MedPAN COLLECTION

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

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Foreword

The Mediterranean Sea has unique marine features that make this region particularly vulnerable to climate change. The narrow connections with the Atlantic Ocean through the Strait of Gibraltar, with the Red Sea through the Suez Canal and with the Black Sea through the Bosphorus Strait restrict the overall extent of water exchange. In addition, Mediterranean seawater can more easily heat up and evaporate, due to reduced size of the basin combined with hot, dry summers and low inflow from rivers. The Mediterranean also lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe, so it is affected both by tropical climate processes (e.g. droughts) and extreme mid-latitude events (e.g. strong winds).

There is a large body of evidence that climate change is already playing a role in modifying both terrestrial and marine features in the Mediterranean, altering ecosystems and inducing habitat changes, as well as creating favourable conditions for the proliferation of non-indigenous and invasive species. All these factors are working to shape a Mediterranean different from the one we know.

Local and regional scale evidence is accumulating to show that the Mediterranean Sea is warming and changing the stratification of the seawater column. Understanding, monitoring and managing such climate-induced change is critical for Marine Protected Areas (MPAs). MPAs are efficient management tools for ameliorating human impact on coastal marine ecosystems. By increasing ecosystem stability, they promote resilience and faster recovery from disturbance.

S'Arenalet d'Aubarca, Spain Nacho Gil

1. Predicted climate change

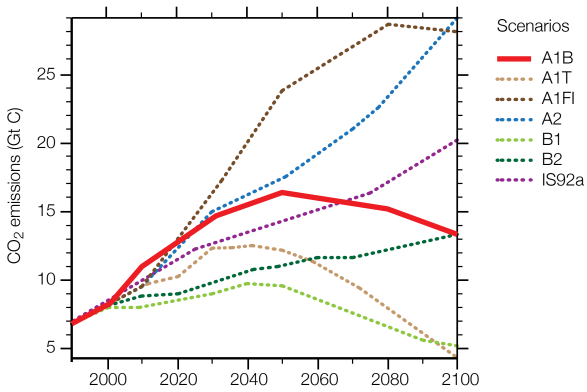
There is ample evidence of the physical and environmental impacts of climate change. Continued emissions of greenhouse gases into the atmosphere will continue to have a strong effect on climate and the oceans in the future. Scientists have prepared a range of projections and models related to the range of emission scenarios and the different policies that governments might choose[1]. Climate models project the following key related changes:

• Air temperature

The majority of climate models suggest that during the 21st century the Mediterranean region will experience a warming period, with an average air temperature increase of 3.2 °C, which is higher than the global average (2.6 °C). Warming is expected to be greater in summer than in winter. Highest mean temperatures are expected in summer over Iberia, the Balkans and Anatolia, where the temperature increase is likely to reach +5 °C by the end of this century. Climate predictions also indicate an increase in the number of extreme warm (air and water) events across the region. The number of warming events is likely to increase threefold by 2025, with three warming events expected every four years, compared to the current rate of one warm event every four years. Moreover, both frequency and intensity of these events will increase with heat waves maintaining higher temperatures for longer periods, particularly in the second half of the century.

• Precipitation

Precipitation (rainfall and snow) is expected to decrease by 25% in summer (as per the A1B scenario[1]) and 10% in winter by 2100. The largest decrease in summer precipitation (by more than 60%) by the end of this century may occur in the same areas affected by the greatest warming (Iberia, Anatolia and the Balkan region). In winter, which is the most important season for replenishing water resources in many Mediterranean areas, precipitation is expected to experience only minor changes (a small increase might even occur) in the northern part of the Mediterranean. In contrast, major reductions in rainfall are expected in the southern Mediterranean. Though the location of the line separating these two opposite tendencies is uncertain, climate models agree that southern Mediterranean countries (Northern Africa and the Middle East), where water resources are already scarce, will experience a further rainfall reduction by 2100 (about -20% in winter and -35% in summer).



