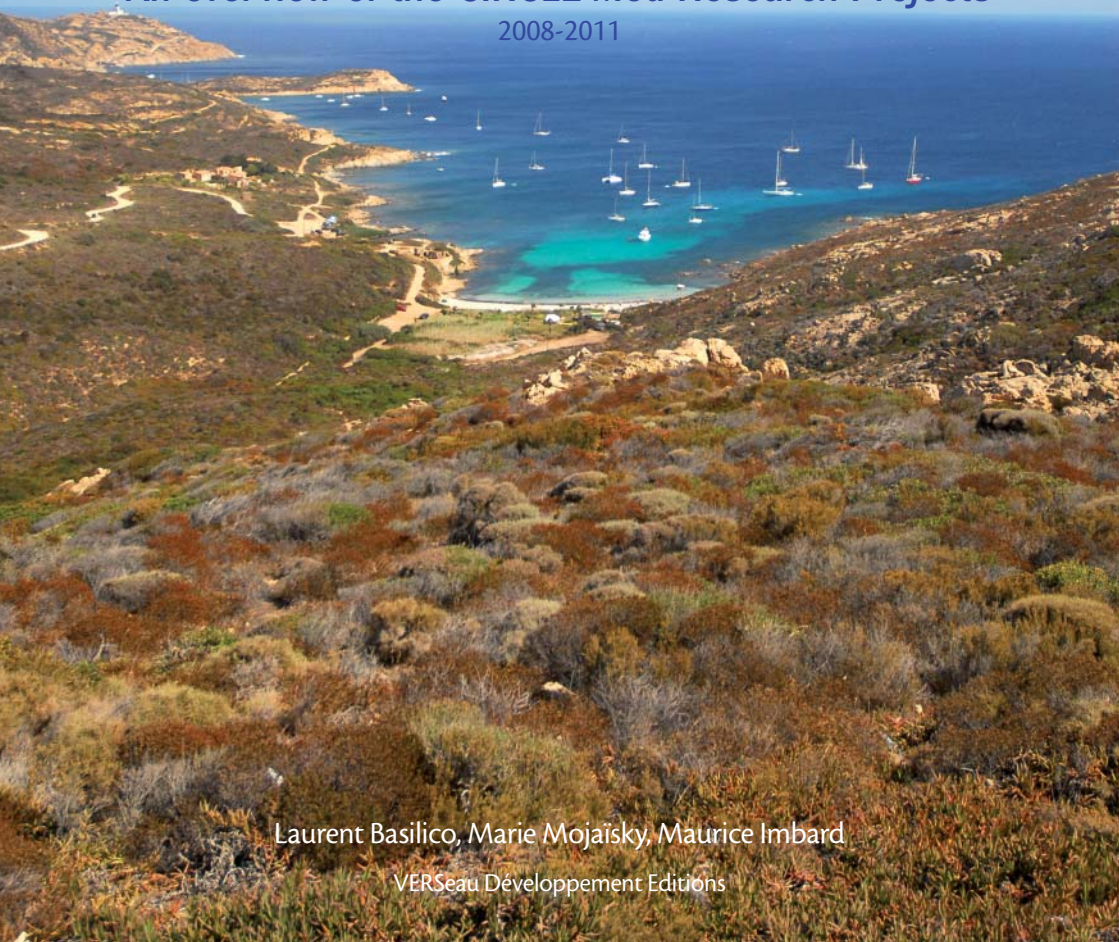
Climate Change and Mediterranean Coastal Areas: Understanding the Impacts and Developing Adaptation Strategies

An overview of the CIRCLE-Med Research Projects

2008-2011



Laurent Basilico, Marie Mojaïsky, Maurice Imbard

VERSeau Développement Editions

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From the cliffs of the Algarve to the Gulf of Tunis, from Spain's Ebro river to the Dalmatian coast, the Mediterranean's 46 000 kilometers of shoreline are home to a wonderfully unique natural and cultural heritage. Birthplace of ancient civilizations and cultural crossroads, today 420 million inhabitants from 21 different nations live around this "inland sea". Its coast is a dense concentration of major societal and economic stakes in a variety of sectors: industry, tourism, agriculture, and port facilities. It's also a region of remarkable biodiversity. A place of refuge during the Quaternary Period's ice ages, the Mediterranean basin also provides a home for 10% of the world's species of flowering plants, and a great number of other plant and animal species.

In a context of ever-increasing anthropogenic pressures, the advent of climate change raises numerous questions. According to the fourth report published by the IPCC (the Intergovernmental Panel on Climate Change), Mediterranean ecosystems would be among the most threatened by the predicted evolution of the climate. So what exactly will be the impacts on the sea's level, on its degree of acidification, or on precipitation patterns—on all of these vulnerable equilibriums? How will these changes impact coastal ecosystems, transitional waters, and the water table? What might be the consequences of climate change on water quality and the availability of water resources—an issue of vital importance to local populations-or for aquaculture and agriculture? How can communities be prepared today so that they will be able to adapt to the coming changes, and to that end, what sort of tools do stakeholders need to be able to do so?

At the interface of the fields of climatology, hydrology, biology, economics, and social sciences, the critical questions about this necessary

Sicily

Introduction

adaptation require a vast array of new scientific knowledge and the answers will provide essential data for decision-makers on both the local and global scale. Having this in mind the international coordination of CIRCLE-Med funded eight research projects, the results of which were presented on the 22nd and 23rd of March, 2011 at a conference in Aix-en-Provence (France) which brought together 65 individuals—scientists, and leaders and representatives of the local authorities from 10 different countries.

Working together on both innovative and complementary projects, research teams from nine different countries worked intensively over two years to collect an extensive amount of new knowledge to better prepare for climate change adaptation. Some of these projects represent foundational advances in fields that had not up until now received much research focus. The information found within the following pages is just a brief overview of these new developments: in addition to the detailed final reports for each project, about thirty scientific publications, as well as numerous papers in the process of being prepared or accepted, have stemmed from the hard work of the CIRCLE-Med teams.

In addition to increasing our understanding of the impacts of climate change on the Mediterranean basin, CIRCLE-Med's projects, carried out with the goal of assisting the decision-making process, have encouraged a dialogue about these complex questions among the scientists, administrative officials, and local authorities at each location. As a result, their work also represents a great number of advances towards an integrated, proactive, and interdisciplinary management approach to the problems facing Mediterranean coastal areas. With this goal in mind, the participatory experiments undertaken at the local level have been equally fruitful in terms of providing precious methodological tools for informing the key stakeholders, for mobilizing them, and for developing adaptive mechanisms in a cooperative manner.

Finally, the CIRCLE-Med series of projects has also provided a precious contribution to the process of networking research data throughout Europe and the different universities and laboratories along the southern Mediterranean coast, within the spirit of the ERA-Net (European Research Area Network) mechanism. From Montpellier to Faro, from Tunis to Haïfa, Palermo to Tirana, strong connections were established between the scientific teams working on these projects, but also with other research partners, public organizations, local authorities, and key economic players. These connections, both the contractual and informal ones, constitute one of the major benefits of such projects. It is essential now that these relationships be maintained, and that good use be made of them, through future collaborative efforts, so that the work initiated by CIRCLE-Med might be pursued or complementary research paths explored. Our societies' responses to the crucial challenges posed by climate change, be they on the global or local level, focused or integrated, must be capable of providing long-term solutions. ■

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CIRCLE-Med: A Brief Introduction

Created in 2002 by the European Commission, the **ERA-Net** (European research area network) mechanism has since played a major role in connecting European research centers: this allows for financial backers of research projects at the national level to coordinate on the European scale and to generate common calls for projects. ERA-Net is most notably at the origin of the ERA-Net **CIRCLE** project *(Climate impact research and response coordination for a larger Europe),* a European network dedicated to coordinating research on adaptation to climate change. Starting in 2004 with financing from the Commission's sixth program framework for research and development (FP6), since 2010 ERA-Net CIRCLE has been financed by the FP7 program. Today it is made up of a network of 34 institutions from 23 different countries (ministries, regional authorities, project management organizations). It operates based on geo-thematic sub-networks—the Mediterranean region, the Nordic region, and mountainous region—for which knowledge of the various impacts resulting from climate change and the possible adaptation solutions requires an integrated and shared approach.

CIRCLE 2
CLIMATE IMPACT RESEARCH & RESPONSE COORDINATION FOR A LARGER EUROPE
EU FP7 ERA-NET

SEVENTH FRAMEWORK PROGRAMME

To this day three calls for research projects have been launched within the CIRCLE framework, corresponding to the three geo-thematic groups:

- "Water resource management in Mediterranean coastal areas" in 2007 (Circle-Med)
- "The Consequences of climate change for policy development in the Nordic countries" in 2007 (Circle-Nordic)
- "Adaptation in Mountainous regions" in 2009 (Circle-Mountain)

In July 2007, the **CIRCLE-Med** call for projects dedicated to the topic of water resource management in Mediterranean coastal areas was launched by five co-financing partners of the ERA-Net CIRCLE: The French, Italian, and Israeli ministries in charge of environmental affairs, the Portuguese Foundation for science and technology (FCT) and Galician Council for Innovation and Industry. Out of sixteen proposals, eight projects were selected for a total budget of 1.65 Million Euros, with each financing partner retaining control of its contribution.

The accepted projects, over a two-year period have brought together research structures in France, Italy, Portugal, Spain, Israel, Morocco, Tunisia, Croatia, and Albania. The coordination and the development of this work has been piloted by the MEDDE (the Ministry for the Ecology, Sustainable Development, and Energy), with the technical support of VERSeau Développement. In addition to the website **www.circle-med.net**, a quarterly newsletter has provided ongoing updates on these projects.

Figure 1. CIRCLE-Med study and project coordination sites

1 Climate Change and Preliminary Concepts and Global Projections

Coastal Regions:

Petit Travers Beach, Hérault
© Michel Dukhan

The fourth report of the IPCC (Intergovernmental Panel on Climate Change), which appeared in 2007, established that climate change was indeed taking place: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea." (IPCC, 2007)

Additionally, the report represents a major advance in explaining the mechanisms contributing to this change, and confirms its anthropogenic origin: "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG (greenhouse gas) concentrations." (IPCC, 2007)

To introduce the research conducted within the framework of CIRCLE-Med, this first part provides a preliminary survey of the current knowledge on climate change and briefly describes the methods and scenarios used in climatology. It gives a general outline of the different consequences—observed or expected—of this change on sea waters and on the coastline: an increase in the average sea level and temperature, and acidification of the oceans. Finally it provides an insight into the unique context of the Mediterranean basin, and introduces, with respect to the area's environmental and societal characteristics, the implications of climate change on its coastal ecosystems, the water table and local usage of water resources.

1.1 – What climate change?

Since 1910, the average temperature of the earth has increased by about 0.6°C. The 1990s were the hottest decade of the 20th century in terms of average value and on the scale of the entire planet, with a record high temperature set in 1998. The current decade does not contradict this trend, and 2010 was the hottest year ever recorded, on a par with 2005. The diagram below shows how quickly and intensely this increase has taken place; such a dramatic change is something without precedent since the Quaternary Period.

Emissions scenarios and climate projections

To produce the climatological models used by scientists and to be able to generate projections, the IPCC establishes various emissions scenarios based on different hypotheses for socio-economic and geopolitical evolution. In the fourth report, two potential scenarios are often cited. The A2 scenario, viewed as the most pessimistic, predicts that global authorities will not act and will be rather inefficient, and as a result they will be unable to avoid that by the year 2100, greenhouse gas concentrations will triple. The result will be an increase in average temperatures for France of 5ºC in a period of 100 years. In contrast, the B2 scenario predicts an efficient and generalized reduction in emissions which would slow the increase in the atmospheric concentration of greenhouse gases, and in turn limit the increase in average temperature to 3ºC in France over the next 100 years. This scenario, presented as "optimistic' nevertheless corresponds to an increase in global average temperatures in excess of anything the earth has ever known over the last 400 000 years.

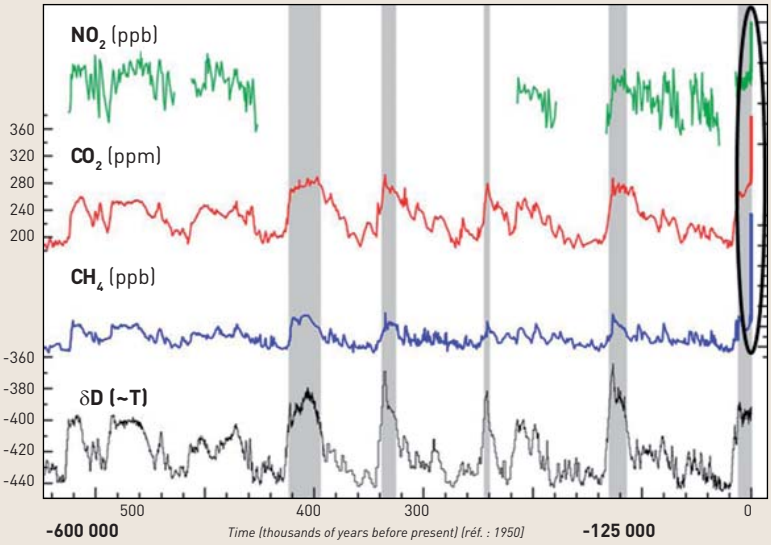

Figure 2. Variations in the average temperature of the earth and in atmospheric concentrations of greenhouse gases, from the Quaternary Period to the present. Paleoclimatalogical reconstruction based on glacial ice cores. EPICA Project dome C.

