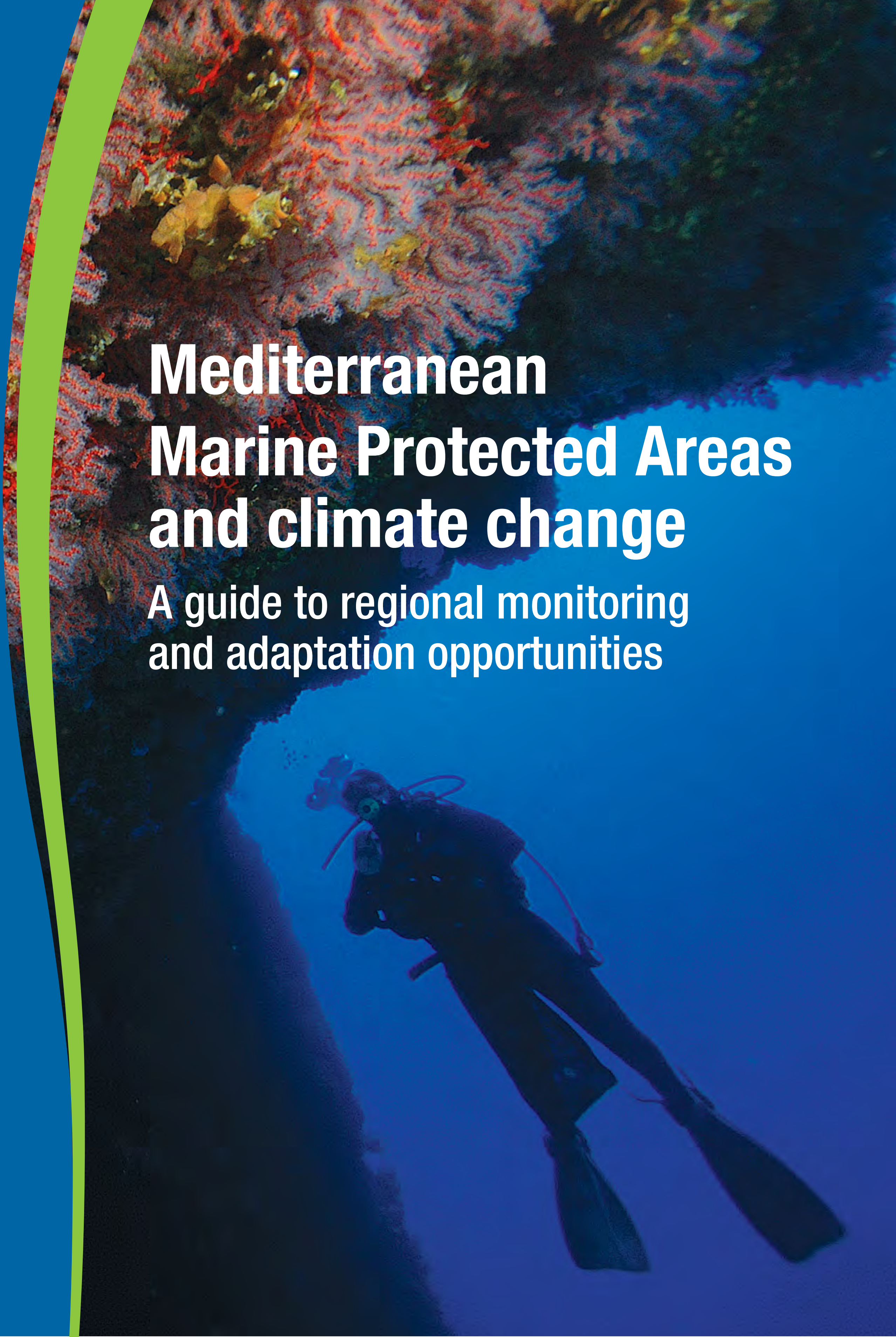
MedPAN COLLECTION

Mediterranean Marine Protected Areas and climate change

A guide to regional monitoring and adaptation opportunities



IUCN

UNEP

MAP

RAC/SPA

Publisher: IUCN Centre for Mediterranean Cooperation, UNEP/MAP-RAC/SPA

Coordination: Maria del Mar Otero, IUCN Centre for Mediterranean Cooperation (IUCN-Med)
Daniel Cebrian, Regional Activity Centre for Specially Protected Areas (UNEP/MAP-RAC/SPA)

Citation: **Otero, M., Garrabou, J., Vargas, M.** 2013. *Mediterranean Marine Protected Areas and climate change: A guide to regional monitoring and adaptation opportunities.* Malaga, Spain: IUCN. 52 pages.

Produced by: IUCN Gland, Switzerland and Malaga, Spain

ISBN: 978-2-8317-1624-4

Layout and design: Nacho Gil / www.parentesis.net

Printing: Solprint, Mijas (Malaga)

Cover photo credit: J. Garrabou

Printed on chlorine-free ecological paper.

Available from:

IUCN Centre for Mediterranean Cooperation
C/Marie Curie 22
29590 Campanillas, Malaga, Spain
Tel: +34 952 028430 - Fax:+ 34 952 028145
www.iucn.org/mediterranean
www.iucn.org/publications

MedPAN Association
www.medpan.org

MedPAN COLLECTION

Mediterranean Marine Protected Areas and climate change

A guide to regional monitoring and adaptation opportunities

Maria del Mar Otero
Joaquim Garrabou
Manuel Vargas

MedPAN COLLECTION

Editor

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges.

IUCN is the world's oldest and largest global environmental organization, with more than 1,200 government and NGO members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 45 offices and hundreds of partners in public, NGO and private sectors around the world.
IUCN Centre for Mediterranean Cooperation was opened in October 2001 with the core support of the Spanish Ministry of Agriculture, Fisheries and Environment, the regional Government of Junta de Andalucía and the Spanish Agency for International Development Cooperation (AECID). The Centre's mission is to influence, encourage and assist Mediterranean societies to conserve and use sustainably the natural resources of the region and work with IUCN members and cooperate with all other agencies that share the objectives of the IUCN.

www.iucn.org/mediterranean

This guide was prepared by the IUCN Centre for Mediterranean Cooperation within the MedPAN North project funded by the European Regional Development Fund, and the Regional Activity Centre for Specially Protected Areas (UNEP-RAC/SPA) biannual programme, funded by the Mediterranean Trust Fund of the Barcelona Convention.

MedPAN North is a transnational cooperation project to enhance Management Effectiveness of Marine Protected Areas in the Northern Mediterranean, conducted in the framework of the MedPan network. www.medpannorth.org

The Spanish Agency for International Cooperation and Development (AECID) provided financial support through the project "Preserving biodiversity and the sustainable use of marine and freshwater resources in Mediterranean high priority areas".

Acknowledgements

Workgroup members

This guide is a product of the expert workgroup discussions on climate change impacts and a monitoring assessment conveyed by IUCN-Med and RAC/SPA. We are grateful to all of them for their advice and guidance:

Aybars Altiparmak, Turkish Ministry of Forest and Water Affairs, Turkey
Marilena Aplikioti, Ministry of Agriculture, Natural Resources and the Environment, Cyprus
Sami Ben Haj, Cabinet Thétis, Tunisia
Jose Carlos García Gómez, University of Sevilla, Spain
José Antonio García Charton, University of Murcia, Spain
Bella S. Galil, National Institute of Oceanography Israel Oceanographic & Limnological Research, Israel
Mª del Carmen García Martínez, Instituto Español de Oceanografía, Spain
Giuseppe di Carlo, WWF Mediterranean Programme Office, Italy
Joaquim Garrabou, Institut de Ciències del Mar, Spain
Dan Laffoley, IUCN's World Commission on Protected Areas
Christophe Lejeusne, Estación Biológica de Doñana-CSIC, Spain
Piero Lionello, University of Salento, Italy
Melina Marcou, Ministry of Agriculture, Natural Resources and Environment, Cyprus
Paula Moschella, CIESM
Petra Rodic Baranovic, State Institute for Nature Protection, Croatia
Maria Salomidi, Institute of Oceanography, Hellenic Centre for Marine Research, Greece
Nadia Suda Lanzon, Malta Environment and Planning Authority, Malta
Leonardo Tunesi, ISPRA, Italy
Robert Turk, Institute of the Republic of Slovenia for Nature Conservation, Slovenia
Manuel Vargas, Instituto Español de Oceanografía, Spain
Marcello Vichi, Euro-Mediterranean Centre for Climate Change, Italy

We also thank Diego Kersting (Marine Reserve of Columbretes Islands), Dimitriadis Charalampos (National Marine Park of Zakynthos), Mark Walton (University of Wales, UK), Boris Weitzmann (Medes Islands MPA), Elena Diaz-Almela (Life Posidonia Project Andalucia) and Jose Carlos García Gómez (University of Sevilla) for their contributing materials and discussion. A special acknowledgement is extended to Dan Laffloley (IUCN-WCPA), Alain Jeudy (IUCN-Med), Jose Antonio Charton (University of Murcia), Sami Ben Haj (Thétis, Tunisia), Paula Moschella (CIESM) and the Marine Reserves of Spain for their time and support for this work. Gratitude also to Sonsoles San Roman who helped pull this guide together in its final phase.

The MPAs of Miramare and Tavolara (Italy), Zakynthos (Greece), Port-Cros and Cap d'Agde posidonies natura 2000 site (France), Cap de Creus and the MPAs from Eastern Andalucian region (Spain) with their respective management organizations and agencies, also helped bring this guide to life by providing local examples of current work, findings and ideas.

The MedPAN Association and WWF-France (leader of the MedPAN North Project) deserve our special gratitude for their support.

Hisarönü Bay, Turkey. Photo: A. Can - www.alpcan.com

Table of contents

Context and aim of this guide

Increasing greenhouse gas concentrations are expected to have a significant impact on world climate over a short time scale. The world's atmosphere and oceans are warming, and the most immediate effects of this on the marine environment include rising sea levels, higher seawater temperatures and acidification, more frequent extreme events and changes in oxygen levels or deoxygenation processes (IPCC Fourth Assessment Report, 2007). Due to these pressures and ecosystem responses, climate change is now considered a major driver of biodiversity change and loss. Its importance has been highlighted by several international conventions and treaties, including the Convention on Biological Diversity and the Kyoto Protocol.

The latest assessment by the Intergovernmental Panel on Climate Change (IPCC) found that the Mediterranean will be strongly affected by climate change over the course of this century. The oceanographic and physical aspects of climate change in the Mediterranean have been described in many reports and scientific studies, although uncertainty remains about the degree of physical and chemical change expected at sub-regional and local scales (Lionello, 2012).

Despite its importance for biodiversity conservation, little is yet known about the biological impact of climate change on Mediterranean coastal and marine biodiversity at all levels, as much of the current understanding is based on models, very few studies and discontinuous data mainly from the north-western part of the Mediterranean Sea (CIESM, 2008; Lejeusne *et al.*, 2009; Coll *et al.*, 2010; UNEP-MAP-RAC/SPA, 2010). Basin-wide monitoring and information gathering on key Mediterranean species and ecosystems therefore remains crucial for mitigating climate change effects and adapting to them. Furthermore, the region's marine and coastal environments are increasingly threatened by the impacts of a growing population and rising demand for natural resources. The combination of these pressures is likely to exacerbate the consequences of climate change.

To address the impact of climate change on biodiversity, the Strategic Action Programme for the Conservation of Biological Diversity (SAP BIO) in the Mediterranean Region set up under the Barcelona Convention Mediterranean Action Plan (MAP) in 2003, was updated on climate change issues in 2009; In addition, the Almeria Declaration was adopted at the 15th Ordinary Meeting of the Contracting Parties to the Barcelona Convention in 2008 to provide an action framework for Mediterranean countries. From a coastal perspective, the Mediterranean ICZM Protocol[1] also provides a platform to mainstream climate change adaptation into the policies and governance of coastal management. At EU level, the Commission recently adopted a Strategy on Adaptation to Climate Change in April 2013 to promote greater coordination and information sharing among Member States, and to ensure that adaptation considerations are addressed in all relevant EU policies.

Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007).

Basin-wide monitoring has to be developed to assist with the above protocols and strategies. It may be easier to observe climate change effects in protected areas as they are normally better shielded from anthropogenic impacts than other areas, and therefore there is likely to be less interference from other causes of change. In this regard, Marine Protected Areas (MPAs) in the Mediterranean can play an important role as 'sentinel sites', where the effects of climate change can be studied and management strategies can be developed to adapt to, and wherever possible counter, such negative effects. Individual MPAs and the Mediterranean MPA network therefore have an important role to play in enhancing our understanding and helping to develop strategies to mitigate climate change effects.

Not only can climate change be monitored in MPAs throughout the Mediterranean as a way of improving our understanding and management of its effects, but it is also becoming a growing challenge to the management of the MPAs themselves. There are currently 675 MPAs in the Mediterranean, covering a total area of almost 114,600 km², about 4.6% of the Mediterranean Sea, or just 1.1% if we exclude the Pelagos Sanctuary (87,500 km²), which alone accounts for 3.5% (Gabrié *et al.*, 2012). Direct evidence of the effects of climate change is already being observed at some sites (Bensoussan *et al.*, 2010; Crisci *et al.*, 2011; Cebrian *et al.*, 2011). However, climate change is still not explicitly incorporated in most MPA management plans and future assessment of MPA performance will need to take these effects into account.

Overall, at the Mediterranean regional level, few programmes aim to assess the impacts of climate change on marine biodiversity or to support adaptation planning in MPAs and other areas of conservation value. In a global context, Marine Protected Areas increase the adaptive capacity of coastal and marine communities and buffer potential climate change impacts. Building the capacity of MPAs through data collection, monitoring and awareness-raising about climate change contributes to the efforts being made across the region to

1. PAP/RAC. 2007. ICZM Protocol in the Mediterranean (signed in Madrid on 21 January 2008)

Cabo de Gata-Nijar Natural Park, Spain. Photo: A. Barrajon

improve information and adapt to change. Moreover, information about the impact of climate change on biodiversity will provide the evidence required to justify investment in mitigation and adaptation measures. Finally, climate change monitoring programmes can furnish valuable baseline information that can feed into current efforts to evaluate the impact of climate change by the end of the current century. Since the impact risk will depend on the areas considered, these efforts will allow resources to be allocated to those areas that are expected to suffer the most.

Mitigation of climate change: It refers to those response strategies that reduce the sources of greenhouse gases or enhance their sinks, to subsequently reduce the probability of reaching a given level of climate change. Mitigation reduces the likelihood of exceeding the adaptive capacity of natural systems and human societies.

Climate change needs to be taken into consideration in all MPA management plans. Incorporating it into MPA monitoring does not require expensive equipment or highly technical abilities. It can further help managers understand the vulnerabilities and diverse responses of their marine communities at different sites and revise MPA zoning and management accordingly. There may also be opportunities to include monitoring actions in MPA management plans and to link them to existing climate and oceanographic monitoring programmes in the Mediterranean region and Europe.

Within the framework of the MedPAN Association and the MedPAN North project, IUCN Med in collaboration with RAC/SPA is addressing the impact of climate change on Mediterranean MPAs with the long-term aim of building a strategy for assessing and minimizing the risk posed by climate change to marine and coastal ecosystems. This work will build towards the medium-term goals of the SAP BIO Programme at the Mediterranean level (UNEP-MAP-RAC/SPA, 2009), which include improving coordinated actions across Mediterranean MPAs, informing adaptive approaches to climate change for effective MPA management, initiating a climate alert warning system at different geographical scales and reducing vulnerability within MPAs.

A key goal of this programme is to identify the most appropriate parameters for monitoring climate change impacts on biodiversity in these MPAs at a Mediterranean scale. That will enhance our understanding of how marine communities respond and help managers assess the condition of their sites and the environmental changes that are occurring there.

To address this goal we organized several meetings to bring together climate change researchers, biodiversity scientists and protected area stakeholders covering a wide range of expertise. The resulting discussions and the work conducted since then have been compiled into this guide for Mediterranean MPA managers. It aims to give some guidance on how to measure the impact of climate change on the marine biodiversity of protected areas and how to improve planning for the mitigation of future impact. It also summarizes the most important threats to and effects on Mediterranean marine biodiversity that have been observed to date and outlines the many uncertainties that still exist in understanding ecological responses to climate change. The guide is thus intended as an aid and managers may choose to use any of the several different monitoring plans and indicators outlined, depending on their particular circumstances and management objectives.

Impact of climate change on marine and coastal ecosystems

Global changes in climate

There is widespread agreement in the scientific community about the ongoing changes to the earth's climate (Trenberth *et al.*, 2007). The causes of this process are manifold: changes in land use and carbon emissions, alterations in both stratospheric and tropospheric ozone, aerosol emissions and other factors. Nevertheless, the main factor inducing global warming seems to be the emission of greenhouse gases. There are many of these gases — nitrous oxide, methane, CFCs, etc. — but it is the emission of carbon dioxide (CO_2) from the burning of fossil fuels that is primarily responsible for the rise in the planet's temperature.

Climate and sea warming

From the mid-19th to the beginning of the 21st century, the air temperature at the earth's surface increased by between 0.6 and 0.8°C, and this warming is expected to accelerate during the current century if mitigating measures are not put in place. The sea plays a key role in limiting this process as more than 80% of the heat absorbed by the planet accumulates in the world's oceans (Bindoff *et al.*, 2007). Because of the high specific heat capacity of seawater, sea temperatures increase much less than air temperatures. The thermal expansion of the oceans caused by rising temperatures and the global increase in seawater mass caused by the melting of continental ice are resulting in sea-level rise. In parallel, changes in precipitation and evaporation rates have also been observed, altering sea salinity.

CO_2 and ocean acidification

Furthermore, increased uptake of CO_2 emissions by oceans is changing seawater chemistry, decreasing the pH (increasing acidity or concentration of hydrogen ions H^+) and reducing the concentration of carbonate ions (CO_3^{2-}) by decreasing the saturation state of calcium carbonate ($CaCO_3$):

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow HCO_3^- + H^+ \longleftrightarrow CO_3^{2-} + 2H^+$$

This consequently has the potential to significantly affect shell and skeleton formation in many marine organisms, including some commercial shellfish species.

Global measurements indicate that average seawater acidity has increased by 30% since the beginning of the industrial revolution (equal to an acidification of 0.1 pH units), and the oceans are predicted to become progressively more acidic as they continue to absorb more carbon dioxide (Denman *et al.*, 2011). The major cause of ocean acidification is not the total amount of CO_2 entering the oceans but the fact that the rate of pH change is faster than anything experienced before.

Variable ocean circulation

Possible changes in atmospheric circulation, the position of high and low pressure systems and other factors could alter the main wind circulation patterns and affect the intensity and/or position of upwelling systems. These are places where wind action brings nutrients up to the well-lit surface layers of the sea, where they fertilize the water and support primary production, which forms the base of the marine food web.

Seawater temperature and salinity are the variables that control the density of the oceans. The natural variations in density at different latitudes of the earth result in what is known as the thermohaline circulation, which has been described as a giant conveyor belt that redistributes excess heat from equatorial and tropical latitudes. This mechanism is one of the main factors influencing the earth's climate, lowering temperatures at low latitudes and warming higher-latitude regions such as northern Europe. It has also been proposed that this mechanism of heat regulation could change drastically or even collapse in the future due to temperature and salinity alterations in the Polar Regions.

Thermohaline circulation: Ocean circulation driven by density differences caused by temperature and salinity.

