DETERMINATION OF POTENTIAL FAVORABLE ZONES FOR PELAGIC FISH AGGREGATION (ANCHOVY) IN THE BLACK SEA USING RS AND GIS

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ABSTRACT

DETERMINATION OF POTENTIAL FAVORABLE ZONES FOR PELAGIC FISH AGGREGATION (ANCHOVY) IN THE BLACK SEA USING RS AND GIS

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Fishing is a significant source of food, and constitutes an important source of income in Turkey. Due to the large extent required to analyse the distribution of fish stocks, information derived from satellites play an important role in fisheries applications.

Chlorophyll concentration and sea surface temperature (SST) are the most significant parameters which define the fish habitat. The accuracy of these parameters in the Black Sea taken from two different satellites, namely Sea-viewing Wide Field-of-views Sensor (SeaWIFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) are evaluated. Results indicate that both satellites give good estimates of SST but the algorithms overestimate the chlorophyll concentration values. MODIS products are used in the subsequent analyses due to their high correlation with in-situ measurements relative to SeaWIFS products. The cause of the overestimation of chlorophyll concentration is further examined and a general description of environmental variability in Black Sea is done using MODIS products.

Anchovy, the most important commercial fish in Turkey, has been selected as the target specie of the study. Level 3 weekly average MODIS chlorophyll and SST products are processed using remote sensing (RS) and geographic information systems (GIS) integration to estimate potential favorable zones for pelagic fish aggregations.

Two different decision rules are employed to generate fish stock maps, simple additive weigthing (SAW) and fuzzy additive weigthing (FSAW). The resultant maps are used to visualize the general distribution of Anchovy in Turkish Seas from May 2000 to May 2001. The resultant thematic fish stock maps generated by FSAW analysis represents the uncertainity in the environment better than the ones generated by SAW analysis.

Keywords: MODIS, SeaWIFS, Black Sea, Anchovy, Fuzzy Logic

ÖZ

KARADENİZ'DE BULUNAN PELAJİK BALIK KÜMELERİNİN (HAMSİ) TERCiH ETMESi MUHTEMEL POTANSiYEL ALANLARIN UA VE CBS KULLANILARAK BELiRLENMESi

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Balıkçılık vazgeçilmez bir besin kaynağı olmasının yanısıra aynı zamanda Türkiye için önemli bir geçim kaynağıdır. Balık stoklarının dağılımının analizi için gerekli olan geniş ölçek göz önüne alındığında; balıkçılık uygulamalarında uydu yolu ile elde edilecek olan verilerin önemi daha iyi anlaşılmaktadır.

Balıkların yaşam alanlarının belirlenmesinde; klorofil yoğunluğu ve deniz suyu yüzey sıcaklığı kullanılabilecek en belirgin değişkenlerdir. SeaWIFS ve MODIS uydularından elde edilen görüntüler ile bu değişkenlerin Karadeniz'deki doğruluğu değerlendirilmiştir. Her iki uydudan elde edilen veriler, deniz suyu yüzey sıcaklığı açısından değerlendirildiğinde gerçek değerler ile oldukça yakın sonuçlar çıktığı görülmüş fakat; uydulardan elde edilen verilerin değerlendirilmesinde kullanılan algoritmalar klorofil yoğunluğunu, gerçek değerden daha yüksek saptamıştır. Yerinde yapılan ölçümler ile uydulardan elde edilen veriler değerlendirildiğinde; MODIS uydusundan elde edilen verilerin, SeaWIFS uydusundan elde edilen verilere kıyasla yerinde yapılan ölçümler ile daha yüksek ilişki düzeyine sahip olduğu saptandığından takip eden analizlerde MODIS uydusundan elde edilen veriler kullanılmıştır.

Klorofil yoğunluğunun gerçek değerinden daha yüksek saptanmasının nedenleri anlatılmış ve Karadeniz'in çevresel değişiminin genel bir tanımı MODIS ürünleri kullanılarak yapılmıştır.

Türkiye için en önemli ticari balık ürününün Hamsi olması sebebiyle; bu çalışmada Hamsi hedef tür olarak seçilmiştir. MODIS uydusundan elde edilen Level 3 haftalık ortalama klorofil yoğunluğu ve deniz suyu yüzey sıcaklığı ürünleri, Pelajik balık kümelerinin tercih edeceği potansiyel alanların belirlenmesinde Uzaktan Algılama ve Coğrafi Bilgi Sistemleri entegrasyonu ile değerlendirilmiştir. Balık stoğu haritalarının üretilmesinde Basit Toplam Ağırlık (SAW) ve Bulanık Toplam Ağırlık (FSAW) olmak üzere iki farklı karar verme yöntemi kullanılmıştır. Sonuçta ortaya çıkarılan haritalarda, Mayıs 2000 ve Mayıs 2001 tarihleri arasında Karadeniz'de Hamsi'nin genel dağılımı görülmektedir.

Anahtar Kelimeler: MODIS, SeaWIFS, Karadeniz, Hamsi, Bulanık Mantık

to the memory of my grandfather

Ahmet Çiftçi

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It was my first year in university when I read a little article and decided to study marine applications. Since then 8 years past, I can not say it's an immediate success! But now I believe the one can achieve anything, you only need to want it by heart and go for it. I would like to express my thanks to all of you who were with me during those years.

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LIST OF ABBREVIATIONS

CDOM -	Colored dissolved organic matter
CZCS -	Coastal Zone Color Scanner
FSAW -	Fuzzy additive weigthing SST- Sea surface temperature
GAC -	Global Area Coverage
GIS -	Geographic Information System
IMS -	Institute of Marine Sciences
LAC -	Local Area Coverage
LIDAR -	Light Detection And Ranging
MCDA -	Multi Criteria Decision Analyses
MHI -	Marine Hydrophysical Institute
MODIS -	Moderate Resolution Imaging Spectroradiometer
MSPHINX -	MODIS Satellite Process Handling Images under Xwindow
OCS -	Orbital Sciences Corporation
RS -	Remote Sensing
RSDAS -	Remote Sensing Data Analysis Service
SAW -	Simple additive weigthing
SeaWIFS -	Sea-viewing Wide Field-of-views Sensor
SEADAS -	Seawifs Data Analysis System

CHAPTER 1

INTRODUCTION

1.1. Purpose and Objectives

Fishing is an important source of income in Turkey. The economic importance of fishing brings the necessity of reaching marine resources with lower costs. According to the State Institute of Statistics for year 2000, the total expenditure for fishing activities is over 45 trillion Turkish Liras (DIE, 2002).

There are different types of expenditures, including liquid fuel and motor oil, special wearing for fishing, toll, net and their repairing expenditures, food, water, electricity, telephone and license expenditures, transportation and rent expenditures and some other expenditures which are not quality of fixed capital. Liquid fuel and motor oil expenditure is over 27 trillion Turkish Liras which holds the 60 % of all the expenditures. To reduce the expenditure of fishing activity, it would be wiser to reduce the fuel and motor oil expenditure. This is only possible by predicting the potential locations of fish stocks to reduce the time spent for searching.

Satellite derived information plays an important role in fisheries applications. Remote sensing techniques can be used directly for detection of fish stocks like visual fish spotting from air crafts or these techniques can be used indirectly to predict the potential favorable zones for fish aggregations by measuring the parameters which affect the distribuiton of fishes (Butler et al., 1988).

The most frequently used parameter in studies that deal with relations between environment, fish behaviour and abundance is sea temperature. Temperature has an important influence over fish species at different stages of their life cycles and also sea surface temperature (SST) is the most succesfully measured parameter among the other satellite data measurements (Santos, 2000).

Phytoplankton biomass, which is the primary source of food within the sea is another important parameter (Santos, 2000). Pyhtoplankton are microscopic marine organisms which are responsible for most of the photosynthetic activity in the oceans (Url 1). Phytoplankton, contain the pigment chlorophyll for photosynthesis. This pigment reflects green and absorbs red and blue wavelengths of light. Different algorithms to detect chlorophyll concentration are developed based on the optical properties of phytoplankton. Although the algorithms may give erroneous results due to the different absorption coefficients of species and available light (Morel and Bricaud, 1981; Kirk, 1983), chlorophyll concentrations can be detected by satellites and they are used as an indicator of available nutrient for marine organisms.

The aim of the study is to define the potential favorable locations for pelagic fish stocks to decrease the fishing expenditures and consequently reach marine resources with lower costs by the help of remote sensing and GIS integration.

Due to their direct effect on fishes, chlorophyll concentration and SST parameters are utilized in the study. The accuracy of these parameters taken from two different satellites, Sea-viewing Wide Field-of-views Sensor (SeaWIFS) and Moderate Resolution Imaging Spectroradiometer (MODIS), are evaluated with respect to the in-situ data. Both satellites give good estimates of SST but the algorithms overestimate the chlorophyll concentration values in the Black Sea.

Ocean waters are divided into two classes according to their optical properties. In case 1 waters, the concentration of phytoplankton and its associated chlorophyll and covarying pigments define the optical properties. In this type of waters the concentration of phytoplankton is usually low.

On the contrary, case 2 waters, are affected by many other substances, which do not covary with chlorophyll. This type of waters may contain suspendend sediments, colored dissolved organic matter (CDOM), gelbstoff, detritus and bacteria (Url 1; Morel and Prieur, 1977 cited in Kendall et al., 1999).

Since the basin consist of case 2 type water, failure of the chlorophyll algorithms was an expected result (Sancak et al., (2005), Yunev et al, 2002, Darecki and Stramski, 2004, Patissier et al., 2004).

MODIS algorithms give relatively better results than SeaWIFS algorithms in the Black Sea. Thus MODIS products were processed to interpret the spatial and temporal variations of SST and chlorophyll concentration in different sub-regions of the area. General description of environmental variability in Black Sea and validity of satellite driven information in marine applications have been stated in various articles using Coastal Zone Color Scanner (Nezlin et al, 1999, Barale et al, 2002, Kopelevich et al, 2002,) and SeaWIFS (Cokacar et al, 2001, Yunev et al., 2002, Oguz et al., 2002,). However until now interpretation of Black Sea using MODIS imagery has not been stated in the literature.

This general description also leads the determination of the areas that are favorable for pelagic fish aggregations. The statistics show that the 77% of the total sea fish catch by the year 2000 is catched in Black Sea and 82 % of this is Anchovy. In other words, Anchovy holds the 63% of the total catch of sea fish in Turkey (DIE, 2002). Being the most important commercial fish, Anchovy has been selected as the target species in the study.

MODIS Level 3 (8 day composite) products are employed in the analyses. Two different methods are used in generation of the potential favorable zones for pelagic fish aggregations to visualize the general distribution of Anchovy in Turkish Seas from May 2000 to May 2001.

The limitations of the avaliable in-situ data and the absence of information about fish stocks and habitat preferences may yield some inconsistencies within the results.

However the overall accuracy of the SeaWIFS and MODIS algorithms and the methodology of estimating potential favorable zones for pelagic fish aggregations are explained in further chapters.

