Sub-chapter 2.1.4

Climate change and fisheries

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There is considerable evidence that Mediterranean marine species have been shifting their ranges, migration patterns, seasonal activities and periodicities, abundances, growth and mortality rates, and consequently their trophic interactions in response to climate change and variability. These responses may ultimately have significant consequences for ecosystem productivity, biodiversity and functioning and hence for the overall goods and ecosystem services they provide, especially the production of living resources (Kirby & Beaugrand 2009, Doney et al. 2012).

Climate change is an additional pressure on marine ecosystems that are already subject to many anthropogenic disturbances such as fishing activities. This is especially true in the Mediterranean Sea, where a series of human impacts co-occur and interact (Coll et al. 2010, Micheli, Halpern, et al. 2013). The consequences of climate change for marine resources need to be evaluated in this context and research and management need to take interactions between fishing, other human impacts, and climate into account (Brander 2010, Perry et al. 2010). This chapter thus has three aims: (i) to investigate the synergy between climate and fishing (a major human impact on Mediterranean marine ecosystems) and, using some examples from the Mediterranean Sea, to highlight how these two factors interact, from the individual to the ecosystem scale, (ii) to assess and quantify the consequences of climate change for the composition of fishery catches in the Mediterranean Sea, and (iii) to address the consequences of climate change for the management tools and strategies implemented in the region.

Fishing and climate act in synergy

Studies that specifically assess the synergistic effects of both climate change and fishing on fish resources and ecosystem functioning in the Mediterranean Sea are rare. However, studies conducted in other regions or at global scale describe a range of changes that can be expected in the Mediterranean. Under climate change, fishing is likely the most significant anthropogenic impact on marine fishes. Fishing has been going on in the Mediterranean Sea for a thousand years and has resulted in overexploitation of the main commercial species, with no less than 90% of stocks assessed in 2015 categorized as overfished (STECF 2016). Fishing does not only reduce the abundance and production of fish populations but also results in changes in their population structure (e.g. by truncating the demographic structure with fewer older fish and by altering life history traits such as mean body size and age at maturity) and in species composition (e.g. by removing populations of large sized fish) (Colloca et al. 2013). In an ecosystem context, where inter- and intra-specific interactions are the main drivers of community structure, fishing exerts direct pressure on the main target species but also indirectly affects their competitors, prey and predators, thereby potentially affecting the whole food web (Scheffer et al. 2005, Daskalov et al. 2007, Coll et al. 2008). In addition to reducing the size of target populations, one direct impact of fishing is simplifying the demographic structure of marine populations, making them more sensitive to climate variability at interannual to interdecadal scales (Perry et al. 2010). Fishing of finfishes and invertebrates can reduce the number of age groups in populations, lead to spatial contraction, sometimes to a loss of population sub-units, and alter life-history traits such as age at maturity and longevity (Perry et al. 2010, Planque et al. 2010). All these effects may make populations more susceptible to climate variability at different temporal scales. For instance in the Mediterranean Sea, Hidalgo et al. (2011) showed that the long-term exploitation pattern has likely eroded the age structure of hake (*Merluccius merluccius*), one of the main commercially exploited species. Hake subsequently became more recruitment-dependent, and thereby more sensitive to climate variability (Figure 1). This phenomenon is called the "age truncation effect" (Hsieh et al. 2006).

In the same way, Ottersen et al. (2006) demonstrated that heavily fished stocks were subject to more pronounced variability in recruitment linked to environmental fluctuations, due to changes in the spawning stock age and size composition. Hsieh et al. (2006) showed that exploited species exhibit higher temporal variability in abundance than unexploited species. Indeed, truncation of the age structure caused by fishing may reduce the capacity of exploited populations to buffer environmental events, especially anomaly events. Fishing can thus cause higher fluctuations in the abundance of commercially targeted species thereby increasing the risk of collapse of a heavily fished population from stochastic environmental events (Scheffer et al. 2001, Hsieh et al. 2006). Fluctuations in fish stocks may have consequences for both ecosystem functioning and fishing sustainability. In addition, fishing communities that depend on just a few local species have become more vulnerable to fluctuations in stocks, whether due to overfishing or climate variability (Brander 2010).

