High and Dry

rranean Climate in the Twenty-first Century

Back cover: What future for the Mediterranean? The time has come to choose.

United Nations

United Nations Environment Programme

High and Dry

Mediterranean Climate in the Twenty-first Century

Preface

A higher sea and drier soil seem to be what global warming has in store for most of the Mediterranean basin, according to climatologists.

The region's agriculture and fresh water resources are already strained by a growing population and intensifying environmental stress. Rising temperatures can only make things worse.

What can the Mediterranean countries do to prepare for the coming change? In October of 1988 the United Nations Environment Programme (UNEP) called together a group of experts to consider this question.

Among those who met in Split, Yugoslavia, were soil scientists, demographers, oceanographers, geologists, ecologists and an archeologist. Their discussions reflected the doubts that plague the issue among scientists everywhere: that we don't really know how much or how fast the climate will change; nor can we say with absolute confidence that it will take place at all.

Such uncertainty makes some scientists and policy-makers reluctant to take part in the debate. But those at Split felt differently. They recognized that there is already enough evidence for the coming change and to wait another decade for certainty would be irresponsible. They agreed that it is more than likely that we will see important changes in 30 or 40 years, and that these will have serious implications for economies and human well-being in many vulnerable regions of the world, including the Mediterranean.

This booklet summarizes their discussions and their recommendations, and presents some of the issues involved in predicting climate change and its effects. It will focus on the Mediterranean — why it is important, why it is vulnerable, and what hardships the region will face in the next century. It will then consider how climate change will affect various Mediterranean subsystems — the soil, fresh water, the coasts and the sea — citing specific examples throughout the region.

Discussion were based on the assumption that a temperature increase of 1.5°C and a sea level rise of 20 cm will take place in the Mediterranean by the year 2025. This was thought to be a conservative estimate.

I. Constructing the greenhouse

Everyone on Earth notices the weather. Almost everyone has a theory about it. Some say if it snows early, the winter will be mild; or that a wet spring presages drought.

Such predictions may hold little water, but they are signs of our dependence on weather: for food and water, for health and pleasure, for economic well-being and even survival.

One very prominent — you might say "popular" — theory about the weather is that the Earth is in the process of getting warmer in an unprecedented way. Human beings, by burning fossil fuels, clearing rain forests, raising domestic animals and manufacturing certain chemicals, are causing carbon dioxide and other gases to build up in the atmosphere where they prevent radiated sunlight from escaping. Heat is trapped at the Earth's surface, causing a rise in temperature known as the "greenhouse effect".

The industrial revolution, fueled by fossil deposits, has changed the Earth's atmosphere at a rate unprecedented in human history.

A look back

A Swedish scientist named Arrhenius was first to predict the warming effect nearly a century ago, and arguments have raged pro and con until recently.

Today there is data to support the theory. Carbon dioxide in the atmosphere is increasing: since pre-industrial times its levels have risen from 280 parts per million to 350 ppm. Most of the CO_2 we inject into the atmosphere is generated by burning coal and oil, although in 1988 about a tenth came from the burning of Amazonian forests.

Other greenhouse gases are also on the rise. Methane from animal husbandry, food production, combustion of organic materials, and direct emissions has been added to that produced naturally in marshes, wetlands and deep ocean sediments. Nitrous oxide from combustion and agriculture contributes 25 per cent of total N_2O emissions, adding to that already produced by oceans and soils. The chlorocarbons and fluorocarbons come entirely from industry.

The greenhouse gases could have a direct influence on crop yields, human health and ecosystems. All of them except carbon dioxide have been implicated in depletion of the Earth's ozone layer. And in recent decades they have begun to rival CO_2 in their contribution to the greenhouse effect.

Meanwhile, global temperatures have apparently risen about 0.4 - 0.5 degrees Celsius over the last century, although not in a continuous or spatially uniform way. This can be compared to a rise of 1 or 2°C in the previous 10,000 years. Global mean sea level is thought to have risen by 10 to 15 cm, with thermal expansion of the oceans responsible for 2-5 cm of this, and melting of glaciers another 3-5 cm. The contribution of the large ice sheets of Greenland and Antarctica is unknown.

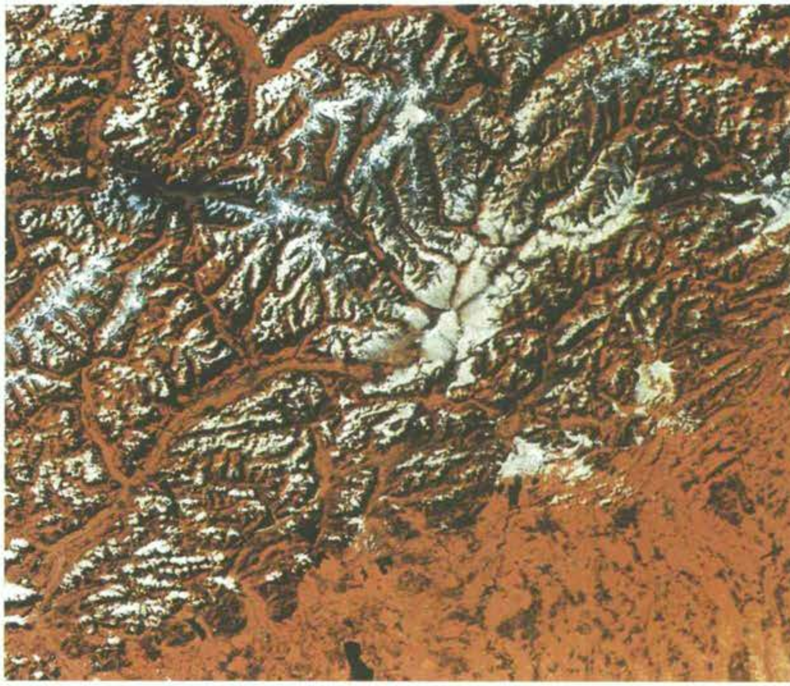
Some scientists think these phenomena are related, while others believe that effects of global warming will not be seen for many decades.

The next century

Even if greenhouse gas concentrations were to stay at today's levels, seas would rise for several decades as they slowly absorb the atmospheric heat already produced. Since warming is bound to continue, the rise could go on for centuries.

In fact, the atmospheric concentration of all greenhouse gases, measured as the "equivalent carbon dioxide level", is expected to double by 2030, with a corresponding warming of somewhere between 0.5 and 2.0°C. A hundred years from now temperatures could be as much as 4.5°C warmer on average.

This warming could cause continued ocean expansion and melting of Alpine glaciers, raising sea level a metre or two in a hundred years; polar ice sheets would melt more slowly, possibly adding several metres to sea level in a few centuries.



As the Earth warms, glaciers will melt and the snow line migrate upward. A great deal of alpine snow will end up in the Mediterranean. Pictured: the central Alps.

How sure are we?

Predictions of climate change and its effects can be made using models of the ocean/atmosphere system known as general circulation models (GCMs). The models currently applied to the problem often give quite different results, which is why we see such different numbers in print. The models are expected to improve with refinement and as more frequent and reliable data become available.

In the meantime, it is useful to compare results from several models to see if they agree. One review of four independent global climate models has revealed that we can expect the temperature of the Earth to rise by about 3.5°C in all seasons by 2050. The lowest, most optimistic limit given by the models — the least warming we can expect — is 1.2°C. This could cause a sea level rise of 10-20 cm by 2025, and 50-200 cm by 2100.

These figures are very close to those accepted by participants at the 1985 International Conference in Villach, Austria, organized by the International Council of Scientific Unions (ICSU), the World Meteorological Organization (WMO) and UNEP. They anticipate that the surface temperature of the Earth will increase by between 1.5 and

4.5°C by 2100, with a sea level rise of between 20 and 140 cm. Some estimates are even higher.

Some beg to differ

There is vigorous dissent from some scientists who maintain that since the models are not yet sophisticated enough to handle feedback effects, their predictions cannot be taken seriously.

For example, warming would cause more evaporation from the oceans and increased cloud formation; since clouds reflect sunlight the Earth could cool, not warm. Conversely, the clouds could trap yet more heat and amplify the temperature rise.

Warming could lead to melting of the polar ice caps and alpine snow cover; this would mean less area for reflection, more absorption by land and sea, and higher temperatures. Or, warming could bring about increased precipitation at the poles, adding enough volume to the polar ice caps to balance their rate of melting.

High CO_2 levels would stimulate plant growth, which might in some ways be advantageous. Or it could merely disrupt ecosystems by favouring new species and depleting soils of nutrients.

Warming increases respiration by plants and micro-organisms; this could release CO_2 even faster than photosynthesis could take it up. It could cause today's grain belts to become dust bowls, increasing the land's reflectivity, or *albedo.* However, agriculture might flourish in enormous regions at the centre of continents which are now too cold.

In spite of some doubts, most scientists and observers seem to think that global warming will occur, and that its effects will be largely damaging to human societies and natural ecosystems — if only because of the speed with which the changes will take place, leaving human and natural systems little time to adapt.

There are those who say that increasing cloud cover will cool the Earth as much as the greenhouse effect warms it.

What can we expect?

The effects of global warming will be uneven; for example, temperature may rise by only 1 °C at the equator and by 12°C at the poles. Thus there will be major regional differences in how warming and sea level rise affect people and ecosystems.

Although it is impossible to predict exactly what the effects of higher temperatures and seas will be in any location, we can expect that all of the following will occur, somewhere:

- agriculture in arid regions will become even more difficult, and water supplies will dwindle;
- rapid temperature changes will cause many forests to die, others to be destroyed by fire;
- higher temperatures will increase demands for irrigation;
- beach erosion and salt water intrusion into aquifers will increase;
- coastal farmland and aquaculture facilities will be lost;
- wetlands, many of which are already under pressure, will be inundated, affecting coastal ecosystems and fisheries;
- rising seas will overwhelm natural barriers such as coral reefs, mangrove forests and seagrass plains, increasing the magnitude of hurricane damage and erosion;
- some islands, sometimes entire island nations, could disappear forever;
- coastal plains could be flooded, and some cities inundated;
- coastal structures such as bridges, breakwaters and port facilities will be threatened, and protected only at enormous cost;
- severe public health problems associated with disease and safety could arise;
- enormous numbers of refugees will require resettlement;
- species will be trapped in the wrong environments with no time to adapt, while terrestrial animals able to migrate are likely to find their way blocked by humans;
- ecosystems will be disrupted, perhaps irrevocably.

Recent droughts in the Sahel, north-eastern Brazil, western China, eastern Australia, and the grain belt of the central U.S. have frightened many of us into awareness of what we may be facing. Whether they have occurred by chance or as a first taste of global warming is anyone's guess.

But we recognize that we are changing the Earth in ways that may become life-threatening to higher animals and plants, including ourselves.

A Mediterranean perspective

Countries bordering the Mediterranean are certain to experience many of the effects of climate change listed above; however, the severity of these effects may be negligible compared to the hardships already in store for Mediterranean peoples, economies and ecosystems.

By 2025, the total population of the eighteen Mediterranean countries will grow from 360 million to 550 million. Although the coastal zone represents only 17 per cent of the area of these countries, it contains 37 per cent of their total population (133 million). By 2025, more than 200 million people will live on Mediterranean shores.

Most population growth will take place along the southern and eastern coasts, and will be concentrated in urban areas. Sixty-one per cent of the coastal inhabitants (87 million) now live in cities; by 2025 this percentage will grow to around 75 per cent (150-175 million). The problems of feeding these people and disposing of their wastes will be enormous.

The number of tourists in the Mediterranean is expected to quadruple by the year 2025.

Expanding destruction

Within the next century, the cumulative effects of air and water pollution and land degradation will begin to take a huge toll on human health, national economies and Mediterranean ecosystems.

Although currently most pollution comes from industries along northern Mediterranean coasts, by 2025 pollution levels in southern cities will have doubled.

Soil erosion, deforestation and water supply problems are increasing as a result of poorly planned development. Damming of rivers interferes with coastal sediment supply, causing shorelines to retreat in delta areas. In many arid regions, soil fertility is being further reduced by damaging cultivation practices, poor land management and degradation of range and forest land through uncontrolled grazing and fuelwood collection.

Tourism is destroying the very monuments and natural scenery which attract 100 million people to its shores every year; by 2025 upwards of 400 million visitors are expected annually. Wastes from holiday resorts are already fouling beaches and coastal waters; car exhaust fumes are consuming facades, monuments and sculptures.

