record from the Adriatic Sea) to the north, and to the Gulf of Sidra to the south west. The flux of Indo-Pacific species has enriched the East Mediterranean with several economically valuable fish (e.g. Mugil seheli, Sphyraena obtusata, Siganus siganus) and crustaceans (e.g. the crab Neptunus pelagicus and the shrimp Penaeus japonicus (Halim, 1974).

With the cessation of nutrient-rich Nile waters to the Mediterranean, biological productivity fell-off dramatically. For example, sardine fisheries suffered a 95% decline in a single year. Recently, fishing has improved near the Nile, but with the increased catches of other species.

The annual yield of marine organisms, both pelagic and demersal, obtained by Mediterranean fishermen amounts to 0.3 - 0.4 tons of fish per km^2 of sea. This is equivalent to about 40 mg of organic carbon $m^{-2}yr^{-1}$. However, fishing activities in the Mediterranean Sea have been going on for centuries, adapting themselves to the local conditions in such a way that a very high ratio catch/primary production exists. Several factors may contribute to this high efficiency; among them, the distribution in time and space of the fertilizing mechanisms.

4. HYDROLOGY AND WATER RESOURCES

The northern Mediterranean coast and islands are relatively well-watered by precipitation (400-1000 mm yr^{-1}) and by the many rivers though with wide seasonal variations. On the other hand, the southern shore of the Mediterranean is essentially arid, with precipitation of less than 100 mm yr^{-1}, excepting the Maghreb (300-600 mm yr^{-1}), and has a very poor hydrographic network, except the Nile delta and a few rivers in North Africa. Apart from these relatively privileged areas, the potential water resources rarely exceed 100 m^3 yr^{-1} $caput^{-1}$.

In all the coastal countries, mainland water is "lost to the sea" as soon as it reaches the coast; from the standpoint of the countries concerned, it is an outflow, whereas for the sea it is an inflow. The basic strategy of these countries is therefore gradually to reduce their "losses to the sea", mainly by building storage dams (Fig. 7), but also by using the supply and storage possibilities of groundwater reservoirs.

The Mediterranean coastal areas are mostly formed by sedimentary rocks and alluvial deposits which, for the most part, constitute groundwater reservoirs. Limestone covers a large part of the Mediterranean littoral, where it forms groundwater reservoirs with intensive circulation. These reservoirs lead to unregulated freshwater Vauclusian springs - coastal and submarine - that are often brackish. Although flow of these springs is estimated at more than 3 cm^3 yr^{-1}, the technology for tapping, exploiting and managing these reservoirs is still non existent.

Water shortage is endemic and (particularly in the north) seasonal (July-September) by reason of the climate. It may attain dramatic proportions in certain "dry" years, which occur once or twice in a decade. In some countries, water shortage has already become a permanent handicap as a result of the deficit in the requirements-resources balance; other countries are on the verge of a crisis. Local shortages have led to inter-basin transfers or to the expensive technology of sea-water desalination. In Spain, there is the inter-basin transfer from the Tajo River basin to the Segura River basin. In France, the canal of Provence transfers water from the Verdon River, a tributary of the Durance River, to the coastal area of Marseille-Toulon. In Lebanon, the Litani waters are transferred to the coastal region of Saida and to the extreme south of the country. In Israel, the Jordan River project represents an inter-basin transfer from the Sea of Galilee to the central and southern coastal plain.

An overwhelming problem is the striking disparity of water potential between the northern and southern shores of the Mediterranean. In view of the rapid increase in water requirements and the relative poverty of some of the coastal countries, international transfers no longer should be regarded as utopian schemes. The sharing of water resources needs to include bilateral or multilateral agreements. Examples are the Vardar River under bilateral study by Yugoslavia and Greece, the Evros-Meric River between Greece and Turkey, the Orontes River in Syria with the upper basin in Lebanon. Cyprus will soon need to have water transferred from Syria or Turkey. Sardinia also is in need of water which could be "piped in" from Corsica.

5. THE PRESENT STATE OF THE ENVIRONMENT

Over the centuries there has been an increasingly serious interference with natural balances throughout the Mediterranean basin. This has altered the original aspects of the countryside and brought about, through a constant process of deterioration, extremely precarious situations requiring urgent and appropriate remedies.

Deltaic and lowland coasts are presently experiencing serious environmental problems, due not to recent climatic oscillations, but to careless development of land use over the last 50 years. These include the urbanization of the coast, the building of deep harbours and coastal defence structures, a decrease of lagoon surface (via land reclamation), enhanced land subsidence caused by water extraction, the deterioration of rivers' water and solid discharges, pollution of coastal waters, salinization of ground waters, etc. Other basin-wide problems include forest degradation, forest fires, soil erosion and desertification.

5.1. Pollution

The introduction of foreign substances is essentially, though not exclusively, from land-based sources. Airborne particles can reach the sea by way of dust storms or fallout from precipitation.

Waste loads of domestic sewage, industrial discharges and agricultural run-off are probably the major contributors to pollution of the Mediterranean. The uneven distribution of runoff and precipitation along the northern coasts of the Mediterranean Sea, combined with the northern concentrations of population and industrial activity, contribute pollutants to Mediterranean waters that to some extent are spread and recirculated throughout the basin. In recent years the increased use of fertilizers and pesticides, combined with increasing coastal populations and poor sewage treatment has meant increasing pollution of the southern coast.

Some 85% of the waste waters from the larger cities is drained untreated into the sea. This figure does not take into account river-borne transport, which accounts for some 40% of all pollution. A significant share of modern equipment for the purification of waste water does not function properly. The solid wastes from cities and industry are not dumped or treated properly, thus causing the pollution of underground waters and aquifers.

All confined or semi-confined Mediterranean localities adjacent to large urban centres appear to be the site of a progressive build-up of contaminants, as a result of continued uncontrolled anthropogenic release. This is observed in the Bay of Algiers, the Lake of Tunis, the Bay of Abu-Kir near Alexandria, the Bay of Izmir in Turkey, the North Adriatic, the coastal belt along most of the north coast of the western Mediterranean.

The Mediterranean is well-adapted for avoiding excessive eutrophication. It loses deep water, relatively rich in mineralized or recycled nutrients, and receives (relatively) nutrient-poor surface Atlantic water. The situation is exactly the opposite of that in the Baltic, where ecological mechanisms tend to recycle and accumulate large amounts of nutrients.

Mediterranean waters are oligotrophic (except perhaps in the neighbourhood of large rivers) and therefore sediments generally have low organic carbon contents. Therefore, local oxygen deficiencies usually are connected with eutrophicating sources, mostly discharges of raw or treated urban effluents. Owing to the strong stratification of surface waters, eutrophication is more acute in summer, when oxygen transport through the thermocline is strongly reduced. Winter mixing allows for the required vertical transport of oxygen to keep the deep waters and sediments well oxidized (Cruzado, 1985).

Long-term build-up of contaminants and the consequences of man-made alterations of the environment can only be assessed where long term investigations provide conclusive observations on populations and community structure. Although an enormous amount of data on pollution in the Mediterranean Sea has been published in the last decade, assessment of the effects of long term accumulation of pollutants still faces several constraints. Many studies have data on pollutant levels in fish, bivalves and crustaceans and not pollution impacts on communities and populations. The areas where such investigations have been carried out are geographically scattered and separated by large gaps.

The characteristic Mediterranean Posidonia oceanica ecosystem appears to be heavily impacted upon and is on its way to extinction in the vicinity of large urban centres. The degradation of this ecosystem results from a combination of factors: (a) encroachments in the upper infralittoral zone and the areas of coastal development of commercial and sporting harbours and marinas; (b) the dumping of dredging material, smothering the P. oceanica meadows; (c) disposal of urban and industrial waste water through large outfalls. In the Gulf of Fos-Marseille, where this ecosystem has been monitored since 1948, the meadows are extinct over large areas.

5.2. Coastal degradation

Nearly all the Mediterranean coastal lowlands and their shorelines presently experience damage from erosion and inundation during storm. Most beaches are subject to erosion, not only because of the recent slow rise of sea-level, but (mostly) because of man's economic and social activities. Coastal processes have been interfered with by construction of jetties, and groines, which initially were meant to stabilize the coast; in fact they usually do the opposite.

The removal of sand from beaches and from river beds has caused coastal erosion. The draining and reclamation of wetlands for agriculture, commercial, industrial and housing use has caused ground lowering due to compaction. There is also a widespread tendency in the Mediterranean countries to reduce the flow of rivers into the Mediterranean Sea, through dam construction and channel diversion, thus decreasing the influx of sediment to replenish the beaches (Fig. 7). The influence of large changes of the river flow and input to the coastal zone is also noted on both coastal zone dynamics and ecological systems, particularly biological productivity.

The entire coast around the NW Adriatic is in a state of physical instability because of subsidence and sediment starvation, and must be classified as high risk in regard to the impacts of sea level rise. The coast of the Gulf of Lion, with its tourist and harbours is also vulnerable, because of its narrow beach width, the low altitude of the dunes and coastal ridges, their levelling for construction purposes and their decayed condition due to abandonment. The damming of the Ebro river has reduced sediment discharge by 98% and the man induced changes at the discharge mouth have led to a notable modification of the Ebro delta; since early 1960's its growth has almost stopped, while its outer lobes are subject to rapid erosion.

Due to human activities, not many natural coastal wetlands, such as marshes and lagoons still remain (Fig. 8). The most important remaining areas are found in the deltas of the Rhone, Ebro, the Po and Nile. In Tunisia Lake Ichkeul is a natural reserve.

5.3. Desertification

Desertification is increasing in the Mediterranean arid zone at the alarming rate of several hundred thousand hectares per year. A study of 106 000 km^2 in southern Tunisia showed that 12 500 km^2 had been transformed into man-made desert in less than ten years (Le Houérou, 1977).

It is generally agreed that desertification results from two main sets of conditions: aridity (periodical prolonged droughts) and destructive land-use practices.

There is wide consensus among scientists concerning the general deterioration of ecological conditions over the past 100 years and especially since about 1930.

In the Mediterranean arid zone population has increased more than 4.5-fold since the beginning of the century, and in all likelihood it will double again by the year 2000. The consequences of this population explosion include: increased cultivation and clearing of steppe; increased numbers of livestock; overgrazing; destruction of forests and woody vegetation in general (for firewood, charcoal, distillation); salinization of large areas as a result of faulty irrigation projects; inadequate human settlements; emigration, etc.

The land left barren after harvest is prey to water and wind erosion. Losses of top soil of 10 tonnes ha^{-1} $month^{-1}$ from wind erosion have been measured in southern Tunisia and annual losses of 200 to 250 tonnes ha^{-1} have been estimated at the fringe of the Sahara. As a result, reservoirs in Algeria and Tunisia were silted up within ten years and sometimes less. Costly irrigation schemes representing large investments remained, in some cases, operative for less than five years.

In addition, probably 30,000 to 40,000 ha are lost annually in the Mediterranean arid zone by salinization or alkalization.

Water development for livestock, whether in the form of new boreholes, wells, ponds, cisterns, etc., has, when carried out without pasture management regulations, resulted in concentrations of animals far beyond the carrying capacity of the pastures. In many places desert conditions were created within a radius of 5-20 km around water points.

There is evidence that desertification is irreversible in the shallow soils of the drier parts of the arid zone. Once the top permeable soil has been removed by erosion, the skeletal bedrock does not have sufficient water-storage capacity to ensure the survival of perennial plants during the long summer drought.

It should be stressed that desert encroachment is discontinuous in time and space and occurs mainly during the periodically-recurring prolonged droughts such as those of 1920-25, 1944-48, 1959-61 in the Mediterranean; and 1913-16, 1944-48, 1968-73 in the Sahel. However, the effects of the droughts have become more and more dramatic because of the sharp increase in human and animal populations and the decrease of natural resources.

6. SOCIO-ECONOMIC ASPECTS

6.1. Population and development

Coastal regions in Mediterranean cover an area of 1,491,977 km^2, 17% of the total area (88,528,914 km^2) of the eighteen countries that border the basin. These countries in 1985 had a total population of 352 millions, of which 37% live directly in the coastal area (UNEP, 1989) (Fig. 9).

Population growth is very pronounced in eastern and southern Mediterranean countries. The population density is greatest in coastal regions, ranging from 250 inhabitants per km^2 to as much as 1,000 per km^2 in the Nile delta (Fig. 10).

The role of coastal regions as focal points of development and construction is particularly pronounced in the southern countries, where all the efforts in the development of the interior have encountered great difficulties with the exception of Morocco. Although the centres of development in the European Mediterranean countries often lie outside the coastal belt of the Mediterranean, even in these countries we find an increasing degree of littoralization. The development and construction in the coastal regions take place themselves mainly in the vicinity of cities and ports, much of the remaining coast being utilized for tourism.

According to one average projection, the population in the Mediterranean can be expected to reach 433 million in the year 2000 and 547 million in 2025 (UNEP, 1987a) (Fig. 9). This phenomenon will lead to a shift in the centre of concentration of the Mediterranean population from the northwest (Spain, France, Italy) to the eastern and southern parts of the Mediterranean (Egypt, Turkey, Algeria).

The characteristic demographic feature is the high percentages of the younger age groups in the south and east (37-49%) compared to the north (21-26%). This fact indicates the difficulties arising in the securing of education and the creation of new jobs for this population.

Life expectancy at birth in 1985 was close to or over 70 years in the northern countries and near 60 years in the east and south. Israel is an exception in that it has all the features of the countries in the northwest (UNEP, 1987a).

Post-World War II development of the Mediterranean region has been extremely pronounced, accompanied by an intensified industrialization and the development of tourism. This has intensified the pronounced urbanization of the coastal areas and immediate hinterland, for example Alexandria, Algiers, Athens, Barcelona, Beyrouth, Genoa, Izmir, Marseille, Naples, Rome and Tunis. Of the total population of the Mediterranean coastal regions in 1980, 57% was urban, with a projected figure of 75% by 2025. In the countries of the southern Mediterranean almost the entire increase of the urban population will take place in the cities in the coastal regions (UNEP, 1987a).

The wide variation in natural political and economic systems (both past and present) within the region, as well as the variation in disposable resources therein have resulted in great differences in the level of development of Mediterranean countries. The highly developed industrial countries in the northwest (France, Italy, Spain) and countries on the way to completing their industrialization (Greece, Yugoslavia, Turkey) compared to the developing countries in the east and south regions of the Mediterranean (except Israel) represents the global North-South economic contrast. The state of development of the Mediterranean countries is illustrated by marked contrast in Gross National Product per capita (GNPC) (UNEP, 1987a), from US$ 670 (Morocco) to US$ 9,760 (France) (in 1984). GNPCs greater than 4,000 dollars have been recorded in France, Italy, Israel and Spain while most other countries have recorded values between US$ 1,200 and 2,500. As a result of a major production of oil, Libya's GNPC of US$ 8,520 represents an exception, but other indicators clearly show that it belongs to the group of developing countries (Fig. 11).