Red star (*Echinaster sepositus*) in *Posidonia oceanica* seagrass bed.
Photo: J. C. Calvin, OCEANA

The changing Mediterranean climate

The changes briefly described above are not homogeneous around the world. Global changes should be understood as those which affect the whole planet, but not necessarily in the same way everywhere. Nor should mean changes averaged for the world's oceans be confused with specific changes operating on smaller spatial scales, such as those observed or expected in regions such as the Mediterranean. Salinity changes are an example. The alteration of the earth's hydrological cycle and the melting of glaciers and ice sheets are affecting the salinity of the oceans on a global scale, but, while salinity is expected to decrease at high latitudes, it will increase at lower latitudes with the reduction in precipitation and increase in evaporation.

The Mediterranean Sea is a good example of a region where particular and specific responses to global changes have been observed. Its relatively small size, high biodiversity, temperate climate and semi-enclosed nature make it a place where the effects of climate change will be most exacerbated. Its semi-enclosed nature prevents rapid water exchange and therefore makes it more sensitive to temperature and pH variations. Together with the high human pressure exerted by densely populated coastal areas, this makes the Mediterranean Sea an especially vulnerable place.

The region has also been recognized by the oceanographic community as a natural laboratory for the study and analysis of climate change, as some of the main processes controlling ocean circulation at a global scale are reproduced on a much more restricted scale in the Mediterranean Sea.

Sea warming

During the 20th and early 21st centuries, the surface seawater temperature of the Mediterranean has increased in a similar way to air temperature (Vargas-Yáñez *et al.*, 2010; Lionello, 2012): the sea's shallow waters have already warmed by almost 1°C since the 1980s. The temperature of intermediate waters, that is, those extending below the upper layer from depths of 200 m down to 600 m, has also risen.

Salinity and sea circulation changes

The salinity of intermediate and deep waters has also increased, apparently due to a combination of factors: decreasing precipitation, increasing evaporation and the damming of the main rivers draining into the Mediterranean Sea.

Surface seawater temperature: Water temperature between 1 millimetre and first metres below the sea surface.

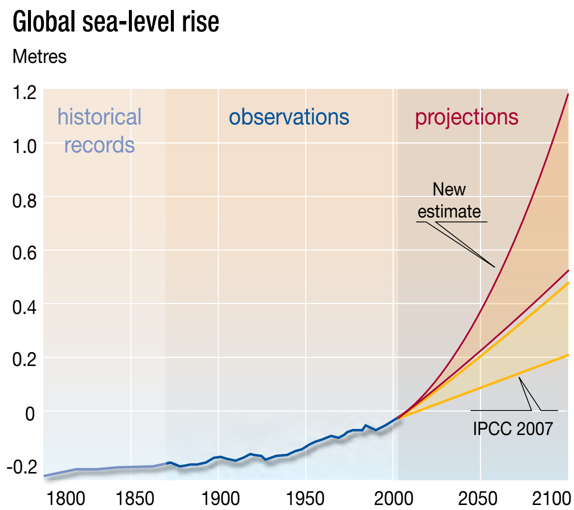
Scandola MPA, Corsica. Photo: J. Garrabou

The waters filling the deepest basins of the Mediterranean are renewed and ventilated almost every year by means of a process called deep-water formation. In this process, which has been reported to occur in the Gulf of Lion, the northern Adriatic Sea and the Aegean Sea, surface and intermediate waters with high salinity due to high evaporation rates are cooled in winter, thereby increasing in density and sinking to the deepest levels of the sea to mix and become part of the new deep-water masses.

The ongoing changes in temperature and salinity may reduce the formation of deep-water masses by affecting the duration, frequency and intensity of this process. As a result of local climate change, this may eventually have an impact on biodiversity (Pusceddu *et al.*, 2010).

Sea-level rise

The rise in sea level in the Mediterranean —which was lower than in the rest of the world in the late 20th century (from the mid-1960s to the mid-1990s) due to anomalous atmospheric pressures— has regained pace since then and seems to be accelerating at a similar rate to that observed throughout the world's oceans.



Source: Cazenave and Llovel, 2009.

According to the 2007 IPCC report, global average sea-level rise will vary from 18 cm to 59 cm by 2100. The IPCC models did not account for the accelerated melting of ice sheets in Greenland and Antarctica. Some of the latest research, however, estimates a global sea level rise of between 0.6 and 1.2 metres by 2100. *By Riccardo Pravettoni, UNEP/GRID-Arendal*

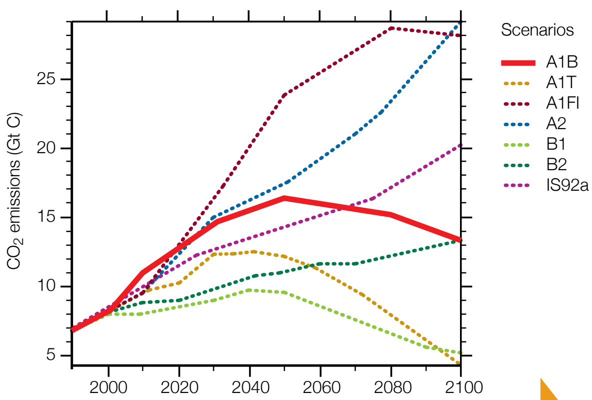
Modelling change

When dealing with climate change, we should consider projections instead of forecasts. For example, the weather or the state of the sea (waves, currents) can be forecast with some accuracy over a short period of days as they are subject to well-known physical laws. Projections, on the other hand, indicate that the outcome is conditional on some hypothesis about the future, such as the rate of CO_2 emissions in an externally prescribed economic scenario.

The evolution of the climate partly depends on physical laws, but also on variables which cannot be predicted with certainty, such as future greenhouse gas emission rates, the development and use of energy technologies, or the growth of the human population. Therefore, the Intergovernmental Panel on Climate Change (IPCC) has constructed different plausible scenarios for the evolution of these factors in order to project the future state of the climate.

The IPCC issues comprehensive reports every five to seven years, with the next one due out by the end of 2013. The reports summarize the state of scientific knowledge on climate change, and are used as the underpinning of international climate talks aimed at reducing greenhouse gas emissions

Computer-generated models have been built from these scenarios, the evolution of the earth's climate over the last century and the available observations to estimate how air and seawater temperatures, precipitation, salinity and other variables will change in the different scenarios considered (Christensen *et al.*, 2007).



Scientists use a range of scenarios based on various assumptions about future economic, social, technological and environmental conditions and alternative development pathways. A1B refers to one of the scenarios described in the Special Report on Emissions Scenarios prepared by the IPCC in 2000. It relates to a scenario with very rapid economic growth, peaking global population and balanced use of fossil and non-fossil energy sources.

Natural Volcanic CO_2 vents of Italy used to assess the response of communities to increased seawater acidity.

Photo: J. Hall-Spencer

The scenarios can provide good estimates of future greenhouse emissions and give information about the uncertainty associated with any particular climate model prediction.

A variety of models have been developed, from one-dimensional energy-balance models through models of intermediate complexity to fully coupled atmosphere–ocean general circulation models (AOGCMs), describing the atmosphere, oceans, sea ice and land, and possibly chemistry, the carbon and nutrient cycles and ice sheets. The level of uncertainty of each of them varies when the variables are projected into the future, producing a range of possible results. Nevertheless, global climate models rarely give adequate resolution for management on a regional scale such as the Mediterranean. For this reason, regional models are now being developed so that climate can be predicted in finer detail and at smaller spatial scales applicable to specific geographical regions in the Mediterranean (Lionello, 2012).

Regional climate models can currently make projections for spatial areas smaller than those considered in general circulation models, with spatial resolutions of 25 km or better, but this resolution is still too low for the management of protected areas. Given that the observational data needed to build these models is not yet available at high spatial resolution (Vargas-Yáñez *et al.*, 2012), the information currently provided by these models about the evolution of sites of special ecological interest is currently insufficient to aid in producing adaptation and conservation strategies for Mediterranean MPAs. For the future, regional models clearly need to improve if they are to provide projections that can serve this purpose.

Modelling efforts at high spatial resolutions (less than 1 km) might, however, be able to cope with the complex coastal hydrodynamic processes that exist in some MPAs and help to simulate climate change scenarios at smaller scales. This type of approach could provide managers with a clear picture of expected changes in temperature regimes, including summer stratification variations, in the areas for which they are responsible. Nevertheless, more research into management techniques and greater efforts to gather basic monitoring data will be needed to develop an understanding of how MPA environments might shift in response to climate change.

Projected change by the end of the century

Most of the models' outcomes for the different scenarios include a rise in air temperature over the Mediterranean region by the end of the 21st century. Comparisons of the projected temperatures with the averages for the first half of the 20th century show an increase of 2–5°C for the Mediterranean, with a mean of 3.2°C, which is higher than the global average (2.6°C). Climate projections also suggest an increase in the number, frequency and intensity of extreme warm air and water events across the region (see review by Di Carlo and Otero, 2012).

Precipitation (rain and snow) is expected to decrease in the Mediterranean area, particularly in summer, when the risk of drought will be higher. In the A1B scenario, precipitation will decrease by 25% in summer and 10% in winter by 2100, with major variations between the southern Mediterranean countries and regions such as Iberia, Anatolia and the Balkans.

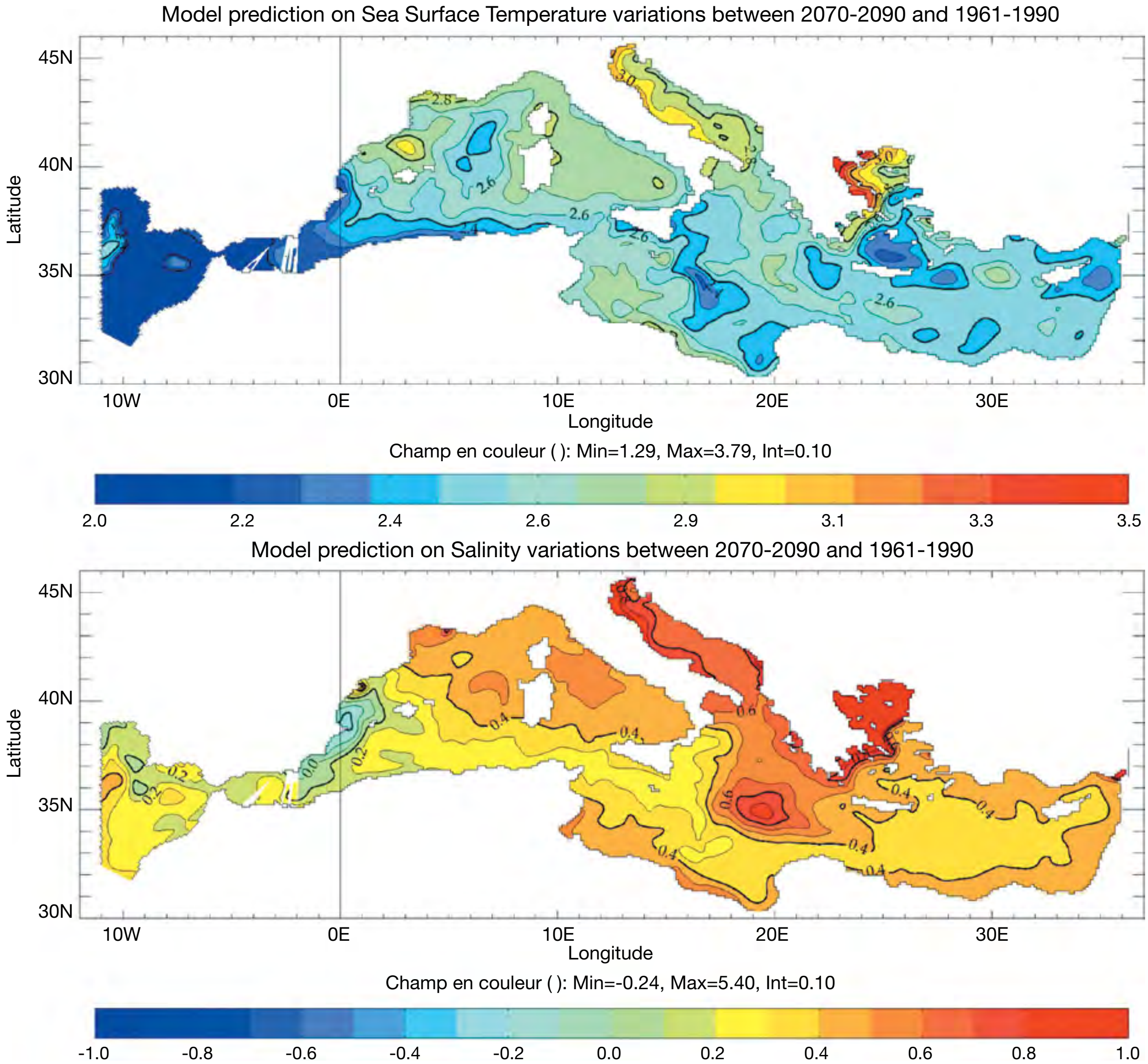
Table 1. Observed and expected marine climate changes in the Mediterranean as well as confidence levels (High, medium or low).

Mediterranean Sea	What is happening	What is likely to happen by the end of the 21st century	References
Temperature	Surface temperatures have risen by roughly 1°C	Surface temperatures will rise by a further 2.5°C on average by 2100, and intermediate and deep layer temperatures will rise as well (High confidence)	Lionello, 2012
Salinity	Increased by 0.05 ppt in intermediate and deep layers in the 20th century	Will tend to increase in surface, intermediate and deep layers; surface salinity could increase by 0.5 ppt by 2100 depending on freshwater inputs, ocean circulation and other factors with a higher increase in the Aegean and Adriatic seas (Medium confidence)	Vargas-Yáñez *et al.*, 2012
Sea-level	Mediterranean sea levels have been rising by 1–3 mm/yr	Temperature and salinity increases would have opposite effects on sea-level (Low confidence). Ocean temperature-driven sea-level rise during the 21st century could be between 3 and 61 cm, while salinity-driven sea-level change estimates between -22 and +31 cm.	EEA Report No 12/2012
Sea acidification	Ocean surface water pH has fallen by 0.1 pH unit, equivalent to a 30% increase in acidity	The Mediterranean Sea will continue to acidify with increasing CO_2 emissions. At global level it is projected to drop another 0.3 to 0.4 units by 2100 (to a pH less than 7.8) (Low confidence)	Denman *et al.*, 2011
Mediterranean circulation	No observed effects at the moment	Possible weakening and disruption of the thermohaline circulation (Medium confidence)	Li *et al.*, 2012 in Lionello, 2012
Coastal erosion	Impacts on estuarine, beach and deltaic coastal areas, with reduced sediment deposition	Expected to increase in the future due to the effects of sea-level rise and storms, particularly in autumn and winter (Low confidence)	Critto *et al.*, 2012; Sano *et al.*, 2010.
Upwellings and current intensity	No observed effects at the moment	Lower intensity (Low confidence)	Lionello, 2012

Temperature and salinity are expected to increase throughout the whole water column, that is, in the upper, intermediate and deep layers. Sea-surface temperatures are expected to be approximately 2.5°C higher by 2100. As a consequence of this general warming, deep-water formation and the ventilation (oxygenation) of deep basins could be reduced. The thermohaline circulation of the Mediterranean, with Atlantic waters entering through the Strait of Gibraltar and Mediterranean waters flowing out to the Atlantic Ocean, is also expected to weaken. In parallel, seawater salinity will become progressively higher by roughly 0.5 units over the next 100 years.

At this stage there are no widely accepted scenarios for the longer-term regional distribution of projected sea-level rise in the Mediterranean. Sea-level for a particular region might be quite different from the global mean. The contributions of ice melt and local factors such as local tectonic movements or storm surge together with temperature and salinity changes will affect the rise in sea levels around the Mediterranean coastline, from hardly any change to rises of many tens of centimetres.

Model prediction on sea surface temperature (°C) and salinity variations in the future climate (2070-2099) relative to the past climate (1961-1990). (From Lionello, 2012.)



Cabo de Gata-Nijar Natural Park, Spain. Photo: A. Barrajon

Impact of climate change on marine biodiversity

The Mediterranean Sea is considered one of the world`s biodiversity hotspots, where the impact of climate change together with other anthropogenic pressures could be most devastating (Lejeusne *et al.*, 2009; Coll *et al.*, 2010).

Climate change is already affecting its environment, ecosystems and species in many ways and evidence suggests that the impact will become more severe as climate change continues. Species may no longer be adapted to the set of environmental conditions where they live and will need to produce adaptive responses fast enough to keep up with the rapid pace of change (Somero, 2012). Individuals, populations or species may suffer severe mortality events, which ultimately could result in their local extinction, while others may migrate to more favourable areas or change their physiology to adapt to the new conditions. These effects in turn will lead to altered species interactions (predation, competition, etc.) and cascading effects, which will propagate at community and ecosystem levels and may significantly alter the structure and function of Mediterranean marine communities in the future (Hughes *et al.*, 2003; Doney *et al.*, 2012).

In addition, species have to cope with additional threats caused by human activities, some of which may act in synergy with climate change. The sum of these major disturbances is known as global change. The effects that the different stressors, and particularly their combination, have on marine organisms are currently poorly understood.

Direct effects of changes in ocean temperature and chemistry (mainly rising sea temperature and acidity) may alter the physiological functioning, behaviour and population growth of organisms, leading to shifts in the size, structure, spatial range and seasonal abundance of populations. Other climate-derived stressors, such as sea-level rise, changes to ocean circulation and mixing, or ocean deoxygenation, might also co-occur in time and space, increasing their simultaneous impact on marine communities.

Ocean deoxygenation: the global trend of decreasing oxygen levels as a result of ocean warming and increasing stratification

Many studies have revealed the substantial impact that climate change has on marine ecosystems and the Mediterranean Sea in particular (Hall-Spencer *et al.*, 2008; Coma *et al.*, 2009; Garrabou *et al.*, 2009; Azzurro *et al.*, 2011). Most of these works have focused on the effects of temperature and the response of organisms under high CO_2 concentrations, while the diminution of oxygen concentration has received less attention. The information available at present is based on observations in the field and from different in situ and ex situ experimental settings. In coastal habitats, where most Mediterranean MPAs are established, the main stressors liable to have an impact on the marine biota are temperature rise, the acidification of waters and decreasing oxygen concentration.

It is outside the scope of this guide to describe in detail all the known impacts on marine biodiversity resulting from the changing climate (see reviews by Gambiani *et al.*, 2009; Lejeusne *et al.*, 2009; Calvo *et al.*, 2011; Di Carlo and Otero, 2013). Instead, it presents an overall review illustrated with examples of the most important effects that are likely to be monitored (or at least reported) in MPAs.

Changes in native species distributions

Shifts in the distribution of marine populations are the most commonly reported effects associated with changing climate conditions. In the Mediterranean, the long-term temperature increase has been shown to affect the boundaries of biogeographical regions, with some warm-water species extending their ranges and colonizing areas where they were previously absent or rare (CIESM, 2008). Fish and crustaceans as well as sessile species such as echinoderms, cnidarians and algae are shifting their geographical ranges in both location and depth, in what seems to be a widespread phenomenon that already involves about 100 native species from primary producers to top predators.