Under fishing pressure, the mean turnover rate of fish communities is expected to increase due to a relative increase in the proportion of smaller individuals with higher metabolic rates and to the depletion of the major predatory demersal fish resources that have a lower turnover rate (Myers & Worm 2003). In this

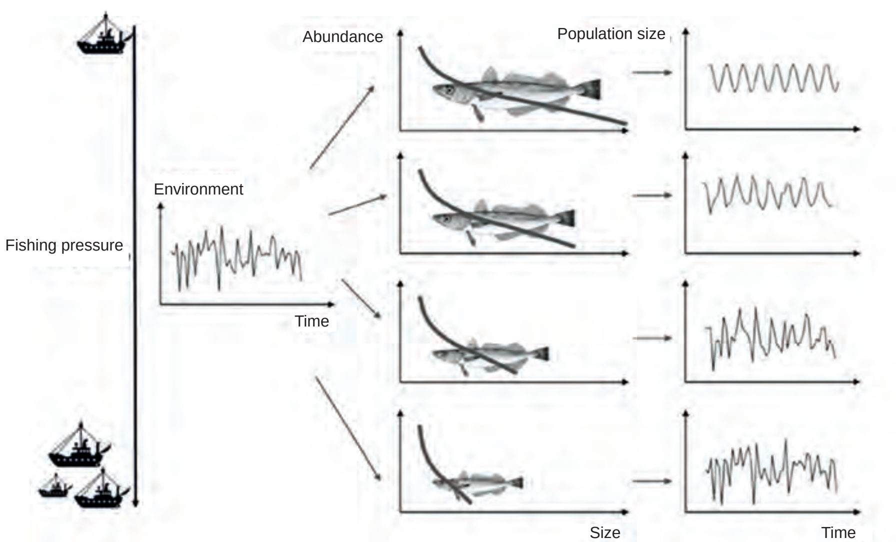

Figure 1
According to Hidalgo et al. (2011), fishing "by altering the demographic structure, populations switch from an internally-generated to an externally-forced fluctuation mode, tracking the environmental variability more closely".
Adapted from Hidalgo et al. (2011).

context, Perry et al. (2010) pointed out that "*these changes are expected to alter how the community responds to climate forcing since exploited fish communities with faster mean turnover times are expected to track more closely the short-term variability in production that results from variability in climate*". In addition, by removing top predators and favoring the dominance of short-lived prey populations with rapid turnover rates, fishing modifies the trophic controls that drive ecosystem dynamics, i.e. generally weakening top-down control and strengthening bottom-up control, which can lead to much greater vulnerability of the marine system to climate forcing (Perry et al. 2010).

In view of the current state of fish stocks in the Mediterranean basin, climate change in the region will strongly affect marine resources with several ramifications in food webs dynamics and ecosystem functioning. The Mediterranean Sea, which for decades has been - and continues to be - subject to intense exploitation of marine resources, is likely to experience stronger bottom-up control. This will lead to greater vulnerability and variability of the system to climate forcing, with implications for fisheries sustainability and biodiversity conservation.

Climate-induced changes in commercial catches

Worldwide, fisheries will be impacted by changes in the distribution and in the catches of exploited marine species (Cheung et al. 2008, 2016, Barange et al. 2014), which will affect the economics of fisheries worldwide (Sumaila et al. 2011). In the Mediterranean Sea, the change in fisheries catch potential is partly due to northward and eastward shifts in fish distribution (see sub-chapter 2.1.3) that result in the invasion of warmer-water species into higher latitudes (e.g. Adriatic Sea) and local extinction in the southern Mediterranean region. Thus, in the near future, species that are commercially important in some areas may no longer be available. This may be already the case of the once abundant sardine (*Sardina pilchardus*), which has decreased drastically in the northern Mediterranean Sea in the last decade (Palomera et al. 2007).

By 2050, under a high emission scenario (Representative Concentration pathway 8.5), Cheung et al. (2016) predicted an up to 5% reduction in the potential catches at the Mediterranean scale (Figure 2). Furthermore, when considering changes in biogeochemistry such as ocean acidification and reduction in oxygen concentration, these authors also predicted a decrease in fish growth performance, which, along with a higher rate of distributional shift, may reduce estimated catch potential (Cheung et al. 2011). Changes in phytoplankton community structure may even reduce the projected catch potential by a further 10% (Cheung et al. 2011).

