Blue Economy

Volume 2 | Issue 1 Article 5

2024

A view on climate change and its impact on the Mediterranean fisheries

Evelyn Ragheb
National Institute of Oceanography and Fisheries (NIOF), Egypt, evelynragheb@yahoo.com

ISSN: 2805-2986 – e-ISSN: 2805-2994

REVIEW

A View on Climate Change and Its Impact on the Mediterranean Fisheries

Evelyn Ragheb

National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt

Abstract

Fisheries in the Mediterranean Sea are multi-species and multi-fleet; the artisanal or small-scale fisheries, the trawling fisheries, and the seining fisheries. Currently, the Mediterranean Sea is a hotspot for climate change. Climate change is a global phenomenon affecting the whole world; its impact is different across regions and is affected by uncertainty. In marine waters, three climatic changes are the most important: warming, acidification and oxygen loss (deoxygenation). There are many observed impacts (positive or negative) on the different regions of the Mediterranean coastal waters, and many regional models are used to predict the implications of the climate change on the Mediterranean. Fisheries vulnerability to climate change is likely to be higher for pelagic Mediterranean fisheries in the eastern region due to the increase of non-indigenous species and for demersal Mediterranean fisheries in the northern-central Mediterranean due to the high diversity of climatic drivers. Southern Mediterranean countries are expected to be more vulnerable as a result of lower capacity to cope with climate change impacts. Adaptation and mitigation of climate change are needed. Marine protected areas (MPAs) and the reduction of fishing efforts are the most effective tools for the conservation of biodiversity and the protection of fish stocks. Different case studies in the Mediterranean were described and discussed special issues in the Egyptian Mediterranean fisheries to prospect and manage the future.

Keywords: Climate change, Fisheries, Mediterranean Sea

1. Introduction

Climate change is a global phenomenon affecting the whole world, but its impact is radically different across regions, requires a long term perspective, and is still affected by a large amount of uncertainty (Galeotti, 2020). In 1988, the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) created an organization named the Intergovernmental Panel on Climate Change (IPCC) to follow the changes, impacts and future risks of climate and its drivers; and to provide solutions to reduce these risks through adaptation and mitigation of these risks. In addition, the annual United Nations climate change conferences (Conference of the Parties, COP) are held in the framework of the United Nations Framework Convention on Climate Change (UNFCCC) to evaluate progress on climate change. The first COP was held in Berlin, Germany, in 1995, the COP 27 was held in Sharm El Sheikh, Egypt, in 2022; and the last was held in Dubai, UAE, in 2023 (COP 28) (Intergovernmental Panel on Climate Change, 2023, https://en.wikipedia.org). The GFCM is the regional fisheries organization for the Mediterranean Sea and is in charge of regional activities to deal with the effects of climate change on fisheries management (Barange et al., 2018). It offers recommendations for the sustainable exploitation of fish populations.

The main factors influencing the climate are: temperature, precipitation, atmospheric circulation, extreme weather, sea-level rise, sea-water temperature, salinity, acidification, population expansion,

Received 5 February 2024; revised 5 April 2024; accepted 16 April 2024.
Available online 1 June 2024
E-mail address: evelynragheb@yahoo.com.

https://doi.org/10.57241/2805-2994.1020

pollution, unsustainable land and sea use practices, and the presence of exotic species (MedECC, 2020). However, for the marine waters, three climate changes are the main ones: warming, acidification and loss of oxygen (deoxygenation) (Findlay, 2023). Currently, the Mediterranean Sea is a hotspot for climate change (Galeotti, 2020; Pisano et al., 2020; Tuel and Eltahir, 2020; UNEP/MAP, 2023). It is one of the vulnerable areas where its organisms are heavily impacted by many variables like climate change, pollution, overfishing and habitat degradation as well; its organisms have a lower chance to migrate as it is a semi-enclosed sea (Hoegh- Guldberg et al., 2014; Hidalgo et al., 2022). On the other hand, the rate at which the climate is changing may lead to modifications in the near future of fisheries productions (Cheung, 2018; Holsman et al., 2020). Therefore, many authors tried to assess the vulnerability of climate change to support an efficient management strategy for the Mediterranean fisheries aimed at sustainable resource utilization and talk about the observed and/ or predicted effects of climate change on the region's fisheries. From the recent articles those of Hidalgo et al. (2018), Moullec et al. (2018), Galeotti (2020), Hassan and Mohamed (2020), Tuel and Eltahir (2020), Albano et al. (2021), Pita et al. (2021), Agnetta et al. (2022), FAO (2022), Hidalgo et al. (2022), Rambo et al. (2022) and Cavraro et al. (2023).

The present article aims to shed light on climate change and its impact on the Mediterranean Sea fisheries sustainability and biodiversity conservation especially in the south-eastern part of Egypt. Finally, it discusses possible measures to mitigate and adapt to these changes and identify major gaps in knowledge that would need to be filled to allow effective management of marine fisheries in the future.

2. The climatic drivers

Climate refers to the long-term dominant weather in a region and is mostly influenced by temperature and precipitation. It develops as a result of variations in the intensity and distribution of solar radiation that reaches the Earth's surface (Stevens, 2010). The climate is also impacted by rising levels of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere (Barange et al., 2018). According to the IPCC, the climate changes can be attributed to either natural variability or human activities and the long-term climate changes include the change in the average climate as the change in the average temperature. Adaptation to climate changes involved both longer-term changes and increase variability (IPCC, 2023). According to Findlay (2023), there are three main climate drivers affecting marine waters: warming, acidification and loss of oxygen (deoxygenation).

3. The Mediterranean Sea fisheries

The principal ecosystem service in the Mediterranean region that has a significant impact on local and regional economies and communities in all of the neighboring countries is fisheries (FAO, 2020). The artisanal or small-scale fisheries (SSF), the trawling fisheries, and the seining fisheries are the three main divisions of the Mediterranean fisheries operations. These fisheries are based on demersal and pelagic (Papaconstantinou and Farrugio, 2000). The most important demersal fisheries resources are European hake (*Merluccius merluccius*) and red mullets (*Mullus spp.*) from the fish species, the deep-water rose shrimp (*Parapenaeus longirostris*), and the deep-water red shrimp (*Aristaeomorpha foliacea* and *Aristeus antennatus*) from the crustacean species, and some cephalopods (*Octopus spp.* and *Eledone spp.*) (FAO, 2020). The main target species of the pelagic Mediterranean fisheries are sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) (FAO, 2020; Hilmi et al., 2021). Other important small pelagic species are the round sardinella (*Sardinella aurita*), horse mackerels (*Trachurus spp.*), and mackerels (*Scomber spp.*) (FAO, 2020).

The diversity of Mediterranean Sea species is high. In 2020, the total production of the Mediterranean Sea is about 674,500 tonnes using a total of 74,265 vessels (FAO, 2022). For Egyptian Mediterranean Water, the total catch was about 49,896 tonnes in 2020 which represented only 7.4% of the Mediterranean Sea production. The Egyptian Mediterranean fishing gear and methods are mainly trawling, purse seine, long liner, trammel and gill nets (GAFRD, 1991−2020). About 2656 mechanized vessels conduct fishing operations with engines/hp (horse power) from less than 10 hp up to more than 800 hp (GAFRD, 1991−2020) and a total of 3804 vessels represented 5.12% of the total Mediterranean vessels operated in 2020 (FAO, 2022). The number of boats operated in the Egyptian Mediterranean are variable annually, in 2021, 3193 mechanized vessels were counted (LFRPDA, 2021).

