

ARP MERMED Forward-thinking Workshop

Adapting to global changes in the Mediterranean Sea

The Mediterranean is a virtually closed intercontinental sea covering approximately 2.5 million km². It opens out into the Atlantic Ocean via the Straits of Gibraltar and is connected to the Black Sea via the Bosphorus and, since 1869, to the Red Sea by the Suez Canal. It lies on the African and Eurasian plate boundaries and is the focus of intense geologic activity, particularly seismic and volcanic.

From a physical perspective, it is broadly split into two well-defined basins (the Western and Eastern Mediterranean) which are themselves subdivided into numerous contrasting entities. Major rivers flowing into it such as the Po, Rhone, Nile and Ebro, together with its different currents, generate rapid horizontal and vertical transfers that are strongly influenced by weather and climate conditions and subjected to wide variations on all time scales.

Biologically speaking, the Mediterranean Sea is recognised as one of the “hot spots” of marine biodiversity. It shelters a great number of species, a high percentage of which are endemic. Coastal lagoons, salt marshes, estuaries, deltas, rocky and sandy coastlines, sea grass and coralligenous beds, soft and rocky substrates, canyons, plateaux, undersea mountains are all remarkable habitats that favour the diversity of organisms in the Mediterranean.

From a geopolitical standpoint, in ancient times, the Mediterranean Sea represented a hub for trade and culture between the people of the region. Today, it constitutes a shared space for 23 neighbouring countries and is both traversed and exploited by these countries as well as third parties. It is a disputed space too, with tensions between users and competition for resources. Nevertheless, for most maritime-related issues, neighbouring countries are bound by a ‘common destiny’. Thus, they need to better cooperate in terms of resource analysis and assessment, observation, monitoring and controls as well as management of the resources the sea provides.

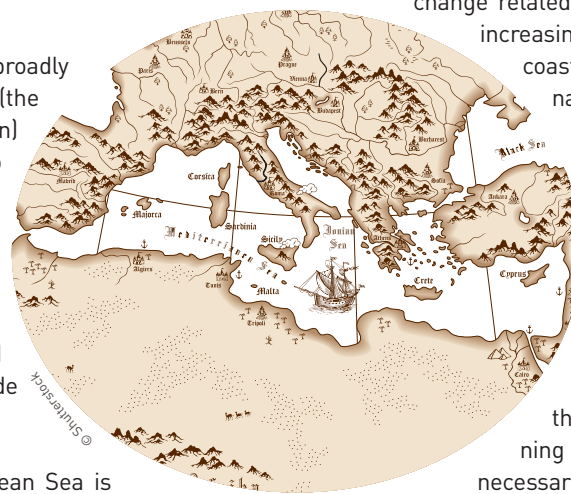
In human terms, in 2011, the neighbouring countries accounted for 475 million people, a third of which lived on the coast and a significant proportion in “mega cities” (Cairo, Istanbul, Athens, Rome, Barcelona, Marseille, Algiers, etc.). From the shore to the open sea, the Mediterranean Sea is the focus of numerous activities. It is a navigation area, its living and mineral resources are exploited as too are its specific landscape, cultural and climatic features which attract more tourists each year than the number of people living there! It also provides a wide range of non-commercial ecosystem services (nurseries for commercial species, recycling nutrients,

atmospheric CO₂ absorption and sequestration, filtering of toxic substances, protection from coastal erosion, etc.) upon which the quality of life of coastal communities and certain economic activities such as fishing, aquaculture, and tourism depend.

There has been an increase in the intensity and frequency of climate change related disturbances such as rising sea levels, increasing water temperatures and acidification, coastal submersion and erosion phenomena, as well as societal changes, including greenhouse gas emissions, over-fishing, rising recreational uses, chemical pollution and biological invasions, etc. As a result, marine ecosystem services, whether regulating or provisioning ones, are affected and will be increasingly so in the future.

In a forward-looking vision for the next thirty years, research, innovation and training have a vital part to play in providing the necessary knowledge to guide and accompany these changes towards a desirable future. This cannot be envisaged without tackling the problems and questions arising by giving consideration to the Mediterranean basin as a whole. As such, the French National Research Agency (ANR) supported a forward thinking workshop on the future of the Mediterranean Sea in response to global changes (ARP MERMED). Its purpose was to define priority areas for research to help build the capacity of Mediterranean societies in terms of anticipation and adaptive management. Coordinated by Agropolis International, ARP MERMED subsequently encouraged 18 French, foreign and international institutions to work together from April 2013 until September 2014 and involved 130 experts from various Mediterranean countries (*see page 12*). As a result, five main areas of research presented in this summary document were proposed by the experts:

- **Understanding the integrated operation of the “Mediterranean Sea dynamic system” (p. 2-3)**
- **Characterising, assessing and anticipating marine environment-related risks for Mediterranean societies (p. 4-5)**
- **Conducting research in support of sustainable activities in the Mediterranean Sea (p. 6-7)**
- **Assessing and defining scales for structuring and managing resources and uses to improve their governance (p. 8-9)**
- **Monitoring changes and developing foresight modelling and analysis capabilities required for decision-making and fostering adaptation capacities (p. 10-11)**



Understanding the integrated operation of the “Mediterranean Sea dynamic system”

Compared to the terrestrial environment, the marine environment is more difficult to access. As such, its exploration has been slower and dependent on technological advances. Despite considerable progress made over the last few decades, the scientific community still faces many challenges about the physical, chemical, biological and biogeochemical dynamics in the Mediterranean Sea and their interactions. Given the particularly rapid climatic and societal changes in the Mediterranean, it is crucial to understand the processes at work to be able to reduce the human footprint on the marine environment.

