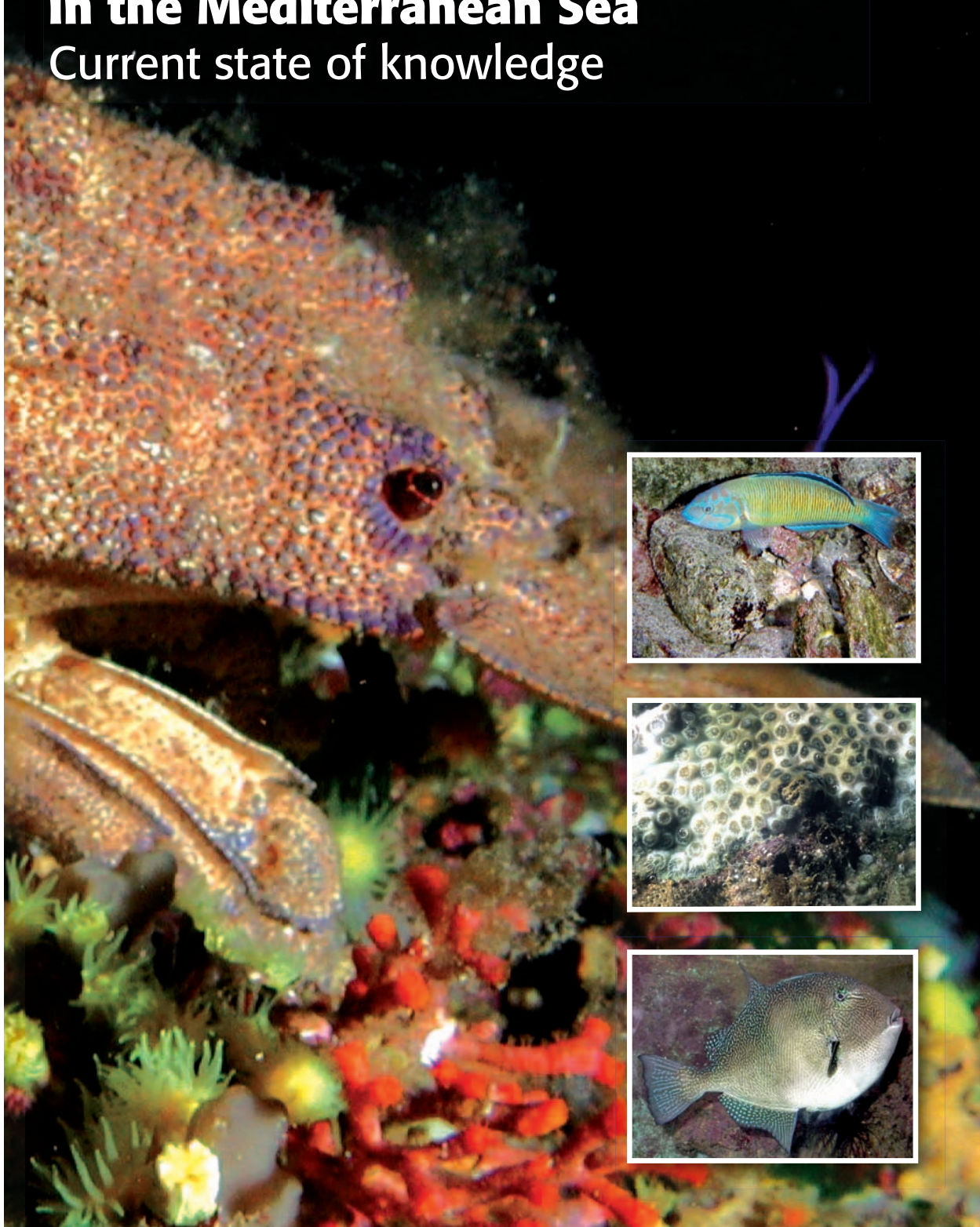




United Nations Environment Programme
Mediterranean Action Plan
Regional Activity Centre for Specially Protected Areas

Impact of climate change on marine and coastal biodiversity in the Mediterranean Sea

Current state of knowledge



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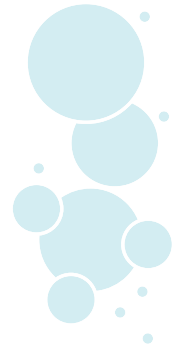
- UNEP-MAP RAC/SPA, 2008. Impact of climate change on biodiversity in the Mediterranean Sea. By T. Perez, .RAC/SPA Edit., Tunis : 1-90.
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FOREWORD



This document constitutes a summary of the work, studies and reflection initiated by the Regional Activity Centre for Specially Protected Areas (RAC/SPA) following the recommendations of the Contracting Parties in Almeria in January 2008. It provides answers to the request to assess the knowledge gathered on the effects of climate change on the Mediterranean coastal and marine biodiversity.

This assessment is part of the present state of knowledge which is still insufficient as the challenges are relatively recent and the future prospects pose one big question.

More information is still needed on the impacts and mechanisms surrounding them but the effects of climate change on the sea and the Mediterranean littorals are already most perceptible and affect without exception the different components of the Mediterranean biome. They also affect the natural resources and threaten the benefits they have for the populations around the Mediterranean basin and there are also social as well as economic repercussions.

Restoring the state of knowledge and identifying the needs on a country and regional level stresses the great necessity for the Mediterranean region and the neighbouring countries to strengthen their capacity and to work together to better tackle the problem of climate change and its connection with other problems such as pollution and the over-exploitation of resources. There is unanimous opinion as to the adaptation aspects; knowhow is still at its beginning especially in connection with the adaptation to the effects of climate change of the biodiversity and natural resources where great efforts need to be deployed in terms of adaptation engineering.

Operational strategy and an adequate organization must be set up on a regional level and in the neighbouring countries to face the perturbations already noted and those still to come. The programmes to be set up must contribute to improve the knowledge on the effects of climate change on the marine and coastal biodiversity and knowhow in terms of adaptation and implementation of solutions for the conservation of natural species, ecosystems, species and natural resources.

Abderrahmen GANNOUN

Director of RAC/SPA

1. INTRODUCTION

Ever since time immemorial climate change has been part of the natural order of our planet. There is evidence that the highly perceptible increase in green house gases has been growing since the beginning of the 20th century and contributes towards the amplification of these changes and makes them perceptible within our own generation. This phenomenon is a real threat to the natural littoral and marine areas, their landscapes, biodiversity and their natural resources.

The Intergovernmental Panel on Climate Change (IPCC) defines climate vulnerability as “the degree to which a system is likely to be negatively affected by the nefarious effects of climate change, including climate variability and extreme phenomena. Vulnerability depends on the character, amplitude and rhythm of climate change to which a system is exposed, its sensitivity and adaptation capacity”.

Box 1: EVALUATION OF ECOSYSTEMS FOR THE MILLENIUM, 2005

By the end of the century, climate change and its impacts could constitute the greatest direct underlying force responsible for the loss of biodiversity and changes in services stemming from the ecosystems. The damage to biodiversity would increase on a worldwide level with the degree of climate change and the overall volume in the relentless progression of climate change.

Urgent and consistent action is necessary at all levels for the protection, mitigation and adaptation of the species, habitats and populations of the ecosystems under these conditions of climate change.

The societies in the south and the east of the Mediterranean and their environment are highly vulnerable to climate change for natural reasons (lack of water), because of their lifestyle and developments concentrated along the coast. These emerging countries are all the more vulnerable as they are not properly equipped in terms of technical and financial means in order to improve their store of knowledge and implement adaptive measures to prevent or to mitigate the effects of climate change.

Climate change is therefore a great threat with two closely interwoven challenges such as:

- pressure on the already fragilized ecosystems due to pollution, destruction and fragmentation of habitats or over-exploitation of natural resources, impacts on sea resources
- questioning of past development strategies through the expected effects on climate change on the integrity of the coastal territory.

The impacts of climate change are extremely varied. Their effects back up and amplify one another, and also amplify the impacts of coastal development and activities. This climate change linked effect (temperatures, rainfall, winds, rise in sea level) and human-origin change (pollution, coastal development, over-exploitation of natural resources, introduction of species) impact and will increasingly impact both the socio-economic sectors and the natural systems

An example of this is the rise in sea level which constitutes a major challenge as this already perceptible phenomenon, which is likely to accelerate, will affect the littoral ecosystems and mainly the wetlands, the foreshores, islands and low-lying islets which constitute a unique or privileged habitat for numerous animal and plant species which again will be affected by accelerated erosion. This phenomenon will also impact on human activities and developments.

The thermal effects and changes in precipitation will be felt on land and the sea and will affect the ecosystems, habitats, biodiversity and economic activities.