In Chapter 2 the literature review about the description of satellite oceanography and RS-GIS applications in fisheries are stated, the metholodogy of the thesis and the data used are explained in Chapter 3. The analyses are given in Chapter 4 which defines the interannual environmental variability and the potential favorable zones for pelagic fish stocks. Discussion, conclusion and recommendations are given in Chapter 5 and Chapter 6 respectively.

CHAPTER 2

LITERATURE REVIEW

2.1. Description of Satellite Oceanography

2.1.1. Description of Marine Satellites

The color of water surface is determined by the color of pure ocean water and the concentrations of different types of particles suspended in the upper water layer. There are three major water color sensors to be used in oceanographic applications (Url 2, 2005).

Coastal Zone Color Scanner (CZCS) on the Nimbus-7 satellite was developed by NASA. It was designed to measure ocean color in terms of chlorophyll concentrations and the distributions of particulate matter and dissolved substances. It was operational from October 1978 until June 1986 and collected data on 6 identical channels with 800 meter spatial resolution at nadir.

SeaWiFS on OrbView-2 satellite was launched on board an extended Pegasus launch vehicle on August 1, 1997. OrbView-2 spacecraft and SeaWiFS radiometer were developed by Orbimage Corporation in cooperation with NASA. It has 8 bands on different wavelengths with spatial resolution of 1.1 km resolution and still operational since 1997.

MODIS is an optical scanner aboard the Terra and Aqua satellites. Terra Satellite launched on December 18th, 1999 and Aqua satellite on May 4, 2002. It has 36 channels with spatial resolution ranging from 250 meters to 1 kilometer. MODIS has the ability to collect information on land, oceans, and atmosphere (Url 3). The spectral and spatial resolutions of MODIS and SeaWIFS are given in Table 2.1.

SeaWiFS data can be downloaded free of charge for research work, but since the SeaWiFS project is a partnership between NASA and a private company, Orbital Sciences Corporation (OCS), researchers should register the SeaWiFs project and obey specified restrictions. Once registered, they can obtain data older than 5 years with no restrictions. MODIS Ocean data (Url 4) and CZCS data are free and have no restrictions. Also further documentation on ocean color satellites and the softwares are available on the NASA - Goddard Earth Sciences Distributed Active Archive Center web page (Url 5, Url 6, Url 7).

2.1.2. Optical Properties of Black Sea

It's hard to analyze case 2 waters relative to case1 waters due to their eutrophic nature. However case 2 type waters are important in terms of their location, biologic activity and their effect on algorithms. According to Acker (Url 1), case2 waters are considerably more productive than case1 waters, which make these regions valuable in terms of their contribution to global carbon cycle. Being more productive, case 2 waters are more reflective, and the atmospheric correction algorithms that is dependent on the fact that "*most ocean water is optically dark at certain wavelengths becomes less reliable*" (Url 1). Furtermore the location of case2 waters, which covers usually the coastal areas, has a negative effect on the atmospheric correction algorithms, due to the terrestrial contribution, haze of pollution and dust.

Morel and Bricaud (1981) and Kirk (1983) suggested that, the absorption coefficient of phytoplankton, which the chlorophyll algorithms rely on, changes with species type, size and nutrient and available light in the environment. As a result the effect of case 2 waters on the algorithms is often misleading.

Table 2.1. Spectral and Spatial Differences Between Modis & Seawifs

MODIS			**SEAWIFS**		
Band	Wavelength Region (μm)	Resolution (m)	Band	Wavelength Region (nm)	Resolution (km)
1	0.620-0.670 (red)	250	1	402-422 (blue)	1.13
2	0.841-0.876 (NIR)	250	2	433-453 (blue)	1.13
3	0.459-0.479 (blue)	500	3	480-500 (cyan)	1.13
4	0.545-0.565 (green)	500	4	500-520 (green)	1.13
5	1.230-1.250 (NIR)	500	5	545-565 (green)	1.13
6	1.628-1.652 (SWIR)	500	6	660-680 (red)	1.13
7	2.105-2.155 (SWIR)	500	7	745-785 (near-IR)	1.13
8	0.405-0.420 (blue)	1000	8	845-885 (near-IR)	1.13
9	0.438-0.448 (blue)	1000			
10	0.483-0.493 (blue)	1000			
11	0.526-0.536 (green)	1000			
12	0.546-0.556 (green)	1000			
13	0.662-0.672 (red)	1000			
14	0.673-0.683 (red)	1000			
15	0.743-0.753 (NIR)	1000			
16	0.862-0.877 (NIR)	1000			
17	0.890-0.920 (NIR)	1000			
18	0.931-0.941 (NIR)	1000			
19	0.915-0.965 (NIR)	1000			
20	3.660-3.840 (TIR)	1000			
21	3.929-3.989 (TIR)	1000			
22	3.929-3.989 (TIR)	1000			
23	4.020-4.080 (TIR)	1000			
24	4.433-4.498 (TIR)	1000			
25	4.482-4.549 (TIR)	1000			
26	1.360-1.390 (NIR)	1000			
27	6.535-6.895 (TIR)	1000			
28	7.175-7.475 (TIR)	1000			
29	8.400-8.700 (TIR)	1000			
30	9.580-9.880 (TIR)	1000			
31	10.780-11.280 (TIR)	1000			
32	11.770-12.270 (TIR)	1000			
33	13.185-13.485 (TIR)	1000			
34	13.485-13.785 (TIR)	1000			
35	13.785-14.085 (TIR)	1000			
36	14.085-14.385 (TIR)	1000			

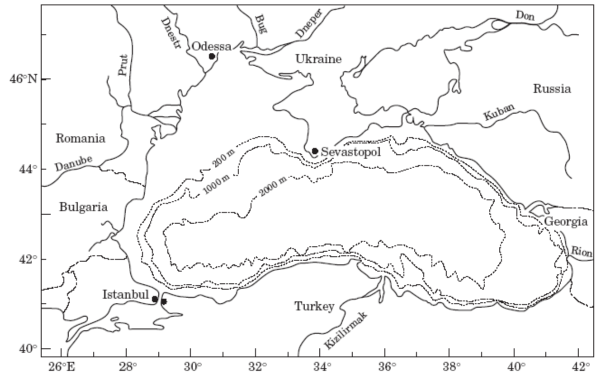
The seasonal variability of the nutrient and light in the marine environment cause changes in dominant species. Kendall et al. (Url 20) described that the remote sensing reflectance model, which is used to develop the chlorophyll algorithm is site and season specific. Since the properties of bio-optical constituents of water are not stationary, they cannot be fixed and implemented for the entire case1 and case2 waters.

2.1.3. Overview of Validity of Algorithms

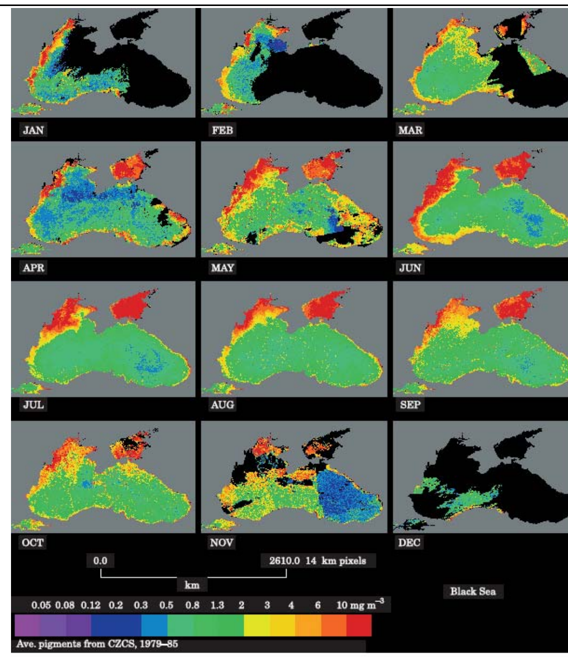
Barale et al. (2002), state that the CZCS, have been used to explore the historical surface water optical conditions. Due to the limitations of the sensor it is not possible to distinguish the suspended materials present in the water. Plumes interacting with the marine environment, due to the major rivers the Danube, Dnestr and Dnepr, and the Don flowing into the Sea of Azov, and the other minor inflows can be seen in Figure 2.1.

Sancak et al., (2005), reflected that Mediterrenean and Black Sea can be described as two extreme cases in terms of their bio-optical properties. Black Sea is dominated by case 2 type waters and the failure of algorithms is expected. However the algorithms also fail in detecting case 1 waters of Mediterranean, which can be due to their specific optical properties.

Yunev et al., (2002) found that there is no statistically significant relationship between Level 2 SeaWiFS imagery and in-situ chlorophyll-a within the open Black Sea during 1997 to 2002. Utilizing daily Level 2 GAC SeaWiFS imagery opticians from Marine Hydrophysical Institute (MHI), in Sevastopol, Ukraine have generated a proper algorithm (MHI algorithm) to define chlorophyll-a concentration in Black Sea. The generated algorithm has relatively better correlation with in-situ data than SeaWIFS algorithm.



a)



b)

Figure 2.1. a) Main rivers flowing into Black Sea (After Barale et al., 2002)
b) Multi-annual composites of water constituents concentration of the Black Sea generated from Coastal Zone Color Scanner (CZCS)

According to MODIS documentation there are three chlorophyll concentration parameters, each derived using a different technique. These are; Chlorophyll MODIS, Chlorophyll a SeaWIFS and Chlorophyll a semi-analytic. Each algorithm provides the concentration of both case1 and case 2 waters. Chlorophyll MODIS is derived using a 4 band algorithm. Chlorophyll a SeaWIFS (Chlor-a-2), is derived from MODIS leaving radiances using the SeaWIFS algorithm. And Chlorophyll a semi-analytic is derived from MODIS leaving radiances using multiple bands in an analytical model (Url 6).

According to the evaluation of MODIS and SeaWIFS algorithms in Baltic Seas, both of the algorithms overestimate the chlorophyll concentration. MODIS Chlor-a-2 parameter, which utilizes the SeaWIFS OC4 algorithm (Url 6) is found to give the best results among other MODIS parameters. It is also stated that SeaWIFS chlorophyll products have relatively higher accuracy than MODIS products. Yet they still exhibit a significant overestimation of chlorophyll concentration in the Baltic Sea. In order to create local algorithms, keeping the equations of the algorithms the same, they have determined new coefficients from field measurements. Darecki and Stramski (2004) reached the conclusion that, the standard pigment algorithms will have inadequate accuracy even if region-specific coefficients are utilized.

Patissier et. al., (2004) also state that SeaWiFS OC4v4 algorithm atmospherically corrected for turbid waters with the Remote Sensing Data Analysis Service (RSDAS) shows better results than MODIS algorithms in Northern European Seas. They suggested that instead of using more complicated chlorophyll algorithms, improving the atmospheric correction over optically complex waters results in more accurate chlorophyll concentrations.