Studying the dynamic components of the physical environment and understanding their interactions

The way the Mediterranean Basin functions physically is influenced by highly contrasting physiography in terms of coastal continental land masses, the shoreline, continental shelves and deep basins and their connections. This physiography is directly inherited from a geodynamic history that tightly controls the Mediterranean Sea’s current geophysical characteristics, especially its seismological characteristics. In addition, the Mediterranean sea is submitted to a complex and still largely unpredictable hydrometeorological process. These two factors interact with hydrodynamics and various types of transfers, particularly sediments.

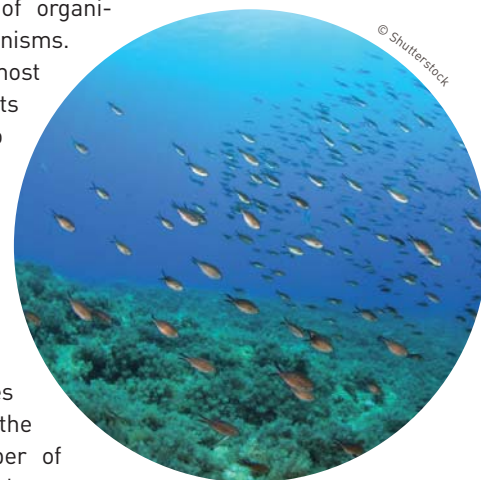
In terms of hydrodynamics, the Mediterranean is characterised by two main processes. These are rapid horizontal transfers (land-sea interface and thermohaline circulation) and vertical transfers (upwellings of deep water, cold water plunging and cascading down and hyperpycnal currents). Such processes regulate Mediterranean Sea water renewal and deep water formation. The contrasting land-sea interface physiography of Mediterranean regions is characterised by low-lying or mountainous coastal areas as well as broad, narrow, or sometimes even absent, underwater shelves. In the latter case, the emerging land mass is therefore directly connected to underwater slopes and deep water basins, leading to numerous and sometimes large deep-sea alluvial fans. Seismic activity can also generate sediment instability as well as mass slope-to-basin transfers and varying degrees of turbidity currents. Flows of materials, whether land-to-sea (strongly affected by human activity), coast-to-open sea (sediment transfers towards canyon heads, then towards slopes and deep basins), or coast-to-coast (lateral transport along the coast) are therefore strongly dependent on hydrometeorological, physiographic and geodynamic forcing mechanisms.

Numerous scientific challenges must be met to better understand how the Mediterranean marine environment functions physically, both in its different constituent parts and in their interactions. In particular, a major stake lies in understanding and modelling the controlling mechanisms at different spatial and temporal scales.

Exploring and analysing how biodiversity is structured and how it functions

When it comes to biodiversity, the first thing we think about is the number of species. The taxonomic inventory of species recorded in the Mediterranean Sea provides an estimate of approximately 17,000 species, not counting prokaryotes. However, other facets of Mediterranean biodiversity have also been explored recently through the phylogenetic and functional characteristics of certain organisms such as fish, which do not systematically appear spatially congruent with this taxonomic diversity. Some coasts can shelter numerous species but limited to just a few phylogenetic lines or functional groups. This lack of congruence not only raises fundamental questions but also has practical consequences about the management and protection of different biodiversity facets. Indeed, the conservation of areas supporting the greatest species biodiversity does not necessarily guarantee the preservation of other facets.

The range of interactions is equally important to the way Mediterranean ecological systems function as well as their resilience. However, the interactions between trophic compartments remain little-studied. Interactions between organisms shape the geochemical, trophic and energy balances of ecological systems. They have developed on different timescales and different levels of organisation of living organisms. They extend to the most extreme environments or those subjected to multiple pressures such as Mediterranean lagoon ecosystems. Changes in the composition of communities of organisms under the effect of global changes might accelerate to the point where a number of taxa and/or functional groups could disappear before they have even been recorded.



There is therefore a long way to go to gain a better understanding of:

- Divergences and convergences of different biodiversity facets (taxonomic, phylogenetic, functional) with anthropic pressures at different scales of organisation in Mediterranean systems;
- Spatial heterogeneity and temporal variability of diversity in biological compartments and the role of interactions between organisms in the spatial and temporal dynamics of marine biodiversity and the way ecosystems function;
- Relationships between diversity and the functions of the main biological compartments involved in supplying ecosystem goods and services.



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Integrating marine environment physical and biological dynamics through eco-regionalisation

The limited spatial scale of the Mediterranean Sea coupled with its strong geological, climatic and meteorological structure on a meso-scale makes it a particularly relevant study area to define eco-regions, *i.e.* the identification of homogenous regions, which differ from adjacent regions, and for which specific environmental conditions and assemblages can be characterised and predicted.

Eco-regionalisation is based on the existence and availability of a large amount of data to characterise the physical environment and describe the distribution of species as well as inferential statistical tools. It is therefore a descriptive method which is complementary to the acquisition of in-depth knowledge about habitats and the way ecosystems function (*i.e.* about the functional communities that constitute it). In an eco-regionalisation approach, collected data must be based on multi-scaled spatialised observation strategies that make it possible to identify the relevant scales that structure functional communities.

Eco-regionalisation therefore constitutes a robust scientific base to implement meta-community or meta-ecosystem-type models in varied environments as well as strategies for the observation and management of marine resource (*see p. 10 and p. 8 respectively*).

Thanks to past and present European programmes, eco-regions are relatively well identified in the three sub-basins on the northern Mediterranean shore. Collaborations already established with certain countries in the Southern Mediterranean should contribute to extend the eco-region approach to the whole of the basin.