(1) 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 Intergovernmental Panel on Climate Change (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.*

S'Arenalet d'Aubarca, Spain Nacho Gil

1.1 What would happen to the sea?

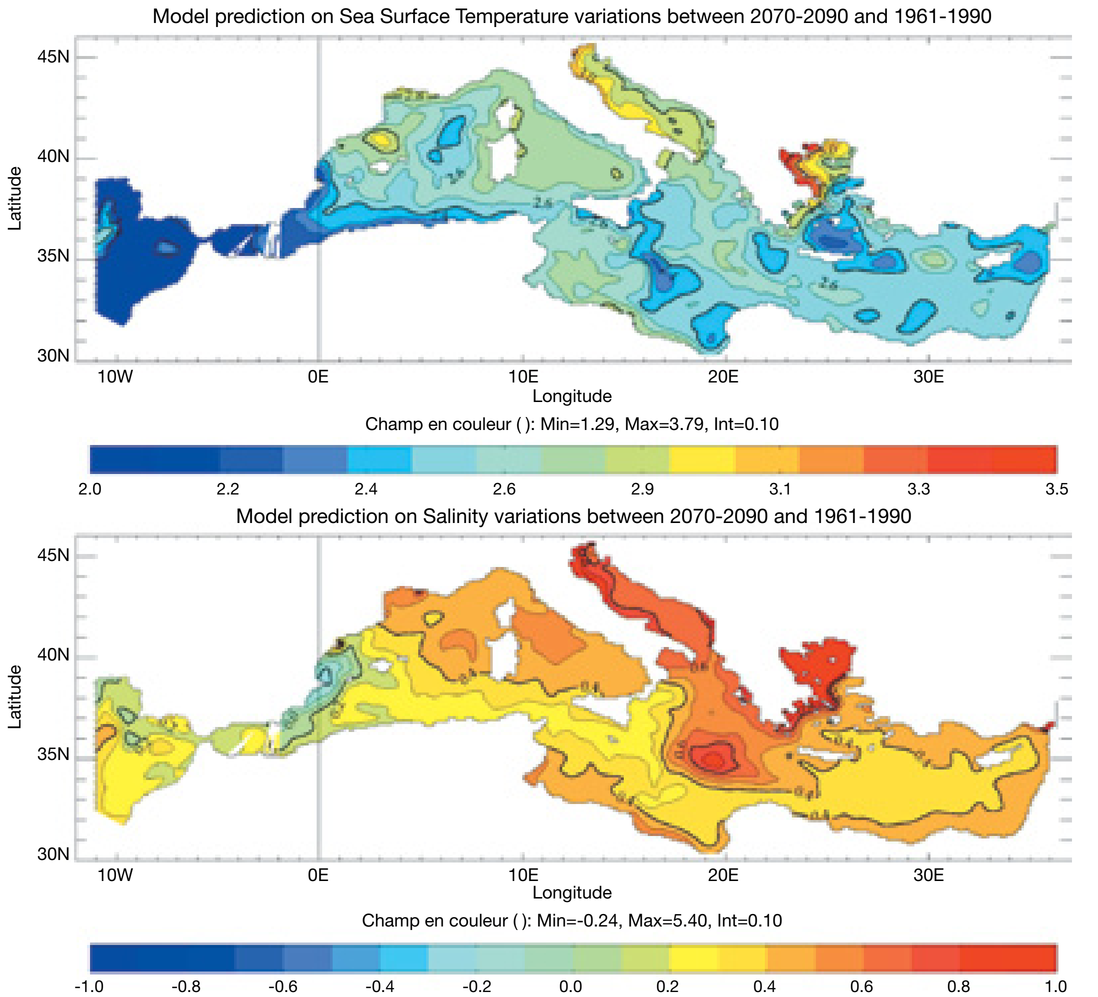
1.1.1 Sea-surface temperature and salinity (SST and SSS)

The shallow waters of the Mediterranean Sea have already warmed by almost 1°C since the 1980s and sea surface temperatures are expected to be approximately 2.5 °C warmer by 2100. By the end of the 21st century the combined effects of declining precipitation and increased evaporation are likely to cause an increase in the sea´s freshwater deficit (by approximately 15cm per year), which in turn will contribute to progressively higher seawater salinity (SSS) in the order of 0.5 units over the next 100 years. These changes in both temperature and salinity may affect other oceanographic processes and be reflected by changes in thermohaline circulation (density-driven water circulation caused by temperature and salinity), lower intensity of upwellings and reduced formation of deep-water masses.

1.1.2 Sea level

Increased seawater temperature implies lower water density and, therefore, a larger water volume. Increased salinity has the opposite effect, as water density increases with salinity. These two factors may balance each other out, but uncertainty as to the magnitude of this variation today makes it difficult to predict sea level changes in the region with any accuracy. Moreover, the total mass of sea water in the Mediterranean is likely to rise, since the global water mass will increase as glaciers and ice sheets melt. Vertical movements of landmasses and different sea level trends in different parts of the Mediterranean will further increase the uncertainty of regional sea level change, and scientific projections still offer a wide range of values, from hardly any change to rises of many tens of centimetres.