Throughout Mediterranean history, overgrazing has contributed to land degradation. Pictured: a Tunisian shepherd.

In the face of these problems, perhaps it is too much to expect Mediterranean peoples to become alarmed at a few degrees higher temperatures and a few centimetres higher sea. However, the population growth, urbanization, and environmentally thoughtless development taking place now will certainly make many regions more vulnerable to the effects of these changes, as droughts, floods, food and water shortages, storms and other catastrophic events become more frequent and damaging.

The Mediterranean Action Plan, adopted by Mediterranean governments and the EEC in 1975, provides a useful framework which can be used to study and address these problems.

A great deal of Mediterranean agriculture takes place on marginal land. This vineyard in Spain is typical.

Before the bora *enters the Mediterranean basin, it must first bypass the Alps. Pictured: Yugoslavia's Julian Alps seen across the Gulf of Trieste.*

II. Change in the air

Ask people who live far from the sea what the word "Mediterranean" first brings to mind, and they will probably say "climate". The celebrated Mediterranean climate has attracted settlers throughout human history, and still lures vacationers, tourists, and retirees from around the world.

Although the Mediterranean climate is generally noted for hot, dry summers and relatively mild, moist winters, it is frequently punctuated by heavy rainstorms, hail, and strong winds.

In winter, cold air entering the Mediterranean from the high pressure areas of central and eastern Europe is forced through gaps in the surrounding mountain ranges. The *mistral* passes through the gap between the Alps and Pyrenees, and the *bora* arrives from the north-east through the Trieste gap.

Southern and south-westerly winds, such as the *sirocco* and *libeccio,* blow across the Mediterranean charged with humidity. From Saharan Africa in spring comes the the south-easterly *gibleh* or *khamsin.* The eastern Mediterranean receives steady winds from the north-west and occasionally from the north.

The amount of rainfall varies considerably. Areas of North Africa may get only 200 mm in a year, while northern coasts can get ten times as much along the mountain fronts.

Looking ahead

Changes in the atmosphere will resonate through all parts of the Mediterranean system. Since many parts of the region are very arid, the first and most severe impacts will be felt on land, as soils bake and erode and as evaporation slows the replenishment of fresh water aquifers.

Another question concerns the contribution to the Mediterranean system of larger-scale climatic changes in the North Atlantic, Eurasia and Africa. For example, Egypt's water comes from the Nile, whose source is in East Africa. Changes in the Indian Ocean monsoons could have either beneficial or detrimental effects on water supplies in Egypt and the Nile delta.

Reliable model simulations will probably not be available to resolve such questions for another ten years. However, present models do agree on one thing: they all show a warming over the whole area of the Mediterranean. By chance, the change foreseen for the Mediterranean is close to the average change predicted by global models.

The fragile land

The soil on which modern Western civilization was built is very delicate; its degradation has been taking place since antiquity, through deforestation, cultivation, forest fires and deliberate burning of shrub and grassland.

Once the earth is eroded, Mediterranean winds and heavy rains fight its replenishment. In many places, such as the *maquis* regions of Greece and France and on many Mediterranean islands, the original soil cover has been almost totally lost, a barren testament to human destructive skill.

Scorching winds

Temperature rise, the lengthening of the summer dry period, and a shifting northwards of the region of unreliable rains are likely to widen the arid zone, seriously affecting many of the Mediterranean's productive lands. Soil processes will be disrupted by increasing evapotranspiration (the loss of water from both living and non-living surfaces) and changes in the balance of moisture, gases, soluble salts, calcium carbonate and organic matter. Even a small change in one of these materials can greatly alter the structure of the soil.

This means that even if the northern Mediterranean gets more rain in winter, as some models predict, changes in soil structure may so reduce its capacity to retain water that the net result is increased aridity.

Areas of the Adriatic island of Krk have suffered dramatic erosion.

No more salt, thank you

Salinization is the process whereby mineral salts are concentrated at the soil surface by evaporation of a saline soil solution. Where rainfall is abundant, the salt is flushed from the surface layer to the subsoil or to rivers. In arid zones, the salts remain to influence soil structure and vegetation.

In general, salinity problems are expected to be most severe in areas receiving between 300 and 600 mm of rainfall a year.

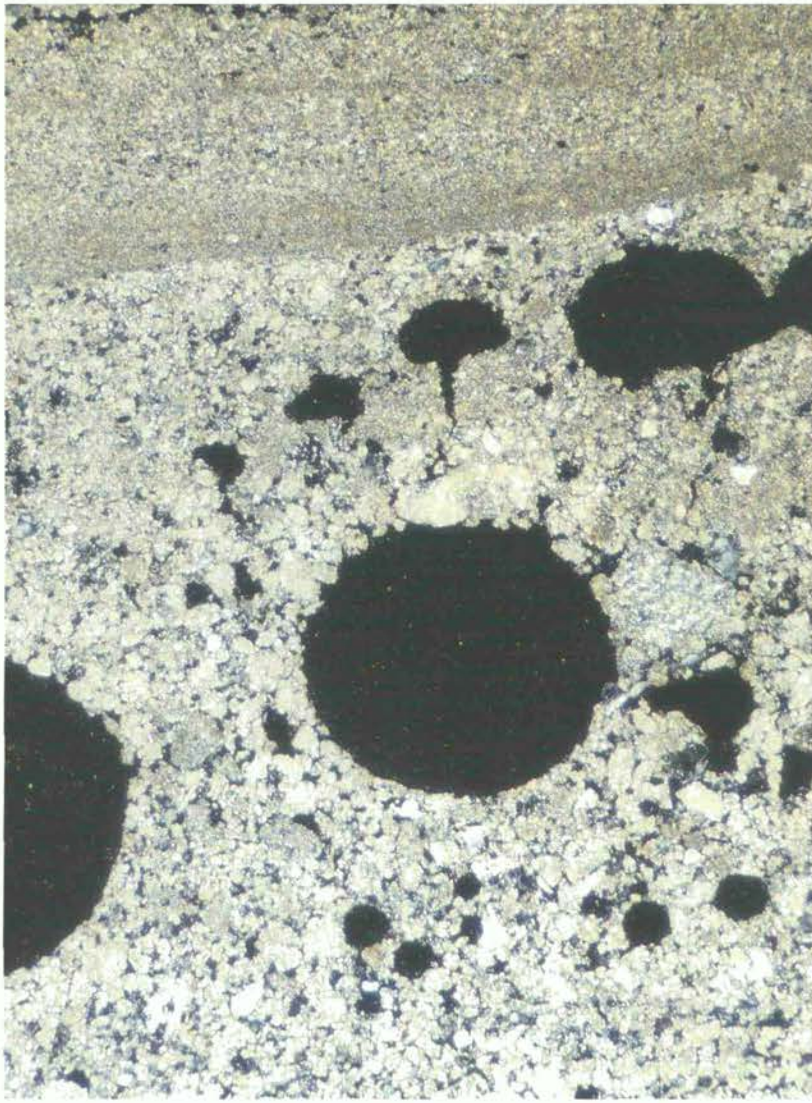
According to international studies, a large proportion of the irrigated lands of some Mediterranean countries is endangered by salinization: 33 per cent in Greece and 30 per cent in the Nile valley. In a warmer climate, irrigation will intensify and the problem of salinization will become much worse. Evapotranspiration could further increase the area of soils already affected by saline or sodic conditions.

A decrease in winter rains could prevent annual flushing of accumulated salts. Slight changes in salt concentrations can initiate a process leading to surface sealing and lowered infiltration rates, more runoff and high erodibility. Irrigation and crop yield management would become more difficult and expensive, and crops with higher salt tolerance would be favoured.

Organic matter and vegetation

One reason the Mediterranean is considered especially vulnerable to climate change is because most cultivated soils in the region are already low in organic content and therefore relatively unstable: any additional reduction in the supply and mineralization of organic matter, even if small, could have a large impact on soil structure.

Highly calcareous soils, such as this in the Alicante region of Spain, will form an impermeable crust when washed by rain.

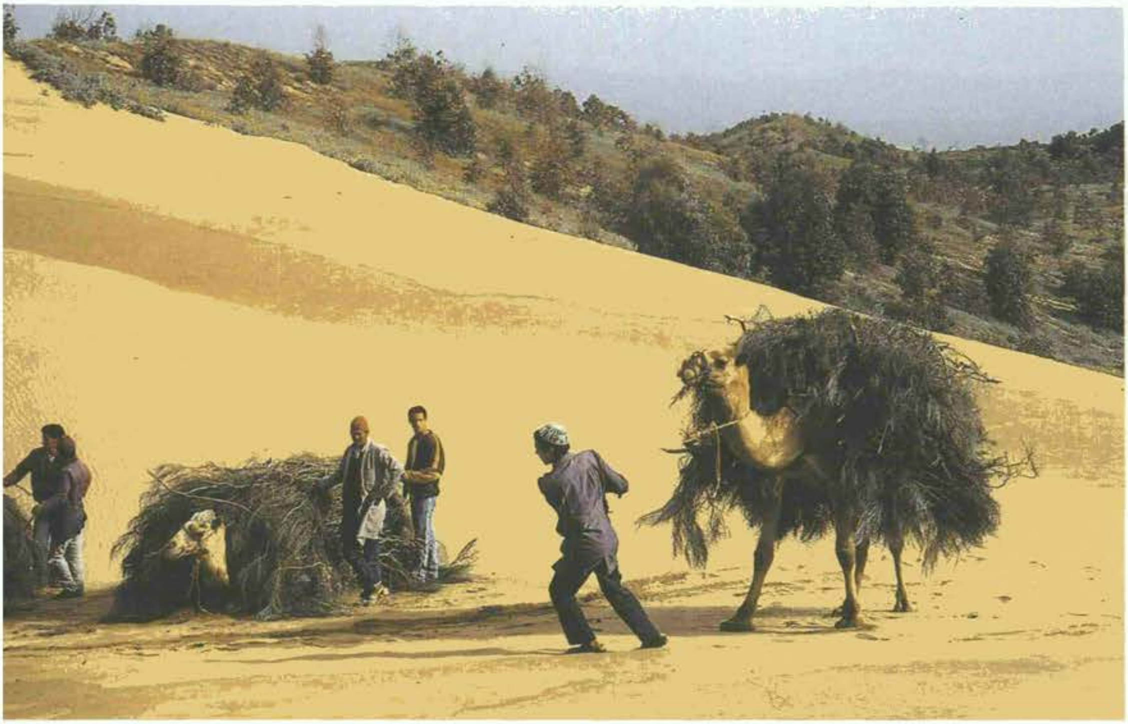


Micrograph of soil pictured on page 12 reveals large air pockets beneath the surface. This soil contains no organic material.

Increased aridity could further decrease organic matter input to the soil through changes in plant species composition. Some scientists foresee vegetational shifts of hundreds of kilometres in latitude, and shifts in altitude of hundreds of metres. However, many forest ecosystems may not have time to shift northwards: they have a lag time of at least several decades when responding adaptively to climate change.

Mediterranean forests will consist increasingly of *maquis*, scrubland composed of drought-tolerant species — such as oleander, bay, evergreen oak, olive and juniper — which provide less vegetation cover than deciduous forests. In many areas which are not irrigated, vegetation will be lost completely; erosion by wind and rain will complete the transformation, leaving the land barren, perhaps irreversibly.

In some areas of North Africa, climate change could lead to renewed movement of sand dunes. The combined effects of higher temperature, increased evapotranspiration and soil salinization would cause a decline in stabilizing dune vegetation.



Efforts to compensate for lack of stabilizing vegetation include piling branches on these sand dunes in Morocco.

Mediterranean deserts?

Mediterranean land degradation has been likened by some to the desertification at the margins of Central Africa. Desertification is loosely defined as a lessening of the land's biological potential and primary productivity, and loss of its ability to recover after dry periods. It is characterized by the disappearance of perennial plants, especially woody shrubs and trees.

The many causes of land degradation — aridity, salinization, loss of organic matter, etc. — can operate together to initiate a positive feedback system culminating in a desert-like environment. If conditions are right, the process could be triggered by a small change, such as a few degrees rise in mean temperature. Some observers have suggested that the drying up of the Sahel is a result of the greenhouse effect. However, the Sahel has experienced alternating wet and dry periods for thousands of years, independent of human activity.