Climate models, uncertainties and regionalization

These global projections are marred by a high degree of uncertainty resulting from forcing (emissions scenarios), the lack of precision inherent in any numerical calculation, and the imperfect modeling of certain mechanisms of the climate system. One avenue for further progression, essential within the perspective of management and adaptation, concerns the spatial resolution of these projections, in other words **"downscaling"**: global projections tend to hide the wide variety of changes that are occurring on a local scale, in terms of temperature and precipitations. For the Mediterranean basin, this downscaling approach was initiated by the CIRCE project **(www.circeproject.eu)**, mentioned in section 1.3 of this report. The following figure is an example of the results of the CIRCE simulations.

1.2 – Multiple consequences for coastal regions

The consequence of climate change along the coast that has received the most media coverage is of course the rising sea level; this has already sparked a number of research projects to study the adaptation of ecosystems, the management of the changing coastline, or the preservation of socio-economic assets. But there are other implications resulting from climate change that have already started impacting coastal areas: for one thing, the acidification and the warming of the oceans is altering ecological equilibriums, and as a result economic sectors such as, aquaculture, fishing, or tourism are affected.

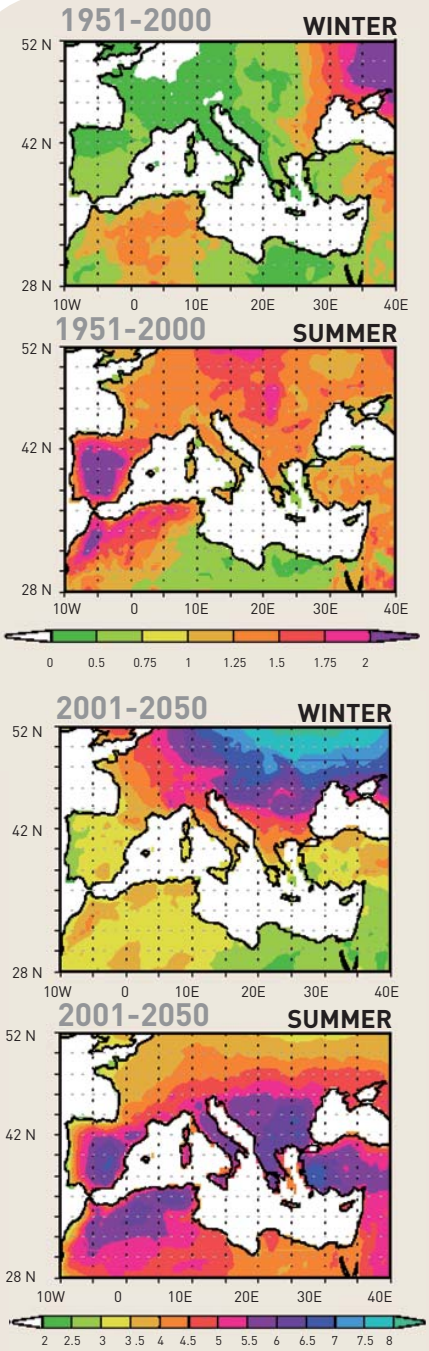

Figure 3. Multi-model average of the temperature 2 meters above the ground obtained from CIRCE project simulations for the periods 1951-2002 and 2001-2050. The unit on this scale is the (°C/decade) multiplied by a factor of 10 for improved readability (Gualdi S. *et al, in press*).

Finally, significant changes can be expected in terms of the quality and availability of fresh water resources in the years to come. Rising sea levels increase the risk of saline intrusions in water tables. Moreover, the pressure on fresh water resources will be even greater due to the forecasted modifications in precipitation patterns, coupled with an increase in societal demand—for irrigation for example. These effects will lead to major management challenges, and researchers have only just begun to examine the problem.

Inevitable rising sea levels

The increase in sea levels has already been observed: between 1900 and 2000 a global average increase of 1.7mm/year was recorded. Now, that trend is accelerating: between 1993 and 2003, the global rate of increase was 3.1mm/year, which corresponds to an increase of **31cm in a century.** There are numerous reasons for this increase: thermal dilation of the water due to global warming, the melting icecaps of Greenland and the Antarctic, the inflow of continental waters. In order to calculate the future consequences of climate change on oceanic bodies of water, climatologists use models that link oceans, glaciers, and the atmosphere. Here are some projections for sea levels for 2090-2099, compared to 1980-1999. For the B2 scenario (an increase in the average global temperature of 2.4°C), the increase in sea level would be between 0.20 and 0.43m. In the case of the A2 scenario (+ 3.4°C), the sea level rise would be between 0.23 and 0.51m (GIEC, 2007).

Warming and acidification of the oceans

Besides the increase in sea levels, climate change also results in modifications of the physicochemical characteristics of sea waters. The first affected parameter is of course temperature: the earth's oceans have stored more than 90% of the increase in heat absorbed planetwide during the second half of the 20th century (Bindoff *et al.*, 2007). Levitus *et al.* (2009) estimate that **the average temperature of superficial waters has increased by 0.17°C** since 1969. Once again, this trend is not equally distributed across the globe: in this case, the North Atlantic has seen the most marked increase (+0.4°C).

This temperature increase is accompanied by a series of changes in the chemical equilibrium of the oceans. While the concentrations of oxygen in sea waters have tended to decrease (Keeling *et al.*, 2010), concentrations of CO_2 have dramatically increased: it is estimated that the oceans absorb 25 to 30% of the CO_2 produced by human activity. This absorption results in the **acidification** of the superficial sea-water layer; its average pH level has dropped by 0.1 since 1800—depending on the region.

This dual dynamic of warming and acidification of the world's oceans is extremely complex and combines to create different feedback mechanisms. Just one example is that the increase in temperature reduces the solubility of CO_2 in the water. There is no doubt that ecosystems will be impacted, and the first biological communities to be affected could be the bivalves, mollusks with calcium carbonate shells whose physiology is tied to the pH-level of the surrounding waters.

Camargue
© Michel Dukhan

The Consequences for ecosystems: a scientific challenge

Understanding and forecasting the possible responses that the marine life will have to these multiple changes—warming, acidification, modified chemical equilibrium—remains a veritable scientific challenge. Some impacts are expected, and in some cases can already be observed in the **range** of species, but also in how the trophic networks function, with for example possible disturbances in predator-prey relationships. Global warming also has the effect of reducing the supply of nutrients to superficial waters by reinforcing the water column's stratification. This nutritional weakening limits the primary production processes in the column and encourages the spread of "ocean deserts" (Polovina *et al.,* 2008). The appearance of **invasive species**, already observed, could also increase due to climate change, and finally the decrease in oxygen concentration in sea waters could aggravate the effects of the eutrophication of coastal waters to the point of anoxia. (Diaz and Rosenberg, 2008).

As for fish, analysis of the variations in their ranges has greatly progressed over the course of the last decade. On a global scale, Cheung *et al.* (2008, 2009) have sketched out a projection of the effects of different scenarios on the organization of 1066 species of fish and marine invertebrates. In the Mediterranean, based on a physical oceanographic simulation published in Somot *et al.* (2006), Ben Rais Lasram *et al.* (2010) mapped the evolution of the potential habitats of 75 essentially coastal endemic species to the year 2100.

The following figure (Fig.4) shows the results they obtained; in the case of the IPCC's A2 scenario for the scaldback (A. kessleri), a species of fish that today can be found throughout the Mediterranean, the data shows that by 2099, 90% of this species' favorable habitats will have gradually disappeared. Under the same A2 scenario, the superficial water temperature will have risen by 3.1 degrees in the period 2070-2099. The habitats will be reduced for 50 of the endemic species under consideration and 14 of them will most likely disappear. Conversely, the range of certain species will expand as in the case of the Egyptian sole, which could occupy the entire basin by the end of this century (CCBio, 2011).

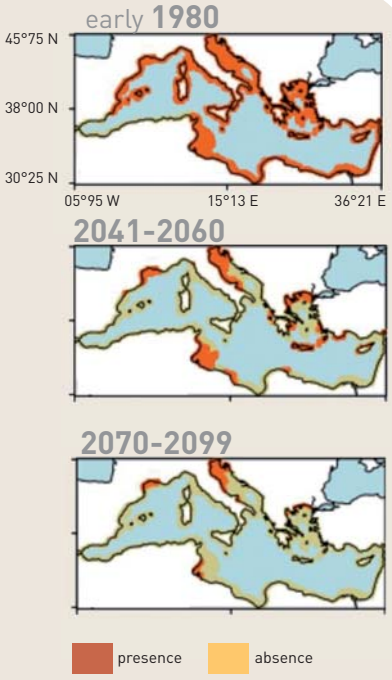

Figure 4. Evolution of the range of the skaldback *(Arnoglossus kessleri)* in the Mediterranean over the course of the 21st century in the case of scenario A2 (Ben Rais Lasram *et al.* 2010).

1.3 –The Mediterranean basin: between integration and multiplicity

At the crossroads of North and South, Orient and Occident, the Mediterranean is a place of entente as well as division. Its densely populated coastline is shared by 22 different countries on three continents. Throughout the region, coastal areas are home to both population centers and critical socio-economic stakes. The contrasts between the developed North and the developing South are evident. On one side, stabilized demographics; on the other, young growing populations. On one coastline a certain level of political stability ensured by the European Union, and on the other, still nascent democracies. On one side the Judeo-Christian world, and on the other, Islamic civilization.

But beyond this simplified cleavage, each country is different from its neighbors because of its history, its culture, and it own practical needs. And yet, these countries also share a common history, culture, and reality: that of the Mediterranean basin.

One of these shared characteristics is tied to a specific climate type, to which the Mediterranean gave its name. With the exception of the Libyan and Egyptian coasts, which have a desert climate, the Mediterranean climate covers the entire basin and extends as far as Morocco's Atlantic coasts and the south of Portugal. It is characterized by having four distinct seasons. It rains very little during the hot summers; droughts occur regularly and may be quite intense. Winters are mild—the monthly average temperatures are rarely below 0°C.

The spring and the fall are the rainiest seasons, and precipitation levels can be relatively

Climate change and global change: how do you determine specific causes and effects?

Climate change is just one of many anthropogenic pressures to which aquatic ecosystems are subjected. Over the course of just a few decades, industry and agriculture have polluted the soil, bodies of coastal waters, estuaries and lagoons. Accelerated urbanism has produced artificial shorelines and caused the degradation of natural environments, while the globalization of transportation networks has led to the invasion of some ecosystems by exotic, sometimes harmful species.

The impact of these pressures on specific environments is often accompanied by climate change, which often leads to more favorable conditions for the proliferation of certain species and accelerates the eutrophication of aquatic environments. Moreover, the increase in temperature results in a greater need for irrigation waters, that in turn creates an additional impact on the flow of coastal rivers or on the water usage—renewal dynamic of the water tables. Within this context of multiple interactions and overlapping effects, determining the specific cause for an observed effect represents a recurrent difficulty for researchers seeking adaptive solutions. Is the observed local decrease in a mussel population due to increasing temperature or to the acidification of the water; is it caused by a chemical pollutant, by an algal bloom—or more likely, by a combination of all of these factors? The notion that climate change is just one component of global change is now commonly accepted. Now, the goal of current research on climate change adaptation is to reduce the vulnerability of ecosystems and human societies to global change. Likewise, improving the environment's ability to adapt presupposes a concerted effort to reduce local anthropogenic pressures.

high: 765mm in Algiers, 862mm in Nice, and even 2 000mm in the Cévennes mountains. Precipitations can sometimes be quite intense in a short period of time: this is true of southern France's *«épisodes cévenols»* which can cause sudden, devastating floods in the autumn. Finally the climate tends to vary greatly from year to year, and this represents an additional source of difficulties when it comes to water resource management.

These climatological characteristics lead to biodiversity in the Mediterranean basin that is both remarkable and vulnerable. The region is home to 25 000 species of phanerogams, in other words, 10% of the whole world's species of flowering plants (source: ENS Lyon). More than half of these species are endemic.

Porquerolle

The CIRCE Project: High-Resolution Climate Projections for the Mediterranean Basin

In order to make progress in the crucial area of adaptation, the first requirement is to develop reliable local climate projections. For the Mediterranean basin, one key step in "downscaling" was reached with the inception of the CIRCE Project, funded by FP6 and co-organized by the National Institute for Geophysics and Vulcanology (INGV, Italy). Thanks to the use of advanced models, it allowed researchers to refine the work of the IPCC on the Mediterranean basin, establishing an array of high-resolution (down to a scale of 30km vs. 300km for the IPCC) climate projections to the year 2050. Their conclusions were presented during the project's final conference (May 23-25, 2011 in Rome). The project's findings show that the region will suffer a more marked increase in average temperature than the rest of the planet, with an increase in superficial seawater temperature of between 0.8°C and 1.8°C in 2050. This will also result in a rise in the sea level of between 6 and 12 cm. Average precipitations will drop by between 5 and 10% with respect to current levels, while extreme weather events (flooding, torrential rains, cyclones) will become more frequent. These figures just represent rough estimates, however: the CIRCE models also highlighted the extreme unpredictability of the Mediterranean system, due to its complex topography and the high degree of variability from one region to another of the whole basin.

In order to go further and to allow for greater adaptation of national, regional, but especially local policies to the impacts of climate change, developing a dialogue that addresses all the dimensions of the issue in a given territory—from research and decision-making to societal usage—is essential (the interconnected elements of a system such as port, catchment basin, and coastal plain, for example). It was with this goal in mind that CIRCLE-Med's research projects were launched.