DIFFERENCES BETWEEN THE FUTURE CLIMATE (2070-2099) AND THE PAST CLIMATE (1961-1990)



Source: Piero Lionello (Università del Salento)

1.2 What do we know about the impacts on marine biota?

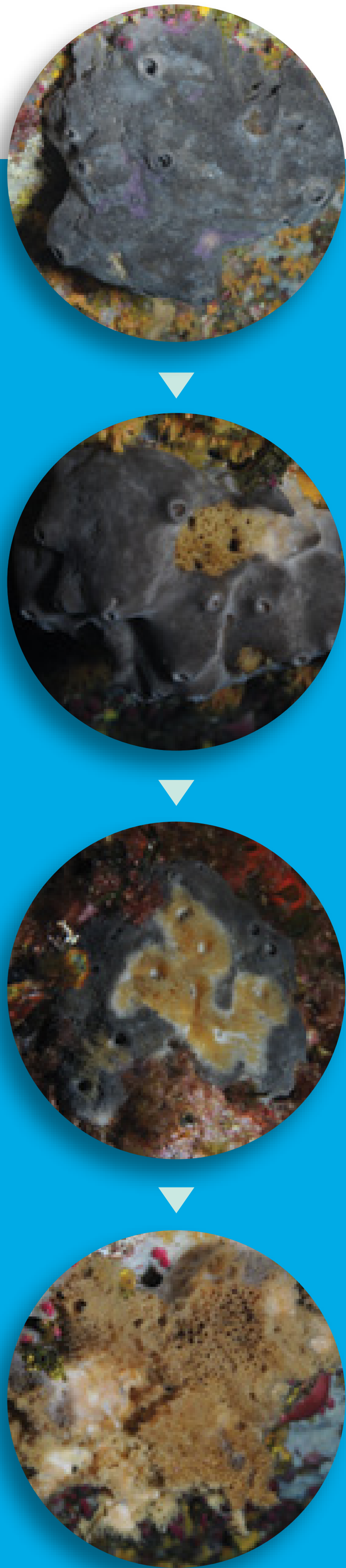
These oceanographic and climate parameters, both individually and in combination, are affecting Mediterranean marine ecosystems. Climate change may affect the diversity, size and composition of marine species and communities through multiple pathways. Marine and coastal communities will also respond differently to climate change impacts in combination with human pressures and local conditions. Despite these variations, however, some general trends of biodiversity impacts are already being observed and provide evidence for future scenarios.

1.2.1 Coralligenous formations

Sea warming and exposure to anomalous, continuously high temperatures may affect coralligenous formations (e.g. gorgonian, sponge and maërl beds) both directly, by causing harmful metabolic changes and physiological stress, and indirectly by reducing their resistance to pathogens. Recent findings have shown that an event involving a 3–4 °C increase in seawater temperature (such as the one recorded during the 2003 heat wave in the NW Mediterranean) can induce mass-mortality events in some gorgonian or sponge communities. During the 2003 event, roughly 80% of gorgonian *Paramuricea clavata* communities were at least partially affected and 35% completely disappeared from some sites in the western Mediterranean. Similar observations were recorded during the summers of 2008 and 2009 with large sponge die-offs in several MPAs (including Cabrera National Park and Scandola Nature Reserve). Coralligenous species with calcareous skeletons (e.g. *Leptopsammia pruvoti* and *Corallium rubrum*) can be affected by increased seawater acidification, which both reduces skeletal growth and tends to dissolve their skeletons. As most of these species are characterized by high longevity and slow growth, a dramatic increase in mortality could have severe consequences in terms of population viability, and consequently could affect the structure and function of coralligenous formations as habitat-forming assemblages in the marine ecosystem.

