THE CLIMATE CHANGE EFFECT IN THE MEDITERRANEAN

Six stories from an overheating sea

ACKNOWLEDGEMENTS

Written and edited by Evan Jeffries and Stefania Campogianni, based on the scientific information and documents provided by the following experts:

- Dr Paolo G. Albano PhD, Senior scientist, Stazione Zoologica Anton Dohrn, Naples.
- Professor Mohamed Nejib Daly Yahia, Department of Biological and Environmental Sciences, College of Arts and Sciences, Qatar University.
- Professor Gérard Pergent, University of Corsica Pasquale Paoli.
- Dr Lorenzo Merotto, Dr Valentina Cappanera, Portofino MPA. The activities of the Portofino MPA on climate change issues are made possible by the European Interreg MED Project MPA Engage.
- Saul Ciriaco, WWF MPA Miramare.

We would also like to thank the following people for their contribution:

Marina Cabrini, OGS Oceanography Section – MAB Group; Camille Loth, WWF MMI; Catherine Piante, WWF-France; Giulia Prato, WWF-Italy; Marina Gomei, WWF MMI; Simone Niedermueller, WWF-MMI; Isabella Pratesi, WWF-Italy; Roberto Danovaro, UNIVPM.

Published in June 2021 By WWF

Text 2021

Citation of this report:

"The climate change effect in the Mediterranean. Six stories from an overheating sea" WWF Mediterraean Marine Initiative, Rome, Italy, 2021

Front Cover: Joruba / iStock

Design/layout: Catherine Perry, Swim2Birds Ltd

Communications: Stefania Campogianni, WWF MMI

CONTENTS

Mediterranean benthic ecosystem, Tabarka coast, Tunisia.© Michel Gunther / WWF

INTRODUCTION

Climate change is the single greatest threat we face as a species – and in the Mediterranean, temperatures are going up 20% faster than the global average. This is already having real and serious consequences across the basin, and they'll increase over the coming decades, with sea level rises expected to exceed one metre by 2100, impacting one third of the population in the region. Urgent and far-reaching action is needed, both to mitigate further greenhouse gas emissions, and to adapt to the new reality of a warming sea.

Climate change amplifies the effects of every other threat to marine ecosystems. Recent studies have shown that more than 90% of the warming that happened on Earth between 1971-2010 occurred in the ocean, with the Mediterranean reaching record levels as the fastest-warming – and increasingly the saltiest – sea.

In addition, the semi-enclosed Mediterranean is one of the most heavily exploited seas in the world, and it's being stretched to breaking point by competing economic sectors and environmental pressures. Marine biodiversity is already under enormous strain and declining from pollution, coastal development, eutrophication, shipping, the introduction of alien species through ballast waters, energy and other anthropic drivers; and decades of poorly managed fisheries have left about three-quarters of assessed stocks overfished.

All in all, the region's ecological resilience has been radically reduced by unsustainable development – and with USD450 billion of ocean-related value generated from the Mediterranean's natural capital each year, the socio-economic future of the region is uncertain.

So when you add a changing climate into this mix, things get worse by an order of magnitude. The Mediterranean is not the same sea it used to be.

This paper provides a series of case studies showing some of the ways in which climate change is already impacting and altering, sometimes irreversibly, Mediterranean marine ecosystems in all corners of the basin – with consequences for socio-economic sectors like fisheries and tourism, as well as for our diet and health. Almost 1000 non-indigenous species are now present in Mediterranean waters warm enough to support them, spreading north and west every year and displacing resident species. Other native species are shifting their ranges north as they track cooler waters, while some endemic species have been left on the verge of extinction. At the same time, jellyfish blooms plague fishers and tourists alike. New pathogens are emerging. Meanwhile increasing extreme weather is ravaging fragile marine habitats from seagrass to coral beds, and rising sea levels are threatening cities and coastlines. Entire ecosystems are changing, and livelihoods are disappearing.

These are not future projections, they're things that are happening right now in the Mediterranean, and they're all caused or accelerated by climate change. This is reality. It's reflected in these case studies, localized snapshots of the impacts that climate change is having on the basin as a whole – and as temperatures continue to rise, these impacts will continue to grow.

The bad news is that there's no quick way of defeating climate change; even with immediate global action to reduce greenhouse gas emissions, temperatures are likely to go on rising for decades. But what we can and must do is reduce human pressure and build resilience – healthy ecosystems and thriving biodiversity are our best natural defences in a warming world.

The science is clear. In the Mediterranean we must protect the sea's natural assets and rebuild its resources: WWF is leading calls for a network of marine protected areas and other effective area-based conservation measures to cover 30% of the Mediterranean Sea by 2030.

The target is ambitious, but it has to be. These case studies show only too clearly the size of the challenge we face.

30%

OF THE MEDITERRANEAN SEA TO BE COVERED BY MARINE PROTECTED AREAS AND OTHER EFFECTIVE AREA-BASED CONSERVATION MEASURES BY 2030

CLIMATE CHANGE EFFECT 1:

THE TROPICALIZATION OF THE EASTERN MEDITERRANEAN IS SPREADING WEST WITH THE WARMING WATERS, THREATENING ECOSYSTEMS AND ECONOMIES ALIKE

Sand beach on the Mediterranean coast, Corsica, France © Michel Gunther / WWF

1. A TROPICAL EASTERN MEDITERRANEAN?

The Mediterranean is not a tropical ocean – at least, not yet. But a process of tropicalization is well under way in the hottest part of the basin, the eastern Mediterranean – and this gives us a taste of what we're likely to see developing across the region as climate change pushes sea temperatures higher and higher.

In addition to already being heavily overfished, native species which prefer cooler waters are shifting the southern edge of their ranges northwards.[1] It's not yet known whether they're primarily driven by physiological stress caused by increasingly frequent extreme warming events, a drop in oxygen levels which affects ecological functions, or competition from invasive species – but whatever the reason, species communities in some areas of the southern and eastern Mediterranean have changed completely.

Meanwhile, in the eastern Mediterranean, which is warming at a rate far above the global average, invasive tropical species – most of which arrived through the Suez Canal – are extending their distribution in line with the rising temperatures.

One recent study on the shallow Israeli shelf – one of the warmest areas in the basin – compared current and historical records of native molluscs, and found only 5-12% of historically present species were still there. Meanwhile, non-indigenous species from the Red Sea were found to be thriving, resulting in a novel ecosystem.[2] "The total lack of common Mediterranean species and the ubiquitous occurrence of non-indigenous ones makes the seascape unrecognizable in comparison with other Mediterranean sites," states Paolo Albano, the researcher who led the study.