* **www.circeproject.eu**

In an era of global change, a great number of these species are subjected to the fragmentation or even the disappearance of their natural habitats: about 5000 species (17% of the total flora) are classified as endangered, rare, or vulnerable, by the International Union for Conservation of Nature (IUCN). As a result, 80% of the plants addressed by the European Union's Directive Habitats can be found in Mediterranean countries. Anthropogenic pressures also affect Mediterranean fauna like the monk seal *(Monachus monachus*), which has virtually disappeared from the Aegean Sea or the coasts of the *Maghreb* where it was once common. Aquatic environments, humid zones, and deltas are home to particularly fragile ecosystems, especially in the south.

Just as it impacts Mediterranean ecosystems, climate change is a cause for growing concern for socio-economic interests in the basin. The first area of concern is **fresh water resources**, of vital importance for supplying populations with drinking water, but also for agricultural practices that rely heavily on irrigation. How will the forecasted increase in temperatures and the modifications in rainfall patterns affect the hydrographs of coastal rivers? To what extent will submersion endanger the water table with saltwater intrusions? How will the quality and the availability of water resources be impacted by these changes? And what indirect consequences might we expect for agriculture, aquaculture, or for tourism in the Mediterranean, the number one destination for this activity, worldwide? ■

Tunisia
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2 Understanding the Impacts: From Ecology to Economy

Oualidia, Morocco
© Tibor Stigter

From 2008 to 2010, CIRCLE-Med's eight research projects explored different facets of the question of climate change adaptation. This research was undertaken with full awareness of the need for constant dialogue with local decision-makers and planners; experiments and collaborative efforts from 22 different research sites, representative of the diversity of the Mediterranean basin formed the basis of the teams' work—from Oualidia on the Moroccan coast to Bat Yam in Israel, from the Camargue natural park to the island of Lampedusa, off the coast of Sicily. As a preliminary phase for the development of adaptation policies, a significant part of the teams' efforts was devoted to acquiring new knowledge of the expected impacts of climate change on these sites—and by extension, on those sites with comparable ecological and economic characteristics.

This second part presents the different scientific contributions for each of the ecosystems under consideration: marine ecosystems, intertidal bands, coastal catchment basins, water tables, and dependent ecosystems.

2.1 – Impacts on Marine Ecosystems: The Bivalve Example

The acidification caused by increasing CO_2 concentrations, coupled with the other modifications of the environment's biochemical equilibrium generated by climate change represents a source of great concern, first of all, for mollusks with calcium carbonate shells. These animals, often of great value from both a heritage and economic standpoint, are an essential link in marine ecosystems: they connect primary production to the higher trophic levels. By affecting the physiology of these species, acidification would cause a chain reaction of changes to their actions on the ecosystem, altering their rates of filtration, respiration, and excretion. The ACIDBIV project's goal was to undertake an **integrated analysis** of these effects, and also of how they would impact the economic sectors of fishing and aquaculture.

Preliminary studies identified **those bivalve species that are the most relevant** for experimentation and modeling as well as the phases of their life cycle to be examined. Given its importance to so many different groups, the choice of the mussel *Mytilus galloprovincialis*, was a natural one for all of the participating parties. Two other species were also studied because of their importance on a regional level: the clam *Chamelina gallina*, harvested in the northern Adriatic, and the clam *Ruditapes decussatus*, present on the Algarve and Tunisian coasts.

Once these species were identified, the teams defined a series of common experimental and analytical protocols to look at 14 different parameters—for example: shell composition, density, reproductive activity, and rate of growth and mortality.

ACIDBIV

The integrated impacts of marine acidification, temperature and precipitation changes on bivalve coastal biodiversity and fisheries: how to adapt?

Funding Organizations

- **IMELS** *Italian Ministry for Environment, Land and Sea*
- **FCT** *Foundation for Science and Technology - Ministry of Sciences, Technology and Higher Education*
- **CII Galicia** *Consellería de Innovación e Industria – Xunta de Galicia*

Partner Organizations

- **UNIPD** *University of Padova - Department of Biology*
- **FSB** *Faculty of Sciences of Bizerta*
- **CSIC** *Consejo Superior de Investigaciones Cientificas*
- **CCMAR** *Centre of Marine Sciences of Algarve*

The pessimistic A2 GIEC scenario was chosen as the basis for their work. Computer models, configured with the help of available historical data, were used to simulate the effects on pH levels and other parameters, for the sites of Ria Formosa (Portugal) and the Venetian lagoon (Northern Adriatic). A large number of laboratory experiments were carried out to describe the short or long term effects (ranging in length from several weeks to several months) of acidification on shell structure, the growth rate of juveniles, and the feeding habitats of individuals.

In the second phase, these observations were refined with outdoor studies undertaken at the Chioggia hydrobiological station (Italy): connected to the lagoon, the experiment's tanks allowed researchers to isolate the effects of the pH forcing, and the other parameters could evolve naturally with exposure to water from the outside.

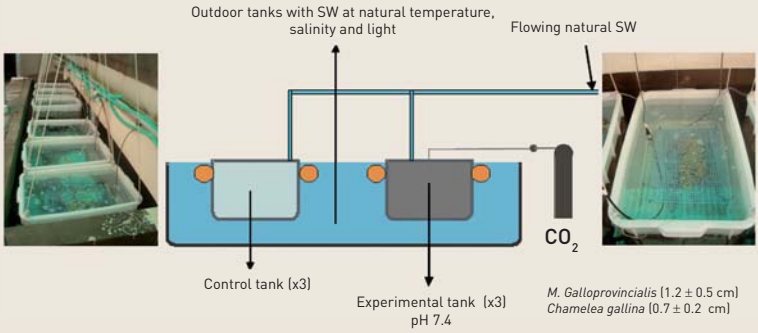


Figure 5. Outdoor experimental plant for long-term experiments on bivalve juveniles

Site-specific impacts

This series of experiments, the first of its kind in any field of research, brought to light contrasting responses to the acidification. In the northern Adriatic, very significant effects were observed for both of the species involved. Selective exposure of adults to reduced pH levels, just as in the case of long-term exposure of juveniles, resulted in considerable damage to their shell formation, and in diminished growth rates in the case of *C. gallina*. Furthermore, when the mollusks were exposed to higher water salinity and temperatures, the mortality rate rose and their ability to survive in the open air was reduced. The research teams also discovered alterations in the respiratory, filtration, and immune response functions of the mussels; this was true for the clam species as well. Overall, these results show a rather dramatic deterioration of those species that were exposed simultaneously to reduced pH levels and temperature and salinity levels equal to their corresponding tolerance limits. **This observation suggests an increase in the risk of extinction of these species on a local level.**

In comparison, the results obtained in the Ria Formosa lagoon showed a reduced impact of acidification on shellfish populations. Young specimens from both species were able to survive very low pH levels (0.7) for more than 80 days without major damage to their shells—although in the case of the mussels, calcification levels were reduced. For *R. dessicatus* the recorded alterations in the physiological parameters as a result of acidification seem to indicate reduced growth rates in the long term: ingestion and respiration rates were lowered, while the rate of ammonia expulsion increased.

The responses of *M. galloprovincialis*, found at both research sites, markedly differed from one location to the other, but there was also variation from one phase to another of the life cycles. These unexpectedly dramatic results show how dangerous it could be to extrapolate from only locally acquired data. Similarly, the responses obtained for a given species are not necessarily true for another. **The impact of acidification on bivalves is site-specific, and also different for each species.**

This variation from site to site highlights the necessity of taking into account local parameters that could reinforce or limit the effects of acidification. Thus it's important to note that the carbonic chemistry of the Ria Formosa lagoon is actually characterized by a very high level of alkalinity, probably as a result of run-offs which are also alkaline, coming from continental waters. This particular context most likely limited the impact of acidification on shell calcification and growth.

In more general terms, those bivalves living in coastal transitional waters and estuaries appear to be naturally more exposed to regular variations in the carbonic chemistry of the water than those populations living in open waters. This point, demonstrated by regular samplings of the intertidal habitats of mussels on the Galician coasts, suggests that shellfish populations in transitional waters could have a higher tolerance to the predicted acidification of the oceans.

As a result, one pertinent avenue for research is the study of the interactions between the local chemical composition of seawater (pollutants, carbon chemistry) and the biological impacts due to acidification from the increase in dissolved CO_2. With this in mind, two follow-up experiments to ACIDBIV have begun, for the same species, in Padua, Italy and in the Algarve.

Clams
© ACIDBIV

A need for further analysis

Due to its partially closed-off nature, the Mediterranean Sea has unique oceanographic and bio-geographical characteristics, which may exacerbate, or alternatively limit, the ecological impact of acidification. The ever-increasing deposits of nutrients from rivers, pollution, fishing or aquaculture, among other anthropogenic pressures, only serve to complicate the interplay of interactions. Considering the importance of bivalves for aquaculture or Mediterranean fisheries, any damage to the viability or the productivity of these populations could cause significant socio-economic harm. The results obtained from the ACIDBIV project are thus a cause for real concern, in particular regarding the future of the North Adriatic's natural clam populations. Increased mortality rates, coupled with intense pressures caused by local fishing are already leading to a significant regression in the population density of this mollusk on the Italian coast of the Adriatic Sea.

Yet, these studies on the impact of acidification are just in their initial phases and solid data remains rare. Within this context, ACIDBIV has been a significant step forward. Its conclusions show the necessity of continuing efforts to acquire a better understanding of the synergetic effects of global changes on the survival, growth, calcification, and physiology of these highly important species from both an ecological and economic standpoint. As such, the partnerships initiated by the project constitute a solid foundation for further investment in this field, from a collaborative viewpoint, bringing teams from both the north and the south of the Mediterranean basin together.

2.2 – Impacts on Intertidal Systems

Where the sea meets the land, the intertidal is that strip of coastline between the high and low tide points; it constitutes a dense concentration of remarkable biodiversity as well as ecosystemic services of vital importance to the proper functioning of coastal areas. These beaches are also where humans can take leisurely strolls, fish, and come face-to-face with sea life. This is true for oceanic coasts, often tens of meters wide, but it is also true also in the Mediterranean basin—where the weak tides often reduce the beach to a strip only a few decimeters wide.

The INTERMED project, organized by the universities of Palermo (Italy), Haïfa (Israel), and Dubrovnik (Croatia), sought to evaluate the impact of climate change on the intertidal communities of the Mediterranean basin, and to analyze the socio-economic consequences.

Resolutely interdisciplinary in its approach, biologists, ecologists, sociologists, and economists worked together on the project. The group decided to concentrate its efforts on six key biological groups living in the rocky or mobile substrate: clams, crabs, mussels, limpets, sponges, and snails. The ecological and socio-economic analyses, carried-out in conjunction with one another, were the object of constant exchange and sharing between both sides. For two years, this work took place at **over twenty different sites,** along the Croatian, Israeli, and Sicilian coasts, in the Golf of Genoa, in Malta, and in Lampedusa. From an ecological as well as socio-economic standpoint, the INTERMED project initially called for an in-depth examination of any prior research that had been conducted.

INTERMED

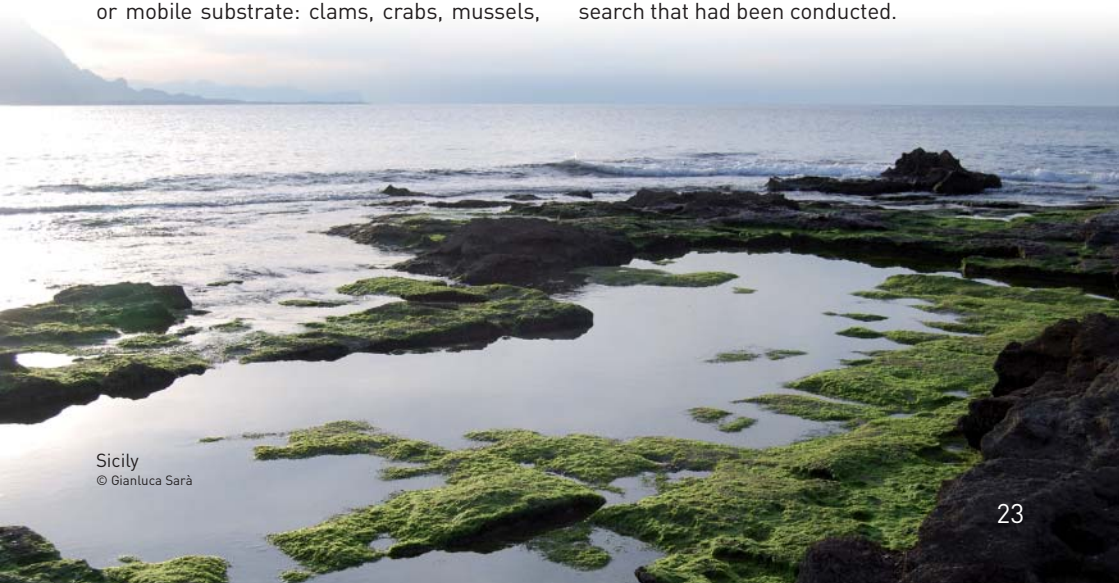
The impact of climate change on Mediterranean intertidal communities: losses in coastal ecosystem integrity and services

Funding Organizations

- **IMEP** *Israel Ministry for Environmental Protection*
- **IMELS** *Italian Ministry for Environment, Land and Sea*

Partner Organizations

- **University of Dubrovnik** *University of Dubrovnik, Dept of Aquaculture*
- **Recanati Institute** *Leon Recanati Institute for Maritime Studies, University of Haïfa*
- **LoEEB** *University of Palermo, Animal Biology Dept., Lab.of Experimental ecology and Behaviour*



Sicily
© Gianluca Sarà

In both cases this first phase turned out to be shorter than expected. In fact, prior studies of the organisms were characterized by **very fragmented data;** overall, information relating to the impact of global changes on the Mediterranean intertidal is quite rare.

