CLIMATE CHANGE IMPACTS ON PRIMARY PRODUCTION AND ECONOMICALLY IMPORTANT FISH STOCKS IN THE BLACK SEA

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CLIMATE CHANGE IMPACTS ON PRIMARY PRODUCTION AND ECONOMICALLY IMPORTANT FISH STOCKS IN THE BLACK SEA

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ABSTRACT

CLIMATE CHANGE IMPACTS ON PRIMARY PRODUCTION AND ECONOMICALLY IMPORTANT FISH STOCKS IN THE BLACK SEA

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Coastal urbanization, heavy nutrient/pollutant loads due to intense anthropogenic activities and unsustainable fisheries have been threatening life-support system of marine environment and getting more drastic with the climatic variations and its impacts. Changes in sea surface temperatures and related dynamical processes have been threatening bottom-up / top-down control of marine food webs via variations in primary production and changes in biogeographic and temporal responses of thermophilic species. All these perturbations, habitat and biodiversity losses consequently affect marine food resources and its economy, coastal life-support systems for human society. Proposed thesis aims to determine relationship between climate change and primary production and to understand how economically important fish stocks have been influenced by the variations in primary production in the Black Sea for the last 45 years. Time series data available through *in situ* measurements of lower trophic level ecosystem parameters (METU-Institute of Marine Sciences) was evaluated, whereas the data on meteorological parameters and biodiversity change/fish stocks was collected from Turkish State Meteorological Service and Turkish Statistical Institute respectively for the same period. Another important deliverable of the thesis will be the proposal of how to strengthen sustainable management strategies, economy and policy tools for Turkish fishery sector under these determined relationships.

Keywords: Climate Change, Primary Production, Fishery, Black Sea, Economical Model

ÖZ

KARADENİZ’DE İKLİM DEĞİŞİKLİĞİNİN İLK ÜRETİM VE EKONOMİK DEĞERİ OLAN BALIK STOKLARINA OLAN ETKİLERİ

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Eylül 2013, 57 sayfa

Kıyı yapılaşması, insan kaynaklı besin elementleri/kirleticilerin girdilerindeki artışlar ve sürdürülebilir temellere dayanmayan balıkçılık deniz çevresinin yaşam destek sistemlerini tehdit etmekte ve iklim değişikliğinin etkileri ile sistem daha da sorunlu hale gelmektedir. Deniz suyu sıcaklıkları ve dinamiklerinde olan değişimler besin ağında düşey kontrol sistemlerini etkileyerek birincil ve bağlı üretim ile türlerin biyo-coğrafik ve zamansal dağılımlarını etkilemektedir. Habitat ve biyolojik çeşitlilikteki kayıplar, üretimdeki tüm bu olumsuz değişikler toplum için gerekli denizel besin kaynaklarını ve kıyı alanlarında yaşam destek sistemlerini etkilemektedir. Önerilen tez, son 45 yılda Karadeniz’de iklim değişikliğinin denizlerde birincil ve bağlı üretimlere olan etkilerini ortaya koymayı hedeflemektedir. Deniz ekosistemi alt beslenme basamaklarına ait zaman serisi verileri ODTÜ Deniz Bilimleri Enstitüsü, meteorolojik parametreler, biyoçeşitlilik ve balık stokları ile ilgili verileri ise Meteoroloji Genel Müdürlüğü ve Türkiye İstatistik Kurumu’ndan temin edilmiştir. Tezin bir diğer önemli getirisi, tüm bu ortaya koyulacak ilişkilerin Türk balıkçılık sektörünün sürdürülebilir yönetimi, ekonomisi ve politikalarının nasıl güçlendirilebileceği konusuna girdi sağlaması olacaktır.

Anahtar Sözcükler: İklim Değişikliği, İlk üretim, Balıkçılık, Karadeniz, Ekonomik Model

To My Parents; *Gülder Küçükavşar* and *Mehmet Küçükavşar*

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1. Global Climate Change

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. It was stated in the Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) that the Earth has been observing warmest global surface temperatures between 1995 and 2006 since 1850. On the other hand, the land parts of the Earth warm quickly relative to the oceans and higher northern hemisphere temperatures were observed which were twice of the global averages within the last 100 years (1).

Considering long term trends and recent CO_2 concentration (399,77 ppm) recorded in May 2013 in Hawaii's Mauna Loa observatory (Figure 1.1), although the current mitigation policies, global Green House Gases (GHGs) will continue to grow up for the coming decades.

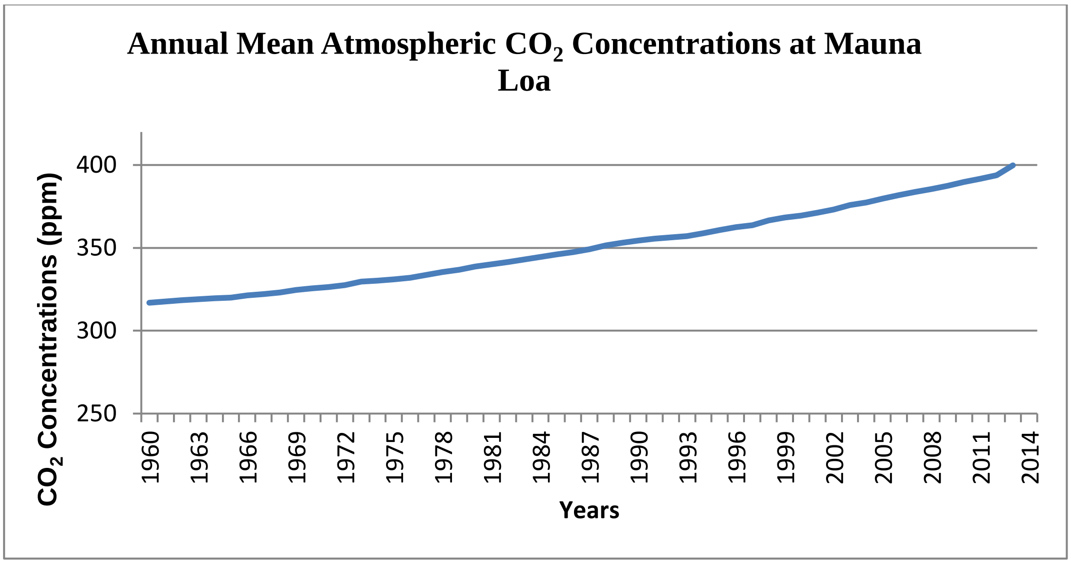


Figure 1.1 Annual Mean Atmospheric CO_2 Concentrations at Mauna Loa observatory (Downloaded from the web site: http://www.esrl.noaa.gov/gmd/ccgg/trends/)

There are four families of emission scenarios as A1, A2, B1 and B2 (Figure 1.2), each of it considers demographic, economic and technological driving forces and resulting **G**reen

House **G**ases (GHGs) emissions in the IPCC Special Report on Emissions Scenarios (SRES, 2000). Assuming that the all of the GHGs concentrations have been kept at the levels of 2000, 0.1 C ° further temperature increases is projected. However, almost 24 ppm increase has already been observed between 2000 and 2012 (2).

Scenario family A1 (has three subsets as A1F1, A1B and A1T) considers the rapid economic growth, a global population reaches 9 billion in 2050 and then gradually declines, available new and efficient technologies while the income and the way of living merge between regions. In contrast with A1 scenarios that represent more integrated World, A2 scenarios represent more divided World and regionally concentrated economic growth and continuous rate of population. B1 and B2 scenarios consider more ecologically friendly attitudes than A1 and A2. Population growth in B1 is similar with the A1, while the increase rate of population in B2 is slower than the one in A2. Economic growth is mostly concentrated on service and information economy rather than a rapid economic growth in A1. B2 emphasize on local rather than global solutions to economic, social and environmental stability (1).

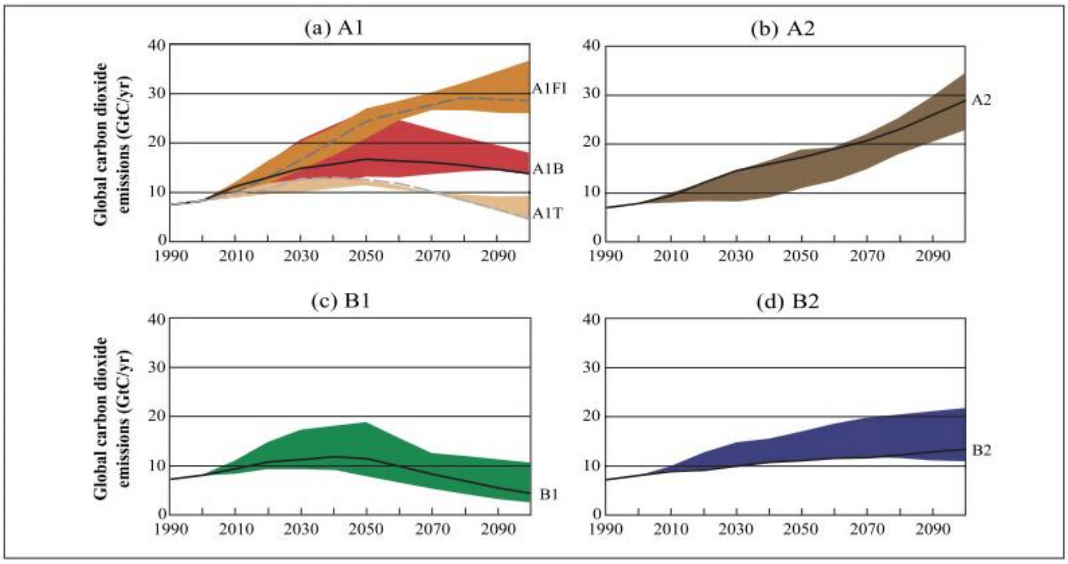
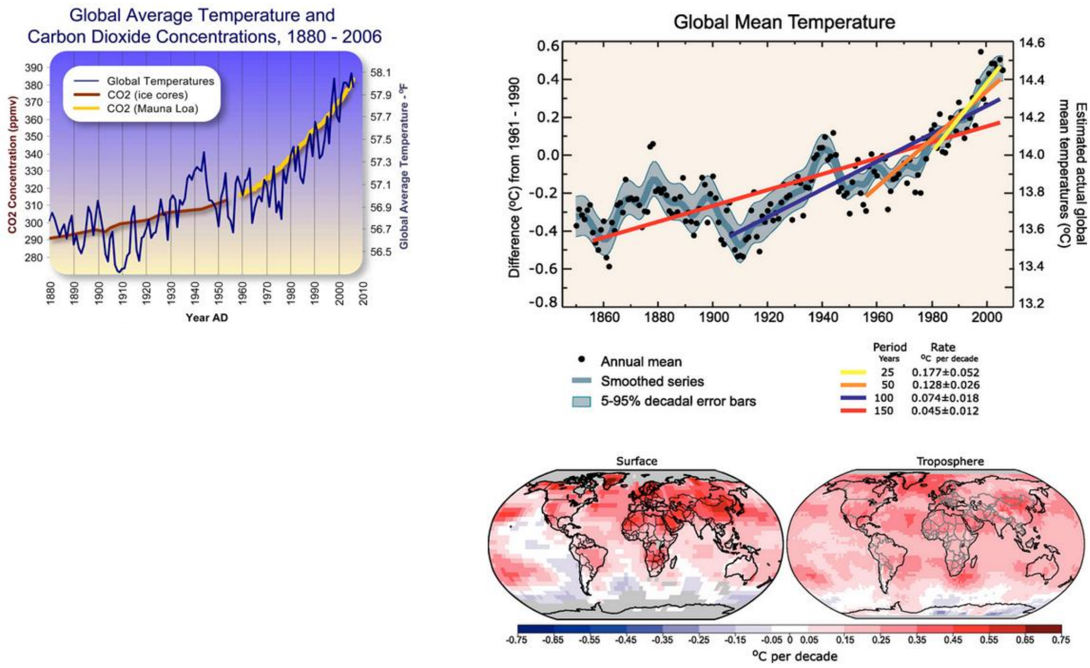


Figure 1.2 Summary of the SRES scenarios is presented by the four families. CO_2 emissions from all sources were taken into account. (a) A1 scenarios family [A1FI: Fossil-intensive (high-coal and high-oil and gas scenarios). A1T: the predominantly non-fossil intensive and A1B is the balanced scenario], (b) A2, (c) B1, and (d) B2 scenarios. Each emission band shows the range of harmonized and non-harmonized scenarios (Source: Fourth Assessment Report of Intergovernmental Panel on Climate Change, 2007).

Changes in global temperatures and CO_2 levels within the last 150 years are presented in Figure 1.3. Records show evitable increase in the global temperature and CO_2 levels. Between 1906 and 2006 global temperatures have raised approximately 0.75 C° [blue line Figure 1.3 (b)]. Rising trend become more serious for the last two decades with regional differences. According to the IPCC Fourth Assessment Report, there was little change up to 1915, and that a substantial fraction of the early 20th-century change was contributed by naturally occurring influences including solar radiation changes, volcanism and natural variability. Following the industrial revolution and especially after 1960s, increased pollution in the Northern Hemisphere, and increases in GHGs dominate the observed warming after the mid-1970s.



(a) (b)

Figure 1.3 (a) Global Average Temperature and Carbon Dioxide Concentrations, 1880-2006 (Source: The Woods Hole Research Center, graphic design by Michael Ernst). **(b)** (Top) Annual global mean observed temperatures (black dots) along with simple fits to the data. The left hand axis: anomalies relative to the 1961 to 1990 average. Linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red) are shown, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. (Bottom) Patterns of linear global temperature trends from 1979 to 2005 estimated at the surface, and for the troposphere (from the surface to about 10 km altitude, from satellite records). Grey areas indicate incomplete data (Source: IPCC Fourth Assessment Report: Climate Change 2007).

1.2. Regional Climate Change

Rapid warming trend in Turkey has been observed especially after 1990s and it is concluded that the main reason behind that warming trend is heat island effect due to urbanization and general global warming (3). Figure 1.4 shows the regional differences from the global anomalies and warming trend after 1990s. Climate change projections for Turkey, studied by the scientists of Istanbul Technical University, Eurasia Institute of Earth Sciences, show that the surface temperature increases will be more severe in the summer seasons with the regional differences in near future (Figure 1.5). Results of projected temperature changes (over the period 1961-1990) in Turkey based on the A2 scenarios of SRES and future projections till 2100 are complimentary for different model studies (Figure 1.5).