6.2. <u>Natural resources</u>

The Mediterranean region is relatively poor in natural resources. There are several medium sized petroleum producing countries (Libya, Algeria, Egypt). Morocco is the world's third largest producer of phosphates, Albania the third largest producer of chrome, and Spain is the world's second largest producer of mercury. The natural gas reserves in Algeria rank fourth in the world.

Off-shore exploration for petroleum and natural gas in the Mediterranean so far has given optimistic results with regard to natural gas reserves, but less so in regard to oil reserves. Coal resources in coastal areas, on the other hand, are insignificant. The transport of petroleum and natural gas throughout the region has necessitated the construction of numerous pipelines.

As a result of relatively significant but nevertheless limited reserves it is estimated that the energy requirements in the period after the year 2000 will be largely met by imported coal or electric powered stations.

Water resources are relatively plentiful in the northern part of the Mediterranean and scarce in the east and south (with the exception of Egypt). The basic water problem manifests itself by a search for new resources and a rational utilization of existing ones (a proper distribution among various users: the prevention of the loss of and the pollution of water: multifaceted utilization and recycling of water, etc. (UNEP, 1987b).

The forests in the coastal region in the majority of cases are of limited economic significance, but are very important for the preservation of the soil; they also play a significant role with respect to the landscape and recreation. Forest fires are frequent. Causes include changes in the culture of the soil, a stronger concentration of the population (including tourists) in the narrow coastal belt, the depopulation of the immediate coastal region, summer drought, carelessness, and in recent times speculative and criminal actions (UNEP, 1987b).

6.3. Agriculture and fisheries

Ancient traditions have resulted in a common, though multi-faceted Mediterranean agriculture. Characteristic products are olive oil, wine, citrus fruits, hard grain and sheep. Agricultural production activities include agriculture by irrigation, rainfed agriculture, livestock production, grazing land management and forestry.

The coastal regions in the Mediterranean have relatively little agricultural land, that is of high quality.

However, Mediterranean agriculture, particularly in the drier parts of the area, is characterized by an extensive misuse and over-exploitation of the natural resources which are (a) limited, due to overall lack of good soils and water supplies, and (b) prone to degradation due to irregular rainfall and "agressivity" of climate towards soils which are often on slopes and fragile. Periodical fires, recurrent windstorms and torrential rains destroy the woody and herbaceous vegetation.

Farmland represents some 36% of the overall area, forest and shrubland 29%, rangeland 22%, wasteland and non-agricultural areas 13%. In Mediterranean Europe land-use is fairly uniform, since forestation varies from 20% (Greece) to 40% (Portugal) (average 29%). The trend is towards an increasing farmland and range land abandonment in marginal areas, compensated by sharp increases in reforestation and urbanization. The opposite trend is witnessed in the south and east, where forest and shrubland decrease and cropland expands, especially land devoted to cereal cultivation. The actual surface cultivated in cereals is probably in the vicinity of 3.5 times what it used to be in the 1950's.

Probably some 50% of the arid steppes rangelands between the 100-300 mm isohytes have been cleared over the past 30 years and are nowadays more or less regularly cropped (barley and wheat) under subsistence farming conditions with very low average yields (100-300 kg ha^{-1} yr^{-1}) (Fig. 12). The evergrowing clearing of arid steppes rangeland is the major cause of desertification in North Africa and the Near East. Given the trends of the past 40 years, in the near future virtually all land soft enough to be tilled, will be cultivated for cereals cultivation, even though the risk involved will be high and the yields low.

In spite of the increase in cultivated area, for example, the annual production of cereals per inhabitant decreased from 260 kg in 1980 to 195 in 1985. Cereal yields have increased six times faster in the northern Mediterranean countries; but population has increased four times quicker in the south (3.2 versus 0.8% per year). The gap in food production per capita between north and south therefore is increasing rapidly. The gap between local supply and demand grows nearly as fast as the demographic expansion of the human population (UNEP, 1989).

As a result, the majority of Mediterranean countries have a food production deficit and are thus forced to import heavily, mainly from non-Mediterranean countries. Many countries have acquired a permanent deficit in foodstuffs balance. The increasingly poor yield of southern farms in the production of wheat means that more land must be devoted to its production and thus less land is used for traditional Mediterranean crops. The number of the total and active agricultural population is constantly declining. A number of countries that used to be net exporters of agricultural products before the 1960's do import at present over 50% of their food requirements.

The Mediterranean is one of the regions of the world where the social and economic importance of fishing is very considerable. Prior to 1940 the annual fishing yield in the Mediterranean and the Black Sea did not exceed 500 000 tonnes. By 1974 it had reached 1 300 000 of which 750 000 came from the Mediterranean. These catches, however, represent only a very small portion (little more than 1.8 percent) of the annual world-wide catch. The region's output of fish is clearly not sufficient to meet the demand, which in 1985 reached 5.5 million tonnes, and at the present time two thirds of the fish consumed come from outside the area, mainly from the Atlantic.

Most demersal stocks along the northern coasts of the Mediterranean are heavily fished, and the introduction of regulatory measures are necessary to maintain high levels of yield and catch rates. Coastal pelagic stocks, which can apparently be more intensively fished, are the best prospects for fishery development. However, for certain localized fish stocks (particularly in the northwestern Mediterranean) there is moderate, and occasionally intensive, fishing (UNEP, 1989).

The Mediterranean possesses a considerable potential for aquaculture in coastal waters. There is a long tradition of breeding fish and shellfish, a favorable climate, large tracts of water that could be utilized, and a large market. Under these conditions, aquaculture in the long term could produce several hundreds of thousands of tonnes of fish and shellfish.

There are, however, a number of limiting factors. Competition for the use of coastal zones, limited knowledge of intensive aquaculture, lack of cheap feed for rearing, and water pollution still impede the expansion of this operation. Whereas most of the current aquaculture techniques in the Mediterranean are of an "extensive" type, development programmes are usually based on methods of intensive culture. Although this latter option seems to yield a higher profit, it is nevertheless beset by complex problems: controlled breeding is difficult, there are critical phases in larvae rearing, suitable feed is usually expensive, epizootic diseases occur, etc.

6.4. <u>Tourism</u>

The Mediterranean region is the greatest tourist destination region in the world and tourism is the greatest user or "consumer" of the Mediterranean coast (Fig. 13). For example, tourist development on the Spanish mainland and islands coasts amounts to 42% of the coast. The total number of international and domestic tourists in the Mediterranean countries in 1984 amounted to some 213 million, and some 45-50% of this number stayed in or visited the coastal regions of these countries. Tourism involves 5,082,000 hotel beds and 28,223,000 beds in other forms of accommodation. All these facilities take up 2,187,890,000 m^2 of space on the coast. Water consumption in 1984 amounted to 569 million m^3 (UNEP, 1989).

According to all estimates the number of tourists in the Mediterranean coastal region in the year 2000 could amount to between 120 million and 180 million. By the year 2025 the number of tourists could amount to between 170 and 340 million (UNEP, 1987).

Such an increase in the number of tourists is accompanied by the necessity for developing coastal areas, an increase in the water consumption and increases in the amount of solid and liquid wastes. Pressure for tourist development in many countries has greatly disrupted sandy beach and adjacent sand-dune habitats. At places, natural ecosystems have been destroyed or endangered (e.g. turtles).

Existing tourist facilities have been constructed for operations in the peak season (July and August). In the future, they could accept the projected increase in the number of tourists if the visits were evenly distributed throughout the year.

6.5. Communications

Out of the total 2,155 trading ports in the world, 183 lie on the Mediterranean. However, only 18 of these ports account for some 90% of the total maritime transport of goods. Some 15% of the total world petroleum traffic transits through the Mediterranean (UNEP, 1989).

The main flow of traffic has been concentrated in the northwest region of the Mediterranean (Spain, France, Italy), followed by the northeast region (Yugoslavia, Greece, Turkey).

Road and railway transport and infrastructure are more developed on the European side. Road transport remains undeveloped in the northeastern, eastern and southern regions. There is still a deficiency in the communications systems between the coastal regions and the more distant interior, particularly in eastern Europe. Plans are being made and construction undertaken for the building of modern road links between the Baltic and the Middle East and Africa. Projects are also being considered concerning the linking of Europe with Africa, via the Strait of Gibraltar, either by means of a tunnel or a bridge.

Air traffic is fairly developed, but mainly in the north-south direction, while coastal links in the east-west direction are, as a rule, very poor. Private car traffic is greatly on the increase and the number of cars is rapidly growing in almost all countries.

6.6. Trends and future problems

Urban, industrial and tourist development has taken up an enormous percentage of the coast. Railway and road communications are often built in the immediate vicinity of the coast. Coastline use in some regions amounts to as much as 90% (the French Riviera, the regions around Alexandria, Athens, Barcelona, Istanbul, Marseille, Naples). In Catalonia 387 out of 580 kilometres of shoreline have been used for urban, port, industrial and tourist development. Urban and tourist occupation in Yugoslavia amounts to some 20%, in the Romagna coast (Italy) to 75% (UNEP, 1989).

In recent decades a growing amount of attention has been paid to the protection of individual land and sea areas with the aim of preserving the natural and cultural heritage, as well as the balance in natural systems.

The existing trends of development could lead to a situation whereby the Mediterranean countries by 2000 and 2025 will have 545 million inhabitants (compared to the present total of 335 million), a consumption of 1000 million tons of petroleum equivalents (compared to the present 500 million tons), 150 million cars (in contrast to the present 50 million), to an overall urbanization of the coast of 95%, as well as to very large increase in the number of tourists (UNEP, 1987).

Such an increase in the population, particularly its shift from the northwest to the south and east, will lead to increased energy needs, particularly electric energy, necessitating 150-200 thermal energy stations. In view of the need for vast quantities of water for the cooling of these thermal power stations, most (particularly in the south) will be built in the coastal region. The need for the creation of new jobs will require heavy industrialization which, in the southern regions of the Mediterranean, will be concentrated in the coastal areas.

7. THE GREENHOUSE EFFECT AND CLIMATIC CHANGES

7.1. Increase in temperature

Carbon dioxide and the other gases (methane, nitrous oxide, ozone, chlorofluorocarbons) are essentially transparent to incoming short wave solar radiation, but they adsorb and emit long wave radiations and are thus able to trap the earths back radiation (the "greenhouse effect").

The concentration of carbon dioxide in the atmosphere increased from 270-290 ppmv to 356 ppmv between 1900 and 1985. A large part of this increase, and especially of the nitrous oxide and the chlorofluorocarbons, is to be attributed to industrial emissions. The average global temperature had been gradually rising since the late XIX century with increases of 0.5^{o} in the tropical regions, 2^{o} in the boreal regions, but cooling in the parts of the Southern Hemisphere. Overall there has been a warming of about $0.5^{o}C$ in the past 100 years (Wigley, 1989).

There is a consensus in the scientific community that if allowed to continue to build up, a doubling of the greenhouse gases concentration (relative to the pre-industrial era) will occur sometime in the 21st century, possibly as early as 2030 AD. A corresponding global increase of temperature of between 1.5^{o}-$4^{o}C$ is predicted, to become effective 2-3 decades later, in consideration of the lag in homogenization effect.

Not since the dawn of civilization, 10,000 years ago, has the earth been 1^{o} warmer than it is today; temperature oscillations since 2000 years have been within $1^{o}C$, although greater local or regional oscillations have been noted (e.g. the little ice Age). Only during the oscillations associated with Pleistocene glacial advance and retreat, did temperature vary by $\pm$ $5^{o}C$. The predicted temperature change, therefore, would have profound effects on global ecosystems, water resources and agriculture.

The mode of climatic change and its impacts on environments and human activities have been discussed extensively in recent years, especially at the 1985 Villach Conference (UNEP/UNESCO/WMO) (Bolin et al, 1986) and at the 1987 European Workshop on Interrelated Bioclimatic and Land Use Changes in Nordwijkershout (The Netherlands). A few theoretical models have been elaborated to predict the distribution of temperature and rainfall with $2xCO_2$.

Regional changes in all climatic variables will occur. So far General Circulation Models (GCMs) cannot simulate the regional details of today's climate reliably. Projections using these models therefore must be treated cautiously.

The existing GCMs (GISS and others) still give average values for climatic parameters on a coarse longitude-latitude grid of 8^{o}-10^{o}, at best 5^{o} latitude and longitude, and do not take into account topographic and marine effects. What is still lacking for the Mediterranean (and other regions) is a model based on realistic topography, with a high spatial and temporal resolution that simulates realistically observed climate patterns. Except for a few regions, there is a certainty only that changes will occur, but changes cannot yet be quantified. Indeed, for precipitation it is not possible to specify even the sign of regional changes with any reliability.

In the present study a mean annual temperature increase of $3^{o}C$ has been assumed. Whether the change would mainly occur in winter or in summer, or would be evenly spread over the whole year would obviously have quite different and significant impacts on the regional Mediterranean climates and environments.

The impacts of any global-mean climatic change will depend on the regional details of changes in a wide variety of climate variables and in changes in the interannual variability of these variables. At present, these changes cannot be predicted. However, GCM results do give us data which can be used to develop scenarios of future changes. For the Mediterranean Basin, GCM results point to a warming similar in magnitude to the global-mean value, with no evidence for any marked seasonal differences. Although the magnitude of this warming is uncertain, we can be fairly confident that, as a prediction, it is qualitatively correct.

It may be many decades before the change can be statistically detected above the noise of natural regional-scale climatic variability, the existence of a background warming trend will still be of considerable importance. With time, the probability of periods of extreme warmth will increase; increased air temperatures will also lead to greater evapotranspiration.

7.2. Precipitation

Projected precipitation changes vary so much from model to model that one cannot say on the basis of model results alone whether precipitation will increase or decrease. Depending on location, model used and season considered, projected changes over the period between now and around 2050 range between $\pm$1mm/day, which is roughtly the mean precipitation rate for the Mediterranean Basin as a whole. Such large changes are undoubtedly unrealistic and probably reflect model deficiencies. However, the possibility of substantial changes (say up to $\pm$30% over the next 40-70 years) must be considered. These possibilities will certainly be amended by more detailed investigation using existing data and models. GCMs themselves are constantly being improved, and much better results can be expected to appear within the next 5-10 years (Wigley, 1989).

Cyclogenesis and rainfall are often promoted by land-sea temperature contrasts. Because land and sea have different effective thermal inertias, a large-scale warming could affect this contrast, possibly reducing it in winter months. This could in turn lead to reductions in rainfall and in storminess, particularly in the eastern Basin. On the other hand, warmer sea surface temperatures both in the Mediterranean and in the North Atlantic could lead to increases in atmospheric moisture and thus precipitation. In addition, since the monsoon circulation is expected to intensify, the number of extreme events resulting from the incursion of monsoon air masses may increase in the east. A more intense monsoon may also lead to increases in precipitation in the headwaters of the Nile, with important consequences for Egypt. The situation here, however, is unclear because the tropical easterly jet, which is an integral part of the monsoon system and which extends over the Nile headwaters area in summer, can also affect precipitation amounts and patterns. A northward movement of the easterly jet could reduce rainfall in Ethiopia and the Sudan.