Similarly, extensive research efforts to find literature on the socio-economic importance of the Mediterranean intertidal failed to turn up any sort of prior research. The surprising paucity of research efforts devoted to the economic significance of intertidal systems is a worldwide phenomenon, with the exception of a few studies looking at the several specific habitats (as in the case of wetlands or mangroves).

Cartography, sampling, outdoor studies: an unprecedented wealth of data

With this in mind, the ecological branch of the project set about describing in detail the Mediterranean intertidal environment. They developed in-depth temperature and solar irradiance profiles for the entire Mediterranean basin. The team also gathered data relating to water salinity, swell size and frequency, as well as other environmental variables.

They also took samples from the rocky coasts of Liguria, Sicily, and Malta. In Croatia, samples were taken from both the rocky and loose substrates. All of these operations allowed each intertidal community to be fully described in terms of abundance, biodiversity, distribution, and morphology. In addition to the aforementioned key species, the teams collected data relating to several invasive species—such as certain crabs in Croatia, mussels in Sicily and Italy. Thanks to measurement and experimental protocols for handling the animals in situ, it was also possible to obtain physiological and behavioral parameters (individuals' heart and growth rates).

To complement this work, studies conducted of the mesocosm were able to quantify to a very precise degree the respiration, feeding, and excretion rates of clams, mussels, limpets, and intertidal sponges under different temperature conditions.

These complementary studies, undertaken in the context of a paucity of existing background research, managed to collect **a considerable amount of new information.**

Figure 6. Satellite Image of Project INTERMED's sites

Of great potential interest to scientists and decision-makers, this data paves the way for future integrated research projects. Several articles dedicated to these advances have already been published or accepted for publication, and others are being prepared. Preliminary results have already been communicated during international conferences or via the press.

Globally, the results suggest that climate change—most notably the expected increase in temperatures—will have an impact on Mediterranean intertidal communities by altering the physiology of several key species and by creating favorable conditions for invasive exotic ones. Given the major ecological role played by most of the species that were the subject of this research, such an impact could have a domino effect on the whole environmental system in question.

The first models and new questions

The data that INTERMED collected led to the first use of a complex computer model simulating the impact of climate scenarios on the Mediterranean's ecosystems; this required at the outset an extensive amount of data ranging from environmental parameters to species behavior. Initial analyses forecast significant disruptions in these environments, compared to the current situation—which is already less than ideal. However, given the narrow nature of the Mediterranean foreshore (beach) breaking waves could act as a mitigating factor for the predicted results. This model is still being fine-tuned; however, this area in particular merits further in-depth analysis in order to better understand how the future effects of climate change will alter it. There are still many unanswered questions.

While it is possible that the narrowness of the Mediterranean intertidal may protect it to some extent from the effects of climate change, it may also be a weakness for those ecosystems with fragmented environments: according to some scenarios, certain species would be able to migrate or adapt, while others would not.

The intertidal's economic services: an area still requiring exploration

The initial INTERMED socio-economic contribution is an article, accepted for publication, that establishes the virtual absence of prior research devoted to the question of the Mediterranean intertidal: as yet no analysis has been made for the rocky intertidal, and a very small number of projects make reference to the loose substrate.

A statistical analysis of the public's perception of the sea was undertaken, based on data collected within the framework of a European Union study reexamined within the INTERMED perspective. This revealed the public's strong attachment to the sea, irrespective of age, sex, education, or origins. It also highlighted a considerable lack of knowledge of marine systems, and also of the science and techniques relating to the sea, as well as the income they generate. Based on this knowledge, INTERMED subsequently identified two main categories of stakeholders in the Mediterranean intertidal: users (tourists, residents, professionals) and environmental decision-makers.

Initial investigations among the different stakeholders, carried out in Croatia, sought to identify their perceptions, uses, and concerns regarding the habitat in question.

They noted very low levels of comprehension and involvement. It was equally difficult to for those people interviewed to identify the benefits of the intertidal (and the economic services it provides). In the total absence of a solid basis upon which to initiate a productive dialogue on a larger scale, INTERMED was forced to abandon its plans to undertake a formal analysis of the interplay of the different stakeholders involved in the intertidal, as had been initially suggested.

The economic services provided by the intertidal stem from its ecology: thus, the pursuit of research projects to improve the understanding how the intertidal functions is the first essential research avenue—the goal being to acquire a thorough understanding of this environment. At the same time, an exhaustive identification of the full range of the intertidal's benefits and economic services must also be undertaken. INTERMED has started this work and proposed a research schedule dedicated to an economic evaluation of this domain.

2.3 – Impacts on transitional waters

Transitional waters—estuaries, lagoons, wetlands, and coastal lakes—play an essential ecological and economic role in the Mediterranean basin. That they remain in good working order is a fundamental requirement for a healthy supply of water resources and food– from aquaculture, fisheries, and agriculture—as well as for the biodiversity that can be found within such waters. This strategic importance has led to increased recognition within public policy, as in the Water Framework Directive adopted by the European Union in 2000, which identifies bodies of transitional waters as a specific category in the global evaluation of water quality.

At the interface of various societal issues, these complex ecosystems are under significant anthropogenic pressure, sometimes worsened by inappropriate management. This observation, a result of limited awareness of the impact of global change on transitional waters, is revealing of insufficient levels of cooperation between scientists and local government.

The Camargue, near Nîmes

2.3.1 – Vulnerability and adaptation paths for three representative sites

The MEDCODYN project mobilized over the course of two years, Italian, French, and Moroccan research teams around three natural sites that are representative of the Mediterranean's variety of transitional waters: Vaccarès pond, 6500 hectares of water at the heart of the Rhône delta, the lagoons of Circeo national park, 100km south of Rome, and the coastal lake of Sidi Boughara, near Kenitra in Morocco.

For each of these ecosystems, the project benefited from a steady dialogue among and with the partners and concerned local and national stakeholders as they worked toward three objectives:

- Collecting and synthesizing the available data in a database that centralized biochemical and climate parameters.
- An analysis of the vulnerability of these coastal ecosystems using computer models.
- Identifying the mechanisms for adapting to climate change.

Databases: an operational tool

The structure of the MEDCODYN database was finalized in May 2009. Since then it has been available on the internet: **www.medcodyn.unisi.it.** Over the course of the whole project, the research team supplemented the database with all of the data available for a whole series of parameters: changes in fish stocks, bird populations, the pH level, water salinity, dissolved oxygen levels, wind speed, air and water temperature, and precipitations. This tool was then used to analyze the patterns and trends over time in the chemical, biological, and physical parameters of the three research sites.

MEDCODYN

An analysis of the vulnerability of coastal ecosystems to climate change and anthropogenic pressures. Exploring adaptation measures.

Funding Organizations

- **MEDDE** *Ministère de l'Ecologie, du Développement Durable, et de l'Énergie*
- **IMELS** *Italian Ministry for Environment, Land and Sea*

Partner Organizations

- **UNISI_CSGI** *Università di Siena, Dipt. Di Scienze e Technologie Chimiche e dei Bioistemi*
- **UC** *University Aïn Chock of Casablanca*
- **TdV** *La Tour du Valat*
- **CRA_LCI** *Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Laboratorio Centrale di Idrobiologia*

Participatory prospects and modeling : Two complementary approaches

In order to better orient the tools that were developed during the project, collaborative workshops were organized in Sabaudia (Italy, December 2008) and in Media (Morocco, June 2009), with the active participation of the involved stakeholders, operators, and researchers. A SWOT (Strengths, Weaknesses, Opportunities, and Threats) approach was employed, with the goal of attaining an optimal scenario by the year 2050 considering past management. Several intermediate scenarios were identified. For Vaccarès pond, a series of meetings with regional decision-makers and associations was held in 2009 and 2010. These actions led to the identification of threats often common to all three locations (climate change, overexploitation of the catchment basin and poor coordination among scientists and decision-makers). Clear differences surfaced, however, in the political and socio-economic contexts of the three different sites.

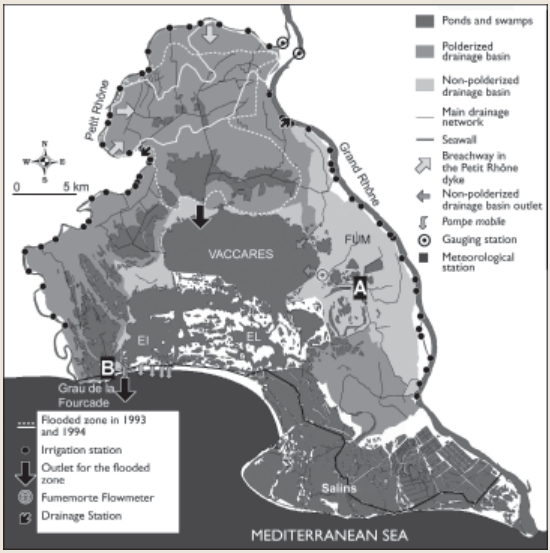


Figure 7. Map of the Vaccarès hydrosystem : catchment basin, drainage network, dikes, and interfaces.

In order to analyze the potential impacts of climate change on the ecosystems in the different management options under consideration, the project made use of **several dedicated computer simulations.**

The researchers from the *Tour du Valat* and the *Consigliio per la Ricerca e la Sperimentazione in Agricoltura* (CRA) collaborated on the development of hydrodynamic models for Vaccarès pond and Fogliano. In the case of Fogliano, a model of dissolved oxygen levels was developed by the CRA in order to study the impact of temperature change in the water, that of the flow of water between the lake and the sea, the effect of the wind, and the role of organic material on oxygen levels in the water column and the sediment- with particular attention paid to anoxia. A model linking photo-degradation/organic material was developed by the University of Sienna for all three sites, based on current data of the optical conditions measured in each ecosystem and on an estimation of the changes in cloud cover to a time horizon of 2050.

For Sidi Boughaba (Morocco) the lack of historical data made modeling and trend analysis difficult. UC's researchers, along with those of the TdV, CRA and UNISI were however able to conduct a thorough analysis of local conditions in May 2009. These measurements were then used to devise a plan for long-term study examining monthly trends in the key ecological, hydrological, and chemical characteristics of the lake.

The value of MEDCODYN's research is not limited to the three sites that were studied. The approaches researchers used for defining potential scenarios and the techniques developed for analyzing their consequences on the ecosystem's parameters and services may be broadly applied to the Mediterranean basin. Environmental and socio-economic forcing is common to numerous transitional aquatic ecosystems in the region, all of which are also facing issues related to dissolved oxygen, high salinity, or hydrodynamics.

2.3.2 Mediterranean Lagoons: a complete inventory conducted in the Mediterranean and the Black Sea

In parallel with MEDCODYN, the CLIMBIOMEDNET project focused specifically on lagoons; their team drew up a complete inventory of these bodies of water, resulting in the largest database currently available for such ecosystems. A preliminary review of existing knowledge of lagoon biodiversity revealed the extent to which the different disciplines involved lacked integration. CLIMBIOMEDNET's research was initially oriented toward the development of a theoretical basis to incorporate this knowledge within a common methodological, conceptual, and lexical framework. This work stemmed from two workshops lasting each three or four days, which brought together contributors with complementary skills and members from the project's scientific team: ecologists, sociologists, economists, modelers, and legal experts.

These productive meetings brought several paradoxes to light (low biodiversity, but high productivity) and common patterns (the dominance of generalist species) for the Mediterranean's lagoon systems. In particular they showed the need to integrate the abiotic parameters of the catchment basins within the project's scope.

On this basis, the teams collected biological (lists of species) and physiochemical (salinity and temperature) data for the 635 different lagoons inventoried—the country-based distribution of which is described in figure 8.These lagoons are characterized by their low average surface area: 314 of them are smaller than one square kilometer in size.

CLIMBIOMEDNET

The Impact of Climate Change on the biodiversity and the economic services provided by Mediterranean Lagoons

Funding Organizations

- **MEDDE** *Ministère de l'Ecologie, du Développement Durable, et de l'Énergie*
- **CII Galicia** *Consellería de Innovación e Industria – Xunta de Galicia*

Partner Organizations

- **University of Vigo** *University of Vigo, Dep. De Ecologia y Biologia Animal*
- **University of Tirana** *Faculty of Natural Sciences of Tirana University, Dept. of Bio-technologies*
- **INA** *Institut National Agronomique de Tunisie, Laboratoire ecosystèmes et ressources aquatiques*
- **Ecolag** *University of Montpellier, Laboratoire "Ecosystèmes lagunaires"*
- **DISTeBA** *University of Salento, Dip.Scienze e Tecnologie Biologiche ed Ambientali*

.

Figure 8. Distribution of lagoons among countries and regional areas

Region	Country	N° lagoons
Africa	Algeria	13
	Egypt	7
	Lybia	16
	Morocco	12
	Tunisia	28
Africa (Sum)		**76**
Asia	Syria	2
	Turkey	66
Asia (Sum)		**68**
Europe	Albania	16
	Bulgaria	1
	Croatia	10
	France	59
	Greece	36
	Italy	244
	Montenegro	3
	Romania	2
	Slovenia	4
	Spain	116
Europe (Sum)		**491**
Grand Total		**635**

The search for data was deliberately exhaustive, and included the full range of publications available over the past 25 years. Researchers devoted a considerable effort to harmonizing the toponymy and standardizing the names of the aforementioned species with respect to international taxonomical data. Scrupulous quality control methods for the collected data led the team to put aside all the original publications, often fraught with errors. The end result is a database which, for each lagoon, incorporates geographical and physiological data, the abiotic parameters of the water and the sediment, information about the catchment basin—the land use, and associated environmental pressures—climate data as well as projections derived from the A1B, B1, and the A2 IPCC scenarios (for air temperature and precipitations).