4. Impacts of climate change on the Mediterranean fisheries

The fish populations may be affected by climate change as a result of many responsibilities as physiological response (as changes in environmental parameters, such as temperature), or behavioral response (as avoiding unfavorable conditions and moving into newly suitable areas). It is also affected as a result of population dynamics, through changes in the mortality, growth, and reproduction in combination with the creation of new populations in new locations, as well as by productivity and/or trophic interaction changes at the ecosystem level. Additionally, commercial exploitation has a significant impact on fish quantity and distribution and may combine with climate change effects (Rijnsdorp et al., 2009).

The climate changes have direct or indirect impacts and positive or negative impacts on fisheries. According to Moullec et al. (2019) there are losers and winners, where, species that contract or shift their distribution are losers and species that expand their distribution are winners. Two characteristic patterns will be widespread namely meridionalization and tropicalization. Meridionalization is the northward extension, colonization and enhancement of thermophilic species into the colder north Mediterranean regions (Lloret et al., 2015; Azzurro et al., 2019), and tropicalization is the increasing introduction and range extension of thermophilic, non-indigenous species, including Lessepsian species from the Red Sea and from the Indo-Pacific region (Boero et al., 2008). The colonized areas could experience both beneficial and negative effects from thermophilic species' northward migration, according to Cavraro et al. (2023). Where the new species might be of commercial interest, acting as a resource for the fishery and overall boosting biodiversity in the areas that have been colonized. Negative effects, on the other hand, include the disappearance of indigenous species, which results in the loss of the local fauna and a decrease in fisheries-targetable species (Azzurro et al., 2011; Hidalgo et al., 2018).

The most important observed impacts throughout the Mediterranean as a result of warmer waters were:

- The tropicalization of the Eastern Mediterranean and the spreading of warm waters to the west which threatens ecosystems and economies. According to Albano et al. (2021), just 5−12% of native molluscs species are still found in Israeli waters, while the non-indigenous species forming a novel ecosystem. In the western Mediterranean, especially in the Italian waters, there is a change in fish population as for examples increased catches of barracuda (*Sphyraena viridensis*), and dusky groupers (*Epinephelus marginatus*) (WWF, 2021).
- Native ecosystems are being destroyed by invading species like lion fish and rabbitfish that expand throughout the Mediterranean. The venomous lionfish (*Pterois miles*) is the most damaging invasive species; its stomach can enlarge up to 30 times its original volume to feed on large quantities of small native fish and crustaceans. It was firstly recorded in Israel in 1991. Today it is well established in Lebanon, Syria, Cyprus, Turkey, Greece, Italy, Tunisia, and Libya (WWF, 2021). The herbivore rabbitfish (*Siganus rivulatus* and *Siganus luridus*) became established in the Mediterranean, especially in the Greek and Turkish coastlines, and destroyed the habitats of native species and their feeding habits. Where algal forests are reduced to rocky barrens (Vergés et al., 2014).
- Blooming of jellyfish in the Mediterranean each year, with serious effects on fisheries, tourism beaches and power stations. They are reducing the efficiency of output power stations, as the jellyfish are blocking the water intakes for cooling. Since around 2003, Jellyfish blooms − where populations breed and rapidly increase, especially in southern waters and today they occur yearly and last longer (Kogovšek et al., 2015).
- The endemic sea grass (*Posidonia oceanica*) that has a direct impact on biodiversity and blue carbon are in threating by warming and rising sea levels. It is a biological indicator for marine water health where, it thrives in clean water. *Posidonia* absence in the south-eastern Mediterranean and its health diminished in western areas may be as a result of warming (Pergent et al., 2015) and sea level rise. *Posidonia* needs light to photosynthesize and the amount of light that reaches a shallowly sloped bottom might vary significantly depending on any changes in sea level and consequently loss of *Posidonia*.
- Gorgonians or what is called sea fans are found in various environments in the Mediterranean. They form underwater forests that provide vital habitats and nursery grounds attraction for divers drawn. They have a 60-year life span. Now, mass mortality was caused by the Mediterranean's fast changing climate. Studies in the Ligurian Sea have revealed that gorgonians died in large numbers down to a depth of around 40 m due to climate change and the severity of extreme weather (Cerrano et al., 2000).
- Climate change affected the small and medium pelagic fish species where, currently the stocks of anchovy and sardine in Mediterranean are decreasing (FAO, 2016; Hidalgo et al., 2018) with an increase in the distribution of *Sardinella aurita* stocks in warmer waters as it is a thermophilic species (Sabatés et al., 2006) and it decreased in cold-water (Lloret et al., 2015). On the other hand, the species composition of the demersal

Mediterranean species has changed with a greater contribution from warm-water species, which are slowly colonizing northern regions (Tsikliras and Stergiou, 2014), together with a decline in cold-water species (Lloret et al., 2015).
- Climate change led to changes in abundance, survival, growth, fertility/reproduction, migration, phenology (Marbà et al., 2015), species composition (Fortibuoni et al., 2015; Tsikliras et al., 2015; Vasilakopoulos et al., 2017), and mass mortality events since the early 1980s (Lejeusne et al., 2010). Regional changes in fish abundance and their distribution will alter species richness, with an expected increase in species diversity in the eastern Mediterranean, and a decrease it in the western (Albouy et al., 2013). A reduction in the size of spawning areas and an increase in the retention of larvae on smaller portions of the continental shelf. Risks associated with heterogeneous species in the northern and southern Mediterranean countries (Pita et al., 2021).
- Climate change in combination with other environmental stressors can lead to sudden ecological crises such as for example the mass mortality of the largest endemic bivalve in the *Pinna nobilis* populations in different areas in Mediterranean waters (Rabaoui et al., 2009). It performs a significant biological role in maintaining water clarity by removing a lot of detritus from the water, and providing a habitat for a wide variety of organisms, and its filament that attach to the seabed used to decorate precious fabrics. Cabanellas-Reboredo et al. (2019) tracked the mass mortality of *Pinna nobilis* populations and mentioned that in autumn 2016, 100% of mortality occurred in the Spanish Mediterranean *Pinna nobilis* populations, and 80–100% mortality spread along coasts of Catalonia, Italy, Sicily and Corsica in the following three years. Again, Katsanevakis (2021) mentioned that in January 2020, 60–80% of *Pinna nobilis* in the Gulf of Trieste, Italy are died. The pathogen *Haplosporidium pinnae*, which may have spread due to the direction of summer marine currents, was responsible for the mass mortality of *Pinna nobilis* populations. Warmer temperatures may favor the development of *H. pinnae* and consequently, affecting establishes of *Pinna nobilis* populations (WWF, 2021).