1.2.2 Coastal fish populations

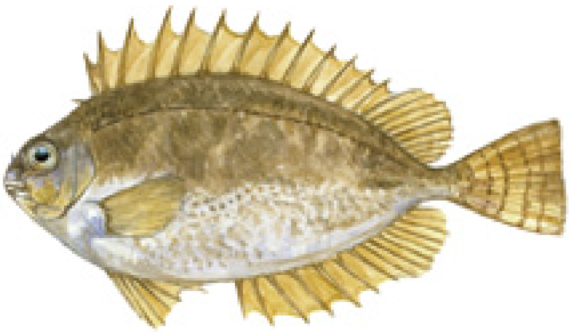
The increase in sea temperature detected during the last three decades (about 1°C in the NW Mediterranean) is driving profound and large-scale changes in coastal fish assemblages. At the global scale climate warming is forcing species distributions toward the northern areas, and a similar pattern may be seen in the Mediterranean, especially for coastal fishes. Species typical of the southern sectors of the Mediterranean, such as the ornate wrasse *Thalassoma pavo*, the Mediterranean parrotfish *Sparisoma cretense* and the barracuda *Sphyraena viridensis*, are now spreading northward into the



A healthy specimen and different mortality stages in Mediterranean keratose sponges.

Author: Joaquim Garrabou

Serranus scriba. Author: Liné1



Siganus luridus. Author: JuanVarela

coldest parts of the Mediterranean as a result of rapid warming (for example, the ornate wrasse has increased its range by about 1,000 km in recent decades). Other thermophilic fishes (species that prefer warm waters), such as the round sardinella *Sardinella aurita*, have increased in abundance with the rise in water temperature. Conversely, cold-water species are contracting their distribution ranges as a consequence of warming. By the end of the century, the coldest areas of the Mediterranean Sea (Adriatic Sea and Gulf of Lion) are likely to become the only refuges for cold-water species and, in the worst-case scenario; they could be a dead end driving particularly endemic species to extinction.

The warming of the Mediterranean also seems to underlie the increasing success of the sea's non-indigenous biota and the changing migratory habits of certain fish species (e.g. the amberjack *Seriola dumerilii*), which today stay longer in the northern and central Mediterranean. The latest reviews of Mediterranean species list more than 140 non-indigenous fishes, including both Atlantic species that have entered through the Strait of Gibraltar and Lessepsian species that have come from the Red Sea through the Suez Canal. Almost all these fishes are tropical or subtropical in origin and hence have an affinity with warm waters. Among the most successful non-indigenous invaders are the bluespotted cornetfish *Fistularia commersonii*, the rabbitfishes (genus *Siganus*)

Author: Joaquim Garrabou

and the goatfish (*Upeneus pori*). In some cases a sudden decline in the abundance of native species has been reported to occur concurrently with the proliferation of non-indigenous invaders.

Overall, a number of coastal and pelagic fishes (e.g. 59 fish species belonging to 35 families, as recently reported from observations along the Italian coast) have changed their distribution and abundance significantly, mainly as a result of the 1 °C rise in seawater temperature over the last 30 years. Some (e.g. barracudas) have increased in numbers and range, whereas the stocks of some others (e.g. sprat and anchovy) have collapsed. These trends, along with modifications of the life cycles of target fishes, are already creating changes to traditional fishing practices.

1.2.3 Coastal benthic assemblages

Benthic organisms inhabiting coastal rocky reefs are both directly and indirectly vulnerable to the multiple impacts of climate change, including rapid sea-water warming and rising sea levels.

Sea level rise can directly affect endemic and habitat-forming species such as the carbonate reef-building vermetid *Dendropoma petraeum* and its associated calcareous red algae. As these vermetid reef habitats are restricted to intertidal zones, they are highly vulnerable to water level changes and physical erosion along the shoreline. Sea acidification can also affect vermetid calcification and have detrimental effects on its growth rate, resulting in local extinction events.

Species replacement (i.e. non indigenous species outperforming native species, such as *Caulerpa racemosa* occupying areas previously inhabited by the sponge *Sarcotragus spinosulus* as recently reported from Croatian coasts) due to effects of climate change can drive both directly and indirectly (through cascading effects) deep modifications in coastal benthic assemblages. In the eastern Mediterranean (e.g. along Turkish coasts), non-indigenous rabbitfishes (*Siganus* spp.) are replacing up to 95% of the individuals of native herbivorous fish species. With their grazing, rabbitfish can remove large areas of algal beds, reducing important nursery areas for other juvenile fishes and changing local algal communities and coastal productivity.