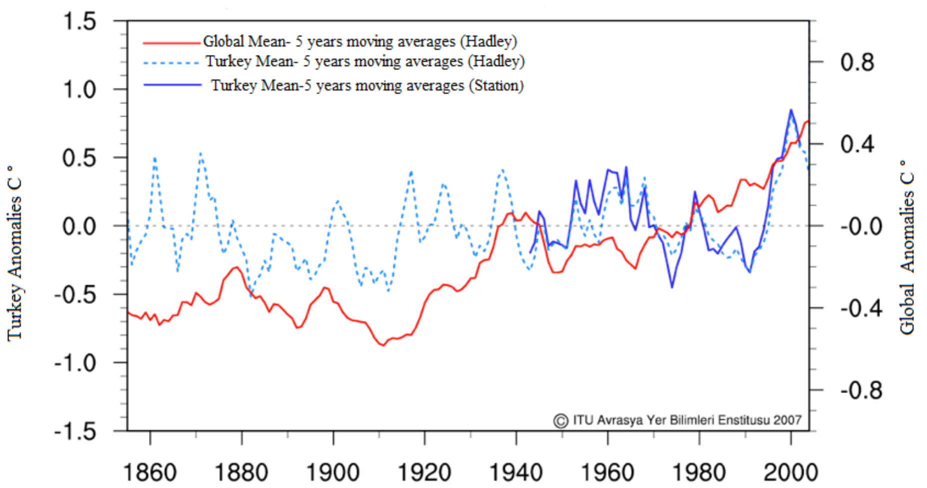


Figure 1.4 Annual Mean Temperature Anomalies in Turkey with respect to the period of 1961- 1990. Graph Designed by Ozan M. Göktürk, İstanbul Technical University, Eurasia Institute of Earth Sciences. Original Graphic translated in English. Source: http://turkiyeiklim.wordpress.com/2012/06/12/kuresel-iklim-degisimi-dunya-geneli-ve-turkiye/

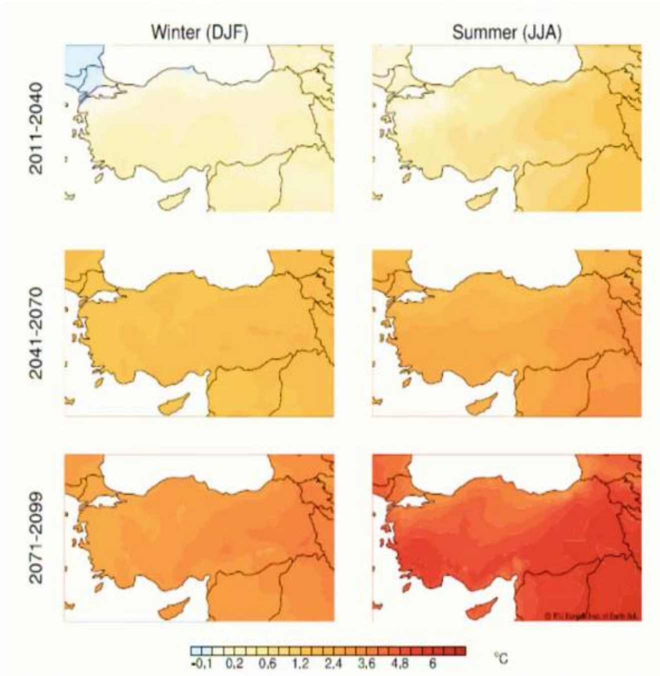


Figure 1.5 Results of projected temperature changes (over the period of 1961-1990) in Turkey based on the A2 scenarios of SRES, run by ECHAM5 (5th generation atmospheric general circulation model.

1.3. Climate Change and Impacts on Marine Ecosystems

Anthropogenic greenhouse gases concentration has been dramatically increasing, enhancing the global warming which drives abrupt changes in both marine and terrestrial ecosystems. Throughout the evolutionary history, it is evident that marine species can adapt such fluctuations, however problem is mainly emerged because of rapid temperature rise experienced regionally and globally (4), (5). Recent studies show that World's marine ecosystems have been facing with unpredictable changes. Though, global effects of climate change has been investigated (6), (7), (8), (9), (10); concluding the consequences of increased GHG's on highly valuable marine ecosystems; unfavorable primary production due to stratification of water column, altered food web dynamics, changes in distribution of species (pole ward migration of fish population and early migration), and increased exposure to diseases are the issues to be concerned. Another problem associated with the rising CO_2 levels in the atmosphere is ocean acidification. Atmospheric carbon released by the burning of fossil fuels is absorbed by the oceans (11). Increased CO_2 levels result in decreased pH and carbonate ion concentration and most of the studies are concentrated on the effects of ocean acidification on calcifying organisms and coral reefs (12), (13), (14), (15) which is excluded from the contents of this study.

Required energy for the marine food web is mainly supported by photo-autotrophic microorganisms. In the presence of solar energy, water and nutrients, inorganic carbon is converted to highly energetic organic carbon. Stratification of water column due to warming of upper layers limits the mixing of nutrient rich deep water and restricts the favorable primary production and consequently reduces fish stocks due reduced energy transfer through food webs by predation. Climate driven fluctuations in the stratification of water column and depth of thermocline and/or nutricline are main controlling parameters in the temperate regions, while seasonal mixing dominates the nutrient transport from deep water at the high latitudes.

Global Chlorophyll concentration which roughly represents primary production has declined since 1800s, and generally related to the climatic variability and particularly to increasing SST (16). Global trends in the Chlorophyll concentrations has been studied by scientists (17), (18), (19) and most of the publications support the hypothesis that warming of ocean is the main contributor of the declining primary production over the oceans (Figure 1.6) (20), (21), (22).

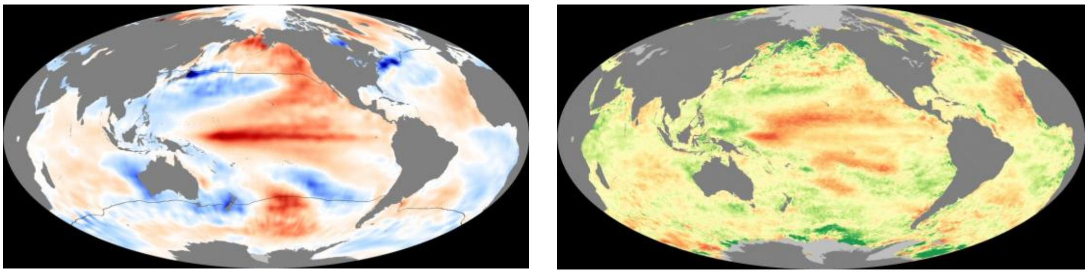


Figure 1.6 SST and Primary Production (PP) changes in between 2000 and 2004. Places where temperatures rose (left, red areas) are the same places where productivity dropped (right, red areas). SST: Advanced Very High Resolution Radiometer (AVHRR) data
Primary Productivity: The Sea-viewing Wide Field-of-View Sensor (SeaWiFS) data.

1.4. Climate Change and the Black Sea

1.4.1. General Features of the Black Sea

The Black Sea is one of the largest almost enclosed seas in the World: its area is about 420 thousands km^2 and the maximum water depth is 2.212 m (Figure 1.6.). The Black Sea is connected to the Mediterranean Sea to the west and to the Sea of Azov to the north. The connection with the Mediterranean Sea is limited to the Bosporus-Dardanelles straits. The Bosporus Strait is a rather narrow and shallow strait restricting but allowing the two-way water exchange between the Black and Mediterranean Seas. A surface outflow of brackish water (salinity 18-20) exits the Black Sea via the Turkish Straits connecting to the Aegean and Mediterranean Seas. In return, denser Mediterranean water (salinity 36-38) flows into the Black Sea as an undercurrent through the same channel and flows over the continental shelf into the deep central basin of the Black Sea, maintaining the salinity of the intermediate and deep water masses at a consistently higher value (~22) than the overlying surface waters.

The Black Sea has many characteristics of a big ocean, but it is a small, semi-enclosed basin. The Black Sea is a dilution basin with a positive water balance resulting from an excess of precipitation and runoff over evaporation (23). The drainage basin of this sea is over five times the area of the sea itself, delivering the industrial, domestic and agricultural runoff primarily via major rivers (e.g. Danube, Dnyster, Dnyper) in the northwestern shelf (Figure 1.7). The Black Sea is very sensitive to environmental changes, anthropogenic impact, and climate forcing on physical, chemical, and biological environments and processes.

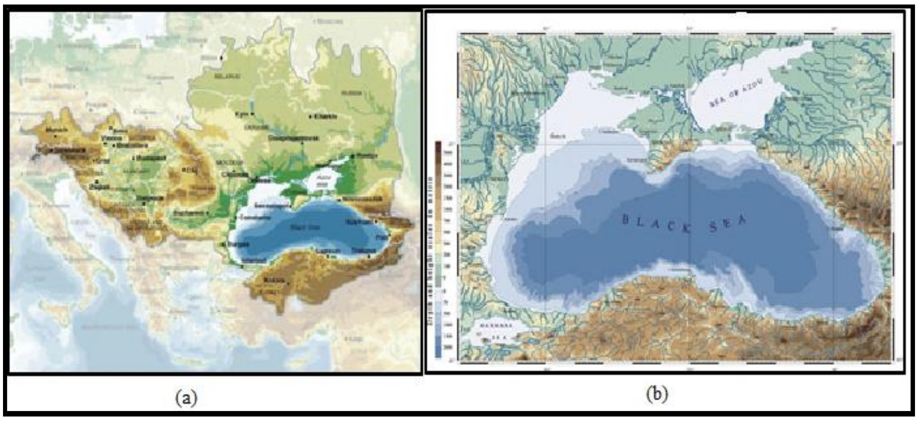


Figure 1.7 Catchment areas of the Black Sea (a) and its topography (b)

Black Sea circulation system is highly dynamic system having cyclonic eddies in the center and a cyclonic boundary current (called as the Rim Current) along the narrow continental slope circumscribes the central gyre region, spawning a chain of permanent and semi-permanent anticyclones along the sea's margin (Figure 1.8) (24), (25), (26). The overall basin circulation is primarily driven by the curl of wind stress throughout the year and further modulated by seasonal evolution of the surface thermohaline fluxes and mesoscale features arising from the basins internal dynamics. Flow structure in the northwestern shelf is driven by spreading of the Danube outflow under temporally wind forcing. In addition, fresh water discharge from the Danube and other northwestern rivers contributes to buoyancy-driven component of the basin-wide circulation system. Eddies, meanders, filaments, offshore jets of the Rim Current often introduces strong shelf-deep basin exchanges and two-way transports of biota (e.g fish migration) and chemicals between near-shore and offshore regions. A Black Sea water mass known as the Cold Intermediate Layer

(CIL) is also important in the supply, fate&recycling of nutrients and finally primary production (24), (27).

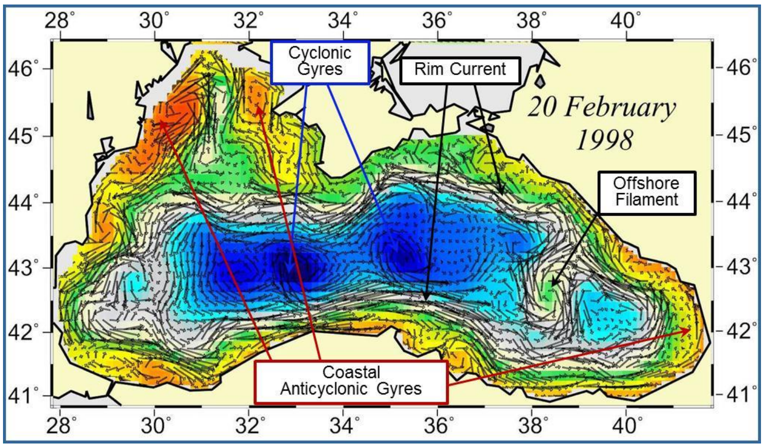


Figure 1.8 Black Sea typical surface layer circulation patterns (after Korotaev *et al.,* 2003).

The Black Sea is a multi-layer system (Figure 1.9). There is a strong vertical density gradient in the water column, due to large input of freshwater from rivers (mainly via Danube) at the surface and input of Mediterranean origin saline waters through the Bosporus. The resulting permanent pycnocline impedes exchanges of dissolved constituents between the surface mixed layer and deeper waters, setting up a multilayer system, with oxic, oxyclinic, sub-oxic and anoxic layers (28), (29). Deep water contains high concentrations of H_2S, since O_2 is totally consumed within the surface layer by the respiration of the sinking organic matter (Figure 1.10). The persistent sub-oxic layer (SOL) at the oxic-anoxic interface in the Black Sea is of particular importance in nutrient cycling (30), (31), (27).

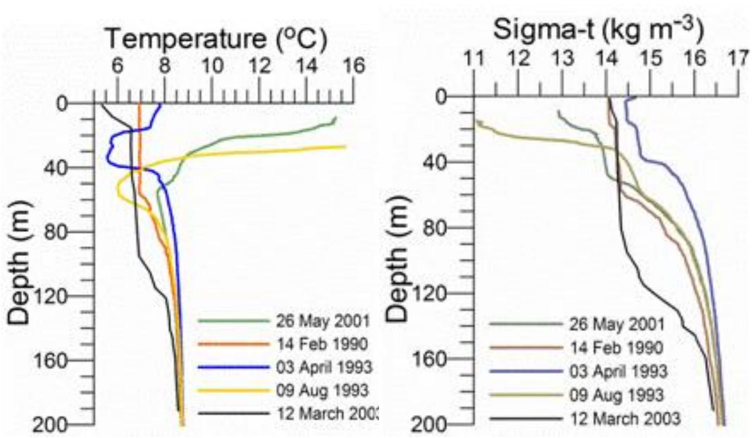


Figure 1.9 Vertical variations of temperature (°C) and density (expressed in terms of sigma-t, kg m-3) at various locations of the interior basin during different months representing

different types of vertical structures (the data are retrieved from the IMS-METU data base; http:sfp1.www.ims.metu.tr/ODBMSDB/) (BSC, 2008).

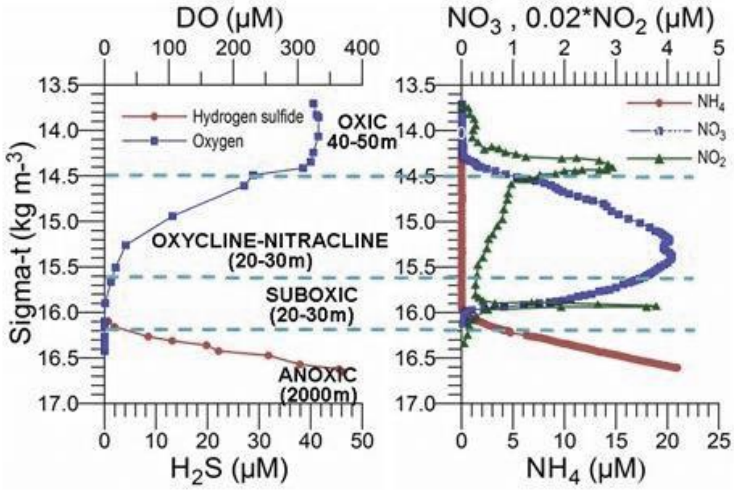


Figure 1.10 O_2 and H_2S profiles (left) and NO_3, NO_2 and NH_4 profiles (right) versus density expressed in sigma-t (kgm^{-3}) in the center of the Black Sea during May 2003. The data source: http://www.ocean.washington.edu/cruises/Knorr2003/index.html (BSC, 2008)

Main nutrient source of open Black Sea is the bottom-up flux from the pycnocline layer. This process is driven by the wind-induced mixing during the winter (32), (27). Stratification occurs in the spring and nutrient rich waters blocked by the CIL (33). This bottom-up nutrient flux is the main source of phytoplankton growth in the Black Sea (34), (27). In other words, N (sum of nitrate and ammonia) concentration has increased and decreased in the CIL and Pycnocline layer, though this shifts in the ecosystem of Black Sea concluded as a result of changes in the bottom-up flux of nutrients from mixed layer to the surface waters (35). Land-based sources of nutrients additionally increase the primary production in the coastal areas in the Black Sea (31), (33), (34).