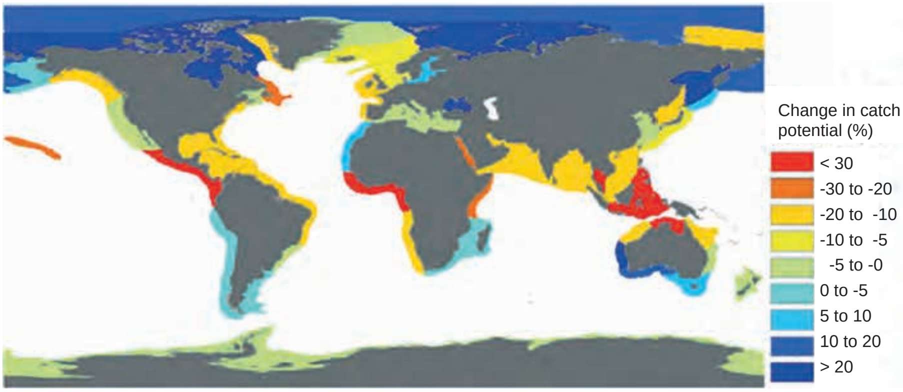

Figure 2
Mean percentage changes in potential catch by 2050 relative to present day, under the RCP 8.5 scenario. From Cheung et al. (2016).

This decrease in catch potential will be accompanied by tropicalization of the catch (i.e. an increase in warm-water species in catch composition). Indeed, Cheung et al. (2013) showed that in the Mediterranean Sea, the Mean Temperature of the Catch (MTC, i.e. the average inferred temperature preference of the exploited species weighted by their annual catch) has significantly increased since 1970, evidence for an increase in the catch of warmer water species and a decrease in the catch of colder water species. This index, which reflects changes in the composition of marine fisheries catch is closely linked to warming of the Mediterranean Sea. For the period 1970-2010, the MTC for the western, central and eastern Mediterranean has increased by 0.56 °C, 1.05 °C and 0.29 °C per decade, respectively (Tsikliras & Stergiou 2014) (figure 3). Moreover, if Lessespsian species are included, the MTC rate would be higher in all areas (Tsikliras & Stergiou 2014).

With the proliferation of non-indigenous invasive species (see sub-chapters 2.1.3), there is a need to explore market options for non-target species currently of low or no economic value. In general, changes in the composition of commercial fisheries catches have detrimental socioeconomic implications for fisheries, markets and consumers (Weatherdon et al. 2016). This is the case of the decline in small pelagic fish species (Van Beveren et al. 2016). However, climate change and the associated increase in sea surface temperature may offer opportunities to some Mediterranean fishermen to increase landings of tropical and subtropical species, some of which are of great commercial interest (e.g. the dolphinfish *Coryphaena hippurus*) (Weatherdon et al. 2016).