This database is the most complete ever assembled on the subject, and was designed to be used as an operational tool for decision-making. It is accessible online at **www.circlemednet.unisalento.it** and provides public access to the full inventory of lagoons and species. It also offers authorized users advanced functionalities for data extraction and analysis, coupled with a computerized geographic information system.

The observations made by the project's teams have showed that most of the recorded species are rare: half of them were unique to one lagoon. The biodiversity of Mediterranean coastal lagoons, and the impact that climate change will have on it, is characterized by a heterogeneous distribution. Analyses undertaken on a regional scale for the 32 lagoons of the Italian coast, revealed a discrepancy between the efforts being made for conservation and the ecological status of the environments in terms of the richness of their macro-invertebrate fauna. Overall, it seems essential to consolidate and better target the preservation policies of these fragile environments. In the case of an A2 IPCC scenario, the temperature of the sea's superficial waters opposite these coastal lagoons will have increased by 0.1°C by the middle of the century and by 1.2°C by its end.The highest increase in water temperature will take place in the Adriatic—in particu-

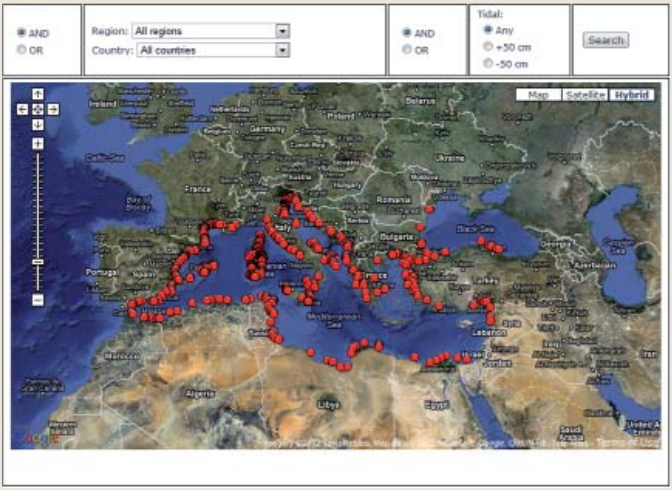


Figure 9. Screenshot of the geographic information system coupled with the CLIMBIOMEDNET database.

lar on the Croatian coast, where an increase of 2.5°C is expected.

Within this context, the database assembled by CLIMBIOMEDNET provides an exceptional tool for teams of researchers working on the lagoons and climate change. It represents a wealth of useful information for those seeking to propose new projects and to obtain funding. It will also shed light on often complex discussions around the identification of protected zones, such as within the framework of the European Lifewatch project, starting in 2012 with the goals of anticipating the impact of climate change on the functioning and biodiversity of Mediterranean lagoons and of identifying high priority conservation zones.

2.4 – Impacts on the water table and dependent ecosystems

Coastal water tables represent an essential resource when it comes to providing local populations with drinking water, with water for irrigation, but also for the equilibrium of the surface ecosystems that depend on them. For these strategically important bodies of water, climate change is a source of growing worry for several reasons: the predicted changes in rainfall will affect the renewal rate of the water tables, while it could also cause the society's need for water to increase—in particular as irrigation becomes even more widespread. Moreover, the increase in sea levels could augment the risk of saline intrusion. With these issues in mind, the CLIMWAT project's goal was to study the impact of climate change on the water tables of three coastal systems: the central Algarve region, the Ebro river delta, and the Atlantic coast of the Sahel.

This work was initially based on in-depth description of the sites in question (from a topographical, temperature, precipitation, and hydrological standpoint); all of these sites have large aquifers upon which people rely for drinking water and irrigation, and they are all linked with wetlands on the surface which are themselves complex ecosystems dependent on the aquifers. In the case of the central Algarve and the Atlantic Sahel, seawater also flows into their wetlands via well-known transitional waterways linking fresh and saltwater.

The project made use of an array of climate projection models taken from the European ENSEMBLES project, which provides data for the period 1950-2100 with good spatial resolution (25x25km) and covers the three research sites in question. It concentrated on the IPCC's A1B emissions scenario, considered to be the most balanced and moderate in its predictions.

CLIMWAT

Assessing and managing the impact of climate change on coastal groundwater resources and dependent ecosystems

Funding Orgnaizations

- **FCT** *Foundation for Science and Technology - Ministry of Sciences, Technology and Higher Education*
- **CII Galicia** *Consellería de Innovación e Industria – Xunta de Galicia*

Partner Organizations

- **FSSM - UCAM** *Faculté des Sciences Semlalia, Université Cadi Ayyad*
- **DTC/UDC** *Dept. de Technoloxia da Construcion , Universidad da Coruña*
- **CVRM/Geosystems Centre** *CVRM/Geo Systems Centre, Instituto Superior Technico/Universitare do Algarve*
- **CEHIDRO, IST** *CEHIDRO, Instituto Superior Técnico*

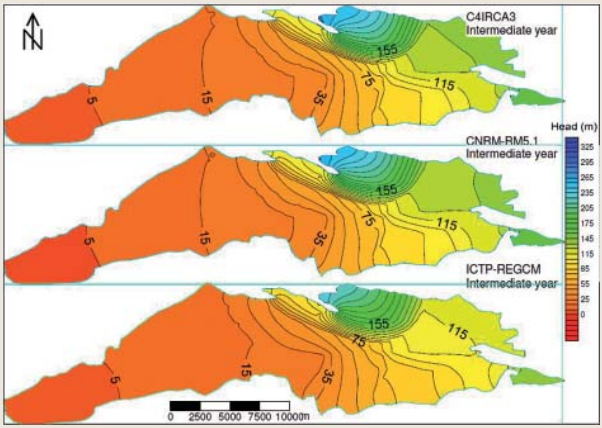


Figure 10. A map showing the piezometric levels of the Quença-Silves water table for three distinct scenarios, obtained using the Penman Grindley method.

Different downscaling methods then allowed the project's teams to refine the temperature and precipitation data and to better account for local conditions. Based on this data, scenarios for predicting surface water infiltration and water table renewal were developed using different tools—calculations of water flow using the Thornthwaite-Mather et Penman-Grindley models, advanced hydrological models for the Spanish and Portuguese sites.

The aquifers were modeled in horizontal and vertical sections using the different sets of climate data, with the resulting calculations providing projections for the evolution of the aquifer's renewal, the evolution in water irrigation needs, and changes in the sea level.

Strong trends and site-specific effects

Every single one of the scenarios concludes that the temperature will rise significantly. This increase would be between 1.1 and 2.6°C by 2060 and between 2.8 and 5.3°C by 2100. The most dramatic warming would take place at the Portuguese and Spanish sites, and would be most pronounced from the end of the spring to the fall, while on the Atlantic Sahel coast, the increase would be more spread out over the course of the year. The projections for precipitations are more varied for the three sites. In Morocco and Portugal, rainfall will be concentrated between November and January, and will be reduced by between 12 and 40% for the period 2071-2100. In the Ebro delta this change will be less dramatic (between 7 and 13% less rainfall). Overall, the projections in terms of water table renewal follow this same pattern, with a more significant decrease predicted for the period 2071 to 2100 for all three systems. These forecasted trends are quite dramatic, especially given the moderate nature of the A1B scenario: a decrease in water table renewal at the Ebro delta by between 9 and 25%, by between 7 and 38% for the Algarve, and by between 38 and 48% for the Atlantic Sahel.

In the Ebro river delta, where surface water infiltration from irrigation contributes on a significant scale to water table renewal, these values vary spatially depending on how much irrigation is taking place. Conversely, in those areas where the water table provides the lion's share of the water for irrigation, the development of improved irrigation systems seems

indispensable, given the predicted increase in demand of water for agricultural purposes.

Even if, at the present time, these locations are not experiencing a problem with water table salinisation, marked periods of drought are already causing a dramatic decrease in the amount of water being provided by the aquifers to their dependent wetlands. This trend is going to worsen. By 2100, calculations predict a drop in the upper level of the aquifers by between 5 and 20m for most of the systems in question, with piezometric levels locally dropping by 100m with respect to current levels in the Ebro river delta and the central Algarve region.

Wherever there is a saltwater—freshwater interface, **salt water intrusions** will occur on a seasonal basis and will take place more frequently during the period 2071-2100. In the short term (before 2050), this trend is less obvious, and there is greater uncertainty. This trend is amplified in those scenarios which incorporate increased irrigation—except in the case of the Spanish site, where water for irrigation is essentially drawn from surface waters.

In the case of the central Algarve, advanced simulations which take into account the uncertainties linked to the different methods for calculating water renewal have produced varied results concerning the amplitude and the length of those inversions of the gradient that lead to saline intrusions. Nevertheless, they all agree that a global decrease in the level of water tables will occur. Salt waters will penetrate the water table over several kilometers, affecting the quality of the aquifer, and compromising its use for human needs. In addition, the renewal of these water tables during the rainy years will be slow and difficult.

Oualidia, Maroc
© Tibor Stigter

Dependent ecosystems—developing bio-indicators

One common source of worry for the three sites in question concerns the predicted reduction in the supply of freshwater for those wetlands which depend on the aquifers. The CLIMWAT project sought to develop a tool for biological evaluation/study to describe the response of these ecosystems to the changes in the water supply. To that end, the research teams took extensive samples of the Moroccan sites (from 10 different stations) and the Portuguese ones (5 stations) at the interface of the water table with the body of surface water. These operations established the composition of the fauna and corresponding physiochemical parameters—including the water salinity.

A total of 6 784 organisms were inventoried. Certain taxonomies were tagged as **potential bio-indicators** of the quality of underground water resources. However, the great number of endemic species that are typical of this type of fauna limits the validity of the models one might develop on a regional scale.

In addition, in Morocco, the absence of certain fragile taxonomies at several sites is probably due to the impact of agricultural pollutants and other human activity.

CLIMWAT's teams then identified those species that would be most likely to benefit or on the contrary to suffer from a decrease in the supply of freshwater resulting from the dual effect of climate change and increasing anthropogenic pressure on the water table. Statistical analysis has confirmed the importance of studying the biological communities in those zones where aquifer and estuary are linked- the goal being to evaluate the effects of climate change on key aquatic ecosystems.

At the end of the day, this research, the first of its kind devoted to studying the invertebrate fauna at the interface of estuary and water table from a bio-indicator perspective has allowed scientists to build an analytical table and a preliminary tool that will allow them to conduct simulations of changing water composition based on salinity.

On the basis of these results, the next step is to initiate follow-up programs to consolidate the proposed bio-indicator tools and to open the door to a more complete understanding of changing salinity and the impact on invertebrate communities both in Morocco and Portugal.

A well in Oualidia, Morocco.

2.5 – Impacts on coastal catchment basins

Mediterranean coastal catchment basins, fertile enclaves in the midst of often arid environments, are zones of high anthropogenic pressures. These areas are often the focal point of considerable tension when it comes to water resources or the use of arable or buildable land. For this reason, it is impossible to separate determination of the future effects of climate change on the catchment basin zone from a study of the changes in land use that will occur in the same area. With this in mind, the WATERKNOW project's objective was to develop an intersecting analysis, in addition to creating an effective tool to help with decision-making that all of the concerned local parties could use for three sites, each with very different characteristics. Quinto, (Italy), is a small (100 km²) polderized catchment basin where agricultural activity irrigated by a drainage network and quarries are the two principal economic activities. In contrast, the Tahaddart basin in Morocco covers more than 1145 km²; here non-irrigated agriculture is the norm, while vast retention basins provide water for the nearby city of Tangier. Finally, the island of Terceira, in the Azores archipelago (Portugal) extends over 640 km². Here the climate is quite rainy (between 1 000 and 3 000 mm of rainfall annually) and crops and pastures are omnipresent.

With the goal of describing how the current system operates (taking into account land use and climate parameters) WATERKNOW used the climate projections to the time horizon of 2100 as forecasted by the IPCC's A1B scenario in its simulations of local changes in hydrology and for calculations of the availability of water resources (as well as its vulnerability to saltwater intrusion); the objective was to come up with different scenarios for land use.

The goal of the first phase of the project, carried out by the University of Lille, the University of Bologna, and Morocco's *École Nationale Forestière d'Ingénieurs* was to develop a **geographical information system** for the three sites being studied. In the case of the Tahaddart basin, given the absence of prior data, this phase led to the inclusion of satellite imagery for the year 2009, as well as field reconnaissance missions for the duration of the project.

Different techniques were used to study the function of the catchment basins. In the case of the Italian site local teams set up a SWOT analysis with the principal actors. As a result of this operation, saline intrusions as well as a lack of coordination among all the parties involved in water resource use were identified as the main threats to the system.

WATERKNOW

Integrated Management of water resources in coastal catchment basins: the stakes and corresponding adaptation strategies in the face of climate change

Funding Organizations

- **MEDDE** *Ministère de l'Ecologie, du Développement Durable, et de l'Énergie*
- **IMELS** *Italian Ministry for Environment, Land and Sea*
- **FCT** *Foundation for Science and Technology - Ministry of Sciences, Technology and Higher Education*

Partner Organizations

- **USTL** *Université des Sciences et Technologies de Lille, Labo. Territoire, Ville, Environnement, Sociétés*
- **GGCN/DCA/UAC** *Cabineto de Gestao e Conservacao de Natureza de Depto de Ciencias Agrarias da Universidade dos Açores*
- **ENFI** *École Nationale Forestières d'Ingénieurs*
- **CIRSA** *Alma Mater Studiorum, Università di Bologna, Interdepartmental Centre for Environmental Sciences*

One of the things that came out of these studies was that climate change appeared to be far from the concerns of local actors who were more focused on short term changes and issues. In Morocco, a quantitative analysis undertaken by the University of Lille 1's team on the images contained in advertisements distributed by the tourism sector, a major economic player, revealed some interesting lessons: key actors in the tourism sector were shown to be very attached to maintaining activities that consume high quantities of water (golf courses, parks, swimming pools, etc.).