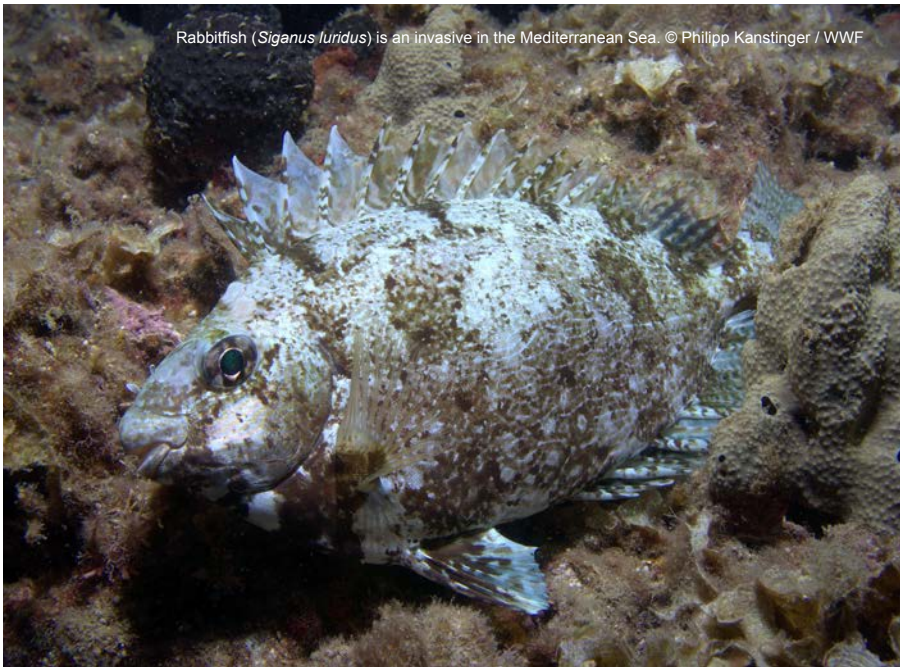
And what has been observed in Israel is most likely occurring in many other areas: "A monitoring plan which compares current with historical species richness is mandatory all over the eastern Mediterranean – in the absence of observed long-term data series, science has now provided the tools for us to find out which species used to live in an area, even if they are now locally extinct," Albano continues, pointing out that death assemblages – the skeletal remains of organisms on the seafloor – are an untapped source of information on the past of marine ecosystems.

Figure 1. The eastern Mediterranean is warming at a rate far above the global average.

In ecological terms tropicalization is an ongoing disaster for the Mediterranean. As tropical herbivore species have moved into waters that were once cooler, reef areas formerly dominated by complex and richly biodiverse algal forests have been transformed. The fish – mostly voracious rabbitfish – indiscriminately graze down the vegetation, which is then unable to regenerate before being replaced by invasive tropical algae on which the fish continue to graze, forming so-called 'turfs' or even 'barrens'.

The difference that the loss of the canopy makes to the marine ecosystem is enormous: recent research found biomass was 44 times lower in turfs than in algal forests, signalling a catastrophic loss of biodiversity.[3] The carbon balance can also be upset by such changes, with the impoverished reefs transforming from carbon sinks to carbon sources. Turfs now cover more than 50% of the shallow reefs in the southeast Mediterranean, with less than 1% covered by native algal forests.

Changes in fish population due to warming waters are occurring in the western Mediterranean too. In the Portofino MPA (Liguria, Italy) for example, local fishers are reporting increased catches of barracuda (*Sphyraena viridensis*), a thermophilic species that was rare until two decades ago and has now become abundant. Dusky groupers (*Epinephelus marginatus*) have also increased considerably in the new warmer conditions of the Ligurian Sea, which means they can now reproduce in more northern latitudes.



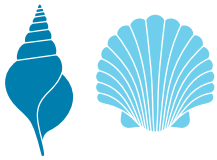
Rabbitfish (*Siganus luridus*) is an invasive in the Mediterranean Sea. © Philipp Kanstinger / WWF

WHAT CAN WE DO?

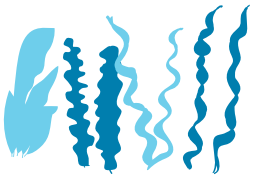
Networks of MPAs managers have an important role: restoring biodiversity and rebuilding stocks of native predatory species weakened by decades of overfishing and human-driven impacts will help control invasive species and keep ecosystems in balance. However, this does require proactive, effective management strategies, rather than just designating an MPA on paper and doing nothing else about it, as is the case in far too much of the region.

Fishers can also help to reduce the damage by directly targeting the new alien species, as they're already doing successfully in Turkey (see next case). This can be a doubly positive strategy as on the one hand it brings down their numbers, while also providing alternative revenue streams to replace the ones lost because of displaced native species. It means professional and cultural change, but the alternative is a loss of livelihoods.

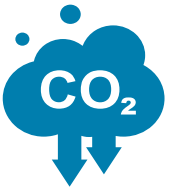
WARMING FACTS



In Israeli waters, only 5-12% of native mollusc species are still present



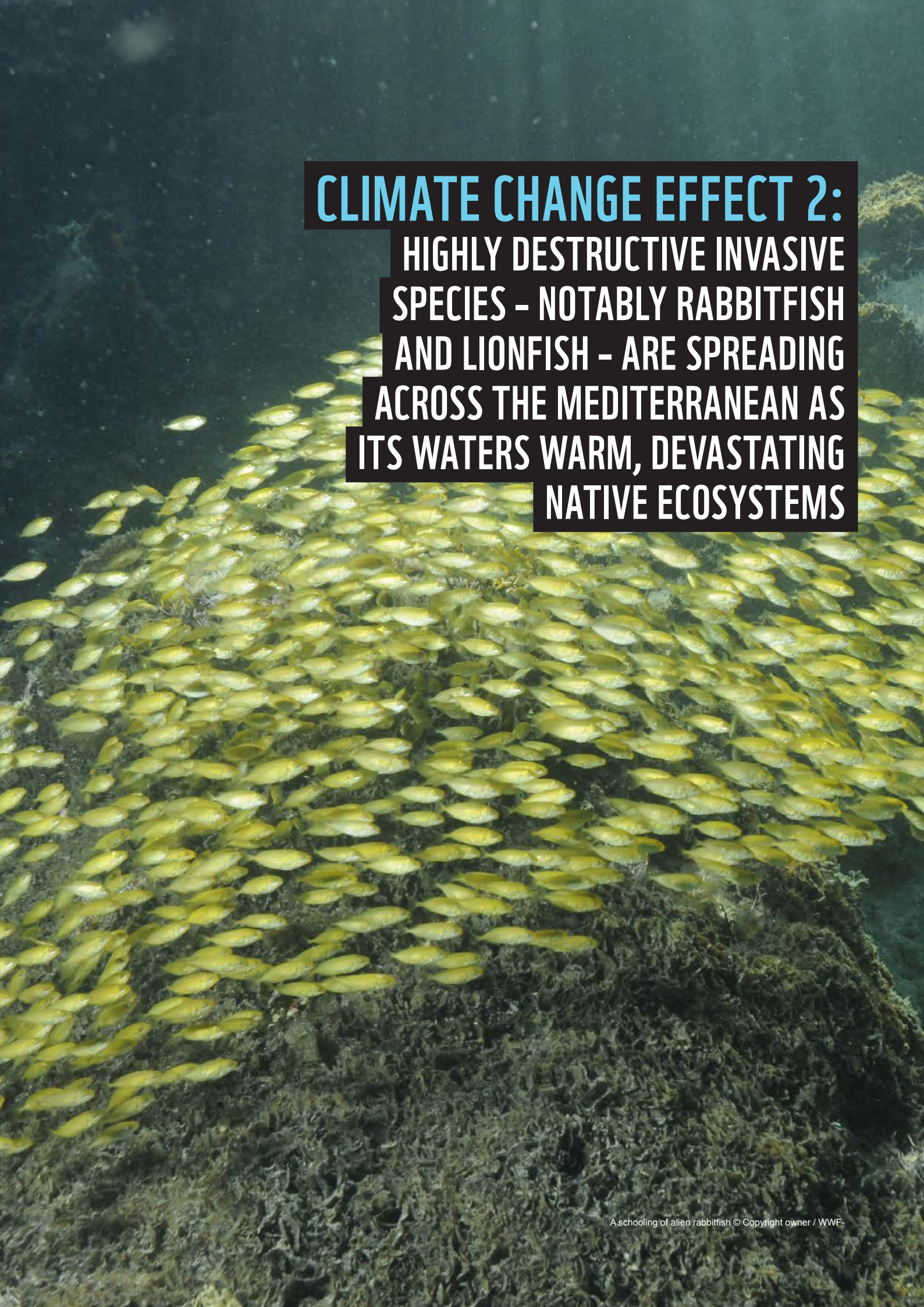
Biomass can be 44 times lower in barren turfs than in algal forests



Impoverished reefs turn from carbon sinks to carbon sources

CLIMATE CHANGE EFFECT 2:

HIGHLY DESTRUCTIVE INVASIVE SPECIES – NOTABLY RABBITFISH AND LIONFISH – ARE SPREADING ACROSS THE MEDITERRANEAN AS ITS WATERS WARM, DEVASTATING NATIVE ECOSYSTEMS



A schooling of alien rabbitfish © Copyright owner / WWF-

2. DESTRUCTIVE INVADERS

The Mediterranean holds one particularly unwelcome distinction: it's the most invaded sea in the world. In recent decades there's been an explosion in the numbers of alien species establishing themselves across the basin, with catastrophic consequences for native biodiversity – interaction with the new arrivals is completely disrupting stable ecosystems.