2.2. RS and GIS Applicaitons in Fisheries

2.2.1. Direct and Indirect Prediction Methods in Fisheries

Butler et al. (1998) stated that remote sensing techniques can be used directly or indirectly in the prediction of fisheries resources. The direct methods comprise the visual fish spotting from aircrafts, interpretation of aerial photographs, echo-sounders, SONAR and Light Detection And Ranging (LIDAR) carried on aircraft. Besides the indirect methods lie on the correlation of environmental parameters with spatial and temporal distribution of fish aggregations.

Direct methods are limited by the range of aircraft and they are only reasonable when the economic return of the catch compensates the expenditures of the aerial survey (Butler et al., 1998). Thus the indirect methods are preferred. However indirect methods also have some problems which are mainly caused by the accuracy of the algorithms at different types of waters.

Valavanis et al., (2004) state that marine productivity hotspots are usually associated with low sea surface temperature distribution due to the surfacing of deep nutrient rich water masses and high chlorophyll concentration. They have created a GIS-based model utilizing time series of SST distribution and chlorophyll concentration gathered from satellite imagery. Combination of marine productivity hotspots and seasonal catch of sardine, anchovy and pelagic squids revealing areas in the Eastern Mediterranean are believed to indicate either as known overexploited fishing grounds or new alternative unexploited fishing activity areas. Success of indirect determination of fishes is dependent on previous knowledge of the habitat preferences and behavior of the fish at different temperatures, information about the oceanography of the area and catch rates occurring under specific conditions.

2.2.2. Usage of Satellite Data in Fisheries Management

Currents, circulation patterns, winds, sediment concentrations, water temperature, and nutrients are the main parameters that define the fish habitat (Url 8). Among these chlorophyll concentration and SST are the most significant indicators in the fish habitat characterization (Santos, 2000).

The satellite measurements can only penetrate few meters into sea surface. Thus the techniques used in defining the potential locations of fish stocks using satellite data are valid for pelagic species only, which live near surface waters. Each pelagic species has a certain tolerance of temperature and different annual migration pattern. The characteristic habitats and behaviors of species allow the indirect determination of potential favorable locations of these species using environmental parameters.

Furthermore to overcome the location and season specific effects of the environment, forming a time series of the data would definitely increase the accuracy of the remote sensing applications in fisheries management (Url 8).

Application of remote sensing to fisheries is widely utilized in various countries, for albacore tuna fishery in North Pacific, shrimp fishery in Gulf of Mexico, sword fishery in Portugal, and for monitoring the fishing zones in Japan, China, Taiwan, India and Peru (Url 9).

NOAA's CoastWatch Program makes images and data available at the NOAA CoastWatch web site in near real-time from various sensors and satellites. Each type of image has many uses and temperature images indicating sea surface temperature are used to locate fishing spots (Url 10).

Furthermore there are commercial companies providing information for fisheries applications such as ORBIMAGE’s SeaStar Fisheries Information Service. SeaStar Service claims that since 1997 it has significantly improve the efficiency of the fish finding process based on plankton information obtained from SeaWIFS imagery of OrbView-2 satellite, combined with other environmental data. SeaStar Service is used by tuna and sardine purse seiners, pelagic longline and trolling vessels, and midwater trawling vessels throughout the world. Enabling to find favorable fishing locations, the service proposes to reduce the fuel costs in the fishing process (Url 11).

According to Food and Agriculture Organization of the United Nations (Url 12), integration of satellite remote sensing and GIS, is increasingly used in marine and inland fisheries projects. Especially among poor communities in coastal areas fish is an important source of food. Nevertheless, due to the open access conditions in fisheries, overexploitation threatens marine and inland stocks. “*Effective conservation and sustainable management of both marine and inland fisheries are needed at national and international levels so that living aquatic resources can continue to meet global nutritional needs*” (Url 12).

2.2.3. Integration of Multicriteria Decision Analysis and GIS

GIS, is a computer-based system that enables acquisition, storage, retrieval, modeling, manipulation and analysis of geographically related data (Aronoff, 1993).

According to Malczewski (1999), geographical data, information and decision making are three concepts that are interrelated. Geographical data constitutes the raw material and processed to gather information by decision making. Multi criteria decision making (MCDM) or in other words, multi criteria decision analyses (MCDA) evaluate a set of alternatives according to conflicting or unequal criteria.

MCDA problems mainly have 3 types of decision variables, deterministic, probabilistic and fuzzy. Deterministic decisions assume that the required data and information are known with certainity and between every decision and the corresponding consequence there is a certain determinisitng relation. The probabilistic decisions deal with the situations which include uncertainty about the state of the environment and about the relationship between the decision and its consequences. Probabilistic analysis treats uncertainty as randomness and likelihood, whereas fuzzy decision analysis deals with the uncertainty due to imprecise information (Malczewski, 1999).

According to Zadeh (1998), "*Fuzzy logic is the logic underlying approximate, rather than exact, modes of reasoning. In fuzzy logic everything, including truth, is a matter of degree.*" In other words, fuzzy logic is related with the formal principles of approximate reasoning when the precise reasoning restricts the study.

Integration of RS and GIS is employed in the definition of potential favorable zones for pelagic fish stocks. Since the conventional GIS applications utilize classical set theory, they are inadequate to state the natural variability in the environment (Wang, 1996).

Fuzzy classification defines the classes as linguistic terms. The linguistic term is used to express concepts and knowledge in human communication, whereas the corresponding numerical data (membership function) is used for processing (Yen and Langari, 1999).

Use of fuzzy set theory within GIS applications provides an approximate description of the real world which is full of uncertainities. Membership functions and their associated linguistic terms incorporate expert experiences in the form of vague definitions to cell-based GIS analysis and make fuzzy set theory superior to the classical set theory (Yanar and Akyürek, 2005).

2.2.4. Fisheries in Black Sea

According to State Institute of Statistics, Anchovy holds the 63% of the total catch of sea fish in Turkey (DIE, 2002). Being the most important commercial pelagic fish in Turkish Seas, Anchovy has been selected as the target specie of the study.

In Black Sea two subspecies of Anchovy are present, *Engraulis encrasiholus ponticus* (the Black Sea Anchovy) and *Engraulis encrasiholus maeoticus* (the Azovian Anchovy) (Salestenenko, 1955/56 cited in Bingel et al., 1995). The Azovian Anchovy lives in the sea of Azov but overwinters in the warm waters of Caucasus and Crimea (Sorokin, 2002), it is therefore fished only by Russia (Ivanov and Beverton, 1985).

The Black Sea Anchovy exist in the Black Sea through out their annual life cycle, but overwinter in the warmest parts of the Black Sea, off the Anatolian and Crimean coasts. Anchovy start seasonal migrations to their wintering places, in the late autumn, and return to their feeding and spawning grounds in spring (Ivanov and Beverton, 1985).

Anchovy leave the wintering places on the Turkish coast and migrate to the north for feeding and spawning in April. They remain dispersed over the whole Black Sea especially in the northern part, from the middle of April until October. Southward migration for wintering starts in November but it's also affected from climatological regime. The migration speed is 10-20 nautical miles per day. Through out the migration anchovy may trace the topography of the coast or directly cross the sea (Ivanov and Beverton, 1985). Anchovy start to move to wintering places when water temperature is 15-17 °C following the slope egdes at 50-200 m depth (Chashin and Alexeev, 1990 cited in Sorokin, 2002). They arrive to their wintering regions where they form large schools over steep shelf area along Caucasian and Anatolian coasts, when water temperature is 11-14 °C (Sorokin, 2002).

Life span of Anchovy changes between 2 to 3 years. They become mature after the first winter and spawning continues from the end of May until September at water temperatures 17-18 °C (Owen, 1979 cited in Ivanov and Beverton, 1985). To be able to interpret the effecs of changing of environment on Anchovy, egg and larvae stages should be observed carefully. Eggs develop into larvae within 24 hours, but highly affected from the temperature. High mortality rates may be observed in May due to the contact with cold water. The best period for spawning is from the end of june to the beginning of July (Slastenenko, 1955/56 cited in Bingel, et al., 1995). Athough the main spawning area of the Black Sea Anchovy is said to be the northern shelf region (Ivanov and Beverton, 1985) studies showed that a significant amount of Anchovy eggs are found within the Turkish Exclusive Economic Zone (Bingel, et al., 1995; Kideys et al, 1999).

CHAPTER 3

METHODOLOGY AND MATERIALS

3.1. Methodology

The methodology of the thesis is described in this chapter and the main steps of the study are given in the flowchart diagram in Figure 3.1.

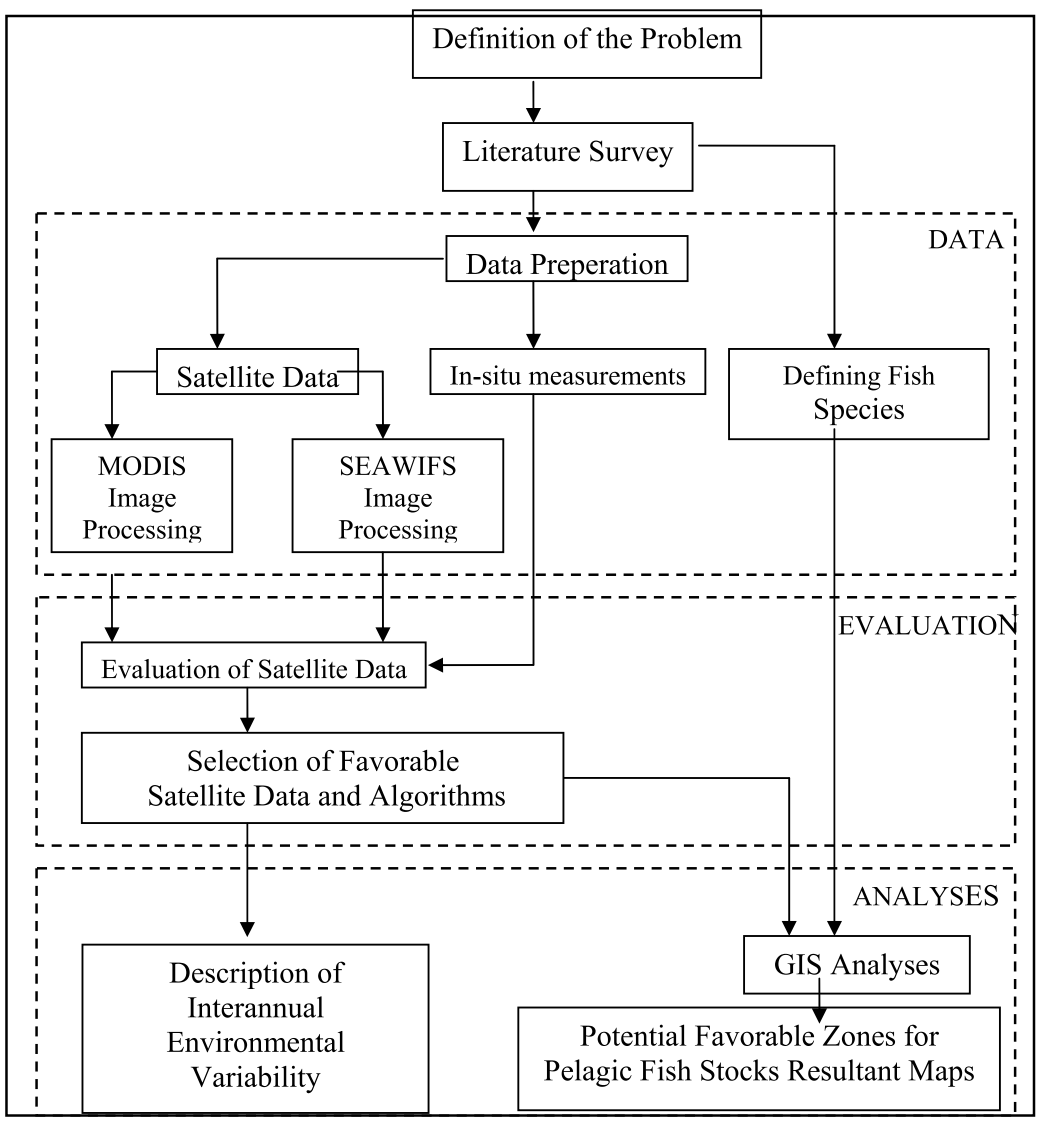


Figure 3.1. Flowchart of the Methodology

3.1.1. Definition of the Problem

The aim of the study is to reach marine resources with lower costs. RS and GIS are used in the study to define the potential favorable locations of pelagic fish species. The problem is defined as the high cost of liquid fuel and motor oil consumption while seeking for fish aggregations and consequently high expenditures for fishing activity.