Much of the Mediterranean region's precipitation is influenced by interactions between the large-scale flow and orography. Changes in the former are virtually certain, and a northward shift of the main upper westerly flow could reduce the length of the rainy season, particularly in the western and central parts of the Basin.

7.3. Sea level rise

Another main consequence of a warmer atmosphere is an accelerated rise of sea level, due to the melting of alpine and polar glaciers and to the thermal expansion of oceanic waters. Sea-level has been rising since the last glacial maximum (120m rise in last 16,000 years at rates as rapid as 8 to 12 mm/year). In recent historical times, the rate has been 0.5 to 1.5 mm/yr. Analysis of tide gauge data, the principal source of evidence for detecting relatively short-term sea level trends, suggest the world-wise rise has been about 10-15 cm in the past 100 years. In Holland the rise from 1870 to 1980 was 18-20 cm, accompanied by a 15-44 cm rise of high tide level (Hekstra, 1986). Discounting local subsidence and uplift, the average global rise has been calculated at

1.22 mm (0.9-1.4 mm) a year (Gornitz and Lebedeff, 1987); or 1.5±0.3mm/year, between 1940 and 1975 (Emery, 1980). According to French National Geographic Institute data, from 1885 to 1979, there was a rise of 10 cm, with an acceleration between 1944-1955 and a decrease afterwards (Wigley, 1989a).

However, there are considerable difficulties in interpreting the tide gauge data on which the above estimates are based, particularly regional tectonics, local subsidence, variations in river discharge, etc. This uncertainty is consistent with our uncertainty regarding the causes of past sea level change. Thermal expansion of the oceans has probably caused a 2-5 cm rise and the melting of small mountain glaciers has probably added another 3-5 cm. The contribution from the large ice sheets of Greenland and Antarctica is unknown, possibly either increasing or decreasing sea level.

Depending on the extent of oceanic thermal expansion and (especially) the behaviour of the polar ice caps (Greenland of the western Antarctic ice shelf), conservative to moderate estimates of sea level rise range 13-39 cm (by 2025), 24-52 cm (by 2050) and 38-91 cm (by 2075) (Hoffman, 1984; Robin, 1986). The Villach 1985 Conference (Bolin et al., 1986) concluded that a global warming of 1.5^{o}-4.5^{o} would lead to a sea-level rise of 20 to 140 cm. Future sea level rises have most recently been estimated at the UNEP Meeting in Norwich, September 1987. The best estimate of change between 1985 and 2030 is 14-22 cm, the approximate rise of sea level over the past 100 years.

There will be a significant lag in sea level rise, however coupled with oceanic thermal inertia. For example, if greenhouse gas concentrations stopped increasing in the year 2030, warming would continue for many decades. Since the glacial melting and thermal expansion of the oceans would continue, so would sea level rise.

Superimposed on sea level rise will be the effects of local tectonic and sediment compaction. Vertical earth movements in the Mediterranean commonly occur at a rate of 1-5 mm/year averaged over thousands of years, and 3-20 mm/year averaged over 15-20 years. Local subsidence can exceed 5 mm/yr. It follows that in the future the economic cost of protecting or abandoning structures or land on the Mediterranean coast will depend strongly upon the local land movement coupled with sea level rise. Where land is subsiding, the net relative change could be much more than the global eustatic rise of sea level; where land is rising, the relative change will be significantly reduced. It is therefore practical to try and construct a regional map of the Mediterranean coast showing the areas which are rising or subsiding.

8. AN EVALUATION OF THE IMPACTS OF CLIMATIC CHANGE ON THE COASTAL ENVIRONMENT

8.1. The approach to impact assessment

Changed mean annual and seasonal temperature, general air circulation and precipitation will affect (Fig. 14):

(a) surface and groundwater flow and river regimes, that is surface and ground-water availability, the incidence of floods and the amount of sediment transported and delivered to the sea;

(b) the movement of marine water masses (waves, currents, tides), especially in terms of direction and intensity of storms (i.e. erosion of the coasts) and of tidal range;

(c) natural ecosystems, due mainly to increased temperature and its effects on water and soil qualities;

(d) occupation and use of the coastal lowland regions (0-5 m) because of sea-level rise, and altered parameters of agriculture, fishing, industry, tourism and the quality of the environment.

The physical impact of sea level rise on the Mediterranean lowland coasts can be predicted, even modelled quantitatively on the basis of the present parameters of morphology, hydrodynamics, sediment budgets, land subsidence and the effects of artificial structures. Equally, the impacts of altered rainfall distribution on surface and groundwater could be modelled quantitatively, and the effects of increased air temperatures and changed soil-water parameters on biosystems can be estimated, at least qualitatively, which then give 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 the threatened lowlands (Jelgersma and Sestini, 1989).

Coastal zone management must be based on "cost-effectiveness", which means an assessment of the "value" of the threatened land uses, not only in terms of their present functions, in the context of the local needs and of the importance of the lowland concerned to its hinterland and further, but especially of those of decades ahead (Fig. 15). The primary needs are determined by the present level of population and its trends of growth or decline; the wider economic role of the region by external market forces. For instance, the future relevance of local industries, agriculture and ports, will largely be conditioned by world-wide commodity prices and trade trends, such as those of mineral and energy raw materials, with their effects on heavy and chemical industries; those of cereals and industrial crops; and by the demand for consumer goods in a competitive international society. The role of individual ports may change, in response to altered trends of maritime trade (e.g. the Suez Canal after substantial decline of petroleum transport); local markets for consumer goods and services could vary in relation to stagnating or reduced urban growth due to shortage, and pollution, of surface and ground water. The demand for beach recreation would certainly continue, but social habits may change, in particular if urban-type resorts (e.g. Italy, Belgium) cannot be physically maintained.

Impact assessment also will depend on the future state of the environment, given its present "manipulated" situation, and on the effects of developments that are planned to last a number of decades.

Some economic activities and land uses cannot be projected into the future because they are interrelated with "external" factors - economic, social and political - and therefore can evolve quite independently of local conditions ("innate systems trends"). Physical protection of un-movable assets (historical cities, harbours, industrial centres) may be unavoidable; but in other areas retreat or re-deployment could be carried out. Other land uses (e.g. factories, powerplants, beach resorts) gradually would deteriorate and become no longer economically sustainable. New approaches and adaptation also could be considered, such as different ways of beach recreation and the return of at least some reclaimed lands to their previous lagoonal state.

If an impact preventing approach to sea-level rise is to be preferred, in some specific cases, the limits of such a preventive approach are governed by the risk factor set by the government, i.e. the probability of coastal defence failure in a given time frame.

Preventive measures in line with the desired risk factor can be designed and constructed (i.e. adequate coastal protection). There is, of course, a strong relationship between the value of the investment in those preventive measures and the social and economic value of what is to be protected. Reactive planning concerns itself with primary factors such as alert systems, public safety and health, including disease control, emergency transportation and communication, drinking water and stocking food supplies, auxiliary energy, emergency shelter, rescue mobilization schemes, rehabilitation outlines, etc.

A typical preventive response is to build high, strong dikes. A reactive structure, on the other hand, would consist of a detailed plan to migrate a population if/when the dikes are breached.

Both a preventive and a reactive response demand quantitative insight into where the impact will be felt, what will happen, and what the effects will be. In the case of a preventive response the implementation of measures is central, whereas with a reactive response planning is the key. Development of either a preventive or a reactive response structure requires:

- firstly, the creation of realistic sea-level rise scenarios;

- secondly, the determination of what certain water levels will do to the shoreline and the coastal area beyond it. This includes inundation (loss of land), and damage (structures, ecology), but also saltwater intrusion/seepage, further inland (e.g. contamination of groundwater, crop failure);

- thirdly, the assessment of the social and economic impacts and thus values of land, structures, etc.

8.2. Impacts on marine parameters

To understand the Mediterranean response to predicted climatic changes it is necessary to understand both forcing functions and responses over the entire subtidal frequency range. The forcing variable at shorter time scales, like atmospheric pressure and wind variations, will be influenced by changes in climate. The likely general northward shift of the atmospheric circulation pattern will influence the path and frequency of passage of midlatitude cyclones over some parts of the Mediterranean area and various marine parameters will also be affected (Gacic *et al*., 1989).

The horizontal density gradient set up by evaporation is an important source of the large scale wintertime circulation. On the other hand, transients in the residual circulation are also strongly affected by local winds. Therefore, any appreciable change in the seasonal distribution of the winds frequency will result in changes of the volume of the formed deep water as well as in changes of the circulation pattern of parts of the Mediterranean (e.g. northern Adriatic).

The wind affects not only the sea level changes but also is very important in generating the vertical convection and deep water formation processes. The sea level slope between connected basins, which dictates water exchange between them, is not due exclusively to differences in the atmospheric pressure between the two areas. Therefore, studies of the sea level response to the atmospheric forcing are rather important from the point of view of the barotropic water exchange between connected basins.

The impact of large scale climatic variations of the order of a few years, probably will not be restricted to the observed salinity and sea level changes, but will influence also other parameters such as horizontal density gradients, evaporation rates etc., and therefore general circulation, production rates of deep and intermediate waters, etc.

In the shallower areas, temperature rise might establish stratification of the seawater masses, especially during the summer months, which will affect the sediment depositional regime in and out of the bays, causing blocking of navigation channels. Stratification would negatively effect the primary producers of the eutrophic zone, which initially might benefit from the warmer environment but will be adversely affected by oxygen depletion. High summer temperatures might lead to frequent anaerobic conditions in the polluted embayments (e.g. Thessaloniki, Abuqir, Izmir bays).

8.3. Impacts on the coastal zone

A significant rise of sea-level, coupled with storm surges and high tidal ranges, would cause the retreat of beaches and possibly the transformation of some lagoons into bays, the flooding of reclaimed lands, salt wedges to move farther inland in rivers, as well as direct damage to harbours, towns and roads. The impact analysis of these effects is complicated, however, by the growing anthropic interference with natural environments and the enormously accrued economic value of the coastal regions.

Deltaic coasts that are shaped by marine processes have the capacity to reform themselves after major storms, and to rise gradually in phase with the average rise of sea level. This response, however, is sharply curtailed if the tributary river(s) is/are dammed and/or diverted. The stretches of the shore that are already unstable or retreating, will be even more so in 2025.

As the level of the sea rises, a normal beach and barrier island would be expected to migrate gradually inland (Brunn and Schwartz, 1985). Actual examples of this recession are available from the upper Adriatic and the Nile delta coasts (Sestini, 1989 and 1989a).

In terms of physical impacts, increases of more than 30 cm should be considered to be moderate, because they could be coped with by gradual adjustments to existing coastal defences and by acceptance of modest losses. Higher water levels in the lagoons and the flooding of estuaries and canals, especially if associated with land subsidence (e.g. Romagna, Italy) would continue. The beaches in most countries will continue to retreat, in spite, and (in some cases) because of defence structures. Greater increases (more than 50 cm), however, at least locally would have catastrophic consequences, involving hard economic decisions about the cost of coastal protection and political decisions about what to protect and what to abandon.

Main concerns would be wave attack on harbour structures, the retreat of the headlands, the flooding of the residential and industrial quarters and the management of the lagoons.

8.4. Impacts on rainfall and water resources

As regards rainfall, the most important climatic change would be the northward shift of winter cyclonic patterns affecting the western and central Mediterranean in winter. There might be a deceleration of cyclonic activity and more erratic rainfall, drier summers, higher evapo-transpiration rates. Air circulation to the mountain masses would, in principle, remain the same, i.e. greater rainfall would characterise, the western Pyrenees, the Eastern Alps, the western Balkan mountains, the mountains of the Near East. The areas of lesser reliable rainfall (presently Africa, Sicily, south Spain, interior Turkey) might increase and shift northward. Overall, rainfall is expected to decrease in the south (Wigley, 1989).

Precipitation and evaporation over the Alps are not expected to change, but larger areas will be frost-free in winter and less water will be stored as snow. This would lead to retreat of the snow-line (upslope by ca. 500m); the disappearance of the eastern alpine glaciers, and a 70-80% reduction of the western glaciers.

Lesser and more erratic precipitation would cause reduced groundwater recharge (also due to lower percolation rates) and therefore lesser groundwater levels and spring discharge. Decreased percolation would result in greater flood risks as well as higher sediment loads. There would be greater sedimentation in channels, with possible increase of braided versus meandering streams. The lifetime of reservoirs will be reduced. The cost of maintaining a sufficient amount of good quality drinking water will increase, because of salinization and waterborne environmental risks (pollution, diseases).

Actual evapo-transpiration in the region will increase by around 10% when mean air temperature rises by 1.5°C. This will result in, at least, a 10% decline in riverflow and a corresponding increase in freshwater salinities. Potential evapo-transpiration and open water evaporation will rise by at least 10%. Despite an increased need for irrigation water, the average storage in the reservoirs will fall by up to 25% due to decreased river flow and precipitation and increased evapotranspiration; reservoirs will be nearly empty up to 19% of the time. An expected 25% filling of the reservoirs with sediment will seriously increase the water supply problems, with mean storage falling to around 60% of the projected levels under present conditions.

Climatic zones may shift northward thus increasing the length of summer at the expense of the other seasons. Increased variability and patchiness of the rainfall might extend summer aridity. Scattered rainfall may totally disappear during the warm season and might be transferred to winter. Reduction of rainfall during the hot summer period might cause deficiency in soil moisture, thus degrading soil structure and agricultural fertility. Moreover, the reduced run-off could cause seasonal salt-accumulation in the top soil of several reclaimed lowlands.

8.5. Impacts on Soils

There is a great diversity of soil types in the Mediterranean region, reflecting differences in the major soil-forming factors, one of which is climate. Some soil parameters are particularly sensitive to temperature and rainfall changes, e.g. soil composition and salt balance, chemical processes and the supply and breakdown of organic matter. The expected climatic changes should not result in a major shift in the boundaries of the main soil types (Imeson and Immer, 1989).

Evapo-transpiration and any decreases in the rainfall duration and intensity would increase salt accumulation. This would particularly affect areas where annual rainfall is less than 600 mm. Areas with salt and sodic conditions will expand, because of greater evaporation, decreased water precipitation and runoff, resulting in the slaking and dispersion of the soil surface.

The impact of climatic change on land degradation in the Mediterranean region will be most serious in areas where soils have an inherently high erodibility, in regions already under environmental stress and in drier regions. Forested areas will also be adversely affected by the increased frequency of fire. Direct impacts on degradation resulting from changes in the magnitude and distribution of precipitation could be extremely important but no information is available concerning precipitation changes. An increased temperature, by influencing the mineralization of organic matter and the form of organic soil material, the water balance, the salt balance and the soil temperature will impart to the soil an increased susceptibility to physical degradation. Special attention is given to the effect of organic matter on soil stability and infiltration in areas having silty and sandy soils. Poor physical properties are likely to be caused by increased areas affected by clay dispersion. Gully erosion and piping could spread into areas that develop slightly drier conditions as a result of quantitatively small changes in the chemical composition of the soils (Imeson and Immer, 1989).