Warm-water species, more abundant in the southern and eastern Mediterranean, where temperatures are higher, are increasing in abundance and extending their ranges northwards. For example, the ornate wrasse *Thalassoma pavo* increased its population density tenfold within less than 5 years of its arrival in the Scandola Marine Reserve (NW Corsica, France) in 1988. Likewise, an increase in landings of other warm-water

Thalassoma pavo. Photo: A. Can - www.alpcan.com

Among the most common native species spreading northwards are fishes such as the ornate wrasse *Thalassoma pavo*, the dusky grouper *Epinephelus marginatus*, as well as the macroalgae *Dasycladus vermicularis.*

Epinephelus marginatus. Photo: A. Can - www.alpcan.com

Dasycladus vermicularis. Photo: I. Rubio - marmenormarmayor.es

species has been reported throughout this region, as in the case of the round sardinella *Sardinella aurita* and one of its predators, the bluefish *Pomatomus saltatrix*, a migratory coastal pelagic species whose northern boundary was believed to be the southern Catalan coast in the western Mediterranean. Both species have been reported to be increasing in abundance in recent years and expanding northwards into the north-western Mediterranean (Sabates *et al.*, 2006). These changes are believed to be associated with higher spring temperatures, which are crucial for the migration and reproduction of these species. Annual cyclical fluctuations related to natural temperature variations could nonetheless have major consequences for the physiology, fitness and abundance of these species.

One of the reasons for the successful range expansion of many of these temperature-sensitive species is their ability to reproduce in the new areas and establish new populations. A well- documented example of this is the recent appearance of juveniles of the dusky grouper *Epinephelus marginatus* in Port Cros National Park (France) and other areas along the French continental coast. The increase in the dusky grouper population at these sites over the last 10 years is due partly to the rise in water temperature resulting from climate change and partly to the success of protection measures that provide the right conditions for reproduction and recruitment in the northern Mediterranean (Harmerlin *et al.*, 2007).

Conversely, there is also evidence for a decrease in the abundance of some cold-water species from the most northerly areas of the Mediterranean (the north-western Mediterranean and northern Adriatic). Suitable habitats for these cold-water species may also shift because they cannot compete for limited resources with the southern species that are moving northwards, and this may lead to a significant reduction in their populations and threaten their survival. For example, a recent study revealed that the changes in the relative abundances of a warm-water species, the ornate wrasse *Thalassoma pavo*, and a cold-water species, the rainbow wrasse *Coris julis,* sharing the same habitat can drive the cold-water species out to less ideal habitats in order to escape competition within the same thermal environment (Milazzo *et al.*, 2013). Therefore, besides changing their geographical ranges, many species could also be changing their habitat preferences within their current areas of distribution.

For the slender goby (*Gobius geniporus*), for example, a species currently found throughout the western, northern and north-eastern Mediterranean, a climate-induced range reduction of 80% by the middle of the century has being predicted, restricting its populations to the Gulf of Lion, southern Sardinia, the northern Adriatic and the northern Aegean (Ben Rais Lasram *et al.*, 2010).

Another example is the European sprat *Sprattus sprattus,* a small schooling pelagic species of high economic importance that only seems to reproduce in the Gulf of Lion and the northern Adriatic Sea (Peck and Mölmann, 2008). The northernmost Mediterranean population occurs at its physiological temperature limit and this, in combination with intensive fishing, makes this population highly vulnerable to climate change.

Spread of alien species into the Mediterranean

The Mediterranean Sea is subject to a continuous influx of alien or exotic species arriving through the Suez Canal or the Strait of Gibraltar, often transported by international shipping among other vectors. The majority of these alien species are thermophilic (warmth-requiring species) and the warming sea temperature is

Alien species —sometimes termed exotic, introduced or non-native species— are plants and animals that have been intentionally or unintentionally introduced, have established populations and have spread into the wild in the new host region (IUCN, 2002).

favouring their rapid spread northwards and westwards in the Mediterranean. The fastest reported of these colonizers is the bluespotted cornetfish *Fistularia commersonii*, which has been able to develop large populations in the warm eastern areas and colonize the entire Mediterranean from there in less than 10 years (Azzurro *et al*., 2012). Other species such as two rabbitfishes *Siganus luridus* and *S. rivulatus* and the ascidians *Phallusia nigra* and *Herdmania momus* have become very common in most parts of the eastern Mediterranean and strongly interact with native species.

The case of Kas-Kekova MPA off Turkey's south-western Lycian coast is a good example of the impact of invasive species. Here two invasive rabbitfish species from the Red Sea (*Siganus luridus* and *S. rivulatus*) are responsible for creating and maintaining underwater barren grounds composed solely of bare rock and patches of crustose coralline algae. These warm-water species are naturally extending their range through the eastern basin towards the northern parts of the Mediterranean.

Photo: P. Bodilis - ECOMERS

The rabbitfish *Siganus luridus* has become very common in most parts of the eastern Mediterranean and strongly compete with native herbivorous fish species. Their spread can result in a drastic decrease in seaweed formations.

Invasive: alien species which become established in natural or semi-natural ecosystems or habitats and become an agent of change, increasing in abundance and distribution and threatening native biological diversity (IUCN, revised 2012).

Climate change is thus not only enabling some existing exotic species to spread into other areas, but it is likely to create welcoming conditions for new invaders or serve as a trigger for these exotics to become invasive. The outcome of the readjustment of interactions by the local native populations will vary, depending on multiple factors. Overall, the result may have a profound impact on both the biodiversity and the functioning of the Mediterranean sublittoral ecosystems where most MPAs are established.

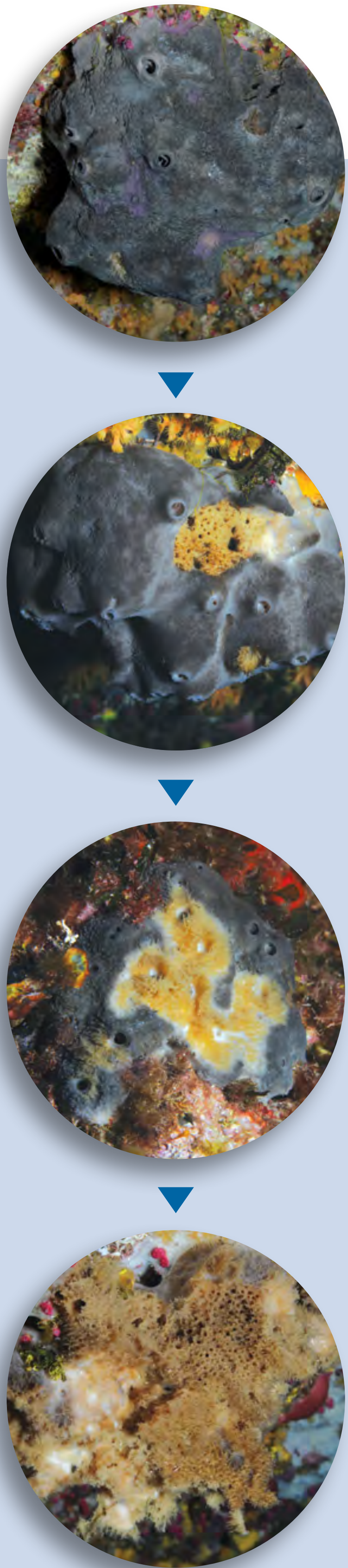


Photo: J. Garrabou

A healthy specimen and different mortality stages in Mediterranean keratose sponges

Mass mortalities of macrobenthic communities

Unprecedented mass-mortality events and diseases linked to climate warming have been observed in the Mediterranean in recent decades. More than 30 species in Mediterranean hard-bottom communities have been affected by mass-mortality events associated with unusual increases in seawater temperature along thousands of kilometres of coastline, mainly in the north-western Mediterranean (Cerrano *et al.*, 2000; Garrabou *et al.*, 2009).

Coralligenous formations, considered one of the richest habitats in the Mediterranean, have suffered most severely. These communities, mostly living in what is essentially a cold-water environment due to the formation of a seasonal thermocline, are adapted to a changing environment produced by intermittent and transitory processes, including upwellings, downwellings, vertical mixing, horizontal advection and heat waves. Conversely, other affected species that live in shallower coastal habitats such as caves and rocky, alga-dominated environments are adapted to a more stable environment during summer periods.

Seasonal thermocline: Temporary layers between which the temperature changes abruptly with depth

Mass-mortality events in these hard-bottom communities have mainly been observed along the north-western Mediterranean coast, from north-eastern Spain and the Balearic Islands to France and the Ligurian coast of Italy, and to a lesser extent around Corsica. In 1999 and 2003, these events were the most severe ever recorded in the area and affected a wide variety of species and taxa along more than 1,000 km of these coasts down to a depth of 50 m (Garrabou *et al.*, 2009). Other similar events, although at a smaller scale, have been observed in other Mediterranean areas involving other organisms (e.g. bald sea-urchin disease affecting *Paracentrotus lividus*). Many of these mortality events have been linked to a particularly strong summer stratification of the water column and a possible reduction in food resources (Coma *et al.*, 2009).

The impact of mortality events on populations has been severe, especially on Mediterranean gorgonians (*Paramuricea clavata*, *Eunicella singularis*, *E. cavolinii*, *Lophogorgia ceratophyta* and *Corallium rubrum*) and sponges (*Ircinia fasciculata*, *Spongia officinalis* and *S. agaricina*). For example, in some affected areas up to 90% of red gorgonian *Paramuricea clavata* colonies show total or partial mortality. Other species however, such as the yellow gorgonian *Eunicella cavolinii*, seem to be more resistant to these warming events, although the effects on their reproductive biology, vulnerability to disease and growth can still be seen several years after the initial stress, and there may be no significant signs of recovery.

Given that the affected species are in general long-lived organisms characterized by slow population growth and limited larval dispersal, the ability of affected populations to recover is probably quite limited. Habitat-forming species such as these gorgonians provide shade and shelter for other species by means of their skeletal structure. Significant changes in their abundance can therefore have a major effect on the organization and functioning of the community.

Mediterranean gorgonia *Paramuricea clavata* affected by rising temperature.

Population blooms

Changes in temperature and other conditions have also been linked to increasingly frequent reports of blooms of a variety of organisms.

Several studies have demonstrated a significant increase in jellyfish abundance in different areas of the northern hemisphere, probably related to climate change and food-web modifications (such as overfishing of predators). Blooms of native jellyfish species (*Pelagia noctiluca* and *Aurelia aurita*) as well as alien species (*Rhopilema nomadica*) in Mediterranean coastal areas are seriously interfering with human activities, including tourism and fisheries. Analysis of a long-term data series covering more than 200 years has revealed that a combination of certain conditions such as high seawater temperatures, stable weather conditions during reproduction and reduced rainfall seems to favour the development and increasing occurrence of *P. noctiluca* blooms in the Mediterranean (Goy *et al.*, 1989). Other data series from the Adriatic Sea as well as from experimental settings have yielded similar findings: blooms of *P. noctiluca* and other jellyfish species are promoted (at least partly) by a warmer sea. Environmental changes, whether natural or resulting from human influence, could lead to changes in the seasonality of jellyfish blooms, so that they develop earlier or last longer, whereas climate change seems to lead to an increase in the ability of these organisms to thrive.

Another type of bloom, mucilaginous aggregates, is caused by the proliferation of several phytoplankton species developing seasonally and at different depths. Marine mucilage floating on the surface or in the water column can have a long life span (up to 2–3 months) and when thick, dense mats of it settle on the sea bottom they can sometimes completely cover entire benthic communities, such as seagrass (*Posidonia oceanica*) meadows and gorgonian (e.g. *Paramuricea clavata*) forests, causing hypoxic and/or anoxic conditions over several square kilometres of sediments (Danovaro *et al.*, 2009). At this stage they can be especially harmful to gorgonian populations, and severe mortality events associated with these outbreaks have been reported from Italy (Sicily) and Spain (Columbretes Marine Reserve) (Mistri and Ceccherelli, 1996). In other cases, however, the mucilage disappeared after several weeks leaving no apparent signs of impact on the communities. A considerable increase in the frequency of these mucilage events has been observed in different parts of the north-western Mediterranean, around Sicily and particularly in the northern Adriatic Sea, the last being the area most severely affected by these outbreaks. The timing of these events and of the climate anomalies observed in parallel with them (e.g. the rise in sea-surface temperatures) indicates a clear relationship with climate change (Danovaro *et al.*, 2009).

Warmer coastal waters combined with eutrophication can also increase the intensity, duration and extent of harmful algal blooms, which can damage marine communities and coastal industries such as aquaculture. Many of these events are thought to be a consequence of climate change. Warming may also raise the possibility that new parasites and diseases will arrive in Mediterranean waters, and some recent studies suggest an increased frequency of such outbreaks in invertebrates, making large mortality events more likely (Lejeusne *et al.*, 2009; Calvo *et al.*, 2011). However, not enough is yet known to predict the consequences of these pathogens and their connection with the changing climate.

Discharges of waste through underwater drainage system.
Photo: V. Tasso, OCEANSNELL

Eutrophication: Process by which a body of water (usually shallow) acquires a high concentration of nutrients, especially phosphates and nitrates and decrease in dissolved oxygen, caused by either natural processes or pollution. This typically promotes excessive growth of algae.

Effects of acidification

The absorption by seawater of atmospheric CO_2 leading to a decrease in pH (acidification) can have a severe impact on the performance and survival of many organisms with calcium carbonate structures, and consequently affect the composition and productivity of marine communities.

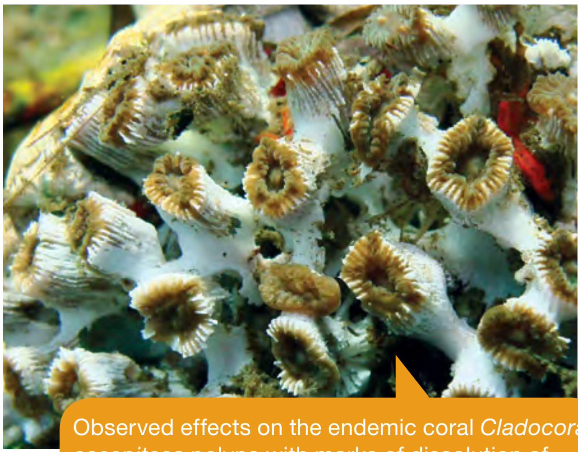
Little is understood at present, however, about the impact that will have on marine biodiversity. Ocean acidification has the potential to affect individuals' growth, reproduction and activity rates. Some animals will tolerate higher acidity; some may even thrive on it, but the overall community changes will be different at each locality. Shifts in species composition along pH gradients suggest that calcified species might not survive the increased metabolic costs of coping with low-pH environments while competing for resources with other, uncalcified organisms.

Understanding how Mediterranean coastal ecosystems will react to increased seawater acidity is one of the priorities for many national and international research groups as very few field studies have been carried out. Besides laboratory experiments, shallow marine habitats with volcanic CO_2 vents have offered researchers a good environment to learn about the effects of acidification

Photo: J. Hall-Spencer

Posidonia oceanica meadows in volcanic CO_2 vents of Italy.

Photo: J.Hall-Spencer



Observed effects on the endemic coral *Cladocora caespitosa* polyps with marks of dissolution of their skeleton under low pH conditions.

in Mediterranean benthic ecosystems. The natural CO_2 emissions from these vents provide a range of pH levels that can be used to monitor what benthic ecosystems will be like in a high-CO_2 scenario. These studies have shown that nearby rocky shore communities exposed to low-pH waters decrease in species number and shift from a calcareous-dominated community structure to one dominated by uncalcified organisms (Hall-Spencer *et al.*, 2008). For example, around the Vulcano vents of Italy, a macroalgae-dominated community decreased in species richness, coverage and reproduction capacity in a low-pH environment. Likewise, the abundance of various calcareous organisms such as scleractinian corals (*Cladocora caespitosa* and *Balanophyllia europaea*), macroalgae (*Lithophyllum incrustans*, *Corallina elongata*, *Padina pavonica* and *Halimeda tuna*), molluscs (*Osilinus turbinatus*, *Patella caerulea* and *Hexaplex trunculus*) and sea-urchins (*Paracentrotus lividus* and *Arbacia lixula*) was lower under low-pH/more acidic conditions (Hall-Spencer *et al.*, 2008; Rodolfo-Metalpa *et al.*, 2011).

Aquarium experiments and transplants in the field into naturally acidified waters have confirmed some of the observed negative effects of acidification. For example, for the scleractinian corals *Cladocora caespitosa* and the alien *Oculina patagonica,* low-pH conditions reduced calcification rates by about 30% (Movilla *et al.*, 2012). Similarly, other species such as the red coral *Corallium rubrum* and the coralline alga *Lithophyllum cabiochae* displayed a significant reduction (by up to 60%) in skeleton growth and feeding activity or increased necrosis, respectively, in a low-pH environment. These and other findings suggest that rich coralligenous communities are likely to be severely affected by the ongoing acidification. Ocean acidification has also been shown to have an impact on shellfish growth, reproduction and structure.

In contrast, a number of species seem to be resistant to or even to benefit from acidification. For instance, *Posidonia oceanica* meadows seem remarkably tolerant of low pH levels and several algal species, among them some aliens (*Caulerpa racemosa*, *Asparagopsis armata* and *Dictyota dichotoma*), and other species such as the sea anemone *Anemonia viridis* can increase their abundance and productivity (Hall-Spencer *et al.*, 2008; Suggett *et al.*, 2012). *P. oceanica* is, on the other hand, highly sensitive to seawater warming, and high mortality rates may be expected in natural populations with the rise in annual water temperature.

Effects of sea-level rise

As seen above, the rise in sea-level is generally considered one of the most significant consequences of climate warming, yet its effects on biodiversity are poorly understood.

Sea-level rise threatens coastal marshes, sea caves and beaches, which are crucial habitats for many species, such as endangered populations of sea turtles and Mediterranean monk seals, which use them for breeding (see page 24). Intertidal bioconstructions such as reefs built by vermetid molluscs together with coralline algae (such as the vermetid *Dendropoma petraeum* and the red alga *Neogoniolithon brassica-florida*) or rims built slightly above sea-level by the encrusting coralline alga *Lithophyllum byssoides* are extremely vulnerable to water-level changes and to wave erosion during major storms (Boudouresque, 2004). Vermetid reefs are found mostly in the central and southern Mediterranean Sea while rims are widely distributed throughout the Mediterranean (Chemello and Silenzi, 2011) and have been used to track past changes in sea-level in the Mediterranean. As these habitats are built from calcium carbonate, sea acidification can also affect vermetid and algal calcification and have detrimental effects on the organisms' growth rate, resulting in local extinction events.

Rising sea temperature, sea-level rise and acidity thus appear to be associated with various changes in biodiversity in the Mediterranean (Rodolfo-Metalpa *et al.*, 2010). The synergic effects of different stressors linked to global change will probably exacerbate the impact on the biodiversity and functioning of coastal ecosystems.

Vermetid platforms at Torre Guaceto MPA, Italy. Photo: M. Otero

Cumulative effects and natural resilience

Marine protected area in Malta, between Rdum Majjiesa and Ras ir-Raheb. Photo: M. Otero

The majority of Mediterranean MPAs have been classified as multiple-use MPAs, which seek a balance between biodiversity conservation and some sustainable level of human use. Less than 0.1% of the Mediterranean's total area is covered by strict protection and/or no-take zones, and MPAs in Categories IV (Management areas for habitats and species) and II (National Parks) with some level of human use are the most common management types (Day *et al.*, 2012; Gabrié *et al.*, 2012).

Even with management, many MPAs may be exposed to several simultaneous stressors such as commercial and recreational fishing, pollution, habitat degradation and climate change, often acting in synergy and thereby amplifying their individual impacts on the marine ecosystem and its communities (Harley and Rogers-Bennett, 2004). Moreover, MPAs are increasingly threatened by the expanding coastal development and intense tourist activities around the Mediterranean, particularly during the summer. The cumulative impacts of these diverse activities are missed, however, if activities are evaluated and managed in isolation from one another.