3.1.2. Literature Survey

The literature is examined and defining potential favorable zones for fish stocks using satellite imagery is found to be the proper solution for the specified problem. The studied literature is already explained in Chapter 2.

3.2. Data Used

The data used in the study are satellite images and in-situ water samples of SST and chlorophyll concentration. Integration of Satellite information and fisheries require previous knowledge of habitat preferences of the fish, behavior of a given species at different temperatures, and catch rates occurring under those conditions (Earth Science Enterprise). The habitat preferences of the Anchovy were gathered from the literature but fish catch data for this specie was not available.

3.2.1. In-situ Data

The in-situ chlorophyll concentration and SST data were taken from METU Institute of Marine Sciences (IMS) archive, which were previously collected onboard R/V Bilim. Chlorophyll-a concentration was measured by the fluorometric method. Water samples were collected from the euphotic zone. 1 to 2 litres of seawater was filtered through filters and processed in METU-IMS. In-situ data was employed for the evaluation of satellite imagery algorithms for our seas. Thus a combination of in-situ datasets and imagery captured on the same date (or within 1 day interval when there is insufficient data) were collected. Due to the absence of satellite imagery and high cloud ratio mostly in winter imagery, in-situ datasets of three cruises out of five were used in the study. The availability of in-situ data is given in Table 3.1.

Table 3.1. Cruise Dates and the Coverage of In situ Measurements

In-situ Measurements (METU-Marine Sciences Institute)							
Dataset Name	**Start**	**Finish**	**Min Latitude**	**Max Latitude**	**Min Longitude**	**Max Longitude**	**# of Stations**
Cruise 2000-1 BLACK SEA	**02/07/2000**	**08/07/2000**	**41º10' 00"**	**42º19'60"**	**29º07'60"**	**36º45'00"**	**70**
Cruise 2000-2	18/09/2000	01/10/2000	36º00' 00"	42º10'00"	29º02'60"	33º50'50"	32
Cruise 2000-3 BLACK SEA	**06/10/2000**	**17/10/2000**	**41º00' 00"**	**43º00'00"**	**28º00'00"**	**41º00'00"**	**142**
Cruise 2000-4	20/10/2000	24/10/2000	40º01' 42"	40º59'27"	26º11'30"	29º00'00"	12
Cruise 2000-5 MEDITTER	**24/10/2000**	**29/10/2000**	**35º00' 00"**	**40º00'00"**	**24º00'60"**	**30º15'00"**	**44**

3.2.2. Satellite Data

3.2.2.1. Ordering and Processing Satellite Data

i – SeaWIFS Images

SeaWIFS instrument is on board the Seastar Spacecraft. It has a sun synchronous orbit and crosses the equator at noon + 20 minutes. It provides data in 8 different spectral bands, with spatial resolution of 1,1 km local area coverage and 4,5 km global area coverage (Url 13).

For the evaluation of SeaWIFS images, Level 1A HRPT Local Area Coverage (LAC) products having 1km spatial and 1 day temporal resolution were selected. SeaWiFS images corresponding to the in-situ data time interval were gathered from METU IMS satellite observatory center archive.

HRPT file consist of the scans received by the ground station while the satellite is above the station's receiving horizon. Processing Level l A HRPT LAC to Level 2 requires additional steps. SeaWiFS Data Analysis System (SeaDAS), working in the UNIX environment, is used for processing Level 1A data to Level 2. Ancillary meteorological data and ozone data is used for atmospheric correction. Using the default settings of the SeaDAS software the geophysical products are produced. In Figure 3.2. SeaWIFS processed chlorophyll concentration parameter is given (Url 14).

Generated SST and chlorophyll concentration images were analyzed using SeaDAS software. The pixel value in the SeaWiFS image that corresponds to the in situ value was taken as the nearest pixel to the exact location. Assuming that the mean value would give better results than the centre pixel value, a 3x3 pixel area centred on that nearest pixel was selected to read the value of SeaWiFS derived parameters. Then the mean value of 9 pixels was calculated and assigned as the final value to be used in the accuracy evaluation analyses.

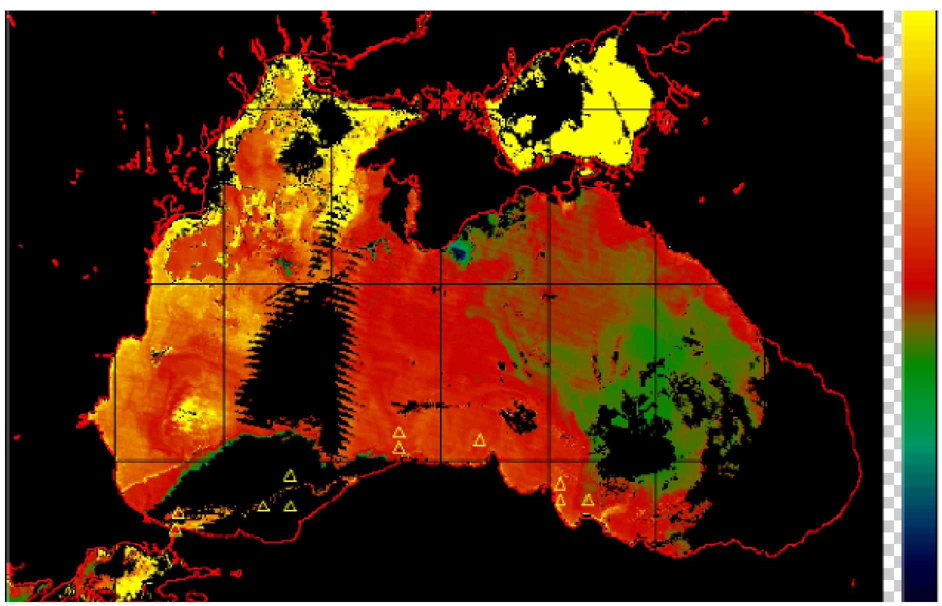


Figure 3.2. SEAWIFS Chlorophyll Concentration Parameter Imagery Overlaid by Yellow Triangles Indicating the In-situ Sample Locations.

***ii*- MODIS Images**

MODIS is an Earth-observing instrument on board the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. MODIS Terra and Aqua view the entire Earth's surface every 1 to 2 days and provide data in 36 spectral bands with spatial resolutions of 250m (bands 1-2), 500m (bands 3-7) and 1000m (bands 8-36) (Url 15).

MODIS Images can be downloaded from NASA - Goddard Earth Sciences Distributed Active Archive Center (DAAC) free of charge (Url 16).

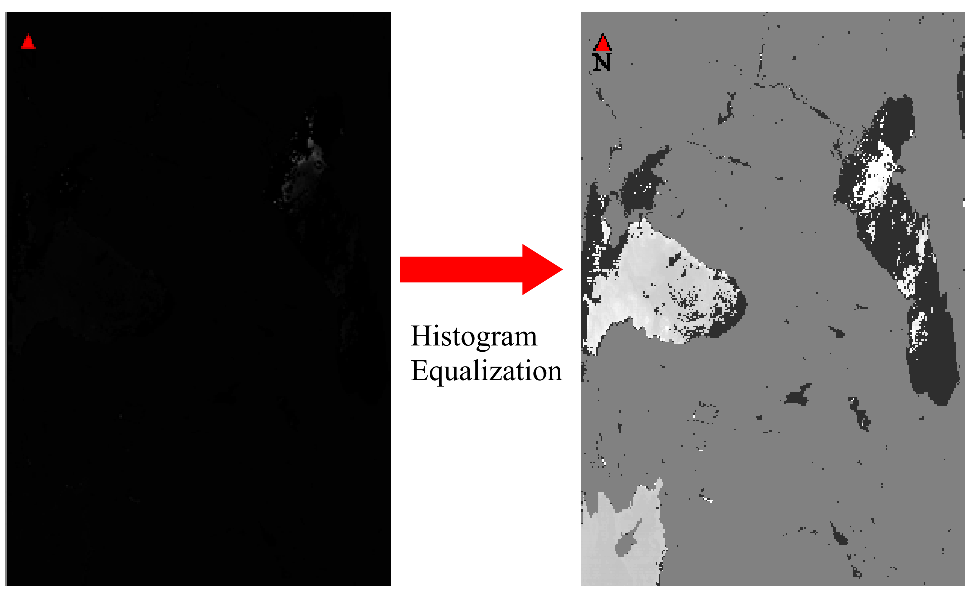
MODIS Terra product archive contains imagery from February 2000 to present, while MODIS Aqua product archive starts from November 2002. Therefore MODIS Terra products are used in the analyses.

Over 100 categories of MODIS Ocean data types can be obtained from the Goddard DAAC. MODIS ocean data types consist of ocean color, sea surface temperature, and ocean primary production. Ocean color and sea surface temperature products are available at processing Level 2 and Level 3 and ocean primary production data are available as Level 4 data (Url 17).

Two different levels of MODIS-Terra Ocean Products were utilized throughout the study. For evaluation purposes Level 2 products with 1km spatial, 1 day temporal resolution and for the fisheries applications Level 3 products with 4.89 km spatial and 8 day temporal resolution were utilized. Having higher spatial resolution than Level 3 products, Level 2 products are preferred for evaluation analyses to increase the level of detail that can be extracted from the imagery. Since in the analyses the correlation of the pixel values and the in-situ data is evaluated, it would be more relevant to match the in-situ data with higher resolution imagery. Furthermore Level 2 products have 1 km spatial resolution, identical to SeaWIFS imagery, which is preferred for the comparison of the accuracy results. One disadvantage of Level 2 imagery is that, having higher resolution, they are bigger in size. In the description of inter annual environmental variability and fish stock analyses, a time series of satellite imagery is occupied. MODIS imagery comprising three chlorophyll concentration parameters and two SST parameters for the whole year were downloaded via ftp. To avoid the heavy data load in downloading, making analyses and also in data storage, Level 3 products, which also have enough resolution for the description of inter annual environmental variability and fish stock analyses were utilized in further analyses. Level 3 images have a global coverage so before the analyses; each Level 3 image is cropped according to the study area. On the contrary Level 2 images are available as subsets.