To assess the impact of climatic change, relationships should be established between climatic parameters and "climate sensitive" processes. Threshold conditions should be identified by laboratory experiments and by field investigation along climatic gradients. The "site specific" impact of climatic change will determine the exact effects of degradation and erosion. Local studies will have to be made to establish exactly how site specific factors determine the impact of general trends.

8.6. Impacts on ecosystems

Aquatic ecology is likely to be affected profoundly by temperature rise. Shallow onshore marine areas would become warmer, and more saline, locally hypersaline. In the ocean a $2^{o}C$ rise in air temperature would result in a water temperature rise of $0.8^{o}C$-1.5^{o} down to 200 m between Lat. $30^{o}N$ and $30^{o}S$; surface currents would change over large parts of the oceans, possibly also in the Mediterranean. Conditions of fish stock and other biological parameters would be dramatically altered. In some areas even a $1^{o}C$ rise might have a marked adverse effect on fish life because of changes of oxygen concentration and changed water chemistry.

Aquatic species have different temperature tolerance and thus assemblages could change in consequence of removal of competition. Cold water species would be forced to migrate or would disappear, sea-river species would be adversely affected by alteration of coastal physiography and inland hydrology. The impact of higher temperatures on inland waters might include algal blooms, massive fish kills, possibly the invasion of diseases (e.g. bilharzia, malaria).

Changes in seasonal rainfall distribution patterns could, no doubt, have significant impacts on natural vegetation. Significant changes in the amount of mean annual rainfall or in its seasonal distribution pattern would have dramatic effects.

An increase in the mean annual evapo-transpiration of 180-220 mm, would have a slight impact on natural vegetation and crops, but it could be significant in areas where climatic or soil conditions are marginal in respect of types of vegetation or crop. One may also expect a slight shift in vegetation belts due to increasing aridity. Expanding desertification at the margins of the Sahara and Near-East deserts will happen, in any case, the result of the exponential growth of population. Climate change would just aggravate the phenomenon (Le Houérou, 1989).

A general $2^{o}C$ warming would lead to a shift of the natural range of species by 300 - 500 km northwards and 300 m in altitude. In the Alps ecosystems would move upwards 600 - 700 m; evergreen species of oak would expand in the mixed woodlands at lower altitudes on the southern and eastern margins of the chain.

Forests are likely to suffer from the increased temperature and aridity. The longer periods of drought will affect forest species that survive at the limit between semi-arid and humid conditions, shifting their occurrence to higher altitude. Forests of deciduous trees require ample moisture during the growing season; many species, would therefore disappear. The coastal plantations will suffer from salinization and, probably, remobilized sand dunes. The Mediterranean maquis cover could be affected by desertification. Finally, forest fires will become more frequent, also involving higher areas than at present.

Nature conservation will require re-assessment and new policies. The protection of species through the maintenance of present natural conditions will be increasingly difficult,if not impossible. In some environments, only species adapted to unpredictable, rapidly changing environments will be able to survive; rare species living in restricted ecological islands might not be able to migrate. Bird migrations will be affected by higher temperatures in the more boreal regions and by the changed ecosystems of their traditional staging and wintering locations.

8.7. Impacts on agriculture and fisheries

Weather fluctuations (temperature, heat waves, availability of water in the plants growing stages, hail or heavy rains in the ripening stages) will affect several Mediterranean crops (wheat, soya beans, sugar beets, tomatoes, tobacco, citrus and other fruit trees).

Change in winter temperature would have a very significant impact in areas where this factor limits plant growth, that is in most of the Mediterranean Europe highlands, and in mountain and continental areas of Northern Africa and the Near East. It would, for instance, increase the areas of cultivation of cold-sensitive crops such as olive, citruses, winter cereals, vegetables. Agriculture is likely to change towards even more intensive irrigation and use of greenhouses, at least in many areas.

Nevertheless, warmer winters and severe water deficits will threaten the existence of tree cultivations (e.g. olives, nuts) that require a dormant period at relatively low temperatures. Crop plants will be adapted by selection of different strains (Le Houérou, 1989).

Soil fertility should tend to decrease, fewer nutrients being available to the plants due to increased soil salinity. Irrigation would become increasingly necessary, but also more difficult and expensive, requiring better soil drainage. Cultivated areas in floodplains could be affected by a greater incidence of floods and by changes in channel morphology.

In a globally warmer climate, some tropical and subtropical plant diseases will move north, and the distribution of insects and pests will be altered. There will be a need for new biological and/or chemical controls of pests and pathogens.

8.8. Impacts on society

Climatic changes should not affect the distribution and dynamics of human population in the littoral zones, because the natural growth of the population will continue to follow the present trends in the individual countries. They are slowly growing (perhaps static and locally decreasing) population size on the north Mediterranean coasts, or large increases in the countries of the southern coast. Migration to coastal areas could accelerate in the south due to increased desertification in the interior (Baric and Gasparovic, 1989).

At the present time approximately 133 million people (37% of total population of Mediterranean countries) live in the littoral zone (only 17% of the total area of these countries). 60% of them live in the urban zones. According to the five Blue Plan scenarios, in the year 2025 there will be between 200 and 220 million inhabitants in the coastal zones, 75% of which in cities.

Any foreseable change in temperature would have an almost negligible impact on the environment compared to the demographic explosion. Nevertheless, sea level rise will affect considerably the economy and well being of many countries, especially because many low coasts will increasingly experience physical instability due to sub-residence and river sediment starvation. A major risk is represented by an increase in frequency and intensity of storms and of storm surge flooding. Major expenditures will be required to control longshore drift and beach erosion. The main concerns include greater wave attack on harbour structures, retreat of headlands, and the management of lagoons.

Expected demographic and economic changes in Mediterranean coastal zones vary considerably. In the Ebro delta, a temperature increase of 1.5^{o}C and a sea level rise in the range of 20 cm, will have much lower effects on the system than the man-induced modifications. Nevertheless, these changes will increase actual erosion processes and lead to more frequent flooding of the wetlands, increasing their salinity and destroying the present flora and the nesting grounds for migratory birds. As the coastline retreats, the bays and lagoons gradually will be closed, affecting the area's marine productivity (Marino, 1989).

In NW Italy and in the Gulf of Lion settlement patterns should change little because of low population growth. The main concerns for regional management would be the availability of water resources. In France, most of the large urban centers (Perpignan, Narbonne, Béziers, Montpellier, Nîmes, Arles) are built back from the shore, thus are protected from any serious impact of sea level rise. On the other hand, the coast, with its tourist resorts and harbours, is particularly vulnerable due to the narrow strip of sand and the low altitude of the dunes ridges (Corre, 1989).

In Italy, the main threats will be to the survival of Venice (and other towns of artistic-historical importance), to the tourist industry, to the activities of important harbours, and to specialized agricultural productions. It might be more economical to turn at least parts of the reclaimed sub-zero level lands back to their original lagoonal state, in favour of fishing, which is at present a more efficient and remunerative activity than agriculture. Lagoons and marshes also could act as buffer zones between the open sea and higher land, as well as nature reserves. Industrial and other activities in the areas less than 1 m would probably move gradually inland without excessive disruption (Sestini, 1989).

In Greece, large scale radical consequences could affect the greater Thessaloniki area. The damming and isolation of the Thessaloniki Bay may become a necessary "buffer zone" in order to diminish the impacts of sea level rise on the low lying urban and industrial coastal area. The Bay would be transformed into a controlled lagoon, with essential navigation outlets, and would not negatively affect the greater Thermaikos Gulf marine environment, as seawater circulation and sewage output regime would remain almost unaffected. Otherwise, sea level rise and sea surges will cause significant damage along the whole coastline, as waves will easily overtop the present sea barriers fronting the reclaimed agricultural land, and the cement seawall along the city of Thessaloniki. The beaches at the eastern end of the bay might gradually disappear due to high erosion, producing significant economic effects on recreational land use (Georgas and Perissoratis, 1989).

In the Nile delta, the nature and extent of climatic impact will depend largely on the degree of coastal development during the next 2-3 decades. Intensified land-use in the coastal zone is inevitable, due to the continued growth of population and the consequent need to augment food production through the further extension of land reclamation and of lagoonal fishing. These developments will place an increasing stress on water supplies. The most serious negative effect of sea level rise could be on ports, lagoonal fishing and lowland agriculture, and thus, indirectly, on population centers, which are tied to port and agriculture-related industries. Therefore, the main impacts of economic significance are those that impair the efficiency of harbours and the proper management of lagoonal fisheries and lowland agriculture. Alexandria will lose its attraction as a summer resort city, but the recreational use of beaches is not threatened elsewhere (Sestini, 1989a).

In North Tunisia the whole area is presently adjusting to a period of accelerating change. Canalization, deforestation and agricultural improvements have all had demonstrable effects on the Ichkeul-Bizerte Lake. A scheme to construct more dams on the rivers flowing into Ichkeul between 1983 and 2000 could even more dramatically change the hydrology and ecology in this area. Overall, existing environmental problems are likely to be exacerbated; agriculture will suffer, inland and lagoon fisheries may have already disappeared through the impact of the dam scheme; sea fisheries may benefit slightly, industry will be largely unaffected, water resources will decline in both quantity and quality; settlements will suffer through their foundations and sewers; the quality of urban life may decline through an accelerated influx of farmers abandoning the countryside (Hollis, 1989).

To mitigate the adverse effects throughout the Mediterranean it will certainly be necessary to increase expenditure for:

- the protection of the low coastal areas from sea level rise;
- the protection of fresh water resources;
- the (re)construction of waste water systems;
- the production of food and other agricultural products

The cost of alleviating the consequences of climatic changes might be easily met in the countries with higher national incomes. Poorer developing countries may experience great difficulties in funding the necessary projects to alleviate (or at least temporize) the expected impacts.

9. CONCLUSIONS

9.1. Summary

- There are still some uncertainties concerning climatic change in the Mediterranean and it will be at least 5 years before better assessments of the problem are available. Together with an assumed temperature increase of 1.5^{o}C by 2025, potential evapo-transpiration will increase throughout the Mediterranean, coupled with a possible decrease in precipitation in the south and an increase in the northern part. Climatic changes generally will occur gradually and will not be specifically manifested for another 3-4 decades. Hot dry summers and exceptional events of drought or rainfall and floods, marine storms, tidal surges and of water stagnation and eutrophication, however, could increase in frequency (UNEP, 1988).

- A 1.5^{0} increase in temperature would lead to an increase of land degradation, deterioration of water resources, decline in agricultural production and damage to natural terrestrial and aquatic ecosystems. It also could alter marine circulation both in the Mediterranean and the Atlantic, thus affecting marine productivity and the pattern of pollutant dispersal.

- The future impacts on Mediterranean society by non-climatic factors (e.g. population increases, present development plans) may far exceed the direct impacts of climate change. Non-climatic factors will cause continuous increases in society's vulnerability to climatic stress, particularly in the south. Together, these demographic and climatic changes should increase the probability of catastrophic events and hasten their occurrence.

- Little can be said specifically about the effects of temperature rise and changed precipitation patterns, especially on water resources, soils and biosystems until a reliable $2XCO_2$ scenario is available for the central and eastern Mediterranean (and East Africa); one based on actual topography with a high spatial and temporal resolution, that simulates realistically the patterns of observed climate, and predicts effects on regional weather by altered, larger-scale circulation patterns. There is still no definite indication as to whether and how precipitation over the Mediterranean would change.

- It is particularly difficult to forecast the effects of climatic change on agriculture, beyond concluding that irrigation systems will suffer increasing stress and soil degradation will reduce yields in rain-fed system. For example, what will be the specific and local impacts on hydrology, water resources, water balance in the Mediterranean Sea itself and how will these factors affect socio-economic patterns and policies?

- The effects of a temperature rise on agriculture and fishing might generally be positive (though negative for some species). Changes, however, would be gradual, allowing time for research and technical adaptations.

- Salinization of irrigation water would have negative consequence on sensitive grain yield. Consequently new varieties of crops have to be introduced, adapted to the new natural setting and yield standards. On the other hand, increased plant growth, due to the CO_2 emission and the temperature rise, might increase fertilizer consumption, as the needs in NO_3 will be higher.

- The effects of sea level rise are more predictable even though the extent of sea level rise is difficult to foresee: 1) direct wave impact on exposed coasts (e.g. the Venice lagoon coastal barrier, beach resorts) and on harbour installations (Alexandria, Port Said, La Golette-Tunis, etc); 2) flooding of estuaries, canals, lagoons, which should be more serious for agriculture than for the increasingly more valuable lagoonal fishing. Degradation of lagoons (e.g. Venice Lagoon), however, could seriously affect wildlife and fish resources; 3) a sea level rise of 10-20 cm will aggravate existing shore erosion problems.

- 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 (e.g. lagoons). However, local sea level changes could be up to five times this amount because of natural land subsidence, that could be enhanced by excessive groundwater withdrawal. Particularly negative effects of this impact will be felt in low lying areas, deltas and coastal cities.

- Most of the deltaic lowlands of the Mediterranean Sea are experiencing serious environmental problems because of agricultural, industrial, urban and tourist developments during the last two decades. Problems range from water pollution and salinization to land subsidence, shoreline erosion, and restriction and deterioration of wildlife habitats. This vulnerability is increased by adverse socio-economic conditions, the effects of which will be superimposed upon those of climatic change.

- How will climate change affect soil degradation and erosion? It is suggested that there may be slightly more soil erosion in the headward valleys but the sediment will be trapped there with a major reduction in the sediment yields in the larger rivers, reservoirs and the downstream lakes. The reduction of sediment flowing out to sea, because of the climatic changes and the effects of reservoirs trapping sediment, may accelerate coastal erosion.

- Generally marine and land weeds are expected to benefit from warmer, CO_2 richer atmosphere. Flora and fauna of the wetlands will be forced to a gradual adaptation to induced conditions which might be crucial for the species that possess reduced tolerance to high salinities. As bioclimatic zonation will gradually shift northwards, several species will migrate to the north, and insect populations might increase. There will be favourable conditions for an increasing risk of agricultural pests, bacteria and diseases, especially in the swamps.

9.2. Future strategies

- To develop a strategy for responding to the impacts of change, it is essential to identify those parts of the Mediterranean coastal regions where knowledge is still inadequate.

- Regarding sea level change, perspective actions can be either preventive or reactive. For example, entire coasts and lagoon margins can be walled in, or choices must be made between irreplaceable coastal uses (e.g. national and military harbours, towns of historical-artistic value, lagoonal resources, specialized agriculture); and adaptations. Examples of such reactive actions would be (a) shifting land uses; and (b) a different approach to beach recreation (i.e. less urbanized), the replacement of extensive, uneconomical crops in sub-zero lands, with lagoons destined to aquaculture and nature reserves. The lagoons would act as a buffer belt, since their inner margins can be more easily protected than the exposed coast.