Developing integrated models to understand the way the Mediterranean basin functions and evolves

The Mediterranean Sea constitutes a unique space, presenting specific scientific challenges for observation and integrated modelling. It is a highly emblematic, relevant study system, combining many of the world's issues. It combines oligotrophic ecosystems (low in phytoplankton, *e.g.* the Ionian Sea) similar to those encountered in open oceans, as well as more productive coastal ecosystems (*e.g.* the Golfe du Lion) with significant socio-economic challenges (subaquatic landslip and avalanche risks, proliferations of gelatinous plankton on the coastline, etc.) up to lagoons subjected to eutrophication and major environmental and socio-economic crises (pollution, shellfish contamination, dystrophic and anoxic crises and the proliferation of toxic micro-organisms). It is also characterised by a large-scale thermohaline circulation which makes it a "reduced-scale model of the global ocean". This circulation largely explains the overall structure of the ecosystem which exhibits greater oligotrophy in the south and the east of the basin and in high sea.

Global changes are affecting the circulation of water (currentology) and the physiology of the species (*e.g.* perturbation of the formation of carbonate structures due to acidification), as well as their biology (modifications in phenology due to changes in temperature), their distribution (more thermophile and/or stenotherm species) and their ecology (changes to inter-specific relationships following the arrival of non-indigenous species). Indeed, global warming could lead to a drastic weakening in circulation with significant consequences for ecosystems. Shorelines and coastal zones, including lagoon areas and key ecosystems in the Mediterranean, widely exploited, feel the brunt of anthropic pressure. They are also linked to offshore areas by a general circulation consisting of powerful unstable boundary currents favouring exchanges between these environments. This exacerbates the multi-scaled character and difficulties in observation and modelling. Finally, change scenarios, whether climatic and environmental or economic and societal, vary widely. Their study requires long-term series' and a capacity for simulation which opens up new challenges for current observation systems and models.

Understanding the effects of global changes on the way the Mediterranean system functions therefore requires a multi-disciplinary approach to develop global models. The advent of a new era in data collection (*see p. 10*) will enable significant progress to be made on existing models by favouring, in particular, 'tailored' data collection and its exploitation for modelling. More comprehensive, global models will therefore be developed with the following challenges: (i) consideration of physical, climatic, biogeochemical, biological and ecological dimensions and their multiple interactions and (ii) integrating the coastal zone and transfer processes, both within the coastal zone and along a coast/open sea gradient. Nevertheless, discipline-based models (physical, biological, biogeochemical, etc.) all still require significant development to be more realistic.

Characterising, assessing and preventing marine environment-related risks for Mediterranean societies

Mediterranean coasts are exposed to multiple complex and interlinked risks. Natural hazards, whether geological or hydrometeorological, result in coastal zone submersion and erosion risks. The effects of climatic and societal changes on the marine environment and organisms (pollution, proliferations of eventually toxic organisms, etc.) result in risks for human health and for the sustainability of ecosystem services which coastal societies depend on. The concentration of population and activities on the coast together with the increasingly artificial nature of coastlines and higher sea-levels, contributes to coastal societies being increasingly vulnerable to risks.

Anticipating submersion and erosion risks in coastal zones

The Mediterranean Basin is located on the Africa-Eurasia convergence zone and is tectonically very active. Seismicity is particularly significant in the Eastern Mediterranean, in the Hellenic subduction zone and to the east along the North Anatolian Fault. By contrast, seismicity is more diffuse in the Western Mediterranean and spread out over a great many faults about which very little is known, especially out to sea. Submarine avalanches or volcanic eruptions also occur in these situations. All these telluric events can provoke devastating tsunamis.

Hydrometeorological hazards are also the source of current and future marine submersion risks. Given the weak tidal influence in most of the basin, marine overtopping events predominate. Atmospheric depressions generate a temporary rise in sea level which, combined with overtopping linked to wind and waves, is often accentuated by relatively steep inshore slopes. General circulations also significantly influence sea level, making it particularly difficult to model overtopping. Flash floods, typical in the Mediterranean, sometimes combined with storms at sea, as well as subsidence in major deltas (the Nile, the Rhone), also have a considerable influence on flooding in the coastal plain.

Combined with hydrometeorological hazards, sedimentological phenomena, sometimes altered by human activities (river engineering and sea defences), play an important part in the evolution of coastal erosion. But they are still poorly described due to difficulties in obtaining *in situ* measurements of sediment flows on different spatial and temporal scales. The Mediterranean is particularly sensitive to deep sea basin sediment transfers (due to the narrow continental shelf in many areas) but also to the mechanical alteration of rocky coasts and to beach erosion.

Climate change will bring about a rise in sea level and alter the hydrological regime (and therefore sediment supply) and storm patterns, with repercussions for coastal hazards. On low-lying Mediterranean coasts, this will result in a gradual loss of coastal land associated with erosion of the coastal strip and temporary submersion linked to storm overtopping reaching areas ever further inland from the coast. In addition, there will be a higher frequency of river floods which will increase the possibilities of combining both types of flooding. The extent of territories

exposed will thus increase considerably in the decades to come. Changes to these hazards can also lead to saltwater intrusions inland, contaminating fresh water drillings in coastal aquifers. This issue is crucial for many countries in the Eastern and Southern Mediterranean, particularly in the Nile Delta.