2. A BETTER UNDERSTANDING OF THE MEDITERRANEAN IN ORDER TO UNDERSTAND THE IMPACTS OF CLIMATE CHANGE

2.1. The Mediterranean: an ever changing climatic and physiographical history

The Mediterranean sea is what is left of ancient Thetys, an equatorial body of water open in the eastern part which separated Laurasia and Gondwana which arose from the fragmentation of Pangea. During the Cretaceous period, after the opening of the Atlantic Ocean, Thetys linked the newly formed ocean to the old Indo-Pacific ocean. At that time Thetys had a highly diversified tropical flora and fauna. At the beginning of the Miocene epoch (10 million of years) the Suez isthmus was formed isolating the Mediterranean from the Indo-Pacific. Towards the end of the Miocene, communication with the Atlantic was closed as well so that the Mediterranean became an almost isolated sea. These Messinian events occurred for about 0,5 to 1 million years and practically dried out the Mediterranean each time. Indo-Pacific biota became almost extinct and only a few forms survived. When communication with the Atlantic was re-established after the opening of the Straits of Gibraltar, the Atlantic waters flowed into the whole Mediterranean basin and a new Mediterranean biota, the ancestors of the present biota, came into being. The alternating glacial (cold) periods with the interglacial (warm) periods during the whole Quaternary period lead to migratory waves of boreal forms or subtropical forms of life. Those areas further east of the Mediterranean remained under -colonized by species from the Atlantic, not because they could not reach these areas but probably because they could not find favourable conditions to establish themselves in these relatively warmer areas.

Figure 1: The Western Mediterranean 18 000 years ago



Source: France 2 Malaterre according to J. Guiot, R. Cheddadi, C. R. Geoscience 336 (2004).

The paleo-climatology work done on the Mediterranean yields quite good reliable results for the past 18 000 years and describe the climate change occurring during that period.

18 000 years ago during the glacial period, the average temperature of the western Mediterranean sea was 7 °C lower than the present temperatures and that of the eastern Mediterranean 1 to 2 °C. On land the temperature was 5 to 10 °C lower than the present average temperature and rainfall was half of what it is today. During that period the climate was highly variable with successive cold and temperature phases with swings of temperature of 10 °C from one phase to another.

A period-by-period analysis shows significant climatic episodes. In the middle of the Holocene period the winter temperatures were significantly higher (plus 1 °C to plus 3 °C) and heavy rainfall, Medieval Warm optimum (10th to 13th century), the Little ice Age from the 14th to the beginning of the 19th century where there was a drop in average temperatures of approx. 1° C and finally the contemporary period during which the temperatures rose by 2 °C on average due to the increase in green house gas emissions (UNEP /MAP-Plan Bleu, 2009).

2.2. Great continental influence

The Mediterranean region has 21 bordering States with different geo- political, demographic and socio-economic characteristics.

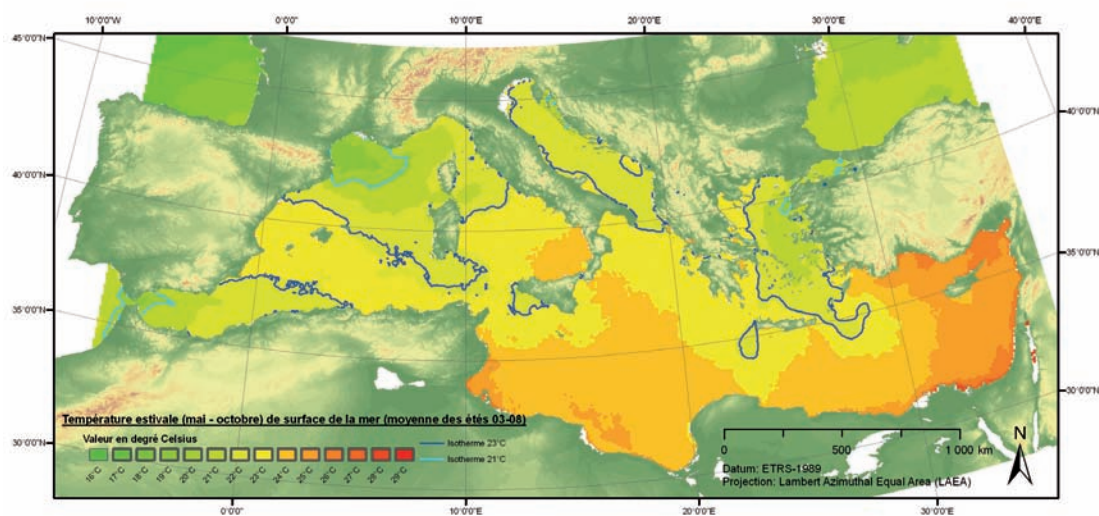
The Mediterranean has a 2.51 million km² surface area and a 46 000 km coastline not counting the 19 000 km of coast of the islands.

From the hydrological viewpoint, the Mediterranean is divided into two deep basins in the west and in the east separated by the Siculo-Tunisian straits with insufficient water which is compensated by considerable inflows from the Atlantic and the Black Sea and it is connected to the Red Sea by the Suez canal. The Mediterranean has a number of sub -systems, the Ligurian, the Tyrrhenian sea, the Ionian sea, the Adriatic, Aegean, Levant and the large marine areas of the South so that hydrologically it has a total of 11 sub-basins. The continental influence is felt through the great rivers, the Rhone, Ebro, Po, Nile and the streams.

The coastal areas are diversified as well with specific sub -systems like the Adriatic, a semi-enclosed sea bordered by the Appenines and the Dinarides, the Alpine arc in the north of the Mediterranean, the coastal reliefs which depend on the Atlas in the Maghreb and the flat coastal belts stretching from Libya to Egypt which are under the immediate influence of the Sahara, the Aegean insular system and the Mediterranean littorals of the Middle East etc.

The region has a "Mediterranean" sub tropical and temperate type of climate with notable difference between the north and the south, micro climates and great differences in rainfall with the ensuing characteristics and consequences. These influences affect the body of water with an increasing and perceptible gradient in temperature from the north to the south and the west to the east and there is also the influence from the Atlantic inputs.

Figure 2: Average water surface summer temperature (May - October) from 2003 and 2008 summers (© RAC/SPA, by Requena Moreno, S., 2009)



2.3. Exceptional biological interest

The Mediterranean has particular sub- systems, the seas, islands, wetland and lagoons including numerous Ramsar sites, deltas, dunes, forest, maquis, garrigue, cliffs etc. The regional ecosystem has limited resources and therefore cannot be over -exploited. It should be recalled that in 2001 there was an ecological deficit in all the bordering countries as the environmental capital was being spent faster than it was being renewed.

In the Mediterranean the inventories show 10 000 to 12 000 species, equivalent to 4 to 18% (depending on taxonomic groups) of known marine species in the world over respectively 0.82 % and 0.32 % of the surface area and the volume of the world ocean. It is one of the 25 recognized biodiversity poles on a worldwide level. The same applies to the continental domain of the Mediterranean basin which represents 1.6 % of the surface areas of the continents and yet covers 10 % of the world's biodiversity.

Endemism is greater in the Mediterranean than in the Atlantic. From the bio- geographical viewpoint, the Mediterranean biota has 55 to 77 % of Atlantic species, 3 to 10 % of pan- tropical species, 5 % of Lessepsian species and between 20 to 30 % of endemic species.

This strong biological diversity is connected to the particular geo- morphological and hydrographical characteristics of the Mediterranean basin, its geological history and its position as an interface between the temperate and tropical biomes so that it can harbor both “cold” and “warm” species.



Figure 3: The Mediterranean, an exceptional biological interest



Table 1: Level of endemism in the terrestrial environment

Phylum	Number of species in the Mediterranean	Number of endemic species	% of endemic species
Vascular plants	25000	12500	50
Freshwater fishes	300	132	44
Reptiles	165	113	68,5
Amphibians	63	37	58,7
Mammals	197	50	25,5
Birds	343	58	17
Insects	150000	?	?

The Mediterranean shores have unique and highly diversified landscapes, the Mediterranean forest, the maquis and garrigue, littoral oases, dunes, sandy beaches and cliffs which yield an impressive range of particular animal and plant species.

Table 2: Level of endemism (number and percentage) in some taxonomic groups in the Mediterranean (cf. Boudouresque, 2004 for sources)

Phylum	Number of species in the Mediterranean	Number of endemic species	% of endemic species
Echinodermata	134	32	24
Priapulida	1	0	0
Polychaeta Errantia	371	88	24
Echiuria	6	1	17
Sipuncula	20	4	20
Brachiopoda	15	2	13
Mollusca	401	65	16
Crustacea Decapoda	286	52	18
Pogonophora	1	1	100
Phoronida	4	0	0
Hemichordata	5	2	40
Pisces	638	117	18
Total	1 882	364	19

3. THREATS TO THE PHYSICAL ENVIRONMENT

3.1. A perturbed climate

Climate change and its effects on the marine and littoral environments are already perceptible. The Mediterranean shores have been classified as hot spots in the last IPCC report. The models associated with the scenario A1B predict an average increase in annual temperatures of 2.2 to 5.1 °C by the end of the century, which is higher than the average figure expected for the planet. There is an estimated 50 % probability of warming between 3 and 4 °C taking place (GIEC, 2007).

The increase would have been greater in the hinterland rather than along the coast, sea or in the islands. It would have been greater in the summer (2.7 to 6.5 °C) than in the winter (1.7 to 4.6 °C). There would have been more numerous, longer and more intense heat waves, with frequent extremely hot days with all the ensuing repercussions on human health and risks of fire.