This accumulation of stressors can considerably decrease the resilience of MPA ecosystems to an additional stress such as climate change. That is, their natural capacity to absorb, resist or recover from disturbances or to adapt to these changes without causing community shifts or local population extinctions.

As the natural resilience of marine habitats is likely to diminish in the future, it is essential that appropriate management actions are implemented to reduce these impacts. The most effective ways include reducing the number and intensity of threats, particularly in areas of projected high risk (vulnerable areas), and incorporating

Natural resilience: Resilience refers to the amount of disturbance or stress that an ecosystem or species can absorb and still remain capable of returning to its pre-disturbance state.

Refugia: Physical environments that are less affected by climate change than other areas (i.e., due to local currents, geographic location, etc.) and are thus a "refuge" from climate change for organisms.

potentially resilient sites (or refugia) into the management design to facilitate the recovery of less resilient areas. The former measure will require collaboration with other coastal users and planners as well as ensuring that good monitoring information is gathered so as to be able to take action and identify targeted approaches to specific pressures. The second type of measure will require the identification of areas that were resilient to past climate change impacts as well as the collection of information on the responses of different communities and sites in these locations.

An illustrative example may be found in the north-western Mediterranean, where different environmental conditions can modulate the impact of anomalous regional warming. The local hydrological conditions found in the Medes Islands MPA (north-eastern Spain) result in the absence of extreme temperatures (short-term anomalies) even in summer, and in attenuated temperature variations during periods of long anomalies. This makes the area less vulnerable to mass-mortality events in coralligenous communities than areas such as Marseille (close to Port Cros National Park) and Corsica (Scandola Nature Reserve), where the hydrodynamics cannot buffer anomalous temperatures, resulting in intolerable conditions for many species (Crisci *et al.*, 2011).

Blue carbon sinks

The organic deposits in Mediterranean saltmarshes and seagrass meadows, principally those of *Posidonia oceanica*, are an exceptional example of a natural carbon sink ecosystem as they considerably reduce the harmful effects of human carbon emissions by capturing and storing part of the excess carbon dioxide (CO_2). Such carbon that is sequestered, stored and released from coastal ecosystems, including mangrove swamps, is known as 'blue carbon'.

Posidonia oceanica meadows can sequester and store large amounts of organic carbon in sediments and biomass: the average storage rate for the Mediterranean is calculated to be 0.15 to 8.75×10^6 tC a year, according to several recent studies (Serrano, 2011). Overall, the historical carbon deposits in the mats below Mediterranean seagrass meadows could amount to as much as 2.5 to 20.5×10^9 tC. Their large capacity together with their extremely long carbon residence time makes *Posidonia* meadows a very important carbon sink relative to the total carbon stored in the oceans (Pergent *et al.*, 2012).


Posidonia oceanica. Photo: M.Otero

When degraded or disturbed (e.g. by trawling, pollution or other cumulative stressors), however, these habitats can release the carbon dioxide back into the ocean and atmosphere, thus having an adverse effect by increasing greenhouse emissions.

Well represented in many Mediterranean MPAs, these seagrass meadows are highly biodiverse habitats whose conservation helps mitigate climate change effects, in addition to increasing the MPAs' natural resilience. MPA managers can assist by preventing the loss of the carbon that is currently stored in these habitats and improving management to enable the seagrass to retain more carbon, through restoration programmes. Mediterranean saltmarshes and seagrass meadows could play an important role in national carbon accounting schemes and provide a source of future funding for conservation efforts.

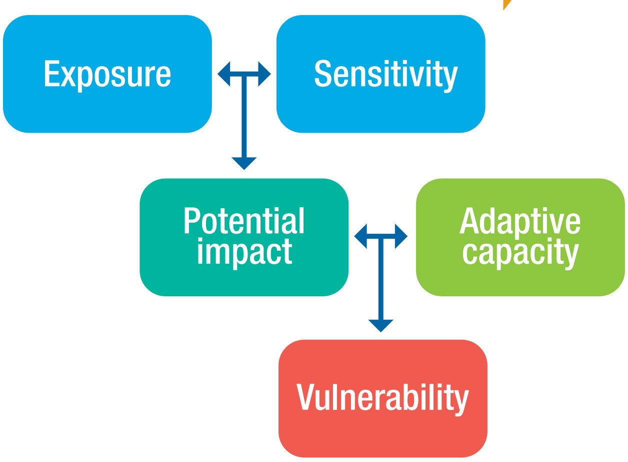
Assessing the vulnerability of MPAs to climate change

Vulnerability of the natural environment is a multi-faceted concept which includes **exposure** (the nature and degree to which a species, habitat, or ecosystem is exposed to significant climate variations, such as higher seawater temperatures) and **sensitivity** (the degree of the effect that may result from a given level of exposure to climate change, e.g. gorgonian populations are sensitive to a rise in seawater temperature) to a **potential impact**, as well as **adaptive capacity**, or the capacity of the environment to adjust to climate change with minimum impact through coping strategies and long-term adaptation (Füssel, 2007).

Non-climate drivers: refers to those current or future pressures impacting species and natural systems that do not derive from climate change such as urbanisation and pollution.

As previously explained, climate change impacts result from the interaction between climate and non-climate drivers and have significant regional variations. Obviously, some Mediterranean MPAs will be more severely affected by climate change than others, but they may eventually lose their resilience and in particular their capacity to adapt to the changing climate, particularly if they are surrounded by a dense human population or feel the effects of tourism and other human-related pressures.

Vulnerability to climate change depends on exposure, sensitivity and adaptive capacity. (From Allen Consulting, 2005, based on IPCC, 2001).



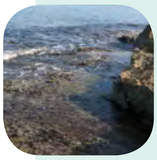
The Mediterranean coastal habitats that are considered most vulnerable, due to a combination of potentially high exposure and sensitivity to climate change, include coastal lagoons, low-lying beaches, estuaries, saltmarshes and mudflats, submarine and coastal karst habitats, saline wetlands and ponds, nursery sites, coralligenous assemblages, vermetid platforms, *Posidonia* meadows, and sites with a high density of endemic, endangered and rare species (UNEP/MAP RAC/SPA, 2009, Table 2). The capacity of each of these habitats to adapt to the interactions of these vulnerabilities with non-climate threats and stressors will then determine the future magnitude of adverse effects (IPCC, 2007b, p. 883).

The vulnerability of an MPA to climate change will thus depend on a range of factors, such as the sensitivity of the site, the degree of exposure and its adaptive capacity. It will therefore be specific to a given location, species or community and depend on its ecological and socio-economic characteristics.

Conducting a vulnerability assessment for a specific site can focus attention on particular management actions that can be useful for MPA managers and other users. The assessment should evaluate impacts caused by climate and non-climate drivers, such as changes in sea level, storms, temperature and sedimentation patterns. The approach to be used will ultimately depend on the objective of the vulnerability assessment (EEA Report No 12/2012). For example, in an MPA one could begin by identifying the areas most vulnerable to sea-level rise and those in particularly critical zones, and then examine the potential combined impacts of other stressors.

Different tools may be used for vulnerability assessments at different spatial and temporal scales, in different regions and for different management purposes, based on the information and data available (see MPA Case Study 1). A range of methods (including indicator-, index-, GIS- and model-based methods) for assessing vulnerability to climate change are outlined in the ETC CCA Technical Paper 1/2011. Index- and indicator-based approaches (including related GIS applications) are simple methods that can provide a 'first-look' assessment to identify priority vulnerable coastal areas and can also be useful for informing stakeholders. GIS-based decision support systems (DSS) can be used to investigate multiple climate change impacts on coastal areas, with prioritization of vulnerable locations and analysis of data uncertainties; while methods based on dynamic computer models are important tools for analysing and mapping the likelihood of climate change and the associated vulnerability of coastal systems. MPA managers rarely use many of these tools and could therefore benefit from assistance from research institutions, consultancy companies or universities.

Table 2. Vulnerable pre-identified habitats (UNEP-MAP, 2009) and potential climate change impacts.

Vulnerable pre-identified habitats	Potential impacts
 **Coastal lagoons, saline wetlands and ponds**	Inundation, flooding, salinization.
 **Estuaries, salt marshes and tidal mudflats**	Accelerated sea-level rise can impact salt marshes through inundation, erosion, saltwater intrusion and landward migration of coastal ecosystems. Loss of wetland communities. Sea-level rise might also cause significant and rapid loss of intertidal flats and bottom communities.
 **Sandy low-lying beaches**	Effects of more frequent and extreme weather events on low-lying coasts can potentially submerge low-laying areas with loss of nesting beaches. Increase in erosion, particularly on the seaward side; it can complete removal the sand from narrow beaches. Sand dune mobility. Acidification and changes in current dynamics can modify the benthic communities.
 **Submarine and coastal karst habitats**	Sea-level rise and reduced precipitation might increase coastal landslips.
 **Nursery sites**	Sea-level rise may impact coastal habitats important as breeding or nursery areas and reduce their size. Temperature increase may reduce populations of coastal fish, affect the life-history and movement of species, including commercial species and induce changes in the distribution of key fisheries and fishing effort.
 **Coralligenous assemblages**	Increase temperature and acidification could threaten calcium carbonate organisms such as coralligenous assemblages (macroinvertebrates and calcareous algae) that sustain important structural habitats. Alien species could be favoured by new climate conditions and/or outcompete species already affected by mass mortalities damages.
 **Vermetid platforms**	Sea-level rise could submergence communities.
 **Posidonia meadows**	An intense floration (i.e. caused by a temperature rise) could increase leaf mortality and have a negative net growth on some meadows.
 **Sites with endemic, endangered and rare species**	Retreat of endemic habitats, keystone species and faunal assemblages.

MPA CASE STUDY **1**

Vulnerability assessment of sea turtle nesting beaches in Zakynthos MPA, Greece

Sea-level rise is likely to dramatically change the Mediterranean coastline, particularly in low-lying areas (Ferreira et al., 2008). Many habitats such as beaches or wetlands may be degraded or destroyed by the rising waters and the overlapping effects of increased precipitation and storm frequency.

In Greece, the National Marine Park of Zakynthos and the University of the Aegean recently conducted a vulnerability assessment to examine the potential climate change impacts and adaptation responses in sea turtle nesting beaches, which in general have not yet been properly examined or fully understood (Fish et al., 2005). The Marine Park, which is situated in the southernmost part of the island of Zakynthos, holds the most important nesting sites for the endangered loggerhead turtle *Caretta caretta* in the Mediterranean. Its management objectives are to preserve the natural environment and conserve the ecological balance of the marine and coastal area of Laganas Bay and the Strophadia Islands, to protect the sea turtles and other species, and to develop conservation activities in Zakynthos.

A rise in sea level would threaten the endangered sea turtle population by reducing the available nesting space on the beaches. Higher temperatures would also affect the growth and sex ratio of the hatchlings. The intensification of sand dune erosion, storm surge frequency, urban infrastructure and disturbances from the growing tourist activities would further exacerbate the problem.

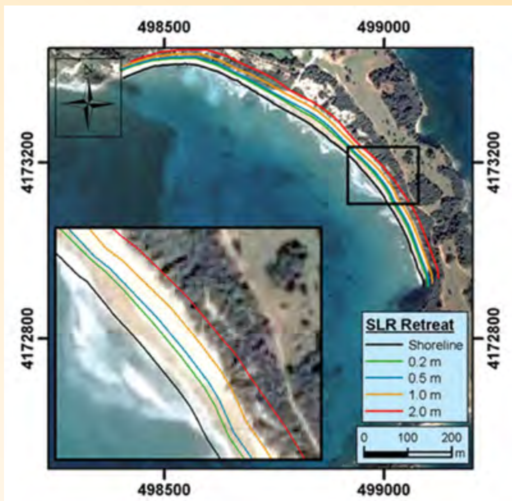
Sea turtle hatchings in the National Marine Park of Zakynthos, Greece

To assess the main effects of climate change on nesting beaches, modeling sea level rise scenarios, beach profile measurements, meteorological data as well as coastal seabed and water column characteristics have been measured. All these parameters were then related to turtle nesting patterns. The results indicated that higher sea levels would have a considerable impact. In the 0.2 m sea-level rise scenario, it was estimated that the beaches would retreat between 0,8 to 15,9m, whereas in the 0,5 m and 1.0 m scenarios, they could retreat between 4,9-25,2 m and 10,8-37,3 m, respectively. In the worst-case scenario (a 2.0 m storm surge), beach recession was estimated between 23,2 to 80,8 m (Velegrakis *et al.*, 2013).

Beach profile transects through Gerakas nesting beach. From Vlegrakis *et al.*, 2013.

These estimates suggest that the beach will potentially lose 44–94% of its width in the first three sea-level rise scenarios, whilst in the worst case of a 2.0 m storm surge it will be entirely inundated. The beach cannot adapt to sea-level rise by transgression, as it is backed by cliffs. The result will be coastal squeezing, which in turn will dramatically reduce the available nesting space and increase conflict related to the recreational use of the beach; it might even force the turtles to nest on other beaches.

Information from this vulnerability assessment will help managers to prioritize conservation efforts, use realistic measures to mitigate potential sea-level threats and establish a long-term monitoring and alarm system. Training for the Park staff in the use of the tools that have been produced will enable them to carry out future vulnerability assessments and develop adaptive planning.



Predicted coastline retreat in Gerakas beach for different sea-level rise scenarios (0.2, 0.5, 1.0, 2.0 m). From Vlegrakis *et al.*, 2013.

Sea turtle hatching of *Caretta caretta*.
Photo: Héctor Garrido, CSIC.

Developing a monitoring and evaluation protocol for the MPA network

Why monitor climate change effects?

Mediterranean MPAs are under growing pressure from both climate change and other anthropogenic influences, particularly coastal development. These pressures require that managers understand and are aware of the environmental changes that are currently occurring and are likely to manifest themselves in the MPA environment in the near future. Rare, endangered or threatened species or sites and habitats that hold large numbers of species might be particularly vulnerable to climate change, as species will need to move or adapt to the changing environmental conditions. Monitoring can be of assistance in identifying these adverse effects and providing early warnings. The inclusion of climate change in standard monitoring programmes would help in assessing and putting in place appropriate management actions to protect the most resilient or least susceptible communities, habitats and areas, and in exploring other potential management adaptation strategies.

Because MPAs cover relatively undisturbed environments in which many important Mediterranean ecosystems are represented, they can also serve as control sites for monitoring climate change and its impacts, for comparison with more disturbed marine and coastal sites outside protected area boundaries. The use of MPAs as sentinel sites to produce long-term datasets will result in a greater understanding of the natural variability in the way MPA environments respond to climate change stressors.


Monitoring. Photo: S. Ruitton - Port Cros National Park

Furthermore, these efforts will contribute to national, regional and international reporting requirements concerning biodiversity conservation and the Convention on Biological Diversity (CBD) targets. For EU countries, monitoring and the development of adaptive management strategies in MPAs could serve as a good basis for reporting and complying with the recently drafted EU Strategy on adaptation to climate change (EU COM(2013) 216) and with the objective of a common framework of action to mitigate and adapt to the changes.

Designing a monitoring framework

Existing monitoring programmes

There are many monitoring techniques, tools and new technologies available to measure the environmental condition of the seas. In the Mediterranean Sea, a number of monitoring activities are conducted by different national, regional and international scientific and research organizations. Some are undertaken regularly while others are one-off studies, and they vary in complexity, geographical context, duration and the parameters measured; in many cases the resulting studies are difficult for non-specialists to understand. Although several countries have made progress with the development of tools for monitoring the marine environment in general and its climate change-related modifications in particular, there is still no clear vision of the possible impacts on MPAs.

Within the framework of marine environment monitoring, there also exist marked differences between countries and between individual MPAs themselves in data-gathering activities and monitoring efforts. Some countries already have monitoring programmes in place, particularly for physical variables, which also cover MPA sites, although the resulting information is not commonly fed back to the site managers. Monitoring information on chemical and biological impacts is less abundant.

Overall, it seems there is a fragmentation of monitoring efforts at the regional and local scales. Climate change projections and scenarios are still limited to overviews at a Mediterranean or global level; to understand the impacts on local sites, however, monitoring data adjusted to the spatial scale of MPAs is needed.

Monitoring for MPAs

For any potential climate change monitoring programme to be implemented in these sites, the individual MPAs already need to be carrying out general monitoring and surveillance of their habitats and species (including such variables as area, cover, quality and population numbers) in order to keep track of the condition of their marine environment. Building on this information, the monitoring programme should incorporate climate change and its impacts within the standard procedure. The results of climate change monitoring supplemented by observations of coastal and marine condition (i.e. physical and biochemical parameters) can then be used to determine causes and effects when changes in marine biodiversity are found.

Given the great range and diversity of climate change impacts and the usually limited resources available to MPAs, a suite of key indicators is needed that can facilitate monitoring and lead to an understanding of the impact of climate change on their biodiversity.

Within each category several indicators can be used to build the required baseline data for assessing the severity of climate change impact on MPAs.

The choice of which indicators and parameters to monitor to some extent reflects current knowledge and estimates of climate change impacts, and will need to be revised in the future. The selected indicators are therefore not intended to be the only ones that should be used to monitor the response of marine communities; they should in fact form part of a broader MPA monitoring programme based on multiple management objectives.

To be effective sentinels of climate change, these indicators will ideally possess all or at least some of the following attributes:

1. They should be few in number and simple: good indicators should be easy to survey and monitor, scientifically sound and technically feasible, inexpensive and reliable.

2. They should assist regional monitoring and modelling efforts and focus on issues of relevance to Mediterranean MPA managers in order to answer key questions on biodiversity impacts and/or adaptation planning.

3. They should be measured at multiple sites, to enable site comparisons among MPAs, within the local region and across the whole MPA network and Mediterranean basin. Hence, they should also take into account the range of geographical settings under different models and projections

4. They should take into account the different vulnerabilities of species, communities and habitats across the MPA network so as to identify target parameters of these species, communities and habitats on which monitoring should focus.

5. They should be backed up by time series data that allow for comparisons and assessments of trends so that observations can be reliably interpreted.

Following the evaluation of a long list of indicators by regional scientists using the criteria described above, five categories of indicators were selected as being of priority interest:

1. Physical and biochemical condition
2. Changes in reproduction and breeding dates of key species
3. Episodic events
4. Shifts in species distribution patterns
5. Migration changes

Monitoring needs to occur at multiple scales and there is no single method or indicator that 'fits all'. Each MPA is unique and represents a particular set of ecosystems, biodiversity, environmental conditions and human uses, all of which result in a specific degree of vulnerability to conditions associated with climate change. Besides, not all monitoring programmes can be relevant to all MPAs. Within this framework, monitoring will serve two goals:

- For individual MPAs, a monitoring programme will track changes in key ecosystem components within the MPA;
- For the network of MPAs, the monitoring programme will provide a joint indication of the changes in biodiversity at a Mediterranean scale.

The proposed indicators represent an initial attempt to put together a climate change-orientated monitoring programme for Mediterranean MPAs. They could include:

- Marine species selected for their rapid potential response to climate change that are already being monitored or could be monitored by the MPAs themselves, and which also provide good information for understanding climate change impacts;
- Specific parameters or species that can elucidate biodiversity responses;
- Other elements (e.g. sea-surface temperature and pH) that can link MPAs to existing monitoring programmes in the region while providing information for assessing impacts and potential adaptive approaches.

The fan shell *Pinna nobilis*, a Mediterranean endemic mollusc.
Photo: J. Cuetos, OCEANA

Observing a colony of *Parazoanthus axinellae.* Photo: Pepe Elías C.