Improving the prediction and prevention of submersion risks and coastal zone erosion in the Mediterranean requires better knowledge of these phenomena and their interactions, based on:

- **Assessing the recurrence of earthquakes using paleoseismological-based approaches, characterising large active faults, better coordination of geophysical observation and warning networks (characterising earthquakes in real time, mapping significant earth movements, improving the prediction of tsunami effects).**
- **Assessing the recurrence of submersion events by studying sedimentary archives, gaining a better understanding of interactions between hazards and the spread of flooding, water body forcing mechanisms and circulations in order to improve models and anticipate the occurrence of hydrometeorological hazards and associated submersion phenomena at an eco-regional level (see p. 3).**
- **Identifying, mapping, sizing and monitoring changes to sedimentary units and modelling sediment transport on different scales.**
- **Observing and understanding hydrodynamic interactions between different levels, waves and currents in the coastal zone and morphological responses as well as their retrospective effects on hydrodynamics to improve overtopping process modelling by taking into account all the contributions.**
- **Analysing the links between ecological and economic vulnerability, mapping the vulnerability of Mediterranean coastlines to submersion and erosion hazards and assessing the value of assets at risk according to context, particularly intangible assets.**

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Greater knowledge about sources, flows, fate and impacts of pollutants in the Mediterranean Sea

Human activities in the Mediterranean are the source of a great deal of waste, pollutants and disturbance. Pollution originating from atmospheric emissions (particles emitted from transportation and incinerators) due to increasingly populated coastal cities, from discharges into the sea (coming from river water and wastewater treatment plant effluents) and from the recreational sector (wastes from swimming, boating, cruises) is considered to varying degrees. Maritime traffic transiting through the Mediterranean (a third of global flows) is an additional source of pollution, both chronic (discharges of toxic compounds from anti-fouling paints, burning hydrocarbons and noise pollution) or accidental (sinkings and loss of containers) while aquaculture sometimes leads to local concentrations of large quantities of organic matter in the marine environment. Pollutants initially affect the coastal environment, then offshore areas and accumulate in secondary reservoirs.

These pollutants contaminate water and living organisms. They affect the balance of marine ecosystems and threaten certain activities and uses (fishing, aquaculture, tourism, etc.). Specific forms of oceanic circulation in the Mediterranean make the residence time of deep water very short which results in particularly rapid impacts. Extremely high concentrations of certain toxic elements such as Mercury and PCB, found in top predators consumed by man, leads to significant human health risks.

Knowledge requirements focus in particular on:

- Characterising inputs (especially emerging pollutants), flows (particularly during floods) and the fate of contaminants (transformation processes by micro-organisms, the creation of secondary reservoirs);
- Measuring their impacts (on species development and reproduction) and their combined effects (sensitivity of discharge zones);
- Studying the contamination process throughout the trophic chain which is vital in the Mediterranean (connection between nutrient cycles and contaminants as well as modelling).

Understanding the processes at work in the introduction and proliferation of species

The growth of human activities and the effects of climate change also result in altering the composition and distribution of certain species in the Mediterranean Basin. This includes the introduction of new species, changes to the distribution areas of some species or even their proliferation with changing environmental conditions. As a result, biodiversity in the Mediterranean Basin is constantly changing due to the passive arrival of new species from the tropical Atlantic via the Straits of Gibraltar or Lessepsian species from the Red Sea via the Suez Canal. Furthermore, global changes also have an impact on the physico-chemical characteristics of Mediterranean seawater (temperature, salinity, pH, etc.) which is not without consequences for species development and distribution. Recent changes, such as the spread of numerous Lessepsian species from east to west, indicate a tendency for the homogenisation of Mediterranean biota and the disappearance of the basin's biogeographic barriers, a so called "meridionalisation" process. Some effects are also observed in bacterial populations such as the change of host, proliferation within the ecosystem and the acquisition of virulence factors which could explain the emergence of pathogenic micro-organisms. Moreover, accidental introductions of non-indigenous species (via ballast water, bio-fouling on ships' hulls, the transfer of shellfish species, micro-waste, etc.) can also turn out to be invasive or toxic to humans.

These changes represent a certain number of risks for marine ecosystems and humans such as the loss of biodiversity, the impact on services provided ("red tides", anoxic events, toxic algae rendering whole aquaculture stocks improper for consumption, proliferation of jellyfish which impacts on tourism, etc.) and human toxicity.

The factors triggering these proliferations of organisms are still poorly understood while detection and monitoring procedures are lacking, hence the following priorities:

- Study the main pathways and vectors concerning the introduction of species in the Mediterranean, their impact on trophic networks, their genetic interactions with indigenous species, emergence mechanisms and the proliferation of pathogenic species populations.
- Design and propose technical solutions to avoid transferring invasive and toxic species and facilitate their detection.
- Explore the future of services provided by ecosystems faced with these different proliferating organisms, whether the impacts are negative (effect on habitats, fisheries, aquaculture, tourism and industry), or positive (if these organisms can be exploited for fishing, aquaculture or marine biotechnology).

Conducting research in support of sustainable activities in the Mediterranean Sea

The interaction between changing environmental conditions, ecosystem services (sometimes still poorly identified and understood) and their sustainable use (by fast-growing populations and, for some, undergoing social, economic and political change) is a relatively new vision which requires innovative research. In the Mediterranean, this research concerns ancient activities such as small-scale artisanal fishing which has been little-studied and considered up to now despite its predominance and heritage value. It also concerns fast-developing activities, such as aquaculture and marine biotechnology, or even technological developments in the field of eco-design and ecological engineering geared to reducing the impact of exploitation by man or to restore the environment.

Provide a future for small-scale fisheries in the Mediterranean

Although industrial fishing, like that for red tuna, is often the focus of attention, most fishing in the Mediterranean is, in fact, artisanal. It consists of, on one hand, specialised flotillas supplying an inter-regional market and, on the other hand, opportunistic flotillas using various techniques to meet a localised, scaled-down and changeable demand. The former operate out to sea on broad continental shelves. They require significant technical and financial resources whereas the latter fish in narrow coastal zones and steep-sloped untrawlable areas, sometimes only using rudimentary means. This small-scale artisanal fishing on the coast often constitutes a 'sea fisherman incubator' for offshore specialised fisheries, but the scarcity of deep water resources combined with the limited continental shelf area and the low productivity of Mediterranean waters have restricted, more than elsewhere, this offshore expansion. Consequently, fishing in the Mediterranean essentially remains an activity of fresh fish landed daily, where 'small professions' predominate in numerical and structural terms for the entire industry and its economy.