Most of these invaders come from the Red Sea or Indian Ocean and reach the Mediterranean via the Suez Canal: 986 alien species (126 fish species)[4] are thought to have become 'Lessepsian migrants' of this kind, a number which is likely to increase following the recent expansion of the Canal.

Climate change is compounding the problem. Rising sea temperatures mean that the new arrivals can survive in increasingly large areas of the Mediterranean where just a few decades ago the waters would have been too cold for them. And many are doing more than surviving, they're positively thriving at the expense of native species. For example, a survey[5] in Turkey's Gokova MPA found that 98% of the entire herbivore fish biomass was composed of alien rabbitfish (*Siganus rivulatus* and *S. luridus*), and even the remaining 2% was made up of parrotfish expanding their range north into the warming waters. This isn't just a modified community, it's a completely new one.

Rabbitfish are a particularly successful new entrant in the Mediterranean. With an adult length of 12-14cm they swim in large shoals and devastate the habitats of native species with their feeding habits. In warmer areas where rabbitfish become established, complex algal forests which provide valuable habitats are quickly reduced to rocky barrens, lessening native species abundance. To put this in perspective, a study[6] of more than 1,000km of Greek and Turkish coastline found that where rabbitfish were abundant there was a 65% reduction in large seaweeds, a 60% reduction in algae and other invertebrates, and a 40% reduction in the overall number of species present. Meanwhile fishers in Kas, Turkey, report that rabbitfish make up 80% of their catches.

Judged by some to be the single most damaging invasive species known to science, the lionfish (*Pterois miles*) is an equally successful alien arrival in the Mediterranean. A single specimen was first caught in a trawl in Israel in 1991, but two decades later lionfish had been found in Lebanon, Cyprus, Turkey, Greece, Tunisia, Syria, Italy and Libya. Today this highly aggressive invader is well established in southern and eastern areas of the Mediterranean, and is heading west and north towards the Aegean and Ionian seas.

A generalist feeder with fierce venomous spines, the lionfish eats large quantities of small native fish and crustaceans – its stomach can expand up to 30 times its original volume to accommodate them. As a new species in the ecosystem, its prey simply doesn't know how to avoid it. Experience from other parts of the world show just how much damage it can do: in the Bahamas, a 40% increase in lionfish numbers

Figure 2. In Turkey's Gokova MPA rabbitfish represented 98% of the entire herbivore fish biomass.

The alien Lionfish *Pterois miles* © Alexis Rosenfeld / WWF

between 2004-2010 has been linked to a 65% reduction in the recruitment of prey species.[7] Meanwhile, recent stomach content analysis in the Mediterranean revealed that 95% of lionfish prey was comprised of ecologically and economically significant native fish.[8]

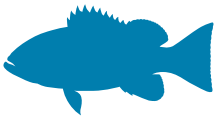
Climate change means it will likely be impossible to stop the continued spread of lionfish, rabbitfish and other potentially destructive invaders across the Mediterranean. But in a region where so much depends on healthy, diverse marine ecosystems – fishing, tourism, recreational diving etc. – the need to at least attempt to control the numbers of these alien species is obvious.

WHAT CAN WE DO?

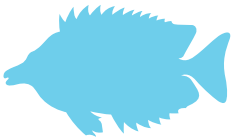
When it comes to the two species here, fishers have a big role to play: both are good to eat, so there's potential for creating consumer demand and deliberately targeting them (see the WWF Seafood Guide). Catching them is relatively easy. Shoals of rabbitfish can be – and are – caught in nets, while slow-moving lionfish are best picked off individually by experienced spearfishers who can handle this venomous species.

An increase in predators would help control numbers too – dusky groupers, for example, are very fond of lionfish. But decades of overfishing in the Mediterranean have removed many of the fish higher up the food web. Increasing the size and effectiveness of marine protection would significantly help to rebuild these stocks.

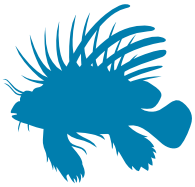
WARMING FACTS



Almost 1000 invasive species have migrated into the Mediterranean



Alien rabbit fish have caused a 40% reduction in numbers of native species in some areas



95% of lionfish prey is comprised of economically significant native fish

CLIMATE CHANGE EFFECT 3:

UNPRECEDENTED NUMBERS OF JELLYFISH ARE BLOOMING IN THE MEDITERRANEAN EACH YEAR, DISRUPTING FISHERIES AND OVERWHELMING TOURIST BEACHES

Pelagia noctiluca, Malta © Wild Wonders of Europe / Zankl / WWF

3. OCEAN JELLYFICATION

Jellyfish have been around since before the time of the dinosaurs. While they're undeniably strange creatures – 96% water, with no brains, no bones and no blood – they're common in all oceans, and are an important part of a balanced marine ecosystem.

But when the ecosystem gets out of balance jellyfish can become a problem, and since around 2003 that's what's been happening in the warming Mediterranean. Jellyfish blooms – where populations breed and rapidly increase – used to be occasional events that took place every few years, but in southern waters today they're happening annually and lasting longer.[9]

The increased blooms have led to an explosion in jellyfish numbers which is radically altering regional ecosystems, with serious knock-on effects for fisheries and tourism. As jellyfish fill up fishing nets across the Mediterranean, gear is damaged and efficiency reduced, and crews waste hours dealing with them instead of catching the fish that support their livelihoods. In Tunisia's Gulf of Gabes some fishers report they can catch more jellyfish than fish. (In Japan, a 10-tonne trawler was recently sunk by the weight of giant jellyfish in its nets.)

Jellyfish can be venomous. Fishers are frequently stung when clearing their gear, and this is a growing problem in Mediterranean tourist destinations too: a swimming beach filled with stinging jellyfish swiftly loses its appeal, and if visitor numbers drop local communities take an immediate economic hit. Jellyfish blooms threaten other economic sectors too: they can flood aquaculture cages and harm the captive fish; and they can even become a major problem for power stations, blocking the water intakes vital for cooling and thus reducing the efficiency of their output.

So what's driving the increase in jellyfish numbers? There are several factors involved, and climate change is one of the most important. Higher sea temperatures lengthen the duration of jellyfish blooms, and increase winter breeding in some species. They're also making the Mediterranean more welcoming for invasive jellyfish from tropical waters.

In parallel, eutrophication due to excessive fertilizer use on land causes marine algal blooms which can create low-oxygen 'dead zones' – here fish are unable to survive, but jellyfish easily adapt to such conditions and thrive where their natural predators have been driven out. Jellyfish eat the same zooplankton and copepods that commercial fish species rely on as larvae and juveniles (or even as adults in the case of sardines and anchovies), so the more jellyfish there are in the system in general, the less food there is for other planktivorous fish. What's more, jellyfish also eat fish eggs and larvae, further impacting fish recruitment and the numbers that reach adulthood.