1.4.2. Climate Change and Ecosystem Regime Shifts in the Black Sea

The North Atlantic Ossilation (NAO) is the dominant mode of atmospheric circulation variability over the North Atlantic region and Europe. NAO is a fluctuation in atmospheric mass between the subtropical high -Ponta Delgada in Azores, Lisbon or Gibraltar, and the polar low – typically Iceland. Associated anomalies are dominant during winter when the NAO is strongest. Positive NAO index describes stronger than usual subtropical high pressure center and a deeper than normal Icelandic low while Negative NAO index accociated with weak subtropical high and a weak Icelandic low pressure. During the positive phase of NAO index Europe observes warm and wet winters; and opposite anomalies (dry and cold winters) seen when it's in negative phase (Figure 1.11) (37).

Strong relationship between NAO and SST was shown by (38). SST data examined for the period of 1958 and 2005 by R. R. Kirby and G. Beaugrand (2009) in the North Sea showed shifts in the ecosystem such as unfovourible primary production and decreased cod recruitment during the 1980's due to increased SST. At the same time intervals, Black Sea experienced negative NAO phase and decresed SST values (39).

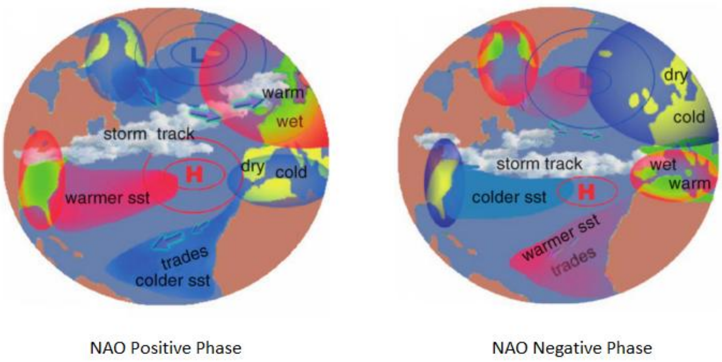


Figure 1.11. Structure of NAO Index. Source: Bojariu, R. & Gimeno, L., 2003

North Atlantic Oscillation (NAO) and East Atlantic-West Russia (EAWR) teleconnection patterns are the dominant hydro-meteorological forcing over the Black Sea Region (40). Hydro-meteorological and biochemical data records were studied by Oguz, et al. in 2006 and robust climatic signature at interannual to interdecadal time scales showed that these climatic driven changes are mainly releted with the NAO index.

In the Black Sea, satellite SST in 1982–2002 rose at a rate of 0.6 °C/decade; the coldest year of 1993 was a turning point after which SST rose through 2002 at a rate of >1.5 °C/decade (41), consistent with the finding of the report of Belkin, 2009 that of the most rapid warming in 1992–2001 at a rate of 2 °C/decade showing the very high sensitivity to regional and global climatic forces (Figure 1.12) (5).

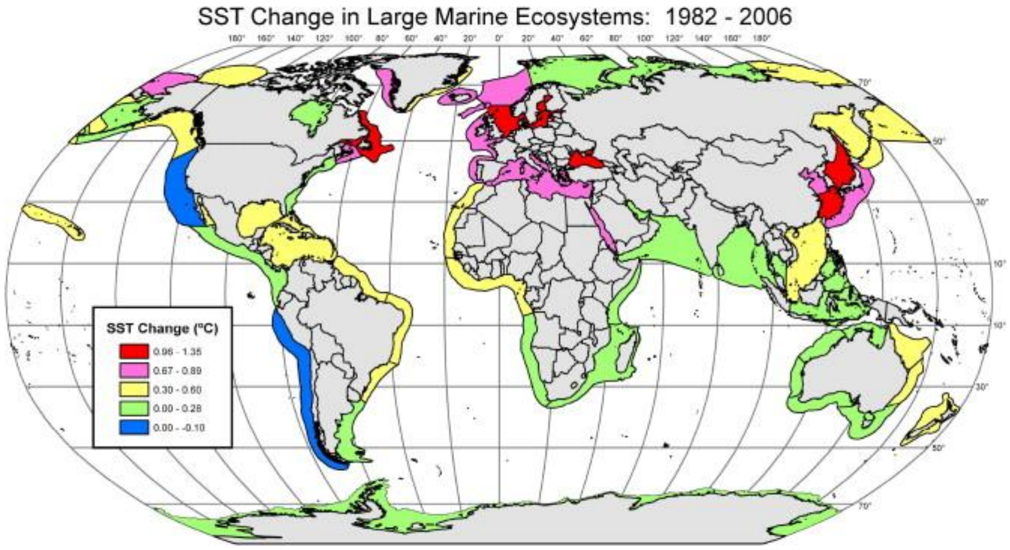


Figure 1.12. Net SST change (°C) in Large Marine Ecostsems, 1982-2006. Rapid warming (red and pink) is observed around the North Atlantic Subarctic Gyre, in the European Seas (including the Black Sea),and in the East Asian Seas. The Indian Ocean seas and Australian-Indonesian seas warmed at slow rates. The California and Humboldt Current systems cooled (5).

Marine ecosytems are controlled by two mechanism called as top-down and bottom-up. Bottom-up control decribed as the change in the biomass of a functional group if it is triggered by the production (or resource availablity); on the other hand if the change occurs as a result of a competition and predation by the higher trophic levels, it is reffered as top-down control of the system. The wind induced bottom-up flux controls the nutrient supply of the Black Sea (27), (32). Production in the photosynthetically active euphotic zone is controlled by SST which is a physical parameter that directly affects the stratification of water column and nutrient pump from nutrient rich deep sea to photosynthetically active euphotic zone. Evident increase in SST has important effects on fish production due to the bottom-up control processes in the lower trophic level ecosystem of the Black Sea.

Black Sea has passed through different stages of eutrophication. The 1970-1983 periods which coincided with the lover nutrient levels and primary production and called as Pre-Eutrophication phase (PR). Black Sea observed eutrophication in 1984-1995 periods (called as EP) due to the excess load of anthropogenic nutrients resulted in 6 time higher phytoplankton biomass. After 1995, phytoplankton biomass has decreased and was still 3 times higher than the PR and this period represented as post-eutrophication (PE) (35) (36). These stages and regime shifts in the Black Sea are well illustrated in Figure 1.13.

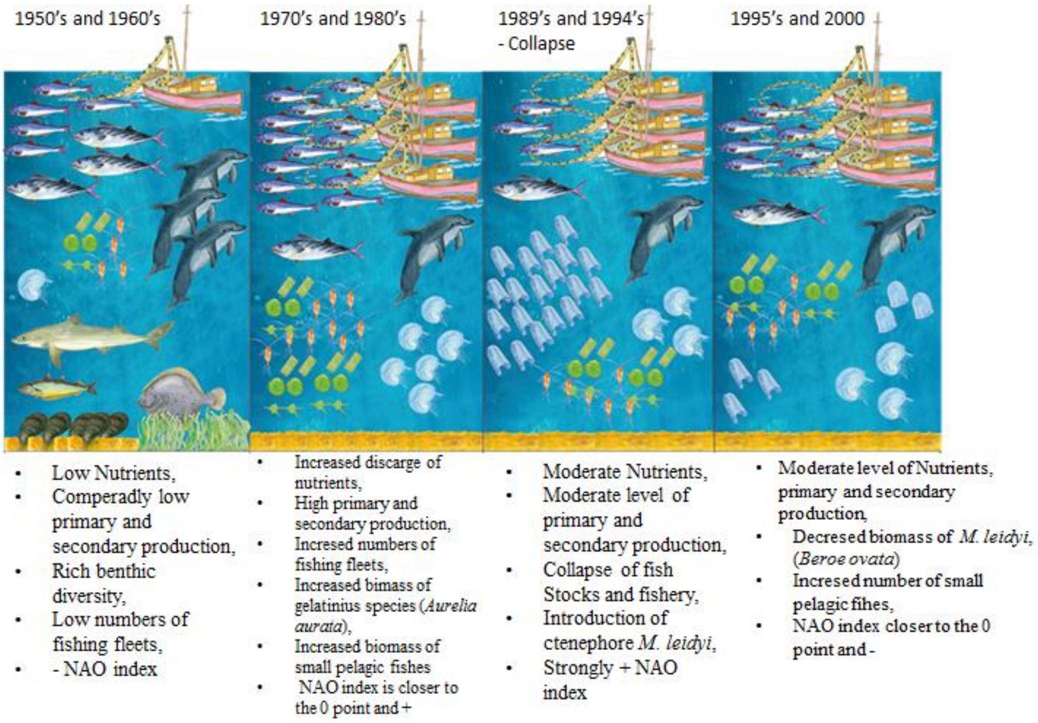


Figure 1.13 Summary of the regime shifts occurred in the Black Sea region between 1950’s and 2000, (Akoglu, 2013-PhD Thesis).

1.4.3. Climate Change and the Black Sea Fishery

Potential threats of global climate change are identified (summarized above) however the future predictions on the fishery production are uncertain because it depends on the Net Primary Production and on what proportion is transferred trough the food web (7). There are increasing numbers of publications (most of them are given) concluding the decline in the primary production due to global warming especially in the low latitudes (5), (18), (16), (21). While the northward migration of fish species will result in decreased fishery production in mid- and low latitudes, fish catches in Arctic are expected to increase (7). Results of the study published by Blanchard et al. in 2012 shows 28-89 % increase in the production of pelagic species in some areas of high latitude shelf seas; while 30 to 60 % decrease projected across the tropical shelf and upwelling seas in the fish production.

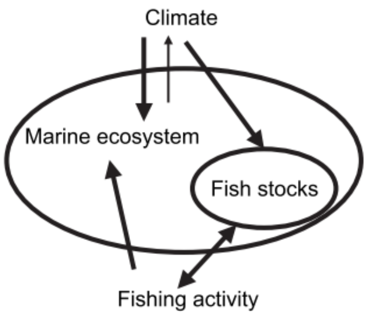


Figure 1.14 Impacts of fishing activity and climate change on marine ecosystems (Brander, 2007)

Since, fishing pressure makes the marine ecosystems more sensitive to the climate change; these two human induced pressures should take into account together for better management strategies and sustainable fishery (Figure 1.14). Also it is important to consider the ages and the geographic distribution of a fish species especially under the stress of warming climate rather than just concentrate on protecting their biomass (7).

Since the early 1970s, Black Sea ecosystem was dominanted in large predator fish populations, zooplanktons and low biomass of small pelagic fishes and phytoplankton. First regime shift observed in the early 1970s and the abundance of small pelagics and phytoplankton biomass increased while large predator fishes decreased (36). In the early 1980s due to the discharge of ballast water of cargo ships, ctenophore *Mnemiopsis leidyi* (A. Agassiz, 1865., Family: Bolinopsidae / Order: Lobata / Class: Tentaculata / Phylum: Ctenophora) invaded the Black Sea ecosystem and this period coincided with the decreased abundance of pelagic fishes and collapse of fishery. Food chain and energy transfer was disturbed by *M. leidyi* by competing with the anchovy for food and feeding on anchovy eggs and larvae. Introduction of *Beroe ovata* in 1997, a predator of *M. leidyi*, helped the ecosystem to recover till the beginning of 2000 (42).

The populations of the top predators such as dolphins (most common one is bottlenose dolphin, *Tursiops truncates*), bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*) decreased in the Black Sea in the early 1970 (43). Due to the invasion of *M. leidyi* (native habitat, Atlantic coastal waters of North and South America) the dominancy of anchovy (*Engraulis encrasicolus*) fishery was evident of the Black Sea fisheries (44).

Black Sea has low species diversity and high habitat diversity which provides favorable conditions for alien species to introduce. Introduction of fish from Mediterranean which was defined as ‘Mediterranization of the Black Sea’ increased the diversity of the Black Sea fish fauna. However, considerable decrease in the number of native fish species was observed due to the anthropogenic pressure (45).

There are very few studies on impacts of climate change and potential consequences on the capture fisheries in the Black Sea. Present study, briefly, aims to investigate the potential effects of climate change on the fisheries production and the economic consequences.

1.5. Impacts on Fishery Economy

Capture fisheries and aquaculture supplied the World with about 148 million tons (almost 90 million tons of capture fisheries) of fish in 2010. Total economic value corresponds to US$ 217.5 billion, and about 128 million tons was utilized as food for people (46). While the capture fisheries and aquaculture production increased smoothly till 1980s, the capture fishery has lost the acceleration in 1990s & 2000s, and culture based fishery developed with in the same period (Figure 1.15).

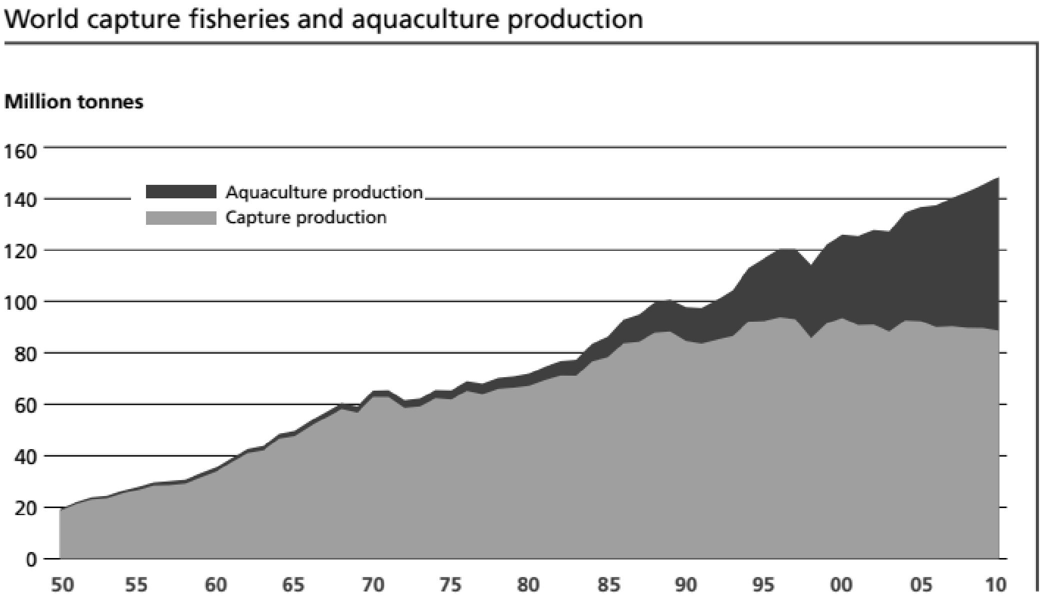


Figure 1.15 World Capture Fisheries and Aquaculture Production between 1950 and 2010. Source: Food and Agriculture Organization (FAO), The State of World Fisheries and Aquaculture, 2012.