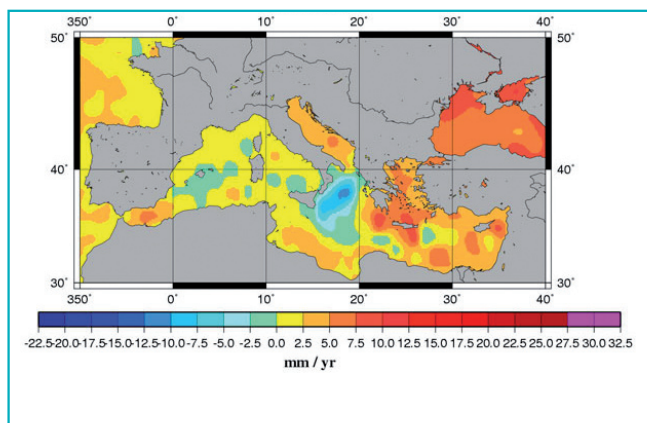


Figure 4: Comparison of current temperatures (°C) and precipitations (%) with 2100 projections

Source: 4th IPCC report

There is a lot of uncertainty as far as the season is concerned, as the values given by the range of probability varies from one to triple.

The projected figures forecast less annual rainfall with a decrease of 4 to 27 %. This decrease would be more noticeable in the summer than in the winter. North Africa would be particularly affected by this drought which has also been noted in other parts of the Mediterranean basin. Periods of drought would be more frequent, longer and more intense. The distribution of precipitation would be modified with intense rainfall in the winter whereas the other seasons would be much drier. Torrential rains would also be more frequent.

Table 3: Expected variations of temperatures, precipitations and extreme events. Differences are calculated between 1980-1999 and 2080-2099 (scenario A1B on the basis of results of 21 global climatic models).

Season	Temperatures variations (C°)		Precipitations variations (%)		Frequency of extreme events (%)		
	Min.	Max.	Min.	Max.	Hot	Humid	Dry
Winter	1.7	4.6	-16	6	93	3	12
Spring	2.0	4.5	-24	-2	98	1	31
Summer	2.7	6.5	-53	-3	100	1	42
Autumn	2.3	5.2	-29	-2	100	1	21
Annual	2.2	5.1	-27	-4	100	0	46

Source: 4th IPCC report

Rainfall models converge towards forecasting more periods of drought with a lesser number of days with precipitation and there would be more and longer periods without rain.

Extreme events will become more frequent with more frequent and intense flooding.

As for storm waves and flooding, the results of the models are still preliminary but there should be a lesser number of depressions and weaker winds so that these risks should be mitigated even if a nuance should be introduced into this assessment on a local level.

There is little probability of real tropical cyclones developing in the Mediterranean in the 21st century. Wind shear at altitude and the low maritime extension should inhibit their development (UNEP/MAP-Plan Bleu, 2009).

3.2. A sea level rise, with heavy consequences

There is a consensus in the Mediterranean on a number of variables which already have or will in the short term have considerable effects on the littoral ecosystems. The first such effect is obviously the sea level rise which is estimated at approx. 1 mm per year (Figure 5). (UNEP-MAP-RAC/SPA, 2008).

It is still difficult to forecast the increase in sea level on a regional level especially in the Mediterranean basin. It could be 23 to 47 cm by the end of the 21st century according to IPCC on the basis of the 2007 projections which today are considered as being rather optimistic. Numerous Mediterranean regions would thus run a huge risk of submersion and erosion, and the extreme cases of Venice, Kerkennah archipelago in Tunisia, Alexandria and the Nile delta in Egypt would be cited as examples.

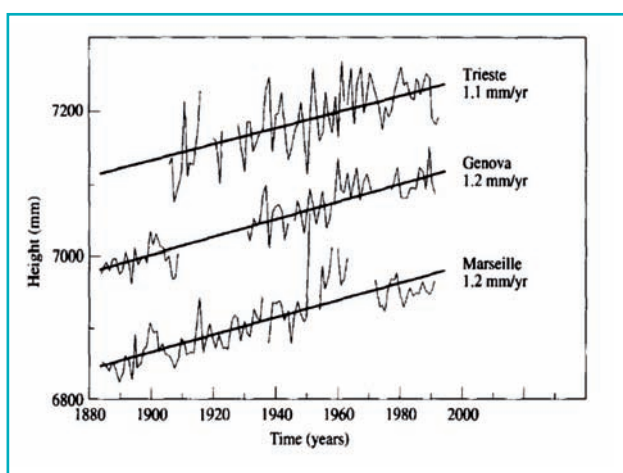


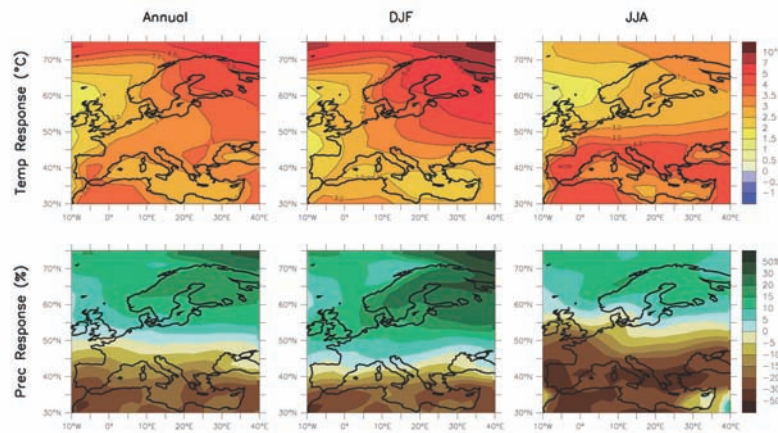
Figure 5: Three sets of data from the western Mediterranean showing the rise in sea level. Data available from the Permanent Service for Mean Sea Level (<http://nbi.ac.uk/psms/> Nicholls & Hoozemans 1996).

(Source: UNEP-MAP-RAC/SPA, 2008)

The consequences to be apprehended are as follows:

- Worse submersions on low-lying coastlines especially delta areas, littorals with lagoons, marsh lands and some islands;
- Accelerated erosion of the cliffs and beaches;
- Greater salinity in the estuaries;
- Reduction in volume of fresh water aquifers.

Figure 6: Variations of sea-level rise observed between 1999 and 2006 by the TOPEX/Poséidon project, mm/year



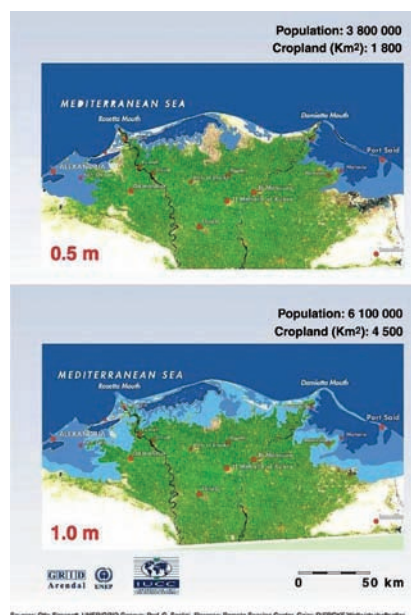
Note: From negative values (purple to dark green) to positive values (yellow to dark red). The difference between the Eastern and the Western sides of the Mediterranean is obvious, with a clear trend to sea level rise.

Source : LEGOS-GRGS-CNES

This increase however is not at all homogeneous and satellite monitoring through the Topex/Poseidon programme on the variations of the Mediterranean sea level between January 1993 and June 2006 has shown a raised Mediterranean sea level especially in the eastern basin.

The Nile delta is an excellent example of the effects of an accelerated sea level rise and the Nile delta plain is one of the most sensitive areas of the Mediterranean. The delta is Egypt's main agricultural area and very densely populated with 1 600 inhabitants per km² on average and it is protected from the rising tide by a 2 to 3 m high sand-bank and some defensive structures in Alexandria. This sort of protection is fragile and a rise in sea level would entail numerous changes as lands which were flooded seasonally would be transformed into marshes and then into a peat bog so that all animal, plant and human life would migrate elsewhere. This rise in level would also lead to an extension and a deepening of the lagoons. The littoral belts would thus be easily sectioned and saline water from the sea would then flow in.