Proposed categories of indicators and monitoring procedures

1. Physical and biochemical condition

INDICATOR

Seawater temperature anomalies

The analysis of the effects of climate change on biodiversity requires robust temperature datasets for coastal areas. First, such temperature time series will make it possible to characterize thermal regimes within MPAs (maximum temperature, mean summer temperature, stratification dynamics, etc.) as a basis for assessing their current vulnerability to warming. Secondly, they will be vital for detecting temperature anomalies and for tracking warming trends in Mediterranean coastal areas. The analysis of temperature conditions associated with reported biological impacts (e.g. jellyfish blooms or the arrival of new species) will determine to what extent warming is responsible for the observed impacts.

Large-scale sea-surface temperature data obtained from satellite images show a clear warming trend in the Mediterranean (Skliris *et al.*, 2011). However, there is still limited information on the warming and changes in stratification dynamics occurring in coastal areas. The available time-resolved temperature series for the water column (0–80 m depth) have shown a warming trend in coastal waters at different depths, but unfortunately the data cover only a few sites in the north-western Mediterranean and northern Adriatic (although there may be other series that are unpublished). The proposed temperature monitoring programme will help to fill the enormous knowledge gap in temperature regimes in coastal areas.

High-resolution temperature series can also be used to validate sub-regional modelling efforts. Validated circulation models can be a powerful and reliable tool for forecasting and evaluating the expected impact of climate change at spatial scales relevant to MPA management. These activities are essential for drawing up appropriate conservation and management plans for the rich Mediterranean biodiversity and for building the capacity to anticipate the impact of climate change in Mediterranean MPAs.

PROPOSED MONITORING PROCEDURE

Long-term temperature data series are very scarce for Mediterranean coastal areas, particularly data acquired at high temporal resolution. Recent technological advances now mean that high-resolution temperature series may be acquired at reasonable cost, thereby providing unique information on the thermal environment (average and extreme temperatures and variability) to which organisms are exposed. Within each MPA autonomous temperature data loggers can be deployed in seawater at 5 m intervals from the surface down to depths of 40–50 m, if geography allows, in sites exposed to dominant winds and currents (Bensoussan *et al.*, 2011). The sensors can be fixed to rocky substrates or along buoy lines or chains, while in seagrass meadows loggers can be installed within the canopy. On beach environments, sand temperature can be measured with similar devices buried at different sites (i.e. nesting beaches).

Temperature data loggers should be set up to collect hourly measurements and should be recovered by divers annually or semi-annually, usually before and after the summer period. For data management and analysis the T-MedNet initiative[2] has developed a web application for uploading and verifying the data and securely backing up all these records. The harmonized database also allows for the development of semi-automatic routines that are very efficient at producing summary reports on temperature conditions, including figures and temperature descriptors (mean, coefficient of variation, etc.).

Alternatively, another type of temperature sensor currently used by research institutions and other organizations is oceanographic buoys. These usually take measurements of oceanographic, meteorological and water quality variables. Specific information from these sensors includes sea-surface temperatures and temperature profiles. Although they are more expensive and require the involvement of research institutions, these sensors could be an alternative or additional source of information if they are placed in close proximity to MPAs.

INDICATOR

Anomalies of salinity, pH and other biochemical environmental conditions

Several chemical and physical parameters of the seawater column, such as salinity, dissolved oxygen concentration, pH, organic and inorganic nutrients, chlorophyll a/primary production, and turbidity, are recommended for measurement in MPAs, as they will provide a direct or indirect indication of the stability of marine communities. Surface salinity and pH are particularly important because they are most likely to change with climate variability and to have observable effects on marine communities (see page 14).

2. http://www.t-mednet.org/presentation

Since several scientific research institutions are working on these issues, it is advisable to check whether monitoring programmes and/or protocols already exist in or near the MPA waters and whether they have data available. A suite of other physical parameters, such as air temperature, wind speed, etc., collected by various different government agencies and institutions could also be useful for interpreting the results.

PROPOSED MONITORING PROCEDURE

MPA sampling is crucial for comparing local variability with the regional observations made by research institution monitoring stations. While there are many programmes designed to detect overall regional temperature variations, few time series exist to detect changes in many other parameters. Physical variables such as salinity can be monitored by means of autonomous devices such as salinity sensors or refractometers deployed in MPAs. The advances currently being made in the field of pH sensors will overcome the limitations of present systems and allow them to be used in the field with automated reading systems that do not require frequent maintenance and calibration.

For other biochemical variables, water samples should be taken at the same time as the in situ sampling for monitoring marine species and other parameters. The measurements should be taken regularly at different sampling locations inside the MPA according to established protocols, or new protocols should none yet exist (see *Water quality indicators for Mediterranean MPAs*, Tempesta and Otero, 2013).

Water transparency can easily be monitored from boats with a Secchi disc, and total organic materials can be measured using benthic sediment traps. Information on water column chlorophyll (either from direct measurements or from satellite data) and other parameters could require more complicated laboratory procedures and/or the services of an expert and a specialist laboratory.

MPA CASE STUDY **2**

Monitoring at sentinel sites: rising seawater temperatures and gorgonian populations

The gorgonian mass-mortality events observed in 1999 highlighted the need to develop a strategy to acquire high-resolution (hourly) temperature records with autonomous temperature loggers so as to provide indirect observations of warming in coastal waters. Nowadays, these high-resolution temperature series are collected by different teams at 21 sites across the north-western Mediterranean. Most of these sites are MPAs and some of their managers are actively involved in collecting temperature data (namely the Cerbère-Banyuls Marine Nature Reserve, Cap d'Agde, Côte Bleue Marine Park, Port Cros National Park and Scandola Nature Reserve). The managers learnt to set up the logging stations, calibrate the sensors and upload the data files for their sites through training sessions and contact with scientists.

These data series have been crucial for the detection and characterization of positive temperature anomalies related to recent mass-mortality events and for providing accurate information on the thermal conditions of species in the MPAs (Bensoussan *et al.*, 2010). In addition, simple protocols have been developed to assess the conservation status of gorgonian populations by quantifying the percentage of affected colonies (those with more than 10% necrosis) at specific depths; these protocols can be implemented by managers on an annual basis.

These applications can significantly expand current research efforts, to provide a more global picture of the status of gorgonian populations. Such concerted initiatives by scientists and managers to acquire data series on temperatures and gorgonian populations and to share their knowledge will increase their ability to detect, understand and forecast the impact of climate change on Mediterranean coastal ecosystems.

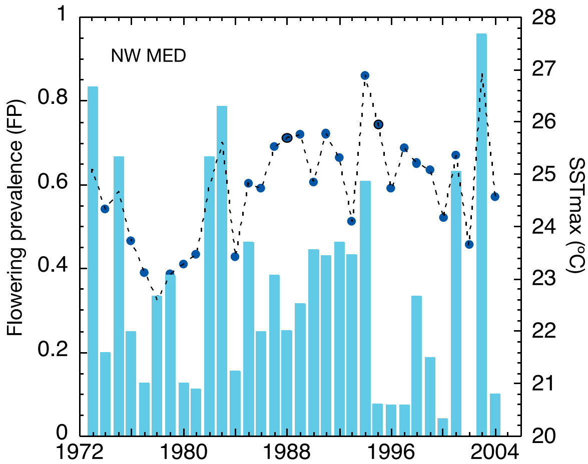
Placing temperature loggers. Photo: J. Garrabou

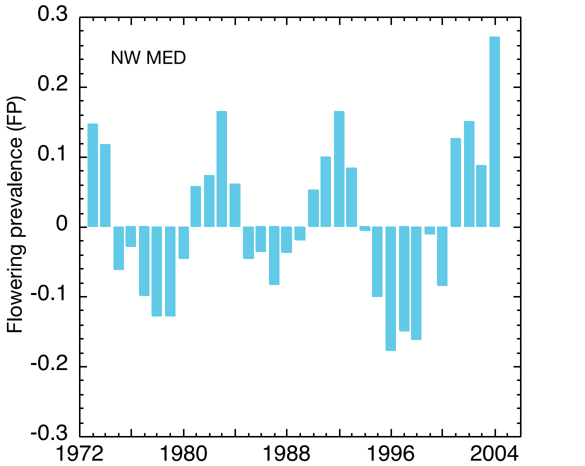
2. Changes in reproduction and breeding dates of key species

Increasing seawater temperature affects physiological processes in marine organisms and consequently influences processes such as foraging, growth, behaviour and reproduction. Physiological performance is the principal determinant of a species' tolerance to environmental variability and change. As climate or other conditions shift, organisms initially respond on the basis of physiological and behavioural adaptations that have been moulded through their evolutionary history. In this way, they may be able to adapt or acclimatize to the new conditions. If conditions are intolerable, however, migration to other areas, life cycle adjustments or local extinction may occur.

There is now good evidence that over the last decade the timing of seasonal events such as breeding and reproduction of many species around the globe has shifted due to climate change. Higher seawater temperatures and acidification are affecting physiological processes in marine organisms and will continue to do so, with eventual impacts on the geographical distribution of species (Lejeusne *et al.*, 2010; Ross *et al.*, 2011). Moreover, as temperature affects reproductive development in many species, seawater warming could result in spawning periods occurring earlier than normal.

Loggerhead turtle (*Caretta caretta*) in the southwest of Sardinia coast, Italy.
Photo: J. Cuetos, OCEANA





Evolution of annual flowering prevalence (bars, FP: flowering records per total records) since 1973 until 2004 in the NW Mediterranean, upper graph: the dashed line represents the annual mean NW Mediterranean sea surface temperature maxima (1°C) for the same period. (From Diaz-Almela *et al.*, 2007).

INDICATOR

Changes in reproduction and breeding dates of selected species

Nesting season and hatching success

In sea turtles, sex determination is dependent on incubation temperature. Lower temperatures result in male hatchlings and higher temperatures produce females. This means that eggs laid early in the season could be more likely to produce male hatchlings than eggs laid later on. For the breeding sea turtle species *Caretta caretta* and *Chelonia mydas*, monk seals *Monachus monachus* and coastal seabirds, by recording the dates of arrival and of the start of the breeding (nesting) season, as well as hatching and nestling success, it is possible to analyse trends in the timing of these events and their potential effects.

PROPOSED MONITORING PROCEDURE

Nesting beaches, coastal caves and other sites should be periodically monitored, and the dates of arrival and of the start of the breeding (nesting) season should be recorded for each species.

Flowering events of *Posidonia oceanica* meadows

Another key parameter to monitor could be the occurrence of *Posidonia* flowering and seed production. The Mediterranean seagrass *Posidonia oceanica* exhibits both vegetative and sexual reproduction. Sexual reproduction in this species is considered a rare and sporadic phenomenon, although some episodic flowering has been observed associated with extreme summer temperatures (Diaz-Almela *et al.*, 2007). Flowering of *Posidonia* meadows takes place in autumn, in September–October in shallow meadows, and November–December in deep ones. Widespread flowering events also seem to occur periodically every 10–11 years in correlation with the solar activity cycle (Pergent *et al.*, 1989).

Posidonia oceanica is highly vulnerable to warming, as rising seawater temperatures can induce declines in shoot abundance, affecting the overall stability of the seagrass meadows and the balance between shoot mortality and recruitment (Marbá and Duarte, 2010). Similarly, the induction of flowering could be a response mechanism by the plant to thermal stress and its prevalence and intensity may increase with the amplitude of the thermal anomaly.

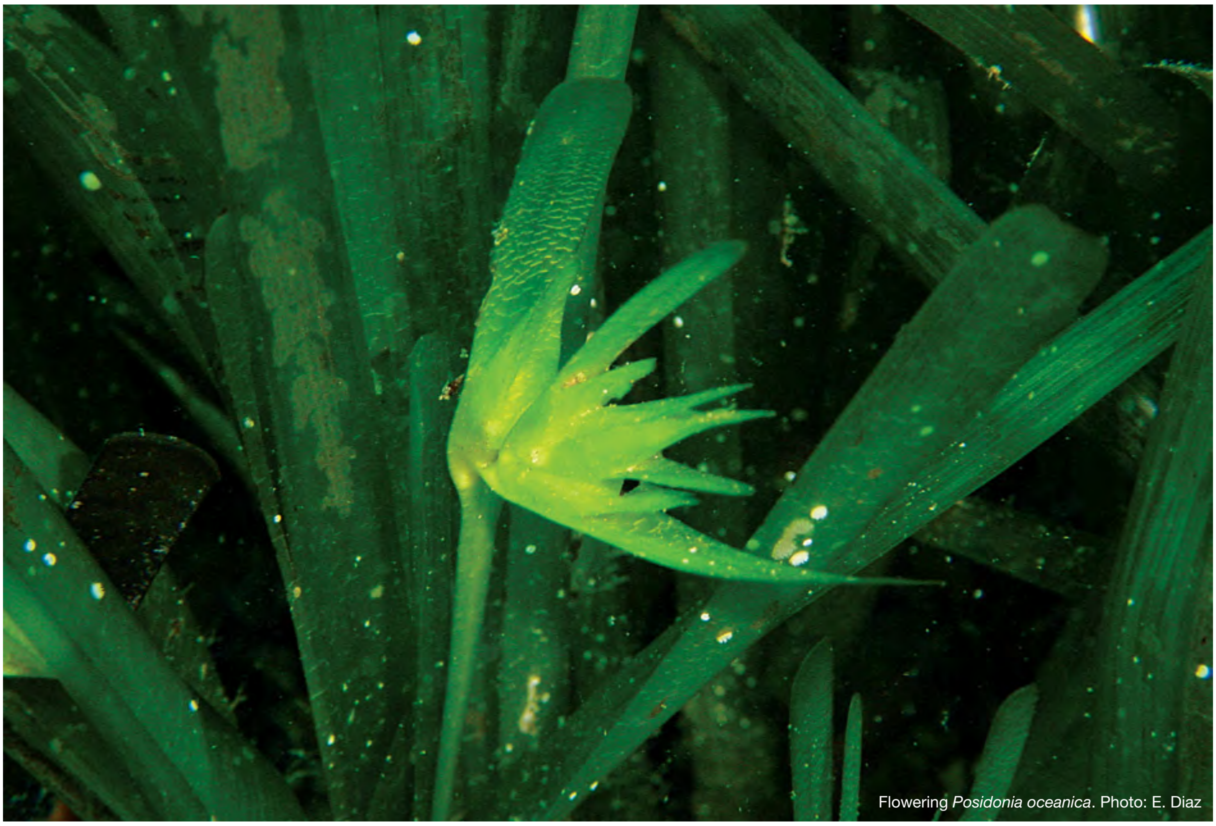
Recent studies seem to indicate that the intensity of flowering correlates with an increase in shoot mortality and negative net growth of the *Posidonia* meadows (Diaz-Almela *unpublished data*). Monitoring the occurrence of Posidonia flowering and fruiting in protected areas together with net changes in shoot density may provide the key to understanding possible trends in the future development of Posidonia meadows and what additional conservation measures should be undertaken.

PROPOSED MONITORING PROCEDURE

The presence/absence of reproductive structures (buds, inflorescences and inflorescence peduncles), shoot density and flowering intensity (per square metre and per shoot) should be measured annually (in October–November) along transects at a given depth, in one or more meadows of an MPA. Whenever possible, flowering and shoot intensity should be measured at different depths in large meadows, from the shallowest limit to near the deepest limit.

Shoot density and mortality are particularly important variables to measure as they can provide an indication of the net population growth of the meadow. Net changes in shoot density can be measured within permanent plots established in the meadow, and shoots within those permanent plots can be marked with cable ties. This procedure can reveal shoot mortality and recruitment, in addition to net changes in shoot density.

It is particularly useful to follow up changes in shoot density and/or mortality as this can provide a direct indication of the effects of climate change on the health of this key habitat. Flowering prevalence and intensity are variables that are easy to add into an existing monitoring programme, especially if it is performed annually between September and December. Temperature sensors placed in the same localities can provide additional data for potential correlation with the observations in the meadows.



Flowering *Posidonia oceanica*. Photo: E. Diaz

3. Episodic events

Since the mid-1970s, large-scale episodic events such as disease epidemics, mass mortalities and biological population blooms have been occurring in marine environments with increasing frequency, intensity, variety and range (Harvel *et al.*, 1999; Hayes, 2001). There is some evidence that climatic anomalies are the underlying (direct or indirect) cause of many of these events (Harvel *et al.*, 1999, 2002). Episodic weather events such as storms change freshwater flows and the export of nutrients to coastal waters, and also affect the salinity of coastal ecosystems. Temperature anomalies, even of short duration, can also trigger population explosions of species such as jellyfish, toxic blooms of phytoplankton, blooms of harmful benthic algae, mucilaginous blooms, and pathogens causing mass mortalities of marine organisms and/or serious harm to tourism and coastal industries.

INDICATOR

Presence of species blooms

Jellyfish blooms

Climate change may be contributing to the increasing frequency and intensity of jellyfish blooms around the world. Jellyfish are opportunistic organisms, responding quickly to environmental changes by increasing feeding, growth and reproduction under optimal conditions (Richardson *et al.*, 2009; Boero, 2013). Beyond their seasonal changes, some sporadic bloom events may also be associated with increased temperatures. High abundances of gelatinous species in the mediterranean Sea have been associated with variations in water mass and high salinity as well as warm temperatures. Changes in the flow of rivers due to dams and other constructions can change the salinity of coastal waters, attracting jellyfish to coastal areas. Moreover, the release of predation pressure on jellyfish, following the reduction in the populations of their main predators due to fishing, is also likely to be playing a significant role in the more frequent occurrence of jellyfish blooms.
Blooms in the Mediterranean usually involve the jellyfish *Pelagia noctiluca*, *Cotylorhiza tuberculata*, *Rhizostoma pulmo*, *Rhopilema nomadica* (a non-native species) and the common jellyfish *Aurelia aurita*, as well as ctenophore species such as *Mnemiopsis leidyi* and *Beroe ovata*.

PROPOSED MONITORING PROCEDURE

In order to track these types of episodic events, several monitoring approaches involving public participation have been developed in certain countries and at Mediterranean level. The CIESM JellyWatch Programme[3] is one of these. It was set up to gather time baseline data on the frequency, extent and persistence of jellyfish outbreaks across the Mediterranean Sea.

3. *http://www.ciesm.org/marine/programs/jellywatch.htm*

Blooms of jellyfish like *Pelagia noctiluca* are becoming more common in the Mediterranean.

Photo: C. Suárez, OCEANA

MPA CASE STUDY **3**

Warm marine waters threaten indigenous Mediterranean coral

Columbretes Islands Marine Reserve (Spain). Photo: J. M. Dalmau

Cladocora caespitosa is the only colonial coral native to the Mediterranean that lives in permanent symbiosis with microscopic algae within the living coral. Its colonies may join to form reef-like structures up to several square metres in diameter and more than 1 metre in height, harbouring a rich community of fauna among their branches.

Large living coral banks are rare but can be seen in locations such as Columbretes Islands Marine Reserve (Spain) or Mljet National Park (Croatia), and smaller banks are found at Cap de Creus and Medes Islands MPAs (Spain), Port Cros National Park (France), Miramare MPA (Italy), the National Park of Brijuni (Croatia) and Strunjan Nature Reserve (Slovenia).