The implications for agriculture in arid regions of the Mediterranean are profound. Much of North Africa could come to resemble the Sahel, with increased grazing on marginal lands and cultivation of heat- and salt-tolerant crops. As it becomes increasingly difficult to prevent degradation of the soil, farming will become less profitable, hastening the migration of discouraged farmers to the cities.

SOS for Spanish soil

A great deal of evidence for the ways that increasing aridity can lead to degraded soils comes from studies carried out in Spain.

Almost all of Spain has less than 600 mm of rainfall per year. In the highly calcareous soils of Alicante, arid conditions have been shown (1) to reduce infiltration rates, nutrient retention and organic matter production, and (2) to increase soil erodibility and crust formation.

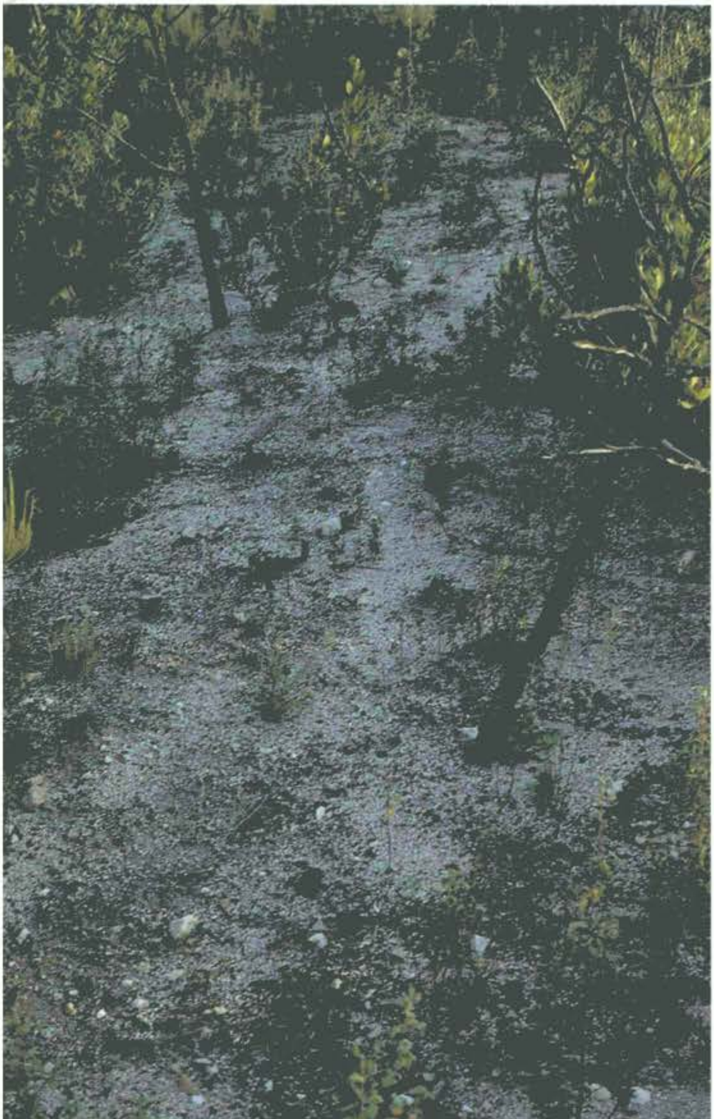
Direct evidence that dryness leads to increased erosion comes from a study in Catalonia. Slopes with a southern exposure were found to be drier, more fire-prone and more affected by erosion than northern slopes.

The study also found that the nature and amount of organic matter in soil is closely correlated with vegetation cover, and that organic matter accumulated on the soil surface prevents erosion.

Organic matter also helps the soil to retain nutrients and water, which is especially important in calcareous, sandy and silty soils where bonding forces between mineral particles are low.

Therefore, when organic matter is reduced, the result is increased soil aridity and diminished fertility. Since aridity has been shown to reduce production of organic matter, a feedback system is initiated.

Fires are an ever-present threat during the Mediterranean's dry, hot summers.



Three years after a forest fire near Geromo, Spain, the soil surface has not recovered and rain still runs off.

The fire factor

Forest fires also cause a decrease in organic matter in upper soils. If no erosion results, recovery can be quick. This is the case in north-eastern Spain, where soil loss after forest fires is generally limited to a few centimetres and the vegetation eventually recovers (although severe erosion is experienced wherever roads are built to make burned areas accessible).

Given certain soil conditions, fires can cause a water-repellent layer to develop, leading to increased runoff when it rains. The soil will erode and nutrients will be washed away. In Sardinia, forest fires are considered the most important cause of severe soil erosion.

Eroding rains

The relation between rainfall and erosion is complex, and depends upon the force and frequency of rains, soil characteristics, vegetation cover, etc. In south-eastern Spain, studies showed a correlation between the amount of rainfall and erosion. Spring and autumn rains were most erosive, since they occur at times of relatively light vegetation cover and low soil organic content.

A simple relationship between soil loss and rainfall was not found in other studies from Spain, Italy and Morocco, although in every case as much as 80 per cent of soil loss could be associated with just one or two rainfall events each year.

In much of the Mediterranean, highly erodible sediments can supply large amounts of silt and clay to river systems, especially in areas where "badlands" have developed (the Guadix badlands in southern Spain, shown on the cover, are an example). This could have severe impact on rivers in drier parts of Mediterranean basin, affecting channels, causing floods and making river engineering necessary.

Fresh water resources: Drying up

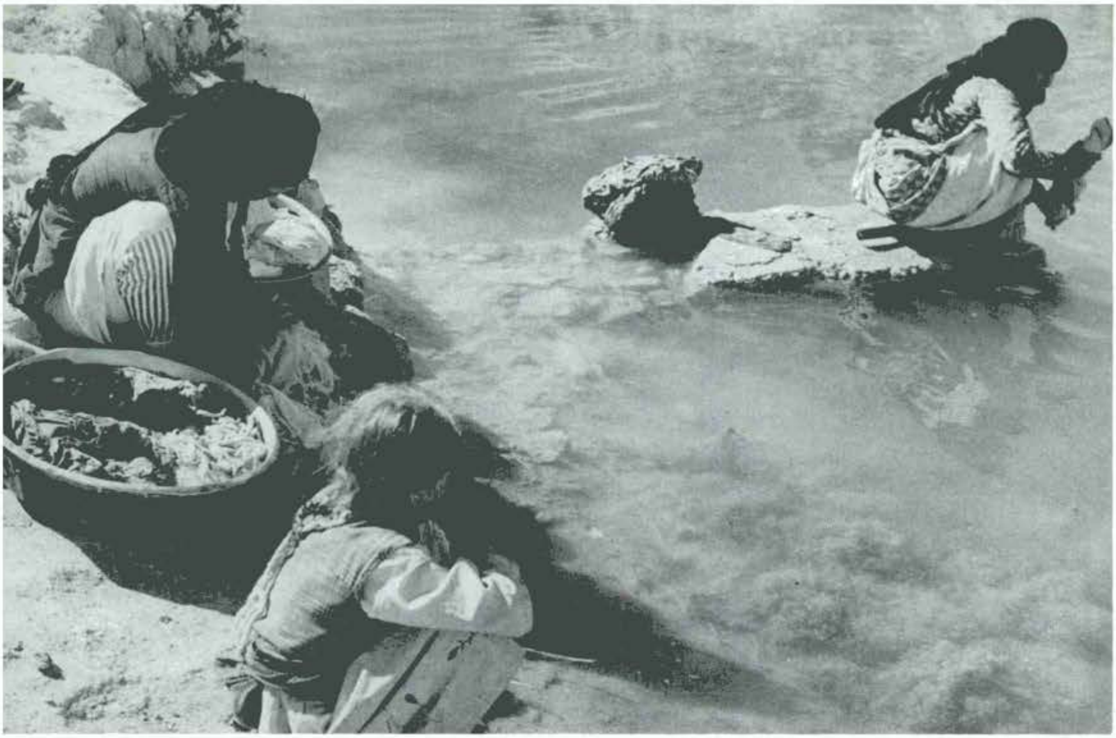
Because of frequently long summer droughts, water is the primary limiting factor for plant growth throughout the Mediterranean. In many countries, water supplies are already critical. Exploitation of water resources exceeds 100 per cent in some, meaning that some water is reused.

A decrease in precipitation in these countries, combined with increased evaporation from soil and open water sources, will further reduce the amount of running surface water and groundwater.

There are already many areas of the southern and eastern Mediterranean which lack permanent rivers. Rising soil aridity and resulting soil degradation will reduce the volume of water infiltrating the ground, leading to more erratic drainage and an increasing number of streams with perennial or ephemeral regimes. Salinity will build up in the dry channels to be washed away during the short periods of flow, reducing water quality.

In studies from coastal Tunisia, it was estimated that an air temperature rise of 1.5°C will cause an increase in evapotranspiration of around 10 per cent. This would result in a decline in river flow of 10-12 per cent and increasing salinization of the water. Storage in reservoirs would fall, and they could be without water for up to 19 per cent of the time — although full of the eroded sediments they trap. Percolation of saline irrigation waters into the water table would exacerbate the problem.

A Tunisian well: water quality could become more of a problem.



Bedouin women in the Lebanese desert. The loss or deterioration of open water sources could be disastrous for them.

In Egypt, higher temperatures are expected to change the chemistry of coastal lakes and lagoons. Although it is hoped that higher CO_2 concentrations and temperatures might favour fishing and agriculture, this could be offset by soil salinity and perhaps an increase in pests and weeds. The study also pointed out the dangers to fishing from pollution of coastal waters by growing use of pesticides and fertilizers.

The intrusive sea

As the sea rises, salt water intrusion can cause salinization of fresh water aquifers, making some water supplies unfit for drinking or industrial use. The effect will be magnified as demand for fresh water grows: depletion of underground aquifers will accelerate, creating a pressure differential that draws sea water in.

Risks to health

Higher temperatures will also stimulate increased growth of micro-organisms in open water sources, creating hazards for human health. Waste water treatment will become more difficult even as the need for water becomes greater.

Rising sea level could hamper drainage in cities where sewage pipes are low and inadequately sloped, which is the case throughout the Mediterranean. Sewers could flood with increasing frequency, spreading disease.

A vanishing source

It is likely that the impact of climate change will first be felt in Mediterranean water resource systems.

Water shortages already plague many areas, and population growth and development will ensure a substantial increase in demands for fresh water.

Mediterranean countries can be divided into three groups according to their water supply problems:

1. Those countries with enough water for the foreseeable future, whether population growth is high (Albania, Turkey, Lebanon) or low (France, Italy, Greece, Yugoslavia); that is, assuming that efforts are made to develop water resources and ensure their quality.

2. Countries where water supplies, although currently adequate, will become marginal given their high population growth. Even if per capita *consumption remains the same, new development schemes will be required to maintain supplies through the year 2025 (Spain, Morocco, Algeria, Cyprus).*

3. Countries where water supplies are already insufficient or will be by the year 2000. This will require a reduction in per capita *consumption, development of non-conventional resources such as fossil water or desalinated seawater, or importing. This category includes countries where population growth is low (Malta), average (Israel, Tunisia), or high (Egypt, Syria, Libya).*

Runoff units such as this in the Israeli desert collect fresh water for irrigation. Their practicality could be jeopardized by increasingly unpredictable rainfall.