Today however, professions in the fishing industry are in crisis. They must overcome multiple challenges to resources such as competition for the use of maritime space (especially from recreational uses), competition for putting products on the market, reduced stocks of certain species, the deterioration of coastal ecosystems as a result of anthropic pressure and the impacts of climate change (rising water temperatures and acidification, proliferation of invasive species). The need to define standards for the sustainable development of fishing activities in the Mediterranean therefore requires greater consideration of biological, historic and human data which influences the maintenance, adaptation and diversification of small-scale artisanal fishing occupations.

As a result, several avenues must be explored:

- Assess the impact small-scale fishing occupations have on the resource and the ecosystems and study with a historical perspective the adjustment of fishing communities to fluctuations in the resource, to market demand and to changes in society.

- Explore the opportunities offered by unexploited native, non-native and invasive species to help sustain the development of coastal fishing (food or biotechnological potential, creating value from products, resource management methods and professional training for fishermen, etc.).
- Understand heritage-related practices and know-how linked to artisanal fishing to enable ancient practices to adapt to the current context and promote the rich cultural heritage of Mediterranean fishing, especially in terms of eco-tourism.
- Develop methods geared to measuring the impact of recreational uses, especially the growth of leisure fishing which is starting to compete with small-scale artisanal fishing.
- Design regulations adapted to artisanal fishing, enabling it to maintain its versatility while respecting sustainable fishing principles, especially by linking it with the development of marine protected areas.

Support the development of sustainable Mediterranean aquaculture

Aquaculture has become a major industry in the Mediterranean with the pioneering development of shellfish farming during the first half of the 20th century, followed by marine fish farming in the 1970's. Today, aquaculture production in neighbouring countries in the Mediterranean (1.7 million tonnes in 2008) has exceeded that of caught fish and its growth should continue at a steady pace for decades to come. This rapid (and sometimes illegal) growth in the Mediterranean is preoccupying. It can be the source of conflicts of use and pollution phenomena, salinization of low-lying land, biodiversity loss, etc. Developing sustainable aquaculture is based on adopting an ecosystem approach that seeks to optimise the supply of commercial services (production of foods or substances of economic interest and cultural heritage for tourism, etc.) while ensuring the long-term future of services engaged for aquaculture production (water quality, producing seed/juveniles, etc.).

To meet these objectives, research must focus on:

- Farmed organisms (the genetic architecture of traits of interest, physiology of sexual development and biological bases of domestication);
- Their systems of production (integration in the environment, design of "mixed-farming" systems to minimise impacts or even improve the ecological footprint);
- Microbiological engineering to try to alter the digestive capacities of farmed marine animals to plant-based foods and developing innovative aquaculture foodstuffs;
- The socio-economic development and governance of the industry (foresight analysis, new tools and management methods).



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Reducing disturbance caused by maritime activities in the Mediterranean

Regulatory and technological innovations will be required to reduce the impacts of human activities in the Mediterranean Sea (reducing waste and chemical, noise and light pollution, preventing the transport of exotic species, restoring degraded habitats, etc.). In meeting this need, ecological engineering and eco-design are emerging sectors in the coastal environment. Eco-design seeks to reduce the environmental impacts of products throughout their life-cycle. Ecological engineering, on the other hand, is based on the use of species, communities or ecosystems with the aim of guiding environmental processes in a way that favours society and is compatible with maintaining ecological balances. It combines design, study and monitoring, project management and construction based on ecological engineering principles.

Among the fields of research judged to be a priority in this field in the Mediterranean, we can refer to:

- The design of sustainable coastal constructions and the co-design of facilities with multiple uses such as marinas or offshore wind turbines. This involves analysing the stakeholder network as well as their interactions, legal means and economic incentives to favour “responsible” construction (e.g. the introduction of labels like “Blue coast”, or “Blue Mediterranean island”) and technological innovations too.
- The knowledge and control of ecological mechanisms and the way ecosystems work which helps in restoring degraded habitats, or creating artificial ones.
- Developing alternatives to current procedures tackling marine fouling deposition on submerged structures (anti-fouling paints) which have a high ecological impact given the density of maritime traffic in the Mediterranean as well as being a major economic issue.



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Developing the “blue biotechnologies” of the future

Technological progress enables increasing access to knowledge about the marine environment and opens the way to discovering and exploiting new biological marine resources. These can be the target, or source, of many biotechnological applications with proven or potential economic interest (production of food, energy and materials, the extraction of molecules of pharmaceutical or industrial interest, the development of new processes, etc.). In particular, unicellular phototrophic organisms present high photosynthetic yields and great metabolic plasticity without requiring arable land or fresh water. Marine micro-organisms are a source of secondary metabolites and specific bioactive compounds. They can be cultivated on a large-scale and at low cost. The development of “omic” technology provides unprecedented access to explore Mediterranean microbial biodiversity. Marine macro-organisms also present significant potential for molecules of interest.

There are nevertheless numerous challenges to overcome to uncover this potential in the Mediterranean and exploit it sustainably. These include isolating, characterising and selecting the most promising strains as well as describing the biosynthesis pathways of the molecules of interest, optimising cultivation techniques for phototrophic organisms to maximise productivity while minimising energy costs, industrialising production processes and reducing costs and environmental impact.