Figure 7: Potential impact of sea level rise, Nile Delta

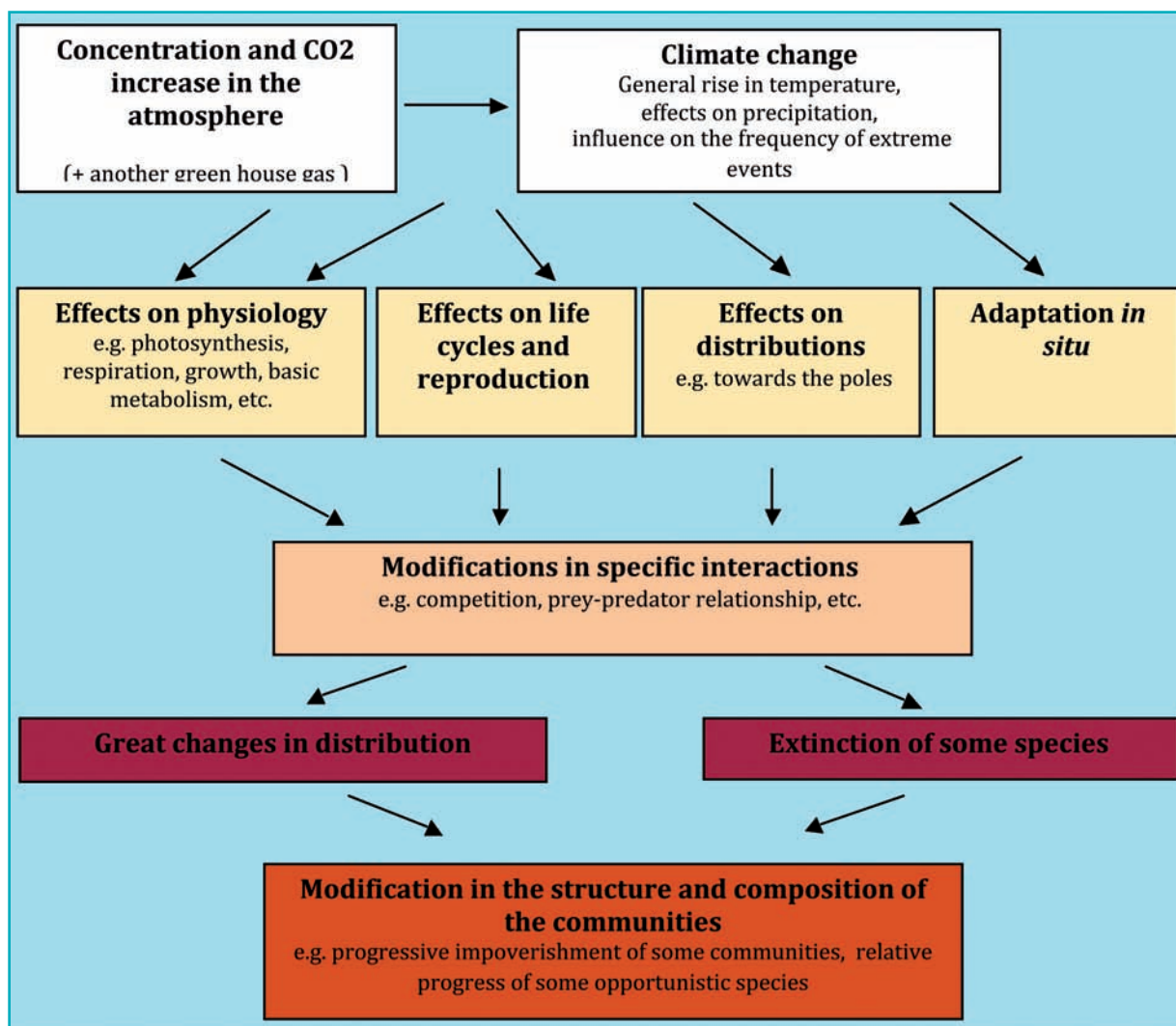


4. IMPACTS ON MARINE AND COASTAL BIODIVERSITY

Climate change today is an additional pressure threatening the biological diversity (Figure 8).

Climate change and especially rising temperatures influence the periods of reproduction and/or migration of some species, the length of the growth phase, frequency of parasite infestations and the emergence of new diseases. It is likely that the changes forecast might modify the distribution of species and the density of the populations by displacing the habitats (e.g. migration towards the pole or higher altitudes of species which prefer a colder climate). The composition of most of the present ecosystems will probably change and there will be a greater risk of the extinction of species especially those that are already vulnerable and in particular those species with a restricted climatic distribution, those that need highly specific habitats and/or small populations which are naturally more vulnerable to modifications in their habitats. Finally the introduction of new exotic species could be facilitated and this is a phenomenon whose long term consequences are difficult to foresee.

Figure 8: Impact of climate change on biodiversity (according to Hughes (2000), TREE)



In the last few years the natural evolution of the Mediterranean biome has been perturbed by the accumulation and amplification of global changes and in particular by the effects of climate change.

4.1. Threats facing the landscapes and coastal biodiversity

Directly or indirectly, a rise in sea level, global warming and changes in the rainfall pattern would greatly modify the coastal ecosystems and the eco-socio-system to a large extent as well: the forest species who can tolerate the least these changes would find that their distribution range had changed and their latitudinal limits had been displaced towards the north. The riverside woodlands and marshes would be reduced with the threat of erosion of the biodiversity inherent in these environments. Agro-systems too are threatened by more frequently occurring unforeseen climatic events and the trend towards a water shortage and insufficient water resources in general.

On a more strictly coastal level the littoral wetlands and the river mouths would be affected as well by the rising sea level. Depending on their configuration they are likely to shrink or to retreat towards the interior. Loosely-packed coasts are likely to retreat or disappear because of the effects of erosion due to the accelerated rise in sea level. During this transitional phase of the accelerated rise in sea level the least mobile organisms will be most severely impacted in contrast to mobile organisms such as fish and water-birds which should be able to adapt. Aspects linked to resistance and resilience of the ecosystems, habitats and birds still remain mostly unknown. (UNEP-MAP-RAC/SPA, 2009^a).

Figure 9: Nesting beaches of the loggerhead turtles are severely threatened by the sea level rise (Photos: L. M. Preau)



There are unanswered questions about the effects of climate change on the monk seal populations for example, whose caves, where they shelter, could be submerged by the rising waters and on the receding beaches which are used as nesting sites by the loggerheads.

There are also questions about the adaptation of sessile organisms and what would happen to particular formations such as the vermetid formations.

Figure 10: What future for particular formations like the vermetid formations in the Mediterranean (Photo: Amir Ibrahim)



4.2. Under water, out of sight, a clear meridionalisation of the ecosystem

These phenomena could have a strong influence on some biotic and abiotic models (dispersion of plankton and larvae, nutrient cycles, etc.) which affect the ecosystems at several levels.

Some unexpected effects of the thermohaline circulation have radically changed the hydrology of deep waters in the eastern Mediterranean strongly affecting the temperature, salinity, stratification and the circulation of bodies of water. The same phenomenon has affected the nitrogen and carbon cycle as well with a negative impact on life in deep waters. Recent evidence shows the presence of signals which had spread to the west of the basin.

The increase in water temperature can affect organisms and entail constraints which sometimes lead to some physiological adaptations. In some cases when the stress exceeds the tolerance threshold, the life cycle or the distribution of species can be modified. At present in the Mediterranean, amongst the direct consequences of global warming, there is a simultaneous increase in the abundance of Mediterranean thermophilic and allochthonous species and the disappearance or rarefaction of "cold" stenothermic species.

The Mediterranean has always been divided into three large bio-geographic provinces: the western basin, the eastern basins and the Adriatic sea. The distribution of species is generally determined by the latitude. Thermophilic and tropical species dominate the southern part of the Mediterranean and temperate species are more abundant in the northern part.

Recently numerous thermophilic species have greatly extended their distribution range and are becoming more abundant especially in the north-western part of the basin. One of the first signs of this trend is the ornate wrasse (*Thalassoma pavo*). Until the 1980s this species was most frequently found in the southern and eastern part of the Mediterranean and rare in the north-western part of the basin. *Thalassoma pavo* adults were recorded for the first time in Scandola in 1988 and juveniles were observed in 1991. At present there is evidence that the distribution range of *Thalassoma pavo* has increased by approx. 1 000 km (UNEP-MAP-RAC/SPA, 2009b).

The presence of *Astroides calycularis*, a very thermophilic species which is quite common in the eastern Mediterranean, in the north-west of the Mediterranean seems to be connected to the increase in temperature of the sea (UNEP-MAP-RAC/SPA, 2008).

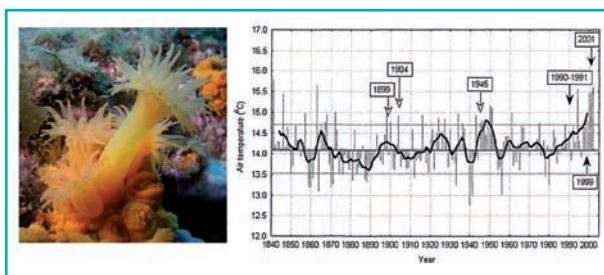
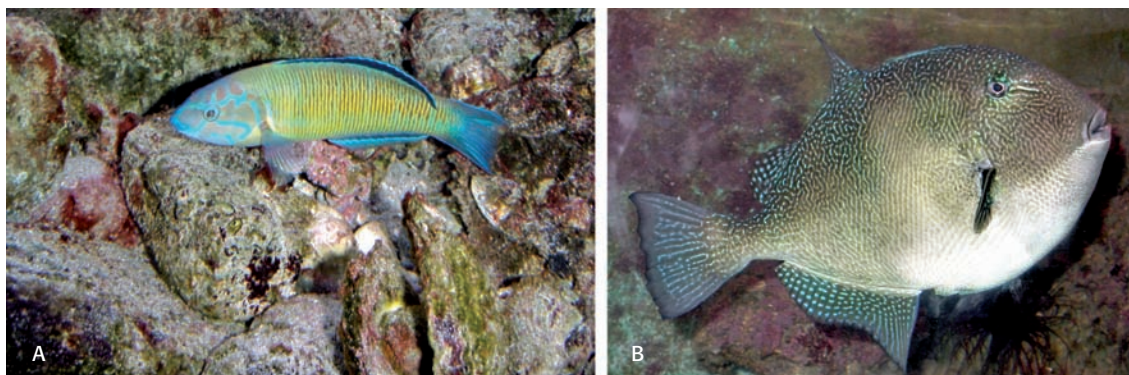


Figure 11: The orange coral *Astroides calycularis*, basically distributed around the south of the western Mediterranean basin and known to be a thermophilous species. Various sightings of the coral are marked on a curve representing annual averages of air temperatures in the Adriatic region (Trieste) (Grubelic et al., 2004). Photo by T. Pérez. (Source: UNEP-MAP-RAC/SPA, 2008)

Other observations illustrating a trend towards meridionalisation have also been made in the Adriatic sea (Lipej et Dobrajc, 2008).