More extremes

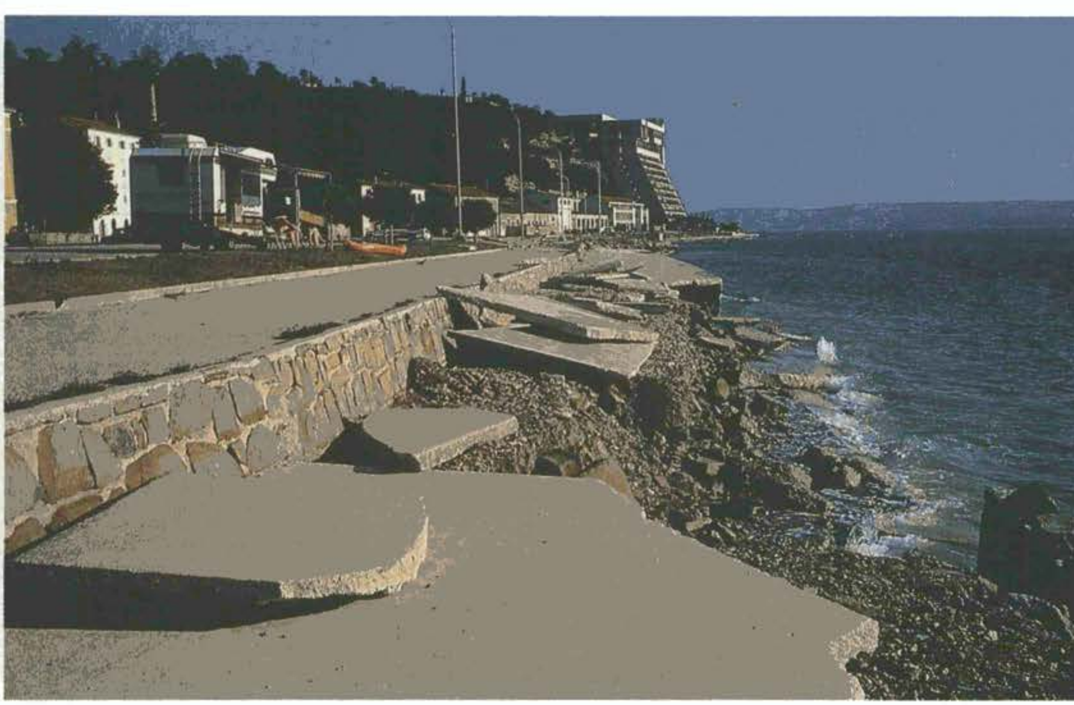
Currently the Mediterranean's wind regime is largely related to the passage of atmospheric disturbances. It is likely that the expected climate change will bring about a general northward shift in atmospheric circulation patterns, which will in turn influence the paths and frequency of mid-latitude cyclones over certain parts of the basin.

Climate models suggest that with a warming of 3.5°C by 2050, winter precipitation could increase slightly in the northern part of the Mediterranean basin, and decrease in the south. Winters would become milder, summers hotter.

The lesser rise of 1.5°C expected by 2025 would primarily be accompanied by increasing irregularity of climatic features. What are now considered rare, extreme events could become more common: a succession of cold winters, or longer and drier summers, for example. The number of droughts, forest fires, sea surges and floods could rise, and storms and heavy rains could increase in frequency and severity.

The region where people, their animals and their fields suffer from unreliable rainfall in summer would shift northwards; the area and persistence of snow cover in the mountains would be reduced, and the snowline would move about 300m higher. Many alpine glaciers would probably disappear.

A battered coast testifies to the strength of Mediterranean storms and waves.



Gulf of Lyon:

The coming storm

Tourist resorts, ranging from elegant to improvised, proliferate along the Gulf of Lyon.

There are many places on the Mediterranean coast where buildings, roads, harbours, tourist resorts and nature reserves are periodically battered by marine storms. Any increase in the strength and frequency of these storms could have serious and expensive consequences.

One such area is France's Gulf of Lyon. The Gulf forms an arc about 270 km long, comprising a low shore punctuated by rocky capes, lagoons, and, at the eastern end, the Rhone delta. It includes the wild, marshy region known as the Camargue, which lies between the twin channels of the Grand and Petit Rhone. The delta was dominated throughout its geological history by the shifting of the river's branches, at least until 1860 when dykes were constructed and the river water diverted for human use. Forty per cent of the Gulf's shoreline was formed by Rhone deposits.

The climate of the region is quite variable, with a mean annual temperature of 14-15°C and between 400 and 750 mm of rainfall. Winds are frequent and sometimes violent.

Tides are of small amplitude, not exceeding 30 cm average springtide. Oscillations from wind and atmospheric pressure are much more important: a range of 1.29m was recorded in the Camargue during one seven-year period.

With the exception of the Camargue, the Gulf shoreline is highly developed. More than 40% of the coastline has been taken over by tourist facilities. A new harbour has been constructed, as well as metal works and a refining complex.

What's in store?

The main threat to the Gulf area from rising temperature is thought to be an increase in the frequency and severity of storms related to cyclogenesis, the triggering of cyclonic air circulation.

A significant rise in sea level would make beaches narrower and increase the frequency of storm washovers, creating new inlets. Coastal lakes and marshes would become saline and lagoons would return to the sea.

The coast is particularly vulnerable because of the narrowness of the sand strip for most of its length, and the low altitude and relatively poor condition of dunes and coastal ridges, many of which were levelled for construction purposes.

The extensive damage caused by a great storm in 1982 showed what could happen. Alarmed public authorities launched measures to control longshore drift and beach erosion, to protect and rebuild beaches and dunes, and to construct physical obstacles to storms. The methods used — rockfills, semi-permeable barriers, vegetation, artificial dunes, and submerged breakwaters for the bottom of the beaches — are costly. But doing nothing could cost a great deal more.

Much of the Mediterranean is an earthquake zone. From top to bottom: Italy (1980), Greece (1981), Turkey (1975) and Algeria (1980).

III. Life on the edge

What effect will the expected rise in sea level have on Mediterranean lagoons, deltas, wetlands, beaches and coastal settlements? How will human and wildlife populations respond, and what will be the implications for tourism and coastal zone management?

Anyone attempting to answer these questions must first take into account the Mediterranean's normal sea level fluctuations.

The moving Earth

Unless we live in areas of frequent earthquakes, most of us are unaware of the land's continual motion and change. Tectonic activity (movements of the Earth's crust) can raise or lower the land surface quite suddenly. In 1908, an earthquake at Messina, Italy, increased the relative sea level by 57 cm.

Many parts of the Mediterranean are tectonically active, characterized by earthquakes and volcanic eruptions in the junction between the African-Arabian and Eurasian continents. For thousands of years, vertical earth movements in the Mediterranean have averaged one to five millimetres per year; when looked at more closely — over periods of 15 or 20 years — the range increases from 3 to 20 mm per year.

An especially strong tectonic influence on the structure of coasts is found in the northern and eastern Mediterranean, from Italy to Egypt.

Give and take

Local changes in sea level also result from the coastal processes of sedimentation and subsidence. When river sediments elevate the fluvial plains, compensating for their rate of natural subsidence, there may be little net movement. When the processes are greatly out of balance, shorelines are transformed almost overnight.

The great Mediterranean deltas — the Nile, the Po, the Rhone and the Ebro — are important sedimentary basins where compaction and subsidence have generally been balanced by sedimentation. In recent decades several factors have upset that balance. Wetlands have been drained and reclaimed for agriculture, industry or housing, lowering the original elevation by compaction. Local land subsidence has followed mining of gas and oil and the extraction of groundwater faster than it could be replenished. Dams constructed upriver have reduced sediment transport to the deltas. As a result, many Mediterranean shorelines are receding.

Erosion vs. accretion

Most Mediterranean beaches are subject to erosion, much of which can be directly attributed to human activities. In Tunisia, development of tourist facilities has resulted in severe shoreline recession. In Israel, sand mining and construction of breakwaters and harbours has interrupted longshore transport and hastened beach erosion. In Egypt, accretion in front of the Port Said breakwater began to interfere with navigation at the entrance to the Suez Canal, making repeated dredging necessary at great expense.

How does the predicted sea level rise of 4-10 mm per year for the next fifty years fit into this picture? The answer will vary, since averages have little meaning when speaking of earth movements. Local predictions of sea level changes would have to take local situations into account.

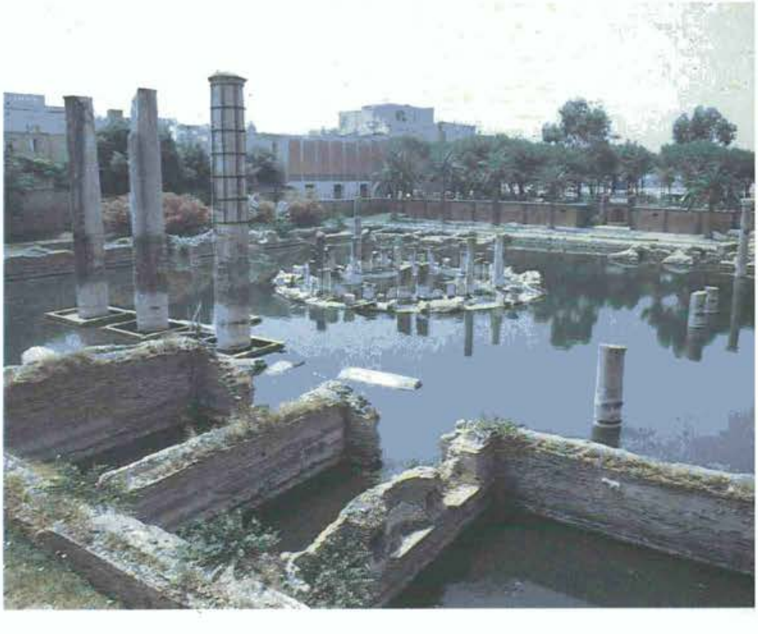
Rising sea or sinking land?

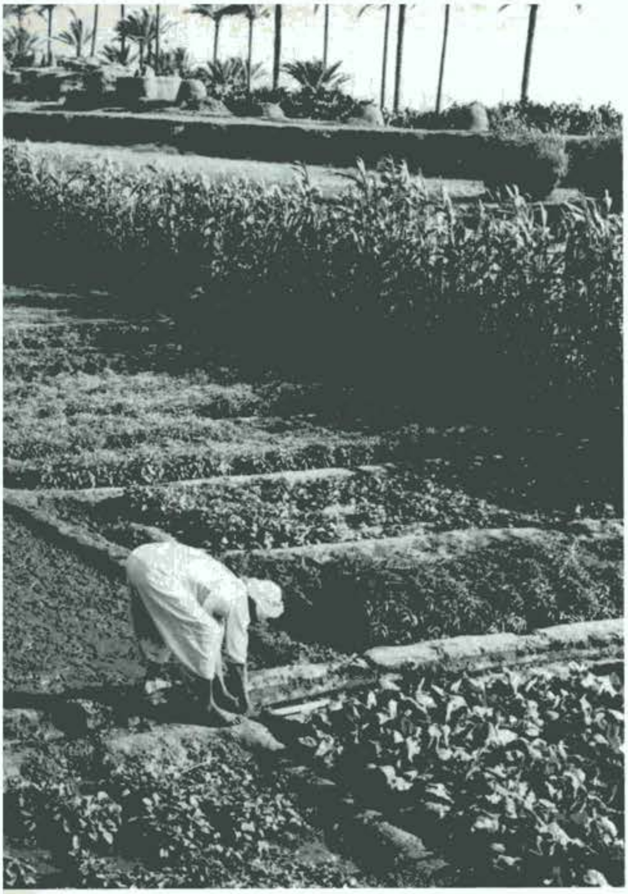
How do we know where land is rising or subsiding? Tide gauges are one way. However, decades of data are needed, and these are good only for the immediate location of the gauge.

An additional body of evidence is provided by the Mediterranean's rich archeology. For example, the elevation of ancient ports and docking structures, jetties and steps to the water, when correlated with tide gauge data, can give an indication of past sea levels and rates of movement.

In the Mediterranean there are more than 1000 archeological sites that contain potent evidence of local changes in sea level.

The Temple of Serapis in Possuoli, Italy (2nd Century A.D.), is partially submerged by water from the Bay of Naples. At one time the water was as high as the dark bands on the columns, but the site was uplifted again in 1530.





Vulnerable shores

The Mediterranean coastline is approximately 46,000 km long, 40 per cent of which is accounted for by islands. Slightly more than half is rocky, the rest made up of low, sedimentary shores.

Mediterranean countries vary greatly in their vulnerability to sea level rise. Some have lowlands below sea level protected by artificial barriers, others have lagoons and lakes separated from the sea by thin strips of sand. Some countries commonly suffer damage to roads and buildings from storm surges, while in others coastal erosion is already severe.

Forty per cent of the area of the Mediterranean coastal zone is devoted to agriculture. A large part of the agricultural production of eastern and southern Mediterranean countries takes place near the coast, with the exception of Egypt's Nile valley. Flooding or salinization of low coastal plains could have severe economic consequences in these areas.

Most Mediterranean farming takes place in the fertile coastal lowlands. Pictured: a Nile valley farmer near Alexandria.

Although most of the Mediterranean basin's productive lands are not likely to be affected by the expected sea level rise of 20 cm, a further rise up to a metre or two would inundate many critical areas.

A narrow strip of land is all that separates this lagoon in Greece's Evron delta from the sea.

The Ichkeul-Bizerte wetlands of Tunisia already suffer the effects of development. Pictured: the shore of Lake Ichkeul.