The most important predicted impacts on Mediterranean fisheries were:

- For small and medium pelagic fish species, an increase in water temperature may lead to earlier spawning, change in food availability and ecological factors that regulate the population dynamics of species (Shulman et al., 2011). For large pelagic species that seasonally enter the Mediterranean Sea for spawning as tuna (*Thunnus sp.*) and dolphinfish (*Corphaena sp.*), Alvarez-Berastegui et al. (2016) found that changes in the temporal and spatial dynamics of mesoscale oceanographic structures, which are crucial for the reproductive behavior of large pelagic fish, may be caused by the anticipated changes in thermohaline circulation with the Atlantic water that enters the Mediterranean becoming lighter (Adloff et al., 2015).
- For demersal fish species, it has been challenging to evaluate the anticipated future changes for demersal species using climate change models, because of the high diversity of physical and geographic variations in Mediterranean waters (Hidalgo et al., 2018).

Indeed, there are several numbers of non-climate stressors that can buffer or strengthen the climate change effects on fisheries (Hidalgo et al., 2011), of which overfishing and pollution are the most affected. Overfishing has a negative effect on aging, size structure and distribution of stocks making populations more susceptible to environmental fluctuations. The Mediterranean is one of the most heavily exploited seas in the world (WWF, 2021). Pollution, especially in coastal regions is an important threat of fisheries. Rising temperatures may facilitate the occurrence and distribution of biotoxins or pathogens (Lloret et al., 2016). Noxious phytoplankton blooms can also deplete oxygen, suffocating and killing fish and benthos.

5. Vulnerability for the main Mediterranean fisheries

According to Hilmi et al. (2021), risks that endanger Mediterranean fisheries can be environmental or attributable to the socioeconomic characteristics of each country or area's fisheries. The risks associated with climate change differ depending on how important fisheries are to a country's economy and trade, as well as how important they are for jobs and food security (Ding et al., 2017). Pita et al. (2021) calculated the fisheries risk for 16 countries out of the 22 countries on the Mediterranean coast and concluded that by 2050 Egypt, Morocco and Tunisia will be most at risk as well as, Malta and Israel which will have a very low fisheries risk. The low vulnerability species are *Etrumeus teres*, *Saurida undosquamis* and *Sprattus sprattus*, while the high vulnerability species are

Belone belone, *Mugil cephalus*, *Phycis phycis* and *Thunnus thynnus*. On the other hand, Hidalgo et al. (2018) mentioned that there hasn't yet been a thorough assessment of how vulnerable fisheries resources are to the effects of climate change in the area and Hidalgo et al. (2022) studied the climatic affections of the different fisheries priorities depending on fishery type as small pelagic or demersal and the different Mediterranean sub regions.

6. Adaptation and mitigation of the climate change impacts on the Mediterranean fisheries

The lack of information and inadequate understanding of the state of existing stocks, particularly in the southern and eastern sections of the Mediterranean, pose a threat to the survival of biodiversity and sustainable fisheries management. In fact, due to climate change, the Mediterranean Sea's biological and physicochemical characteristics are changing at a previously unheard-of rate (Moullec et al., 2018). Both reducing overfishing and managing fish stocks can lessen the effects of climate change and boost the financial gains from marine capture fisheries (Barange et al., 2018).

Additionally, the possible future of the Mediterranean Sea depends on the level of protection. Marine protected areas (MPAs) are an effective management tool for preserving marine habitats, biodiversity, sustainable ecosystem services, the livelihoods of fishermen, the local economy, and the opportunity for tourists to reclaim their connections with nature (Moullec et al., 2018; WWF, 2020; Grorud-Colvert et al., 2021). MPAs have been scientifically proven to combat both the climate and biodiversity problems, and well-managed MPAs have been shown to meet the requirements of both nature and humanity (WWF, 2020).

As of 2020, only 8.33% of the Mediterranean Sea is formally recognized as being under protection legislation according to the system of MPAs, whereas 97.33% of the protected Mediterranean surface is found in the waters of EU member countries. Only 0.04% of the Mediterranean is protected by such rules, according to data on the total area covered by no-go, no-take or no-fishing zones (MedPAN, 2021).

On the other hand, combining international and national efforts to adaptive approaches has been needed to inform the main policymakers of the FAO, the GFCM, the European Commission, and national governments to carry out fisheries management (Hidalgo et al., 2022).

7. Cases study

Many models are used to predict the adaptation and mitigation of climatic change in short and long term as Generalized Least Squares (GLS) models (Hilmi et al., 2021), Climate Risk Assessment (CRA) methodology (Pita et al., 2021; Hidalgo et al., 2022), Bayesian Belief Network (BBN) development modeling (Rambo et al., 2022), Ecopath with Ecosim modeling approach (Agnetta et al., 2022), and Maximum Entropy models (Cavraro et al., 2023) with different scenarios in different regions of the Mediterranean.

7.1. In Western Mediterranean

Rambo et al. (2022) unravel the effects of increased sea surface temperature (SST) on SSF in the Western Mediterranean, especially for the catch of dolphinfish, *Coryphaena hippurus*, and the authors predicted increased profitability for fishers with the options of advancing the opening date of the fishing season in response to climate-induced changes with the uncertainty in all scenario predictions measured. Previously, Moullec et al. (2019) predict that under a high greenhouse gas emission scenario and current fishing mortality, dolphinfish biomass in the Mediterranean Sea may increase by up to 34% by the end of the century, while Moltó et al. (2021) predict increases in the average length at the catch under warming scenarios. Dolphinfish, *C. hippurus* is a thermophilic species (FAO, 2019).

7.2. In Central Mediterranean

Agnetta et al. (2022) mentioned that fishing has a faster impact on marine ecosystems than climate change, thus developing fisheries management methods as soon as feasible is crucial to achieving sustainability. Accordingly, Agnetta et al. (2022) aimed to resolve the effect of climate change on fisheries by improving ecosystem health. They deduced that when the bottom trawling fishing effort is decreased direct and indirect effects are done. According to Russo et al. (2019) and Agnetta et al. (2022), reducing bottom trawling effort involves a temporary transition period with a loss in catches and profits, but positive long-term effects may outweigh the negative ones. Long-term growth is predominantly driven by commercial biomass rebuilding, which will make long-term fisheries and resource exploitation more sustainable.

7.3. In Adriatic Sea

The Adriatic Sea is semi-closed basin. It is a significant productive area for fisheries in the Mediterranean Sea. It is characterized by a strong river outflow of nutrients and the periodic mixing of Mediterranean nutrients. The north and Central Adriatic Sea are the most productive and most exploited areas of the Adriatic Sea with an average depth of approximately 35 m (Cavraro et al., 2023). According to Cavraro et al. (2023), the climatic change in the north-central Adriatic Sea acted on biodiversity, altered the trophic network, favored of thermophilic alien species, and became critical for the survival of species and for fisheries. Fortibuoni et al. (2010) and Lotze et al. (2011) identified a number of long-term observations in the fish community of the Adriatic Sea as the decline of elasmobranchs, tuna, swordfish, and marine mammals. However, thriving populations of the bluefish (*Pomatomus saltatrix*) and the barracuda (*Sphyraena viridensis*) as well as an increase in thermophilic species like the lionfish (*Pterois miles*) and the rabbit fish (*Siganus rivulatus*) are both positive (Dulčić and Pallaoro, 2004; Azzurro et al., 2011; Tiralongo et al., 2020; Di Martino and Stancanelli, 2021; Cavraro et al., 2023). On the other hand, Cavraro et al. (2023) predicted a decrease in landings from 13.5 to 86.9% and only the blue crab, *Callinectes sapidus*, out of 17 species had an increase in the Adriatic habitat suitability in the short (2040–2050) and medium (2050–2100) term.