1.2.4 Blooms

Recent evidence indicates that moderate sea warming (0.5–1 °C) may have the potential to trigger abrupt increases in abundance (known as blooms or outbreaks) of some planktonic organisms, including jellyfish and harmful algal species. The jellyfish species *Pelagia noctiluca* and *Rhopilema nomadica* and the toxic dinoflagellate *Ostreopsis ovate* are the best-known examples. Gelatinous organisms like jellyfish are particularly responsive to temperature and freshwater input. Jellyfish growth and reproductive rates increase with rising water temperature, which can thus be a direct cause of blooms. Reduced freshwater inflow from rivers, due to the decrease in summer rainfall, also favour jellyfish blooms. Salinity and water density, together with summer winds, will further help jellyfish to migrate from open to coastal waters.

Pelagia noctiluca Hans Hillewaert

Intertidal vermetid reefs. Photo: IUCN

1.2.5 Seagrasses and macroalgae

Recent findings strongly suggest that seagrass, such as *Posidonia oceanica*, could be affected by sea warming. *P. oceanica* is highly sensitive to seawater warming, and high mortality rates may be expected in natural populations with the increase in annual water temperature.

Under present climate projections, a sea water temperature rise to 28 ºC will have adverse effects on plant survival during the second half of this century. Moreover, these slow-growing meadows will take a very long time to recover from any decline. The regression of *P. oceanica* meadows may give a competitive advantage to other species, particularly those with warm-water affinities, and may favour the proliferation of competing algae, in particular invasive macroalgae (e.g. *Caulerpa racemosa*) of tropical and subtropical origin.

Among other notable climate-induced changes, some native macroalgal forests such as those of the brown alga *Cystoseira* sp. may be driven into virtual local extinction. A shift from structurally complex benthic habitats to low-diversity habitats dominated by turf-forming, filamentous or other ephemeral seaweeds is the ultimate consequence of these declines. The resilience of these formations and their potential restoration will further depend on the multiple stressors on the local environment.

Models of climate change also predict an increase in the probability of the occurrence of extreme meteorological events such as severe storms. Together with other sources of disturbance, wave regimes can reduce the resilience of these macroalgal forests, affecting the survival of new settlers and making their natural recovery slow or even implausible.

Cystoseira sp. Esculapio

Caulerpa racemosa. Author: Juan Valera

Posidonia oceanica David Balata

2. Socio-economic consequences on the marine environment

Author: Tyra Koppenol

Marine ecosystems provide critical services and benefits for the well-being of the communities that depend on them, including food security, climate regulation, water provision, recreation, etc. In this section we explore the key direct and indirect socio-economic effects of climate-change impacts on the Mediterranean marine environment.

1.1 Impacts on fisheries

Mediterranean fisheries are already overfished (89% of stocks) or fully exploited, which means that fish diversity and fishing catches are already vulnerable. However, increases in salinity and seawater temperatures and the spread of invasive species will further affect Mediterranean fisheries. In specific terms, the impacts of climate change on fisheries can be examined from two angles. Firstly, increasing water temperatures and salinity will induce migration (particularly of large species, such as the

Fishing port in Al Hoceima, Morocco. Photo: IUCN bluefin tuna) towards higher latitudes or deeper waters. As a result, species that are commercially important in some areas may no longer be available in the near future. Secondly, with the proliferation of non-indigenous invasive species, certain natives may be outcompeted or replaced (e.g. *Diplodus* spp. could be replaced by the invasive *Siganus* spp.). These could mean that markets would have to explore other target species rather than those currently sold.

In addition, as habitat changes are expected due to alterations of the marine biota, some habitat functions could be compromised with important consequences for the reproduction or juvenile development of commercial species. Overall, the small-scale fishing industry is expected to be less resilient to these changes as it relies on specific fishing gears, smaller boats (and engines) and limited investment opportunities.

1.2 Impacts on tourism

The impacts of climate change on tourism are complex and multifaceted. Changes and reductions in freshwater resources may cause water shortages (and local food shortages, through impacts on agriculture), and may increase the costs of securing alternative water sources, particularly on islands and in more arid coastal areas. Desalination will increase the running costs of tourism facilities and their dependency on alternative energies. Coastal erosion, flooding and habitat loss could significantly affect tourist access to beaches, which often drive tourism demand.

In some areas of the Mediterranean (and certainly in some MPAs), scuba diving is the most important tourist activity, bringing high revenues to diving centres, hotels and restaurants. The potential regression or decline of charismatic underwater habitats and species could damage the diving tourism industry.