Figure 3. In southern waters, today jellyfish blooms are happening annually and lasting longer.

Stinging jellyfish *Pelagia noctiluca*, Mediterranean Sea, Azure coast, France © Damsea / Shutterstock

It's not just here that jellyfish have a growing advantage. Years of overfishing have destroyed many of the stocks that used to compete with jellyfish for food, including many of the sharks, tunas and other larger fish that are sometimes their natural predators. Since they prey on fish larvae and compete with them too, it's the jellyfish themselves that are becoming the new top predators in the Mediterranean – a future ecosystem dominated by jellyfish is a genuine possibility, and the 'jellyfication' of the sea is becoming a reality.

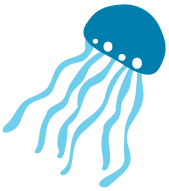
WHAT CAN WE DO?

Solving the jellyfish problem is a complex challenge, and will require coordinated action on several fronts.

Increasing competition by reducing overfishing on key fish species is critical. Some of these fish species also eat jellyfish eggs and adults. In addition, eutrophication and land-driven pollution must be brought under control to reduce hypoxia and eliminate the dead zones in which jellyfish thrive.

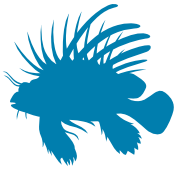
But in the short term the jellyfish are here and we need to adapt. Tourist operators are taking the simple step of installing nets around popular beaches to keep out the jellyfish.[10] In Tunisia, meanwhile, fishers are starting to try to sell their unwelcome catch, looking for inspiration to Asia where jellyfish have long been a source of food. There's also rising global demand for collagen for the cosmetics industry – this can be extracted from jellyfish, although the technology is still in its infancy.

WARMING FACTS



In southern waters jellyfish blooms are happening annually and lasting longer

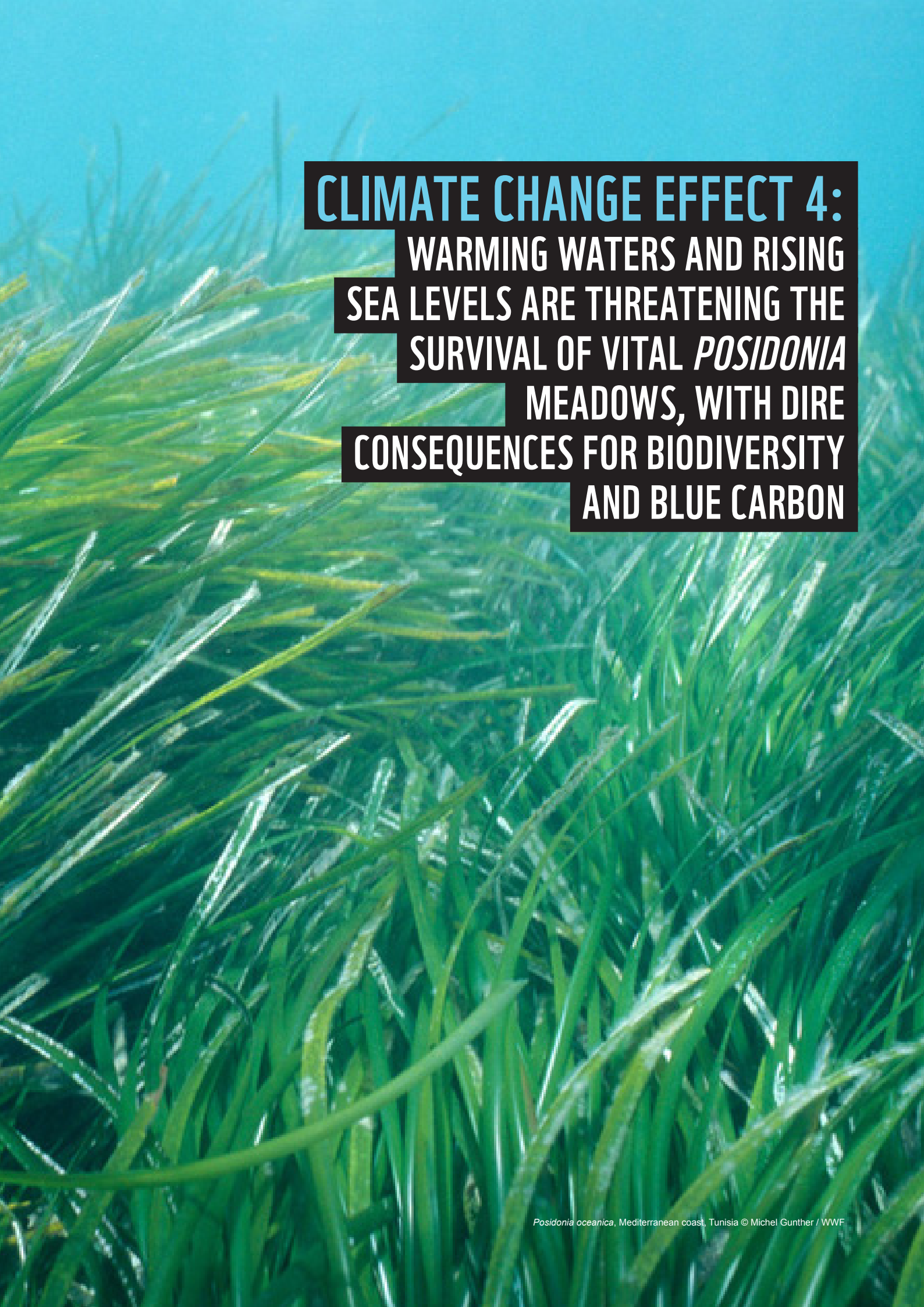
In Tunisia's Gulf of Gabes some fishers can now catch more jellyfish than fish



Overfishing has reduced predator and competitor species competing with jellyfish for zooplankton food

CLIMATE CHANGE EFFECT 4:

WARMING WATERS AND RISING SEA LEVELS ARE THREATENING THE SURVIVAL OF VITAL *POSIDONIA* MEADOWS, WITH DIRE CONSEQUENCES FOR BIODIVERSITY AND BLUE CARBON



Posidonia oceanica, Mediterranean coast, Tunisia © Michel Gunther / WWF

4. POSIDONIA, OUR BLUE CARBON SINK IN PERIL

Posidonia oceanica, a seagrass endemic to the Mediterranean, is one of the most important species in the whole of the marine ecosystem. Forming vast meadows on sandy seabeds to a depth of about 40m, *Posidonia* oxygenates the ocean and provides a vital habitat for some 20% of marine species found in the Mediterranean. Reservoirs of biodiversity, the meadows serve as nursery areas for the many important commercial species which need them to reproduce and grow.

Posidonia also has an increasingly significant role to play as climate change takes hold. As storms and hurricanes become more frequent and severe, *Posidonia* fields reduce the energy of waves and currents, stabilizing the seabed and securing sediment. In autumn as the weather worsens its dead leaves float to calm sea swells, and build up dense deposits on beaches which can remain for years and protect against coastal erosion.

As well as mitigating the physical impacts of climate change, *Posidonia* is itself a vital carbon sink, fixing carbon in a thick matte of dead sheathes, rhizomes and roots up to 4m deep on the seabed. *Posidonia* meadows are estimated to store between 11-42% of the total CO_2 emissions from Mediterranean countries since the Industrial Revolution: keeping this reservoir intact is essential as the world strives to reduce levels of greenhouse gases in the atmosphere.[11]

Its ecological role, sensitivity and extensive range mean *Posidonia* is a biological indicator for wider ocean health – and in the overstressed, overdeveloped Mediterranean of today, it's in serious decline. Direct human pressure is partly responsible: indiscriminate anchoring in recreational boating areas is the key threat, as this tears its leaves and uproots plants across the fragile meadows, leaving scars that may take years to heal. Coastal development of all kinds causes severe damage, not just to the plants but to the carbon-storing matte beneath. In more general terms, *Posidonia* thrives in clean water, but pollution and turbidity are increasing in the Mediterranean.