7.4. In Eastern Mediterranean

The main observed impact as a result of warmer waters is the tropicalization of the Eastern Mediterranean which is threatening ecosystems and economies (Boero et al., 2008; Hidalgo et al., 2018, 2022; WWF, 2021; Cavraro et al., 2023). This phenomenon could be driven by physiologic stress caused by more frequent extreme warms, a decrease in oxygen levels that alters ecological functioning, or competition from invasive species (WWF, 2021). Tropicalization phenomenon of the Eastern Mediterranean led to changes in fish abundance and their distribution with increased species diversity (Albouy et al., 2013). The species of the indo-Pacific origin compete with native species or include highly damaging poisonous species such as pufferfish *Lagocephalus sceleratus* (Ünal and Göncüoglu Bodur, 2017). Furthermore, a change in the primary production has been observed (FAO, 2022).

The eastern Mediterranean is particularly vulnerable and at risk for pelagic fisheries (Payne et al., 2021; Pita et al., 2021), with serious consequences, because of the lower preparedness adaptive measures for the species. Because of its higher exposure to many drivers in combination with the increase in non-indigenous species in this sub-region compared to elsewhere (Gücü et al., 2021; Öztürk, 2021). In the future, it is predicted that the surface production in the eastern will increase (Macias et al., 2015).

8. Special issues on the impact of climate changes in the Egyptian Mediterranean waters (Southeastern – Mediterranean)

The Egyptian Mediterranean territorial waters are estimated at approximately 6.8 million acres, with a length of about 1050 Km (650 mi) (Harhash et al., 2015). The available recent data of the Egyptian Mediterranean trend line of the annual SST were reported by Gentilucci et al. (2021) for 7 stations along the Egyptian Mediterranean coasts from El-Arish to El Sallum during the period from 1991 to 2020 and the most significant physical and chemical impact variables from the fishery coastlines of Alexandria, which extend from El-Montazah to Sidi Kirayr were reported by Abdel-Halim and Aly Eldeen (2016) and Alprol et al. (2021).

Additionally and according to the author knowledge, the studies available on the impact of climate changes in the Egyptian Mediterranean fisheries were studied by Hassan and Mohamed (2020) and Gentilucci et al. (2021). Hassan and Mohamed (2020) studied the fishery activities along the Egyptian Mediterranean coast through interviews with fishermen and survey with questions were done. Gentilucci et al. (2021) monitored the advances with a new vision of the assessment of Egyptian coastal climate change.

8.1. Production of the Egyptian Mediterranean waters

Assessment of past fishery's productivity helps to predict and manage future changes (Plagányi, 2019). The author tried to analyze the primary production of the Egyptian Mediterranean according to the statistical publications of the National Institute of Oceanography and Statistical Fisheries from 1962 to 1990 (Anonymous, 1962 –

1990), the publications of the General Authority for Statistical Fisheries from 1991 to 2020 (GAFRD, 1991 - 2020), and the publications of the Lakes and Fish Resources Protection and Development Agency for Statistical Fisheries in 2021 (LFRPDA, 2021). The total landing per ton from the Egyptian Mediterranean waters between 1962 and 2021 are graphically represented in Fig. 1.

8.2. Observed and prospected impacts

The analysis of the Egyptian Mediterranean Water production (Fig. 1) reflects that the primary production goes through 4 phases:

8.2.1. From 1962 to 1968

The results of the Egyptian-Soviet research trip during 1970–1971 (NIOF, 1975) proved that the main reasons for the decrease in fish production in the Egyptian Mediterranean waters may be due to increasing the fishing effort, and the construction of the High Dam which is considered as the strongest in influencing the decline in productivity, as the annual rate of flooding decreased from 43.5 cubic kilometers to 4.4 cubic kilometers. In addition, the results of the research trips at that time recommended by the development of the northern lakes and the cultivation of fish and shrimp to compensate for the shortage in marine production.

8.2.2. From 1967 to 1975

The War 1973 in that phase is the main reason for the production decreasing as a decrease of fishing days besides the impact of the construction of the High Dam.

8.2.3. From 1976 to 2008

The increase in productivity from 1976 to 2008 may be a result of the emergence of the biological impact of the Suez Canal where, the Suez Canal is helping to increase the biological diversity in the Eastern Mediterranean by introducing new invasive species (Lasram et al., 2008). In addition, the increase in the production may be also due to the increase in the fishing fleet and the development of fishing methods. Indeed, enforce the fishing laws also has increased productivity even the risk of a continued decline in production since 2008.

8.2.4. From 2009 till now

Table 1 shows the annual fish production of Egyptian Mediterranean Waters during the period from 2009 to 2021. There are gradual decreases in the production from 2009 till now, and some notifications are:

- The severe decrease in the total productivity is as a result of the very low productivity of the majority economically important fish species. Despite the fact that other species in the Egyptian Mediterranean Sea have been documented to have increased their productivity recently.
- Periodic surveys of the catch also revealed that some indigenous species (Ex: *Sardina pilchardus*) or non-indigenous species (NIS) (Ex: *Siganus luridus*) disappeared from the catch, and their production was limited in small quantities. This

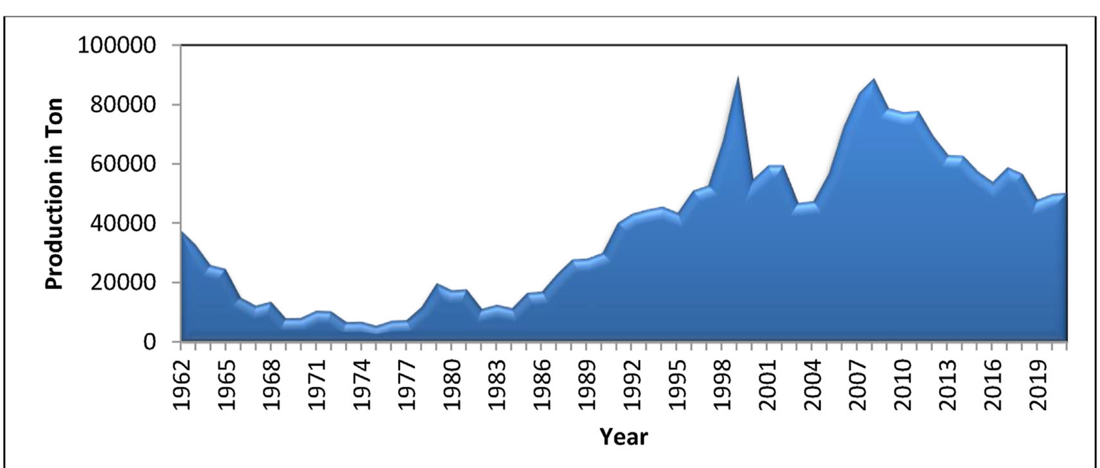

Fig. 1. ***Total catch landing per ton from the Egyptian Mediterranean waters (1962–2021).*** *Note: Production according to the publications of the National Institute of Oceanography and Statistical Fisheries from 1962 to 1990 (Anonymous, 1962 – 1990), the publications of the General Authority for Statistical Fisheries from 1991 to 2020 (GAFRD, 1991 - 2020), and the publications of the Lakes and Fish Resources Protection and Development Agency for Statistical Fisheries in 2021 (LFRPDA, 2021).*

Table 1. Annual fish production for Egyptian Mediterranean waters during the period from 2009 to 2021.