Research on impacts of warming temperatures generally investigates the biological consequences. However, the other dimention- harvesters- of the problem is given little importance (47). Vulnerability of 132 national economies to the climate change on capture fishery was investigated using indicator based approach (Figure 1.16). Three components of vulnerability taken into account for the nations: Exposure, Sensitivity and Adaptive Capacity. Turkey is classified as Highly Vulnerable under the IPCC scenarios B1 (48).

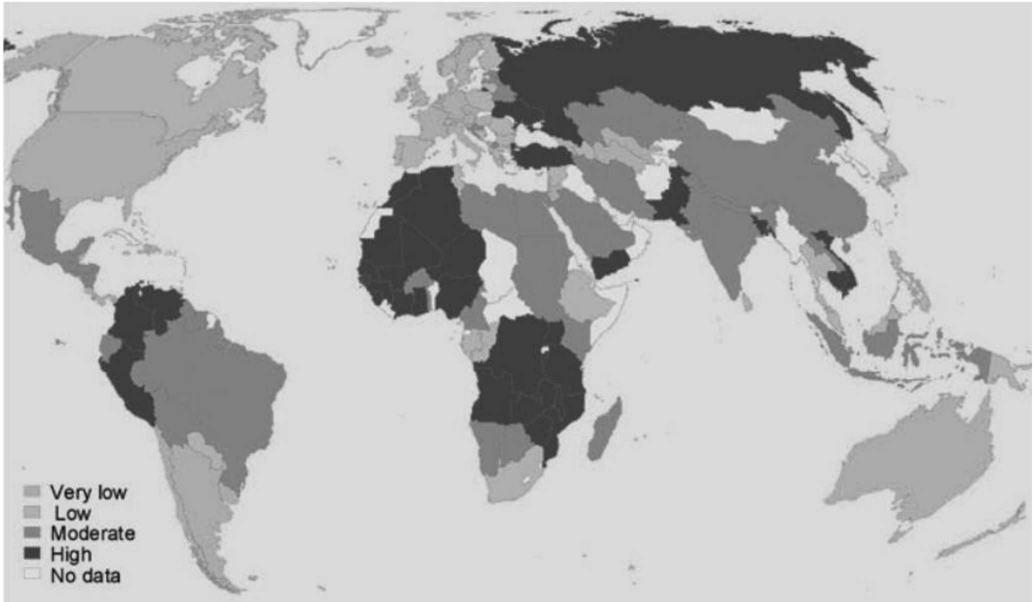


Figure 1.16 Vulnerability of national economies of projected climate change scenario B2 (IPCC) on fisheries. Dark colour represent quartiles with for highest vulnerability index value.

Fisheries management to date only accounts for maximizing the profits and ignores the ecosystem components and interactions (49), besides conservation measurements generally focuses on the management of the fish net size. There has been increasing interest on Ecosystem Based Fisheries Managements (EBFM). EBFM was discussed as effective shorthand for more integrated approaches to resource allocation and management (50). The goal of the EBFM is, stated by The Ecosystem Principles Advisory Panel, to maintain health and sustainability of the ecosystem. Turkish anchovy fishery is controlled by the mesh size of the fish nets, closed seasons and restriction of the fishing vessels number to ascertain the sustainability of biomass for the future fish catch (51). However, more holistic and adaptive management strategies should be taken especially when considering the degradation of ecosystem (eutrophication and invasion of *M.leidyi*) experienced in the past and its consequences on the fishery economy and the projected climate change scenarios and their possible effects. Response of the fishermen to the possible changes is another dimension of the problem should be accounted (47).

Total numbers of fishery employees were 46,361 in Turkey, in which the number of workers in Black Sea region correspounds to the 43.5 % of total number of workers in 2010 (52). Fishing activities intence in the eastern Black Sea and the fish population dominated by anchovy which is harvested by purse seine technique. Number of purse seine vessels increased from 98 in 1984 to 168 in 2010 (number of Trawler-Purseseiner vessel is 241).

Investigating the socio-economic impacts of climate change together with the response of biological system in the Black Sea has crutial importance to better menagement and adaptation strategies.

1.6. Purpose and Objectives of the Present Study

Turkish fish catch is the largest portion of the Black Sea fish catch in the region. Fishing activity is intense in this region and it is reported to be highly vulnerable to climate change (48), and classified as rapid warming sea between the period 1995-2001 by Belkin, 2009 and Oguz et al. 2006. Therefore, Black Sea was selected as study region. Climate change is a global problem; however national adaptation strategies are needed especially for the vulnerable nations such as Turkey. Biological responses and the consequences of changes in the Sea Surface Temperatures are examined to propose national adaptation strategies. In this study, changes in the SST data between 1970 and 2010 were examined to investigate the effect of increased GHGs in the Black Sea region. Black Sea was reported as rapid warming sea, Regression analysis among total fish catch, SST, and number of vessels harvesting in the Black Sea Turkish coasts data were held to understand relationship between SST and its potential effect on economically important fish stocks in the Black Sea. State of the fishery sector in Turkey considered and the consequences of climate change in the Black Sea were discussed.

CHAPTER 2

MATERIAL AND METHODOLOGY

Long term (45 years) data are available through *in situ* measurements of lower trophic level ecosystem parameters (Chlorophyll, 1986-2003; METU-Institute of Marine Sciences) and from the literature (Phytoplankton Biomass, 1969-2008). Whereas the data on meteorological parameters (Sea Surface Temperature, 1970-2011) and fish captures (1967-2010) are collected from Turkish State Meteorological Service and Turkish Statistical Institute respectively. Regression analysis was performed to investigate the relationship between the above parameters and to propose sustainable management strategies, economic and policy tools for Turkish fishery sector.

2.1. Material- Data Profile

2.1.1. North Atlantic Oscillation (NOA) Index and Sea Surface Temperature (SST) Data for Open Black Sea

The winter (December through March) station-based index of the NAO is recorded and analyzed on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1864 (53). Winter NAO index is free of charge and available at: http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based. Positive values of NAO indices are related with stronger-than-average westerlies over the middle latitudes, associated with colder SST values and the opposite for the negative NAO index.

Winter SST data (has inaccuracy and smoothed by three-point moving averages) for the interior part of the Black Sea, with depths greater than 1500m, between 1877 and 2001 were extracted from Oguz et al. 2006. Data was constructed by using the monthly mean data compiled by Hadley Centre, UK Met Office (http:// badc.nerc.ac.uk/data/hadisst) and the Advanced Very High Resolution Radiation (AVHRR) satellite observations.

2.1.2. Sea Surface Temperature (SST) Data for Coastal Black Sea

SST data for the coastal zone of the Black Sea between 1970 and 2011 was obtained from Turkish State Meteorological Service. Daily SST (C°) data is available for the western and eastern part of the Black Sea. For the western part, two meteorological stations were selected

(Inebolu and Sinop provinces) to evaluate the variations in the SST winter data. Giresun, Ordu, and Samsun meteorological stations' data used for the construction of winter SST time series for the eastern Black Sea. The other stations' data (Zonguldak, Trabzon, Rize) were excluded in the present study due to discontinuous data set. Daily averages were used for the given stations for the construction of the corresponding SST time series.

2.1.3. *In-situ* Chlorophyll-a and Phytoplankton Biomass Data

Chlorophyll-a (Chl-a) is one of the important indicator of the lover trophic level biomass. *In-situ* measurements are available for the western Black Sea coastal areas between 1986 and 2003, collected during the cruises of IMS-METU (IMS publications, Technical Reports, AyÇen Yılmaz personal communication).

Another important indicator of lover trophic level is the Phytoplankton Biomass. Depth integrated phytoplankton biomass measurements available from 1969 to 2008 for the depths more than 100m, was extracted from the Mikaelyan et al., 2013.

2.1.4. Fishery Data

Fishery data were provided by the Turkish Statistical Institute which covers data on sea products, freshwater and aquaculture products. This data is available as printed material for the years between 1967 and 2010 and required data for this study transferred to the electronic environment as meta data files.

Data on sea products are compiled by the Turkish Statistical Institute and surveys are generally conducted annually in January-February period. All registered professional fishermen are covered and fishermen were surveyed by two methods: full census for large scale fishermen and sampling for small scale fishermen.

For the years between 1967 and 1969, complete enumeration method used (individual interviews with all fishermen at their addresses) and the sampling surveys were performed for the years 1970 and 1971. The method of complete enumeration was used again from 1972 through 1980. Large scale fishermen are covered by complete enumeration and small scale fishermen have been covered by sampling methods since 1980. Data on fishery statistics in Turkey were compiled by the Ministry of Commerce until 1967 based on records of provincial fish markets through correspondences with provinces (Fisheries Statistics Reports, Turkish Statistical Institute, 1967- 2010).

Selected parameters related with the sea products are as follows: the total fish catch (western and eastern part of the Black Sea), the total amount of anchovy catch, total fishing vessel numbers.

Stations where the sea products data are collected in the Black Sea are listed below:
Eastern Black Sea Region: Artvin, Rize, Trabzon, Giresun, Ordu, Samsun and Sinop.
Western Black Sea Region: Kastamonu, Zonguldak, Düzce, Sakarya, Kocaeli (Kandıra), Istanbul, (Beykoz, Sarıyer, Çatalca, ġile), Kırklareli and Bartın.

Table 2.1. Data Profile Summary for the Black Sea

Data	Region	Time Period	Source
Sea Surface Temperature (Winter)	Open Open Coastal	1877-2001 2002-2012 1970-2011	Oguz *et al.*(2006) and the references cited there. Predicted SST from NAO index Turkish State Meteorological Service
NAO Winter Index	-------	1864-2012	http://climatedataguide.ucar.edu
Chl-a (*in-situ*)	Coastal	1986-2003	IMS-METU Data (AyÇen Yılmaz personal communication, Publications, Technical Reports)
Phytoplankton Biomass	Open	1969-2008	Mikaelyan et al.,2013
Fisheries Statistics	Coastal	1967-2010	Turkish Statistical Institute

2.2. Methodology

2.2.1. Missing SST Data

SST data is missing in the open Black Sea for the period of 2002-2012 since the original data could not be obtained from the data sources [e.g. Hadley Centre, UK Met Office (http:// badc.nerc.ac.uk/data/hadisst) and the Advanced Very High Resolution Radiation (AVHRR) satellite observations]. Therefore regression analysis was performed between averaged (winter eastern and western Black Sea) winter coastal SST data (1970-2011) and winter SST belong to the open Black Sea data available till 2001 to predict the data using the STATA program.

Also, regression analysis performed between open Black Sea winter SST data and winter NAO index. Although the fit of predicted data was good, we have obtained better results by using eastern and western coastal Black Sea surface temperatures as the explanatory variables. We have taken the east and west coastal temperature average as the explanatory variable in a regression of open sea surface temperature on this averaged variable. This way, we have predicted the final nine years of open sea surface temperature. This, in turn, will be one of the explanatory variables in our final regression of fish catch on several variables that are described later.

2.2.2. Mann-Kendall Trend Test and Trend Analysis

Sea Surface Temperature (SST) time series derived from Turkish State Meteorological Service for the period between 1970 and 2010. Daily SST data was available for the western Black Sea region Inebolu and Sinop; for the eastern region Giresun, Ordu, and Samsun meteorological stations. Average SST was used in the analysis in order to overcome the problem of missing data for some stations and time intervals. In December 2004, there is no available data for all the stations so replaced by the average of the previous and next months' average using the statistical analysis program itself. December to March SST data was analyzed for the winter SST trend detection. For instance, data between 1970 December and 1971 March was dated as 1971 Winter SST. Nonparametric Mann-Kendall trend test was employed to test the trend in the SST data. Winter SST data and annual data were investigated for western and eastern Black Sea regions by XLSTAT. Seasonal Mann-Kendall Test is used to take into account the seasonality of series. So the trend in the one month of January to another and so on was analyzed.

Trend analysis conducted for the SST data, which was extracted from Oguz et al. 2006 and regression analysis performed to predict the last decade's values, between 1877 and 2010 to investigate if there is a warming trend. Results are given in Chapter 3.

2.2.3. Detecting Effects of SST on In-situ Chlorphyll-a and Fish Catch

Stratification of water column which limits the bottom-up flux of nutrients (required for production of energy in the euphotic zone) triggered by the sea surface temperature so, winter SST was used in the present study. Production of energy and efficiency of energy transfer is highly important for fish production. Winter SST and the corresponding year's total fish catch data and the number of fishing fleets in the same year was used.

Before conducting analysis to investigate the effects of SST on fish catch, relationship between SST and chlorophyll concentrations was shown. Regression analysis performed by XLSTAT to investigate the effects of SST on Chlorophyll-a concentrations in the Black Sea western coast.

After discussing the relationship between SST and Chlorophyll-a, regression analysis performed by STATA to show the effect of SST on the total fish catch. Total fishing fleet number, SST data (open Black Sea) completed in the study and total fish catch in the Black Sea region was used.

Another regression analysis was also conducted to show the degree of the explanatory degree of fishing vessel number on fish catch.

CHAPTER 3

RESULTS & DISCUSSION

3.1. Long Term Sea Surface Temperature (SST) Change in the Black Sea

Two data sets (details are given in Chapter 2) of SST were statistically analyzed and interpreted in the present study. First data set which belongs to the winter period for the interior part of the Black Sea, with depths greater than 1500m, between 1877 and 2001 was extracted from Oguz et. al. 2006. SST data for the period between 2002 and 2010 is predicted by the regression analysis between coastal SST data and and SST data for open Black Sea before 2002. NAO index and SST variations were also discussed in order to complement the missing data for the 2002 and 2010 in section 3.1.1.

Trends in the second data set of SST (the eastern and western coastal zones of the Black Sea) were analyzed by Mann-Kendall trend tests and the results are discussed in Section 3.1.3.

Impact of the SST on total fish catch was investigated by regression analysis in the sections 3.3 and 3.4.

3.1.1. Open Black Sea SST Changes

Water Temperature is the most important physical parameter reflecting the climate signal on ecological changes (40). Regression analysis conducted between open Black Sea Winter SST data and the average of the east-west coastal SST data. Regression results (Appendix B) were highly significant with the R-square = 0.99 and p- value 0.002 which is lower than the 0.05. To improve the quality of regression analysis intercept adjustment technique was applied**. d1914, d1982** represents the adjusted intercept periods between 1914-1981 and 1982-2012.