All the products were processed using MSPHINX (MODIS Satellite Process Handling Images uNder Xwindow) software. This is free UNIX software, designed by Laboratoire d'Optique Atmospherique, a French planetary research institution. It is available via web (Url 18).

MSPHINX software can directly read MODIS images. Before the analyses a spectral enhancement technique called histogram equalization is applied to reach a better view of imagery. The resultant image is given in Figure 3.3.



MODIS Ocean Parameter Chlor-a2 July,3 2000

Figure 3.3. Histogram Equalization of MODIS L 2 Products

Level 2 images need more processing due to the distortion in this level of MODIS imagery, called the panoramic bowtie effect. As it is seen in Figure 3.3 the image is distorted near the edges. The reason of the distortion is that MODIS scans 10 lines at a single pass, whereas SeaWIFS scans 1 line at a time. As the distance between the sensor and the pixel location increases, the pixel size increases accordingly. Thus the pixels near the edge of an image are bigger than the ones in the middle. On the scan line the pixel sizes are identical to each other, whereas as the scan angle decreases the pixels might be 6 times wider and 4 timer longer at the edges (Url 19).

MSPHINX reprojects Level 2 products to a standard projection and remove the bow tie artifacts using geolocation products of MODIS imagery. The reprojected MODIS imagery can be seen in Figure 3.4.

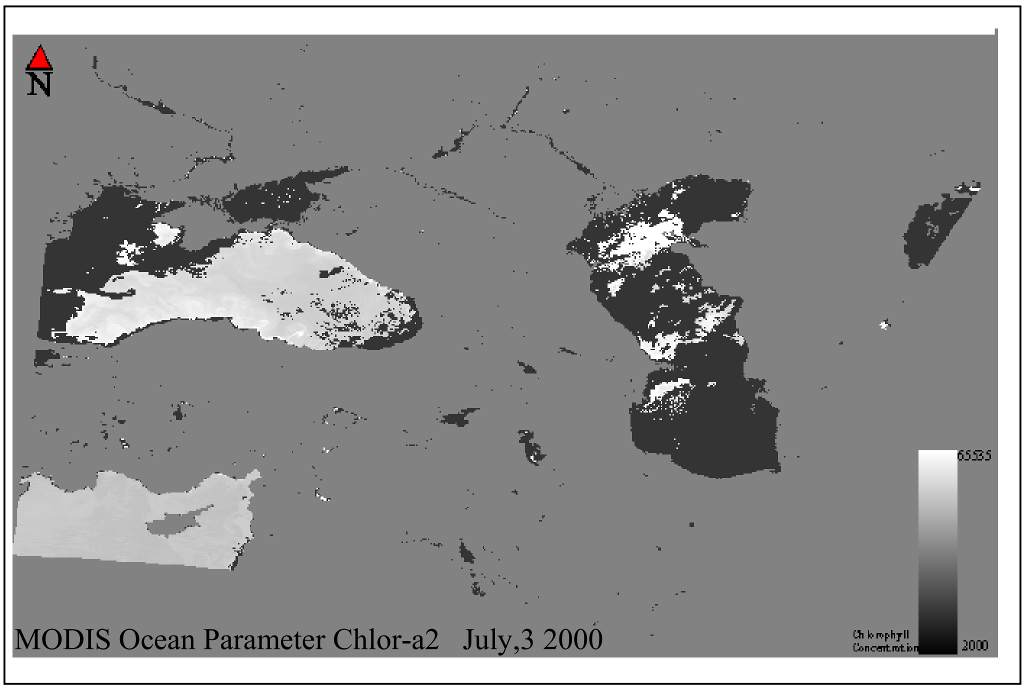


Figure 3.4. Reprojection of MODIS L2 Products

MODIS products provide many paramaters for oceanographic studies. In Figure 3.4 the parameter indicating chlorophyll-a pigment concentration is given. This product gives the chlorophyll-a pigment concentration in terms of mg/m3. In the legend, it is seen that the pixel values start from 2000 and rises up to 65535. This indicates that the Level 2 images also need to be rescaled. Rescaling process is also done in MSPHINX and the chlorophyll concentration distribuiton is gathered in terms of mg/m3. Figure 3.5 represents the rescaled imagery.

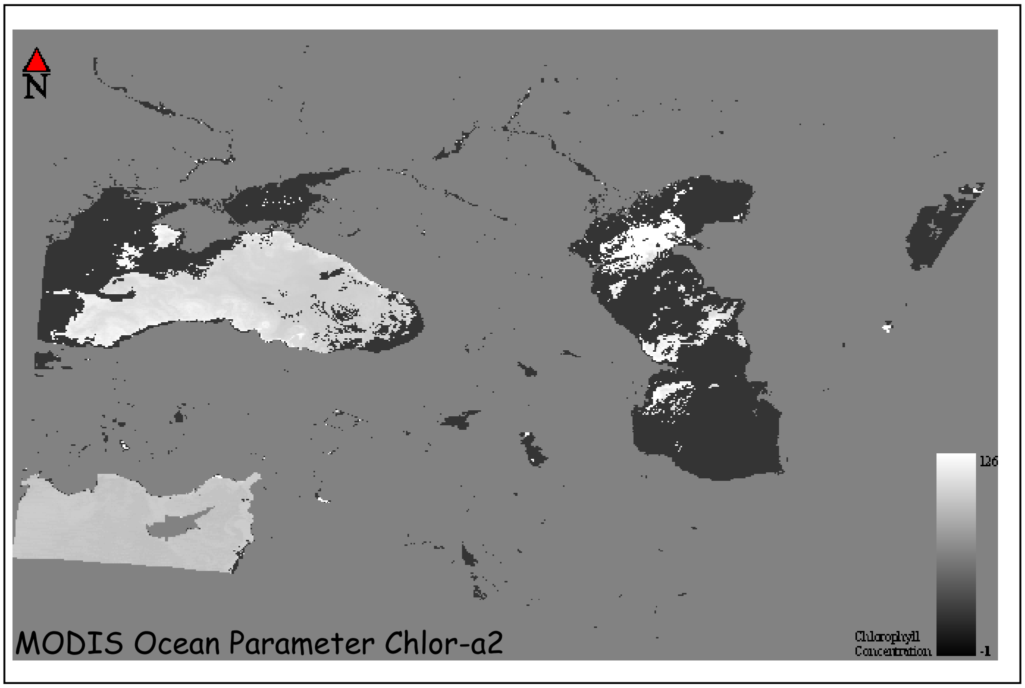


Figure 3.5. Rescaling MODIS L2 Products

The processed image is displayed in color as in Figure 3.6 for better visual interpretation and used in the evaluation analyses.

Assuming that the mean value would give better results than the centre pixel value, again a 3x3 pixel area centred on that nearest pixel was selected to read the value of MODIS derived parameters. The mean value of 9 pixels was calculated and assigned as the final value to be used in the analyses. The correlation of those values and the in-situ data is examined to asses the accuracy of the satellite algorithms.

Processing of Level 3 images are identical to Level 2 image processing. But Level 3 images are easier to process since they are not distorted. Adding pseudocolor and rescaling of imagery is done by MSPHINX and the resultant imagery is given in Figure 3.7.

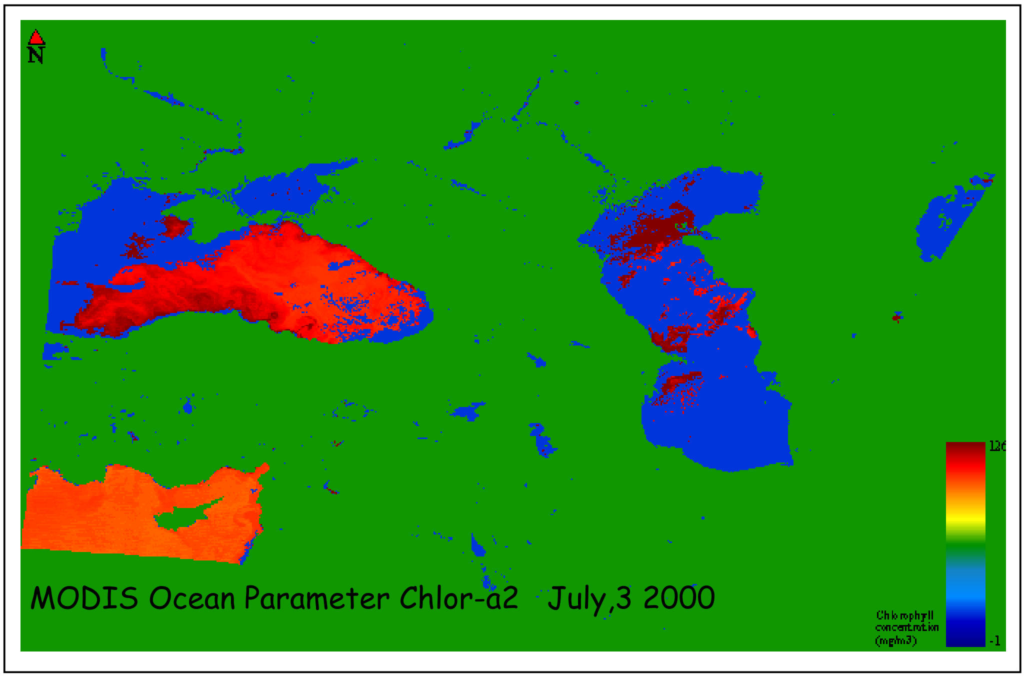


Figure 3.6. Coding of MODIS L 2 Products

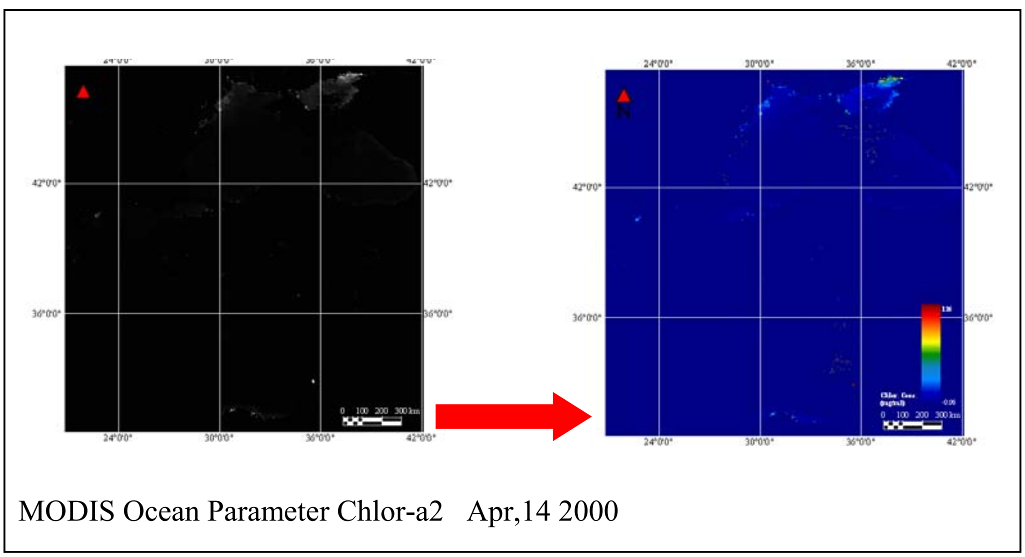


Figure 3.7. Rescaling and Adding Pseudocolor to MODIS L3 Products

Spectral enhancement techniques are applied to improve the interpretability of the chlorophyll concentration images as seen in Figure 3.8.