Assessing and defining scales for structuring and managing resources and uses to improve their governance

Despite there being a long history of exploitation and management practices of marine resources by Mediterranean civilisations, the operational implementation of current management measures often appears to fall short while their effectiveness is not always demonstrated. Fisheries management (largely mono-specific) has not prevented over-fishing and the provision of marine protected areas has not enabled the functional dimensions and dynamic aspects of biodiversity to be effectively preserved (*see p. 2*). These management measures are often delineated in space, not only for practical reasons (it is easier to control a defined geographical space), but also because of governance rules (the Mediterranean is divided into states, regions and exclusive economic zones, etc.). A key factor in the effectiveness of management measures is therefore based on how compatible their spatial scales are with those of the uses and resources that they attempt to regulate. These observations suggest step-by-step research operations focused on the spatial dimension, *i.e.* defining the spatial-temporal structuring scales of ecosystems, mapping uses and management systems, analysing the congruence between the functional structuring scales of resources, uses and governance to make current management measures more effective.

Identifying spatial-temporal scales in which ecosystems function by cross-referencing habitat distribution and connectivity

The sustainability of an ecosystem's operation is based on the persistence of those species forming it. The functions ensured by this community of organisms (likely to provide ecosystem services) are necessary to maintain the ecosystem itself but can also be exploited by humans. The management framework put in place can therefore address various objectives in connection with the

conservation of ecosystems and biodiversity and maintaining productive functions exploited by humans. The persistence of a species means that it can complete a full life-cycle by sustaining its abundance (generational renewal). In marine environments, most species have a complex life-cycle, occupying distinct habitats at various stages of their lives. Consequently, the spatial-temporal scales of an ecosystem can be defined by the scales of successive habitats occupied during their life-cycle by the individual species forming the functional community and the scales of transfer of individuals between these habitats (connectivity) which enables the community to be sustained.

To evaluate the persistence of these functional communities and test the impact of several conservation scenarios, the identification of spatial and temporal scales of an ecosystem requires the following aspects to be included in mechanistic demographic models:

- Identifying an ecosystem's functional community, *i.e.* specific composition, trophic relations and spatial-temporal distribution (developing specific methodologies, collecting spatialised data and using conceptual models to describe the way it functions).
- Identifying species habitats forming the functional community at different stages of their life-cycle. For pelagic habitats, this means assessing the relevance of water body descriptors obtained from satellite images. For benthic habitats in hard substrates, it involves assessing the relevance of descriptors on the nature of the sea floor. For mesopelagic habitats, it is necessary to develop dedicated observation strategies.
- Characterising the transfer of individuals between these habitats (connectivity), *i.e.* identifying the traits controlling species dispersion at the pelagic larval phase, developing a multi-level and multi-scale connectivity approach with sufficient spatial and temporal resolution.





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Identifying spatial-temporal scales of organisation and structuring of uses and their governance modalities

Numerous stakeholders and/or institutions acting in an international, national/regional and local context are involved in the sustainable management of the Mediterranean Sea. On a regional level in the Mediterranean, the four main instruments are the Barcelona Convention, the General Fisheries Commission for the Mediterranean (under the auspices of the FAO), the ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area) and the CIESM (the Mediterranean Science Commission). All are linked by memoranda of cooperation enabling improved institutional connectivity and, as such, greater effectiveness. At a European sub-regional level, Europe exerts considerable influence on national and regional institutions to standardise structures and regulations.

Among the processes or key tools supported by the various regional, national or international institutions, we can mention the ecosystem approach (EcAp), integrated coastal zone management (ICZM), marine spatial planning and marine areas with specific management scope such as fishing and navigation or conservation and protection (e.g. Natura 2000 at Sea, Marine Protected Areas).

The spatial-temporal scales of organisation and structuring of uses, together with their modes of governance, can only be defined based on understanding and analysing historic ways of governing this semi-enclosed sea as defined in the present-day Law of the Sea (Article 122 of United Nations Convention on the Law of the Sea) and the ways states can intervene in their waters. These include mandates, programmes and various intervention levels of instruments, institutions and processes involved, the tools used and their effectiveness and finally, the impact of human activity and sensitivity of ecosystems, especially to the combined effects of various impacts.

A significant step would be to:

- Analyse the links between these instruments and administrations at a Mediterranean level (institutional connectivity) and assess the compatibility of governance methods currently in place in different countries (European / non European), taking into account the anticipated replacement of international waters by exclusive economic zones.
- Survey, map and monitor uses, institutions and areas of governance across the Mediterranean Basin, taking into account the intensity of activities and human pressures exerted on different environments and their sensitivity to cumulative impacts.

Improving current management measures

A strategy to improve management measures must be initially based on assessing the effectiveness of current measures in relation to set targets. However, these assessments are relatively rare and difficult to implement. There can be many reasons for their limited effectiveness. These range from the failure to apply measures properly (due to a lack of control, their non-operational nature and a lack of take-up by the users, etc.) to a lack of knowledge about uses and/or resources (for example, fishing stock renewal rates or trophic relationships at the base of ecosystem management) leading to a mismatch between management measures and the functioning of the system. In addition, the need for a more operational application for the entire Mediterranean Basin involves consultation, collaboration and cooperation between neighbouring countries and consultation and dialogue between stakeholders. The proposed measures must rely on the institutions in place. This includes the European Marine Strategy Framework Directive (EMSF), the Mediterranean Action Plan (MAP – as part of the Barcelona Convention) and the General Fisheries Commission for the Mediterranean (under the auspices of the FAO), etc. Furthermore, there are several types of governance at a global level following a gradient between two extremes. These range from a “bottom-up” management style like the Japanese model, based on a maritime register with controlled joint-management (close to *Prud’homies* or *Cofradías* in some Mediterranean regions) to “top-down” type management like the Anglo-Saxon model based on federal hyper-control and policing.