Year Com. Name	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Swordfish									4	4	5	4	12
Rock goby													49
Black barred halfbeak									1				
Octopus					215	218	201	138	289	384	389	282	287
Cartilagenous fish nei	2468	3056	3333	2338	2112	1843	1141	1300	1375	1292	1037	881	1050
Greater amberjack										4	11	126	131
Anchovy & Small sardine	3167	2988	2003	2903	3604	3641	3242	2657	3448	4570	4491	4962	4718
Blue runner								600	720	655	714	825	797
Red mullets	3058	3577	4124	2623	1924	1417	961	881	989	1152	642	549	608
Spinefeet	945	1008	1005	903	931	822	911	742	968	828	690	705	612
Purple-spotted bigeye										78	48	35	26
Little Tunny	1939	1302	951	712	849	712	1045	901	1094	1003	1006	1071	959
Albacore							264	77	396	429	278	316	622
Atlantic Bluefin Tuna							155	115	124	181	266	122	327
Squirrelfish										4	2	2	3
Shrimp	10632	10563	10799	6636	5953	8061	7071	6432	8068	5610	4666	5462	6270
Deep Sea Red Shrimp							504	757	979	845	475	605	650
Narrow-Bared Spanish Mackerel	1689	1578	939	494	478	658	699	895	1019	1017	696	595	999
Gilthead seabream	1481	1431	1198	1096	1022	1019	355	344	367	337	440	404	457
Annular Seabream	1479	1937	1417	1439	1031	934	551	555	496	369	311	251	122
Common Cuttlefish	2473	2957	2480	2421	1760	1782	1376	1452	1515	2039	1593	1876	1858
Sardinellas nei	11917	8971	7878	10634	10244	10105	9943	9147	8580	8902	6557	6806	7854
Largehead hairtail	1549	1812	2087	1125	1042	1395	1608	1508	1889	2004	2005	2627	2551
Med. Horse mackerel	874	854	971	995	732	719	623	680	504	446	400	484	594
Striped piggy					170	180	225	7	292	301	75	60	261
White seabream	845	875	949	808	772	639	542	455	406	405	343	366	395
Chub Mackeral							899	871	650	606	634	604	519
Red sea mantis shrimp	300	295	260	260	215	310	370	455	490	799	427	376	276
Thread fin Beams							821	744	864	623	764	672	638
Grey Mullets	4733	4713	4191	3619	3069	3131	1883	1767	1559	1444	1183	1329	1190
Rainbow Wrasse										82	74	129	124
Common Pandora							533	492	469	372	327	254	239
Pompano										9	10	6	5
Grey gurnard	1211	1383	1648	1091	927	892	475	452	596	720	695	529	462
European seabass	1336	1326	969	969	967	873	426	314	272	296	243	258	145
Marine molluscs nei	3231	3365	3615	4006	4094	4146	4329	4141	4171	4087	3570	4019	3271
Blue Swimming Crab	3949	3792	3814	2475	2274	2427	2611	2790	3892	3275	3066	3688	4358
Squid										7	29	19	29
Filefish										8	5		
Atlantic mackeral									8	1			
Jacks								66		5	2		4
Meagre	1031	896	687	2387	599	602	533	690	651	929	823	994	899
Red porgy	2801	3183	3990	2884	1905	1366	592	609	541	615	486	520	491
European Barrcudas	919	615	469	966	826	959	641	583	521	573	615	469	527
Brushtooth lizasrdfish	1600	1960	2371	1304	821	853	710	608	682	694	653	590	763
Bogue	2711	3230	4156	3625	4202	2565	2240	2150	1820	1542	1471	1022	995
Sole, common	738	860	1145	634	682	801	764	655	689	653	544	663	784
Bluefish	560	776	566	313	620	674	429	444	470	445	391	382	325
Shrimp Scad fish									83				
European hake									270	677	459	455	494
Spotted Seabass	586	587	469	418	338	387	345	378	312	421	294	339	248
Groupers nei	1018	985	878	549	504	509	379	413	438	448	390	379	251
Others	7550	6513	8437	8705	8145	8106	7205	5699	5955	4540	3723	2784	1135
Total	78790	77388	77799	69332	63027	62746	57602	53964	58926	56730	48018	49896	50384

Source: GAFRD (2009 − 2020) and LFRPDA (2021).

disappearance may be due to their horizontal migration to cooler areas, and this horizontal migration was as a result of change the degree of salinity and the rise in temperature.

- Some indigenous species disappeared from the catch, and their production was limited in small quantities, which prompted the statistics staff to add them to other categories. Their disappearance may be due to the vertical migration to greater depths, and this vertical migration may be a result of a change in the degree of salinity, the rise in temperature and/or feeding competition between species. Fishing in deep waters of more than 150–1000 m is helped in restoring the species authentic (Ex: hake fish) and facilitates the capture of other species (Ex: Deep water red shrimp). Concerning the European hake *Merluccius merluccius* catch is added to GAFRD under the title of others species due to its small quantity. It was restored in the catch since 2017. The hake *M. merluccius* can be found in depths ranging from a few meters off the shore to 1000 m. The largest individuals live in water deeper than 200 m, while the coastal shelf is usually populated by juveniles (Turner and El Quari, 1986; Fisher et al., 1987; Meiners, 2007; Belcaid and Ahmed, 2011). The recent increase in hake captures is explained in part by the beginning of fishing in deeper waters, 100–250 m, where hake began to be abundant.
- Many of lessepsian migrant species that have recently recorded and have positive impacts on the catch since their productions are tons (As for example: Narrow-Bared Spanish Mackerel *Scomberomorus commerson*; Squirrelfish *Sargocentron rubrum*; Thread fin beams *Nemipterus randalii*; Striped piggy *Terapon puta*).
- Although, from 2009 many lessepsian species were first recorded in tons and many other endemic species are beginning to emerge in economic production due to the start of deepwater fishing as European hake, after it was added among the other species in the table of the Egyptian Mediterranean annual fish production (Table 1), and there is an increase of NIS from Atlantic origin (Ex: Atlantic bluefin tuna *T. thynnus*) and Indo-Pacific origin but the production continuously decreases.

In the state of point, the decline in production in general during the period from 2009 till now is due to climate change in combination with overfishing, an increase in the number of juvenile fish caught in the catch, use of nets that do not conform to specifications, using prohibited fishing methods, fishing in coastal waters (less than 3 mile), fishing for fry, and negligence in the application of penalties for fishing offenses. Indeed, a range of non-climate stressors can buffer or enhance the effects of climate change on fisheries (Hidalgo et al., 2011), with overfishing and pollution being the most affected.