Over the past 10 years, seawater warming has led to recurrent mass mortalities in *C. caespitosa*. These events are becoming more frequent and widespread and are severely affecting this coral in many Mediterranean locations, including Islas Columbretes, Strunjan and the Gulf of Trieste (Kersting and Linares, 2009; Climaparks News, 2012). A rise in sea temperature by a degree or more above the average for extended periods of time or an increase in maximum temperature can cause coral necrosis (tissue death).
Furthermore, the spread of invasive algal species, such as *Caulerpa racemosa* and *Lophocladia lallemandii*, is threatening this coral in Mljet (Croatia), Columbretes Islands and other locations (Kružic and Benkovic, 2008; Kersting and Linares, 2012). Since 2003, up to 50% of *Cladocora* colonies in Islas Columbretes have died in repeated events in response to higher summer water temperatures (Kersting, pers. comm.). Comparable phenomena have recently been observed in Strunjan Nature Reserve as well as other locations in the Gulf of Trieste (Kersting and Templado, 2006; Climaparks news, 2012).

The percentage of coral cover affected by necrosis and the presence of disease outbreaks could be valid indicators of Mediterranean climate change and could be used for monitoring the resilience of coral populations.

Necrosis of *Cladocora caespitosa* in Columbretes Marine Reserve. Photo: D. Kersting

INDICATOR

Mass-mortality events

In recent years, rocky coastal habitats have been badly hit by several mass-mortality events. The most severe reported events affected large areas (more than 1,000 km of coastline) and the populations of some 40 macrobenthic species belonging to several different phyla (sponges, cnidarians, bryozoans, molluscs and ascidians) in the north-western Mediterranean. There have been reports of similar happenings in other parts of the Mediterranean. Habitat-forming species, including gorgonians and sponges, have suffered the worst impact down to depths of 45 m.

In general, these events have been associated with an anomalous rise in seawater temperatures in late summer and early autumn. Under these conditions organisms have suffered from a variety of stressors, including energetic constraints, physiological stress, reaching thermal tolerance limits and development of thermo-dependent pathogens, leading to the observed mortality events.

PROPOSED MONITORING PROCEDURE

In order to monitor the effects of mass mortalities within MPAs, scuba diving surveys carried out by technical diving teams, MPA personnel or recreational diving centres should be conducted in late summer or early autumn. The surveys should encompass several sites and the most representative habitats in each MPA. The species affected during past mass mortalities can be used a priority list for surveys (see MPA Case Studies 2 & 3). Annual surveys carried out even in years when there are no apparent signs of mortality are important to provide a good baseline for assessing subsequent impact. Two kinds of survey can be carried out:

- Qualitative surveys report on species showing clear-cut signs of recent necrosis, such as denuded skeletons in gorgonians, sponges and scleractinian corals.

- Quantitative surveys report on the degree of impact on populations of certain species. During the surveys the goal is to observe the state of specimens — that is, whether they are healthy or show signs of partial or total mortality — along random transects or within random quadrats, depending on the abundance of the targeted species. In order to provide a representative impact value, surveys should include observations on a significant number of specimens (150–300) for each species at each site. From these surveys the percentage of affected specimens in each population can be used as the main indicator.

MPA CASE STUDY **4**

Thriving invasive alien species

New marine invasions have been recorded in increasing numbers throughout the Mediterranean Sea, including in many MPAs (Otero *et al.*, 2013). Rising water temperatures and climate fluctuations, together with the ability of many of these species to tolerate a broader thermal range than native species, are partly responsible for their rapid and successful spread (CIESM, 2008).

Unfortunately, there are not yet many effective measures for fighting marine invasions, which highlights the importance of early detection, the development of rapid response actions and the periodic monitoring of sites, especially vulnerable habitats.

Photo: B. Weitzmann

The invasive red seaweed *Asparagopsis armata* probably introduced into the Mediterranean by aquaculture disperse with water currents, attached to floating objects.

In the Montgrí, Illes Medes i Baix Ter Nature Park (Catalan Coast, Spain), surveys for the early detection and monitoring of invasive species are conducted every two years with the assistance of researchers from the CEAB-CSIC Institute. The monitoring is performed by scuba divers at several stations along the coast and around the islands, exposed headlands and open-sea rocks, from the surface to the maximum depth at sediment level. The communities and species present are identified and their relative abundances are estimated. The monitoring programme also keeps an eye on the abundance of alien species such as the algae *Asparagopsis armata*, *Womersleyella setacea* and *Dictyota cyanoloma*, the coral *Oculina patagonica* and the calcareous sponge *Paraleucilla magna.*

Standard, periodic monitoring of these species provides the foundation for assessing the combined effects of climate change and invasions as well as any feasible management response in the MPA environment.

4. Shifts in species distribution patterns

Rapid and significant shifts in the ranges of non-native fishes, crabs and other invertebrates have been recorded in the Mediterranean in recent decades (CIESM, 2008). Native species are also moving northwards and/or to greater depths in response to warmer waters. Besides, the Mediterranean is threatened by introduced non-native species. Some of these species have warm-water affinities and the rising temperatures could be favouring their spread (see Case study 4). Overall the shifting distribution of native and alien species may modify species interactions (competition, predation, etc.) and may ultimately result in the loss of species, including protected species, and changes to local communities.

Shifting distributions can therefore lead to a number of new challenges for MPA managers, such as the arrival of invasive alien species, the loss of protected species or major changes in marine ecological communities.

Long-term data can reveal the arrival of any warm-water and alien species or shifts in the distribution and abundance of cold-water species within MPAs.

INDICATOR

Changes in ranges, distributions and abundance of temperature-sensitive species

Species that tolerate a wide range of temperatures may not exhibit a response to increasing sea-surface temperatures over a short time period. Some species, however, are more sensitive and respond quickly, and their ranges may shift further north or to greater depths as a result of thermal stress caused by the rising temperatures.

PROPOSED MONITORING PROCEDURE

The presence and abundance of climate-sensitive species should be monitored in each MPA over the long term to detect range shifts. These results should be compared with those from other MPAs and across a network of sites. Such monitoring data will constitute the MPA's baseline for future reference (see Case Study 5).

The aim of the survey is to monitor the presence and distribution of key climate warming indicator species across the Mediterranean or over a smaller region. The methodology adopted by the CIESM Tropical Signals Programme uses three types of protocol, suited to the intertidal zone, shallow waters (0–3 m) and the zone from the seabed to 30 m depth, which are surveyed by means of appropriate techniques (snorkelling and diving). The methods are based on replicated visual searches lasting for a fixed time and covering a specific stretch of coastline or seabed, where an observer records the presence or absence of species and makes a semi-quantitative assessment of their abundances using pre-determined categories: abundant, common, frequent, occasional and rare (the 'ACFOR' scale).

The parrot fish, *Sparisoma cretense* more common along the eastern and southern Mediterranean coasts is moving towards northern areas.

Photo: A. Can - www.alpcan.com

The protocols have the objective of recording:

1. Range extensions of native warm-water species;

2. Range contractions, 'deepening' and/or decline of native cold-water species;

3. New introductions and range extensions of tropical non-native species.

A guide to identification and monitoring protocols for marine invasive species of tropical origin can also be found in the recent publication *Monitoring marine invasive species in Mediterranean Marine Protected Areas (MPAs): A strategy and practical guide for managers* (Otero *et al.*, 2013).

In addition to methods for monitoring and tracking invasive species, another technique that could be used to track particular biodiversity changes in benthic communities along a depth gradient is the use of ground-based photo points (see MPA Case Study 6). This method can produce a rapid, cost-effective assessment of trends in the biodiversity of benthic communities over time and show whether climate change is causing significant shifts in species distributions.

MPA CASE STUDY **5**

Shifting spatial distribution of marine species

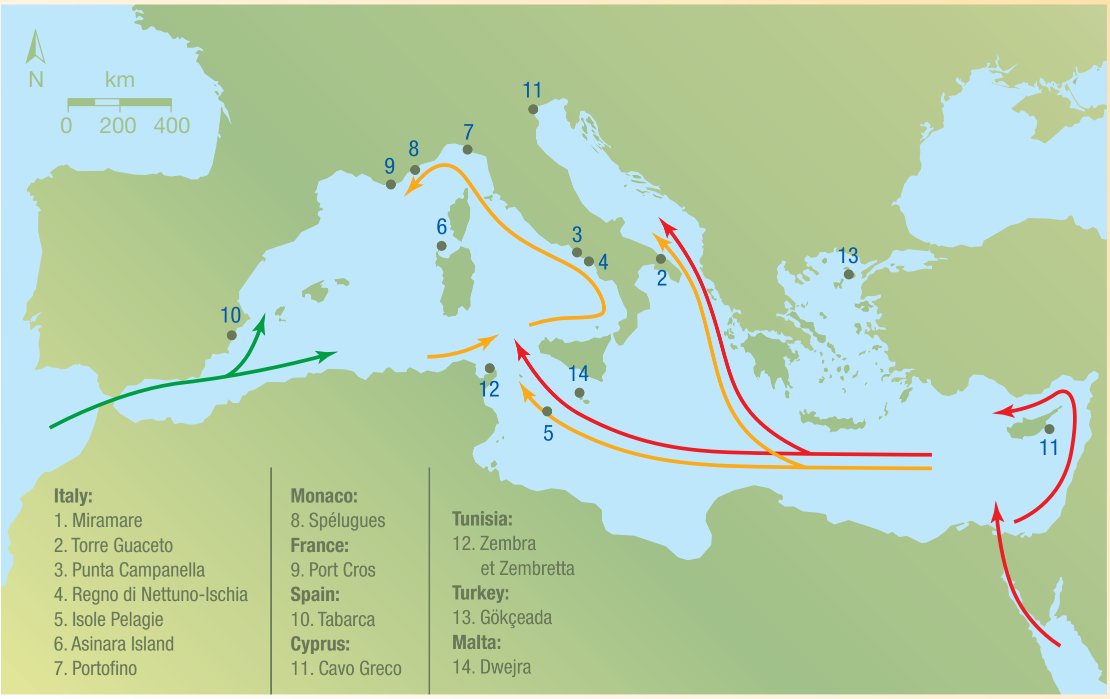
Throughout the Mediterranean Sea, species are moving in response to climate change. Subtropical species normally occur mostly in the south-eastern region, where water temperature is higher than average, while cold-adapted species generally occupy the northern regions. Higher temperatures are shifting the geographical distributions of many species, often moving them further north or to greater depths.

In areas such as the Gulf of Lion and the northern Adriatic Sea, the coldest areas of the Mediterranean coast, these shifts might make species more vulnerable to climate variations. Some species might not be able to adapt to changing conditions and could experience population declines as a result. The combination of these potential effects with the arrival of invasive species, changes in natural communities or the potential loss of particularly endangered or endemic species poses new challenges for MPA managers.

For example, in Miramare MPA (Adriatic Sea, Italy), long-term monitoring data have revealed substantial regressions in the area covered by the Adriatic endemic brown alga *Fucus virsoides* and the appearance of other species such as the seagrass *Cymodocea nodosa* and the brown algae *Cystoseira* spp. New warm-water fish species such as the Mediterranean rainbow wrasse *Coris julis,* barracudas *Sphyraena* spp., and the dusky spinefoot *Siganus luridus* have also recently been observed for the first time in the area (Piron *et al.*, 2007; Poloniato *et al.*, 2010).

In order to reveal the changes and range shifts in marine species, many Mediterranean MPAs have joined the broad-scale survey at Mediterranean level conducted by CIESM scientists and other collaborators under the CIESM Tropical Signals Programme. The monitoring results are expected to improve our understanding of how the changing distribution of species will affect the balance of native communities and what new opportunities might be created.

Main routes of species range expansion [Mediterranean natives (orange), Atlantic migrants (green), and Red Sea migrants (red)] and MPAs participating in the Tropical Signals Programme.



5. Migration changes

Evidence from regional studies of climate change effects have shown that some migrant species are shifting their migration departure time, the route they take or the time of their arrival in their wintering or breeding grounds (UNEP-CMS, 2006). Discrepancies between the new times of arrival or breeding and the availability of food supplies could have important consequences for the productivity and abundance of these populations or their prey.

Long-term data can reveal trends in the spring or autumn arrival dates of these migratory species in MPAs.

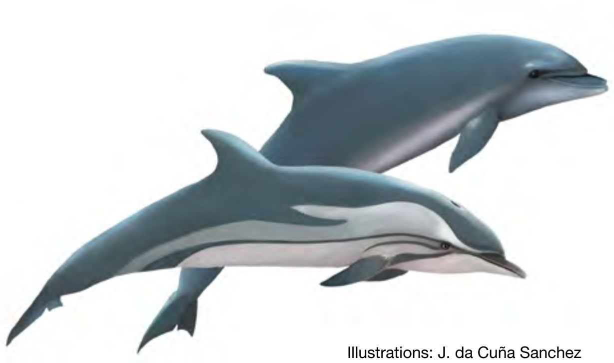
INDICATOR

Recorded arrival dates of migratory species

Analysis of long-term data can reveal timing shifts in selected species. Some large migratory fish species are already responding to warming (Bombace, 2001). A well-documented example is the time when bluefin tuna *Thunnus thynnus* and amberjack *Seriola dumerilii* in the northern and central Mediterranean return to their winter territories, which has shifted from autumn to mid-winter (Bombace, 2001). Spawning condition is also closely correlated with water temperature.

Migratory changes could in turn affect the productivity of these populations and the livelihoods of the fishing communities depending on them.

In the case of most marine mammals, their distribution, abundance and migration are strongly influenced by prey availability. The habitat of the bottlenose dolphin



Illustrations: J. da Cuña Sanchez

Tursiops truncatus was found to shift from coastal to open waters in some areas during the abnormal temperatures recorded in 2003. Similar observations could give an idea about changes in their migration patterns. Oceanographic variation associated with climate change (e.g. temperature anomalies, stronger thermal stratification or differences in nutrient loads) can affect the abundance and distribution of prey species, producing a mismatch that may lead cetaceans to choose different habitats and feeding strategies in order to adapt to the new conditions.

PROPOSED MONITORING PROCEDURE

MPA managers could select a number of migrant species that are common in their areas and keep a record of their spring or autumn arrival dates. Suitable species could be the fin whale *Balaenoptera physalus,* striped dolphin *Stenella coeruleoalba* and bottlenose dolphin *Tursiops truncatus.* Alternatively, specific campaigns could be organized annually to search for the selected species and estimate their abundance.

Local fishermen or other stakeholder groups might also be able to contribute invaluable information on trends in migratory fish of commercial importance (such as *Sphyraena viridensis*, *Caranx crysos*, *Sparisoma cretense*, *Coryphaena hippurus*, *Seriola dumerili* and *Balistes capriscus*), particularly to estimate their abundance (e.g. by counts of fish caught) and the timing of fish availability in or close to MPAs.

Thunnus thynnus. Photo: K. Ellenbogen, OCEANA

MPA CASE STUDY **6**

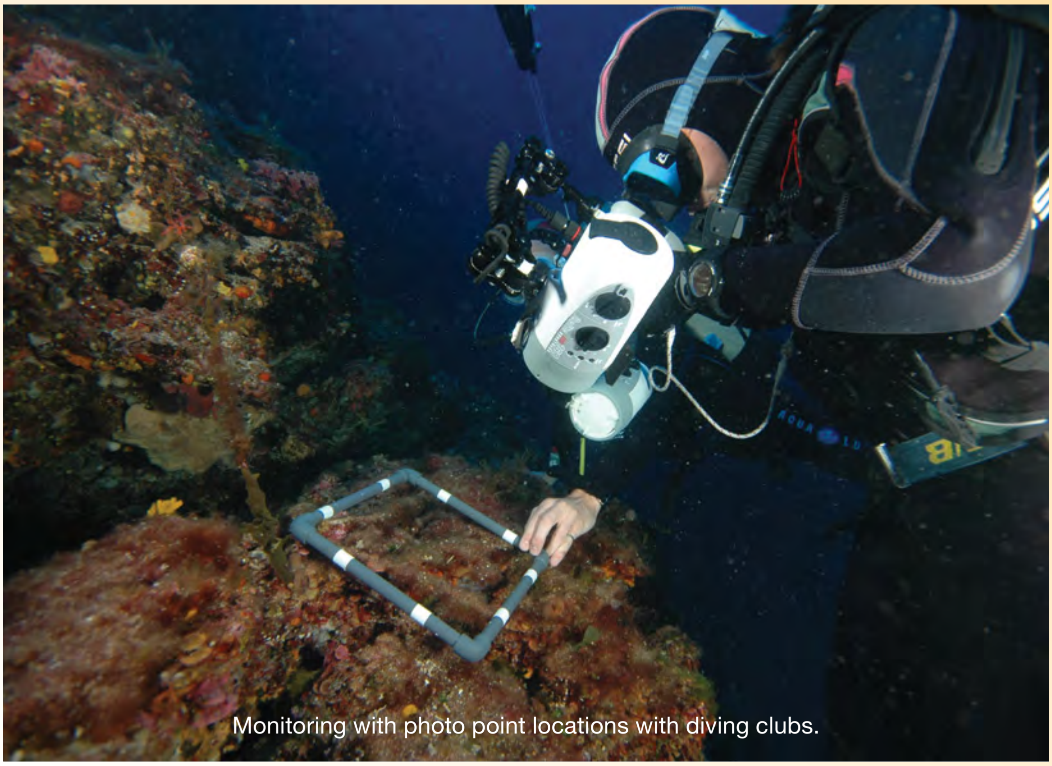
Increasing public awareness and participation in monitoring efforts

Seabed photo points are an inexpensive and very effective technique for monitoring changes in benthic marine communities, in which photographs are taken from fixed points at intervals over a period of time. The technique is being used, for example, in Estrecho Natural Park (Andalusia, Spain) in the Gibraltar Strait, where a photographic monitoring programme has been set up in rocky habitats with the help of local diving clubs, nature lovers and university researchers.

The monitoring involves photo point locations at 10–15 sites below the 20 metre depth band, where coastal impacts are more mitigated. Here, markers enable the divers to easily identify the sites, where they record their observations at different times of the year. The composition and abundance of the benthic communities in the various quadrats are monitored to reveal range shifts and the establishment of new species. Particular attention is given to temperature indicator species such as the orange coral *Astroides calycularis* and the red gorgonian *Paramuricea clavata* by examining the coral surface area over time.

A time series of digitized photographs covering several years, collected with the assistance of researchers from the Marine Biology Laboratory of Seville University, should provide the protected area's management team with a useful tool for assessing changes in the benthic community under climate change. The methodology also makes it possible to assess how populations respond to climate change in the absence of certain coastal pressures and provides an opportunity to involve local communities in monitoring the marine environment.

Astroides calycularis. Photo: M. Otero



Monitoring with photo point locations with diving clubs.

Photo: J. Garrabou

Integrating climate change into MPA monitoring

The indicators and monitoring procedures described above should help determine what is changing in MPAs and what individual actions, if any, can be taken to address these changes. Regular surveys and specific monitoring programmes can help reveal the vulnerabilities of the ecosystem and suggest possible adaptations to provide the best chance for MPAs to adapt and recover from the threats ahead.

For individual MPAs, the first steps in establishing a monitoring programme that integrates climate change objectives should be to analyse existing monitoring methods and adopt monitoring targets at different scales, and then to develop a sampling strategy based on the key elements identified for the particular sites. Monitoring using automatic devices such as temperature loggers and salinity sensors can produce a considerable amount of information on environmental conditions for a limited outlay. This can be supplemented with field-based monitoring at specific sites to examine key characteristics of marine communities and species, in order to determine the particular effects of climate change. As further information is generated by regional climate change surveillance programmes and by MPAs, it may prove necessary to place greater emphasis on specific issues or to add particularly vulnerable sites or habitats in order to assist with adaptive planning.

From a management effectiveness perspective, management plans should not only assess whether there is evidence of climate change impact but also measure the management improvements resulting from the mitigation of this impact and its potential outcomes.