Figure 12: A trend towards meridionalisation has been also detected in the Adriatic sea. A) the ornate wrasse *Thalassoma pavo*; B) the triggerfish *Balistes carolinensis*. Photos: B. Mavric



The present warming trend can also enhance the propagation of several predators such as the barracudas *Sphyraena spp.* and the common dolphinfish *Coryphaena hippurus*.

The temperature increase can affect the behavior of large pelagic fish such as the Northern bluefin tuna *Thunnus thynnus* and the Mediterranean yellowtail *Seriola dumerili*. These great migratory fish now seem to stay longer in the western basin with considerable consequences on their stocks and the trophic network.

In view of the global warming trend, a homogenization of the Mediterranean biota can be foreseen perturbing the present bio-geographical entities. The southern part of the Mediterranean will be increasingly occupied by tropical exotic species; the North will be invaded by indigenous warm water species. The cold water stenothermic species will be confined to the north of the basin. They might become rarer with the probable possibility of extinction if the warming trend continues. The sprat *Sprattus sprattus* for example, which was abundant in the gulf of Lion, has become very rare, even though it was not particularly sought after by professional fishermen.

There is a substitution of species in some of the confined biotopes. The communities of submarine caves, with their endemic and specialized species, are particularly threatened as they are naturally fragmented and more sensitive to perturbations. In the Marseilles region, the crustacean mysid *Hemimysis speluncola* has for a long time been the dominant and even the only species in dark caves where it formed enormous swarms until the end of the 1990s. Precise monitoring of the Mycidae populations made it possible to observe the rapid disappearance of this cold species during great summer anomalies and *Hemimysis margalefi* taking over the vacant ecological niche in the Balearic Islands and in Malta.

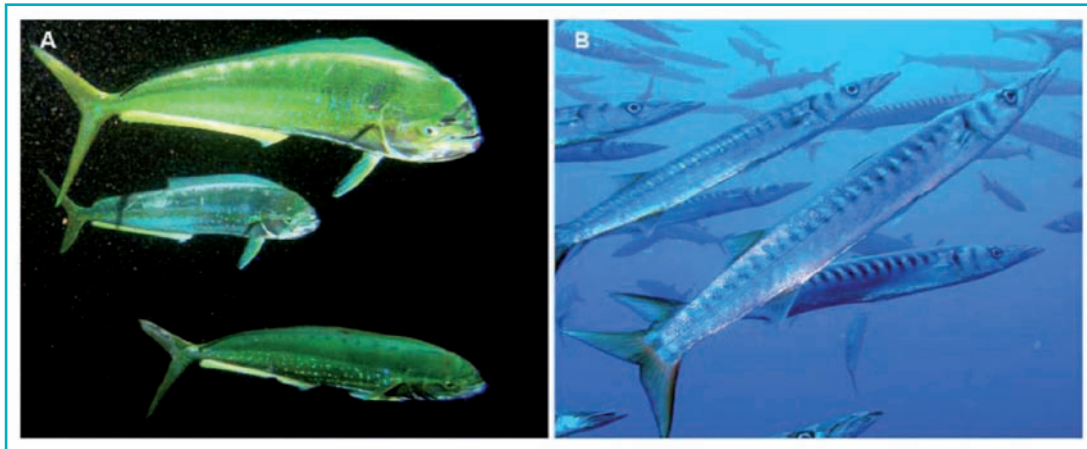
Figure 13: Indicator species of the meridionalisation of the north-western Mediterranean. A) the ornate wrasse *Thalassoma pavo*; B) the grey trigger fish *Balistes carolinensis*; C) the sea-urchin *Centrostephanus longispinus*; D) the dusky grouper *Epinephelus marginatus*. Photos R. Graille (A), J.G. Harmelin (B) and T. Pérez (C,D), (Source: UNEP-MAP-RAC/SPA, 2008)



On the basis of a moderate climate change scenario, a hypothesis has been forecast for the extinction of 15 to 37 % of the species occupying the north-western Mediterranean by 2050.

For the time being it does not seem possible to foresee the magnitude of the proliferation of thermophilic species. The Mediterranean at present is undergoing a process of meridionalisation.

Figure 14 : Southern-origin (even tropical) fishes that have made their appearance on the fishmongers' slabs of the north-western Mediterranean: A) *Coryphaena hippurus*; B) *Sphyraena viridensis*. Photos by T. Pérez. (Source: UNEP-MAP-RAC/SPA, 2008)



4.3. Climate change is amplifying biological invasions

Biological invasions, considered as a component of global climate change as they affect the biodiversity, are often linked to climate change and other environmental perturbations. Other factors come into play as well such as the intense maritime traffic which transports invasive species in the ballast water and in the form of fouling, the lagoons and bays which harbor large numbers of aquaculture farms which use seed-oysters and juveniles and this makes it possible to introduce exogenous organisms. The biggest invasions are attributable to the opening of the Suez canal in 1869 which made it possible for species from the Red Sea and the Indo-Pacific to get into the Mediterranean so that today there are macrophytes, invertebrates and exotic fish which are quite common in the habitats of the eastern Mediterranean. Even if climate change does not seem to be the most determinant factor in more species being introduced into the Mediterranean, there is a strong probability that the progress and extension of Lessepsian species like those from the sub-tropical Atlantic are fostered by the rise in temperature of the marine waters.

Numerous examples bear witness to this phenomenon (UNEP-MAP-RAC/SPA, 2008):

The Lessepsian crab *Eucrate crenata* which continues expanding towards the north and the west, and *Percnon gibbesi*, another crab from the Atlantic ocean whose larvae probably came into the Mediterranean through the currents from the Atlantic, was recorded in Mediterranean waters already in 1999. At present the distribution range of *P. gibbesi* is limited to the north in the Tyrrhenian sea. In the central Mediterranean it is to be found on the island of Ponza in Italy, in the south on the coasts of Libya and to the east in the Aegean and the Ionian sea.

As can be seen from the sudden population explosion of the brushtooth lizardfish *Saurida undosquamis* and the Indo-Pacific goldband goatfish *Upeneus moluccensis* after the temperature increase from 1 to 1.5 °C during the 1955 winter months, the water temperature increase has a positive effect on thermophilic exotic species.

Another clear example of dissemination westwards of Lessepsian species is that of the rabbitfish *Siganus luridus* which recently reached the Gulf of Lion.

The hypotheses linking climate change and the amplification of invasions is confirmed by the proliferation of exotic species of phytoplankton. There are two thermophilic species from the Indian ocean, *Asterodinium gracile* and *A. libanum* recorded for the first time in the Ligurian Sea and the Tyrrhenian Sea during the 1999 thermal anomaly and the authors even suggest them as bio-indicators of the warming of the north-western Mediterranean.