Results were shown for the period between 1970 and 2012 in Figure 3.1 and scatter plots of open SST data versus fitted values from regression on coastal east-west SST averages were shown in Figure 3.2.

Black Sea was classified as Rapid Warming Sea by Belkin, 2009. It was stated that the most rapid warming in the period of 1992–2001 at a rate of 2 °C/decade. This was consistent both with the open Black Sea SST values and coastal SST values (Figure 3.3 and Figure 3.7) examined in the present study. However, ups and downs were shown in the coastal SST measurements after 2001. Decrease in the warming rate of 2 °C/decade 1992 and 2001 was evidently observed after 2001.

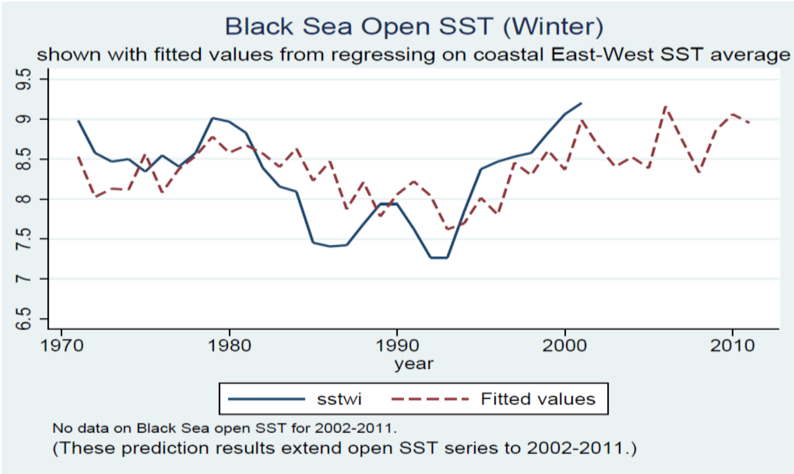


Figure 3.1 Open Black Sea SST data between 1970 and 2001 with the fitted values from regression results on coastal east-west SST averages. **sstwi** represents SST winter data of the interior Black Sea. **Fitted values** represent regression results on coastal east-west SST averages.

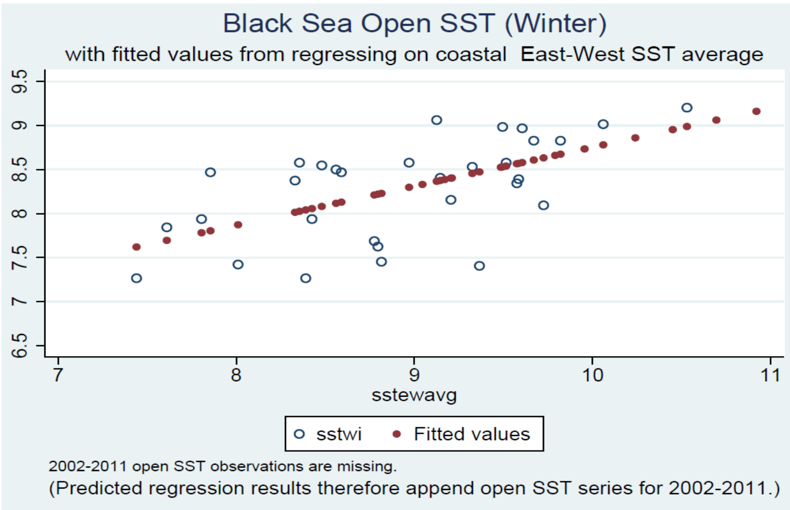


Figure 3.2 Scatter plots of open SST data versus fitted values from regression on coastal east-west SST averages (1970-2010).

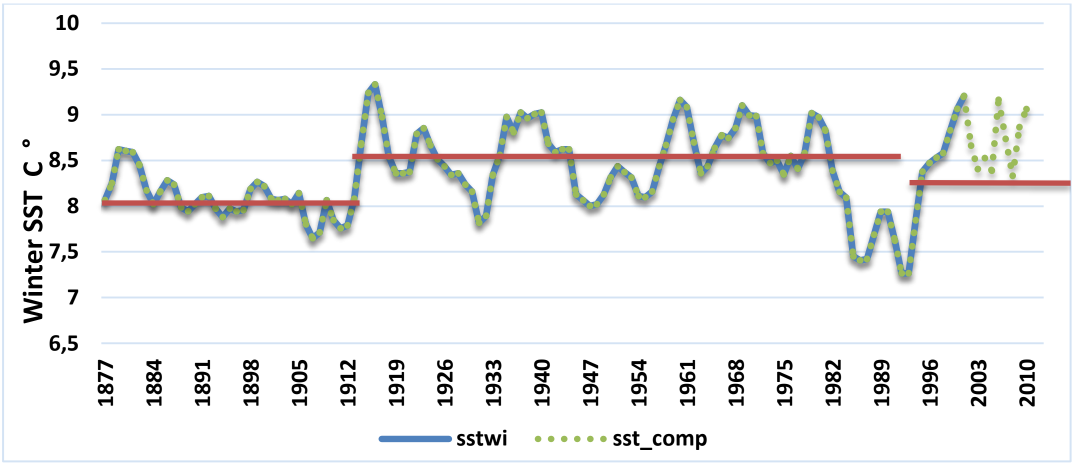


Figure 3.3 Completed interior winter SST data for the period 1877- 2010. **sstwi**; SST winter data of the interior Black Sea between 1877 and 2001 (blue line). Completed winter SST data after 2001 is represented with **sst_comp** (green points). Red bars represent mean values of the periods 1877-1913, 1914-1981 and 1982-2012.

As seen in the Figure 3.3, there was warmer period between 1914 and 1981 (mean=8.57) than last 15 years (mean=8.28). However, standard deviation in the last 15 years was high than other two periods.

After 1913, warmer period in the SST was observed compared with the periods of 1877-1913 and 1982-2012. Lowest SST temperature was observed in 1992 winter over the last 135 years. Spring phytoplankton biomass in the same year was the highest among the measured phytoplankton biomass between 1969 and 2008 (Figure 3.9). However, the highest fish catch was not observed in the corresponding year due to the invasion of the predator ctenophore *M. leidyi*.

The North Atlantic Ossilation (NAO) is the dominant mode of atmospheric circulation variability over the North Atlantic Region and Europe. In the present study, variations of the NAO index was discussed especially after 2001, since previous period was discussed by Oguz et al. 2006.

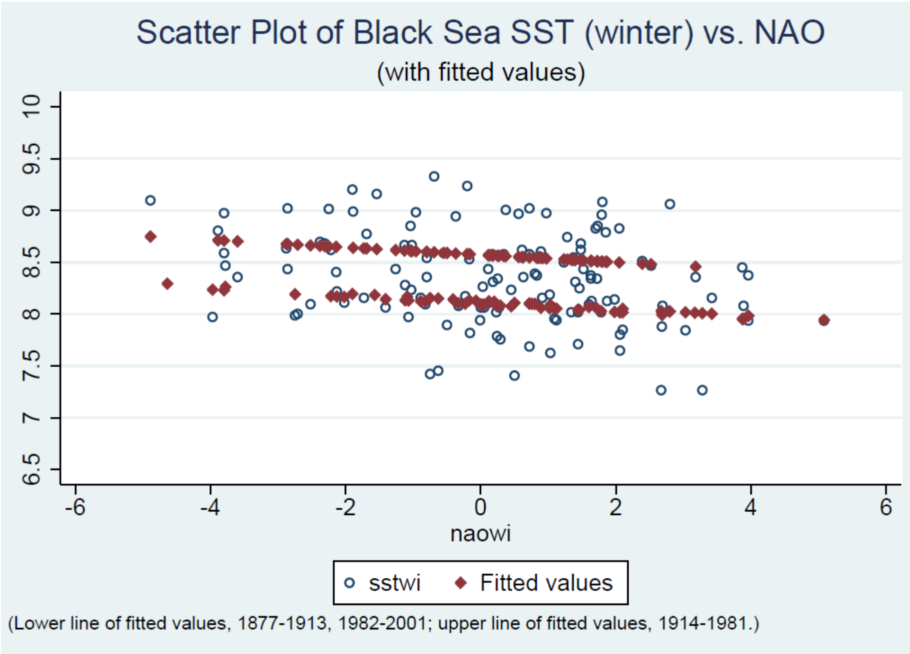


Figure 3.4 Scatter Plots of the Black Sea winter SST vs. NAO Index.

NAO winter index was downloaded from [http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based are analyzed and presented](http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based). For predicting SST for the years between 2002 and 2012**,** regression analysis was performed between winter SST and winter NAO index. While the significance level is 0.99, P- value (p- value 0.04) is slightly lower than the 0.05. Results are shown in Appendix B.

To improve the quality of regression analysis intercept adjustment technique was applied**.** **d1877, d1914, d1982** represents the adjusted intercept periods 1877-1913; 1914-1981 and 1982-2012 (Figure 3.4). Results of predicted SST values from regression between open SST on coastal SST and regression between open SST and NAO index were almost the same (Figure 3.3 and Figure 3.5). However, this predicted SST values were not used for the investigation of the effects of SST on fishery but the predicted results given in the 3.1.1 since it is completed by the real SST data and the p- value of the average of the east-west coastal SST data is lower than the p-value calculated from the regression between winter SST and NAO index. Distribution of NAO index is skewed to the left as shown in the Figure 3.5.

Effect of GHGs on the NAO index is still a debate. Upward trend in the NAO index was simulated in a number of global warming scenarios which was run by different general circulation models (54), (55). This upward trend corresponds to the stronger than the average westerlies (positive NAO index), represented as cold SST. However, Gillet et al., 2003, concluded that climate models underestimated the magnitude of sea-level pressure response and impact of antropogenic climate change on the climate of Europe (56).

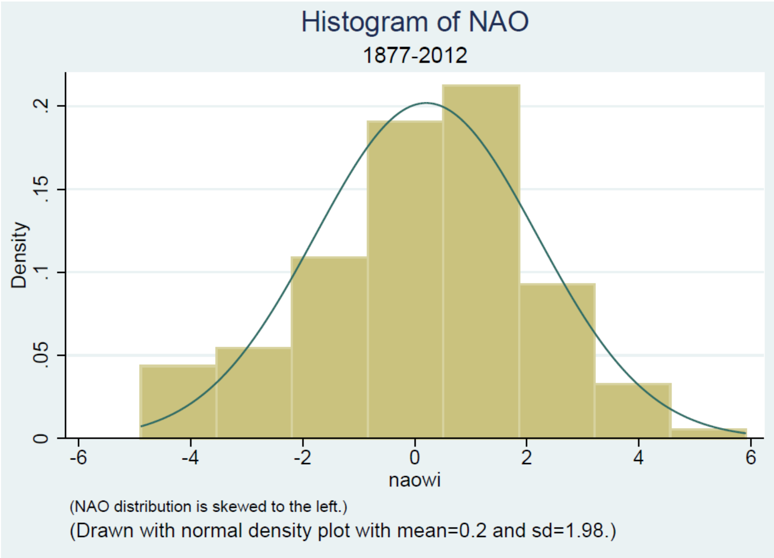


Figure 3.5 Histogram of NAO index.

Winter SST variations were well discussed by Oguz et.al, 2006 and 0.25 C ° warming trend was stated for about 100 years. Period denoted as phase 4 (1980-1995) includes the eutrophication period (1984- 1995) of the Black Sea when the highest positive winter NAO index is observed (e.g 5.08 in 1989) over the last 135 years while the very cold winters (e.g. 1992, 1993) were experienced within the same period.

Period after 1995 was stated as a new warming period by Oguz et.al, 2006 consistent with Belkin, 2009. Increasing trend seen in Figure 3.6 is in consistency with the negative NAO index which is recorded as -3.96 in 1996. However, the second highest negative value of NAO index is observed in 2010 over the last 135 years and the positive values observed in 2000, 2007 and 2012. It is not evident to conclude there is an increasing trend in the negative NAO index after the period 1995 as it is concluded by Oguz et al, 2006.

3.1.2. SST Changes in the Coastal Black Sea

Second data set regarding the Sea Surface Temperature belongs to the coastal part of the Black Sea. Details of the data set, provided from the Turkish State Meteorological Service were given in the Chapter 2. Mann- Kendall trend test performed by XLSTAT for eastern and western part of the Black Sea coasts for the period between 1970 and 2011 and the variations are given in the Figure 3.5. Trend test conducted for winter SST data and annual SST.

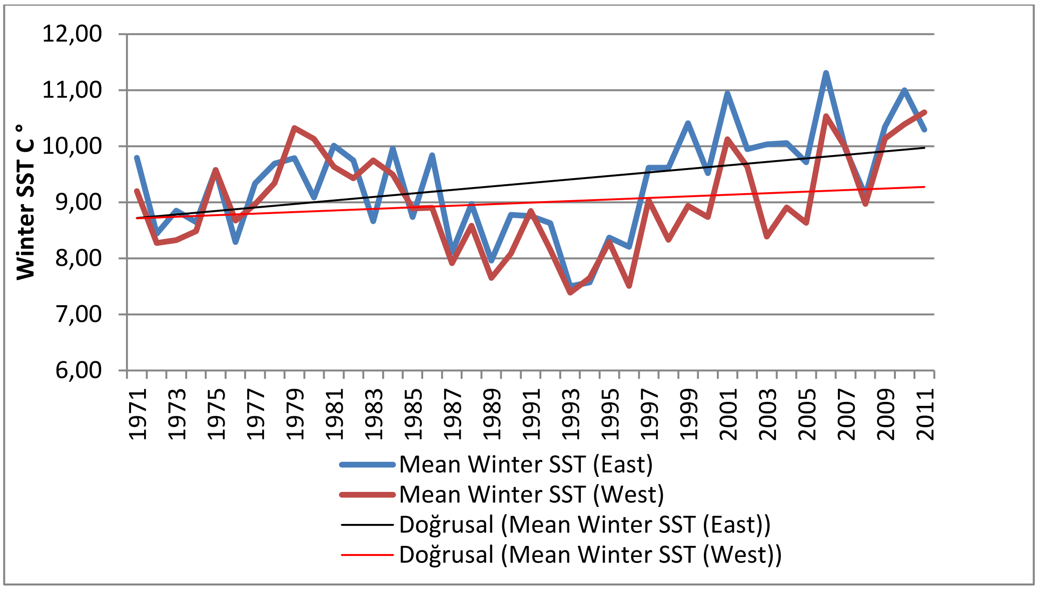


Figure 3.6 SST variations in the coastal Black Sea between 1970 and 2011 and corresponding trend lines.

SST variations in the coastal Black Sea region for the period between 1970 and 2011 (Figure 3.6) were under the strong influence of NAO index as open waters of the Black Sea. Cooling period, stated as phase 4, defined by Oguz et. al. 2006, between 1980 and 1995 and the warming trend after the 1995 were observed in the SST data set for western and eastern coastal areas of the Black Sea.