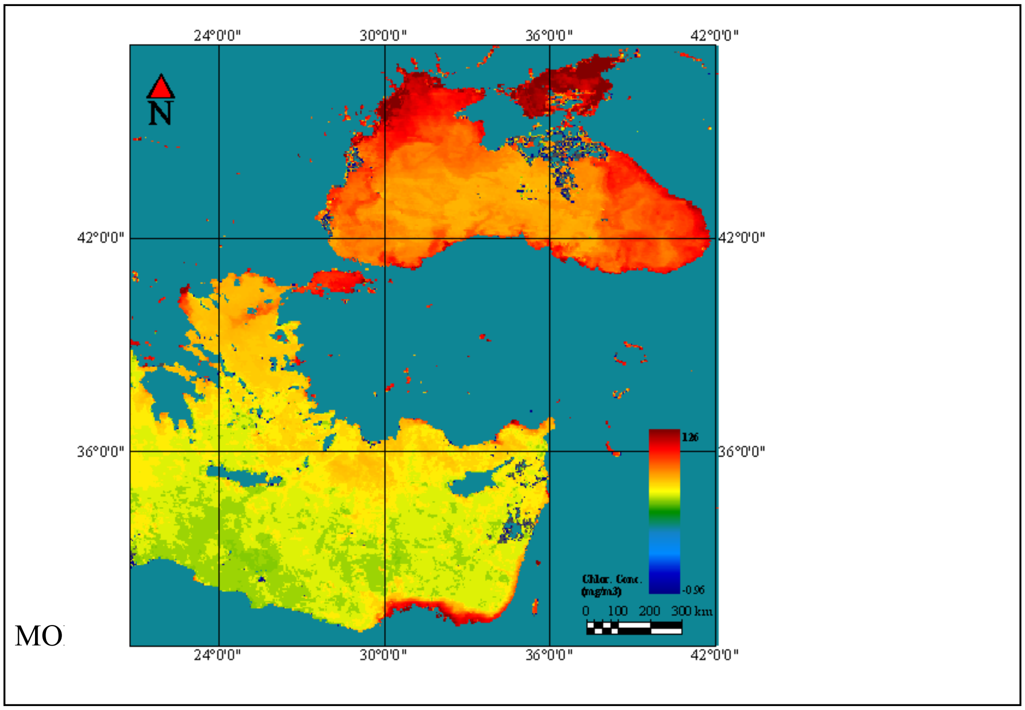


Figure 3.8. Histogram Equalization of MODIS L 3 Products

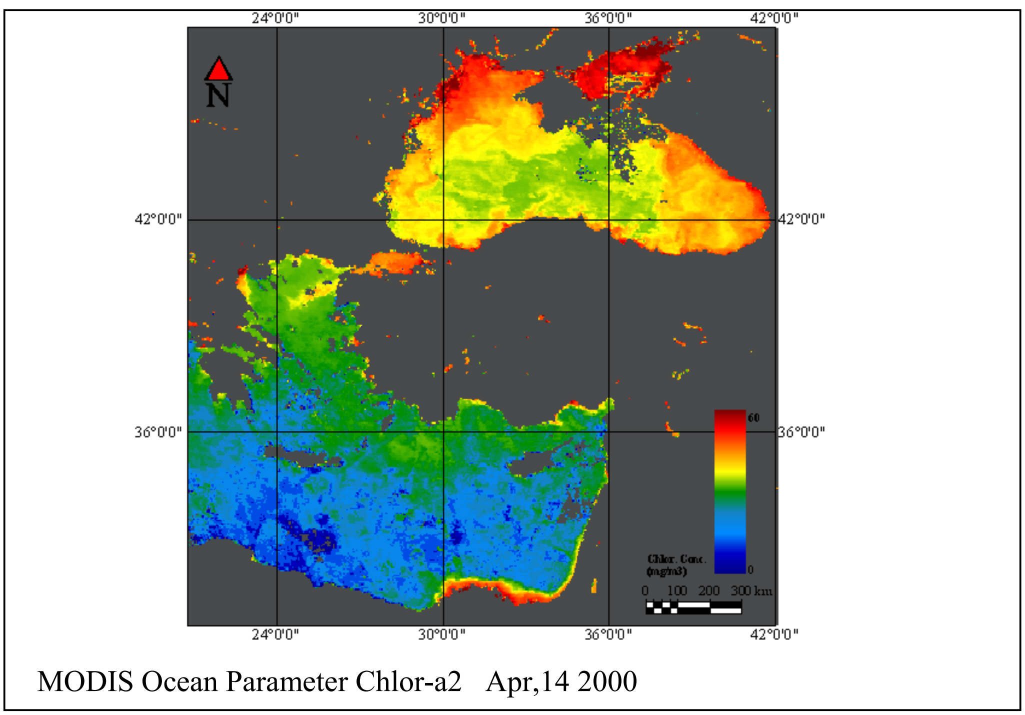


Figure 3.9. Masking Extreme Values of MODIS L 3 Products

Even if the results are overestimated according to the literature (Yunev, 2002) the concentration values over 60mg/m3 is assumed to be erroneous and neglected during the processes, given in Figure 3.9.

Finally the land areas are masked to overcome the confusion in the further analyses and for a better visual appearance. The resultant imagery is given in Figure 3.10.

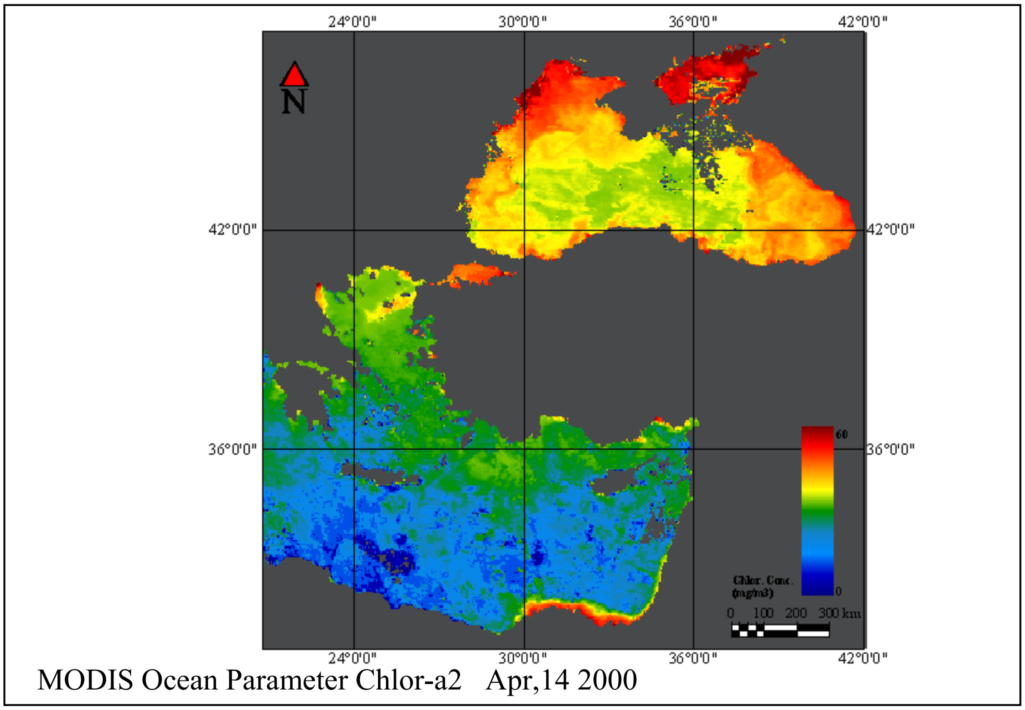


Figure 3.10. Masking Land Areas of MODIS L3 Products

Level 3 images are used in two different kinds of analyses. First one is to interprete the interannual environmental variability and the second is the determination of potential favorable locations for pelagic fish stocks. The analyses steps are explained in the fourth chapter.

3.3. Evaluating Satellite Data

Although the characteristics of marine environment differ from region to region, like the Black Sea and the Mediterranean, the algorithms used in the satellites are global.

Accuracy of the satellite driven data is directly related with the satellite algorithms, but unfortunately regional algorithms for the Turkish Seas have not been developed yet. Since we lack the information that confirms the validity of the satellite data in our seas, before the analyses, SeaWIFS and MODIS chlorophyll and SST products are evaluated according to in-situ measurements taken from the seas around Turkey. The evaluation results are examined in this chapter.

3.3.1. Evaluation of MODIS Products According to In-situ Measurements

3.3.1.1. Chlorophyll Concentration Products

MODIS chlorophyll concentration parameters are evaluated. Chlorophyll-a (SeaWIFS), in other words Parameter 26, which has the highest correlation with in-situ data is used in the analyses. This parameter utilize the SeaWIFS "OC4" algorithm using MODIS water-leaving radiances and valid for both case 1 and case 2 waters (Url 15). The algorithm needs input of the water-leaving radiance bands centered at 412, 443, 488, and 551 µm. (Url 20).

Figure 3.11. represents the correlation of all the in-situ data taken in different cruises and the satellite derived values. Each cruise has taken place either in different seas or in different times as it can be in seen in Table 3.1. There are three subgroups within the graphic. So the data is divided into three groups, representing different cruises.

Cruise 1 indicates the measurements taken from Black Sea in summer. As it is seen in Figure 3.12 although the correlation of in-situ chlorophyll-a data with the satellite derived ones are high, the equation shows that satellite derived concentration values are seven times higher than in-situ results.