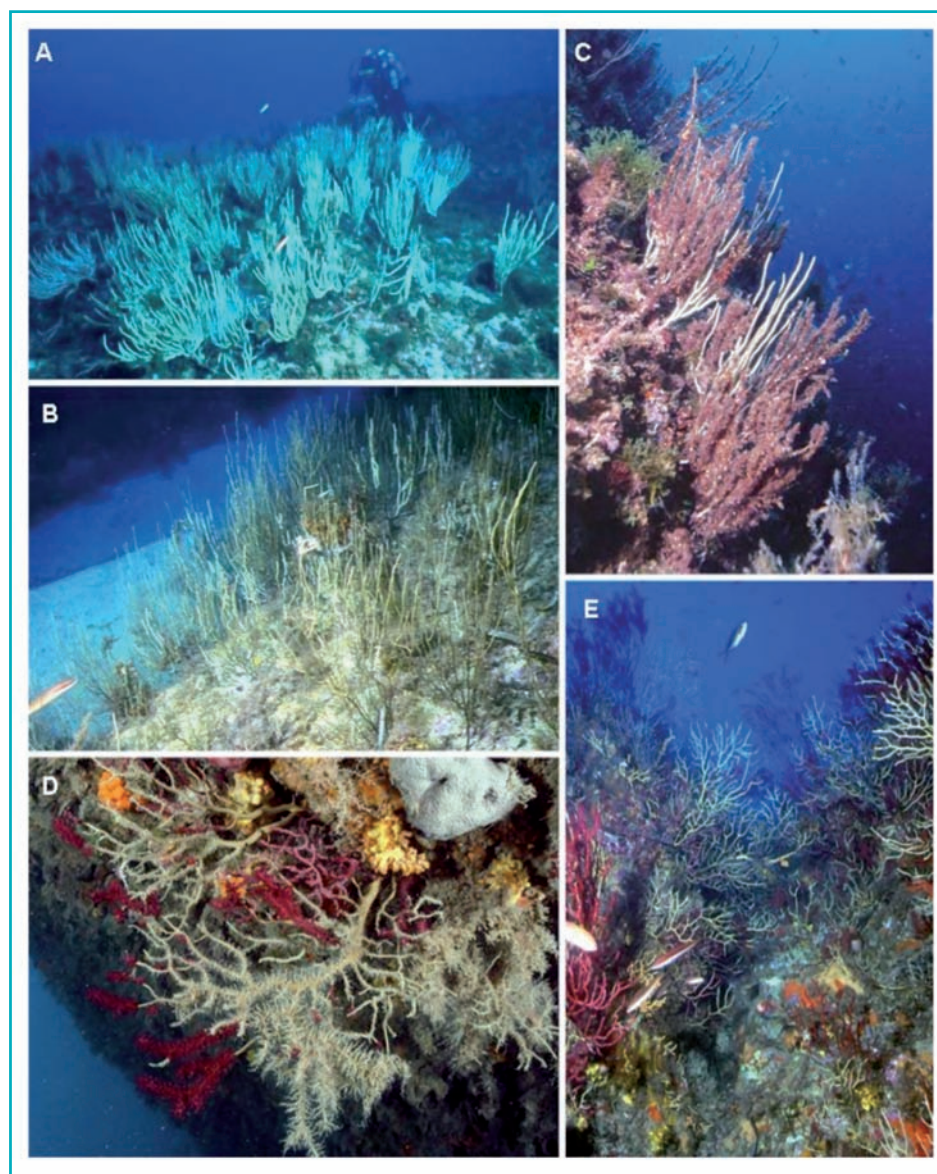
4.4. Proliferation of pathogens and diseases endanger both humans and biodiversity

The expansion of subtropical and tropical marine species also includes the toxic dinoflagellates. Some species such as the *Gambierdiscus toxicus* (the principal agent of ciguatera) can have very serious consequences on human health: *Ostreopsis ovate* causes irritation, cough, fever and respiratory problems.

Gymnodinium catenatum which so far had been confined to the Alboran Sea, was observed for the first time in Algeria and it managed to reach the Italian coasts. This species is used to eutrophic waters but it has a great trophic adaptation capacity and seemed to be dominant in sub-surface waters in some low salinity sectors. Its geographical extension is a problem because of its toxicity but also because of the perturbations it causes to the structure of the Mediterranean pelagic trophic chains. There is probably a connection between climate change and the proliferation of this species. Species in general react to environmental stress through physiological, biochemical and molecular adaptations. When the tolerance threshold of the organisms has been exceeded, then this can lead to diseases and massive mortality rates and they can be replaced by other more resistant species. There has been a clear increase in the frequency of epidemics and mass mortality rates in the last two decades.

Amongst the marine organisms, the sponges and corals (many of which are stenothermic endemic Mediterranean species) seem to be the most sensitive taxons.

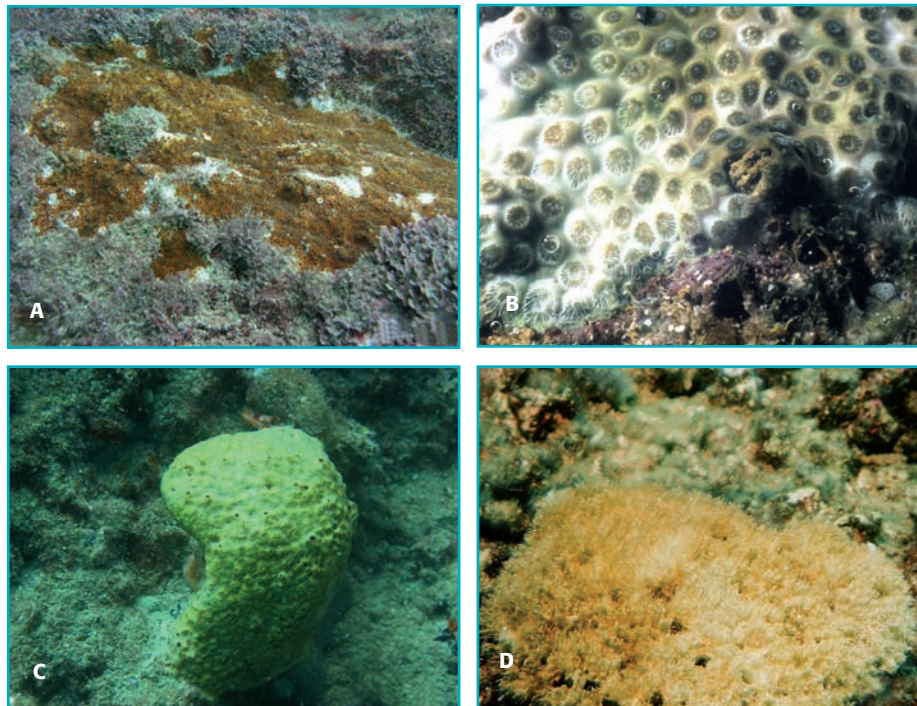
Figure 15: The impact of mass mortality of gorgonians on landscapes. A) Population of *Eunicella singularis* before (A) and immediately after (B) the mass mortality of 1999. Several months later, the gorgonians' naked skeletons are colonized by opportunistic species of algae, hydrozoa and bryozoa (C). The coralligenous community can be dominated by the big gorgonia *Paramuricea clavata*. The impact of the mortalities on the appearance of this community on a face (D) or a plateau (E). Photos by J.G. Harmelin (A, B, C, E) and R. Graille (D), (Source: UNEP-MAP-RAC/SPA, 2008)



About 40 high mortality events over a large range between the Tyrrhenian sea and the Gulf of Lion were recorded, probably due to exceptional temperatures, in the summers of 1999 and 2003. A pathogenic strain of *Vibrio* from warmer seas had been identified and it affected the gorgonian *Paramuricea clavata* in the Tyrrhenian sea and the starfish *Astropecten jonstoni* along the Sardinian coast.

Biological invasions can amplify the effects of global warming and constitute an additional stressor for species already weakened by climatic fluctuations (Bitar, 2008).

Figure 16: State of stress: whitening of *Oculina patagonica* in Lebanon. A) Normal *Oculina patagonica* colony; B) Whitened *Oculina patagonica* colony; C) *Ircinia* in good condition; D) Spoilt *Ircinia*, (Source: Bitar, 2008)



4.5. Acidification of water, another factor of diseases and mortality rates

Greenhouse gases are increasing in the atmosphere and carbon dioxide is absorbed by the oceans and thus decreasing the pH. Even though the process is well known, the potential effects of acidification of the oceans on the Mediterranean marine ecosystems have been insufficiently evaluated so far. Acidification affects some organisms such as the coccolithophoridae and several calcareous species.

Acidification of water can affect numerous important benthic ecosystems such as the coralligenous assemblages, vermetid reefs and *Posidonia oceanica* meadows. As for the latter species, the CO₂ increase leads to greater densities but reduces the epiphytic cover. Plants living with a low pH get a reduced "belt" of calcareous epiphytes and thus become more vulnerable to browsers.

4.6. Key factors for the adaptation of species: resilience, resistance

The knowledge on the mortality rates and the introduction of species is constantly under review and the knowledge about their recovery capacity is very recent indeed. With the sessile species, it seems that the long-lived species with relatively slow dynamics (low growth rate, limited reproduction efforts) are the most affected. This data is vital in order to evaluate the resilience of the populations facing these perturbations and also to set up the necessary biodiversity management and conservation measures in order to preserve the ecosystems which are sensitive to global warming.

As for the sponges for example, *Spongia officinalis* has shown its recovery capacity after climatic crises whereas species like *Spongia agaricina* and *Hippospongia communis* seem to be more vulnerable. This is not surprising as this species seems to be reproducing throughout the whole year with two reproduction peaks per year and a reproduction effort which could attain 20 % of the biomass of the mother sponges.

The gorgonian *Paramuricea clavata* is another example of a species which is very sensitive to warming and if this vulnerability is quite clear there are still some examples to mitigate this observation.

The perception of the medium term effects of these mortality levels is highly variable, with a pessimistic outlook which envisages an extinction of this species in the next thirty years or a brighter outlook whereby there would be an apparent recovery of the initial conditions due to considerable recruitments in other populations.