Mann-Kendall Trend Test

<u>Winter SST:</u>

Daily SST data was available for the eastern region stations namely Giresun, Ordu and Samsun. Monthly mean winter (December through March) SST data set is constructed for all the stations using daily measurements. Data between 1970 December and 1971 March was dated as 1971 Winter SST. Also, monthly mean winter SST data set is constructed by the same method for the stations of western region (Inebolu and Sinop).

Mann-Kendall Trend test is used and analyzed by XLSTAT for this data set.

For the eastern part of the Black Sea, as the computed p-value (0,010) is lower than the significance level alpha=0.05, null hypothesis (there is no trend in the series) is rejected. And the risk to reject the null hypothesis while it is true is lower than 1, 04%.

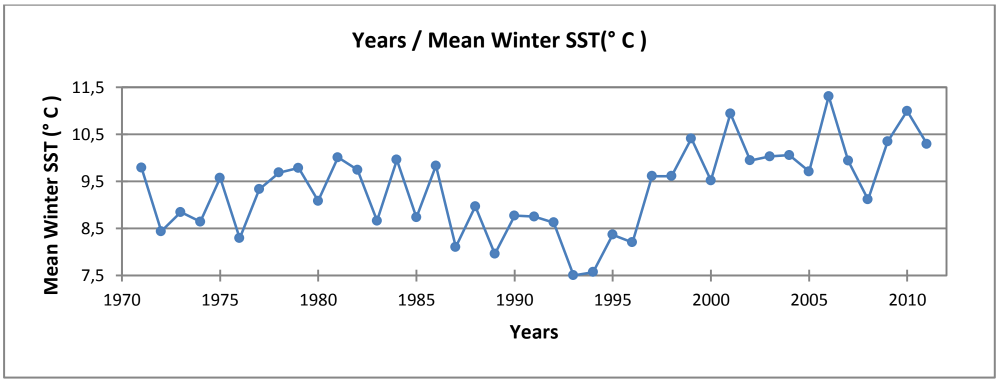


Figure 3.7 Mean Winter (Dec-Mar) Sea Surface Temperature (SST) in the coastal areas of the eastern Black Sea.

While it is confident to say that there was the trend in the eastern winter SST, trend tests results for the western SST accepted the null hypothesis (there is no trend in the series). As the computed p-value (0,231) is higher than the significance level alpha=0.05, null hypothesis accepted and the risk to reject the null hypothesis while it is true is lower than 23, 12.

Eastern Black Sea hydrology is more stable than the western part of the Black Sea. This could be the reason why there is no significant trend in the winter SST of western Black Sea.

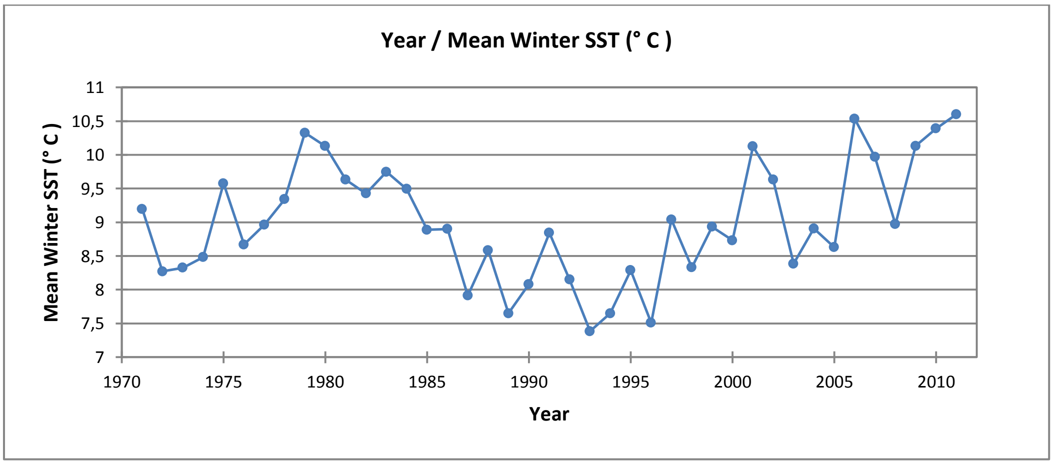


Figure 3.8 Mean Winter (Dec-Mar) Sea Surface Temperature (SST) in the coastal areas of the western Black Sea.

Annual SST Data:

Montly avareges of the SST data is used for both estern and western part of the Black sea Seasonal Mann-Kendall Test is used for both region to take into account the seasonality of series. For the eastern and western part of the Black Sea seasonal Mann-Kendall test showed significant trend in both series. As the computed p-value (0.003) for the eastern Black Sea is lower than the significance level alpha=0,05, null hypothesis H_0 is rejected, and alternative hypothesis, H_a is accepted. Positive trend in the data set is detected. Computed p-value (< 0,0001) for the western Black Sea is lower than the significance level alpha=0,05, null hypothesis H_0 is rejected, and alternative hypothesis, H_a (there is a trend in the data) is accepted.

3.2. Long Term Changes in the Ecosystem

Long term changes in the Black Sea ecosystem was well defined by Oguz and Gilbert, 2005. In the 1970s, drastic changes in the Black Sea ecosystem started with the removal of large predator fishes. This was followed by the eutrophication period (1980-1995), which was triggered by the nutrient upload in the north-western coast and the western shelf of the Black Sea and the positive NAO index which brought the cold climatic conditions enhancing the vertical dynamical processes for the bottom-up nutrient pumping. The sharp decrease in the fish catch experienced in the late 1980s was due to the invasion of a ctenophore, *M. leidyi* which reached very high biomass level (> 1 kg/m^2) in 1989. This caused devastation in the regular food chain of the entire Black Sea and a sharp decline in the total catch (especially the anchovy catch) observed in 1990s. The introduction of *B. ovata* in 1997, a predator of *M. leidyi*, helped the ecosystem to recover till the beginning of 2000 (42).

Phytoplankton biomass (g/m^2) data (1969-2008), extracted from Mikaelyan et al., 2013 was used to investigate the long term changes in the ecosystem and how it is affected by the increasing trend of the sea surface temperature. Figure 3.19 shows the decreased phytoplankton biomass after 1999.

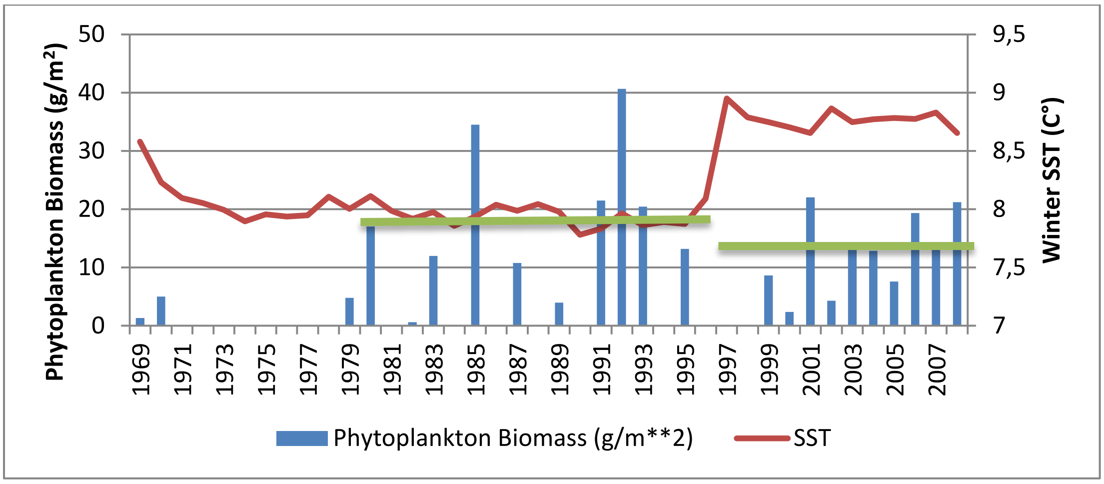


Figure 3.9 Total phytoplankton biomass in the open waters during May-October extracted from Mikaelyan et al., 2013. Winter SST data extracted from Oguz et al., 2006 with additional data (2002-2008) predicted in the present study. Horizontal green lines show the average phytoplankton biomass for the corresponding periods; first horizontal line shows eutrophication period while the second line shows post eutrophication period.

Eutrophication period between 1980 and 1995 was more intense and coincided with the positive NAO index (See Figure 3.4) which brought the cold and severe winters to the Black Sea region and reflects deep winter convections and low SST (40), (35). Black Sea ecosystem stabilized after the eutrophication period due to the controlled discharge of nutrients (42) and decrease in the phytoplankton biomass was identified.

Chl- a data from the western coasts of the Black Sea collected by the IMS-METU cruises showed a strong correlation with the sea surface temperature data provided by the Turkish State Meteorological Service (Figure 3.10). Regression analysis was performed between the in situ chlorophyll-a data and sea surface temperature data. Average monthly SST data set is derived from the daily SST measurements which corresponded to the related months of Chl-a measurements. Result did not show strong relationship between two parameters (Appendix B, the regression between SST and Chl-a), since 36% significance level was calculated. The regression between SST and Chl-a was found negatively correlated as expected.

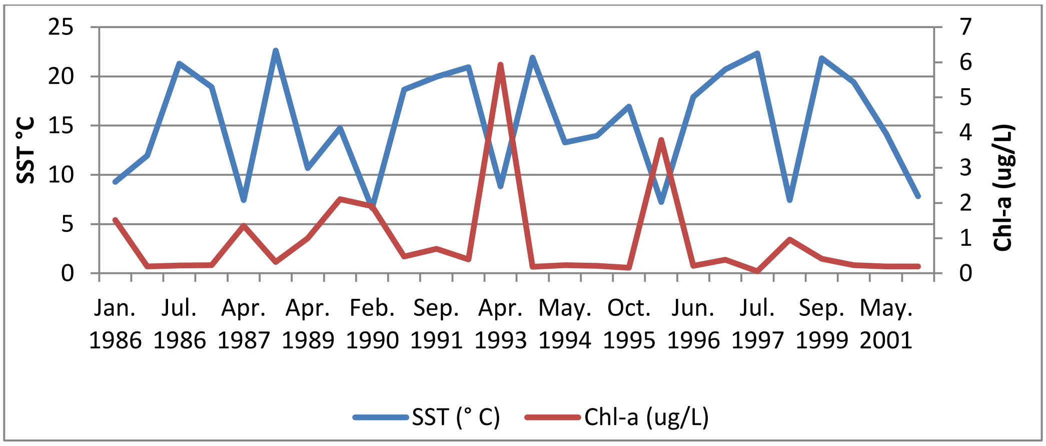


Figure 3.10 Western Black Sea Chlorophyll-a in situ concentrations (ug/L) (IMS-METU cruises data) and corresponding Sea Surface Temperatures available from Turkish State Meteorological Service.

Similar study conducted to investigate the relationship between Chlorophyll and Sea Surface Temperature of the Black Sea, using the SeaWiFS and Advance Very High Resolution Radiometer Satellite imagery. 60% of the correlation was concluded at the significant level $p<0.05$ between 1999 and 2008 of whole basin (57).

In the analysis conducted in the present study (Appendix C-3) was significance level was not high when compared with the regression results done by Kavak and Karadogan, 2011, This difference was possibly due to the coastal processes (nutrient availability, mixing) effecting chl-a concentrations examined in the present study.

3.3. Black Sea Fishery

After the removal of the pelagic top predators such as dolphins, bluefish and bonito by the 1970 (43), small pelagic fishes reported to be the target for the industrial fishery in the Black Sea (44). Present data showed that after 1977, fishing activities gradually increased till 1988 and 61 % of the total fish catch (480,400 tons) was anchovy (Figure 3.12) in the Turkish fishing industry. Collapse of the fish stocks in the Black Sea region due to the invasion of *M. leidyi* also affected the Turkish fishing sector and experienced the 38% decrease in the total fish catch (Figure 3.11). Also the decreased nutrient level compared with the eutrophication period, possibly has impact on this decrease.

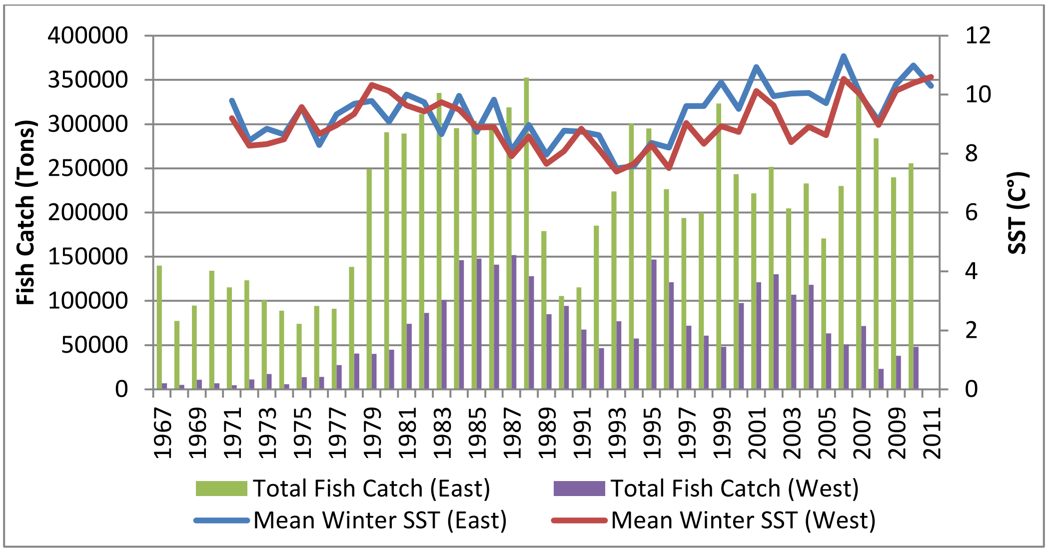


Figure 3.11 Total fish catch data provided from Turkish Statistical Institute for Eastern and Western Black Sea region, and winter SST data for eastern and western Black Sea region provided from Turkish State Meteorological Service.

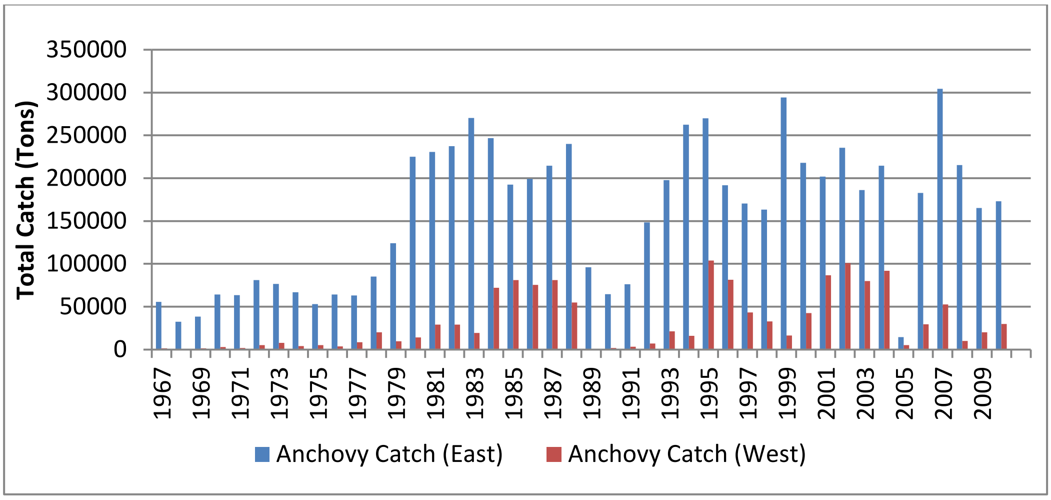


Figure 3.12 Total Anchovy Catch by regions of the Black Sea. Data provided from the Turkish Statistical Institute, 1967-2010.