Still, regulation and enforcement can go some way to lessening these impacts. What they can't do, though, is stop the other growing threat to *Posidonia's*

Figure 4. *Posidonia* fields reduce the energy of waves and currents, stabilizing the seabed and securing sediment.

survival: climate change itself. Temperature stress is expected to change its distribution as ocean waters continue to warm: its absence in the south-east of the basin is probably due to temperature, and scientists have found its health diminished in western areas following exceptional rises in temperature.[12]

These temperatures are also attracting invasive new aquatic algae species which colonize the weakening meadows. Although the precise effects of such changes can be hard to predict, the resulting ecosystems tend to be less complex, offering less support to biodiversity, storing less carbon etc. Increasing numbers of invasive herbivorous fish – tracking the spread of warmer waters across the basin – further increase the pressure, and can leave once-healthy *Posidonia* meadows as barren areas.

Sea level rise – again a result of climate change – is another factor causing the regression of meadows around the Mediterranean. *Posidonia* needs light to photosynthesize, and it dies out when light can't reach it. Small changes in sea level can make a relatively large difference in the amount of light reaching a shallowly sloping bottom: an extra 2cm in the water column pushes *Posidonia's* lower limit a metre towards the shore on a 2° slope. With sea levels in some areas of the Mediterranean rising by 6mm a year,[13] the cumulative loss at basin level is growing all the time.

"*Posidonia oceanica* prairies have enormous ecological but also socio-economic value," says Lorenzo Merotto of Portofino MPA. "In fact, their protection not only ensures the survival of many marine species, but also guarantees ours thanks to all the ecosystem services they provide, from the removal of CO_2 to coastal protection and sustenance from fishable species. It is therefore essential to take all necessary measures to protect this valuable habitat."

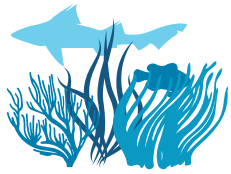

Thriving Posidonia habitat, Corsica, France, Mediterranean Sea © Damsea / WWF/ Shutterstock

WHAT CAN WE DO?

Posidonia decline fuels a vicious circle: as the meadows die back their ecosystem services are lost and the carbon-rich matte they protect is exposed, releasing CO_2 into the atmosphere and further fuelling the climate change that's harming them in the first place. Increasing protection and management to guard against destructive anchoring and fishing in the remaining areas of this essential part of the ecosystem is crucial.

Future effort of increasing protection should prioritize carbon-rich ecosystems and incentives should be provided for restoration, through payments for ecosystem service schemes, such as carbon and nutrient trading credits. Finally the contribution of MPAs to protecting seagrasses should be recognised as nature-based solutions within Nationally determined contributions and other relevant climate policies for mitigation and adaptation.

WARMING FACTS



Posidonia provides habitat for 20% of marine species in the Mediterranean

Posidonia meadows store 11-42% of CO_2 emissions from Mediterranean countries

Anchoring tears Posidonia's leaves and uproots plants

CLIMATE CHANGE EFFECT 5:
EXTREME WEATHER IS DESTROYING THE CHARISMATIC CORAL SPECIES THAT UNTIL NOW HAS PLAYED A KEY ROLE IN MANY COMPLEX MEDITERRANEAN ECOSYSTEMS

Paramuricea clavata coralligeno © Lorenzo Merotto

5. A PERFECT STORM FOR CORAL

Gorgonians – so-called 'sea fans', only a few millimetres wide but reaching up to a metre high and across – are among the most beautiful soft corals in the Mediterranean. They're among the most important, too: the slow-growing species forms underwater forests that provide vital habitats supporting rich marine ecosystems, providing shelter and nursery grounds and withstanding invasive algae. Gorgonians are colonial organisms, and not just important in the sea – they contribute to Mediterranean economies too as a major attraction for divers drawn by the complex and colorful submarine landscapes it creates.

With low natural mortality, gorgonians can live up to 60 years – but now the rapidly changing climate in the Mediterranean is killing them. The effects cascade through the ecosystem. When gorgonians die and fall down, the three-dimensional nature of the habitats they engineer is reduced: fewer erect forms leads to a general loss of habitat complexity, which in turn diminishes marine biodiversity and can leave room for invasive species to move in.

Gorgonians can be found in various environments in the Mediterranean. The most important species, the red gorgonian (*Paramuricea clavata*), is typical of the coralligenous habitat at depths below 25m where the water doesn't usually reach temperatures as high as on the surface. The organisms that populate it are therefore more susceptible to increases in temperature, which makes them particularly vulnerable to the increasingly frequent heatwaves in the Mediterranean basin.

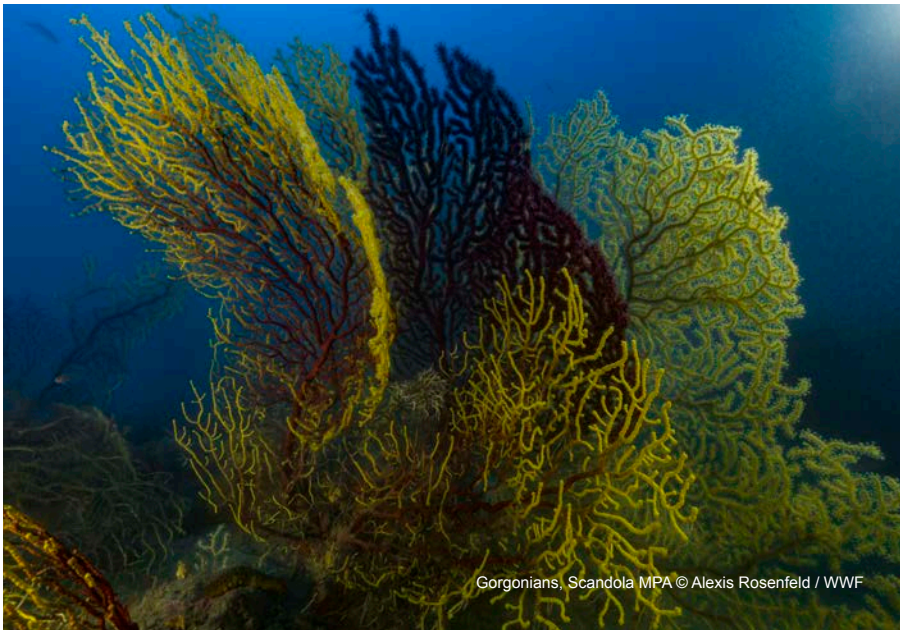
Coral across the world is being hit hard by warming seas. While it can be hard to separate the impacts of climate change from other stressors, long-term monitoring of complex gorgonian communities shows that periods of rapid warming lead to mass mortalities. Studies in the Ligurian Sea have shown that warming events starting in the 1990s caused mass mortalities among gorgonians down to a depth of about 40m.[14] And this trend is unlikely to get any better: figures released in 2019 show that 2014-2018 were the warmest years on record in the region, where temperatures have risen by about 1°C over the last decade.