- The above simplified scenarios of physical impacts suggest that there would be an increasing need to "protect" present coastal uses or else local economies gradually will deteriorate. The immediate task should be to identify all "high risk" areas, and a re-examination of the present factors of coastal dynamics in the context of increasing air/water temperatures and sea levels. Storm impact maps should help provide a scientific basis for proper coastal zone protection. Engineering solutions, such as dikes and walls, are not likely to represent a realistic long term solution to the problem of rising sea level, except in very special cases. The coastal dynamics of erosion and deposition, the relative life span of most human installations, and the possibility of providing complete protection for small areas of special importance mean that it is most likely that adaptation, evolution and land use change will represent the most appropriate responses to sea level rise.

- Both timely action and acknowledgement of future requirements is essential.

- Clearly the first need is to develop a realistic sea level rise scenario. Secondly determination of the physical impact on the inshore area is needed. Thirdly social and economic values have to be assessed, i.e. magnitude of existing investment in protective measures. The range is wide; in some developed countries the risk factor of coastal defense safety may be 1 in 10,000, whereas in other countries it is no more than 1 in 20. Preventive and/or reactive planning depends on this factor.

- Close attention needs to be paid to the conservation of soil, groundwater and wetlands resources in the Mediterranean, because they contribute substantially to environmental stability. The overall adverse effects on downstream human settlements and ecosystems by large dam schemes have not been considered sufficiently in past planning. Future water management plans must be scrutinized more closely in relation to climatic change.

- Coastal developments in the next decades should therefore be carefully controlled and directed to locations that could be most economically and effectively defended, avoiding the mistakes made elsewhere which would eventually lead to considerable ruin and disruption.

- Studies of the frequencies of extreme events (high temperatures, high and low precipitation events, storms surges, etc), and how these frequencies relate to mean climatic conditions, are required to help predict probabilities of occurrence.

- The implications of climate impacts for some regions and processes are of very high complexity and therefore systems analysis seems to be the best approach to their study.

- Attention should be given to identifying and accessing data that can be used for climatic impact assessment. The value of long-term data series is stressed. Monitoring programmes to collect such data should be maintained and/or extended. Emphasis should be given to monitoring the effects of climatic impact both for practical reasons and because these may amplify the impact of climatic change. Tidal gauge stations are not adequate to identify either regional/local trends or short-term variations in sea level rise and subsidence; satellite GPS-based geodetic measurements may be needed.

- Of particular importance is the need to initiate research on all climatically-induced changes and to control and plan coastal development well in advance of the postulated sea-level rise in order to minimize the negative effects of man-made dis-equilibriums already experienced in many parts and to make future protection cost-effective.

- It is recommended that organisational and legal instruments be developed to control coastal development, land reclamation and groundwater exploitation. Lowlands could be analysed and zoned in high, medium and low risk categories.

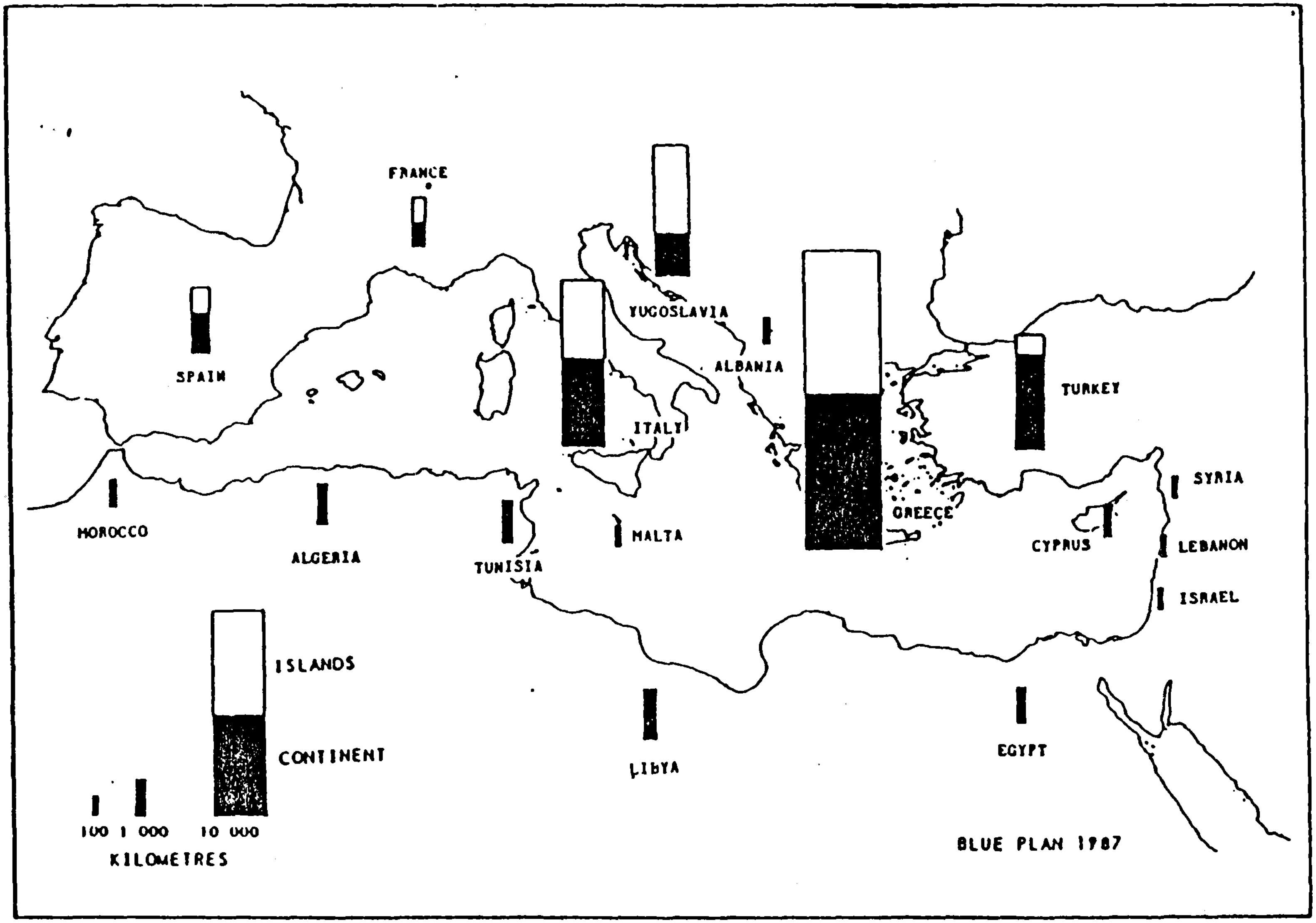


Fig. 2: The Mediterranean coastline (UNEP, 1987b)

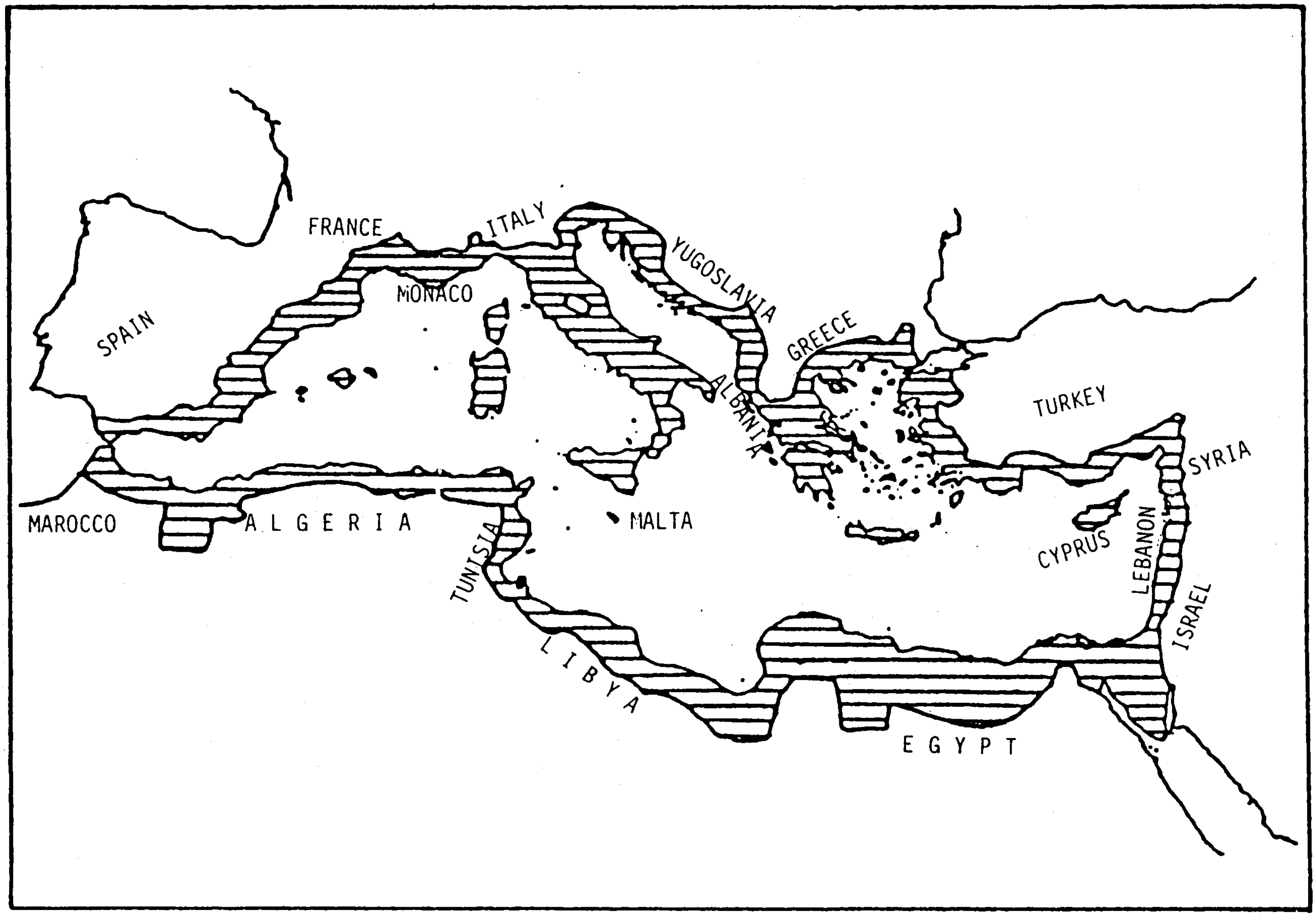


Fig. 3: The Mediterranean coastal regions (UNEP, 1987b)

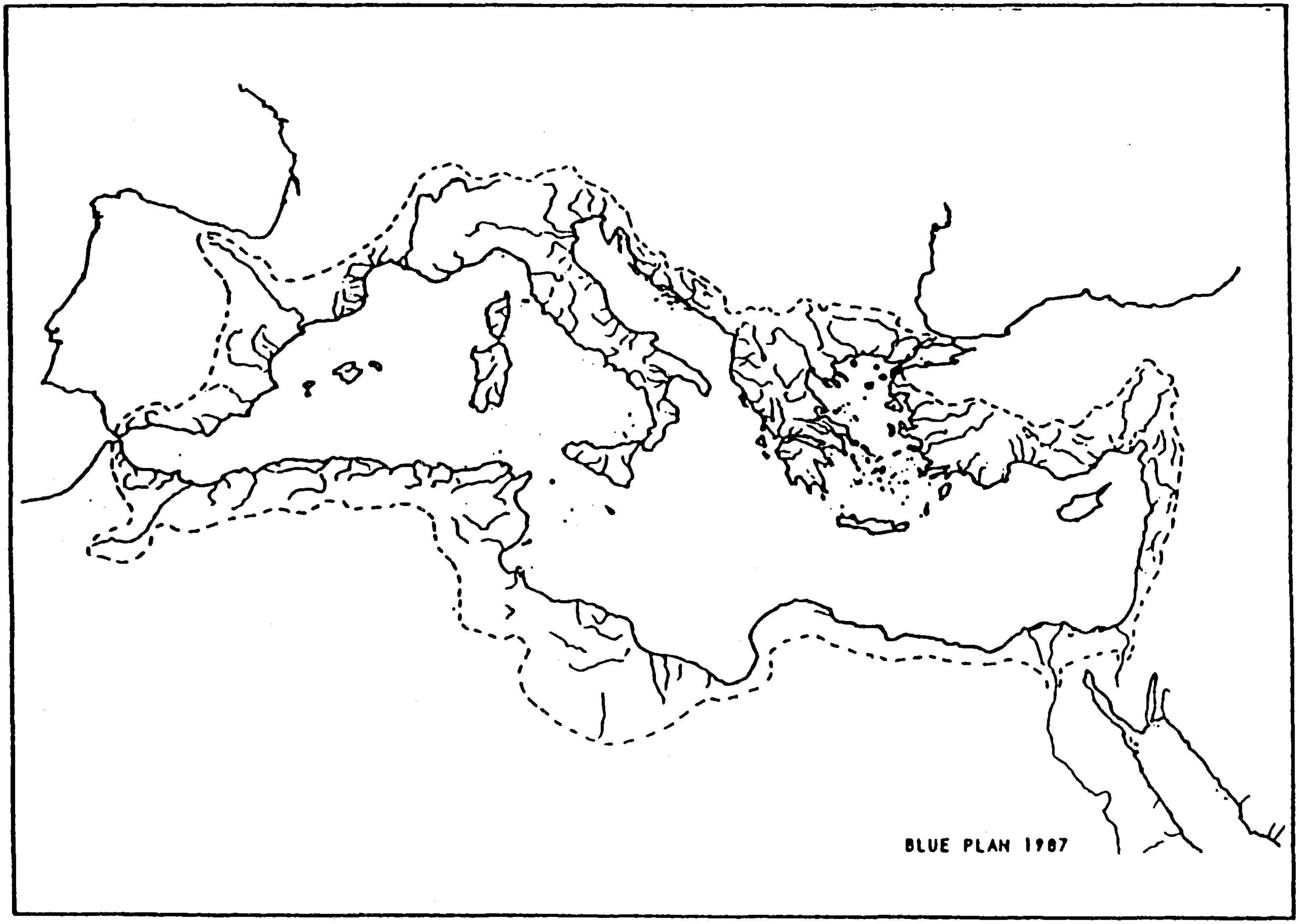
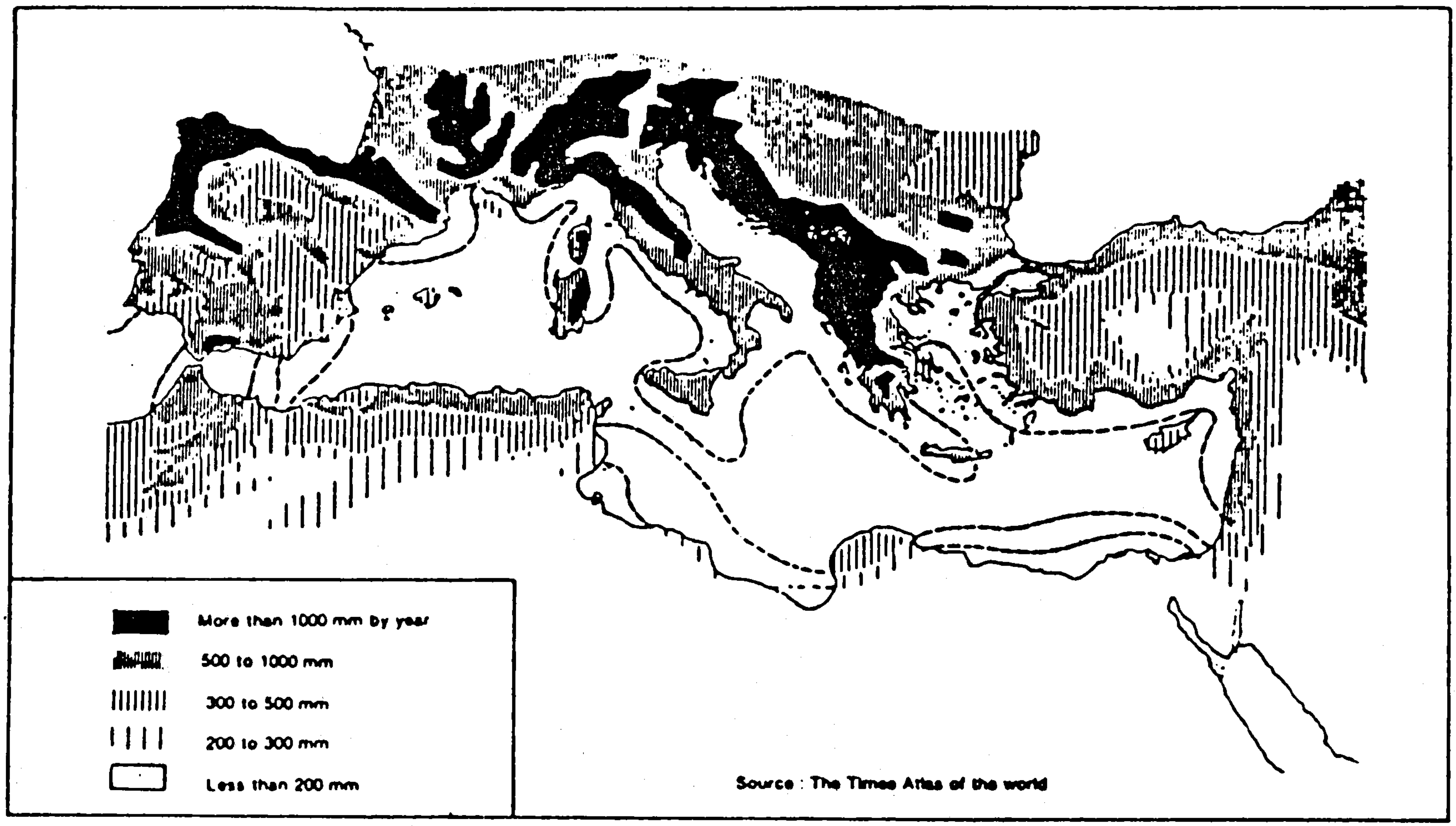