This leads to the following priorities:

- Conduct pilot projects in the Mediterranean to assess how applicable these management models are in terms of environmental governance and ecological management of ecosystems.
- Develop a “maritime” method to assess ecological functions (even ecosystem services) using a standardisation approach for indicators and metrics, based on indicators in the Water Framework Directive (WFD) and the EMSFD, with the creation of reference points (atlas of reference standards for functions/services) to evaluate the success of management measures.
- Formulate national and international legal and regulatory proposals to better supervise and monitor sources of pollutant discharges which are sometimes located far from national observation and inspection facilities (assessing the cost of restoring ecosystems, defining levels of responsibility of polluters as well as their financial implications in the full chain of treatment and clean-up based on the “polluter-pays” principle) and to limit the introduction of exotic species (analysis of methods to develop, implement and control international law on conventions like the Ballast Water Management Convention – BWM).

Monitoring changes and developing foresight modelling and analysis capabilities required for decision-making and fostering adaptation capacities

Maintaining ecosystem services provided by the Mediterranean Sea appears vital for food security, economic growth and the future well-being of neighbouring populations. Environmental and social changes are particularly rapid in the Mediterranean and it is essential to have the adequate monitoring and follow-up tools and to build prospective analytical capacity to better understand the vulnerability of coastal societies and services provided by the sea when faced with the changes taking place. These tools will help anticipate the future of these services and alter management methods to ensure their sustainability while promoting the ability of societies to adapt in both the north and the south.

Generating data, designing indicators and organising collection networks

A great deal of data is collected at sea and around the Mediterranean region by various types of stakeholders in widely different settings. Whether related to society and the economy, or the physical and biological environment, they remain scarce and not always accessible, compatible nor interoperable, even though offshore marine environment observation systems have now begun an integration process to better meet research and operational oceanography needs. Nevertheless, the lack of systematic *in situ* observation in the south of the basin compromises the monitoring of important parameters to understand how the whole basin functions in general as well as tracking changes. Better organisation, sharing and standardisation of this data would greatly benefit progress in scientific knowledge, to create useful guidance information for managers and decision-makers and for more effective monitoring and warning systems. In the Mediterranean, these concepts take on their full meaning given the coherence of this geographical space and the multiple challenges centred on it:

■ **In terms of collecting source data:** Observations are made from space but also *in situ* both on land, in the water column and on the seabed. This involves significant technological developments (satellite resources, automated devices, data transfer and “omic” techniques, etc.).

||| **These tools must enable both effective environmental monitoring (coastal risks, early detection of invasive or toxic species and water quality) and the development of joint data-model approaches to better understand the way the Mediterranean Basin functions and to track its evolution.**



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■ **In terms of organising data collection systems:** These technological developments make it possible to multiply data sources. The use of platforms of opportunity (ships, crowdsourcing, marine protected areas, etc.) is well-developed in some European seas, but remains a challenge in the Mediterranean, especially in the south. The observatories begin by organising themselves and pooling their data to cater for needs and services, although work still needs to be done to boost the interoperability and integration of measuring platforms to cover the entire range of spatial-temporal scales required.

||| **The Mediterranean Sea’s characteristics (dimensions, accessibility) make it possible to envisage a high level of performance from observation systems, particularly the creation of a network of pilot sites for marine observation (kind of Long Term Environmental Research observatories) throughout the basin to address scientific challenges (notably covering the main eco-regions see p.3) as well as specific socio-economic features enabling complementary and comparative work to be conducted on a north-north north-south and south-south cooperative basis by pooling methods, data, models and techniques for a coordinated approach to the Mediterranean region.**

■ **In terms of data processing and analysis:** These technological developments also generate steady growth in the volume and complexity of databases.

||| **Although questions linked to “big data” and “data mining” form a scientific field in their own right, scientific research in the Mediterranean has to deal with it in its most complicated aspects linked to the strong multi-dimensional nature and wide range of data collection facilities. Furthermore, exploiting collected data is made easier by the use of synthetic indexes. Although these are well-developed for climate or continental land sciences, they are much less so for marine sciences where efforts must be continued to develop physical, biochemical or biological indexes.**

Using modelling to understand the past state of the Mediterranean Sea and to anticipate its future

One of the current challenges for research is to develop models based on predictions for climate change and economic scenarios which make it possible to assess impacts on a regional scale. Nevertheless, one of the inherent limitations of models describing complex systems lies in the difficulty to comprehend their overall behaviour, their strengths and weaknesses, their validation and the degree of uncertainty in their outputs.

One of the ways of addressing these issues is to undertake a coordinated cross-comparative exercise of impact-models at different spatial and temporal scales for different types of models. This coordinated and integrated exercise can be carried out by French and European partners and by the entire basin, involving both northern and southern shores.

These types of exercises have already been conducted in the Mediterranean for continental-scale climate change impacts (hydrological regime and overtopping), but never for regional seas. This significantly limits the scope of oceanic impact studies on global changes in the Mediterranean (biogeochemistry, biodiversity, ecology, fisheries, tourism and transport, etc.).

Another challenge consists of describing the past state of the ocean as precisely as possible to understand its variability and re-constitute its evolution. This challenge can be met by re-analysing old data with current models. Developing a re-analysis exercise draws on scientific methods that provide a realistic and coherent description (on both finely-detailed and large scales) over a period of 10 years to reproduce slow movements at depth and the rapid surface layer movements while being compatible with models describing the physics and different scales to make the necessary couplings.

Numerous obstacles must be overcome to achieve these targets in terms of modelling (improving ocean models as well as their parameterisations and couplings, especially physical-biogeochemical couplings), data assimilation (better characterising and analysing of forecasting errors in models and adopting probability-based approaches) and IT resources (which can constitute a limiting factor for re-analysis exercises).