From qualitative and quantitative analyses of catch composition of a small tuna trap along the Ligurian coast, Cattaneo-Vietti et al. (2015) showed that in the last few decades there have been notable changes in species composition, with a decrease in the abundance of certain scombroids such as mackerel (e.g. *Scomber scombrus*) and bullet tuna (i.e. boreal species) and an increase in the abundance of carangids such as horse mackerel (*Trachurus* spp.) and amberjacks (e.g. *Seriola dumerili*) and other typical southern-water fish species (e.g. the dolphinfish *Coryphaena hippurus* and the east Atlantic barracuda *Sphyraena viridensis*). Using 'local ecological knowledge' (LEK), a recent study showed an increase in Carangidae and Sphyraenidae (thermophilic species) over time, but a simultaneous decrease in Scombridae and Clupeidae (Azzurro et al. 2011). In the western Mediterranean Sea, LEK information made it possible to record the proliferation of some species, including cephalopods, jellyfish and small-sized fish (Coll et al. 2014). These proliferations may be partly due to the impacts of fishing on the ecosystem and to climate change. Tzanatos et al. (2014) also demonstrated that fisheries landings showed significant year-to-year correlations with temperature for approximately 60% of 59 species. Based on these species, these authors showed that approximately 70% of landings were negatively correlated with temperature (e.g. hake, common sole, sardine and Norway lobster) and had decreased by an average of 44%. However, increasing trends were also found in the landings mainly for species with short life spans (e.g. anchovy, greater amberjack). Finally, Tzanatos et al. (2014) detected a shift in the landings of the 59 most important species/taxa indicating that most of them had undergone a significant abrupt change in the mid-late 1990s paralleling an increasing SST regime shift during the same period. For instance, a negative shift for hake and sardine has been reported along with a positive shift for anchovy (*Engraulis encrasicolus*) or white seabream (*Diplodus sargus*). In addition to northward migration, invasive and endemic populations respond to climate warming by bathymetric displacement. This is particularly true in the case of red mullet (*Mullus barbatus*), hake and spottail mantis shrimp (*Squilla mantis*), three species (local, native and indigenous, respectively) that have been reported to move into cooler and deeper waters to avoid warm-water competitors (Galil & Zenetos 2002). This shift in the distribution of stocks of exploited species is expected to affect their availability to fisheries and possibly to reduce commercial catches. Here, we mainly addressed the effects of warmer temperatures on fish resources and their fisheries, but a rise in CO2 levels also triggers ocean acidification and can affect Mediterranean fisheries. For example, sponge fisheries are seriously threatened by acidification of the sea because of the low capacity of most sponges for acid-base regulation (Linares et al. 2005, Goodwin et al. 2014). Ocean acidification is looked on as a major threat to the marine environment in the coming years and may have dramatic effects on calcifying organisms such as the precious Mediterranean red coral (*Corallium rubrum*), which is a long lived, slow growing gorgonian endemic species in the Mediterranean Sea. Sold at US$ 230-300 per kg, it is one of the most valuable corals thanks to its bright red durable skeleton used in the jewelry industry (Tsounis et al. 2010, Bramanti et al. 2013).

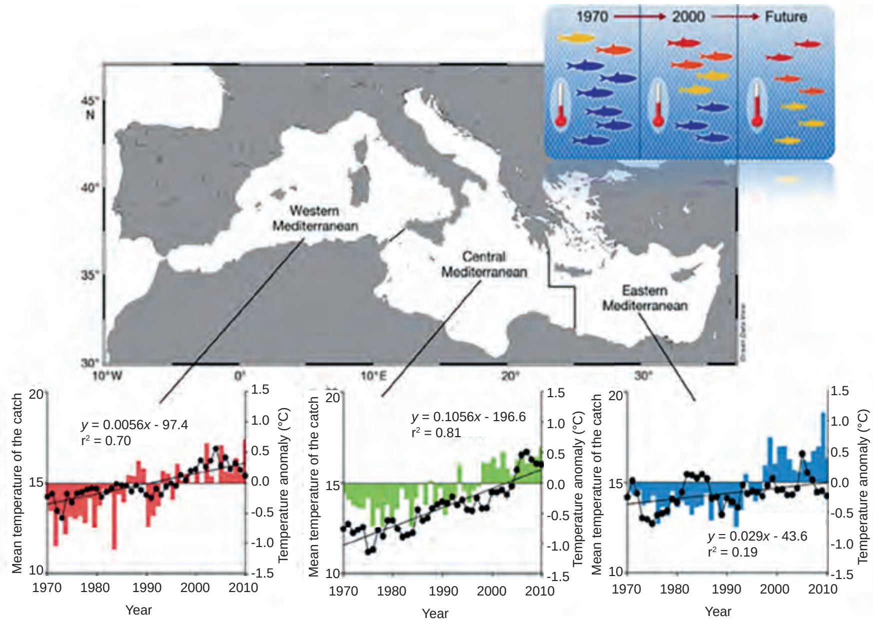

Figure 3
Evolution of the mean temperature of the catch between 1970 and 2010
in the western, central and eastern Mediterranean Sea.
From Tsikliras & Stergiou (2014). The picture at the top right is from Cheung et al. (2013).