Mediterranean lowlands: a brief overview

Lowlands are scarce on the Mediterranean coast of Morocco. The only areas likely to be affected by a rising sea are a lagoon south-east of Melilla, the small delta of the river Moulowya, and a sandy tourist beach near Al Hoceima.

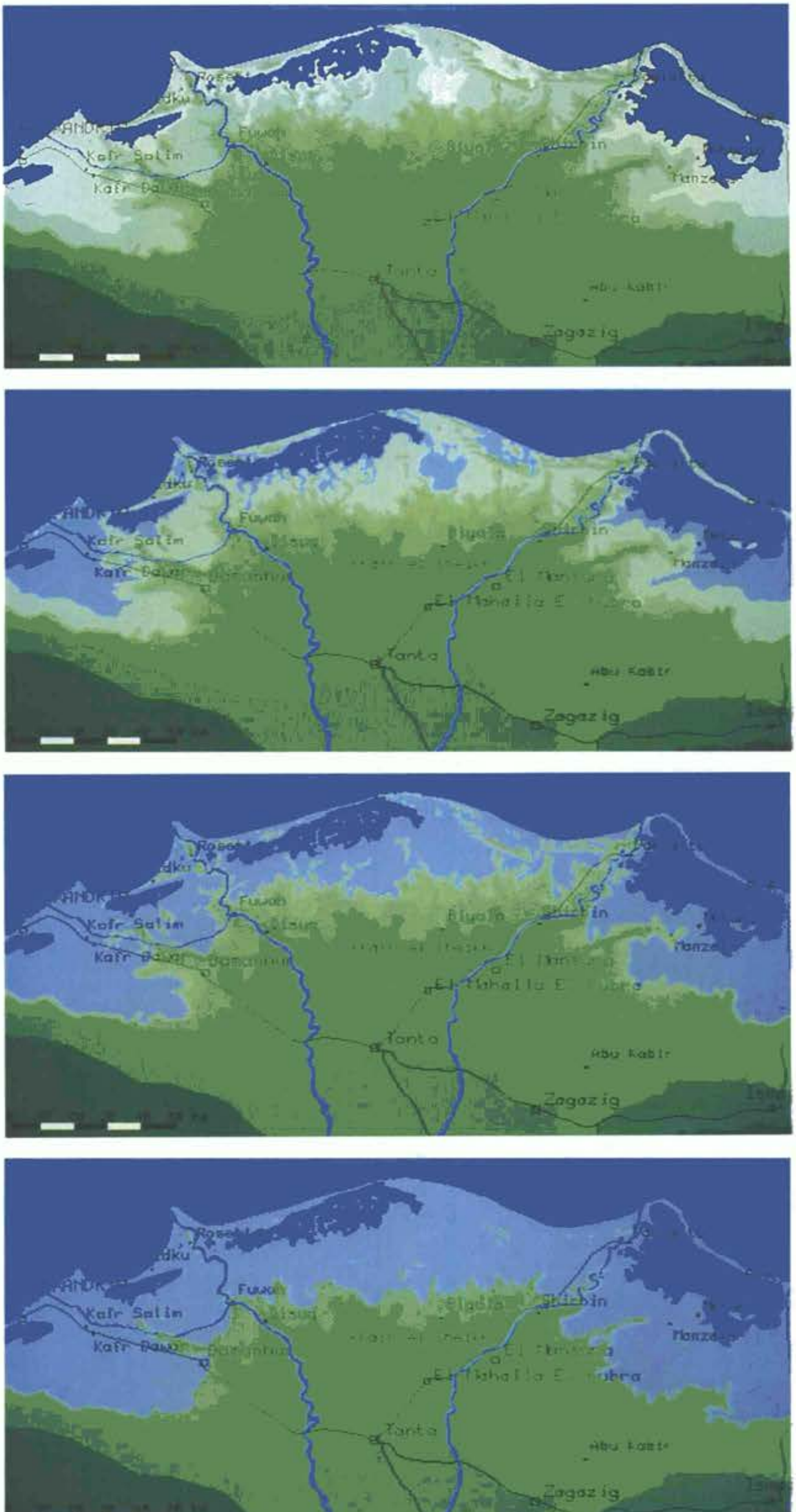
Algeria is bordered by ridges of the Atlas mountains, whose cliffs fall directly into the sea, and a narrow continental shelf. Between the ridges are the main ports. Since most of the country is arid, intensive agriculture takes place on the coastal plains of Oran, Algiers and Annaba; these extend a short distance south between the *massifs* and receive adequate rain from the Mediterranean side.

Tunisia has several lowlands of ecological and economic importance, including lagoons, lakes, and the delta of the river Medjerda at the Gulf of Tunis. Beach-bound tourists are an important source of foreign exchange for the country; cities, harbours and industries could also be threatened by a rising sea.

Libya's coast is about 1900 km long. The Gulf of Sirte has a barrier lagoon coast with dunes, *sebkas* (salt lakes) and some agricultural lands. There are no perennial rivers. There are several ports, with Tripoli and Benghazi the largest. Coastal oil trans-shipment facilities are of great economic importance to the country, and could require protection from a rising sea.

The island state of Malta features coralline limestone uplands and plateaux, with sparse vegetation. Soils are shallow and infertile, so farming takes place on strips of soil held together by rubble walls and terraces. A great deal of food is imported. There are no permanent lakes or streams, and water supply is often a problem. Malta's main economic assets are its deep harbours and strategic location.

Egypt's Nile delta is the most important coastal lowland of that country's shoreline, and vital to its economy. It constitutes 46 per cent of the country's cultivated and densely populated land, itself only about one per cent of the total area of the country. The shoreline features a series of brackish lagoons separated from the sea by beaches, spits and sand barriers, where rising water could add to the severe problems already expected.



UNEP's Global Resource Information Database (GRID) used computers to create a topographical map of the Nile delta in order to identify areas at risk of inundation from sea level rise. Shown are "digital terrain models" which give an idea of what would happen if the sea rose suddenly by one half to two meters today. In fifty years' time, the contours could be very different, but the effects of a rising sea just as dramatic. Top to bottom: today; .5m sea level rise; 1.0m rise; 2.0m rise.

A case in point: the Nile delta

One area where the problems people face in the next few decades overwhelm those expected from climate change is the Nile delta.

The lower delta contains large areas of less than one metre elevation. Some, including coastal lagoons, are below sea level. High sand dunes protect some parts, but others are flooded by winter storm surges.

Nearly all productive land in Egypt lies within the Nile delta between Alexandria, Port Said and Cairo, and inland along the river. Agriculture in the coastal zone of the delta accounts for 15 per cent of national production. The area's rich fishing grounds provide 60 per cent of the country's annual production. Alexandria and Port Said are two of Egypt's main industrial and commercial centres.

Any assessment of the impact of climate change has to consider the coastal development to take place during the next few decades. The delta is home to 48 per cent of Egypt's population. By the year 2000, the number of people living in the area of the delta below 3m is expected to swell from 10 million today to at least 12.5 million.

Feeding, housing, and employing such numbers will mean increased demands on existing agricultural areas, reclamation of new lands, extension of fishing in the lagoons, and intensified water use. Urbanization will further magnify problems of food and water availability.

Sea level rise will contribute to this already distressing picture.

Tide gauge measurements in the eastern part of the Nile delta near Port Said indicate a sinking rate of 1.2 mm/year, from tectonic subsidence and sedimentary compaction. Meanwhile, sediment supply to the Nile has been reduced to near zero by the Aswan Dam and other reservoirs, contributing to severe coastal retreat or erosion at several important locations: Ras el Barr, Baltim Resort, El Burg, Rosetta and Abuquir. The effects have been felt as far east as Israel, where beach erosion is a problem.

A sea level rise of 10-20 cm will accelerate the retreat of the coastline; local rises of more than 30-50 cm could have serious effects and require extensive protection measures. The cities of Alexandria and Port Said as well as new settlements would be threatened. Government plans to expand beach tourism in the delta would be frustrated.

A relative rise of a metre or more (including subsidence) could submerge lowlands to within 30 km of the coast, affecting 12-15 per cent of Egypt's arable land and a few million people.

Fortunately, Egypt already has dykes in place to protect its cultivated lands, so that lowland flooding can be prevented with additional effort.

The most serious impact of sea level rise on Egypt will be the financial burden from construction of protection works, water preservation schemes, land reclamation projects, and harbour adjustments. Added to the costs of providing for its growing population, this could cripple Egypt's economy.

Israel's coast consists largely of cliffs of carbonate-cemented sands and loams. The mountains of Galilee overlook the northern coast. Coastal plains are relatively wide for the region — about 30 kilometres in the south. Most of the coastal rivers, called *wadis,* are seasonal, except for the Yarquon near Tel Aviv and the Qishon near Haifa.

A moveable coast: in the 7th Century these now-submerged stones formed a breakwater off Amathus, southern Cyprus.

Some of the oldest human settlements in the world — the Phoenician ports of Tyre, Sidon and Byblos — were situated on what is now the coast of modern Lebanon. Except for the plain of Akkar, the coastal strip is narrow and discontinuous, bounded by the Lebanon Mountains. Major coastal cities are the capital Beirut and the oil-exporting port of Tripoli.

Syria's straight coastline features low shores backed by mountains. There are several short rivers with small, intensely cultivated alluvial plains. The largest of the deltas — that of the southern Kabir river which empties into the Bay of Akkar — is shared with Lebanon. Syria has two principal ports, Latakia and Tartus.

The island of Cyprus is especially plagued by soil erosion in its normally dry river valleys during periods of heavy rainfall. Its coast is generally indented and rocky, with long sandy beaches. Much of its central plain is cultivated under irrigation.

Turkey's coast is mostly rocky cliffs alternating with deltaic lowlands and sandy beaches. Most of the deltas are small but economically important. The Cukurova plain in south-eastern Turkey is relatively large, and home to two million people. Formerly marsh and swampland, the plain is now a large, well-drained and highly productive agricultural area. The sediment supply from two rivers, the Seyhan and the Ceyhan, is in equilibrium with tectonic subsidence, so shoreline erosion has not been a threat so far. However, these rivers have now been dammed, and problems could arise in the future.

Fishing in Greece's Stafnokari lagoon.

Greece's shoreline is extremely long in comparison with its area. Only one small part of the country is more than 80 kilometres from the sea. Greece is very mountainous; although its coastal plains are limited, they are important economically as sites for harbours and related industry.

Albania's coast includes 190 km of beaches, marshes and lagoons, six river deltas, and prime agricultural lowlands supporting a population of around 700,000. The Kune nature reserve of several hundred hectares at the mouth of the river Drin is a wetland of importance as a waterfowl habitat. Elsewhere the country is mostly mountainous and rugged. Vlone and Durres are the major ports and industrial centres of the country.

Fresh water marshes, such as this one in Dalmatia, are important wildlife habitats. Climate change could mean more salt, less water.

The coast of Yugoslavia is highly indented, with several large islands paralleling the shore. The shoreline consists mostly of large limestone cliffs with occasional small lowland patches. One exception is the Neretva delta — 500,000 hectares in southern Dalmatia with salt marshes, saline lagoons, sandbanks and wet meadows. Its fresh waters are used for controlled hunting and fishing. Numerous dams upriver and hydrographic controls at the river's mouth have contributed to deterioration of the wetland habitat, an important passage and wintering area for migrant waterfowl.

Italy has 7500 km of coastline, which features rocky coast alternating with low-lying sandy beaches. The most important lowland on the Adriatic Sea is that of the Po river basin. On the Tyrrhanian Sea, coastal plains are related to the deltas of the Arno, Ombrone, Tevere and Volturno, and contain important harbours, industries and cities. Most Italian beaches are eroding, at least partly from the effects of dams and reservoirs on the supply of river sediments.

A case in point: The Po delta

The monuments of Venice and other northern Adriatic cities are threatened by rising waters and sinking land.

An unstable coastline and degraded shallow water environments make the northern Adriatic lowlands especially susceptible to the effects of climate change. At risk are the very existence of Venice and neighbouring towns of artistic and historical importance, a thriving tourist industry, unique agricultural lands and important harbours.

For the last 30 years, many parts of the shoreline have been retreating, while lagoons have experienced increasingly high storm surge levels. Subsidence and sediment starvation has left the coast in a state of physical instability. Natural disasters have regularly struck the area, including devastating floods in 1955 and 1966.