Once a **relational database** was established for each site, a wide range of tools was put to use to simulate the evolution of each system: these included the Food and Agriculture Organisation's (FAO) CROPWAT model for calculating water budgets, hydrological and geochemical models coupled with indicators of trends in salinity, or MODFLOW and SEAWAT models to estimate the depth of the freshwater-saltwater interface.

These simulations confirmed a trend that had already been detected concerning the salinity of both Terceira and Quinto's subterranean waters as well as the global degradation of hydroclimatological conditions for all three basins in the case of an A1B scenario. Another significant trend for Tahaddart and Quinto, was that the increase in the rate of evaporation of aboveground bodies of water will result in considerable damage to coastal ecosystems and a reduction in the availability of drinking water.

A **model of geographic interaction** was developed by the University of the Azores and the University of Lille 1 in order to conduct a cartographic analysis for land use that would take into account the geomorphological characteristics of the basins and local economic factors. The resulting maps have been a valuable tool for plotting scenarios of change in future land use which can then be applied to hydrological models.

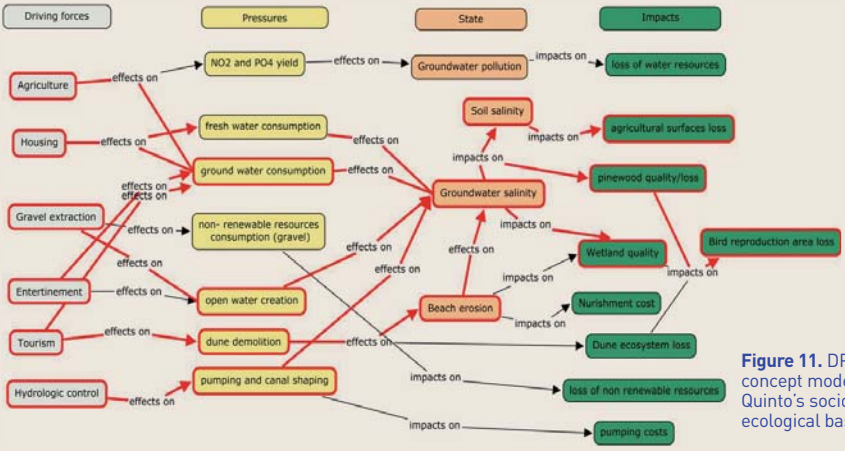


Figure 11. DPSIR concept model for Quinto's socio-ecological basin.

A practical tool for decision-making

One of the main goals of the WATERKNOW project was to develop a useful tool to assist in decision-making that would allow local authorities to make better choices in terms of land use and when it came to questions relating to the availability of water resources and the risk of saline intrusion in a context of climate change. Baptized WATDSS, this tool was developed with ease-of-use in mind for non-specialists. It works off of simple files (Excel spreadsheets), and allows users to import the data from geographic information systems relating to the three basins in question, with each cell corresponding to a 100-meter sided square plot of land. It consists of three linked modules whose parameters can be easily adjusted, dedicated respectively to climate change, land use, and hydro-geology. The result is that maps can be developed that show the water budget for each climate scenario and the envisaged use of the land. This highly interactive tool recalculates very quickly the results when a user modifies one of the spreadsheet's cells.

In Quinto's catchment basin, the tool (figure 12) was used by the project's teams to study the availability of freshwater in detail by looking at different climate change and/or land use scenarios. Regardless of the scenario, however, the end result is always the same: **a reduction in the availability of freshwater.** It was rather surprising to discover that the most optimistic scenarios in terms of climate change (i.e. with more rainfall) are also those in which the most water is consumed, because of the corresponding increase in surface area of forests and wetlands.

Large diameter well near Tangier, in Morocco.

In general terms for all three basins, the following observations can be made based on the projections for scenario 1B (2070-2100):

- The availability of freshwater will be affected by a dramatic reduction in winter rainfall, coupled in the case of Tahaddart, with a strong increase in water evaporation during the summer.
- The number of extreme events will probably rise in Terceira; in Tahaddart the risk of drought will increase; and in the Quinto basin, the risk of drought and flooding will also increase.
- In certain areas around Terceira, the vulnerability of coastal aquifers to saltwater incursions will increase to a moderate degree, and to a much greater extent in the coastal zones and pine forests of the Quinto basin. Any change in land use, from irrigated agriculture to a different activity for example, will increase the area's vulnerability.

These observations led the project's research teams to develop an array of recommendations for decision-makers, detailed in section 3.1 of this document.

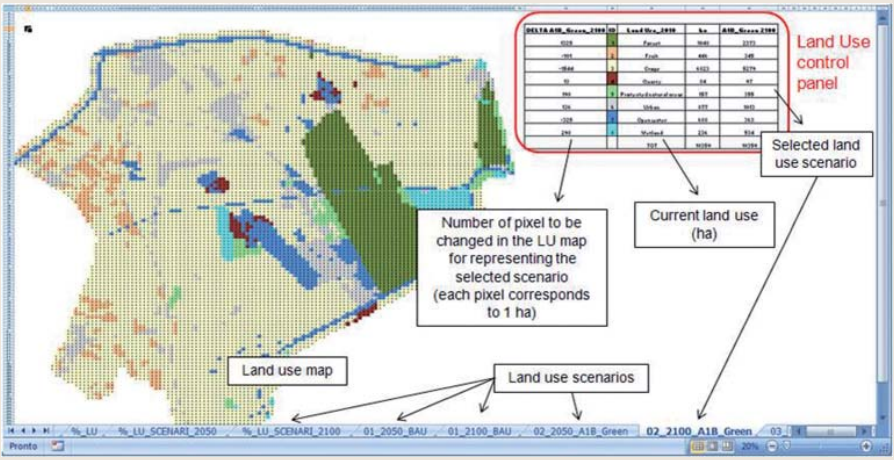


Figure 12. Screenshot of the graphical interface of the WAT-DSS tool.

2.6 – Toward integrated management: a pilot study in Tunisia's Gulf of Gabès

The preceding sections of this booklet have highlighted the various impacts of climate change on different coastal zones—maritime ecosystems, intertidal areas, estuaries, coastal water tables and catchment basins. They provided an overview of the complex interactions between these climate effects and anthropogenic pressures on the environment, and also showed the need to consider, with the perspective of adaptation in mind, the relationship between environmental effects and socio-economic consequences. The need to account for, on a regional scale, the full range of these challenges in the creation of adapted policies is the essence behind the concept of Integrated Coastal Zone Management (ICZM) *"a process whose goal is to unite all of the stakeholders with often widely divergent interests, around a common goal in sustainable development"* **(www.developpement-durable.fr).**

CANTICO

Climate and local Anthropogenic drivers and impacts for the Tunisian Coastal area: prioritizing risks by means of an integrated approach

Funding Organizations

- **MEDDE** *Ministère de l'Ecologie, du Développement Durable, et de l'Énergie*
- **IMELS** *Italian Ministry for Environment, Land and Sea*
- **IMEP** *Israel Ministry for Environmental Protection*

Partner Organizations

- **OGS** *Istituto Nazionale di Oceanografia e Geofisica Sperimentale*
- **Météo-France CNRM** *Centre National de Recherches Météorologiques*
- **IPSL - CNRS** *Institut Pierre Simon Laplace*
- **IOLR** *Israel Oceanographic & Limnological Research*
- **INSTM** *Institut National des Sciences et Technologies de la Mer*
- **CMCC** *Centro Euro-Mediterraneo per i Cambiamenti Climatic*

The CANTICO project adopted a firmly interdisciplinary approach, and their objective was to integrate the spatial issue (both maritime and coastal zones) and pressures (linked to climate change and anthropogenic activities), on the scale of the entire Gabès Gulf in Tunisia.

Initially, the method consisted of using existing tools to create an interconnected series of models that would allow them to simulate the local effects of climate change, integrated with calculations of the pressures caused by human activity in the area. This series of models includes both global and regional models of atmospheric and oceanic circulation (especially Météo France's ARPEGE Climate model and the LMDZ of the CNRS/ISPL) as well as simulation tools for those biochemical processes subjected to anthropogenic forcing. They were able to generate a large number of projections on different spatial scales: the sub-national, regional, and local levels. These results allowed the project to describe, under different forcing scenarios, present and future changes in key parameters (temperature, rainfall, sea level), and this data served as the basis for defining an array of scenarios of local "risks".

This in turn led to the development of a method for assessing local risks (**Regional risk assessment,** RRA) and its application to the whole of the Gulf of Gabès.

Prioritizing the risks

This method generated a set of maps highlighting various aspects such as vulnerability, exposition, and risk: these high definition maps identify the areas and the different stakes (beaches, wetlands, agricultural zones, urban areas, marine or terrestrial ecosystems) that are the most exposed to the impact of each feature of climate change—rising sea level, floods coastal erosion or degradation of the water quality, and others.

Among the various trends this data revealed, it became clear that beaches and wetlands are the areas that are the most exposed both to rising sea and river levels. Indeed rising sea and river water levels are forecasted, on a larger scale, on the southern coasts of the gulf and around the island of Kerkenna. Another lesson that came out of this study was that the most dramatic impacts on freshwater quality will take place near the main cities and port infrastructure.

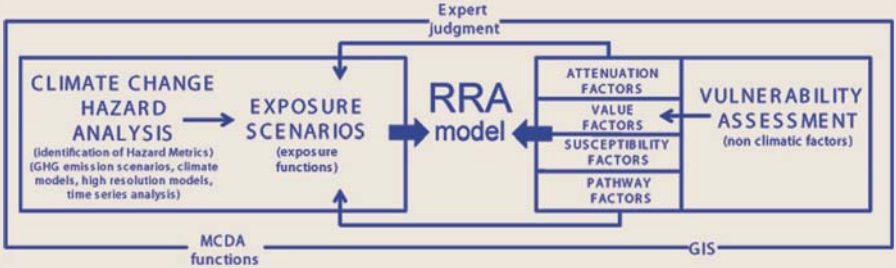


Figure 13. Conceptual model of regional Risk Assessment in the framework of the CANTICO project.

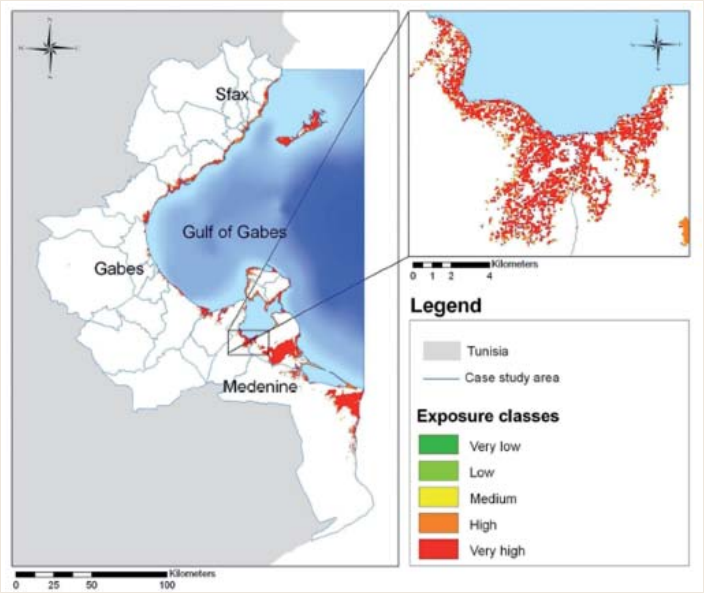


Figure 14. Map showing areas in danger of marine submersion in the Gulf of Gabès.

Finally the CANTICO project initiated a dialogue with local decision-makers. Efforts were made to show them the methods being used and the preliminary results, and a survey conducted among these same groups allowed the team to better orient the use of the model based on their expectations, in preparation for adaptation measures for climate change.

One of the key issues this survey identified was that problems of water quality and coastal erosion were perceived of as the most worrisome changes, while beaches and tourism were considered to be the most fragile areas of the local economy. Generally speaking, the CANTICO analysis confirmed the usefulness of the RRA approach for integrated management of global change in coastal zones. ■

Sicily
© Maurice Imbard

3 Developing adaptation
Tools and methods

strategies:

The Beach
at Palavas-les-Flots, France
© Michel Dukhan

The preceding chapters outlined the full range of the scientific advances made by CIRCLE-Med's projects in terms of *understanding* the impacts of climate change and other anthropogenic pressures on different types of systems (the intertidal, water tables, lagoons...) of the Mediterranean basin. One of the features common to all of the various impacts studied is their site-specific nature: that is to say that even though the methods that CIRCLE-Med has developed are broadly applicable, beyond the actual zones that were examined, to any comparable site, the results that were obtained revealed that it would be dangerous to extrapolate trends that were identified locally to other systems, even those in neighboring regions.

This essential point reiterates the paramount importance of the **local component's** role in these systems—in other words those features that are specific to each ecosystem, to the socio-economic fabric of an area, and to its governance—as adaptation measures are designed for the predicted effects of global change. Similarly, from the perspective of adaptation, this work has shown that the orientation of public policy and those methods defined on the national or supranational level cannot produce efficient measures if they are rejected locally.

To that end, local stakeholders (decision-makers/managers, users, and the civil society) need to become aware of what is truly at stake with climate change, and beyond that, the process of **assimilating** the knowledge acquired over the course of these projects and the specific recommendations developed by each research team needs to be facilitated as well. As much as possible, determining what form the local adaptive measures should take must be the result of continuing dialogue between scientists and the involved parties. The cooperative development of adaptive policies on a local level will ensure their relevance to a specific context, and will also ensure that such measures are implemented in the long term.