Adapting the whole management system

Effectiveness of Marine Protected Areas

Marine protected areas (MPAs) are the flagship management tool for conserving biodiversity and ensuring sustainable ecosystem services (Garcia et al. 2013). The objective of creating MPAs is conserving sensitive habitats and associated species and biodiversity, while taking economic and social considerations into account. Beyond preventing habitat destruction resulting from anthropogenic activities by protecting species from exploitation within a defined area, MPAs are also expected to have beneficial effects outside the protected perimeter through the spill-over effect (i.e. net emigration of adult and juvenile fish) and export of pelagic eggs and larvae from restored spawning stocks within the MPA (Harmelin-Vivien et al. 2008; Stobart et al. 2009; Garcia et al. 2013). More than 100 MPAs have been established in the Mediterranean Sea since the 1960s (Abdulla et al. 2009). However, the most recent investigations suggest that Mediterranean MPAs do not perform as expected in several important respects. First, they do not meet international conservation goals (e.g. Aichi Target 11 of the Nagoya CBD Strategic Plan for Biodiversity, aiming at protecting at least 10% of coastal and marine areas by 2020) with less than 4.6% of the surface area of the Mediterranean continental shelf covered, i.e. 114 600 km^2 (1.1% if we exclude the Pelagos Sanctuary, which is dedicated to the protection of marine mammals) (http://www.medpan.org). Second, MPAs were established based on national or local initiatives and lack cross-regional consistency (Guidetti et al. 2008, Claudet & Guidetti 2010)). Finally, there is evidence for a mismatch between MPAs and the current state of Mediterranean marine biodiversity, with 70% of fish species failing to benefit from improved protection in the current MPA system than could be expected if MPAs were located at random across the continental shelf (Guilhaumon et al. 2015) and Mediterranean MPAs do not protect a substantial proportion of species at risk (Coll et al. 2015) and consensus areas for conservation (Micheli et al. 2013).

Since climate change affects marine species in a number of ways scaling from individual (e.g. vital rates, mortality, timing of migration) to populations (shifts in abundance-size structure or in spatio-temporal distribution), the potential beneficial effects of MPAs on marine populations facing climate change will depend on their ability to enhance the resistance of the populations to these different impacts and to adapt to changing spatial distributions of marine species.

Regarding individual fitness and population resilience, MPAs can act as enhancers and disrupt the detrimental synergistic effects between climate change and fisheries. By maintaining larger individual sizes and higher larval production and recruitment compared to fished populations outside reserves, MPAs enhance the resilience of exploited populations (Micheli et al. 2012).

Beyond the poor performance of the Mediterranean MPA system with regard to current biodiversity patterns, the efficiency of Mediterranean MPAs in the future is called into question by the impacts of climate change on marine populations. Indeed, conservation actions, such as the protection of land or sea, have traditionally been implemented under the assumption that species geographical distributions change relatively slowly, unless they are directly affected by human activities (Araújo 2009). However, climate change is predicted to have profound impacts on the geographical distribution of Mediterranean organisms over the 21st century. For example, modeling studies predict that 25% of the Mediterranean continental shelf will have undergone a complete modification of the endemic fish assemblages by the end of the 21st century (Ben Rais Lasram et al. 2010) (see sub-2.1.3). In a context in which marine species are shifting their geographical ranges, MPAs can lose the very same species that justified their implementation, therefore calling their future relevance for biodiversity conservation into question (Alagador et al. 2016). In the Mediterranean Sea, we observed a strong bias in the geographical distribution of MPAs, with a higher density of MPAs on the northern coast of the Mediterranean Sea than on the southern coast with only eight MPAs located on the North African continental shelf out of the 99 included in the study (Figure 4) (Guilhaumon et al. 2015).

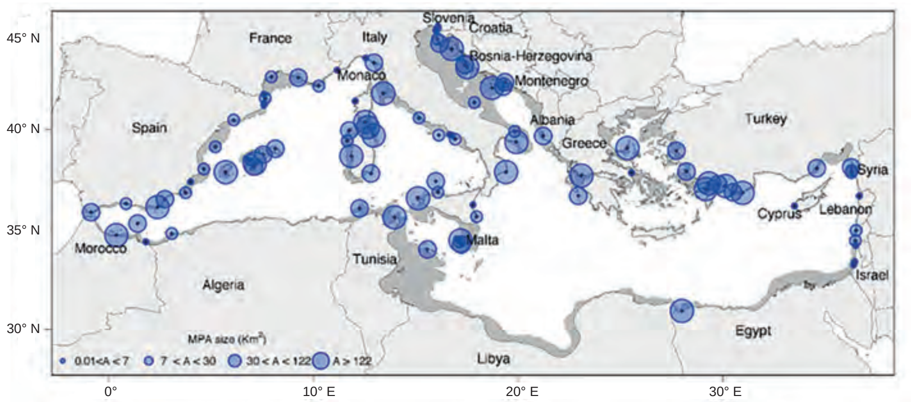

Figure 4
Map of the Mediterranean Sea showing the continental shelf in grey and the location of the 99 MPAs mentioned in the study by Guilhaumon et al. (2015) (blue circles whose size is proportional to the size of the MPA).