Awareness-raising activities can further help to create community understanding of issues and develop effective partnerships for future actions. The funding for a monitoring programme might not currently be available, but MPA managers or administrative bodies should actively seek to form partnerships with other organizations involved in similar programmes to find the funding required.

An effective MPA network will require coordinated, integrated programmes that address a combination of key elements, and the monitoring involved will be improved through international collaboration and/or integration with existing surveillance networks.

The development of collaborative e-tools (web platforms) devoted to the management and analysis of the data generated by MPA climate change monitoring schemes should be considered an essential step in tracking climate change effects in the Mediterranean. The adoption of common standard monitoring protocols across the MPA network would facilitate the development of such web platforms. The results of climate change monitoring and reported impacts could be uploaded and presented on them, forming a basis for creating shared databases, through which local situations could be displayed and presented at a regional level.

Coastal marshes and seagrasses, particularly *Posidonia oceanica,* are important habitats for carbon sequestration and storage (Pergent *et al.*, 2012, see page 21). Currently, carbon emissions from the conversion of vegetated coastal ecosystems are not included in emissions accounting or carbon market protocols, but it is highly likely that they will be in future, providing a potential alternative source of funding for conserving these habitats in MPAs. It would be useful to develop a study or programme to examine the specific contribution made by these habitats and to monitor carbon flow in them in order to help assess their importance in mitigating climate change.

Tissue necrosis in the Mediterranean sponge *Crambe crambe*.

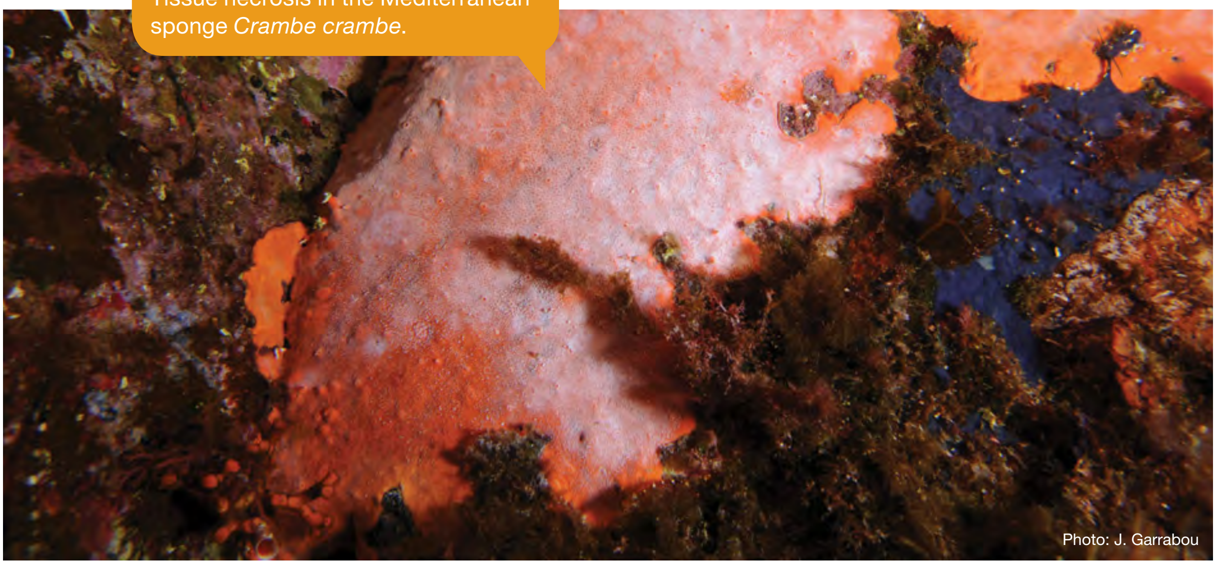


Photo: J. Garrabou

Climate adaptation opportunities:
Towards a future common strategy for MPAs

Global warming is predicted to last for several centuries even if greenhouse gas emissions decline substantially, making further degradation of the marine ecosystem and some degree of change inevitable. Adaptation, as it moderates vulnerability to climate change, is therefore an essential strategy for reducing the severity and cost of climate change impacts. Although marine communities will adapt naturally, the importance of MPA environments means that influencing the direction of adaptation at some sites would be beneficial and, in some cases, essential to protect their biodiversity values.

Adaptation actions and strategies provide a complementary approach to reducing the likelihood of adverse impacts. In recent years, some individual Mediterranean MPAs have started to gather information on the impact of climate change in their areas, but there have not yet been any significant efforts to establish a regional strategy to increase the capacity of MPAs to adapt, manage and monitor impact. To help focus this future strategy at the Mediterranean MPA network level, a few key action areas are highlighted below.

1. Conserving and managing MPA habitats under climate change

MPA managers have a range of options for mitigating the effects of climate change and adapting to that change (see summary by Di Carlo and Otero, 2012; also Keller *et al.*, 2009; NRC, 2010). The options available for terrestrial zones include maintaining vegetation along beaches and the coast to create natural shading; reusing and recycling waste; incorporating climate change considerations into the planning of infrastructure maintenance and replacement; and minimizing coastal modifications so as to retain natural habitats that protect water and species and regulate local climate.

Identifying and mapping high-priority marine areas for conservation — particularly those currently experiencing rapid climate impact and those that act as refugia and are likely to be resilient to climate change and/or support a broad array of species — will help in prioritizing future conservation efforts in the marine environment of MPAs.

Additionally, managers should assess the possibility of restricting the movement of invasive non-native species and reducing non-climate stressors in vulnerable habitats. Appropriate actions include limiting fishing gear and species-specific catches. It is especially important to control species that are detrimental to sensitive fish species and to encourage those that perform major ecological roles or compete with alien species, as such measures can assist in adapting to disturbances while maintaining the resilience of marine habitats.

2. Enhancing the capacity for effective management

The ability of management to help their protected areas adapt to climate change will be crucial to the future of Mediterranean MPAs. Incorporating adaptation into MPA management requires an overall view of the marine area (and any adjacent land areas) and integration across all sectors, including commercial and recreational fisheries, tourism, science, etc. Through partnerships with scientists, communities and other coastal stakeholders, MPA managers can take part in efforts to maintain the capacity of the marine environment to cope with climate change.

MPAs need to be evaluated to determine how effective they are in the face of climate change, in order to improve their management (Tempesta and Otero, 2013). Hence, monitoring plays a vital role in climate change adaptation. It can alert managers to changes in the environment and their associated impacts and consequences in the marine communities.

3. Increasing knowledge and information on impacts for adaptive management

The effective adaptive management of MPAs requires both long-term monitoring and collaboration with local and regional partners to implement this programme. Some of the indicators described previously and the monitoring strategies proposed will have to be refined and enhanced on the basis of future scientific knowledge.

Monitoring results can be used to identify key vulnerable habitats and communities and, as information is gathered, to aid in developing effective management strategies. The most important of such adaptation strategies will include creating no-take zones; adjusting buffer zones to protect areas of upwelling and nursery habitats that provide high marine productivity; identifying and incorporating resilient sites (refugia) into the management design to facilitate the recovery of less resistant areas; and reducing local impacts and stressors in projected high-risk (vulnerable) areas.

By increasing communication with scientists and participating in meetings and forums, managers can ensure that research objectives are aligned with their MPAs' needs and priorities for addressing climate change. The participation of MPAs in research programmes might allow these goals to be incorporated in research funding opportunities and in feedback to the managers.

4. Using decision support tools for adaptive management and dialogue

Decision support tools for MPA managers, such as vulnerability and risk assessments, strategic habitat conservation approaches and scenario planning, can be created in pilot projects to help improve the understanding of adaptation options and assist decision making under uncertain conditions. Existing knowledge should be collated, the climate analysed and data integrated to produce readily usable information, which can help managers to rapidly assess climate change impacts, facilitate the adaptation of individual species, increase habitat resilience and identify pressures that may conflict with ecosystem needs.

As climate change models become more precise through the acquisition of local and regional information, the modelling of different scenarios could help describe the varying vulnerabilities of the MPA network. These results, together with knowledge of the direct and indirect effects of climate change, will help to determine the range of possible mitigation measures and adaptive strategies in MPAs.

Collaboration and dialogue with research groups and other institutions can provide guidance on conducting assessments and reporting, and can encourage other stakeholders to become involved in effectively managing MPAs in a changing climate.

5. Increasing awareness and information

Communicating the benefits of MPAs, their vulnerabilities and expected future changes can motivate stakeholders (the public and nature resource managers) to take part in planning efforts and actions to mitigate impacts. Protected area information centres should inform visitors about what climate change means and what effect it may have on the MPA.

Moreover, raising awareness among local residents and MPA users is vitally important, and involving them in monitoring activities can be an effective way to engage communities and raise their awareness of climate change.

6. Building a Mediterranean monitoring framework that incorporates the variety of MPAs' situations

Designing a suitable monitoring programme that accommodates the various degrees of complexity in Mediterranean MPAs and takes into account the current monitoring efforts in the region at several levels is a complicated task that will need several phases of development. Individual MPAs should make use of existing local monitoring programmes and the indicators of climate change described above as a relatively inexpensive way of starting to collect information to support adaptive management. The various research and government agencies involved in monitoring in each particular region should work together to increase the efficiency of monitoring activities involving MPAs.

A number of MPA 'sentinel sites' in specific Mediterranean regions could be established to monitor climate change impacts and responses in more detail. These sentinel sites could perhaps be selected because they occupy important locations, are involved in current collaborative projects with research institutions, are the subject of historical data, or display higher resilience or greater vulnerability to climate change impacts.

At the MPA network level, further discussion will be needed on how information should be brought together and analysed. Findings and results will need to be fed back to the MPAs. There, the focus should be on examining how this information is to be followed up and what actions should be taken at local level.

7. Sharing experiences

The final key action area consists of reporting on the progress achieved in adaptive management in response to the challenges of climate change, sharing management experiences, and thereby increasing our understanding of climate responses and effects at local levels. These actions are key to the success of the Mediterranean MPA network in mitigating the impact of climate change.

The results of these efforts will help to increase awareness and understanding of present and future impacts and highlight ways of working together in a more strategic, efficient and less costly manner.

Medes Islands MPA. Photo: J. A. González Nieto

In conclusion

There are still large gaps in our knowledge about the future impact of climate change, but we can already see some early signs of its effects on marine communities in the Mediterranean. Climate change is likely to have drastic effects on the habitat of the flora and fauna of MPAs but the impact will vary between different Mediterranean regions and between individual MPAs within each region. MPAs located in the more northerly Mediterranean areas could have an important role to play in preserving endemic and native species as they shift their ranges with warming temperatures. Local hydrodynamic conditions or other factors might also result in different vulnerabilities for the marine communities within those MPAs. Overall, this makes it difficult to delineate specific adaptation approaches for the entire MPA network. Effective management will thus require a flexible approach, in which capacity building and monitoring will be crucial for understanding the changes that occur and informing the conservation approaches to be adopted, which will have to be adjusted as new information becomes available.

The dusky grouper *Epinephelus marginatus*. Photo: J. Garrabou

For further reading

Allen Consulting, 2005. 'Climate Change Risk and Vulnerability'; Final report to the Australian Greenhouse Office by The Allen Consulting Group, March 2005, 159 pp.

Azzurro, E., Moschella P., Maynou F., 2011. Tracking Signals of Change in Mediterranean Fish Diversity Based on Local Ecological Knowledge. PLoS ONE 6(9): e24885. doi:10.1371/journal.pone.0024885.

Azzurro, E., Soto S., Garofalo G., Maynou, F., 2012. *Fistularia commersonii* in the Mediterranean Sea: invasion history and distribution modeling based on presence-only records Biological Invasions, DOI 10.1007/s10530-012-0344-4.

Ben Rais Lasram, F., Guilhaumon, F., Mouillot, D., 2010. Global warming and exotic fishes in the Mediterranean Sea: introduction dynamic, range expansion and spatial congruence with endemic species. In: Golani D, Appelbaum-Golani B (eds) Fish invasions of the Mediterranean Sea: change and renewal. Pensoft Publishers, Sofia-Moscow, pp 35–56.

Bensoussan, N., Linares, C., Cebrian, E., Crisci, C., Kipson, S., Teixido, N., Romano, J.C., Bianchimani, O., Kersting DK., Lorente, A., Riera i Arago, V., Cadene, F., Laffon, J.F., Payrot, J., Bachet, F., Charbonnel, E., Zuberer, F., Pairaud, I., Sartoretto, S., Bergere, H., Houard, T., Dominici, J.M., Harmelin, J.G., Garrabou, J., 2011. T-MedNet: A temperature network for high resolution and long term monitoring of Mediterranean coastal waters stratification. Vulnerability of coastal ecosystems to global change and extreme events - At the crossroads of knowledge to the benefit of coastal and marine ecosystem services. 18-21 October 2011, Biarritz, France.

Bindoff, N.L., J. Willebrand, V. Artale, A., Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley and A. Unnikrishnan, 2007. Observations: Oceanic Climate Change and Sea Level. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bombace, G., 2001. Influence of climatic changes on stocks, fish species, and marine ecosystems in the Mediterranean Sea. Archives of Oceanography and Limnology 22, 67–72.

Boero, F., 2013. Review of jellyfish blooms in the Mediterranean and Black Sea. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 92. Rome, FAO 2013. 53 pp.

Boudouresque C.F., 2004. Marine biodiversity in the Mediterranean: status of species, populations and communities. Sci. Rep. Port-Cros natl Park, 20 : 97-146.

Calvo, E., Simó R., Coma R., Ribes M., Pascual J., Sabatés A., Gili J.M., Pelejero C., 2011. Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. Climate Research 50: 1–29.

Cebrian, E., Uriz M.J., Garrabou J., Ballesteros E., 2011. Sponge Mass Mortalities in a Warming Mediterranean Sea: Are Cyanobacteria-Harboring Species Worse Off? PLoS ONE 6(6): e20211. doi:10.1371/journal.pone.0020211.

Cerrano, C., Bavestrello G., Bianchi C.N., Cattaneo-Vietti R., Bava S., Morganti C., Morri C., Picco P., Sara G., Schiaparelli S., Siccardi A., Sponga F., 2000. A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (northwestern Mediterranean), summer 1999. Ecol. Lett. 3:284–293.

Chemello, R. C. R. and S. Silenzi, 2011. Vermetid reefs in the Mediterranean Sea as archives of sea-level and surface temperature changes. Chem. Ecol. 27: 121-127.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007. Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

CIESM, 2008. Climate warming and related changes in Mediterranean marine biota. No. 35 in CIESM Workshop Monographs (F. Briand, Ed.), 152 pp, Monaco.

Climaparks news, 2012. Monitoring of marine biodiversity in Landscape park Strunjan. http://climaparks.eu/cp2/node/326

Coll, M., Piroddi C., Steenbeek J., Kaschner K., Ben Rais Lasram F., et al., 2010. The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. PLoS ONE 5(8): e11842. doi:10.1371/journal.pone.0011842

Coma, R., Ribes M., Serrano, E., Jiménez E., Salat J., Pascual J. 2009. Global warming-enhanced stratification and mass mortality events in the Mediterranean. Proc. Natl. Acad. Sci. USA 106:6176–6181.

Crisci, C., Bensoussan, N., Romano J.-C., Garrabou J., 2011. Temperature Anomalies and Mortality Events in Marine Communities: Insights on Factors behind Differential Mortality Impacts in the NW Mediterranean. PLoS ONE 6(9): e23814. doi:10.1371/journal.pone.0023814.

Critto, A., Gallina, V., Torresan, S., Rizzi J., Zabeo, A., Carniel, S., Sclavo M., Marcomini, A., 2012. Coastal erosion impacts under climate change scenarios at the regional scale in the North Adriatic Sea. Geophysical Research Abstracts, Vol. 14, EGU2012-11590.

Danovaro, R., Fonda Umani S., Pusceddu A., 2009. Climate Change and the Potential Spreading of Marine Mucilage and Microbial Pathogens in the Mediterranean Sea. PLoS ONE 4(9): e7006. doi:10.1371/journal.pone.0007006.

Day, J., Dudley, N., Hockings, M., Holmes, G., Laffoley ,D., Stolton S. and S. Wells, 2012. Guidelines for applying the IUCN Protected Area Management Categories to Marine Protected Areas. Gland, Switzerland: IUCN. 36 pp.

Denman, K., Christian, J.R., Steiner, N., Pörtner, H-O., and Nojiri, Y. 2011. Potential impacts of future ocean acidification on marine ecosystems and fisheries: current knowledge and recommendations for future research. – ICES Journal of Marine Science, 68: 1019–1029.

Denman, K.L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox P. M., Dickinson R. E., Hauglustaine D., Heinze C., Holland E., Jacob D., Lohmann U., Ramachandran S., da Silva Dias P.L., Wofsy S. C. and X. Zhang, 2007. Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Diaz-Almela E., Marbá N., Duarte C.M., 2007. Consequences of Mediterranean warming events in seagrass (*Posidonia oceanica*) flowering records. Global Change Biology, 13: 224–235.

di Carlo, G., Otero M. (ed.), 2012. A changing Mediterranean coastal marine environment under predicted climate-change scenarios. A manager's guide to understanding and addressing climate change impacts in marine protected areas. MedPAN Collection, 9 pp.

Doney, S.C, Ruckelshaus, M., Duffy J.E, Barry, J.P, Chan, F., English, C.A, Galindo, H.M, Grebmeier J.M., Hollowed A.B., Knowlton N, Polovina, J., Rabalais, N.N., Sydeman, W.J., Talley, L.D., 2012. Climate Change Impacts on Marine Ecosystems. Annu. Rev. Mar. Sci. 4:11–37.

EEA Report No 12/2012. Climate change, impacts and vulnerability in Europe 2012. An indicator-based report, 304pp.

ETC CCA Technical Paper 1/2011. Methods for assessing coastal vulnerability to climate change. 93 pp.

EU COM, 2013, 216. Communication from the Commission to the European Parliament, the Council, the European Economic and social Committee and the Committee of the regions. An EU Strategy on adaptation to climate change, 11 pp.

Ferreira, O., J.A. Dias and Taborda, R., 2008. Implications of sea-level rise for continental Portugal. Journal of Coastal Research, 24, 317-324.

Fish, M.R., Cote, I.M., Gill, J.A, Jones, A.P., Renshoff, S. and Watkinson, A.R., 2005. Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat. Conservation Biology 19, 482-491.

Füssel, H. M., 2007. Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change, 17: 155-167.

Gabrié, C., Lagabrielle E., Bissery C., Crochelet E., Meola B., Webster C., Claudet J., Chassanite A., Marinesque S., Robert P., Goutx M., Quod C., 2012. Statut des Aires Marines Protégées en mer Méditerranée. MedPAN & CAR/ASP. Ed: MedPAN Collection. 260 pp.

Gambiani, D.D., Mayol, P., Isaac, S.J. and Simmonds, M.P., 2009. Potential impacts of climate change and greenhouse gas emissions on Mediterranean marine ecosystems and cetaceans. Journal of the Marine Biological Association of the United Kingdom, 89(1), 179–201 doi: 10.1017/S0025315408002476.

Garrabou, J., Coma R., Benssoussan, N., Chevaldonné, P. et al., 2009. Mass mortality in NW Mediterranean rocky benthic communities: effects of the 2003 heat wave. Glob. Change Biol. 15:1090–1103.

Goy, J., Morand, P., Etienne, M., 1989. Long-term fluctuations of *Pelagia noctiluca* (Cnidaria, Scyphomedusa) in the western Mediterranean Sea. Prediction by climatic variables. Deep-Sea Res. 36:269–279.