But climate change is about more than just sea temperatures: it's also increasing the frequency and intensity of extreme weather. While this primarily affects

Figure 5. Gorgonians can be found in various environments in the Mediterranean.

surface environments, it can also reach deeper habitats and can have a devastating impact on gorgonians already weakened by other factors. For example, in October 2018, a huge storm with winds of up to 130 km/h swept through the Ligurian Sea, destroying what researchers from Genoa University estimated was 30% of all the gorgonians in the area.[15] Colonies at depths down to 25m were completely destroyed. Some of the damage was due to boulders falling from the cliffs above and waves overturning rocks, while the exceptional movement of water on the sea floor also damaged the delicate structures. Abandoned fishing gear (mainly lines) tangled around deeper colonies also proved to be a major threat, rubbing against the coral with the force of the wind and waves, damaging its living tissue.[16]

The longer-term impacts of this particular storm on the surviving gorgonians remain to be seen – secondary mortality and reduced recruitment are possible – but the real point is that we can expect more frequent storms of this magnitude around the Mediterranean in the years to come as temperatures continue to increase, and they're only likely to continue to damage the remaining colonies. When native structural communities are destroyed, the door is left open for algae and other species to replace them and create a simplified, less biodiverse turf-style ecosystem (which is also of far less interest to economically important divers).


Gorgonians. Scandola MPA © Alexis Rosenfeld / WWF

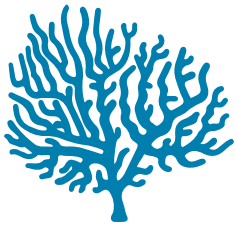
WHAT CAN WE DO?

It's essential to reduce stress on remaining populations as much as possible. MPAs have an important role in protecting gorgonians, by prohibiting the use of recreational and professional fishing gears that impact the seabed and regulating the scuba-diving activities that impact the corals on which the sport relies.

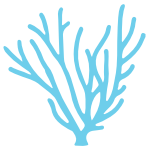
Research work on reducing climate-related damage to gorgonians is ongoing in Portofino MPA. Broad stakeholder involvement is essential, since mitigating anthropic pressures is the best way to increase the resilience of habitats in the face of rising temperatures.

Some experiments with transplanting gorgonians are taking place, but as waters keep warming and storms keep intensifying, it's going to be very challenging to conserve the remaining gorgonians of the Mediterranean.

WARMING FACTS



Gorgonians can live up to 60 years

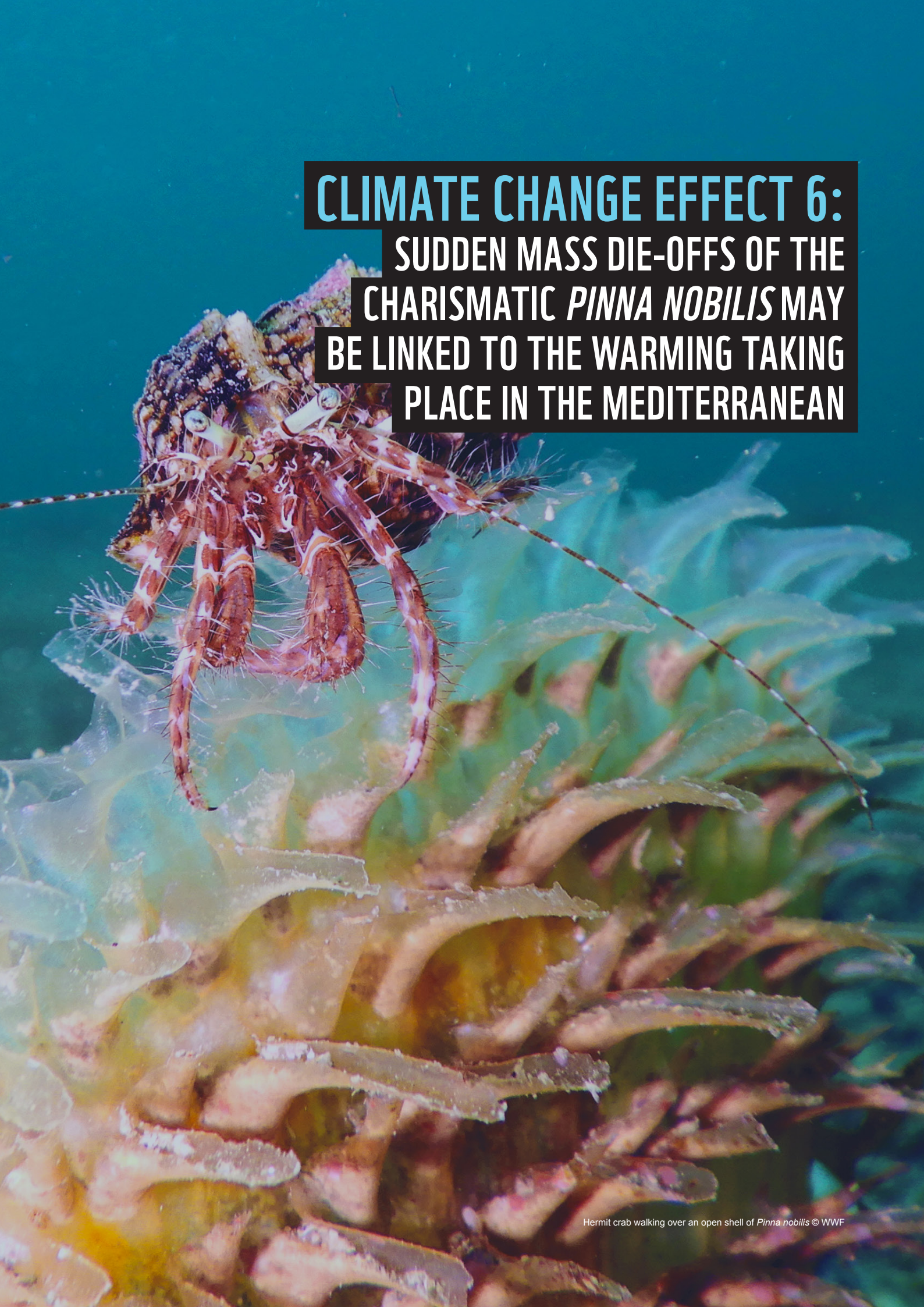


Long lasting periods of warm water lead to mass mortalities of gorgonian communities

In Liguria 30% of all gorgonians were destroyed by a single storm

CLIMATE CHANGE EFFECT 6:

SUDDEN MASS DIE-OFFS OF THE CHARISMATIC *PINNA NOBILIS* MAY BE LINKED TO THE WARMING TAKING PLACE IN THE MEDITERRANEAN



Hermit crab walking over an open shell of *Pinna nobilis* © WWF

6. THE PINNA NOBILIS POPULATION CRASH

Although climate change is a gradual process with incremental effects, it can combine with other environmental stressors to precipitate sudden ecological crises. In the Mediterranean, it has been linked with the recent catastrophic mass mortality events that have decimated populations of fan mussels – *Pinna nobilis* – across large areas of their home range.

Pinna nobilis is a flagship species – the largest endemic bivalve in the Mediterranean, and one of the largest in the world. It plays an important ecological role, contributing to water clarity by filtering large amounts of detritus, and provides a habitat where many different species aggregate: 146 of them were found in one study.[17]

Its byssus threads – the filaments that attach it to the seabed – have been valued since the days of the Romans, who used them to decorate precious fabrics. This 'sea silk' was harvested for artisanal use and the species was also targeted by recreational and commercial fishers into the 1980s, when populations saw rapid declines before *Pinna nobilis* received protection under the Barcelona Convention.

The species was recovering well until the autumn of 2016, at which point a devastating mass mortality event (MME) occurred in *Pinna nobilis* populations across the Spanish Mediterranean, causing 100% mortality in some areas. In the following three years, 80-100% MMEs spread west to east along the coasts of Catalonia, Italy, Sicily and Corsica.[18] In January 2020, the scientific team of the Miramare MPA (Gulf of Trieste, Italy) announced the death of 60-80% of *Pinna nobilis* in the area, and other mortality spots continue to be detected in several countries across the Mediterranean. *Pinna nobilis* was declared Critically Endangered on the IUCN Red List in 2019.