Fig. 4: Main rivers of the Mediterranean basin (UNEP, 1987b)



<u>Fig. 5:</u> Average annual rainfall on the Mediterranean basin

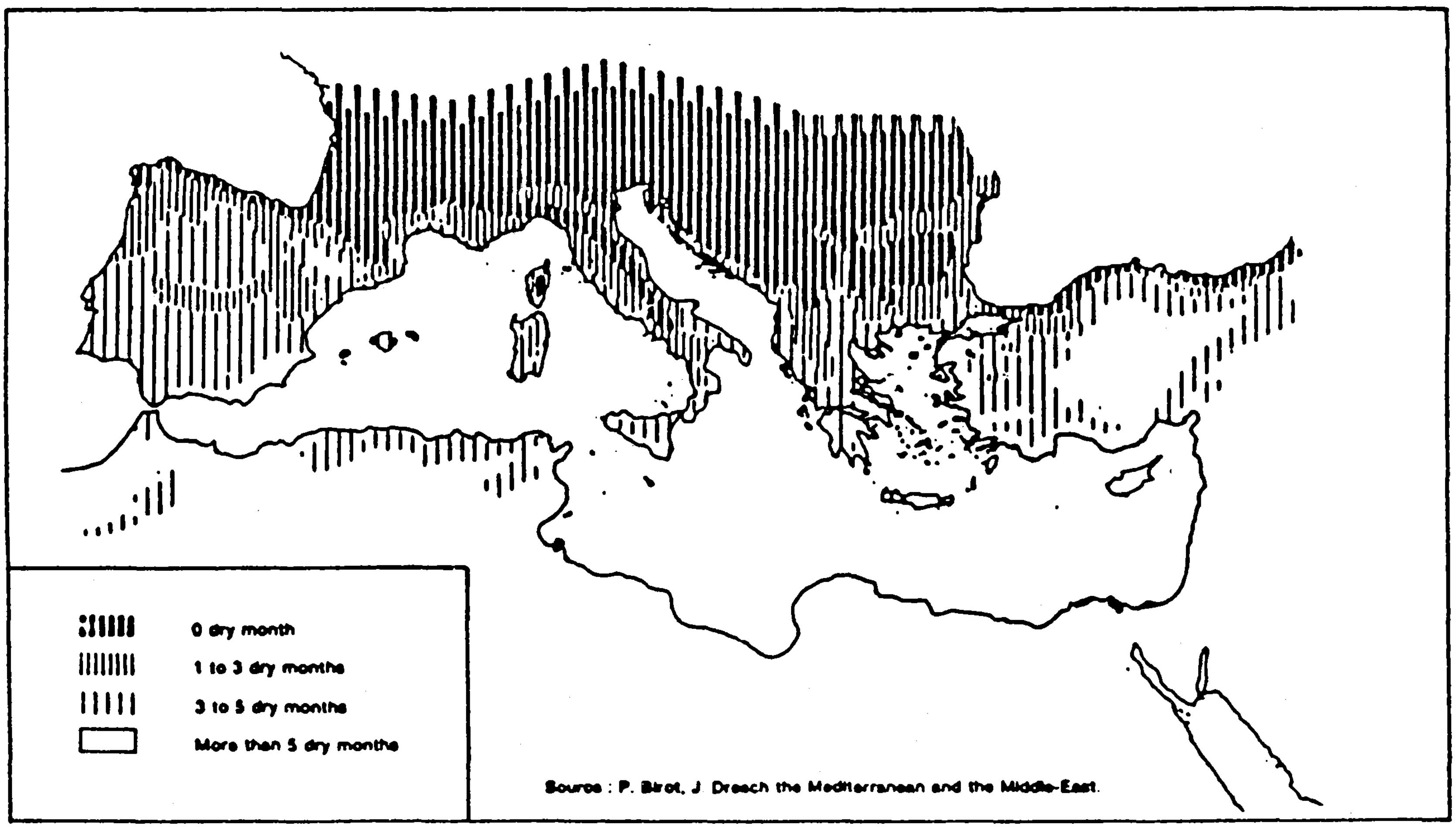


Fig. 6: Duration of dry season in the Mediterranean basin

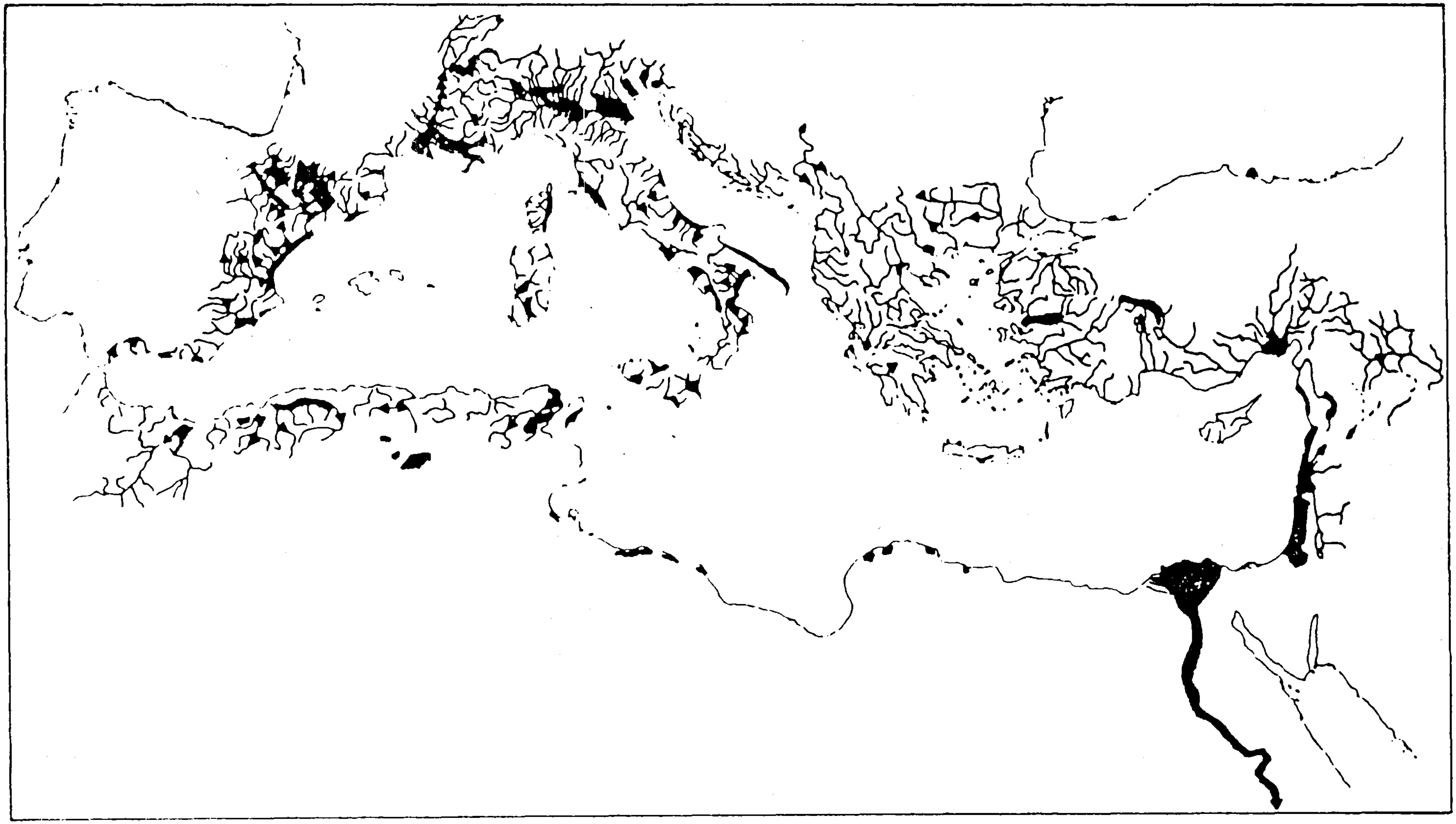


Fig. 7: Reservoirs and irrigated zones (UNEP, 1987a)

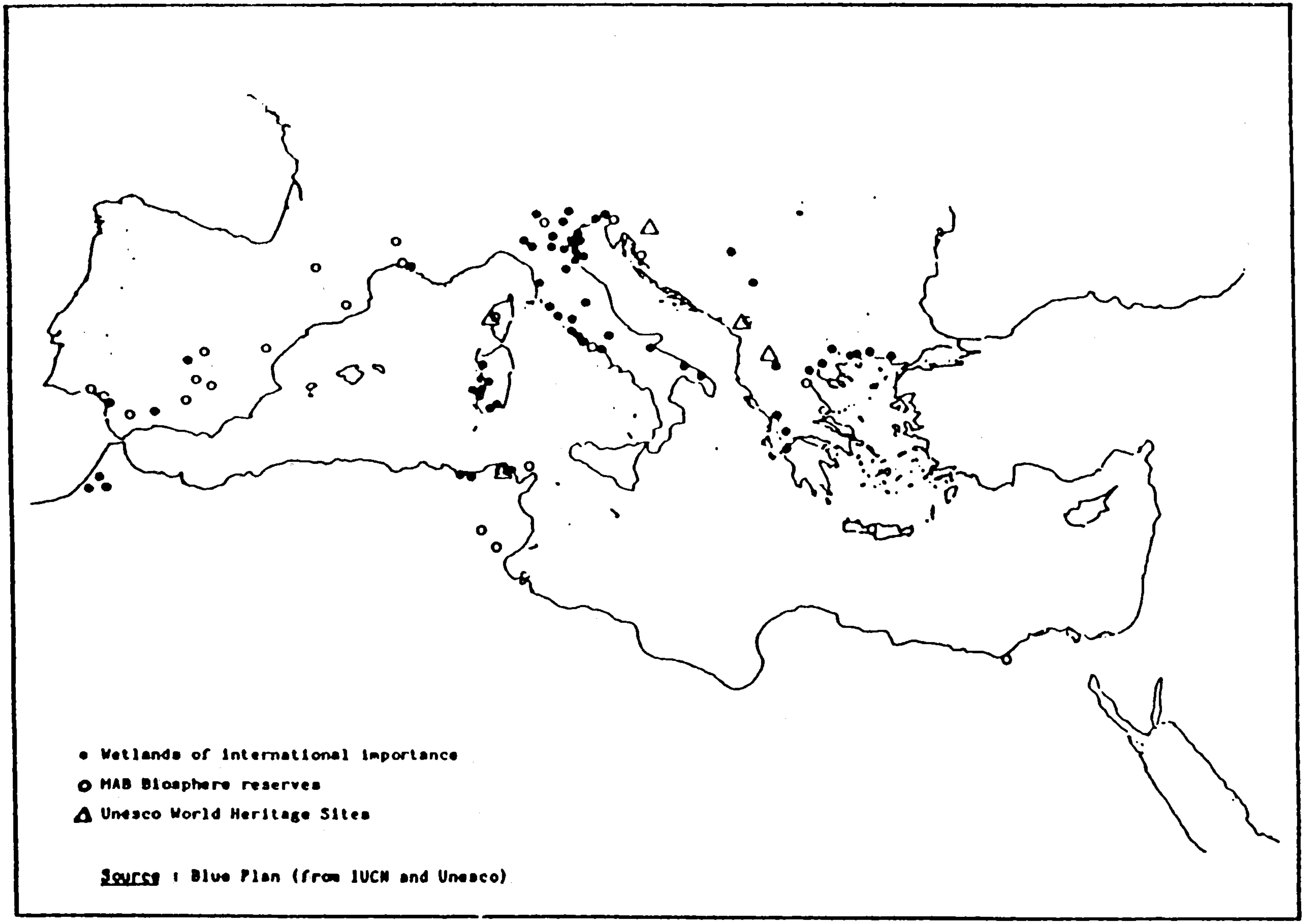


Fig. 8: Wetlands of international importance, MAB biosphere reserves and UNESCO world heritage sites (UNEP, 1987b)