Unexpected algal and jellyfish blooms can also affect tourism activities with consequences for revenues and job security. Dinoflagellate and jellyfish blooms can be detrimental in the tourist season, preventing swimming and other water activities particularly in popular destinations, and can be dangerous to human health. Similarly, proliferation of non-indigenous toxic species such as the silver-cheeked toadfish *Lagocephalus sceleratus* are venomous and can have serious consequences for both amateur and professional fishers. Heat waves and increasing air temperatures may have both detrimental and beneficial effects: they create discomfort for tourists during the hottest months (usually July–August) but otherwise prolong tourist seasons and extend tourism opportunities to other coastal destinations.

1.3 Other relevant impacts

Climate-change impacts could affect MPA environments in several other important ways. Warming temperatures (on both land and sea) are thought to increase the risk of droughts, wild fires and desertification, particularly in the southern Mediterranean area. This could have consequences for local water access, agriculture and human health. Agriculture could also suffer from changes in precipitation (less frequent and/or more intense rainfall), reduced soil moisture and salt-water intrusion into freshwater aquifers. Sea level rise and coastal erosion can in the longer run reduce the effectiveness of coastal defences, resulting in flooding in low-lying coastal areas and disrupting transport activities and social services (roads, sewage systems, housing, etc.).

Strunjan Park, Slovenia. Author: Milena Tempesta

3. Recommendations for MPA managers

Climate change is already altering the balance of the Mediterranean marine environment with serious and irreversible consequences for its ecosystems and the services they provide. The disruption of ecological functions and ecosystem services has severe impacts on human communities, especially in coastal areas where most MPAs are located and human dependencies on marine resources are high. Immediate and substantial actions need to be taken to increase the adaptive capacity of coastal marine ecosystems and the people that depend on them. At the same time, the implications of climate change impacts on the marine environment for coastal communities need to be understood and properly managed, as do the interconnections between terrestrial and marine vulnerabilities, which should be managed through integrated climate adaptation strategies. This is particularly important for MPAs that have territorial competence over land and sea.

The following ideas aim to provide guidance to the managers of MPAs to monitor, understand, prevent and effectively address climate-induced changes, so as to maintain ecological functions and increase resilience.

- **CREATE** no-take zones and adjust buffer zones to protect areas of upwelling and nursery habitats that provide high marine productivity. No-take zones are the vital pulse of MPAs, from which larvae spread and where fish can seek refuge. No-take zones should also be established in areas that are naturally resilient to climate change. Collaboration with research centres and other institutions can help identify these naturally resilient sites.

- **MAINTAIN** vegetation along beaches and the coast to create natural shading. Trees and shrubs mitigate high summer temperatures as well as reducing coastal erosion. Vegetation both inland and along the coastline also helps to retain moisture and protect water sources, particularly important in areas where rainfall is set to decrease.

- **SET UP** monitoring programmes[2] for sentinel species (e.g. *Posidonia oceanica*), climate-sensitive indicators (e.g. *Paramunicea clavata*) and invasive species (e.g. *Siganus luridus* or *Rhopilema* spp.), to help assess changes and inform management decisions. If possible, INTEGRATE species monitoring with environmental quality monitoring, using temperature and pH loggers, as well as the monitoring of sporadic events (such as blooms, mass mortality and bleaching), to aid in identifying the vulnerability of habitats and species.

- **LIMIT** fishing gear and species-specific catches that are detrimental for sensitive fish species, for species that have major ecological roles or those in competition with alien species. Decreasing fishing pressure increases resilience and gives species a chance to recover from changing environmental conditions. Unstable populations are more likely to be outcompeted by new species.

- **MINIMIZE** by-catch and avoid the use of non-selective fishing gear to avoid stressing stocks and exacerbating overfishing. Keeping small-scale fisheries productive secures food and livelihoods.

Għar Lapsi and Filfla MPA, Malta. Photo: IUCN

• **REDUCE** impacts and stressors on sensitive species (e.g. *P. oceanica*, gorgonians and other calcareous species). As climate change will make living conditions harder for these species, any further stress may cause mass mortality or total extinction. for these and other associated species.

• **UNDERSTAND** the impacts on the environment and visitors' activities and what future scenarios may hold. Assessments of climate-induced impacts and future scenarios specific to a particular MPA region are very valuable tools for developing adaptation strategies and building monitoring frameworks with climate-change indicators in mind.