Favoring collaboration between scientific teams and local involved parties was one of the goals common to all of the operations funded within the framework of ERA-Net CIRCLE. Each of the research projects described in the preceding pages took this cooperative aspect into account, to varying extents based on the initial objectives and the possibilities that unfolded once the team was on-site: examples include the development of recommendations, the organization of participatory workshops, or the creation of tools to assist in decision-making.

This third chapter summarizes the experiments undertaken within the CIRCLE-Med framework for building just such a dialogue, the difficulties that were encountered locally, and the questions that arose. Finally, the chapter outlines the methodological responses developed by the AQUIMED project, dedicated to building participatory strategies for adapting to climate change.

3.1 – Recommendations for decision-makers

All of CIRCLE-Med's projects were carried out with the understood goal of producing tools to help people make decisions: each of the projects approached climate change from the perspective of developing adaptation measures in the Mediterranean basin, and therefore it was only normal that recommendations originating from the scientific developments be formulated and provided to the involved parties.

In practice, several different projects carried out this last phase, but in some cases just the groundwork was laid out, or in others, CIRCLE-Med's research teams let their institutional partners be the ones to the ensure that the local parties learned about the research results. This was due to the time constraints imposed on the project: the two years allotted for CIRCLE-Med's work at times seemed like too short a time considering the extent of the work to be done.

ACIDBIV: The results in good hands

One of the recommendations common to all of the CIRCLE-Med projects was of course to encourage promoting awareness of climate change and its impacts on the Mediterranean basin. To that end, the ACIDBIV project, working on the effects of acidification on bivalves, put a great deal of effort into enhancing and making their work accessible to the non-scientific community. In that vein, the ACIDBIV team participated in various academic events open to the general public and also organized 14 talks in schools, libraries, high schools, and cultural and scientific centers, welcoming each time between 50 and 100 people, ranging from students to the general public.

In addition to that pedagogical perspective however, the teams also worked relentlessly to develop operational recommendations for the stakeholders, in particular those involved in the aquaculture sector. Time constraints made it difficult to attain this objective in a formal sense. On the other hand, ACIDBIV developed a productive relationship with organizations known for their ability to influence local involved parties / stakeholders. This is certainly true in the case of Portugal's IPIMAR, a branch of the INRB (National Institute for Biological Resources), whose commitment to the ACIDBIV project , formalized by a written agreement, will allow local, regional, and national stakeholders to make

use of the tools and services it developed: i.e. associations of fishermen, aquaculture cooperatives, municipalities.

INTERMED: Making sure the intertidal is on scientific and political agendas

The INTERMED project gathered a considerable amount of data on an essential—and up until now—neglected area of research. A number of noteworthy scientific publications have come out of INTERMED's work; a 16-page brochure, summarizing this information and making it accessible to the non-scientific community, is now available online to decision and policy makers.

This brochure highlights the current lack of resources devoted to questions linked to the Mediterranean intertidal, given the ecological and socio-economic importance of this environment. With this in mind, INTERMED's contributions to the understanding of how this environment works represent a precious foundation for an eventual full acknowledgement of the intertidal's vital importance. These efforts must of course be pursued from an ecological standpoint but also by identifying, as the project did, the benefits and socio-economic services linked to the intertidal zone.

Finally the project devised **three key recommendations** for decision and public policymakers that are equally applicable to the entire Mediterranean basin:

- The intertidal must be included on the scientific agenda, and an effort must be made to ensure the proper functioning of its ecosystems and its connectivity with adjacent systems.
- The intertidal zone must also be included on the political agenda. Its functions, benefits and services must be evaluated so as best to develop adapted management strategies
- Resources need to be dedicated to educating and making the public aware of questions related to the sea, how it functions, and research connected to the ocean environment.

Bevano Estuary, Italy

The MEDCODYN Project: From diagnosis to recommendations

The scientific findings of this project led to numerous articles that have been accepted for publication or that are currently being evaluated by peer-reviewed international journals. These findings have been widely communicated to regional and European decision-makers by means of specialized publications or through international conference presentations. The contributions provided by climate evolution simulations, in conjunction with the conclusions drawn from participating workshops, led to the identification of a series of adaptation measures to be put in place by 2050, based on their potential for success within local and regional contexts of global change. These propositions are resolutely operational in nature, and are also specific to each of the three sites that were studied.

For the Pontic lagoons:

- Option 1: Modification of aquaculture activities (shellfish)
- Option 2: Hydraulic modifications of the entry points for salt and fresh water.
- Option 3: Harvesting submerged aquatic macrophytes

For Vaccarès Pond:

- Option 1: Reduction in the number of entry points into Vaccarès Pond for drainage water from agriculture by either changing practices (resulting in a 30% reduction) or by means of land reclamation (a 100% reduction for the FUM basin)
- Option 2: Enlargement of the hydraulic connectivity between the lagoon network and the sea
- Option 3: Restoration of an ancient connecting waterway between the east of the lagoon system and the sea.

For Sidi Boughaba:

- Option 1: A long-term monitoring plan for the lake and the wetlands.
- Option 2: A management plan for the site that will take into consideration the different stakes of the catchment basin.

On the local level, this project created a relationship between researchers and decision-makers and stakeholders, and the collaboration continues to this day by different means. The initial network of researchers mobilized by MEDCODYN has spread to other regions of the southern Mediterranean: this expanded network is already hard at work on collaborative projects and on improving the exchange of knowledge and experience.

WATERKNOW: An operational tool, local recommendations

The main contribution of the WATERKNOW project has been, as noted in section 2.5, the development of a practical tool to assist in decision-making: WATDSS—very simple to use for non-specialists, this tool simulates the effects of land use in terms of the availability of fresh water and the risk of saltwater intrusions in a context of climate change. The scientific teams were able to make effective use of this tool, as well as other models designed over the course of the project in their formulation of a series of recommendations for managers and water resource users summarized below:

- The issue of water storage will be essential for the three basins in question: any excess water supply will need to be recovered so as to limit the effects of likely winter flooding and prolonged summer droughts.
- Evaporation will become a serious problem for the Tahaddart and Quinto basins.

It will therefore be of vital importance that water be stored below ground as much as possible: this could be done within the framework of management projects for aquifer renewal, or by using local traditional techniques as in the case of Morocco.

- Local conflicts among stakeholders must be resolved: setting up a long term plan for water resource management is an imperative for all the parties involved.
- Existing hydraulic infrastructures need to be rethought: it is possible to make great improvements in terms of the availability and the quality of freshwater resources by making some simple adjustments.


A discussion during a site visit in Ravenna, Italy (Waterknow)

In Italy, the collaborative efforts that were initiated with regional authorities for water distribution in Emilia-Romagna freed up funding for further study of the potential for local water storage in artificial underground reservoirs.

Involving local stakeholders

These recommendations, as well as the tools that have been made available, to the greatest possible extent should benefit the people in the field as well as the political decision-makers for whom they were designed. This is certainly true for all the CIRCLE-Med projects: the integrated risk management approach designed by CANTICO for the Gulf of Gabès, the operational database developed for the 635 lagoons in the framework of the CLIMBIOMEDNET project, or the analytical tool produced by CLIMWAT to develop bio-indicators at the freshwater—saltwater interfaces; each of these projects represent an equal number of precious contributions of which the local stakeholders should make vigorous use as they adopt the most objective decisions possible for dealing with the complex challenges of climate change.

This necessity leads to the obvious question: how does one get the stakeholders to follow the recommendations stemming from the all the different research projects? It is unfortunately a recurring problem in any work linked to climate change adaptation, and it renders imperative the need to go beyond the phase of simply making academic publications accessible to a broader readership: it requires that the **stakeholders become involved** in any work that takes place at these sites through organized consultations, field surveys, or participatory workshops. All of CIRCLE-Med's projects made this concern a priority to as much an extent as the means and the time allotted for each task available allowed it, and also within the constraints of each research goal's specific features, as the preceding pages have shown. In fact, several of these projects carried out rather unique, trailblazing experiments: it is essential that lessons be learned from the contributions these initiatives have made, but also from the difficulties they encountered. The following section discusses the feedback from these experiments.

Meeting with farmers in Morocco
© Nicolas Faysse

3.2 – Mobilizing Key Local Stakeholders: A Debriefing

The first difficulty CIRCLE-Med's scientific teams encountered for cooperatively building adaptation strategies lay in reconciling the gap between the **time horizon** for climate change, situated at the very least several decades away, with the stakeholders' means of action and planning (for public policy planners, and more importantly farmers and other economic players) which rarely operates beyond a time-frame of several years. This point is underlined by the final report of the MEDCODYN project: the forecasted limit of the participatory outlook was set for the year 2050, although the models developed over the course of the project have the potential to extend well beyond that date. Most of the stakeholders view 40 years to be a *long term* projection, while the majority of climate change scenarios consider the year 2050 to be within the *midterm* range.

In addition to this potential pitfall, there is also the issue of the widely divergent levels of awareness of the realities of climate change among the different stakeholders and of the need to adapt as soon as possible. In the case of the farmers, two types of situations can be identified. In those areas that are already under considerable pressure in terms of the availability of freshwater resources, people identify current changes in the climate as the primary constraint on their activities—and these concerns tend to overshadow any consideration of changes in climate in the long term. Conversely, in those zones where there is enough freshwater, any questions related to water management are perceived of as secondary to the economic and commercial problems of the region's day-to-day life.

Another limitation that several research teams noticed was the great lack of awareness of **the connections between coastal ecosystems and economic services.**

This problem surfaced over the course of consultations in Israel and Croatia within the framework of INTERMED's projects among local stakeholders (fishermen and coastal managers). What came out of these meetings was the stakeholders' lack of knowledge concerning the ecological and economic importance of the Mediterranean intertidal. Yet numerous human activities depend precisely on the equilibrium of this intertidal zone—i.e. tourism, aquaculture, urbanism, etc. INTERMED's teams made a similar observation, to a lesser extent, when it came to transitional waters and lagoons.

Faced with these difficulties, organizing **participatory workshops** that bring together scientists, public managers and local stakeholders in a decision-making perspective around a specific problem is essential. This sort of action helps to make the scientific data more accessible—a necessary step to instilling awareness of what is at stake when it comes to adaptation. In addition, such workshops allow the research teams to acquire more information and knowledge from the stakeholders in the field, and to understand the needs of each party so as to better orient scientific policies. It is especially important, however, that each party be included in the development of diagnostic and operational measures: these ensure that any decisions are consensual in nature, and will therefore be carried out by the participants. Among the seven CIRCLE-Med projects that have already been presented, the MEDCODYN project chose to make good use of this type of approach, by setting up SWOT workshops (in Italy and in Morocco) with the field teams, or through meetings that link local decision-makers and associations (in France). These actions helped identify the dangers facing the three ecosystems in question as well as those new findings that would be of use to local stakeholders.

WATERKNOW's team also carried out a participatory SWOT-type analysis with the local players around the waters of the Quinto basin (Italy). Here again, this type of action produced some useful lessons *(see section 2.5),* but it has its limits, in particular because of the small number of participants: of the 34 actors invited, only four actually came, of which only two said they would be interested in pursuing a collaborative effort. The low participation rate, a common pitfall in the current participatory approach, is of course linked to the aforementioned limitations—the perception that potential problems are too distant to be of relevance, coupled with operational difficulties, and the inability to see any possible "benefits" that preventive measures would bring.

At the end of the day, this highlights the still experimental and punctual nature of participatory workshops aiming to produce adaptive measures in the absence of structures that might promote such cooperation in a given territory. Several projects (INTERMED, WATERKNOW, MEDCODYN) picked up on the **inadequacy of existing local governing structures** in their efforts to help resolve conflicts over water usage and to acknowledge the various issues linked to adaptation. But from one area to another in the Mediterranean basin, the situation is different. In some countries, especially in the south, organizations dedicated to water management still need to be established, while in others, existing tools (the SDAGE for example in France), could be adapted to eventually become pertinent organizations for the cooperative development of adaptation policies.

3.3 – The AQUIMED Project: Participatory tools for developing adaptation strategies

Although it's still a recent issue, the necessity for society to acknowledge the scientific work carried out in the area of climate change has opened up a new field of interdisciplinary research. At the interface of ecology, economics and the social sciences, the creation of strategies and participatory methods appears to be a major step toward a veritable understanding on the part of stakeholders of the vital importance of adaptation. This was the goal of the AQUIMED project: the development of adaptive strategies around three distinct Mediterranean coastal aquifers, all of which are either being overexploited or in danger of being so. There were three phases to this highly method-based approach. An initial analysis, common to the three systems in question, allowed the team to determine how the local population perceives climate change and variations in water resource availability. In the second phase, a series of participation-based workshops with groups of local famers and institutions in charge of agriculture and water resource management was set up. Finally, an information exchange network among scientists and local stakeholders was established in France, Morocco, and Portugal.

The status at each of the three sites and preliminary investigations

The three sites examined by the project could be described as having contrasting situations. In France, research focused on the **Roussillon plain**, where a multilayer aquifer stretches over 700 km² in the Pyrénées-Orientales department. This body of water, under considerable pressure from various sources, is exploited for its water supply, tourist activities, and irrigation (orchards, grain crops, and wine-growing). The surface layer of the aquifer has been affected by diffuse pollutants, while the deeper layers are increasingly exploited by local authorities and agricultural activities, especially in the produce sector. The result is an observable, progressive degradation of the water table's capacity for renewal over the past twenty to thirty years. This trend will most likely continue, as the population grows, and older surface drainage canals fall into disuse, abandoned in favor of deep drilling. Faced with this situation the local authorities and managers of water resources have actively supported the establishment of concerted water management through SAGE (Water Management and Development Schemes/ *Schémas d'Aménagement et de Gestion des Eaux)*.