The MMEs turned out to be caused mainly by a pathogen, *Haplosporidium pinnae*, which may have spread in the direction of summer marine currents. The question is the extent to which climate change may also have been a driver: warmer temperatures may favour the development of *H. pinnae*, in which case there's a serious risk that continuing climate-driven warming will help it spread throughout the Mediterranean.

This would be a disaster for the remaining populations of the charismatic fan mussel. What's more, climate change may also be affecting its health directly. Scientists remain uncertain, but warming waters could influence processes

Figure 6. In the Gulf of Trieste 60 to 80% of Pinna Nobilis is reported to be dead.


Pinna nobilis @ Miramare MPA

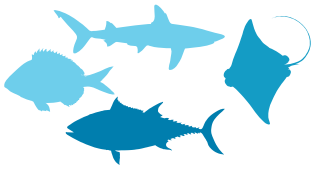
including reproduction and recruitment, along with decreasing the numbers of juveniles that survive. Additionally, *Pinna nobilis* needs high levels of oxygen and has the fastest shell growth of any bivalve, so it may be vulnerable to ocean acidification.

Rising numbers of invasive species – again due to climate change – pose a further challenge to the remaining Pinna nobilis populations. These range from invasive algae which could alter their food sources to voracious invasive crabs which could eat their juveniles.

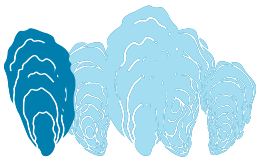
WHAT CAN WE DO?

It's by no means certain that we'll be able to save this flagship Mediterranean species, but trying to do so is an urgent conservation priority. Active ecological restoration, also through the recruitment of larvae is one potential way of repopulating areas affected by MMEs, but *Pinna nobilis*' slow growth rates and low recruitment levels mean it remains a challenging prospect.[19] Strengthening the resilience of remaining populations is key, but this will mean large-scale multi-stakeholder collaboration to address the full range of threats to the Mediterranean marine environment. Climate change compounds the problem exponentially.

WARMING FACTS



Pinna nobilis beds can host up to 146 different species



80-100% of Pinna nobilis populations were recently lost in mass mortality events in Spain, Italy and other Mediterranean sites

Warming waters could impact Pinna nobilis' reproduction

POLICY RECOMMENDATIONS FOR INTEGRATED CLIMATE, OCEAN AND BIODIVERSITY POLICY AGENDAS

More than ever, people are aware that our climate and our ocean are in danger – and they are two sides of the same coin. As these cases clearly show, while climate change has serious impacts on the ocean, and a depleted ocean further exacerbates the effects of climate change, we also know that by protecting the ocean we contribute to the fight against climate change, and by fighting against climate change we contribute to protecting the ocean.

However, the magnitude of the problem requires bold and ambitious policy action, using every tool and mechanism at our disposal. In a biodiversity hotspot like the Mediterranean Sea, severely impacted by climate change, the ocean-climate nexus must be central to discussions about creating the solutions that will allow people and nature to thrive. Increased coordination across relevant policy agendas is needed to strengthen the mitigation, adaptation and resilience potential of marine and coastal ecosystems – and everything and everyone that depends on them.

WWF'S FOUR OVERARCHING PRINCIPLES TO GUIDE EFFECTIVE INTEGRATED OCEAN AND CLIMATE ACTION INCLUDE:

- **Raise ambition and urgently deliver stronger and sustained mitigation and adaptation actions**
- **Make nature a key part of the solution**
- **Put people at the centre**
- **Join up the climate and ocean finance agendas.**

Based on these principles, WWF is calling on decision-makers to integrate the ocean into the global and regional climate agendas at the Convention on Biological Diversity COP15, the United Nations Framework Convention on Climate Change COP26, and the Barcelona Convention COP22 that will take place in 2021. They can do this by:

- Capturing and strengthening the contribution of coastal and ocean ecosystems to greenhouse gas mitigation efforts.
- Capturing and strengthening the contribution of coastal and marine ecosystem protection, restoration and management for climate adaptation, resilience and related planning efforts.
- Strengthening the resilience of coastal and marine ecosystems and dependent societies and economies.
- Increasing the capacity of coastal developing countries to respond to ocean-related effects of climate change by leveraging support for finance, capacity-building, inclusive planning, education and technology transfer.

For the full list of recommendations, see WWF's *Blueprint for a Living Planet: Four Principles for Integrated Ocean-Climate Strategies* (2021).*

***Sources:** "Blueprint for a Living Planet: Four Principles for Integrated Ocean-Climate Strategies" WWF 2021 and Gomei, M., Steenbeek, J., Coll, M. and Claudet, J. 2021. 30 by 30: Scenarios to recover biodiversity and rebuild fish stocks in the Mediterranean. WWF Mediterranean Marine Initiative, Rome, Italy, 29 pp. https://wwfeu.awsassets.panda.org/downloads/wwf_med_30x30_full_report_2021__1_.pdf

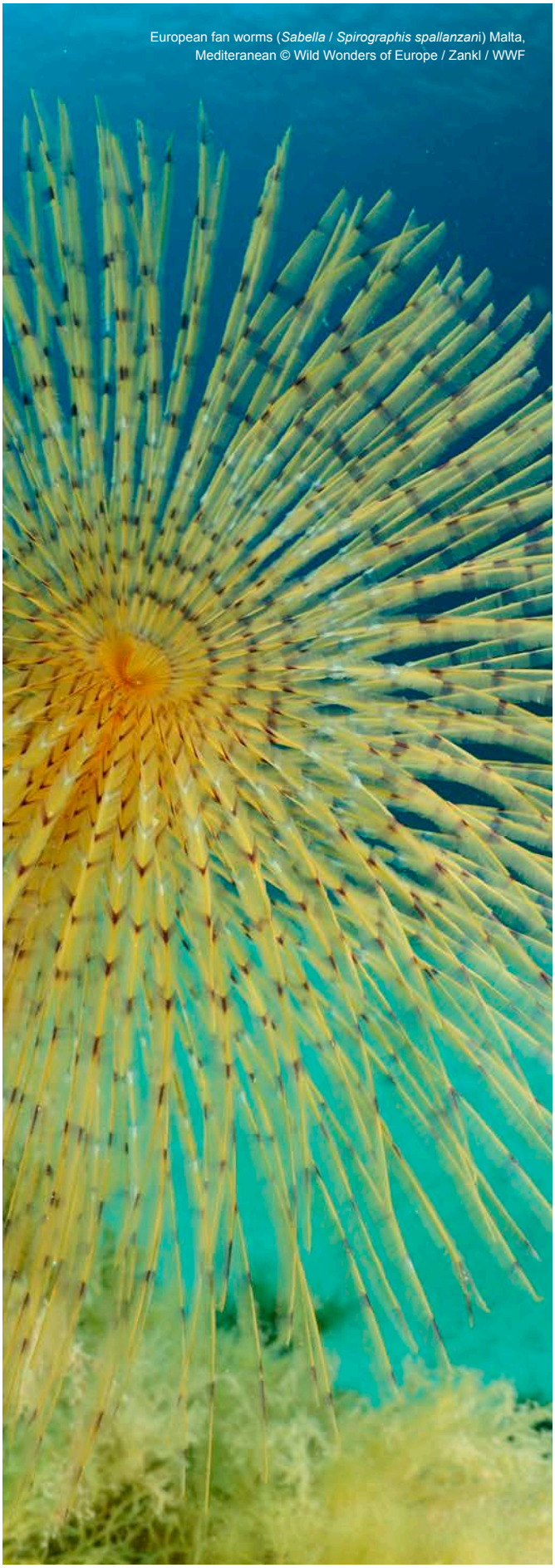
SCALING-UP MPAS AS NATURE-BASED SOLUTIONS TO MITIGATE THE IMPACT OF CLIMATE CHANGE

Given the interdependence of climate, biodiversity and ocean, it is of the utmost importance that Mediterranean countries make the best use of nature-based solutions to mitigate climate change impacts, in particular by scaling up networks of marine protected areas (MPAs).