It is not climate change which has brought this about, but coastal development carried out with little consideration of natural environmental processes: land reclamation, intense urbanization of the coast, construction of deep harbours and coastal defense structures. Lagoon areas have been reduced, river waters redirected, the shallow sea and surface waters polluted.

Another problem has come from the excessive use of groundwater resources for the region's population and industry. The Po delta, like other deltaic costal plains, experiences continued subsidence caused by tectonic sinking and compaction of clays and peats. In recent decades, groundwater extraction has caused large areas around Venice and the Po delta to subside even faster — up to 30 cm a year: the famous "sinking" of Venice. The process was slowed when authorities prohibited overpumping and started providing water by aqueduct from rivers; the aquifers quickly recovered and subsidence decreased. At present it has returned to its natural rates, but the lowering of the land surface is irreversible.

Human influence on the delta is not new: like the Ebro, the Po delta is young, formed largely by human activity. For four centuries the Po has been guided and confined for human use; channels were cut, water flow diverted, river beds fixed. Erosion resulting from inland deforestation and agricultural expansion contributed sediment for the new delta.

Recently, dam construction and sand extraction upriver has brought about a retreat of the coastline by reducing the sedimentation which once compensated for coastal erosion. The natural flexibility of the shore has *been constrained by numerous fixed structures meant to protect resorts, harbours and fields.*

The outlook for the Po delta is not bright. It is thought that even a rise of 1.5°C in temperature is likely to increase the frequency of hot, dry summers, marine storms, tidal surges, and stagnating and eutrophic waters.

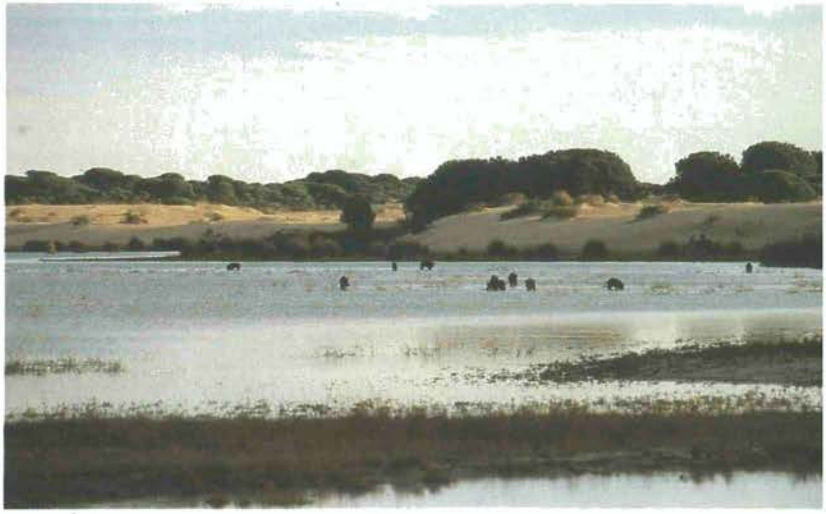
A sea level rise of 10-20 cm would aggravate lagoonal flooding and accelerate degradation of tidal flats, marshes, lagoons and reclaimed agricultural land. Land-use conflicts would intensify: even today industrial, tourist, agriculture and fishery sectors are increasingly at odds in the region, as population and capital concentrate at the coast.

Since much of the coastal zone is below sea level, a rise of more than 40-50 cm could disrupt the agricultural and tourist economy, greatly impair harbour and industrial activities, and destroy much of the region's cultural and historical legacy.

Monaco covers a strip of coast with an area of less than two square kilometres. One of the most luxurious resorts in Europe, its main industry is tourism, largely centred around its beaches and marinas.

France's coastal lowlands, lying between the Pyrenees and Provence, are the site of cattle breeding, rice and vegetable cultivation and vineyards. Salt extraction enterprises, major industries at Sete and Fos de Mer, and rapidly growing tourist resorts are scattered along the coast.

The Mediterranean coast of Spain has a few low areas at the edges of sandy bays, backed by lagoons, dunes and marshes. Beaches are subject to erosion, and in places have been protected by groynes. The main economic activities of these areas are tourism, fishing and agriculture. To the north lie the deltas of the Llobregat and Ebro rivers.



Wild boars cool off in the marshes of Spain's famous Coto Doñana.

Clearly, each Mediterranean country faces a different set of problems related to climate change. Some are more dependent on coastal agriculture, industry and commerce than others; some are especially vulnerable to sudden catastrophes; all of them have coastal cities and harbours but vary in the financial resources that will be required to protect them.

IV. The shifting stream

The Mediterranean Sea covers three million square kilometres. It has an average depth of 1500m, with a maximum of around 5000m in the central Ionian Sea.

The Sea has two main basins, separated by a submarine ridge between Sicily and Africa. Each has its own separate counterclockwise current. There are three principal water layers: a surface layer of variable thickness, an intermediate layer of warm, saline water from the eastern Mediterranean, and a homogeneous deep layer reaching the bottom. Evaporation keeps salinity high, averaging 38 parts per thousand compared with 35 in the oceans. Temperature ranges from a summertime high of 31°C off the coast of Libya to a winter low of 5.2°C in the northern Adriatic.

Since the Mediterranean is mostly nutrient-poor, its primary production is generally low, with minimum values in the eastern Levantine and Ionian basins. As a result, the fishing industry is relatively modest, although high demand and high prices for fish allow small-scale fisheries to survive. Mediterranean countries produce as much as four million tonnes a year of sea food. In 1987, 26 thousand tonnes of high quality fish were produced by aquaculture, mostly in lagoons.

A sea-change

Sea water circulation is a function of several factors, including wind and rainfall patterns, evaporation rates, density differences between adjacent water masses, river discharge and coastal structure.

Since higher temperatures are expected to influence all of these, some oceanographers believe that the changes expected in the next century could alter the dynamics of the entire Mediterranean Sea: formation of intermediate and bottom water, movement through straits, generation of local currents and eddies, patterns of marine productivity and pollutant dispersal.

Most Mediterranean surface water enters from the Atlantic through the Strait of Gibraltar.

Winds affect sea level and are very important in generating vertical convection and deep water formation. The expected northward shift in atmospheric circulation and increased cyclogenesis could affect currents over the continental shelf and water exchange between the Adriatic and Ionion Seas. It could also shift sites of coastal upwelling, such as that off the west coast of Cyprus.

Fishing has always been a mainstay of Mediterranean economies. This Roman mosaic shows one method.

Wind-generated currents are also important on a local scale where they interact with coastal topography to determine the shape and movement of the shoreline. This is especially the case in the northern Mediterranean, where the coast is complex and highly indented, giving rise to small eddies and currents. Many sewage disposal systems have been designed to take advantage of such currents for dispersal away from shore.

Getting into hot water

Because the Mediterranean basin is mostly arid, the sea loses much more water to evaporation than it receives from rivers; this means there is a continuous flow of surface water from the Atlantic through the Strait of Gibraltar and eastward past North Africa. As it evaporates, its salinity and density are raised; this heavier water sinks and moves westward with subsurface currents to flow back over the Gibraltar sill.

Evidence that higher temperatures will affect this process can be seen every summer, when the Gibraltar current gains in strength with the increase in evaporation. Oceanographers have noticed that local water masses also respond to seasonal variations, and suggest that they could be a sensitive measure of climatic change. Some have even speculated that a changing climate could be the cause of the increase in salinity and upward displacement of the intermediate water of the Levantine basin observed since 1982.

If the sea's response to summer heat is a reliable indicator, then the predicted temperature rise could spell catastrophe for the relatively shallow, enclosed bays of the Mediterranean. This is because high water temperature is one of several factors which can bring about a stable vertical stratification of the water in such bays, leading to oxygen depletion and sometimes the death of entire biological communities.

Deadly layers

If we are attentive to what is happening beneath the sea's surface, we are likely to find that the life of the sea is as exposed to the effects of climate change as the life of the shore.

The sea's biological communities are sensitive to even small physical and chemical changes. More radical disruptions, such as severe storms, major changes in salinity or temperature, toxic pollution, and oxygen depletion, can cause the deterioration and death of entire communities. When this happens, many years are required for recovery.

Mass mortalities caused by oxygen depletion are not unusual in the Mediterranean. They tend to occur in shallow bays with a soft substrate, where nutrient input is high and late summer plankton blooms commonly lead to eutrophication and lowered oxygen concentration.

Perhaps the single most important cause of oxygen depletion is stratification. This occurs when a layer of warm, low salinity water sitting on top of a cool, dense lower layer prevents mixing and replenishment of oxygen at the bottom. If there is abundant life on the bottom, or benthos, its respiration can easily exceed its production and the result is oxygen starvation.

The sea is most likely to become stratified where it is relatively enclosed, where there are marked variations of temperature, and where rivers discharge a great deal of low salinity water. Add some pollution by sewage and agricultural runoff and you have a potentially lethal combination.

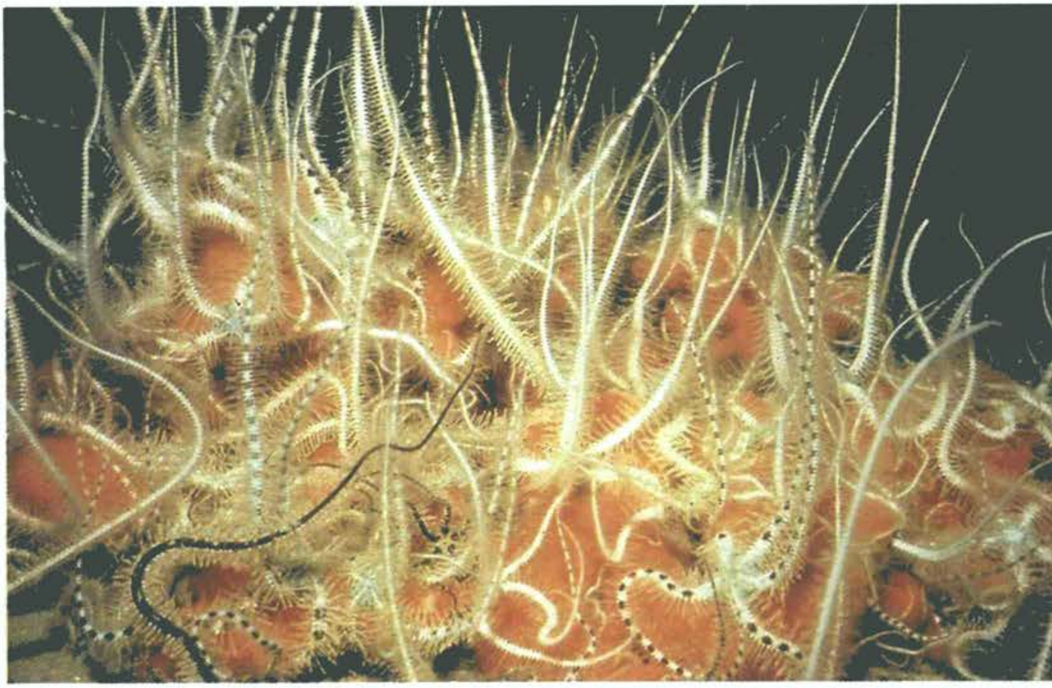
A suffocating sea

The northern Adriatic and parts of the coast of Greece are two such sensitive regions. An "oxygen crisis" resulting in mass mortality was reported in the North Adriatic in 1977, and another in Elefsis Bay, Greece, in 1979. In September of 1983, a research team was finishing up an extensive study of a brittle star community in the Gulf of Trieste when oxygen depletion killed 93 per cent of the surface organisms within four days.