Although this geographical bias may be responsible for the current poor performance of the Mediterranean MPA system (Guilhaumon et al. 2015), it can also be seen as an opportunity for the future conservation of fish species. Since endemic and native fish are expected to move northward in the Mediterranean due to sea warming (Ben Rais Lasram et al. 2010; Albouy et al. 2012, Cheung et al. 2015), a potential increase is possible in the congruence between native and endemic biodiversity patterns and MPAs. However, the small size of MPAs on the northern Mediterranean coast and the lack of MPAs in the south are not only obstacles to rebuilding overexploited populations but may also prove problematic for the conservation of newly exploited tropical and subtropical species.

Future climate change may also have notable impacts on connectivity patterns between MPAs and other natural refuges of marine species (such as deep sea canyons and rocky areas). But although connectivity between MPAs is a critical criterion in the design of MPAs, it has not yet been taken into account when establishing MPAs in the Mediterranean Sea. In a recent publication based on the SRES IPCC A2 scenario, Andrello et al. (2015) explored the effects of adult reproductive timing and larval dispersal on the connectivity among MPAs and their ability to seed fished areas with larvae in the Mediterranean. These authors show that, over the 1970-2099 period, larval dispersal distances would decrease by 10%, the continental shelf area seeded with larvae will decrease by 3% and larval retention inside MPAs would increase by 5% (i.e. a higher concentration of larvae in smaller areas of the continental shelf). In fact, these results suggest that climate change will produce higher benefits for fished areas surrounding the MPAs but lower benefits for fished areas that are located too far from the MPAs (Andrello et al. 2015).

Climate change could influence the connectivity and the effectiveness of MPA networks via changes in hydrodynamics, adult reproductive timing, larval growth rates and shifts in population range. The fact that Mediterranean protected areas are geographically fixed, and increasingly isolated by habitat destruction, could be cost-ineffective, as major investments are being made today in areas that will potentially have limited positive impacts in the next several decades (McLeod et al. 2008). Thus, for scientists, managers and planners, designing adaptive and effective MPA networks in the face of climate change is a challenge.

Current stock assessments in the context of climate change

The global climate change context questions the relevance of current models for managing ecological resources and fisheries stocks (Hoegh-Guldberg & Bruno 2010). Lack of understanding of the sources of temporal variability in fish abundance affects the robustness of biological reference points, decision making, and risk assessment in precautionary fisheries management (Hsieh et al. 2006). For instance, Brander (2010) wrote that: "*Reductions in stock productivity mean that levels of fishing to which a stock was previously resilient, become unsustainable. The decline will be exacerbated if underlying changes in growth are not recognised*". As mentioned above, climate change acts on several population processes including mortality, maturity, growth, distribution and recruitment that influence the levels of biomass produced. However, these processes are involved in the definition of biological reference points used as thresholds and targets in fisheries management strategies and decision making. Since the production of biomass is uncertain in the context of climate change and is subject to greater variability, these targets and biological reference points should be adapted to take these risks into account (Grafton 2010). Ignoring the effects of climate change in stock assessment could compromise the validity of stock forecasts and rebuilding plans (Brander 2010; Link et al. 2011). For example, ignoring the fact that fish may shift their range, and not including spatial dynamics could significantly affect the management advice based on stock assessment and associated projections (Link et al. 2011). It is crucial that the effects of changes in ocean properties (i.e. temperature, oxygen, carbonate system, etc.) are incorporated into stock assessment, and that their combined effects with fishing are quantified, in order to build ecosystem-based fisheries management.

According to the evaluation of the current state of the resources and the projected impacts of climate change, the future of the Mediterranean Sea appears to be jeopardized. The levels of exploitation of most assessed fish stocks are outside safe biological limits and several fish populations are now endangered by the strong impacts of this millennium activity (Tsikliras et al. 2015). In the context of global change, combined with other anthropogenic disturbances such as biological invasions, pollution, habitat losses and in particular, climate change, the biological and physicochemical features of the Mediterranean Sea are changing at an unprecedented rate. The lack of data and the poor knowledge of the status of existing stocks, especially in the southern and eastern parts of the Mediterranean, strong human population pressure along the coasts of the basin, and weak governance at regional scale threaten the conciliations of biodiversity conservation and sustainable fisheries management.