Between the period of 1967-2010, anchovy dominated the Black Sea fish catch, almost 69 % of the total fish catch was occupied by anchovy (Turkish Statistical Institute Reports, 1967-2010).

In the present study, effect of SST on Black Sea fishery was investigated (Section 3.4). History of the vessel numbers and the incentives given to the fishery sector is quite important since it is one of the important factor effecting fish catch amounts.

After the 1980, operation of the fish meal/fish oil factories and incentives given to the fishery sector caused increase in the number fishing fleets and the total fish catch. After the drastic consequences of invasive *M.leidyi* between 1988-1995 (Figure 3.15), minimum anchovy catch length set to the 9 cm and the entrance of new fishing fleets were restricted as a management strategy in 1991. However, in 1994, 1997 and 2001 new certifications were given (51). The most important increase in the vessel numbers were observed after 2001 (gradual increases the number of certified vessels seen in the Figure 3.13).

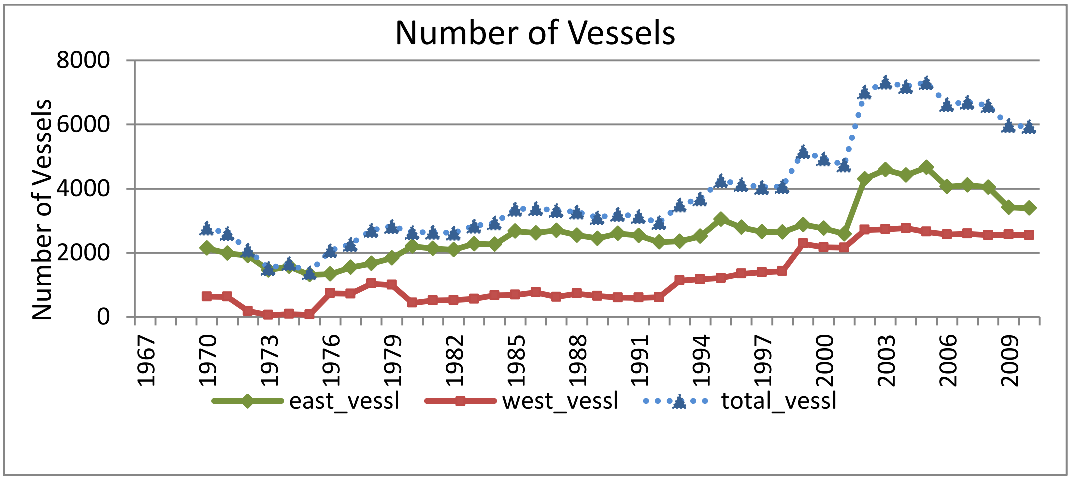


Figure 3.13 Number of certified fishing vessels in the Black Sea Region. Blue line and red line denotes logged vessel numbers in the east and west part of the Black Sea, respectively where the total number of fishing vessel given with the green line.

Changes in the each tonnages categories given in the Figure 3.14. Entrance of new vessels especially the increase in the lowest tonnage category seen in the years corresponds with the years 1994, 1997 and 2001 when the new certifications were given. Since, the vessel given the permission to log to the certification system, fisherman can improve the capacity of the vessel without any additional permission, causes the increase in the number of the lowest tonnage category. Even the number of fishing vessels stays constant, the fishing pressure will be continue to increase because the improvement of the tonnage category is not under the restriction. After 2004, categorization of tonnage groups in the reports of Turkish Statistical Institute was changed. Number of vessel in tonnage category corresponds to the 500-999 kg (in the Figure 3.14 it is given as t05) as not included in the reports. The reason may be either the portion was too small to represent or there is no vessel in this tonnage category. Either way, increases in the fishing effort and related pressure on the recovery of the harvested fish populations was evident.

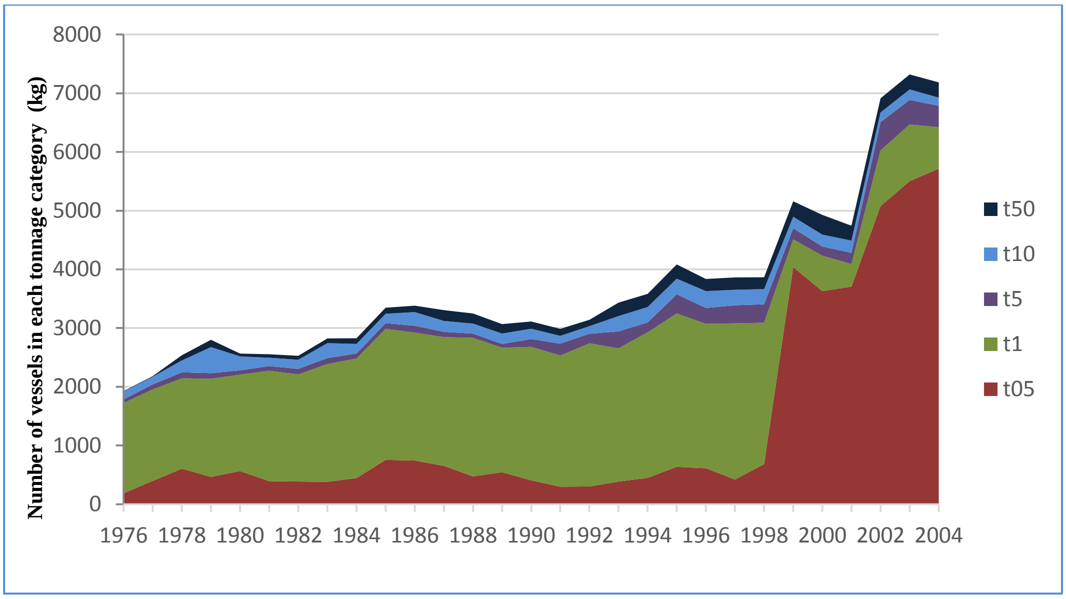


Figure 3.14 Number of vessels in each tonnage category (1976-2004). t05, 500-999 kg (red fill); t1, 1000-4999 kg (green fill); t5, 5000-9999 kg (purple fill); t10, 10000-49999 kg (blue fill); t50, 50000 + kg (black fill).

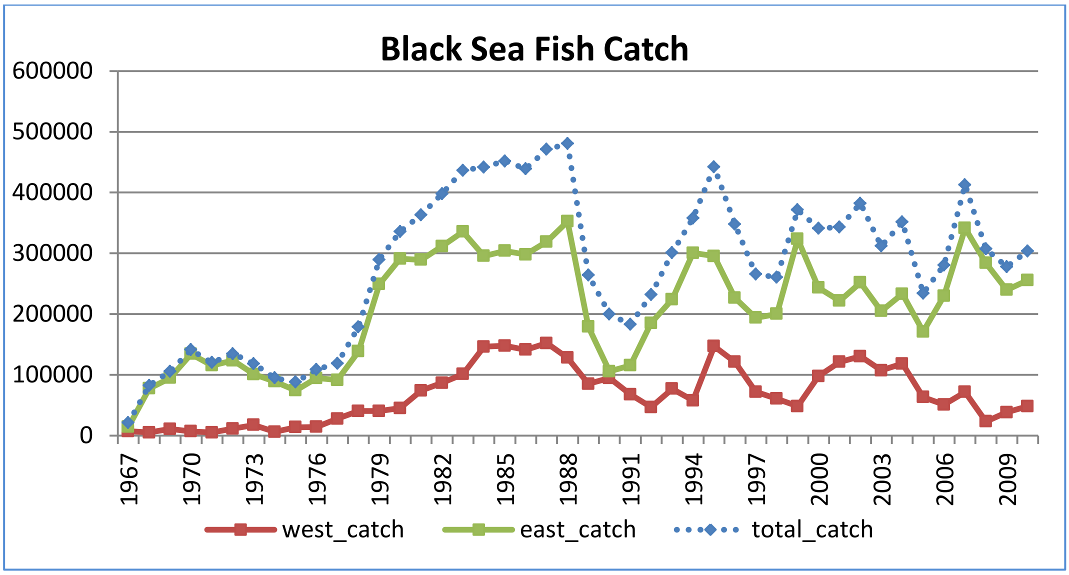


Figure 3.15 Black Sea Total Fish Catches.

After the eutrophication period (1980-1995) and especially after the invasive ctenophore was controlled naturally by *B. ovata* (42), there was no gradual increases in the total catch as seen in the number of fishing vessels. There were ups and downs in the total fish catch, while increase in the vessel number was observed. Relationship between these two variables was not strong (Appendix B, regression results between total fish catch and total vessel numbers) when compared with the regression analysis performed (SST and the impact of *M.leidyi* considered) and discussed in the section 3.4.

3.4. Effect of SST on Fish Catch

Total fish catch and associated profits are influenced by the cumulative impacts of many parameters like eutrophication, invasion of the competitive non- native ctenophore, and increase in the number of fishing vessels (fishing pressure). Conceptual framework of the interactions in the Black Sea ecosystem was given in the Figure 3.16. In the present study effects of climate change investigated via changes in the SST and its impacts on the ecosystem parameters like primary production and fish stocks. It is important to stress that, effects of changes in the SST on the total fish catch was investigated using the data of fishing vessel numbers, data of predicted SST (2002-2010) in the present study while considering the periods of 1989-1993 (invasion of *M. leidyi*) and artificial increase of fishing vessel numbers which was not related with the increased profits from increased fish catch.

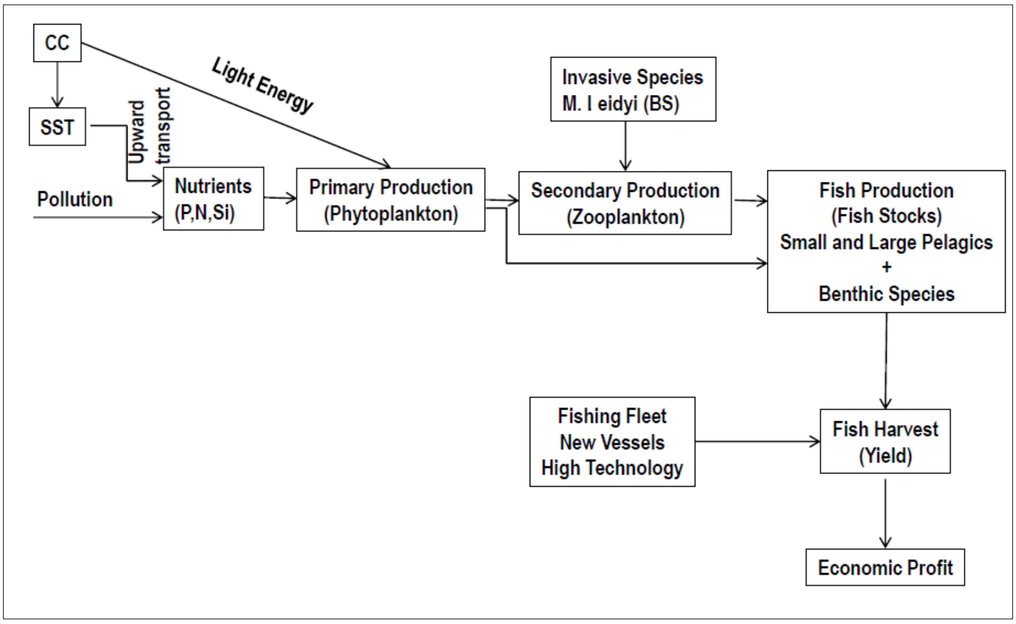


Figure 3.16 Conceptual framework of the effects of climate change on fish catches. CC, represents the **C**limate **C**hanges effects; Pollution (e.g. excessive nutrient loads) increased in the Black Sea between 1980 and 1995; catastrophic effect invasive species M. leidyi was seen between 1989 and 1993.

Effect of total fleet numbers on total fish catch was also investigated (Appendix C, regression results between total fish catch and total vessel numbers). 13% of the correlation was concluded at the significant level $p<0.05$ between 1970 and 2010.

To investigate how significant the effect of SST on the total fish catch between 1970 and 2010 above influences considered and the regression analysis was performed. Total fishing fleet number, SST (open Black Sea) completed in the study (completed 2002 and 2010) was used. Two dummy variables were used in this study. The impact of invasive *M.leidyi* which was seen in the period of 1989-1993 adjusted by intercepts adjustment method (represented in the results Table 3.1 as ***dmn***). Also, the most significant increase in the vessel numbers due to the additional certification given after 2001 was adjusted by the same technique between 2002 and 2010 (represented as ***d2002*** in Table 3.1) which is known the increase in the vessel number was not the result of the increase in the total fish catch and the profits.

Dummy variables used;

- ***dmn***; Between 1989 and 1993, M. leidyi effect,
- ***d2002***; Between 2002 and 2010, artificial increase in the fleet numbers and the control of the nutrients levels compared to the eutrophication period.

Table 3.1 Results of the regression analysis conducted to investigate the effect of SST changes on total fish catch. *tot_catch*, represents the total catch; Dummy variables; *dmn*, M.leidyi effect; *totalfl*, total vessel number and *sst_comp* denotes SST data completed in this study.

```
      Source |       SS       df       MS              Number of obs =      41
-------------+------------------------------           F(  4,    36) =   10.02
       Model |  2.8391e+11     4  7.0978e+10           Prob > F      =  0.0000
    Residual |  2.5492e+11    36  7.0812e+09           R-squared     =  0.5269
-------------+------------------------------           Adj R-squared =  0.4743
       Total |  5.3884e+11    40  1.3471e+10           Root MSE      =   84150

------------------------------------------------------------------------------
   tot_catch |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         dmn |    -156254   47848.55    -3.27   0.002    -253295.3   -59212.62
       d2002 |  -220237.7   65636.11    -3.36   0.002    -353353.9   -87121.49
     totalfl |   74.87864   15.60101     4.80   0.000     43.23832     106.519
    sst_comp |  -112505.7   29837.41    -3.77   0.001    -173018.8   -51992.67
       _cons |    1010153   256446.7     3.94   0.000       490055     1530251
------------------------------------------------------------------------------
```

In the present study, statistical relationship between predictor variables (total vessel number, SST) and the response variable (Total Fish Catch) were analyzed controlling for M. leidyii and artificial increase in the fleet numbers. We are confident about prediction capacity of our model, with $F(4,36)$ is bigger than 4. The p-value (Table 3.1, P>|t| column) for each term tests, the null hypothesis that the coefficient is equal to zero, predictor variable do not have any effect on response variable was tested. A low p-value (< 0.05) indicates that you can reject the null hypothesis. In other words, a predictor that has a low p-value is likely to be a meaningful addition to the model because changes in the predictor's value are related to changes in the response variable.