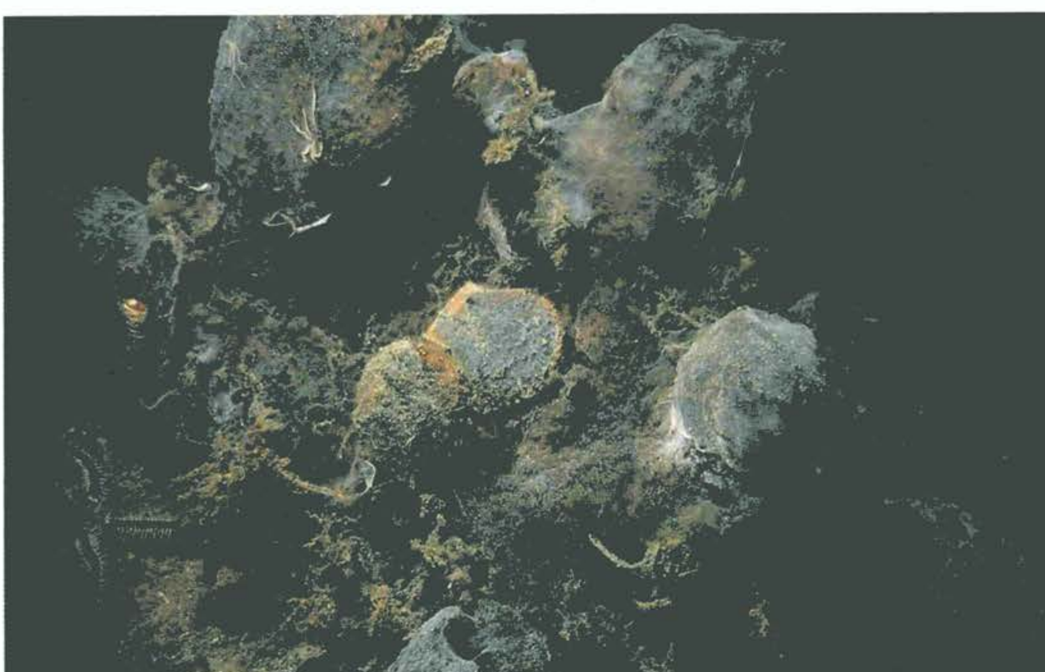
There are, no doubt, many such occurrences we never know about, unless the area happens to be under observation by scientists. But we do know where to expect them.

Many of the predicted effects of climate change bear directly on the likelihood of such catastrophes. The most important is increased late summer stratification of shallow bays as the air and upper water layers warm. As summers lengthen, so will the period of stable stratification.

Since such mass mortalities result from a combination of natural and human causes, prevention is possible. It is important to keep such regions from being overloaded with oxygen-consuming wastes and fertilizers.



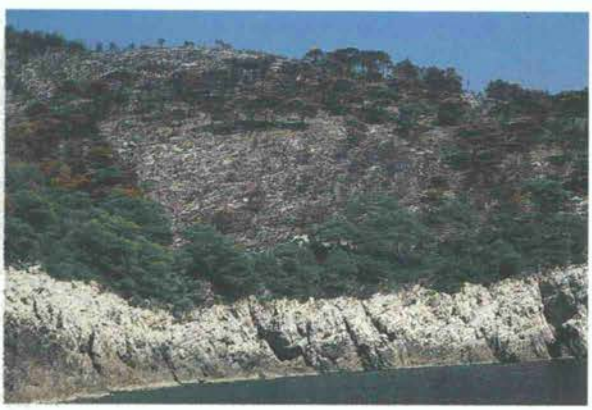
A brittle star community in the Gulf of Trieste, before and after four days of stratification and oxygen depletion.



V. Parks in peril

The Mediterranean coast is rich in areas of biological and ecological interest, and it is here that many of the European migratory bird species find refuge. Around 100 protected areas are located in the coastal zone, in 15 of the 18 countries.

Many of the reserves and much of their wildlife are threatened by human activity in spite of protection measures. Climate change could intensify these threats by increasing the likelihood of fires, provoking the salinization of wetlands, raising the turbidity of rivers and coastal waters, and altering marine currents which disperse sewage and industrial wastes.



Fires can destroy habitat right to the water line.

Fires. Summer fires are a major problem in many national parks. The forests of El Kala national park on the northeast coast of Algeria face a constant threat from fire, as do all of Greece's coastal reserves, including the Gorge Samaria park and biosphere reserve and Vai nature reserve on the island of Crete. At special risk are parks which are heavily frequented by tourists, such as the Corsica Natural Regional Park, which, with 220,000 hectares and 75 km of coastline, covers more than a third of the island. Parts of Lokrum Nature Reserve and Mljet Island National Park near Dubrovnik, Yugoslavia, are regularly denuded by fires during the dry, summer tourist season.

Another example of extreme fire damage is found in Dilek Yarimadasi National Park on the western coast of Turkey, where forest fires have greatly altered the vegetation. An entire forest was destroyed in 1943, and between 1963 and 1979 there were seven major fires. Cluster pine has vanished from the western region, and grazing by domestic animals contributed to the destruction.

One Mediterranean park which has introduced effective fire control measures to protect its rich, highly endemic vegetation is Beydaglari National Park in Turkey. Among the measures adopted are a warning and communications system, a network of fire control roads, a series of observation towers and a trained fire-control team.

Deforestation and overgrazing. Cutting and intense grazing added to fire damage have left a degenerate *maquis* at Tunisia's Zembra and Zembretta National Park, small mountainous islands in the Gulf of Tunis. The barren, rocky islands of Yugoslavia's Kornati National Park were once covered by evergreen forest; today most are

Although once covered with vegetation, Yugoslavia's Kornati National Park is strikingly barren above water.

nearly bare. Overgrazing by rabbits is a problem on Tunisia's Galiton Island Marine Reserve, whereas in Libya's El Kouf National Park goats and sheep are the culprits.

Dessication. Higher temperatures could cause the loss of many wetland reserves which are dry, or nearly dry, in summer. Two examples are the game reserves of Larnaka and Limassol Lakes on the coast of Cyprus.

Development. In many countries, coastal development has already greatly reduced land available for wildlife. The wetlands in Algeria's El Kala national park are being drained and dredged. Construction of irrigation canals and agricultural expansion threaten Egypt's Bardaweel Nature Reserve, a lagoon covering 60,000 hectares on the Mediterranean coast of the northern Sinai peninsula.

Another example is Libya's El Kouf National Park in a relatively populated north-eastern coastal region, which contains the only naturally forested mountain range of the North African coast east of the Gulf of Gabes. It is an arid area with 300-600 mm rainfall per year and summer temperatures reaching 35°C, and is already damaged by overgrazing. Urbanization is considered a serious threat for all of Spain's coastal parks and reserves. The marshes of Algeria's Reghaia wetland reserve are under heavy pressure from tourism, industrial pollution and illegal hunting.

Sewage and agricultural wastes. All of Israel's parks, including Alexander River park and nature reserve between Tel Aviv and Haifa, are vulnerable to sewage pollution. It is likewise a chronic problem for Italy's varied and ecologically rich Circeo National Park and Biosphere Reserve south of Rome, which is also classified as a wetland of international importance under the Ramsar Convention. In Kotor Bay, a World Heritage Site in southern Yugoslavia, industrial and domestic wastes have been blamed for the impoverishment of the commercial fishing industry.

Seagrass beds, found close to the shore, are easily affected by turbid and polluted water.

Sedimentation. *Posidonia oceanica* seagrass beds, such as those which grow extensively in Monaco's underwater nature reserve, are abundant throughout the Mediterranean. Considered a crucial part of the Mediterranean system, they stabilize and build the sea-bed; they supply oxygen, produce organic matter and nourish fisheries; they provide a habitat and nursery for innumerable marine animals; and they protect the beaches and coasts from storm surges and erosive currents.

Sea level rise and increased coastal erosion could mean the end of many *Posidonia* beds, from water turbidity and sedimentation. The seagrass is diminishing in Italy's Castellabate fishery reserve partly as a result of land erosion. And in the Gulf of Fos-Marseille (France), meadows have disappeared from large areas.

Rising Sea. A rising sea could be a problem in wetland reserves separated from the sea by a narrow strip of land, such as Burano Nature Reserve on the Tuscany coast of Italy, already threatened by pollution and fires, and Bardaweel Nature Reserve in Egypt.

Orbetello nature reserve is a sea level brackish lagoon separated from the sea by two long, narrow strips of dune (*tomboli*) and divided into two parts by a third. Construction of a marina has already caused one *tombolo* to erode, and further construction is planned.

The Orbetello lagoon is one of many Mediterranean ecosystems which are particularly vulnerable to sea level rise.

Several protected areas are located in the deltas, where they are at risk from receding shorelines and rising water. These include the Ebro delta (Spain); Bardaweel and El Arish-Rafal (Nile delta); Comacchio, Sacco di Bellochio (Po delta); the Camargue (Rhone delta), and Ichkeul Lake (fed by the Tunisian rivers Djoumine, Rhezala and Sedjenane).

The Mediterranean's magnificent birds will be among the first to suffer from deteriorating wetland habitats. This grey heron was seen at the Kuscenneti National Park in Turkey.

Ebro Delta

This small but important delta, noted for rice and shellfish production, is young. It was formed primarily by deforestation of the drainage area during the last 1000 years, before which it was an estuary.

Two of the lagoons in the delta's southern part are classified as protected areas. Many migratory birds pass through or winter here. In the northern part, 49 sq km have been declared a natural park, and five sections of the delta are areas of special ecological value.

The main threats to the delta and its wetlands stem from increased erosion of the shore and more frequent flooding, which will damage the nesting grounds of migratory birds. A rise in the salinity of wetlands would destroy the present flora.

Since 1970, the damming of the Ebro river has almost totally stopped the delivery of sediment to the delta. Along with other modifications at the river's mouth, this has subjected the front and south lobes of the delta to rapid erosion. Closure of the bays is possible as the coastline retreats, which could have severe effects on the area's marine productivity.

The Ebro delta is a dramatic example of how human activities can modify coastal dynamics in a very short time. Since the expected changes in climate and sea level can only make matters worse, a complete reassessment of the Ebro basin is needed if the management, if the deltaic lagoons and wetlands are to be protected.

Ichkeul National Park

The Tunisian National Park at Ichkeul is one of the most important sites in North Africa for wintering waterfowl, habouring between 200,000 and 300,000 birds. It has been declared a UNESCO World Heritage Site, a Biosphere Reserve, and a Ramsar site. It includes a 90 km^2 lake of seasonally variable salinity and 30 km^2 of fresh water marsh. Approximately a third of the lake is taken up by a pondweed

Forsaking a treasure: Lake Ichkeul is almost certain to become a shallow salt lake.

Potamogeton pectinatus, which is the major food for overwintering pochards, wigeons and coots. The marshes are dominated by a bullrush, *Scirpus maritimus,* a staple of greylag geese.

The lake is already suffering the effects of development. A canal was cut in 1895, allowing sea water to enter into nearby Lake Bizerte; deforestation, channelization, and land reclamation have had further demonstrable effects. Domestic stock has been allowed to overgraze, which apparently caused the death by malnutrition of 18 water buffaloes reintroduced to the marshes in 1980. The massive use of fertilizers and pesticides on surrounding fields is expected to take an increasing toll on the marshes.

Three new dams on the rivers feeding Ichkeul are planned by the year 2000. Nearly 70 per cent of their waters will be diverted for urban and industrial use and irrigation.

The major impact on Lake Ichkeul will result from reduction in river flow by dam construction and atmospheric warming. Even if the release of water from the reservoirs is carefully managed, Ichkeul is likely to be completely transformed into a saline *sebka* with salt-tolerant species replacing the current flora and fauna. Ichkeul's turtles would be lost almost immediately, and immature mullet would lose the brackish water plants and crustacea on which they depend. A nationally important fishery will be threatened.

The dam scheme is likely to cause complete dessication of the marshes. Even if the marshes survive, their vegetation will be affected by changing patterns of inundation and water salinity as sea level rises. Marsh vegetation would migrate upward, and fresh water species could be restricted to river channels.

Scientists are pessimistic about conservation and management measures proving adequate to save Ichkeul National Park, given the cumulative effects of the dams and projected climate shifts.

The Camargue:

Local business lends a hand

The Camarge is famous for its unique biotopes, its diverse wetlands and its importance as a breeding, resting and wintering place for large numbers of migratory birds — at least 323 species of which have been recorded here.

Protected since 1927, the area was declared a Regional Nature Park of the Camargue in 1972, and became a Biosphere Reserve in 1977.

In many places in the Mediterranean, salt is still produced by evaporation of brine in crystallizing pans constructed at the edge of the sea. Deserted salt pans make excellent artificial lagoons which can be reclaimed as breeding and nursery grounds by birds, fish and invertebrates. Malta's Ghadira Wetland Reserve is such an area.

Salt extraction has been carried out for more than 100 years in the Camargue, with only slight impact on the reserve. In fact, the local salt industry has recently begun to use its expertise to save the Camargue's flamingos.

Elevated islands in the Camargue provide important breeding sites for 15,000-20,000 rose-colored greater flamingos. The only other known area in the Mediteranean is Fuente de la Piedra in Spain, and there are fewer than 35 in the entire world.