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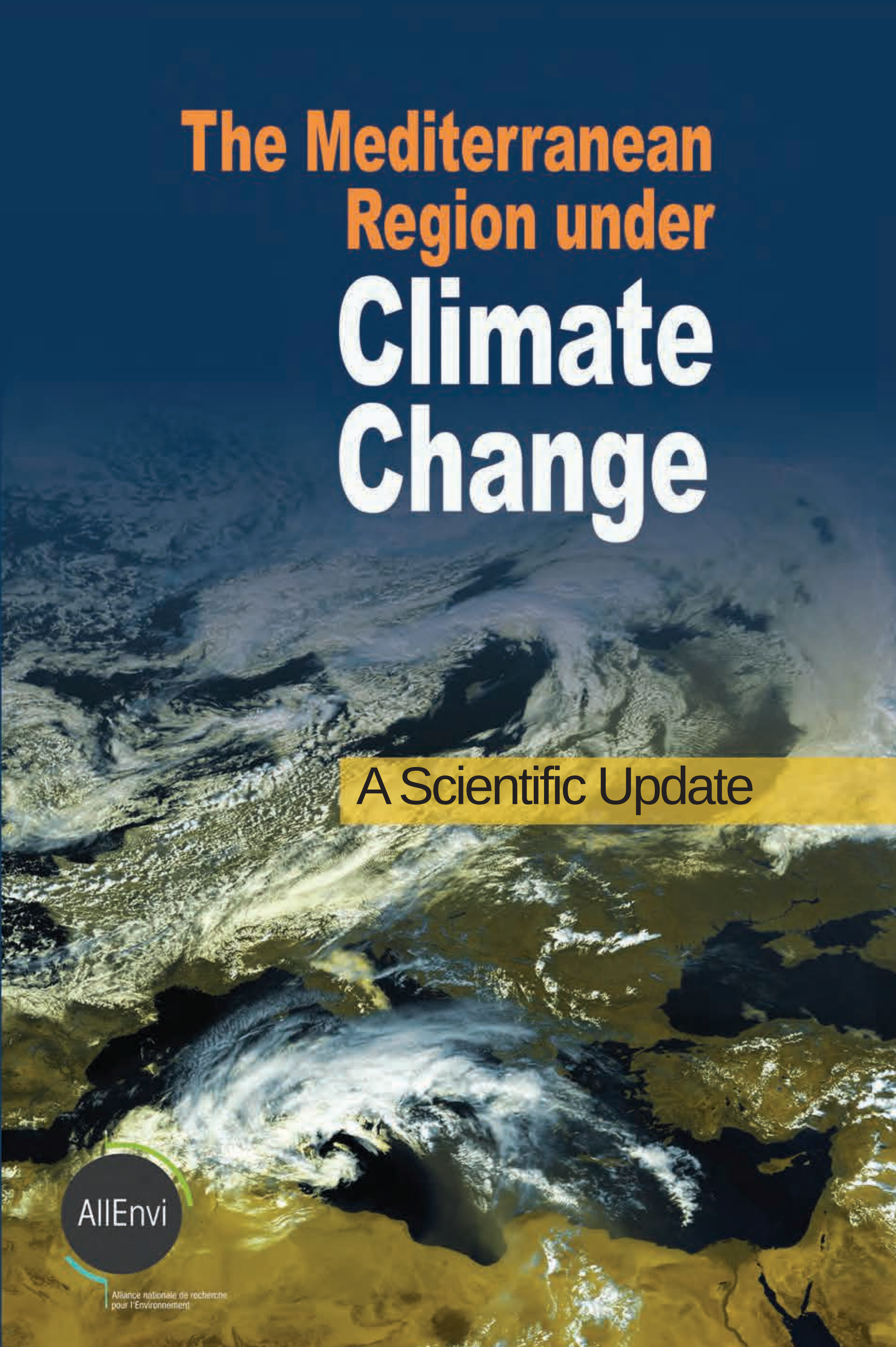
A Scientific Update



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The Mediterranean Region under Climate Change

A Scientific Update

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