To enable the recovery of marine ecosystems and to mitigate climate change impacts, at least 30% of the Mediterranean Sea area should be protected and effectively and equitably managed through an ecologically representative and well-connected network of MPAs and other effective area-based conservation measures (OECMs).

A coherent network of MPAs and OECMs can make a major contribution to climate adaptation and mitigation. For this to happen, the following steps must be taken:

- Enhancing the resilience of marine ecosystems and restoring their natural biodiversity, which in turn supports climate adaptation, mitigation and disaster risk reduction.
- Protecting and restoring 'blue carbon' ecosystems to provide coastal protection, carbon storage and resilient biodiversity; in particular, seagrass beds which are highly productive ecosystems that remove carbon dioxide from the atmosphere and store it in the seabed.
- Protecting vital habitats of large marine animals, including fish and marine mammals, that accumulate carbon in their bodies during their long lives: once they die, their biomass and captured carbon often sinks to the deep sea.
- Carrying out vulnerability assessments as an integral part of the establishment process of new MPAs to assess how climate change, ocean acidification, alien and invasive species will impact the conservation objectives of the MPAs/MPA network, and how many replication sites within a given biogeographic area are needed to safeguard particular vulnerable ecosystems.
- Integrating climate-specific objectives in MPA management plans in addition to biodiversity conservation objectives.
- Developing climate change mitigation, adaptation and increased resilience strategies to avoid/mitigate the impacts, including those identified in the vulnerability assessment.
- Monitoring MPA management effectiveness in response to climate change and adopting science-based (including traditional knowledge) adaptive measures, as needed, in order to achieve the biodiversity and climate-related objectives.



European fan worms (*Sabella / Spirographis spallanzani*) Malta, Mediteranean © Wild Wonders of Europe / Zankl / WWF

Paramuricea clavata © Lorenzo Merotto / WWF

KEY REFERENCES

TROPICALIZATION

1. Givan, O., Edelist, D., Sonin, O. and J. Belmaker. 2017. Thermal affinity as the dominant factor changing Mediterranean fish abundances. *Global Change Biology*. 24. 10.1111/gcb.13835.

2. Albano, P. et al. 2021. Native biodiversity collapse in the eastern Mediterranean. *Proceedings of the Royal Society B: Biological Sciences*. 288. 20202469. 10.1098/rspb.2020.2469.

3. Peleg, O., Guy-Haim, T., Yeruham, E., Silverman, J. and G. Rilov. 2019. Classification to traits of various taxa from three shallow rocky reef habitats in the southeastern Mediterranean. PANGAEA, https://doi.org/10.1594/PANGAEA.908353; In supplement to: Peleg, O. *et al.* (accepted): Tropicalisation may invert trophic state and carbon budget of shallow temperate rocky reefs. *Journal of Ecology*, doi.org/10.1111/1365-2745.13329

RABBIT AND LIONFISH

4. Zenetos, A. et al. 2012. Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. *Mediterranean Marine Science*. 13. 328-352. 10.12681/mms.327.

5. Giakoumi, S. et al. 2019. Exploring the relationships between marine protected areas and invasive fish in the world's most invaded sea. *Ecological Applications*. 29. e01809. 10.1002/eap.1809.

6. Vergés, A., Tomas, F., Cebrian, E. et al. 2014. Tropical rabbitfish and the deforestation of a warming temperate sea. *The Journal of Ecology*. 2014 Nov; 102(6):1518-1527. doi: 10.1111/1365-2745.12324.

7. Savva, I., Chartosia, N., Antoniou, C., *et al.* 2020. They are here to stay: the biology and ecology of lionfish (Pterois miles) in the Mediterranean *Sea*. *J Fish Biol.* 2020; 97: 148–162. doi.org/10.1111/jfb.14340

8. Eddy, C., Pitt, J., Morris, J., Smith, S., Goodbody-Gringley, G. and D. Bernal. 2016. Diet of invasive lionfish (*Pterois volitans and P. miles*) in Bermuda. *Marine Ecology Progress Series*. 558. 10.3354/meps11838.

JELLYFISH

9. Kogovšek, T. et al. 2015. Progress in understanding scyphomedusae outbreaks in the Mediterranean sea: distribution and phenology. 10.13140/RG.2.1.1967.0644.

10. Piraino, S. et al. 2016. Are anti-jellyfish nets a useful mitigation tool for coastal tourism? Hindsight from the MED-JELLYRISK experience.

POSIDONIA

11. Pergent, G. et al. 2014. Climate change and Mediterranean seagrass meadows: A synopsis for environmental managers. *Mediterranean Marine Science* 15. 462-473. 10.12681/mms.621.

12. Pergent, G. et al. 2015. Dynamic of *Posidonia oceanica* seagrass meadows in the northwestern Mediterranean: Could climate change be to blame? Comptes Rendus Biologies 338, Issue 7, 484-493. doi.org/10.1016/j.crvi.2015.04.011.

13. European Environment Agency Indicator Assessment: Global and European sea level rise [online]

GORGONIA

14. Cerrano, C. et al. 2000. A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-Western Mediterranean), summer 1999. *Ecology Letters* 3. 284-293. 10.1046/j.1461-0248.2000.00152.x.

15. Betti, F., Bavestrello, G., Bo, M., Enrichetti, F. and R. Cattaneo Vietti. 2020. Effects of the 2018 exceptional storm on the *Paramuricea clavata* (Anthozoa, Octocorallia) population of the Portofino Promontory (Mediterranean Sea). *Regional Studies in Marine Science* 34. 101037. 10.1016/j.rsma.2019.101037.

16. Betti, F. et al. 2020. Evidences of fishing impact on the coastal gorgonian forests inside the Portofino MPA (NW Mediterranean Sea). *Ocean & Coastal Management* 187. 105105. 10.1016/j.ocecoaman.2020.105105.

PINNA NOBILIS

17. Rabaoui, L., Tlig-Zouari, S., Cosentino, A., Ben Hassine, O. 2009. Associated fauna on the fan shell *Pinna nobilis* (Mollusca: Bivalvia) in the northern and eastern Tunisian coasts. *Scientia Marina*. 73. 129-141.

18. Cabanellas-Reboredo, M., Vázquez-Luis, M., Mourre, B. et al. 2019. Tracking a mass mortality outbreak of pen shell *Pinna nobilis* populations: A collaborative effort of scientists and citizens. Sci Rep 9, 13355. doi.org/10.1038/s41598-019-49808-4

19. Katsanevakis, S. 2021. Transplantation as a conservation action to protect the Mediterranean fan mussel *Pinna nobilis*. *Marine Ecology Progress Series* 546: 113-122. doi: 10.3354/meps11658.

Seabirds flying in the sky and a shoal of fish in the Mediterranean Sea, Spain © Damsea / Shutterstock / WWF

WWF

Working to sustain the natural world for the benefit of people and wildlife.

together possible™

wwfmmi.org

WWF Mediterranean Marine Initiative - Via Po 25/c, 00198, Rome, Italy.
Follow us on Twitter: @WWF_Med & Instagram: wwf_med
Please visit our website: at wwfmmi.org