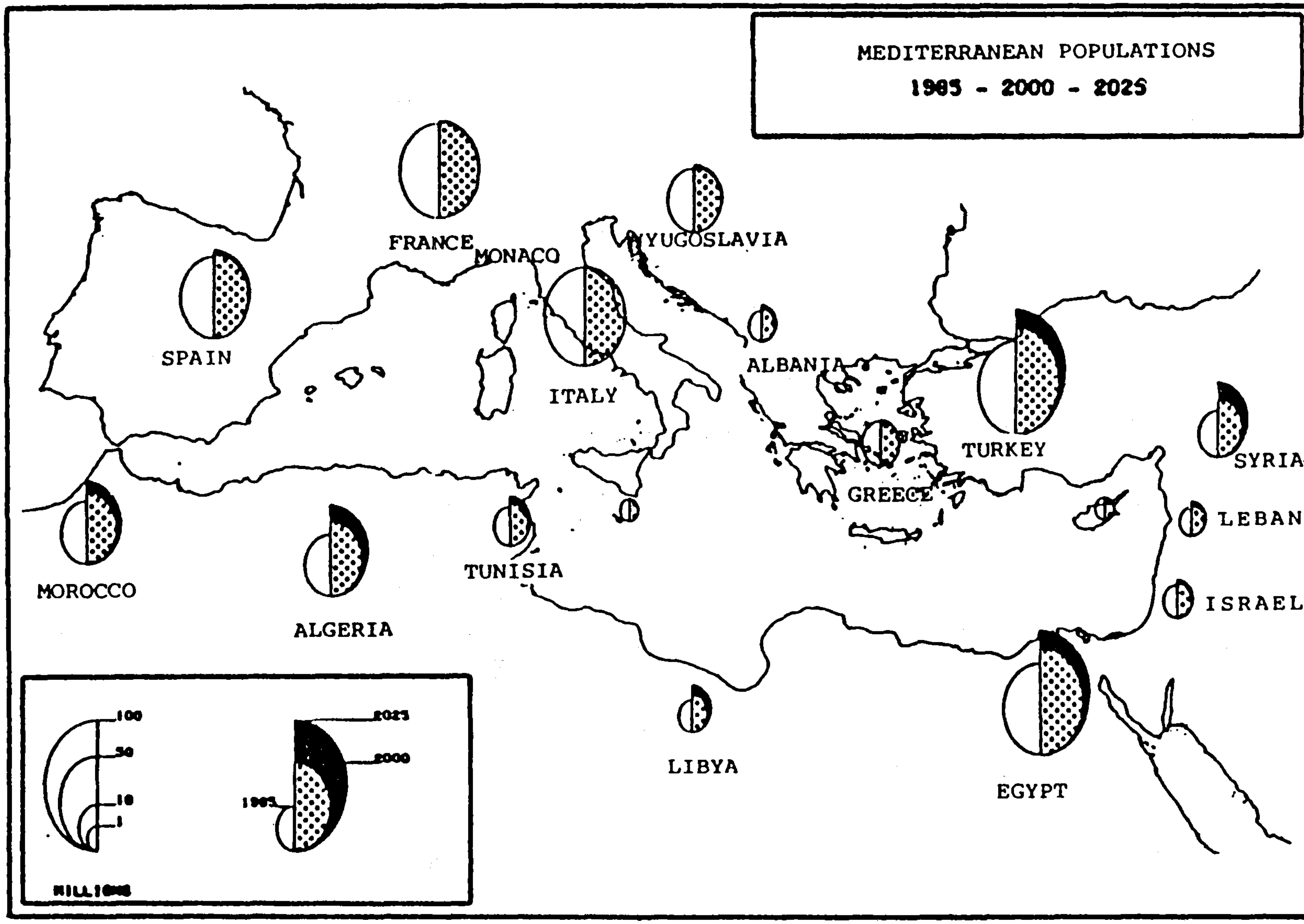


Fig. 9: The Mediterranean Population (UNEP, 1987a)

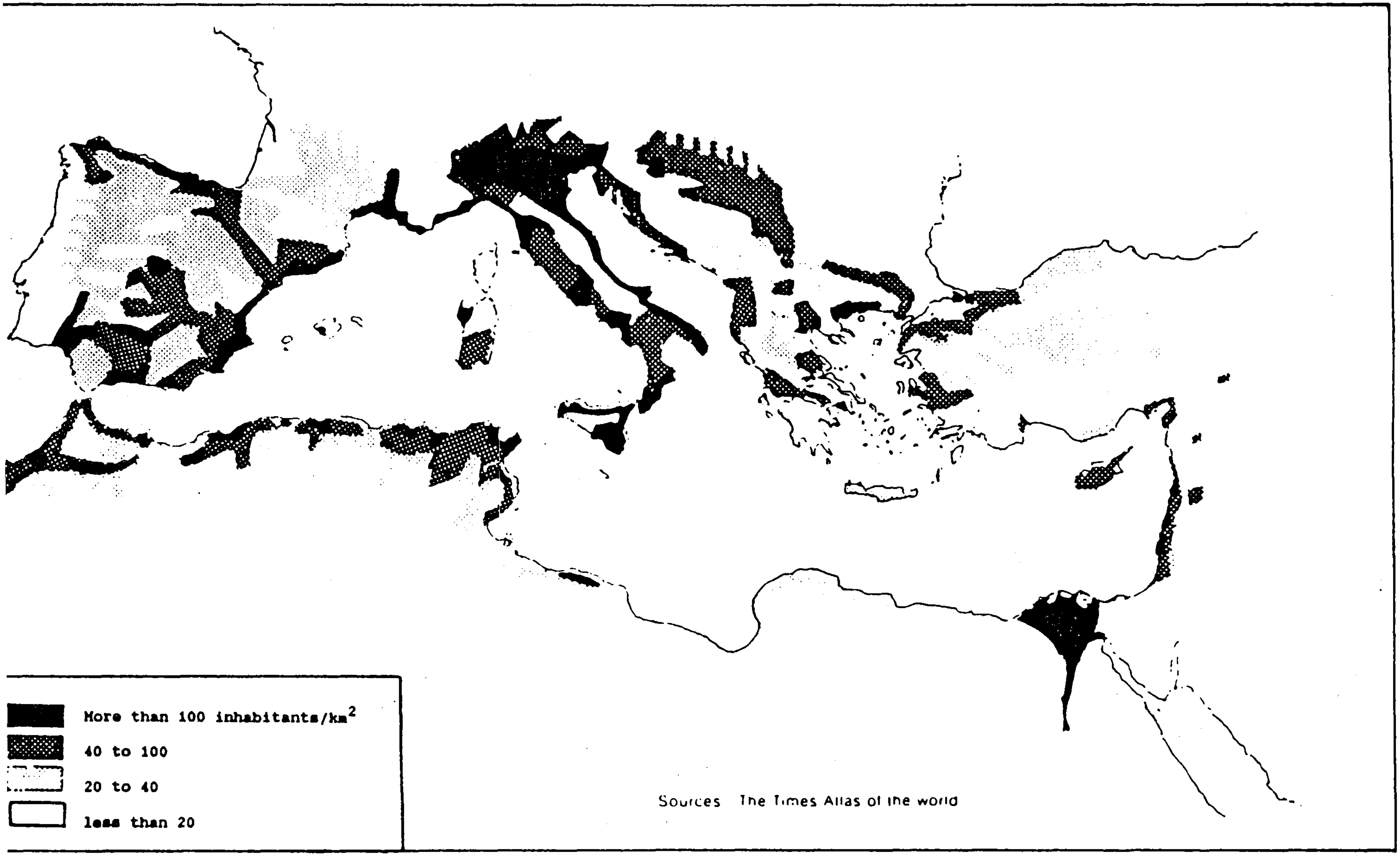


Fig. 10: Density of population in the Mediterranean region

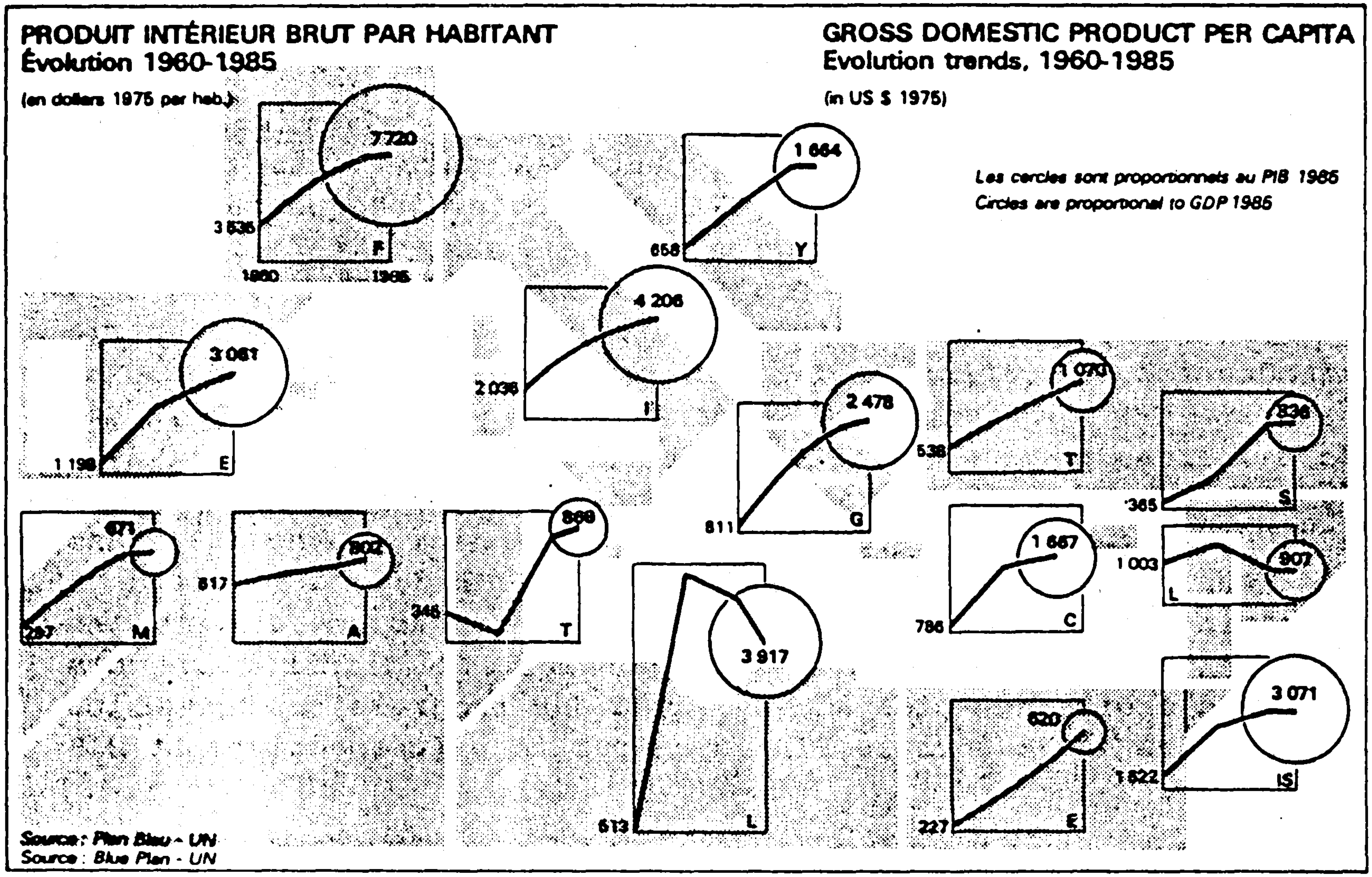


Fig. 11 : Gross domestic product per capita, evolution trends (UNEP,1988a)

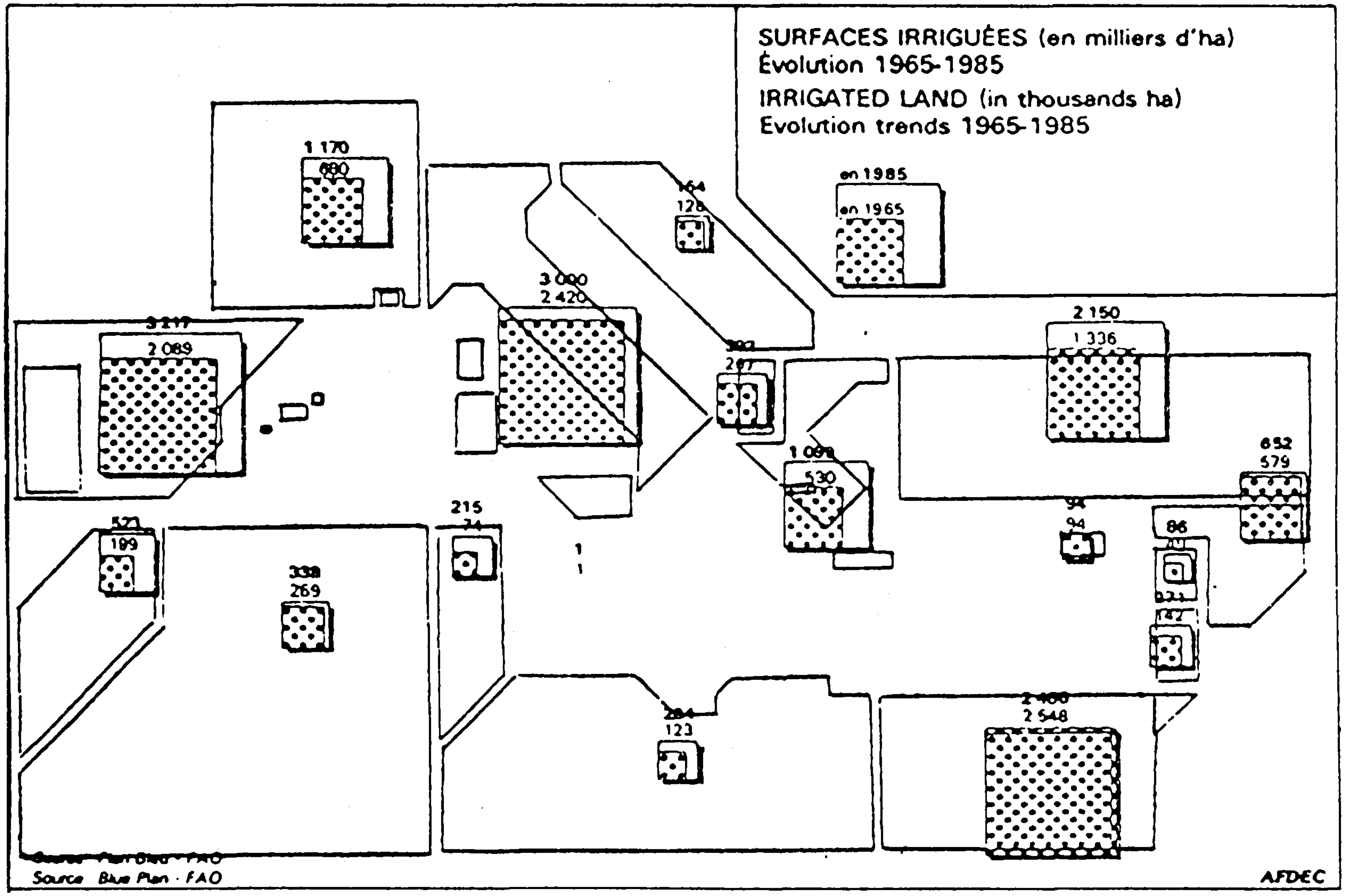


Fig. 12: Irrigated land (in thousand ha),evolution trends 1965-1985 (UNEP, 1988a)