Vulnerability of Turkish Black Sea fishery to the changes in the Sea Surface Temperature was investigated in the present study. After missing SST data (open Black Sea) completed by regression analysis (Table 3.2, first row), effect of SST on total fish catch between 1970 and 2010 was investigated. Relationship was not statistically strong; however when the missing ecosystem parameters considered impact of SST is high. All statistical analysis performed in the present study was summarized in Table 3.2.

Table 3.2 Summary of the regression analysis conducted in the present study. * Results used in the regression analysis to investigate impacts of SST on total fish catch (5th row).

Regression analysis	Predicted Variable	Response Variable	R-square	P-values of response variables
*Predicting Open Black Sea SST	Winter SST (open Black Sea)	Average of the east-west coastal SST data	0.9976	0.002
Predicting Open Black Sea SST	Winter SST (open Black Sea)	NAO Index	0.9982	0.040
SST & Chl-a	Chl-a	SST	0.3650	0.0017
Total Fish Catch & Total Vessel Number	Total Fish Catch	Total Vessel Number	0.1367	0.017
Total Fish Catch & Total Vessel Number & Winter SST	Total Fish Catch	Total Vessel Number Winter SST (last 9 years excluded)	0.3991	0.000 0.026
Total Fish Catch & Total Vessel Number & Winter SST& M.leidyi	Total Fish Catch	Total Vessel Number Winter SST (last 9 years excluded) M.leidyi (dummy variable)	0.6180	0.000 0.000 0.001
Total Fish Catch & Total Vessel Number & Winter SST& M.leidyi	Total Fish Catch	Total Vessel Number Winter SST (last 9 years included) M.leidyi (dummy variable)	0.3789	0.002 0.001 0.009
SST Impact on Total Fish Catch	Total Fish Catch	- Effect of *M.leidyi* (1989-1993) - Artificial Increase of Fishing Vessels (2002-2010) - Total Number of Fishing Vessels (1970-2010) - SST (1970-2010)	0.5269	0.002 0.002 0.000 0.001

All the predictor variables have significant effects on total fish catch in the Black Sea region. Controlling the *M. leidyi* between 1989 and 1993, and the increase in the vessel number after 2001 was significant as expected. Since the impact of SST chances investigated by using the total fish catch, fishing fleet number data was included to the regression analysis. While the impact of fishing vessel numbers on total fish catch is the most significant parameter, SST also has highly important effect on the total fish catch. Model shows, 1 ° C increase in the SST causes 112505 tones decrease in the total fish catch holding other parameters (vessel numbers) constant. If the fish stock data was available for economically important fishes in the Black Sea, impact of the variations of the SST would be more significant. Between 1970 and 2010 there was an increasing trend in the coastal SST of the Black Sea. Also, the most important GHG, CO_2 is still rising and evidently causes increase in the SST. This evident increase is faster than the adaptation capacity of fisherman. Cautions should be taken for safeguarding the fishery sector form the negative impacts of climate change.

To maximize profits of fishery sector under such circumstances could not be provided by letting more or stronger vessels' entrance to the sector. Health of the ecosystem and the potential effect of global warming should be wisely considered and holistic management strategies should be implemented. Countries sharing the fishing resources in the Black Sea should implement fishery management strategies together and the participation of all the countries, Bulgaria, Georgia, Romania, Russian Federation, Ukraine and Turkey, are needed. Economy of the fishery sectors in these countries depends on the health of the ecosystem and sustainable use of the resources.

In this study, only the changes (warming) in the sea surface temperatures due to the global warming on the total fish catches between 1970 and 2010 was considered. On the other hand regional predictions (for the Black Sea region) on the magnitudes of fluctuations in the NAO index, changes in the ocean chemistry (acidification), northward migration of species and potential impact of introduction of non- native species on the ecosystem and changes in the reproductive biology and spawning areas of species due to increase in the water temperatures and the harvesters decision problem against rapid changes in the ecosystem should considered together.

CHAPTER 4

CONCLUSION

Positive trend in the SST data for the coastal regions of the Black Sea was found and the relationship between western SST data and the coastal *in- situ* Chlorophyll-a was shown. Fluctuations in the North Atlantic Oscillation index after 2001 was discussed and the decrease in the rate of the warming of SST was concluded. Variations in the SST ware found to be the second important parameter affecting total fish catch after the number of the fishing vessels. However, warming of the SST is the one dimension of the increasing greenhouse gases. Other effects should also be considered.

To maintain health and sustainability of the ecosystem, Ecosystem Based Fishery Management strategies should be implemented. Regional ecosystem dynamics, projected changes in the temperatures under the IPCC scenarios, vulnerability of fishery sector to these changes and their adaptive capacity is important. Multidiscipline researches are emerged to cope with the sustainability problems.

When social, economic and the ecologic dynamics considered, the Black Sea is highly vulnerable to changes in the ecosystem. Integration of all the Black Sea countries to the implementation studies of ecosystem based management strategies and their willingness is urgent to develop more effective policy tools.

During the development and implementation of new policy tools, scientific research and knowledge is highly important.

Planetary boundaries which we have already exceeded should be taken into account while implementing the new management strategies. Besides, to avoid the misunderstandings of the concept Sustainable Development (used as a justification of economic growth), new definition should be accounted which was defined by David Griggs and colleagues, 2013, as the development that meets the needs of the present while safeguarding Earth’s life support system on which the welfare of the current and future generations depends.

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APPENDIX A

ABBREVIATIONS

AVHRR: Advanced Very High Resolution Radiation

Chl: Chlorophyll

CIL: Cold Intermediate Layer

EAWR: East Atlantic- West Russia

ECHAM5: 5th Generation Atmospheric General Circulation Model

EP: Eutrophication Phase

ESS: Earth System Science

GHGs: Green House Gases

IMS- METU: Institute of Marine Science- Middle East Technical University

IPCC: Intergovernmental Panel on Climate Change

METU: Middle East Technical University

NAO: North Atlantic Oscillation

PE: Pre-Eutrophication Phase

PS: Post-Eutrophication Phase

SOL: Sub-Oxic Layer

SRES: Special Report on Emissions Scenarios

SST: Sea Surface Temperature

TSMS: Turkish State Meteorological Service

APPENDIX B

RESULTS OF REGRESSION ANALYSES PERFORMED-1

1. Regression results between open Black Sea Winter SST data between and the average of the east-west coastal SST data.

Source	SS	df	MS
Model	2131.05708	3	710.35236
Residual	5.0478993	28	.180282118
Total	2136.10498	31	68.9066123

Number of obs	= 31
F(3, 28)	= 3940.23
Prob > F	= 0.0000
R-squared	= 0.9976
Adj R-squared	= 0.9974
Root MSE	= .4246

sstwi	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
d1914	5.247867	.9834985	5.34	0.000	3.233261	7.262472
d1982	4.821001	.9362353	5.15	0.000	2.903209	6.738792
sstewavg	.3704765	.1059925	3.50	0.002	.1533607	.5875922

Depended variable winter SST (sstwi) with the predictor variable average coastal SST. P-values are significantly smaller than the 0.05, showing the strong relationship.

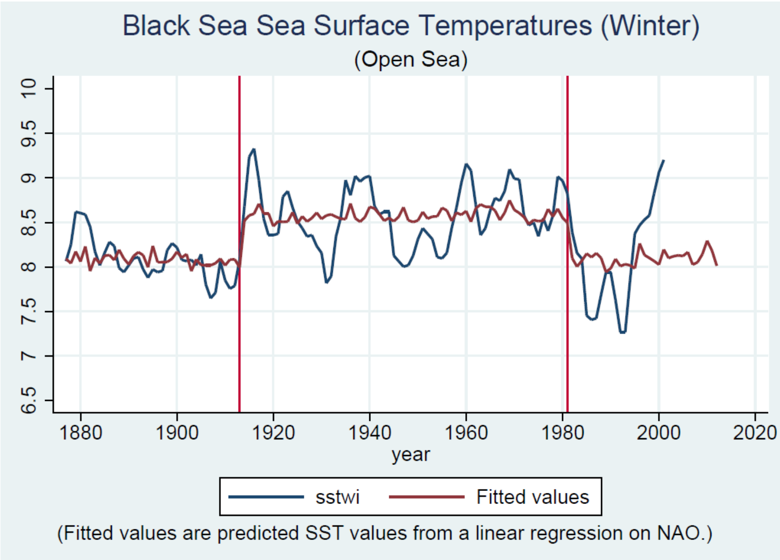
2. Regression results between winter SST and winter NAO index for coastal Black Sea waters

Source	SS	df	MS
Model	8727.13153	4	2181.78288
Residual	16.1475729	121	.133451016
Total	8743.27911	125	69.9462329

Number of obs	= 125
F(4, 121)	=16348.94
Prob > F	= 0.0000
R-squared	= 0.9982
Adj R-squared	= 0.9981
Root MSE	= .36531

sstwi	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
d1877	8.093013	.0602436	134.34	0.000	7.973744	8.212281
d1914	8.572563	.0444002	193.07	0.000	8.484661	8.660465
d1982	8.127183	.0852489	95.33	0.000	7.95841	8.295955
naowi	-.0361056	.0173959	-2.08	0.040	-.0705454	-.0016658

Depended variable winter SST (sstwi) with the predictor variable winter NAO index (naowi), and dummy variables representing start of the different periods. P-values are significantly smaller than the 0.05. However we have obtained better fit SST- SST east-west average.



Open Black Sea winter SST predicted from NAO index. *sstwi* denotes winter SST data from Oguz et al, 2006 and fitted values represented as red line shows the predicted SST values. Red bars separate the periods 1877-1913, 1914-1981 and 1982-2012.

3. The regression between SST and Chl-a

Regression Statistics	
Multiple R	0,604229
R Square	0,365093
Adjusted R Square	0,336234
Standard Error	1,112992
Observations	24

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15,67113	15,67113	12,65074	0,001766
Residual	22	27,25254	1,238752		
Total	23	42,92367			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	3,245695	0,679837	4,774224	9,11E-05	1,835799	4,655591	1,835799	4,655591
X Variable 1	-0,14591	0,041023	-3,55679	0,001766	-0,23099	-0,06083	-0,23099	-0,06083

Depended variable Chl-a with the predictor variable winter SST. SST and the Chl-a is negatively correlated. SST could explain only the 36% of the chances in the Chl-a depending on the R-square value. Discussion made in the section 3.2.

APPENDIX C

RESULTS OF REGRESSION ANALYSES PERFORMED-2

In this section, we provide a step by step analysis that culminated in the final regression model shown and discussed in section 3.4. We started with the most naïve assumption that fish catch is directly proportional to fishing fleet size. Here is the regression for the fishing fleet size.

Regression results between total fish catch and total vessel numbers (1970-2010);

```
      Source |       SS       df       MS              Number of obs =      41
-------------+------------------------------           F(  1,    39) =    6.18
       Model |  7.3668e+10     1  7.3668e+10           Prob > F      =  0.0173
    Residual |  4.6517e+11    39  1.1927e+10           R-squared     =  0.1367
-------------+------------------------------           Adj R-squared =  0.1146
       Total |  5.3884e+11    40  1.3471e+10           Root MSE      =  1.1e+05

------------------------------------------------------------------------------
   tot_catch |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     totalfl |   24.65077   9.918925     2.49   0.017     4.587846    44.71369
       _cons |   195689.8   42393.51     4.62   0.000     109940.8    281438.8
------------------------------------------------------------------------------
```

Depended variable total fish catch (tot_catch) with the predictor variable number of fishing vessels (totalfl).

In the second assumption, winter SST data (open Back Sea, 1970-2001) included to the model. Assuming, only fishing fleet number and SST could explain changes in the total fish catch. Regression result is given below. F- value increased from 6 to 11 and R-square from 0.13 to 0.43.

```
      Source |       SS       df       MS              Number of obs =      32
-------------+------------------------------           F(  2,    29) =   11.29
       Model |  2.2182e+11     2  1.1091e+11           Prob > F      =  0.0002
    Residual |  2.8477e+11    29  9.8198e+09           R-squared     =  0.4379
-------------+------------------------------           Adj R-squared =  0.3991
       Total |  5.0660e+11    31  1.6342e+10           Root MSE      =   99095

------------------------------------------------------------------------------
   totalprod |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     totalfl |   80.91379   19.12122     4.23   0.000      41.8065    120.0211
       sstwi |   -73162.1   31177.68    -2.35   0.026    -136927.6   -9396.593
       _cons |   640196.1   263721.2     2.43   0.022     100825.6     1179567
------------------------------------------------------------------------------
```

Our final assumption was given and discussed in the section 3.4.

APPENDIX D

RESULTS OF REGRESSION ANALYSES PERFORMED-3

Fluctiation (volatility) in the SST data for the last 9 years was analized. In the first analysis, completed SST values in the present study excluded (*sstwi* represents the winter SST data between 1970 and 2001). Effect of M. leidyi was controlled for the period 1989-1993 in the following two analysis.

Result is as follow;

Source	SS	df	MS
Model	3.1307e+11	3	1.0436e+11
Residual	1.9353e+11	28	6.9118e+09
Total	5.0660e+11	31	1.6342e+10

Number of obs	=	32
F(3, 28)	=	15.10
Prob > F	=	0.0000
R-squared	=	0.6180
Adj R-squared	=	0.5770
Root MSE	=	83137

totalprod	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
dmn	-174272.4	47964.92	-3.63	0.001	-272524.1	-76020.69
totalfl	84.36532	16.07017	5.25	0.000	51.44707	117.2836
sstwi	-133511.6	30985.18	-4.31	0.000	-196981.8	-70041.32
_cons	1157831	263154.5	4.40	0.000	618783.2	1696878

F-statistic and R-square decreased when the SST of the last 9 years included. The p-value (P>|t| column) for each term tests also decreased.

Regression results after including the last 9 years' SST data to the model;

Source	SS	df	MS
Model	2.0419e+11	3	6.8062e+10
Residual	3.3465e+11	37	9.0446e+09
Total	5.3884e+11	40	1.3471e+10

Number of obs	=	41
F(3, 37)	=	7.53
Prob > F	=	0.0005
R-squared	=	0.3789
Adj R-squared	=	0.3286
Root MSE	=	95103

totalprod	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
dmn	-148632.9	54015.71	-2.75	0.009	-258079.2	-39186.7
totalfl	29.73038	8.923813	3.33	0.002	11.64901	47.81174
sst_comp	-123165.3	33529.47	-3.67	0.001	-191102.4	-55228.12
_cons	1226939	280478.2	4.37	0.000	658636	1795242