In general important information is still missing and required for the precise evaluation of the resilience of the invertebrate populations which are affected by extreme climatic events: (i) good knowledge of life cycles, reproduction efforts, successful reproduction and recruitment of larvae, the contribution of asexual reproduction and regeneration in the maintenance of the populations; (ii) good characterization of the genetic structuring of the populations so as to evaluate the flow of genes between them and the dispersion capacity of the propagules; (iii) tools to assess the adaptation possibilities to stress caused by the global changes in the Mediterranean, these could be physiological adjustments (phenotypical plasticity) or micro-evolutive processes. These various questions are at present at the heart of various research programmes.

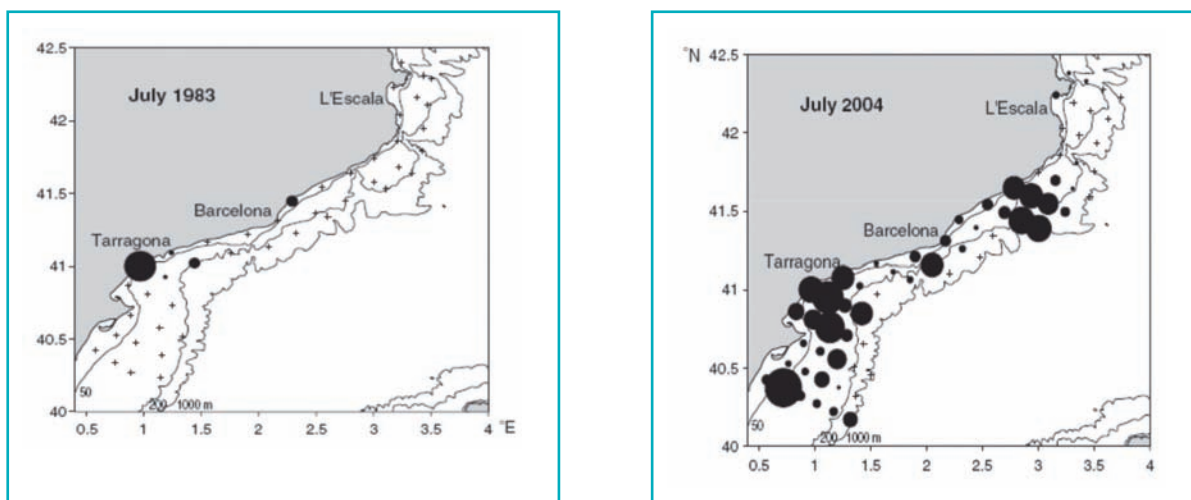
5. WILL CLIMATE CHANGE AFFECT THE FISHERIES ?

It is highly probable that the regional effects of climate change will contribute towards the perturbation of sea activities in the Mediterranean where the pelagic, demersal and benthic species are severely affected by artisanal, semi-industrial and industrial fleets.

The role of hydro-climatic variations in regulating the abundance of the fish populations is recognized today. The structure and the fish population dynamics of the continental shelf in the Mediterranean should respond to the effects of fishing and warming with significant consequences for the fisheries. In the north-western Mediterranean the most recent inventory describes several species whose distribution range has changed significantly since the 1970s. Several species of fish have arrived (sardinellas, barracudas, coryphenae) which gradually find their place in regional fisheries. These consequences can be illustrated by the modifications in the reproduction areas between 1983 and 2004 near Catalonia of a species of sardine (*Sardinella aurita*) which is used to warm seas (UNEP/MAP –Plan Bleu, 2009).

Apart from the positive effects, there are also depleted stocks of small pelagic fish such as sprat and anchovy and/or modifications in the life cycle of some highly appreciated species such as the bluefin tuna and seriola.

Figure 17 : Breeding zones of *Sardinella aurita*, Catalonia in 1983 and 2004



(Source: Sabatés, Martín, Lloret, Raya 2006 Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. *Global Change Biology* 12, 2209–2219)

The salubrity of some aquaculture farms could be affected by the excessive development of phytoplankton. Fishing along the migration routes of the madrague will become less profitable. The sea bass needs highly specific temperature and photo-period conditions for its breeding and perhaps could no longer have efficient breeding and breeding management would be modified. (UNEP/MAP- Plan Bleu, 2009).

6. INSTITUTIONAL AND LEGAL ELEMENTS

In the Mediterranean all the countries have ratified the CBD, UNFCCC and the Kyoto Protocol.

The Mediterranean represents a small portion of the global emissions and only a small number of Mediterranean countries have obligations in terms of reduction or stabilization of greenhouse gases and most efforts were deployed to evaluate and mitigate greenhouse gas emissions. Less work was done on the effects of climate change on socio-economic challenges connected mainly with agriculture and water and on the consequences of an accelerated increase in the sea level and finally practically nothing was done on the effects of climate change on the marine and coastal biodiversity and the little that was done is still at the stage of intentions or declarations.

The institutional framework for the challenges and effects of climate change on the marine and coastal biodiversity is the Mediterranean Action Plan (MAP) with mainly the Regional Activity Centre for Specially Protected Areas (RAC/SPA) as the executing agency. The legal framework is underpinned by the Convention for the protection of the Mediterranean sea against pollution (Barcelona Convention) and its relevant protocols: the SPA/BD protocol which came into effect on 1999 and the newly adopted "ICZM" Protocol - Integrated Coastal Zone Management Protocol. Still within the MAP context, there is the Almeria declaration adopted in 2008 at the 15th Ordinary Meeting of the Contracting Parties to the Barcelona Convention which includes important decisions on the impacts of climate change on the Mediterranean biodiversity. Other international conventions pertaining to climate change and/or biodiversity (UNFCCC and CBD) have been ratified by the bordering States of the Mediterranean.

The newly adopted ICZM protocol for example, already in its preamble, expresses the concerns of the Mediterranean States about the inherent risks to the coastal zones and recommends the adoption of prevention, mitigation and adaptation measures to tackle the effects of climate change. These measures must make it possible to maintain and to restore the coast's natural capacity to adapt to the changes taking place, including the changes caused by the rising sea level.

The Strategic Action Programme for the Conservation of Biological Diversity in the Mediterranean region (SAP BIO) is a strategic action plan for the protection of biodiversity in the coastal and marine Mediterranean regions. This action plan, adopted by the Contracting Parties to the Barcelona Convention in 2003, considered the impact of climate change on BD as priority activities.

Box 2: Almeria Declaration, excerpts

Preamble:

- environmental priorities changed over the decades ...
- environmental awareness not sufficiently translated into practical action ...
- environmental protection/preservation not sufficiently integrated into other policies ...
- the adaptation effort ... all countries requested, in order to reduce the impact of climate change ...
- importance of capacity building, technology transfer, mobilization of financial resources ...
- need to strengthen regional, international co-operation within spirit/provisions of UNFCCC
- rapid rates of loss of biodiversity, continuing degeneration of marine and coastal environment ...

Conclusions:

- problem of climate change to be seriously addressed to reduce effects on Med. marine and coastal environment ...
- early measures needed to mitigate effects ...
- strategies to include ecosystem approach, risk management, strategic environment assessment and marine and coastal ICZM ...

Décisions:

- to identify by 2011: the marine and coastal species and habitats most sensitive to climate change, and measures for the Med Network of marine protected areas ...
- to estimate values of products from services by marine and coastal ecosystems and the impacts by climate change ...
- Contracting Parties to present regular reports on progress made concerning climate change and effects on biodiversity for each Ordinary Meeting of the Contracting Parties and to CBD ... „

6.1. Various actors involved

In the Mediterranean three major groups of actors are involved in the action in view of the climate change and its interaction with marine and coastal biodiversity:

- 1) The scientists involving (i) the specialists in the impacts of climate change who are striving to define indicators in order to characterize the vulnerability and impacts of climate change on marine and coastal biodiversity, (ii) the economists who are seeking to link the consequences of this higher vulnerability to economic activities and (iii) the meteorologists whose aim is to set up forecasting models,
- 2) The political decision makers who have objectives to attain in terms of possible adaptation and mitigation strategies,
- 3) The private sector wants to preserve its competitiveness in a changing physical environment

The political decision makers in the widest meaning of the term including the Focal Points of the Climate Convention in each country (all Mediterranean countries are signatories), those of MAP and RAC/SPA pertaining to aspects linked to marine and coastal biodiversity.

In each country, centred on this “hard core”, the Ministry of the Environment is generally in charge of this dossier. In Turkey, Bosnia & Herzegovina and in France, specific inter-ministerial authorities have been set up to coordinate the efforts deployed in each sector, to monitor the evolution of international negotiations and define the mitigation and adaptation strategies. Most countries do not have specific tools to monitor the progress made in terms of prevention or adaptation to climate change, with particular reference to marine and coastal biodiversity. The Mediterranean decision makers have formulated a strong request for impact indicators and for the elaboration of adaptation strategies and there is also a wide consensus for better regional cooperation.

Some countries, like Greece, are already forging ahead and setting up a monitoring and evaluation system for climate change impact on biodiversity and Greece can be cited as an example (see Box 3).