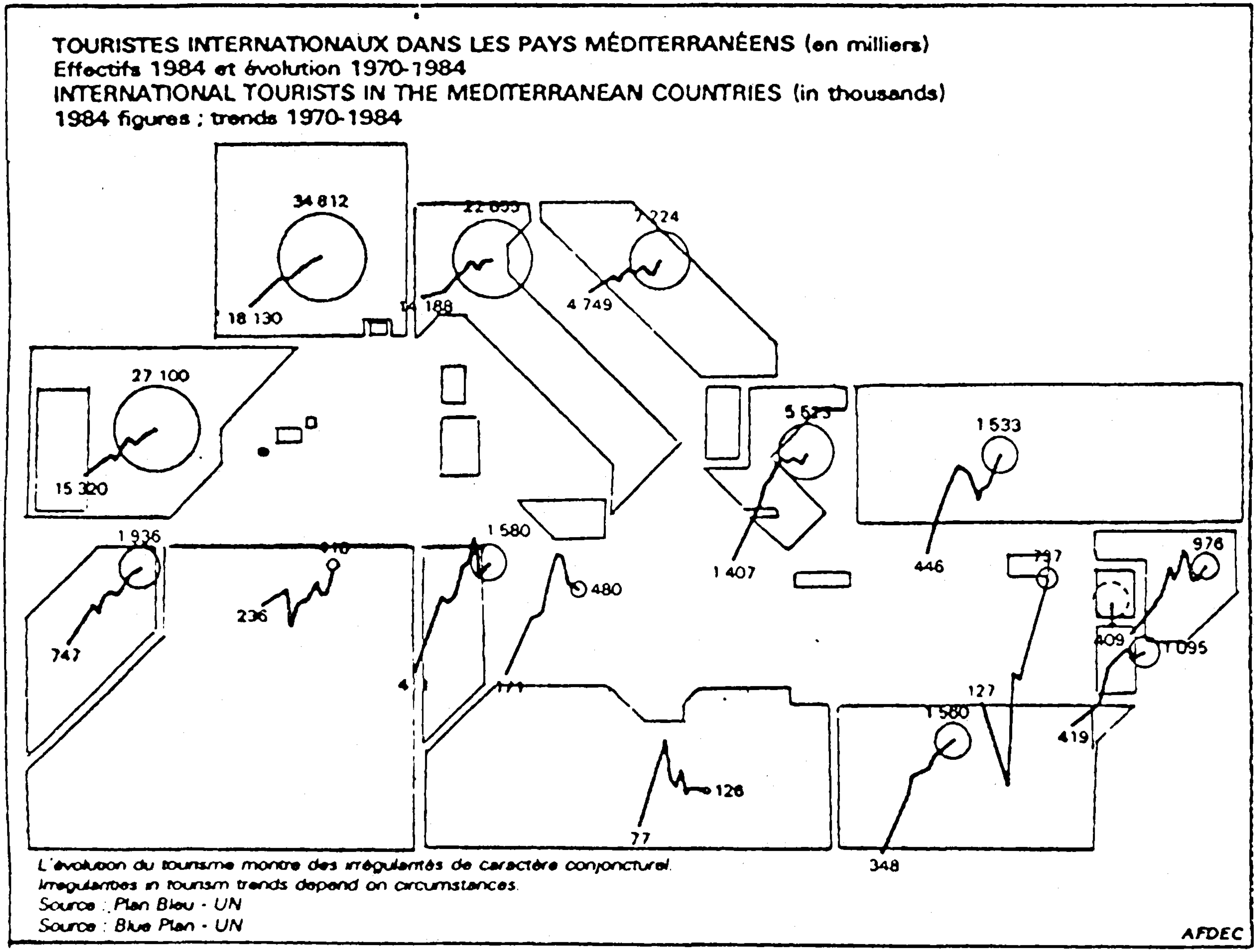


Fig. 13: International tourists in the Mediterranean countries (in thousands) 1984 figures; trends 1970-1984 (UNEP, 1988a)

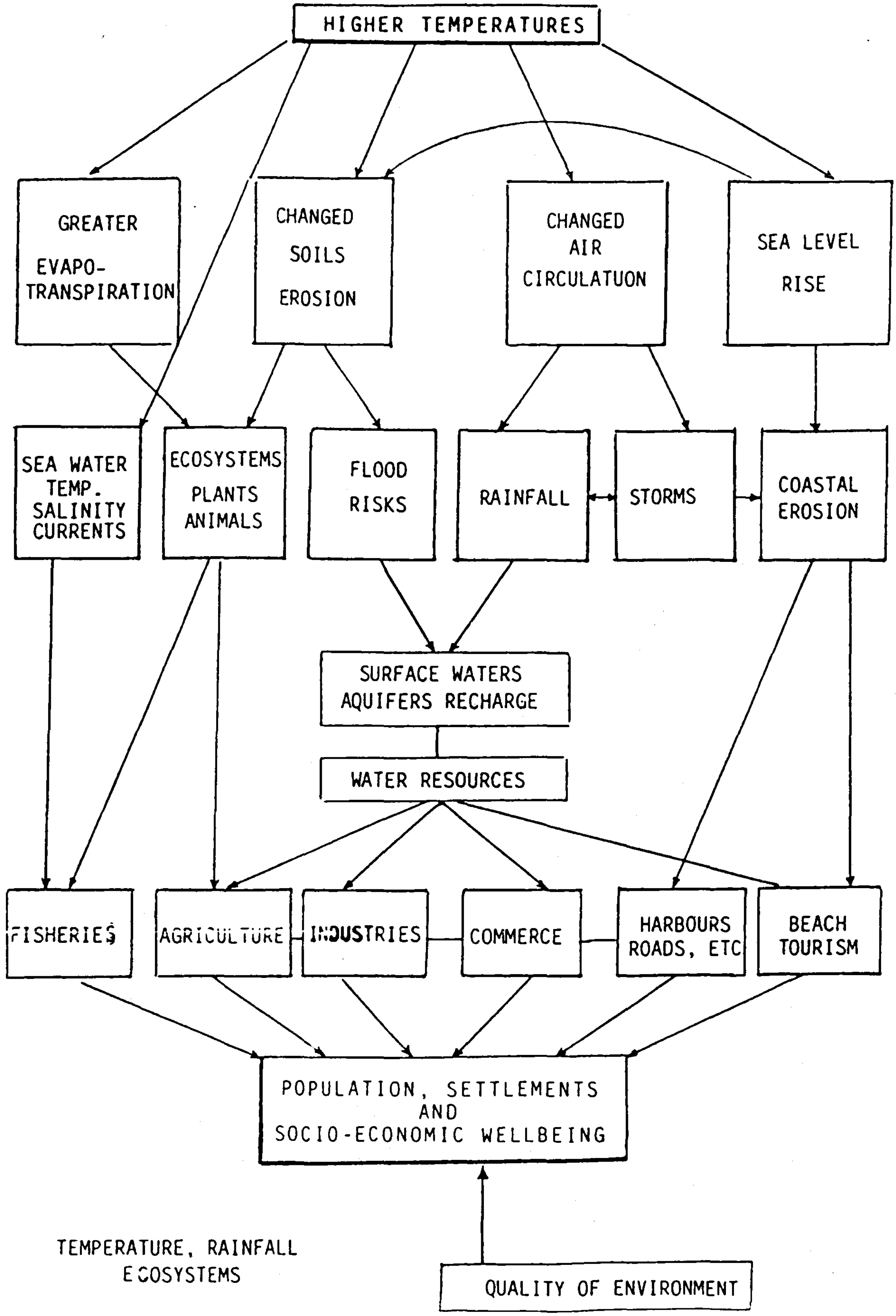


Fig. 14: Impact of climatic changes

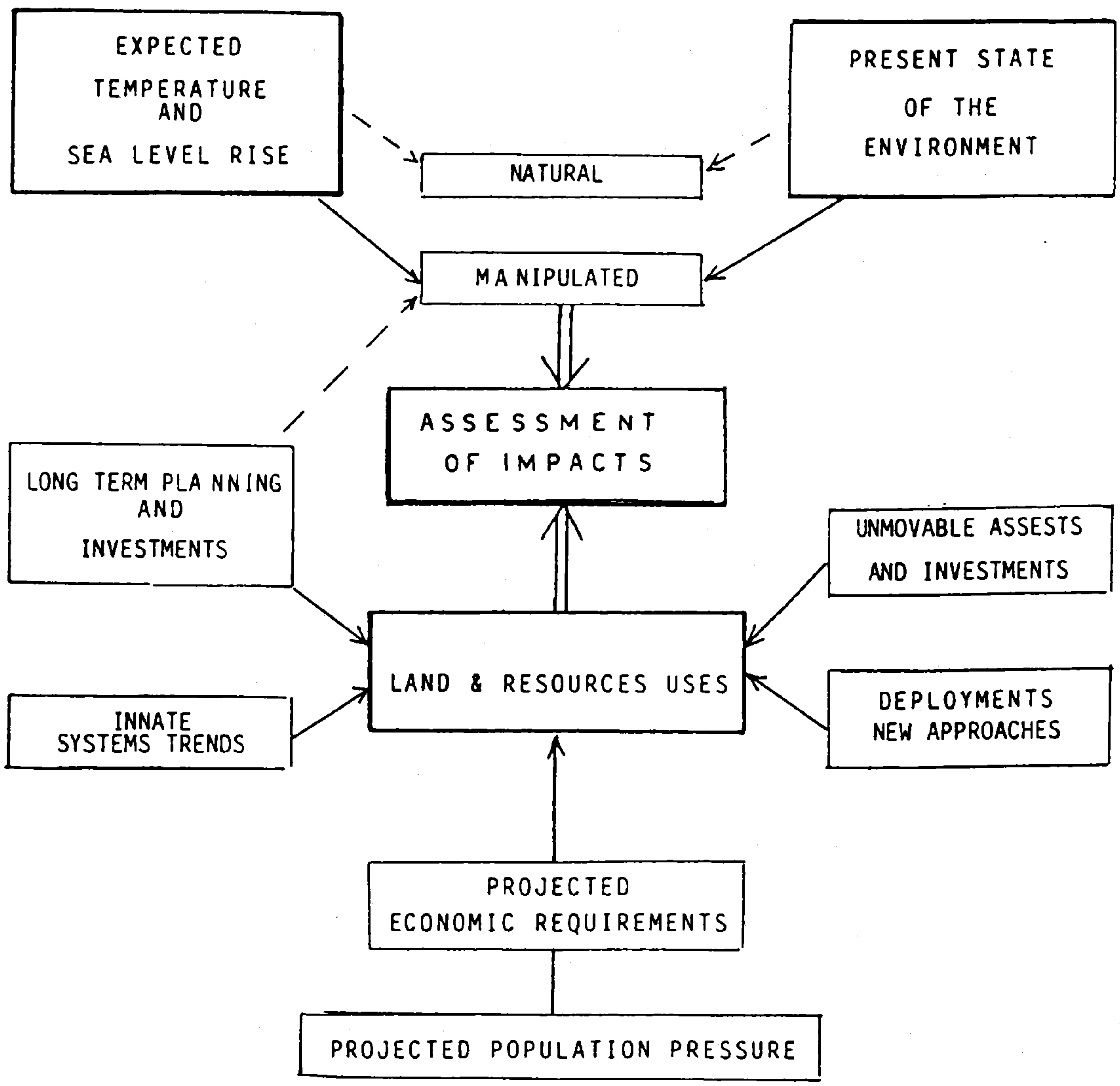


Fig. 15: Assessment of the impact of climatic changes

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ANNEX

FOURTEENTH SESSION OF THE GOVERNING COUNCIL
(Nairobi, 8-19 June 1987)

UNEP/GC/DEC/14/20. Global climate change

The Governing Council,

Aware that national and international studies continue to conclude that a global climate change will result from increases in the concentration of greenhouse gases from human activities,

Concerned that such change would have potentially serious consequences for human welfare and the natural environment,

Mindful of the need to improve expeditiously scientific understanding of climate change, its causes and its consequences, as a basis for formulating appropriate policy responses at the global, regional and national level,

Recognizing the importance of initiating international consideration of possible policy responses,

Recognizing that the United Nations Environment Programme, by effective implementation of its lead responsibility within the World Climate Programme for climate impact studies, as well as through the Global Environmental Monitoring System and its Global Resource Information Data Base, can make important contributions in this area,

Considering that the recently concluded Tenth Congress of the World Meteorological Organization has stressed the importance of close co-operation with the United Nations Environment Programme and the International Council of Scientific Unions on global climate change, in particular to improve scientific assessments, including impact assessments,

1. *Notes with satisfaction* the importance being attached by the United Nations Environment Programme to the global climate change problem, including efforts to raise public awareness and to assess climate impacts;

2. *Urges* the Executive Director to ensure that the United Nations Environment Programme, working in close co-operation with the World Meteorological Organization and the International Council of Scientific Unions, in particular, the Special Committee on Global Change of the International Council of Scientific Unions, maintains an active, influential role within the World Climate Programme through the fulfilment of its central responsibility for climate impact studies and by ensuring that the World Climate research programme includes studies on the causes and effects of atmospheric changes, taking account of social and economic aspects;

3. *Welcomes* the Executive Director's plans to join with the World Meteorological Organization and the International Council of Scientific Unions in convening a second World Climate Conference in late 1989 or early 1990, and to support the World Conference on the Changing Atmosphere: Implications for Global Security, being convened by the Government of Canada in June 1988;

4. *Urges* the Executive Director to respond positively to the decision by the Tenth Congress of the World Meteorological Organization requesting its Secretary-General, in co-operation with the Executive Director of the United Nations Environment Programme to explore and, after appropriate consultation with Governments, to establish an *ad hoc* intergovernmental mechanism to carry out internationally co-ordinated scientific assessments of the magnitude, timing, and potential impact of climate change 50/;

5. *Requests* the Executive Director to report to the next regular session of the Governing Council on:

(a) Progress with climate impact studies;

(b) The work of the *ad hoc* intergovernmental mechanism;

(c) The full range of possible responses by Governments and international agencies to anticipated climate changes, including possibilities for reducing the rate of climate change, taking into account, *inter alia*, the findings of the World Meteorological Organization/International Council of Scientific Unions/United Nations Environment Programme Advisory Group on Greenhouse Gases and those of other relevant agencies.

15th meeting
18 June 1987

50/ Resolution 3.20/1 (Cg-X) of the Tenth Congress of the World Meteorological Organization.