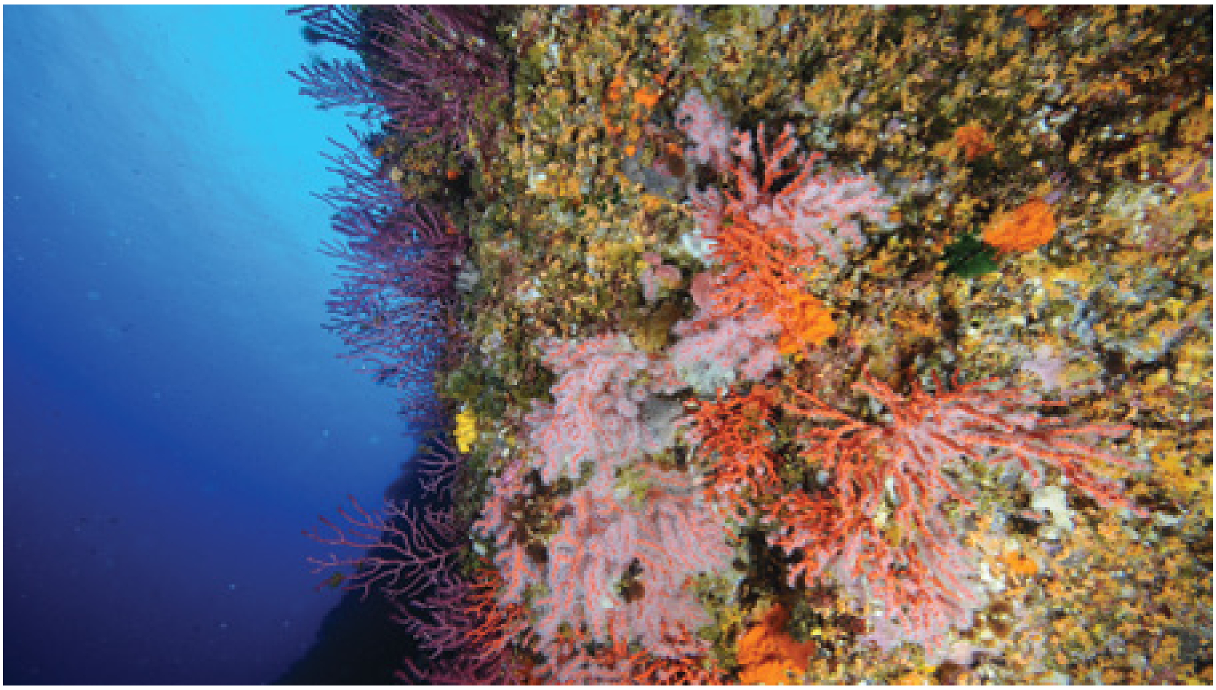
• **DEVELOP** ad-hoc climate-smart strategies that integrate adaptation measures for both terrestrial and marine ecosystems and communities. These strategies should take into account the connectivity between terrestrial activities (impacts and changes) and those at sea (for example, agriculture will be affected by low rainfall, so increased use of desalination systems will be necessary with a consequent impact on the marine biota).

• **MINIMIZE** modification of the coastline to retain natural habitats that protect water and species and regulate local climate. Coastline development (ports, pipelines, etc.) also increases the risk of salt water intrusion, which can be highly detrimental for water-poor areas (e.g. islands).

• **REUSE** waste and recycle, especially rainwater, particularly in areas where precipitation is expected to decrease or become sporadic. In general, reuse and recycling is good practice as urban waste and landfills produce greenhouse gases (methane and carbon dioxide), which further contribute to climate change. Cooperation with the tourist industry (including cruise ships and large hotel operators) could be key to minimizing the environmental footprint of tourism within MPAs. Appropriate waste and water management contributes to good-quality drinking and sea water, which can be limiting factors for tourism operators.

• **IMPLEMENT** communication and education programmes for communities, local stakeholders (fishers, divers, etc.) as well as tourism operators to create consensus and an awareness that the issue of climate change is a complex one that requires the involvement of all stakeholders. Only through strong cooperation and willingness can social and ecological adaptation be achieved.

(2) Guidelines for monitoring climate-change impacts
Funded by the European Regional Development Fund through the European Union's Med Programme, the MedPAN North project is preparing operational guidelines for MPA managers and the Mediterranean network of marine protected areas to address the issue of climate change in Mediterranean MPAs. More information may be found at: www.medpannorth.org



Mediterranean gorgonian cliff wall. Author: Joaquim Garrabou

For further reading

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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.

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The network of Marine Protected Areas managers in The Mediterranean

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