Hall-Spencer, J. M., Rodolfo-Metalpa, R., Martin, S. et al., 2008. Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature, 454, 96–99.

Harmelin, J.G., Robert, P., Cantou, M., Harmelin-Vivien, M., 2007. Long term changes in the dusky grouper (*Epinephelus marginatus*) population from a NW Mediterranean marine protected area, the national park of Port-Cros (France). *In:* Francour P., Gratiot J (Eds). 2007. Second International Symposium on the Mediterranean Groupers. Nice University publ., May 10-13th 2007, Nice: 154 pp.

Hayes, M.L., J. Bonaventura, T.P. Mitchell, J.M. Propero, E.A. Shinn, F. Van Dolah, and R.T. Barber, 2001. How is climate change and emerging marine diseases functionally linked? Hydrobiologia 460: 213–220.

Harley, C. D. G. and L. Rogers-Bennett, 2004. The potential synergistic effects of climate change and fishing pressure on exploited invertebrates on rocky intertidal shores. CalCOFI Reports 45: 98–110.

Harvell, C. D., Kim, K., Burkholder J.M., Colwell R. R., Epstein, P. R., Grimes, D. J., Hofmann, E. E., Lipp, E. K., Osterhaus, A. D. M. E.; Overstreet, R. M., Porter, J. W., Smith, G. W. and G. R. Vasta, 1999. Emerging marine diseases – Climate links and anthropogenic factors. Science 285: 1505–1510.

Harvell, C.D., Mitchell C., Ward J., Altizer, S., Dobson, A., Ostfelt, R. and M. Samuel, 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158–62.

Hughes, T.P., Baird, A.H., Bellwood, D.R. et al., 2003. Climate change, human impacts, and the resilience of coral reefs. Science, 301, 929–933.

IPCC, 2007. Climate Change 2007: Mitigation. Eds. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer, Working Group III contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Technical Summary, chapters 3 (Issues related to mitigation in the long term context) and 11 (Mitigation from a cross sectoral perspective).

IPCC Fourth Assessment Report, 2007. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., et al. (eds.)] (Cambridge, UK: Cambridge University Press). 996 pp.

Keller, B., Gleason D., McLeod, E., Woodley, C., Airamé, S., et al., 2009. Climate Change, Coral Reef Ecosystems, and Management Options for Marine Protected Areas. Environmental Management 44: 1069–1088.

Kersting, D.K., Linares, C., 2012. *Cladocora caespitosa* bioconstructions in the Columbretes Islands Marine Reserve (Spain, NW Mediterranean): distribution, size structure and growth. Marine Ecology 33: 427–436. doi: 10.1111/j.1439-0485.2011.00508.x.

Kersting, D.K. y Templado, J., 2006. Evento de mortandad masiva del coral *Cladocora caespitosa* (Scleractinia) en las Islas Columbretes tras el calentamiento anormal del agua del verano de 2003. XIV Simposio Ibérico de Estudios de Biología. Marina, Barcelona.

Kersting, D. K., Linares, C., 2009. Mass mortalities of *Cladocora caespitosa* in relation to water temperature in the Columbretes Islands (NW Mediterranean). ASLO Aquatic Sciences Meeting 2009. Nice, France.

Kružic, P. and Benkovic, L., 2008. Bioconstructional features of the coral *Cladocora caespitosa* (Anthozoa, Scleractinia) in the Adriatic Sea (Croatia). Marine Ecology, 29: 125–139. doi: 10.1111/j.1439-0485.2008.00220.x.

Lejeusne, C., Chevaldonné, P., Pergent-Martini, C., Boudouresque, C. F. and Pérez, T., 2010. Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea, Trends in Ecology and Evolution 25, 250-260.

Lionello, P (Ed), 2012. The climate of the Mediterranean region: From the past to the future. Elsevier Edit. 584 pp.

Marbá, N. and C. Duarte, 2010. Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality. Global Change Biology (2010) 16, 2366–2375, doi: 10.1111/j.1365-2486.2009.02130.x

Milazzo, M., Mirto, S., Domenici, P. and Gristina, M., 2013. Climate change exacerbates interspecific interactions in sympatric coastal fishes. Journal of Animal Ecology 82:468–477 doi: 10.1111/j.1365-2656.2012.02034.x

Mistri, M. and Ceccherelli V.U., 1996. Effects of a mucilage event on the Mediterranean gorgonian *Paramuricea Clavata*. 2. Population Recovery After Two Years. Italian Journal of Zoology 63 (3): 231-236.

Movilla, J., Calvo E., Pelejero C., Coma R., Ribes M., Serrano, E., Fernández-Vallejo, P., 2012. Calcification reduction and recovery in native and non-native Mediterranean corals in response to ocean acidification. Journal of Experimental Marine Biology and Ecology 438: 144-153.

NRC, 2010. Adapting to the Impacts of Climate Change. National Research Council. The National Academies Press, Washington, DC, USA.

Otero, M., Cebrian, E., Francour, P., Galil, B., Savini, D. 2013. Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): A strategy and practical guide for managers. Medpan North project. Malaga, Spain: IUCN. 136 pp.

Peck, M. and C. Mölmann, 2008. Resolving Climatic impacts on fish stocks Specific Targeted Research Project on “Modernisation and sustainability of fisheries, including aquaculture-based production systems”. 1.6 Report of WP1, Chapter 15 – Sprat. 12 pp.

Pergent, G., Ben Maiz, N., Boudouresque C.F., Meinesz A., 1989. The flowering of *Posidonia oceanica* over the past fifty years: a lepidochronological study. In: C.F. Boudouresque, E. Fresi, A. Meinesz & V. Gravez (Eds), "Second International Workshop on *Posidonia oceanica* Beds", GIS Posidonie Publ., Marseille: 69-76.

Pergent, G., Bazairi H., Bianchi, C.N., Boudouresque, C.F., Buia M.C., Clabaut, P., Harmelin-Vivien, M., Mateo, M.A., Montefalcone, M., Morri, C., Orfanidis, S., Pergent Martini, C., Semroud, R., Serrano, O., Verlaque, M., 2012. Mediterranean Seagrass Meadows: Resilience and Contribution to Climate Change Mitigation; A Short Summary. Gland, Suiza y Málaga, España: IUCN. 40 pp.

Piron, M., Balasso, E., Poloniato, D. and R. Odorico, 2007. First record of *Coris julis* in the Miramare Nature Reserve. Annales, Ser. Hist. Nat., 17, 2, 165-170.

Poloniato, D., Ciriaco, S., Odorico, R., Dulcic, J., and L. Livej, 2010. First record of the dusky spinefoot *Siganus luridus* (Rüppell, 1828) in the Adriatic Sea. Annales, Ser. Hist. Nat., 20, 2, 161-166.

Pusceddu, A., Mea, M.; Gambi, M. Bianchelli, S., Canals, M. Sanchez-Vidal, A., Calafat, A. Heussner, S., Durrieu, X. Avril, J. Thomsen, L. García, R. and R. Danova, 2010. Ecosystem effects of dense water formation on deep Mediterranean Sea ecosystems: an overview. Advances in Oceanography and Limnology Vol. 6; 1:67-83.

Richardson, A.J., Bakun A., Hays G. and Gibbons M. J. 2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends in Ecology & Evolution, 24 (6): 312–322.

Rodolfo-Metalpa, R., Houlbrèque F., Tambutté, R., Boisson, F., Baggini, C., Patti, F. P., Jeffree, R., Fine, M., Foggo, A., Gattuso J. P. & J. M. Hall-Spencer, 2011. Coral and mollusc resistance to ocean acidification adversely affected by warming. Nature Climate Change 1, 308–312.

Ross, P. M., Parker, L., O'Connor, W.A., Bailey, E.A., 2011. The Impact of Ocean Acidification on Reproduction, Early Development and Settlement of Marine Organisms. Water 3, no. 4: 1005-1030.

Sabatés, A., Martín, P., Lloret, J., Raya, V., 2006. Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. Global Change Biology 12 (11), 2209–2219.

Sano, M., Marchand M., Medina R., 2010, Coastal setbacks for the Mediterranean: a challenge for ICZM, Journal of Coastal Conservation, Vol. 14, n°1.

Serrano, O., 2011. Insights in the mat of *Posidonia oceanica*: biogeochemical sink and paleoecological record. PhD Thesis, Ecology Department, University of Barcelona, Barcelona: 38 pp.

Skliris, N., Sofianos S., Gkanasos A., Mantziafou A., Vervatis V., Axaopoulos P., and A. Lascaratos 2011. Decadal scale variability of sea surface temperature in the Mediterranean Sea in relation to atmospheric variability. Ocean Dynamics, Vol. 62, Issue 1, 13-30.

Somero, G., 2012. The physiology of global change: linking patterns to mechanisms. Annu. Rev. Mar. Sci. 4:39–61.

Suggett, D.J., Hall – Spencer, J.M. , Rodolfo-Metalpa R., Boatman T.G., Payton R., Tye Pettay D., Johnson V.R., Warner M.E. and Lawson T., 2012. Sea anemones may thrive in a high CO2 world. Global Change Biology doi: 10.1111/j.1365-2486.2012.02767.x

Tempesta, M., Otero M., 2013. Guide for quick evaluation of management in Mediterranean MPAs. WWF Italy, IUCN. 68 pp.

Trenberth, K.E., Jones P.D., Ambenje P., Bojariu R., Easterling D., Klein Tank A., Parker D., Rahimzadeh F., Renwick J.A., Rusticucci M., Soden B. and P. Zhai, 2007. Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Vargas-Yáñez, M., Moya F., García-Martínez M.C., Tel E., Zunino P., Plaza F., Salat J., Pascual J., López-Jurado J.L. and M. Serra, 2010. Climate change in the Western Mediterranean Sea 1900–2008. J. Marine Systems, 82, 171-176.

Vargas-Yáñez, M., Mallard E., Rixen M., Zunino P., García-Martínez M.C. and F. Moya, 2012. The effect of interpolation methods in temperature and salinity trends in the Western Mediterranean. Mediterranean Marine Science, 13(1), 118-125.

Velegrakis, A., Hasiotis, T., Monioudi, I., Manoutsoglou, E., Psarros, F., Andreadis, O. and Tziourrou, P., (2013). *Evaluation of climate change impacts on the sea-turtle nesting beaches of the National Marine Park of Zakynthos Protected Area.* MedPAN North Project, Final report, 81 pp.

UNEP-MAP-RAC/SPA, 2009. Synthesis of National Overviews on Vulnerability and Impacts of Climate Change on Marine and Coastal Biological Diversity in the Mediterranean Region. By Pavasovic, A., Cebrian, D., Limam, A., Ben Haj, S., Garcia Charton, J.A., Ed. RAC/SPA, Tunis; 76 pages.

UNEP-MAP-RAC/SPA, 2010. *Impact of climate change on marine and coastal biodiversity in the Mediterranean Sea. Current state of knowledge.* By S. Ben Haj and A. Liman, RAC/SPA Edit, Tunis:1:28.

UNEP-CMS, 2006. Migratory Species and Climate Change: Impacts of a Changing Environment on Wild Animals. UNEP/CMS Secretariat, Bonn, Germany. 68 pp.

Mediterranean gorgonian cliff wall. Photo: J. Garrabou

Supporting climate change programmes and environmental observation networks

Intergovernmental Panel on Climate Change (IPCC)

http://www.ipcc.ch

The IPCC is the definitive scientific intergovernmental body tasked with reviewing and assessing the most recent scientific, technical, and socio-economic information produced worldwide relevant to the understanding of climate change.

EU Action against Climate Change

http://ec.europa.eu/clima/policies/eccp/index_en.htm

At European level a comprehensive package of policy measures to reduce greenhouse gas emissions has been initiated through the European Climate Change Programme (ECCP). The goal of the ECCP is to identify and develop all the necessary elements of an EU strategy to implement the Kyoto Protocol. The Commission adopted an EU Strategy on Adaptation to Climate Change in April 2013 to supports action by promoting greater coordination and information-sharing between Member States, and by ensuring that adaptation considerations are addressed in all relevant EU policies.

http://climate-adapt.eea.europa.eu/

The EU also addresses knowledge gaps through research and the European climate adaptation platform (Climate-ADAPT) that supports adaptation policy and decision making.

Regional Activity Centre for Specially Protected Areas (RAC/ SPA)

http://www.rac-spa.org/

The institutional framework for the challenges and effects of climate change on the marine and coastal biodiversity is the Mediterranean Action Plan (MAP) for the Barcelona Convention with mainly the Regional Activity Centre for Specially Protected Areas (RAC/SPA) as the executing agency. The Strategic Action Programme for the Conservation of Biological Diversity in the Mediterranean region (SAP BIO) is a strategic action plan for the protection of biodiversity in the coastal and marine Mediterranean regions. This action plan, adopted by the Contracting Parties to the Barcelona Convention in 2003, considered the impact of climate change on biodiversity as priority activities (Almeria Declaration, 2008).

Priority Actions Programme/Regional Activity Centre (PAP/RAC)

http://www.pap-thecoastcentre.org/

Climate change adaptation in the coastal zone has been incorporated into the "Marrakesh Declaration" on Adaptation to Climate Change (UNEP (DEPI)/MED IG.19/8 Annex I) and the proposed five-year Programme of Work of UNEP/MAP of the Barcelona Convention (2010-2015). As part of this programme and the work conducted by PAP/RAC, the ICZM Protocol provides an important tool for climate change adaptation through the adoption of prevention, mitigation and adaptation measures to tackle the effects of climate change.

CIRCLE 2

http://www.circle-era.eu/np4/2

EU project (2010-2014) to facilitate cooperation, design and fund joint initiatives, share knowledge and establish a research funding network oriented towards climate change impacts, vulnerability and adaptation.

Ghar Lapsi and Filfla MPA, Malta. Photo: IUCN

Regional environmental observation networks

International Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS)

http://www.wmo.int/pages/prog/gcos/index.php?name=AboutGCO

GCOS is an internationally coordinated network of observing systems with a programme of activities that support and improve the network. It is designed to meet evolving national and international requirements for climate observations including ocean climate observations monitoring.

Mediterranean Operational Oceanography Network (MOON) and MONGOOS network

http://www.moon-oceanforecasting.eu/index.php?option=com_frontpage&Itemid=1

It focus on Mediterranean forecasting system of meteo-oceanographic (temperature, currents) and biochemical pelagic variables. At present they are part of the new MONGOOS network.
Among the MONGOOS network are included the Greek national system (Poseidon Ocean Forecast), the Sicily Channel forecasting system, Cyprus coastal forecasting and observing system (CYCOFOS), the Adriatic Sea, Puertos del Estado Sea level forecast system (Nivmar, Spain), the southeastern and northern Levantine forecasting system among many others.
Observing products might include in-situ water temperature and salinity, sea level and atmospheric pressure with remote sensing SST-sea surface temperature and chlorophyl concentration. The network is also part of EuroGOOS, the European Global Ocean Observing System.

Eurosites, European Ocean Observatory network

http://www.eurosites.info/

Integrated European network of nine deep-ocean observatories sited in waters off the continental shelf and of greater than 1000m depth, measuring variables from sea surface to sea floor.

Mediterranean Ocean Forecasting System Bulletin

http://gnoo.bo.ingv.it/mfs/

Electronic report that can offer forecast information on sea surface temperature and anomalies, salinity, heat flux and wind stress at different depths.

MyOcean2

http://www.myocean.eu/

Monitoring service at European and National levels with long time-series of in-situ (physical and biochemical) and remote sensing (ocean colour and SST) products. Among the parameters measured is temperature, salinity, currents, sea level, chlorophyl-a, dissolved oxygen, nutrient and light penetration.

MedGLOSS

http://medgloss.ocean.org.il/

http://www.ciesm.org/marine/programs/medgloss.htm

The MedGLOSS programme of sea level monitoring network in the Mediterranean and Black seas was established jointly by CIESM and IOC/UNESCO in 1997 in response to the forecasted global climate change and sea level rise.

HYDROCHANGES network

http//www.ciesm.org/marine/programs/hydrochanges.htm

Long-term monitoring of basic hydrological parameters (temperature and salinity), Mediterranean network of autonomous conductivity, temperature, and depth (CTD) sensors, deployed on mainly short and easily manageable subsurface moorings.

SeaDataNet Infrastructure network

http://www.seadatanet.org/

Standardized system for managing the large and diverse data sets collected by the oceanographic fleets and the automatic observation systems.

RADMED

http://www.ba.ieo.es/es/investigacion/grupos-de-investigacion/coplamed/proyectos/263-radmed

It provides historical data series of oceanographic parameters from the Spanish Mediterranean coast.

T-MedNet

http://www.t-mednet.org/

T-MedNet network is devoted to spread the acquisition of long term high resolution temperature series in Mediterranean coastal waters (0-40 m) as well as to facilitate data sharing and analysis.

Tropical Signals Program

http://www.ciesm.org/marine/programs/tropicalization.htm

Basin-scale, long-term monitoring programme to detect the expansion or retreat of key species (exotic tropical species, native warm-water species and native cold-water species) in response to climate change.

MEDSEA

http://medsea-project.eu/

EU FP7 project to study the impact of ocean acidification in the Mediterranean (2011-2014). The project focus on a selected set of key ecosystems and socio-economic variables that are likely to be affected by both acidification and warming, to provide best estimates and related uncertainties of future changes in Mediterranean Sea pH, $CaCO_3$ saturation states, and other biogeochemical-ecosystem variables as well as to asses the changes in habitat suitability of relevant ecological and economically-important species.

Climaparks

http://www.climaparks.eu

Regional project for monitoring and study the effects of climate change at nine parks (terrestrial and marine) from Slovenia and Italy. It aims at research and raising public awareness of climate change, conservation of biodiversity, and sustainable attitude towards the environment in these protected areas.

CLIM-RUN

http://www.climrun.eu/

EU FP7 Project (2011-2014) that aims at developing a protocol for applying new methodologies and improved modeling and downscaling tools for the provision of adequate climate information at regional to local scale that is relevant to and usable by different sectors of society (policymakers, industry, cities, etc.) in key economic sectors: energy and tourism.

CLAMER

http://www.clamer.eu/about-clamer

EU FP7 Project to raise the awareness of European citizens and society at large to the effects of climate change on the marine environment and its socio-economic consequences.

ClimCares

http://climcares.medrecover.org

Regional project (2011-2013) focus to assess the potential impacts of climate change on coastal benthic ecosystems in the Northern Western Mediterranean basin through the acquisition of realistic warming scenarios of the coastal areas at regional scale combined with the biological responses to thermal stress. The main output of the project is to assess the risk of mass mortality events in the NW Mediterranean basin.

Water sampling carousel equipped with a CTD (Conductivity-temperature-depth) profiler used for sampling at different depths and equipped with temperature and salinity sensors.

Photo: M. Vargas, IEO.

The MedPAN collection

The MedPAN collection is a series of publications designed to provide Marine Protected Areas (MPA) managers and other stakeholders in the Mediterranean, guidance, practical and useful information, experience feedback or overviews on key MPA management issues.

The MedPAN collection is fully adapted to the Mediterranean context. It gathers publications developed by different key players in the Mediterranean MPA community under a unified look and feel.

The MedPAN collection is an initiative of the MedPAN organization and several partners, including RAC/SPA, WWF, IUCN Mediterranean, ACCOBAMS, the French MPA Agency and the Conservatoire du Littoral. It is edited by MedPAN, the network of MPA managers in the Mediterranean.

MedPAN

The network of Marine Protected Areas managers in The Mediterranean

www.medpan.org