AQUIMED

Participatory design of adaptive groundwater management strategies and instruments in Mediterranean coastal water scarce areas as a response to climate change

Funding Organizations

- **MEDDE** *Ministère de l'Ecologie, du Développement Durable, et de l'Énergie*
- **FCT** *Foundation for Science and Technology - Ministry of Sciences, Technology and Higher Education*

Partner Organizations

- **SOCIUS** *Research center in economic and organizational sociology*
- **ENA** *Ecole Nationale d'Agriculture*
- **CIRAD** *Centre de coopération internationale en recherche agronomique pour le développement*
- **IRSTEA (former CEMAGREF)** *Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture*
- **BRGM** *Geosciences for a sustainable Earth*

In Portugal, the 318 km² of the **Querença-Silves aquifer** represent the largest water table of the Algarve region, in the south of the country. It's also one of the zones of the Portuguese coast that draws the most tourists: the population increases tenfold during the summer. Beyond the need to supply hotels, secondary homes and golf courses with water, this resource is also used by local agriculture (primarily citrus fruit production) and certain industries. During the summer of 2005, when Portugal suffered the worst drought in 40 years, this aquifer experienced the lowest level of renewal ever recorded. As a result, the authorities took extraordinary measures: water consumption was reduced by 50% in the aquifer and other solutions for providing water where it was needed were set up. The difficulties encountered in the summer of 2005 foretell problems to come, given the predicted increase in domestic demand for water and by the tourism sector. In 2009, Algarve's hydrographic Administration launched a participatory initiative to define a concerted plan for the use of local surface and subterranean water resources.

Finally, the Moroccan site of **Chaouia** is a coastal aquifer located between the cities of Casablanca and Azemmour. Since the 1970s this 1 200 km² water table has been intensively exploited for irrigation purposes, essentially for citrus fruit crops, but also, and to a greater and greater extent, for other produce such as tomatoes or potatoes. The overexploitation of water resources has led to saline intrusions in the coastal water table (water conductivity in areas reaches 10 mS/cm) and a decrease in the piezometric level in the continental water tables. Farmers have had to adapt to this environment

Project AQUIMED Meeting.
© Nicolas Faysse

of hydric stress since the 1980s by adopting various strategies: by placing water channeling mechanisms deeper in the ground, by transporting freshwater to their farms, or by renting land plots, either upstream in the same zone, or in areas that are further from the coast. The increasing shortages in usable subterranean water have been the first factor which has led the region to its current state of crisis and instability, where previously, intensive agricultural exportation had been the norm. Although as yet no mechanism for water resource management has been put in place, public policy makers foresee reducing the pressures on the water table by supplying surface water to certain areas of the aquifer, and by encouraging the transition toward activities that are less dependent on water such as poultry farming.

A preliminary analysis, carried out by means of a survey among the farmers at all of the sites in question, revealed that in any case, none of them foresaw a major change in the climate. For each of these sites, agriculture, the principal culprit when it comes to water resource consumption, is undergoing a crisis period. The specific contexts of each site however present two major differences.

First of all, in Roussillon as in Querença, the availability of water resources is not perceived of as a significant constraint for users; climate change and the need to adapt to it still appear as distant problems. In contrast, for Chaouia, the rareness of water, worsened by salinisation problems, are the primary constraints on local agriculture. The second major difference concerns those institutions which govern water usage. A veritable plan for water resource management is emerging in Roussillon and in Querença, while in Chaouia, such a thing is not even planned for as yet. This results in significant divergences in the ability of public institutions to tackle problems related to climate change within a long term perspective.

Types of participatory measures

Different contexts require different methods. In France and in Portugal, scenarios forecasting the changes in agriculture to the 2030 time horizon have been pre-designed based on local data and interviews with key local actors and experts. In Roussillon, three groups of farmers were trained and invited to debate these different scenarios. Those farmers who were invited came from different agricultural backgrounds, from different types of farms (organic or conventional, family-based or corporate), from different geographic zones in the plain, and with varying levels of experience in the profession. In Portugal, two groups of farmers received instruction: one came from the Algoz region (in the west) and the other from the Querença region (to the east). Workshops with these two groups of farmers helped to specify the factors of change and to provide forecasting models for agricultural development to the 2030 time horizon.

A common protocol was then applied to both areas/regions, where three workshops were set up with each group. In the first workshop, possible scenarios for changes in agriculture to the time horizon of the year 2030 were presented and debated. During the second workshop, retrospective and forecasting data on the climate were presented, and their impact on crops and the pertinence of adaptive measures were discussed. Finally, during the third and final

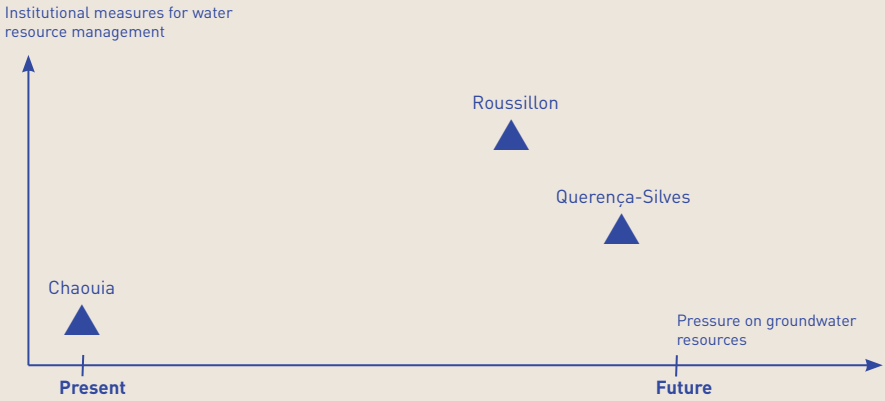


Figure 15. A comparison of the different degrees of governance with respect to pressures on subterranean water resources for the three sites of the AQUIMED project.

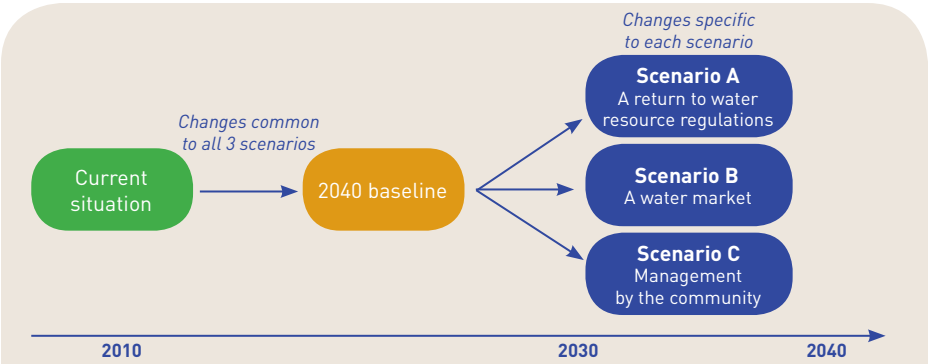


Figure 16. The three potential scenarios for the 2040 time horizon identified in collaboration with the farmers on the Roussillon plain.

workshop three possible scenarios for the management of subterranean waters were presented and examined: one scenario for state intervention, one scenario for a "water market" and one scenario for communal management.

Workshops were also organized with local institutions for local development in the region of Querença-Silves that took into account scenarios for future development and for the impact of climate change. At the end of the project a final workshop took place bringing together both the institutions and the farmers from each of the work groups.

In Morocco, three groups of farmers conducted a diagnostic of their zone, designed scenarios for their future agricultural activities, and also defined possible actions to be undertaken at the aquifer level that would lead to an ideal scenario. A similar project took place with a group of administrative personnel in charge of agricultural development. One final workshop brought all these different groups together, where they compared and discussed the results of the various analyses, the scenarios that had been developed and the proposed solutions.

The status of each site: Validated methods, identifiable measures

The Roussillon workshops confirmed the ability of farmers to think about the long term prospects, despite the economic instability of the sector. Another result was that the relevance of an approach based on stakeholders developing an action plan using methods such as "scenario workshops" and "scenario planning" that had up until now seen little use in the field of water resource management was confirmed. Generally speaking, participants underlined how pertinent the exercise had been for them. Besides the methodological contributions, the adopted approach produced substantial results. The workshops allowed participants to identify those economic and territorial policy measures that farmers view as essential for the future of their work. Several possible adaptation measures were also indentified and debated: changing crops, irrigating vineyards, and policies for resupplying water tables.

Generally speaking, farmers tended to highlight the uncertainties and the controversial nature of the diagnostics proposed

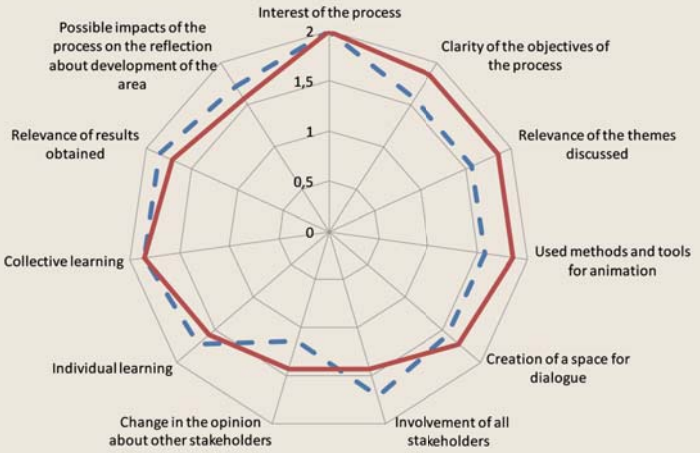


Figure 17. Evaluation by the participants (farmers and public institutions) of the interest for the workshops that took place in Morocco.

by scientists and water resource managers when it comes to the climate and its impact on agriculture. But they especially view climate and water as constraints and not as valuable assets from an adaptation standpoint: for them the decisive factors are the markets, labor costs, and public policies.

Finally, the third workshop provided a forum for discussing management methods and the particular role of the State and users, respectively. Within a context of difficult discussions between the agricultural sector and that of water resource protectors, this workshop highlighted the necessity of devising local management rules with State arbitration by reaffirming water as a heritage asset to be cherished by all.

The future outlook workshops in Querença-Silves revealed important data concerning the relationship of farmers to their crops and the climate. Globally, they did not consider themselves to be in any danger of lacking water, but rather they felt the danger came from difficulties commercializing their products. Nonetheless the participatory workshops revealed their detailed knowledge of the connection between agriculture and climate variation. Thus, in the case of citrus fruit (the primary crop of the region), climate events—an increase in the average temperature in summer and spring for example, a lack or an excess of precipitation, freezing temperatures, excessive winds, prolonged exposure to solar radiation—were discussed in depth by the farmers. This knowledge represents a precious conceptual foundation within the perspective of dialogue among farmers, stakeholders, and scientists.

These workshops confirmed the results of the preliminary survey: the farmers now know and are measuring the effect of the climate on the profitability of their operations and that of their entire economic sector of activity. They are interested in the development of new agronomic crops (in particular indigenous species) and they recognize the need to come up with improved techniques

for water retention. The scenarios covering the modes of water governance for the time horizon of 2030 - 2050 also helped to enrich the discussions of water table management.

Finally, in Morocco, the project led to the creation and testing of a participatory planning method for agricultural development on a regional level. In particular the progressive accompaniment of farmers' collectives, from the diagnostic of the problems in their village to a discussion of possible development options on the scale of the zone in question led to a productive exchange during the final workshop. The different development scenarios that were defined and discussed opened up the debate and helped identify avenues for evolution in agricultural activity (i.e. development of the cattle sector—for dairy products and beef, rain fed tree-farming, poultry farming) and innovative mechanisms for gaining access to water (by connecting villages to networks of drinking water with the goal of reducing the cost of watering herds in those zones where the water has become too contaminated by saline intrusions).

In terms of methods, what lessons have been learned?

The first requirement for successful forecasting is a **solid preliminary diagnosis of the interplay among key local players.** On the basis of this diagnostic, the method needs to be adapted to each particular context—land use, the status of the resource, the level of development of the governing institutions, and the level of awareness of the stakeholders. Within AQUIMED's framework, the methodological differences applied to the **time horizon** under consideration (starting with the past state and proceeding forward in time either progressively year-by year or by leaping forward to the years 2030 and 2050), to the **geographical scale** (by working closely with farmers to understand the stakes starting on the scale of the village, and moving from there to that of the water table, or by simply look at the situation on the scale of the entire region). These differences also applied to the **means of generating scenarios** (by having participants react to preconceived scenarios or by designing them cooperatively).

Yet beyond these differences, the AQUIMED experiments revealed several aspects common to all of the contexts in question. For one thing, it is clear that any discussion about how to adapt to climate change cannot take place independently of a future outlook on agriculture and the region in question, on different levels. In all three sites, where agriculture is the principal activity making use of water resources, it was productive to start discussions with local stakeholders by initially talking about agriculture and the land, and to talk about water afterwards (note that the goal of discussing water resources was never hidden—on the contrary, it was explicitly presented at the start of the process in Portugal and France). In other words, discussions about climate change, by focusing on the long term, are a very real opportunity to renew questions about water resource management with the agricultural sector.

As such, **the AQUIMED project underscores how essential it is not just to consider agriculture as making use of water resources; in a given region, agricultural and water policy are inextricably connected and should be discussed together.** ■

List of Publications

Pink flamingoes in the Camargue region.
© Marie Mojainsky

This section includes several reference articles written by CIRCLE-Med's researchers; many other articles have been written or are in the process of being published.

The website, **www.circle-med.net**, provides links to more.

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