9. Recommendations

The author suggests that the development of fishing gear and the urgent need to develop the fishing fleet to increase the number of boats fishing in the deep waters are probably important. The increase in the numbers of trawlers that operate in deep waters affect the restoration of some indigenous species in the catch. Furthermore, sailboats that naturally operate near the shore have the effect of damaging fish stocks because they catch a large proportion of small fish. As a result of the fishing of some boats near the shore and a distance of less than 3 nautical miles, and the increase in the number of sailboats, the harmful effect on fish stocks, so it is recommended to close the coastal areas for fishing. Additionally, expanding the fishing grounds, designating weekends and bank holidays as no-fishing days, reducing the number of licenses, reducing catches by daily catch quotas and restocking endangered species, adopting new fishing methods, and increasing the coverage of Marine Protected Areas (MPAs) are recommended.

10. Conclusions

As climate change is a continuous process, the impacts of the climatic conditions will continue to grow and we must protect the sea's natural assets and rebuild its resources. If the species can adapt quickly enough to climate changes in their environment, they survive and they are sustainable. Furthermore, the impact of climate change on fisheries depends on the adaptability of the fleets where, under the effect of climate change, cold affinities species may migrate northward or seek refuge in deeper and cooler waters. Although climate change is threatening the fish stocks, it also creates new opportunities for fishing and fishing sustainably requires adopting new fishing methods.

Declaration of competing interest

There are no conflicts of interest.

References

Abdel-Halim, A.M., Aly-Eldeen, M.A., 2016. Characteristics of Mediterranean Sea water in vicinity of Sidikerir Region, west of Alexandria, Egypt. Egypt. J. Aquat. Res. 42, 133−140.

Adloff, F., Somot, S., Sevault, F., Jordà, G., et al., 2015. Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. Clim. Dynam. 45 (9−10), 2775−2802. https://doi.org/10.1007/s00382-015-2507-3.

Agnetta, D., Badalamenti, F., Colloca, F., Cossarini, G., et al., 2022. Interactive effects of fishing effort reduction and climate change in a central Mediterranean fishing area: Insights from bio-economic indices derived from a dynamic food-web model. Front. Mar. Sci. 9, 909164. https://doi.org/10.3389/fmars.2022.909164.

Albano, P.G., Steger, J., Bošnjak, M., Dunne, B., et al., 2021. Native biodiversity collapse in the eastern Mediterranean. Proc. Biol. Sci. 288, 20202469. https://doi.org/10.1098/rspb.2020.2469.

Albouy, C., Guilhaumon, F., Leprieur, F., Lasram, F.B.R., et al., 2013. Projected climate change and the changing biogeography of coastal Mediterranean fishes. J. Biogeogr. 40 (3), 534−547. https://doi.org/10.1111/jbi.12013.

Alprol, A.E., Ashour, M., Mansour, A.T., Alzahrani, O.M., et al., 2021. Assessment of Water Quality and Phytoplankton Structure of Eight Alexandria Beaches, Southeastern Mediterranean Sea. J. Mar. Sci. Eng. 9, 1328. https://doi.org/10.3390/jmse9121328.

Alvarez-Berastegui, D., Hidalgo, M., Tugores, M.P., Reglero, P., et al., 2016. Pelagic seascape ecology for operational fisheries oceanography: modelling and predicting spawning distribution of Atlantic bluefin tuna in Western Mediterranean. ICES J. Mar. Sci. 73 (7), 1851−1862. https://doi.org/10.1093/icesjms/fsw041.

Anonymous, 1962−1990. Year Book of Fishery Statistics. Alex. Inst. Oceanogr. Fish., A.R.E.

Azzurro, E., Moschella, P., Maynou, F., 2011. Tracking signal of change in Mediterranean fish diversity based on local ecological knowledge. PLoS One 6, e24885.

Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., et al., 2019. Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: a largescale survey based on local ecological knowledge. Global Change Biol. 25, 1−14.

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., et al., 2018. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. In: FAO Fisheries and Aquaculture Technical Paper No. 627. FAO, Rome, p. 628.

Belcaid, S., Ahmed, S., 2011. Growth, mortality and exploitation of European hake *Merluccius merluccius* in the Moroccan North Atlantic Sea. Egypt. J. Aquat. Res. 37 (2), 139−145.

Boero, F., Féral, J.P., Azzurro, E., Cardin, V., et al., 2008. Executive summary. In: Briand, F. (Ed.), Climate warming and related changes in Mediterranean marine biota. CIESM Workshop Monographs, No.35. CIESM, Monaco, pp. 5−21. http://www.ciesm.org/online/monographs/Helgoland.html.

Cabanellas-Reboredo, M., Vázquez-Luis, M., Mourre, B., Álvarez, E., 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. https://doi.org/10.1038/s41598-019-49808-4.

Cavraro, F., Anelli Monti, M., Matíc-Skoko, S., Caccin, A., et al., 2023. Vulnerability of the Small-scale fishery to climate changes in the Northern-Central Adriatic Sea (Mediterranean Sea). Fishes 8 (1), 9. https://doi.org/10.3390/fishes8010009.

Cerrano, C., Bavestrello, G., Bianchi, C.N., Cattaneo-vietti, R., Bava, S., Morganti, C., Morri, C., Picco, P., Sara, G., Schiaparelli, S., Siccardi, A., Sponga, F., 2000. A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-Western Mediterranean), summer 1999. Ecol. Lett. 3, 284−293. https://doi.org/10.1046/j.1461-0248.2000.00152.x.

Cheung, W.W.L., 2018. The future of fishes and fisheries in the changing oceans. J. Fish. Biol. 92, 790−803. https://doi.org/10.1111/jfb.13558.

Di Martino, V., Stancanelli, B., 2021. The alien lionfish, *Pterois miles* (Bennett, 1828), enters the Adriatic Sea, Central Mediterranean Sea. J. Black Sea Mediterr. Environ. 27, 104−108.

Ding, Q., Chen, X., Hilborn, R., Chen, Y., 2017. Vulnerability to impacts of climate change on marine fisheries and food security. Mar. Pol. 83, 55−61. https://doi.org/10.1016/j.marpol.2017.05.011.

Dulčić, J., Pallaoro, A., 2004. First record of the marbled spinefoot *Siganus rivulatus* (Pisces: Siganidae) in the Adriatic Sea. J. Mar. Biol. Assoc. U. K. 84, 1087−1088.

FAO, 2016. The State of Mediterranean and Black Sea Fisheries. In: General Fisheries Commission for the Mediterranean. Rome, p. 134. http://www.fao.org/3/a-i5496e.pdf.

FAO, 2019. *Coryphaena hippurus* (Linnaeus, 1758). In: Species fact sheets. http://www.fao.org/fishery/species/3130/en.

FAO, 2020. The State of Mediterranean and Black Sea Fisheries 2020. In: General Fisheries Commission for the Mediterranean. https://doi.org/10.4060/cb2429en.

FAO, 2022. The State of Mediterranean and Black Sea Fisheries 2022. In: General Fisheries Commission for the Mediterranean. Rome. https://doi.org/10.4060/cc3370en.

Findlay, H.S., 2023. Warming, Acidification and Deoxygenation of the Ocean. In: Obaidullah, F. (Ed.), The Ocean and Us. Springer, Cham. https://doi.org/10.1007/978-3-031-10812-9_2.