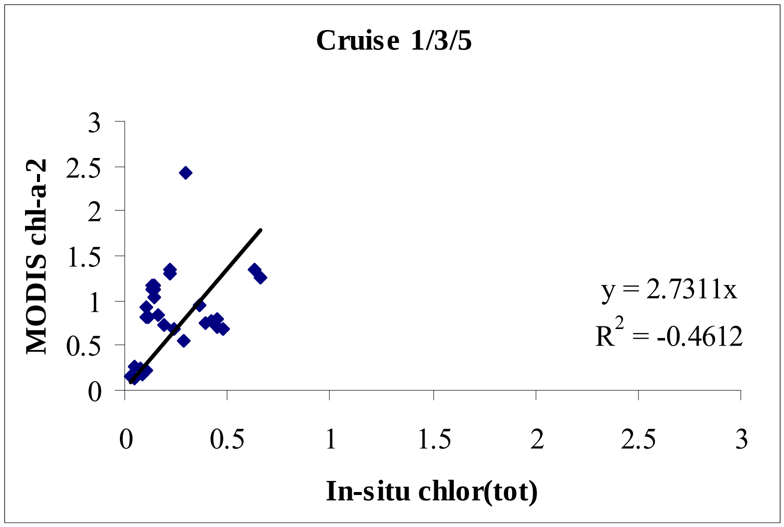


Figure 3.11. Satellite Derived MODIS Chlorophyll_a Concentration Values Versus In_situ Measurements

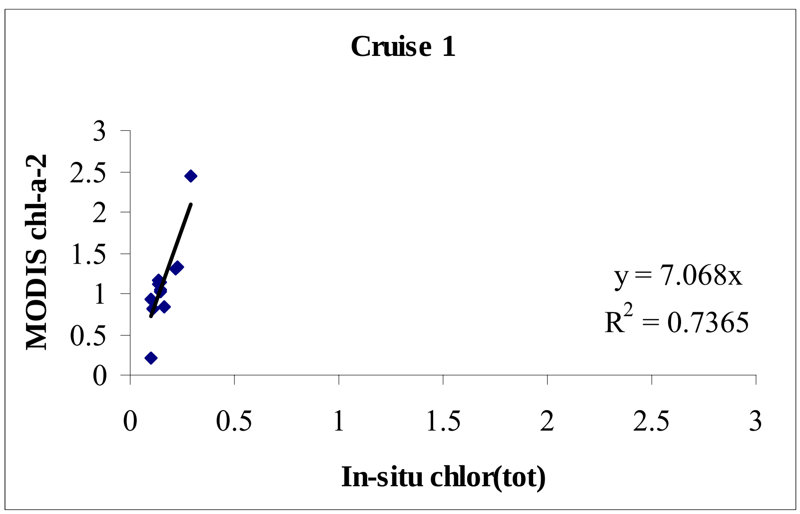


Figure 3.12. Satellite Derived MODIS Chlorophyll_a Concentration Values Versus In_situ Measurements in the First Cruise

MODIS algorithm highly overestimates the chlorophyll concentration values. Black Sea is Case 2 type of water, which is mostly problematic for the algorithms and this might also indicate that certain species can cause failure of the algorithms. According to the MODIS Algorithm Theoretical Basis Document, *the remote sensing* *reflectance model used to develop the chlorophyll algorithms has a few parameters that cannot be fixed and applied to the entire globe; as a result, they are site and season specific. This is due to the variability of many bio-optical constituents.* For example, absorption at 440 nm per unit chlorophyll a by phytoplankton can change with species and with nutrient and lighting conditions by as much as a factor of 5 (Morel and Bricaud, 1981; Kirk, 1983; Carder et al., 1991; Morel et al., 1993).

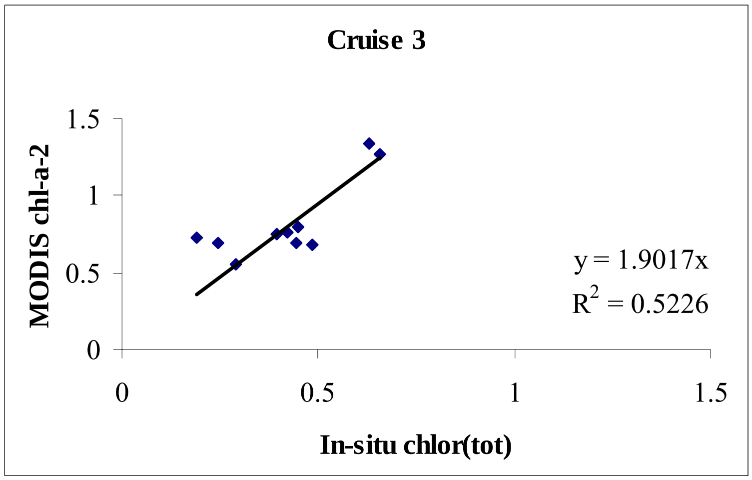


Figure 3.13. Satellite Derived MODIS Chlorophyll_a Concentration Values Versus In_situ Measurements in the Third Cruise

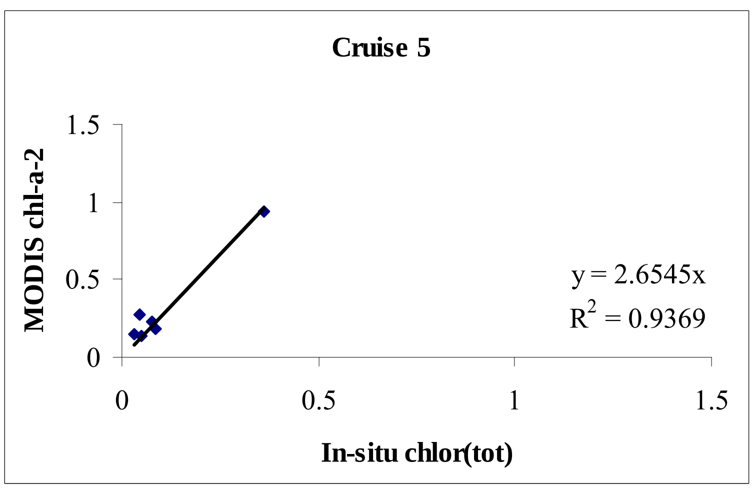


Figure 3.14. Satellite Derived MODIS Chlorophyll_a Concentration Values Versus In_situ Measurements in the Fifth Cruise

The results of Cruise 3, which was taken place in Black Sea like Cruise 1 but in different season, give only two times higher results as indicated in Figure 3.13. This might lead to the conclusion that the increase of certain type of species that cause the failure of the algorithms due to season changes. Moreover, cruise 3 represents autumn, cruise 1 represents summer period. Since algorithms are affected by solar contamination, the difference between the satellite measurements and the in-situ values might occur due to the different illumination conditions instead of different species.

Cruise 5 represents Mediterranean Sea. Due to the fact that the Mediterranean Sea is case 1 water, the correlation within the data is higher. But as it is represented in Figure 3.14 the number of in-situ data is insufficient. Thus, although high correlation value is expected, the result is not reliable.

3.3.1.2. Sea Surface Temperature Products

There are two MODIS SST algorithms namely sst and sst4. According to the MODIS documentation sst4 is composed of three bands near 4µm which are mid-infrared bands. SST algorithm have two far-infrared bands which are between 10 and 12µm.

It is also stated that the atmospheric window covering mid-infrared bands is more transparent than the one covering far-infrared bands, which provides the chance to derive more accurate SST values. However algorithms using mid-infrared bands are susceptable to high solar contamination risk, so the usage is limited to night-time use, or to daytime where the risk can be ignored (Url 21). In this study sst4 algorithm (daytime) is used due to the higher correlation of values with in-situ data and to be able to compare the satellite data with in-situ data taken in day time.

For evaluation of sst4 parameter satellite imagery and in-situ data taken at the same date are used. Even though the risk of solar contamination is high as indicated in MODIS documentation, sst 4 daytime parameter shows high correlation with the in-situ data as indicated in Figure 3.15. The in-situ data is divided into groups belonging Black Sea and Mediterranean to experience the sst4 validity in each sea.

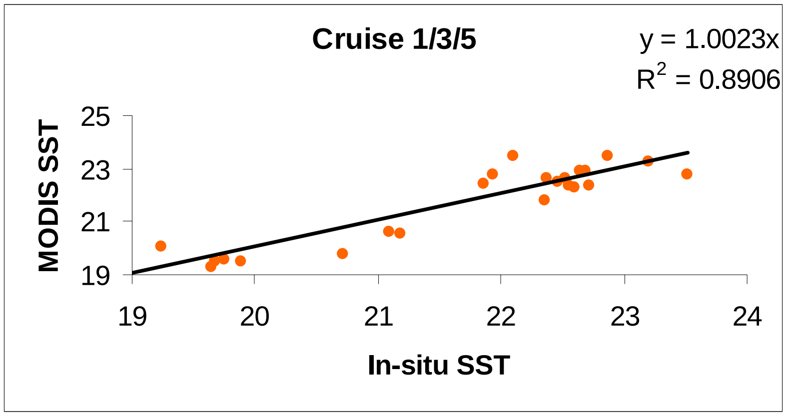


Figure 3.15. Satellite Derived MODIS SST Values Versus In-situ Measurements

In-situ values for Black Sea are taken in two different seasons, summer and autumn. As indicated in Figure 3.16 and 3.17. The MODIS sst4 parameter has overestimated the in-situ values for summer but underestimated them for winter. When the Black Sea cruises further divided into groups, it is seen that the correlation coefficient fails for summer but still gives good results for winter. This might be the effect of solar contamination.

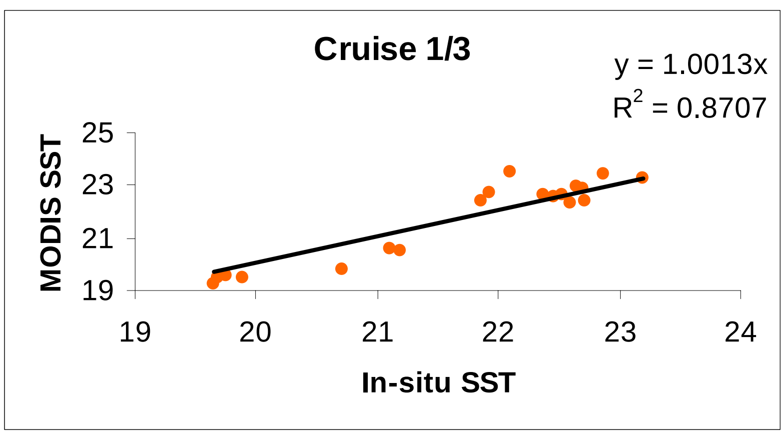


Figure 3.16. Satellite Derived MODIS SST Values Versus In-situ Measurements in the Black Sea.

Satellite measurements have a good correlation with the in-situ values in the Mediterranean. But the numbers of the in-situ measurements are not enough to give accurate results as seen in Figure 3.17.

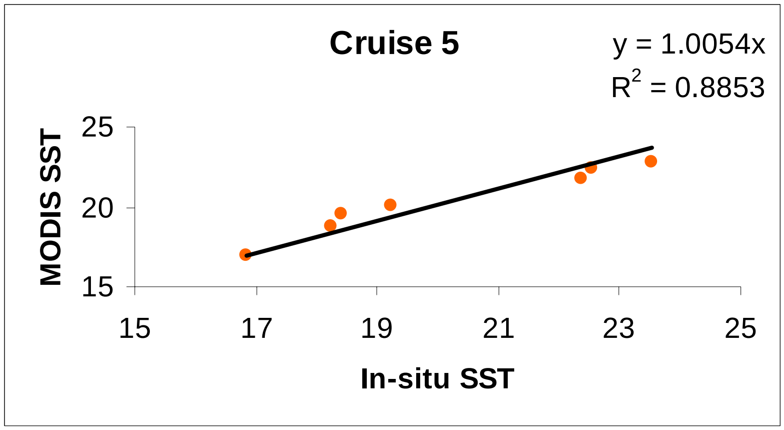


Figure 3.17. Satellite Derived MODIS SST Values Versus In-situ Measurements in the Mediterranean Sea.