Building scenarios to explore the future of resources and uses in the Mediterranean

The scientific community must have a long-term scientific strategy boosting its ability to provide expertise tailored to the marine resources ecosystem approach. Recently, the ecosystem approach to fisheries (EAF) significantly transformed the thinking about

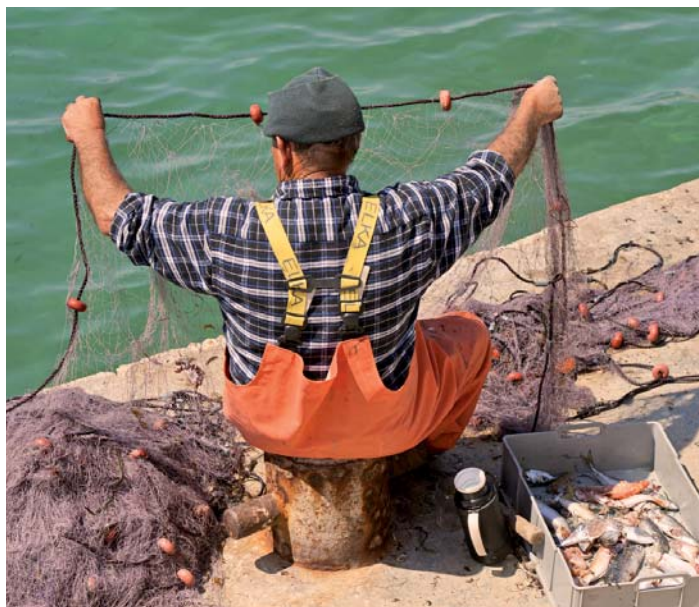
marine fishery resources. Numerous scientific conceptual frameworks now make it possible to consider its effective implementation, so much so that the United Nations Organisation used this approach to define concrete targets for fishing even though the introduction of the EAF in the Mediterranean is still in its infancy. Monitoring and managing other services provided by the Mediterranean Sea could therefore be largely inspired from methodologies and approaches developed to manage fish stocks whereas observation, forecasting and the governance of other services could, in turn, contribute to the EAF. Indeed, knowledge about marine environmental services is fragmented and lacks integration. Yet, most uses of the sea generate environmental disturbance while also suffering from these alterations. The vulnerability of the main services provided by the Mediterranean Sea to future environmental changes is currently unknown and its economic impact has not been calculated. The same goes for the costs and benefits of potential management activities concerning these services. As per the model for managing fish stocks, it therefore seems necessary to have performance indicators on the state of environmental services which make it possible to establish the basis of a future ecosystem management process of activities in the Mediterranean.

The tools for such a sustainable management system will not emerge without a collaborative and multi-disciplinary approach combining ecology, sociology, economy and governance, based on in-depth knowledge of ecosystem processes and their uses, including the development of normative medium-term scenarios. These would then make it possible to explore the future of Mediterranean marine ecosystems as well as possible paths leading to desirable goals, using various environmental, economic and social projections, to result in recommendations for decision-makers and managers.

Promoting the abilities of coastal societies to adapt to global changes

Lastly, it is worth considering the abilities of coastal societies to deal with systemic and multi-dimensional risks linked to the impacts of global changes which they are going to face.

Such analyses must include the territorial changes from both a socio-economic standpoint (land use, demographic structures and the growing desire of people to live in these areas, etc.) and a geographical one (evolution of the morphology in coastal areas, the increasingly artificial nature of coastlines, etc.) while taking into account contrasts between the north and south shores of the Mediterranean. They will be based on an assessment of adaptation measures introduced in the Mediterranean at various levels as well as how these strategies, with their different objectives, connect. They will also give consideration to threshold effects (economic, social, environmental, etc.) from which adaptation becomes difficult or very costly.



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Organisation

A **steering committee** made of 19 members:

■ **5 French research institutes:**

BRGM, CNRS, IFREMER, INRIA, IRD

■ **5 French universities:**

Aix-Marseille Université, Université de Montpellier 2, Université de Nice – Sophia Antipolis, Université Pierre et Marie Curie, Université du Sud Toulon – Var

■ **3 French interface structures:**

Agropolis International, Pôle mer Méditerranée, Confédération Nationale de la Pêches Maritimes et des Élevages Marins (CNPMM)

■ **2 foreign institutes:**

Bibliotheca Alexandrina (Egypt), Dokuz Eylül University (Turkey)

■ **4 international structures:**

Plan Bleu, Groupement Inter-académique pour le Développement (GID), Réseau Maghrébin des Instituts Nationaux de Recherche Halieutique, International Union for Conservation of Nature (IUCN)



A **cross-cutting, pluridisciplinary experts group**, made of around 40 experts in the different fields of the project, in charge of analyzing the collected foresight studies, designing and guiding the thematic working groups and synthesizing their work.

Five thematic working groups, each consisting of around 15 experts, in the following areas:

- Characterizing and reducing coastline vulnerability to global changes and natural hazards
- Devising the use of Mediterranean Sea goods and services for a sustainable development in the region
- Controlling the effects and consequences of maritime and terrestrial activities impacting on the Mediterranean Sea
- Assessing and defining scales of organisation and management for resources and uses
- Developing and organising data collection and management, interdisciplinary modelling and simulation

How it works

17 workshops organised over 18 months (April 2013 to September 2014), in 4 steps:

- **Phase 1:** inventory and synthesis of existing forward-looking studies
- **Phase 2:** setting-up and framing of the thematic working groups
- **Phase 3:** identification of priority research areas within each thematic working group
- **Phase 4:** cross-cutting analysis of the research priorities developed by each group leading to the final report

130 experts involved (including 18 foreigners)

in all the fields investigated (physical oceanography, biology, ecology, social sciences...), from 47 institutions or organizations (from 10 countries: France, Italy, Spain, Greece, Algeria, Morocco, Tunisia, Egypt, Turkey, Belgium).

A **final report** of 150 pages and about 100 foresight studies fact sheets compiled, available online:

www.agropolis.org/arp-mermed

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■ **Layout:** Olivier Piau, *Agropolis Productions*

■ **Print out:** *Les Petites Affiches* (Montpellier, France)

■ **Publication:** September 2014



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