In the 1960s, many islands were being rapidly eroded by waves stirred up by the *mistral,* interfering with the birds' breeding. Recently a series of unusually cold winters has caused high mortality — in 1985 3000 birds died.

Flamingos in the Camargue: protecting their breeding islands from a rising sea may require teamwork.

An association of ornithologists at the Tour du Valat Biological Station and the local salt-producer, the *Compagnie des Salines du Midi et des Salines de l'Est* (CSME) have been rebuilding breeding islands for the birds and creating artificial islands from scratch. The salt company has maintained a steady water level in a shallow lagoon where the flamingos have nested successfully since 1969.

The work in the Camargue is an encouraging example of a coastal industry working to help one of the Mediterranean's most treasured birds. It shows how salt companies' technology and experience can be called upon when sea level rise and shoreline recession threaten coastal wetlands.

VI. Playing it safe

What can the Mediterranean countries do to prepare for climate change? What *should* they do, given the problems they already face and the limited resources of many to deal with them?

They can help by joining other countries in attacking the causes of global warming, in the hope of keeping its magnitude and its effects to a minimum. Like others, they can reduce their rate of burning of fossil fuels; phase out their production and/or use of chlorofluorocarbons; support international efforts to protect tropical forests; and promote smokeless energy — solar power, wind generators, and safer and cleaner nuclear reactors.

Realistically, they must also accept that climate change is coming and prepare for it.

What we need to know

The Split meeting recommended that a model, or scenario, of climate change in the Mediterranean be developed. In connection with this, a number of questions need to be answered:

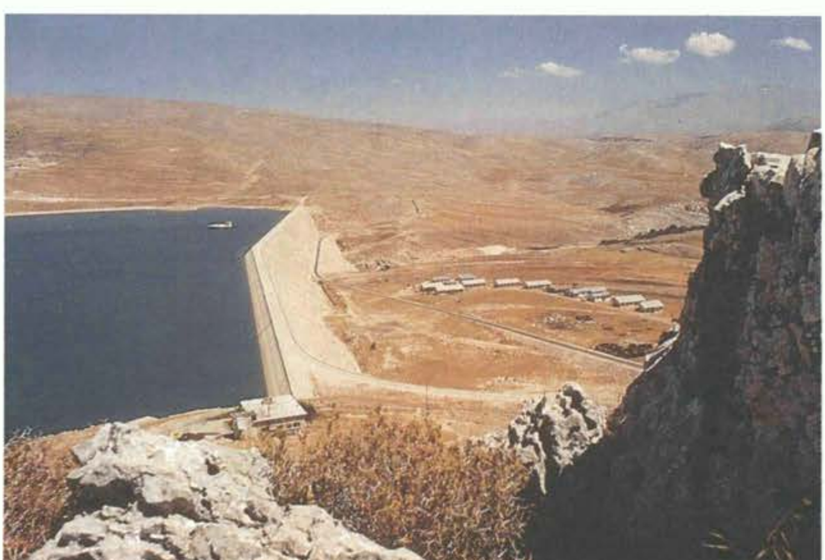
How does large-scale atmospheric circulation relate to local and regional weather features?

What are the mechanisms of cyclogenesis?

What are the trends in precipitation, evapotranspiration, and occurrence of extreme events?

Where are subsidence, compaction, sedimentation and tectonic movements causing changes in relative sea level?

In addition, we must find out more about the likely impact of climate change on the rivers that feed the Mediterranean, on water circulation between the Mediterranean and Atlantic, on soil degradation, and on management of fresh water resources.



Fresh water at what price? New dam schemes should be carefully evaluated to ensure they do not do more harm than good. Pictured: the Litani dam on Lebanon's largest river.

Reforestation of Mediterranean watersheds is one way to conserve soil and prevent sedimentation downstream.

What we need to do

In general, engineering solutions to the problem of sea level rise, such as large dykes and walls, should only be considered as a last resort, since they will probably not be economically realistic in the long term. Although there may be exceptions, such as Greece's Thessaloniki Bay and the Venice lagoon, social adapation and changes in land use should be preferred.

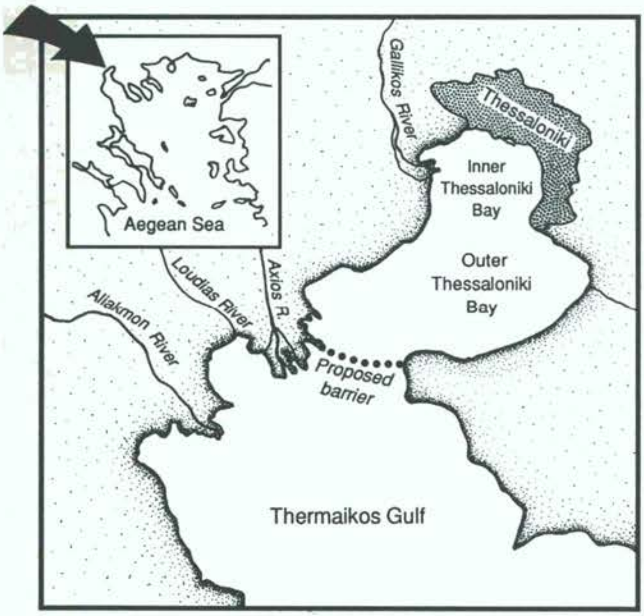
For example, reclaimed agricultural lands currently below sea level, such as in the Po delta, should be allowed to revert to their previous state as lagoons for fishing and aquaculture, while industrial plants are moved inland. The lagoons would serve as protective buffers between the sea and higher lands, and perhaps as wildlife reserves.

Water. Current water management schemes in the Mediterranean will have to be altered. Funds should be invested in construction of waste water treatment plants and facilities to protect existing waters from pollution. Technologies to reduce water consumption should be exploited; for example, closed systems of irrigation which bring water close to plant roots. New dams and other water management schemes, which have often had damaging effects downstream in the past, should be very carefully scrutinized.

Sewage. New sewage systems will have to be constructed to protect public health against flooding of sewage systems by the sea. The possible effects of altered marine currents and more frequent water stratification on the dispersal of piped effluents must not be forgotten.

Tourism. New approaches to beach recreation should be investigated, to minimize the impact of erosion and sea level rise on summer tourism.

Conservation. More attention must be given to conserving soil, groundwater and wetland resources. Coastal habitats — grass beds, lagoons, marshes and dune systems — should be protected for their contribution to the resilience needed to maintain environmental stability.



A technological fix?

When is construction of barriers to sea level rise feasible and economical? One place where it might be is Thessaloniki Bay.

If the proposed climate scenario is realized, this region can expect to suffer many of the most extreme consequences.

The Thessaloniki Bay - Thermaikos Gulf region is a shallow, semi-enclosed area in northern Greece fed by four rivers: the Gallikos, Axios, Loudias and Aliakmon.

Much of the coast consists of low, reclaimed land. As the sea rises, there would be gradual flooding, first of the intertidal zone, then of the deltas, lagoons and parts of the unprotected lowlands of the northwestern industrial coastal zone. This would put low-lying industries and Mikra airport at risk.

Also, sea surges would easily roll over present barriers protecting reclaimed agricultural land and the city of Thessaloniki (population one million). Current sea walls for the port are also insufficient. The tourist area to the east could be threatened by erosion.

The expected rise in temperature could cause stratification of Thessaloniki Bay, which is already heavily polluted, and cause eutrophication and oxygen depletion during peak summer temperatures. Fishing has already been banned

Seagulls gather at a small tidal mud flat near the Thessaloniki harbour.

Fishing boats in Thessaloniki Bay have remained idle since pollution made fish consumption dangerous.

in the Bay. The sedimentation patterns of the Bay could also be altered, blocking channel navigation.

Scattered summer rainfall could disappear. Reductions in volume of the Axios and Aliakmon Rivers could hurt irrigation schemes and hydroelectric stations. Agriculture on the Thessaloniki plain would suffer from loss of fertility and moisture.

Barrier to change

In the face of such potentially disastrous consequences, a daring solution is being proposed for the Bay area. It would involve the isolation of Thessaloniki Bay from the Thermaikos Gulf by a barrier between the Axios delta and M. Envolo Cape (the maximum depth is 27 m).

This would require construction of a 4.5 km barrier across the mouth of the Bay, an undertaking thought to be well within the capabilities of future engineers. Thessaloniki Bay would become a controlled lagoon with essential navigational outlets, and serve as a buffer zone between the low-lying coastal area and the rising sea. Care would be taken to ensure that the sea water circulation and sewage output of the greater Thermaikos Gulf remains normal and that the lagoon is not polluted further.

Such enormous construction projects represent an extreme solution, and one out of the reach of the economies of most Mediterranean countries. But when money is available, it may be a way to prevent even greater financial loss.

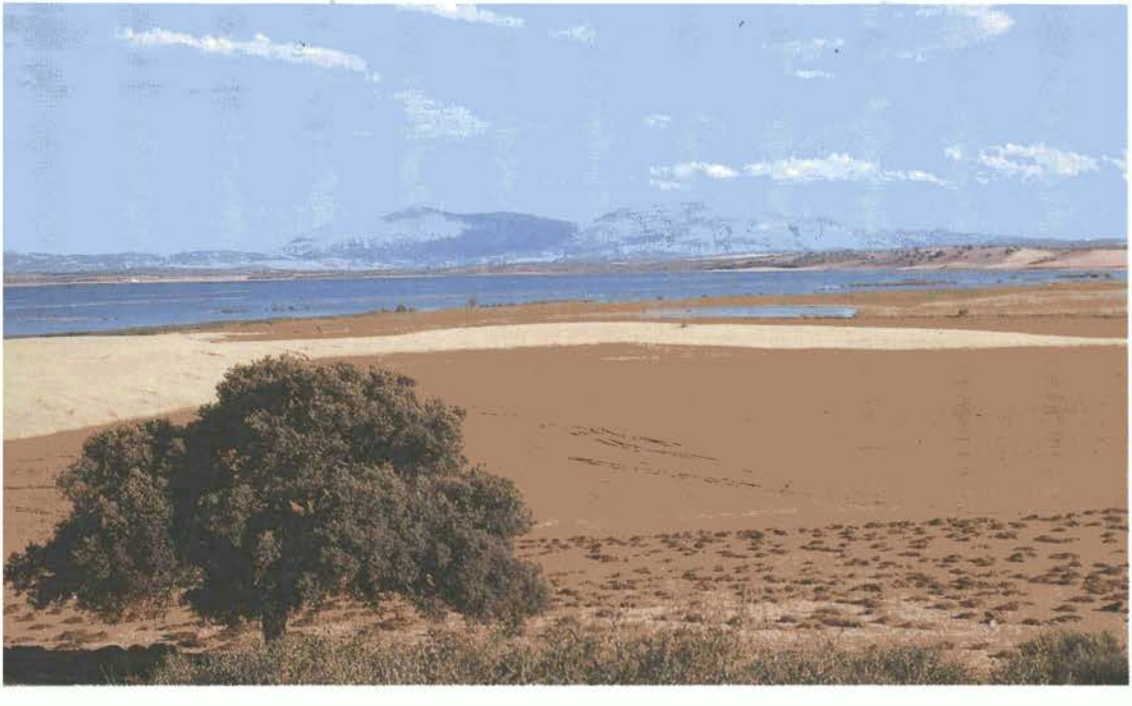
It's never too soon

This book could best be described as "informed speculation". It describes what *could* happen as a result of a certain rise in temperature and consequent changes in sea level, precipitation, prevailing winds and ocean circulation.

If the assumptions are wrong, and if the 2025 climate is the same as today's, nothing has been lost: everything the scientists at Split recommended needs to be done in the face of the changes already taking place in the Mediterranean Basin. We still need to know how to stop land degradation, manage fresh water resources, reduce pollution of the sea, and mitigate the effects on coastal environments of expanding cities and industries. We need to find out more about Mediterranean systems — the soil, the rivers, the wetlands and the sea — and how they relate to the climate of the region and the world. We need to learn how to respond effectively to catastrophic events. And we need to develop different attitudes to coastal land uses which do not bring about, or exacerbate, environmental problems.

If the envisioned changes do take place, they will intensify the Mediterranean's problems and make the recommended measures even more urgent. There is no excuse not to begin.

We must start now if we are to protect Spain's Fuente de la Piedra and other Mediterranean treasures from the effects of climate change.



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A quiet moment in the Nile delta near Cairo.

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Back cover: What future for the Mediterranean?
The time has come to choose.