Fisher, W., Bauchot, W.M., Schneider, M., 1987. Fiches FAO d'identification pour les besoins de la peche revision I: Mediterrance et mer Noire. In: Zone de Peache 37, Vertebres, vol. 2. FAO, Rome, pp. 761−1530.

Fortibuoni, T., Aldighieri, F., Giovanardi, O., Pranovi, F., et al., 2015. Climate impact on Italian fisheries (Mediterranean Sea). Reg. Environ. Change 15, 931−937.

Fortibuoni, T., Libralato, S., Raicevich, S., Giovanardi, O., et al., 2010. Coding early naturalists' accounts into long-term fish community changes in the Adriatic Sea (1800e2000). PLoS One 5, e15502.

GAFRD, 1991−2020. General Authority for Fish Resources Development (GAFRD). In: Fisheries Statistics Yearbook.

Galeotti, M., 2020. The Economic Impacts of Climate Change in the Mediterranean. IEMed. In: Mediterranean Yearbook 2020, pp. 46−54. https://www.iemed.org/publication/the-economic-impacts-of-climate-change-in-the-mediterranean/.

Gentilucci, M., Moustafa, A.A., Abdel-Gawad, F.K., Mansour, S.R., et al., 2021. Advances in Egyptian Mediterranean Coast Climate Change Monitoring. Water 13, 1870. https://doi.org/10.3390/w13131870.

Grorud-Colvert, K., Sullivan-Stack, J., Roberts, C., Constant, V., et al., 2021. The MPA Guide: A framework to achieve global goals for the ocean. Science 373, eabf0861. https://doi.org/10.1126/science.abf0861.

Gücü, A.C., Ünal, V., Ulman, A., Morello, E.B., et al., 2021. Management responses to non-indigenous species in the Mediterranean and the Black Sea in the face of climate change. In: Adaptive Management of Fisheries in Response to Climate Change. FAO, Rome, pp. 161−176.

Harhash, K.A., El-Henawy, M.T., Abdel Fattah, H.F., Antar, M.S., 2015. Conservation oriented habitat classification scheming and mapping of Egypt. Environ. Syst. Res. 4, 8. https://doi.org/10.1186/s40068-015-0034-1.

Hassan, N.H.S., Mohamed, E.E.E., 2020. Impacts of the climatic changes on the fishery activities Along Egyptian coast of Mediterranean. Egypt. J. Aquat. Biol. Fish. 24 (5), 403−411.

Hidalgo, M., El-Haweet, A.E., Tsikliras, A.C., Tirasin, E.M., et al., 2022. Risks and adaptation options for the Mediterranean

fisheries in the face of multiple climate change drivers and impacts. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 79, 2473–2488. https://doi.org/10.1093/icesjms/fsac185.
Hidalgo, M., Mihneva, V., Vasconcellos, M., Bernal, M., 2018. Climate change impacts, vulnerabilities and adaptations: Mediterranean Sea and the Black Sea marine fisheries. In: Impacts of Climate Change on fisheries and aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options. FAO, Rome, pp. 139–158.
Hidalgo, M., Rouyer, T., Molinero, J.C., Massutí, E., et al., 2011. Synergistic effects of fishing-induced demographic changes and climate variation on fish population dynamics. Mar. Ecol. Prog. Ser. 426, 1–12. https://doi.org/10.3354/meps09077.
Hilmi, N., Farahmand, S., Lam, V.W.Y., Cinar, M., et al., 2021. The Impacts of Environmental and Socio-Economic Risks on the Fisheries in the Mediterranean Region. Sustainability 131, 670. https://doi.org/10.3390/su131910670.
Hoegh-Guldberg, O., Cai, R., Poloczanska, E.S., Brewer, P.G., et al., 2014. The ocean. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 1655–1731.
Holsman, K.K., Haynie, A.C., Hollowed, A.B., Reum, J.C.P., et al., 2020. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat. Commun. 11 (1). https://doi.org/10.1038/s41467-020-18300-3.
Intergovernmental Panel on Climate Change, 2023; IPCC, 2023. https://en.wikipedia.org/wiki/Intergovernmental_Panel_on_Climate_Change.
IPCC, 2023. https://www.ipcc.ch/report/ar6/wg1/.
Katsanevakis, S., 2021. Transplantation as a conservation action to protect the Mediterranean fan mussel *Pinna nobilis*. Mar. Ecol. Prog. Ser. 546, 113–122. https://doi.org/10.3354/meps11658.
Kogovšek, T., Angel, D.L., Deidun, A., Lučić, D., et al., 2015. Progress in Understanding Scyphomedusae Outbreaks in the Mediterranean Sea: Distribution and Phenology. https://www.um.edu.mt/library/oar/handle/123456789/26455.
Lasram, F.B.R., Tomasin, J.A., Guilhaumon, F., Romdhane, M.S., et al., 2008. Ecological correlates of dispersal success of Lessepsian fishes. Mar. Ecol. Prog. Ser. 363, 273–286.
Lejeusne, C., Chevaldonné, P., Pergent-Martini, C., Boudouresque, C.F., et al., 2010. Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. Trends Ecol. Evol. 25 (4), 250–260. https://doi.org/10.1016/j.tree.2009.10.009.
LFRPDA, 2021. Lakes and Fish Resources Protection and Development Agency (LFRPDA). In: Fisheries Statistics Yearbook.
Lloret, J., Rätz, H.J., Lleonart, J., Demestre, M., 2016. Challenging the links between seafood and human health in the context of global change. J. Mar. Biol. Assoc. U. K. 96 (1), 29–42. https://doi.org/10.1017/S0025315415001988.
Lloret, J., Sabatés, A., Muñoz, M., Demestre, M., et al., 2015. How a multidisciplinary approach involving ethnoecology, biology and fisheries can help explain the spatio-temporal changes in marine fish abundance resulting from climate change. Global Ecol. Biogeogr. 24 (4), 448–461. https://doi.org/10.1111/geb.12276.
Lotze, K.H., Coll, M., Dunne, J.A., 2011. Historical changes in marine resources, food web structure and ecosystem functioning in the Adriatic Sea, Mediterranean. Ecosystems 14, 198–222.
Macias, D., Garcia-Gorriz, E., Stips, A., 2015. Productivity changes in the Mediterranean Sea for the twenty-first century in response to changes in the regional atmospheric forcing. Front. Mar. Sci. 2, 79. https://doi.org/10.3389/fmars.2015.00079.
Marbà, N., Jordà, G., Agusti, S., Girard, C., et al., 2015. Footprints of climate change on Mediterranean Sea biota. Front. Mar. Sci. 2, 56. https://doi.org/10.3389/fmars.2015.00056.
MedECC, 2020. Summary for Policymakers. In: Cramer, W., Guiot, J., Marini, K. (Eds.), Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report, Union for the Mediterranean, Plan Bleu. UNEP/MAP, Marseille, France, p. 34.
MedPAN, 2021. The System of Mediterranean Marine Protected Areas in 2020, MedPAN and UNEP/MAP-SPA/RAC, November 2021. https://medpan.org/en/system-mediterranean-mpas-2020.
Meiners, C.G., 2007. Importancia de la variabilidad climática en las pesquerías y biología de la merluza europea *Merluccius merluccius* (Linnaeus, 1758) de la costa Noroccidental Africana. Tesis Doctoral. Universitat Politécnica De Catalunya (UPC), p. 187. http://books.google.es/books/about/Importancia_de_la_variabilidad_clim%C3%A1tic.html?id=7eZPMwEACAAJ&redir_esc=y.
Moltó, V., Palmer, M., Ospina-Alvarez, A., Pérez-Mayol, S., et al., 2021. Projected effects of ocean warming on an iconic pelagic fish and its fishery. Sci. Rep. 11 (1), 8803. https://doi.org/10.1038/s41598-021-88171-1.
Moullec, F., Barrier, N., Drira, S., Guilhaumon, F., et al., 2019. An end-to-end model reveals losers and winners in a warming Mediterranean Sea. Front. Mar. Sci. 6, 345. https://doi.org/10.3389/fmars.2019.00345.
Moullec, F., Ben Rais Lasram, F., Coll, M., Guilhaumon, F., et al., 2018. Sub-chapter 2.1.4. Climate change and fisheries In: The Mediterranean region under climate change. In: Moatti, J.-P., Thiébault, S. (Eds.), A Scientific Update, 261, pp. 249–261. https://books.openedition.org/irdeditions/23439.
NIOF, 1975. Fisheries of the south-eastern Mediterranean Sea along the Egyptian coast Soviet-Egyptian expedition 1970-1971. Bull. Inst. Oceanogr. Fish. 5, 279pp.
Öztürk, B., 2021. Non-indigenous Species in the Mediterranean and the Black Sea. In: Studies and Reviews, No. 87, (General Fisheries Commission for the Mediterranean). FAO, Rome.
Papaconstantinou, C., Farrugio, H., 2000. Fisheries in the Mediterranean. Mediterr. Mar. Sci. V1/1, 5–18.
Payne, M.R., Kudahl, M., Engelhard, G.H., Peck, M.A., et al., 2021. Climate risk to European fisheries and coastal communities. Proc. Natl. Acad. Sci. USA 118 (40), e2018086118.
Pergent, G., Pergent-Martini, C., Bein, A., Dedeken, M., et al., 2015. Dynamic of *Posidonia oceanica* seagrass meadows in the northwestern Mediterranean: Could climate change be to blame? Comptes Rendus Biol. 338 (7), 484–493. https://doi.org/10.1016/j.crvi.2015.04.011.
Pisano, A., Marullo, S., Artale, V., Falcini, F., et al., 2020. New evidence of Mediterranean climate change and variability from Sea surface temperature observations. Rem. Sens. 12, 132. https://doi.org/10.3390/RS12010132.
Pita, I., Mouillot, D., Moullec, F., Shin, Y.J., 2021. Contrasted patterns in climate change risk for Mediterranean fisheries. Global Change Biol. 27, 5920–5933. https://doi.org/10.1111/gcb.15814.
Plagányi, E., 2019. Climate change impacts on fisheries. Science 363 (6430), 930–931. https://doi.org/10.1126/science.aaw5824.
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. Sci. Mar. 73, 129–141.
Rambo, H., Ospina-Alvarez, A., Catalán, I.A., Maynou, F., et al., 2022. Unraveling the combined effects of sociopolitical and climate change scenarios for an artisanal small-scale fishery in the Western Mediterranean. Ecol. Soc. 27 (1), 43. https://doi.org/10.5751/ES-12977-270143.
Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Möllmann, C., et al., 2009. Resolving the effect of climate change on fish populations. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 66, 1570–1583.