Box 3: Good practices in climate change monitoring, the case of Greece

Greece developed an effective method and strategy to monitor climate change and its impact on marine biodiversity, and recommend appropriate solutions. A growing number of scientific publications issued from national research efforts are being published on climate change issues. The ongoing scientific research at the national and international level is at a good level, regarding namely climate issues (including oceanic observation and forecasting), and cataloguing and detecting changes in marine biodiversity likely to be directly or indirectly linked to climate change. Also, the spread of alien species and the thermal tolerance of important marine species are topics approached through research coordinated projects.

Monitoring actions include: sea level and surface water temperature, water quality, response of marine organisms to sea temperature rise, changes in commercial fish species and communities (through fisheries data), changes in coastal planktonic assemblages, shifts in spatial distribution of marine habitats.

International cooperation actions are being developed on the establishment of European networks of infrastructures for marine observation and research (including coastal observatories and ships), and on the development of climate change forecasting models.

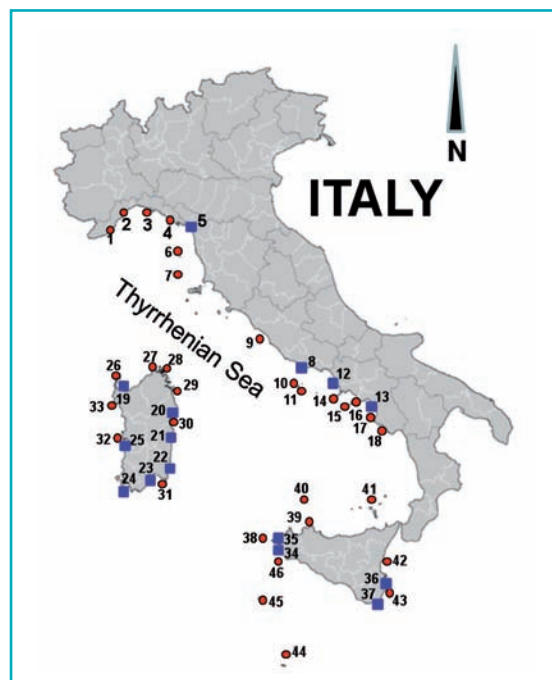
Different awareness-raising activities (conferences and meetings) have been recently organised for policy-makers and managers, researchers, university students, stakeholders, NGOs and the general public.

Source: RAC/SPA

6.2. RAC/SPA: a key role in tackling the impact of climate change on marine and coastal biodiversity

Being aware of the knowledge gaps on the impacts of climate change on marine and coastal biodiversity in the Mediterranean and with reference to the recommendations of the Almeria declaration, RAC/SPA is actively involved in contributing to fill this gap and is tackling the challenge of the effects of climate change on marine and coastal biodiversity. Thus in concertation and in collaboration with the bordering countries, a summary of national reviews on vulnerability and the impacts of climate change on marine and coastal biodiversity has been elaborated within the framework of the SAP BIO activities for the 2008 and 2009 biennium. This made it possible to evaluate the state of knowledge and the activities in connection with the impacts of climate change on marine and coastal biodiversity undertaken hitherto. This participative exercise made it possible to define future activities in response to the changes of "climate change/marine and coastal biodiversity" in the Mediterranean.

Figure 18: Number of marine and coastal sites considered to be especially at risk (or endangered) in the short-term by the effects of climate change in Italy (Adriatic excluded).



Note: Squares refer to areas at risk from rises in sea level and circles refer to areas at risk of impact on biodiversity.
(Source: UNEP-MAP-RAC/SPA, 2008)

7. WHAT STRATEGY TO MITIGATE THE IMPACT OF CLIMATE CHANGE ON MEDITERRANEAN BIODIVERSITY ?

Societies throughout the whole world have always tried to adapt and to reduce their vulnerability to the consequences of weather and climate phenomena such as flooding, droughts or storms. Additional adaptation measures will however be necessary on a regional and local scale to reduce the nefarious effects of the anticipated evolution and variability of the climate in addition to the ample mitigation measures which will be set up in the next twenty or thirty years. (IPCC report, 2007) Adaptation on its own will surely not be enough to offset all the anticipated effects of climate change, especially in the long term as there is a clear trend that most of the repercussions are being amplified. There are numerous adaptation possibilities, but it is vital for the action already engaged in to be intensified if vulnerability is to be attenuated in view of the climate change taking place. There are obstacles, limits and costs involved which are not always truly grasped.

As for the consequences, the nature and progression of climate change are today singular challenges on a regional level.

There are three ways of tackling the impacts on biodiversity in order to reduce them:

- Actions to attenuate the causes responsible for climate change and setting up measures to reduce the emissions of greenhouse gases
- Adaptive measures to the effects of climate change whilst at the same time reducing the ensuing costs which make it possible to strengthen the means of combating climate change effects.
- Better public awareness for better and more effective participation of the public.

The aim of adaptation measures is to limit the negative aspects of the impacts by reducing the vulnerability of the ecosystems and by making the most of the positive aspects and opportunities. The adaptation strategies must aim to increase the flexibility through good management of the vulnerable ecosystems, enhance the inherent adaptation capacity of the species and ecosystems and finally reduce the environmental and social pressures which could increase vulnerability to climatic variability (Hulme, 2005).

In order to elaborate an effective adaptation strategy the vulnerability of the Mediterranean to climate change must be clearly understood. Three factors define this vulnerability:

1. The nature of climate change,
2. Climatic sensitivity of the system or the region in question, and
3. The capacity to adapt to the ensuing changes.

In view of the great geographical, ecological and economic diversity of the Mediterranean, these factors vary considerably just like the vulnerability to climate change as clearly demonstrated by the studies carried out in the Mediterranean region (Jeftic et al., 1992) so that any interventions against these events must be adapted to each local situation.

8. CONCLUSIONS AND RECOMMENDATIONS

Despite an uneven contribution to greenhouse gas emissions, all the countries round the Mediterranean will be faced with the effects of climate change and will therefore have to deal with the serious perturbations which will affect their natural heritage.

Today it is quite clear that the effects of climate change are perceptible in the Mediterranean at all levels; human health, animal health, water resources, biological resources, quality of the environment and economic activities (agriculture, industry, transport, insurance etc.) and will become even more amplified and throughout the whole Mediterranean they will have particular impacts on supply and demand, the future quality of water resources and will modify the frequency, spatial distribution and intensity of droughts and flooding.

The Mediterranean and its bordering countries will be facing climate change and modifications which are likely to be amplified in the future.

The challenge is a priority one for the marine and coastal areas so that the first adaptation and mitigation measures should be urgently undertaken. The coasts of the whole earth which are already under various types of pressure already have a concentration of 60 % of the human populations on a 60 km wide belt. Littoral waters represent 14 to 30 % of the ocean primary production and 90 % of the fish catch. The Mediterranean is no exception to this rule, quite to the contrary, as this region is particularly sensitive to the effects of climate change which are an additional burden on littoral biodiversity.

Some consequences of climate change will in any case be irreversible with no possibility of adaptation. This concerns in particular those activities which depend on marine biodiversity (fishing, aquaculture, recreational activities). In the long term the major challenge will probably be to succeed in forecasting the future of Mediterranean biodiversity, the future composition of fisheries, submarine landscapes and to adapt ourselves to these changes in consequence.

This new emerging problem is highly complex and unevenly documented so that it is absolutely vital to expand the existing basic knowledge especially on the physical and biological aspects, effects of climate change on ecosystems and biodiversity and in particular the cross-over effects of climate change and other sources of disturbance.

In view of the various future scenarios, it is important to set up models pertaining not only to species but specifically also to the mechanisms regulating the Mediterranean ecosystems so as to evaluate their resistance and resilience capacity. These models could surely contribute to define a range of cross-cutting and sectoral adaptation and mitigation strategies in order to face the different climate change scenarios.

The community of stakeholders involved should not expect rigorous and intangible results from these predictive models as their reliability is limited by numerous uncertainties including the uncertainty about the quantities of greenhouse gases which will be emitted in the future.

No decision should therefore be left pending until perfect and illusory knowledge is gathered in order to undertake ideal adaptation measures for a given coastal zone. What is needed on the contrary is to learn how to cope and manage with this uncertainty on the basis of often incomplete scientific data.

Adaptation or at least mitigation can be envisaged in as far as the ecosystems are often already fragilized by pollution, fragmentation of habitats, biological invasions and can thus be highly sensitive to climate change with diminished adaptation capacity. The response to existing or potential impacts of climate change can be an indirect one by reducing the nuisances which can be tackled by the human society. One of the things that could be done is to multiply the marine and coastal protected areas as well as the dedicated areas and if the ecological corridors are taken into consideration then this would reinforce the resilience and resistance capacity of the ecosystems and species.

Adopting action plans stemming from holistic concepts such as integrated management or the ecosystem approach are absolutely vital even if it means having complex governance mechanisms at several spatial levels (regional, trans-national, national, local and pluri-thematic).

To obtain truly effective implementation it is also necessary to pool human, technical and financial resources and to set up a system to ensure a fluid circulation of data and information in formats which are appropriate for each target group on a national and regional level. RAC/SPA is the appropriate organism to take on the responsibility and facilitation of such an approach on a regional level and to catalyze its implementation.



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