Russo, T., D'Andrea, L., Franceschini, S., Accadia, P., et al., 2019. Simulating the effects of alternative management measures of trawl fisheries in the central Mediterranean Sea: Application of a multi-species bioeconomic modeling approach. Front. Mar. Sci. 6, 542. https://doi.org/10.3389/fmars.2019.00542.

Sabatés, A.N.A., Martin, P., Lloret, J., Raya, V., 2006. Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. Global Change Biol. 12 (11), 2209—2219. https://doi.org/10.1111/j.1365-2486.2006.01246.x.

Shulman, G.E., Nikolsky, V.N., Yunev, O.A., Yuneva, T.V., et al., 2011. Present condition of small pelagic fishes in the Black Sea. J. Appl. Biol. Sci. 5 (2), 65—67. http://www.nobel.gen.tr/yayindetay.aspx?yayin_id=1820.

Stevens, A., 2010. Introduction to the Basic Drivers of Climate. Nat. Educ. Knowl. 3 (10), 10.

Tiralongo, F., Crocetta, F., Riginella, E., Lillo, A.O., et al., 2020. Snapshot of rare, exotic and overlooked fish species in the Italian seas: A citizen science survey. J. Sea Res. 164, 101930.

Tsikliras, A.C., Stergiou, K.I., 2014. Mean temperature of the catch increases quickly in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 515, 281—284. https://doi.org/10.3354/meps11005.

Tsikliras, A.C., Peristeraki, P., Tserpes, G., Stergiou, K.I., 2015. Mean temperature of the catch (MTC) in the Greek seas based on landings and survey data. Front. Mar. Sci. 2, 23. https://doi.org/10.3389/fmars.2015.00023.

Tuel, A., ElTahir, E.A.B., 2020. Why Is the Mediterranean a Climate Change Hot Spot? J. Clim. 33, 5829—5843. https://doi.org/10.1175/JCLI-D-19-0910.1.

Turner, J., El Quari, M., 1986. State of the exploitation of *Merluccius merluccius* off the coast of Northern Morocco. In: Rapport du premier Groupe de travail special sur les pêcheries de merlus et de crevettes profondes dans la zone nord du COPAC COPACE/PACE Se' ries, 86/33. FAO, Roma, Italia, pp. 51—71.

Ünal, V., Göncüoglu Bodur, H., 2017. The socio-economic impacts of the silver cheeked toadfish on small-scale fishers: a comparative study from the Turkish coast. Ege J. Fish. Aquat. Sci. 34 (2), 119—127. https://doi.org/10.12714/egejfas.2017.34.2.01.

UNEP/MAP, 2023. Climate change in the Mediterranean. https://www.unep.org/unepmap/resources/factsheets/climate-change.

Vasilakopoulos, P., Raitsos, D.E., Tzanatos, E., Maravelias, C.D., 2017. Resilience and regime shifts in a marine biodiversity hotspot. Sci. Rep. 7, 1—11.

Vergés, A., Tomas, F., Cebrian, E., Ballesteros, E., et al., 2014. Tropical rabbit fish and the deforestation of a warming temperate sea. J. Ecol. 102 (6), 1518—1527. https://doi.org/10.1111/1365-2745.12324.

WWF, 2020. Marine Protected Areas: our allies in good ocean governance and climate change mitigation. https://www.wwf.eu/?907241/Marine-Protected-Areas-our-allies-in-good-ocean-governance-and-climate-change-mitigation.

WWF, 2021. The Climate Change Effect in the Mediterranean. Six Stories from an Overheating Sea. WWF Mediterranean Marine Initiative, Rome, Italy, p. 26. https://www.wwf.fr/sites/default/files/doc-2021-06/20210607_Rapport_The-Climate-Change-Effect-In-The-Mediterranean-Six-stories-from-an-overheating-sea_WWF-min.pdf.