3.3.2. Evaluation of SeaWIFS Products According to In-situ Measurements

3.3.2.1. Chlorophyll Concentration Products

LAC Level-1A products were analyzed in SeaDAS software to generate the chlorophyll concentration parameter. Due to the availability of imagery and the cloud ratio, the number of the SeaWIFS images used for the analyses are not the same. This fact decreases the reliability of the comparison between the evaluation result and in some cases the number of satellite imagery was not enough to match with the in-situ data. MODIS Chlorophyll-a2 (Chlorophyll SeaWIFS) parameters utilizes SeaWIFS algorithms so the satellite driven result were similar. Satellite derived SEAWIFS chlorophyll_a concentration values versus in_situ measurements are given in Figure 3.18.

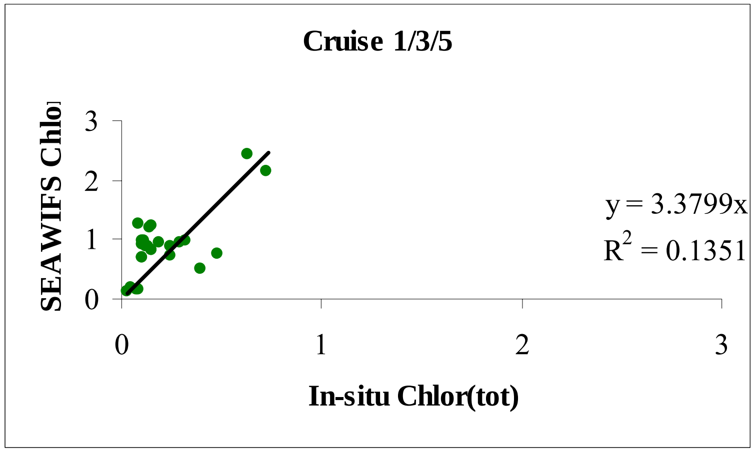


Figure 3.18. Satellite Derived SEAWIFS Chlorophyll_a Concentration Values Versus In_situ Measurements

SeaWIFS chlorophyll algorithm is widely used in marine studies but according to the results the correlation of in-situ chlorophyll-a data with the satellite derived ones are negative as seen in Figure 3.19. This failure might again be a result of a temporary increase of certain specie or by solar contamination. The equation shows that satellite derived concentration values are seven times higher as the MODIS derived results. So we might also state that, both algorithms fail within similar situations, but the MODIS algorithms still have higher correlation coefficient.

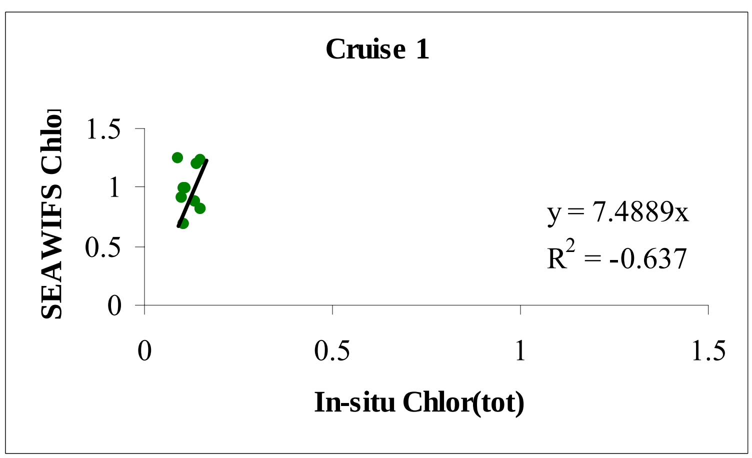


Figure 3.19. Satellite Derived SEAWIFS Chlorophyll_a Concentration Values Versus In_situ Measurements in the First Cruise

Satellite derived SEAWIFS chlorophyll_a concentration values versus in_situ measurements in the third cruise in the Black Sea is given in Figure 3.20.

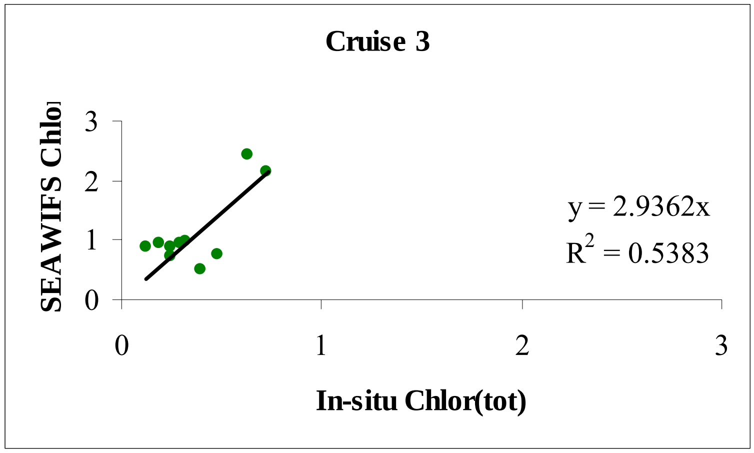


Figure 3.20. Satellite Derived SEAWIFS Chlorophyll_a Concentration Values Versus In_situ Measurements in the Third Cruise

The graphical representation of Cruise 5 is not given in the thesis due the insufficient number of satellite derived SEAWIFS chlorophyll_a concentration values versus in_situ measurements.

3.3.2.2. Sea Surface Temperature Products

LAC Level-1A products were analyzed in SeaDAS software to generate the SST parameters. SeaWIFS parameter shows high correlation with the in-situ data as indicated in Figure 3.21. This dataset includes both Black Sea and Mediterranean so the data is divided into two to check the algorithm in each sea.

Figure 3.21 represents the correlation between satellite derived SEAWIFS SST values and the in-situ measurements. Although MODIS algorithm yields better results, the correlation coefficient is high.

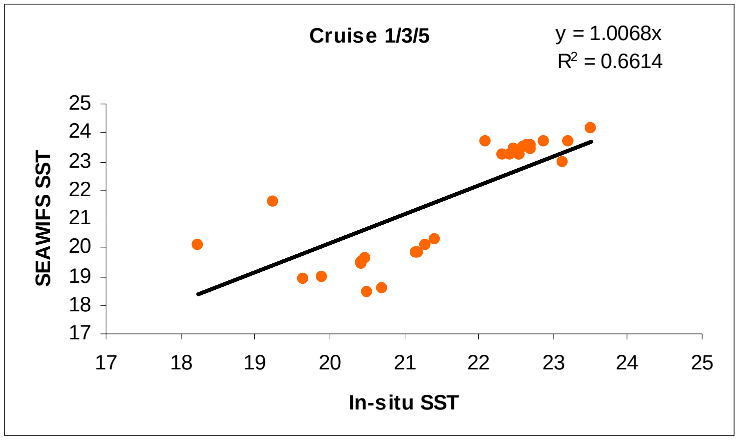


Figure 3.21. Satellite Derived SEAWIFS SST Values Versus In_situ Measurements

In-situ values for Black Sea are taken in two different seasons, summer and autumn. SeaWIFS SST parameter has overestimated the in-situ values in summer like MODIS sst 4 parameter and underestimate them in winter. The representation of the Black Sea and Mediterranean cruises are given in Figure 3.22 and Figure 3.23 respectively.

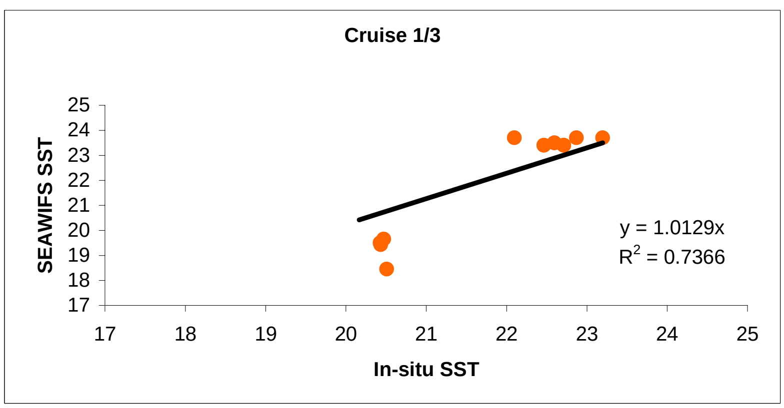


Figure 3.22. Satellite Derived SEAWIFS SST Values Versus In_situ Measurements in the Black Sea.

SST measurements seem to have a good correlation with the in-situ values in the Mediterranean, but the numbers of the in-situ measurements are not enough as given in Figure 3.23.

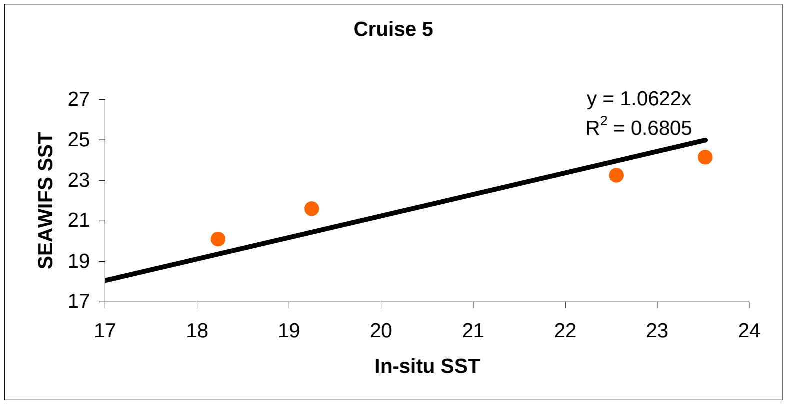


Figure 3.23. Satellite Derived SEAWIFS SST Values Versus In_situ Measurements in the Mediterranean.

According to the results, both algorithms overestimate the chlorophyll concentration values in Black Sea but MODIS chlor_a2 algorithms is selected for relatively higher accuracy as it is given in Table 3.2. On the contrary, satellites have higher correlation with the in-situ SST values. MODIS sst4 parameter is selected for the further analyses.

Table 3.2. Comparison in Evaluation Results

Correlation coefficents			**BLACK SEA**		**MEDITTER.**
			Summer	**Autumn**	**Autumn**
			July _2000	**Oct_2000**	**Oct_2000**
			Cruise_1	**Cruise_3**	**Cruise_5**
MODIS Algorithms	**SST**	sst4	0.8707		0.8853
		sst	-	-	-
	CHLOR	chlor_SeaWIFS	0.7365	0.5226	0.9369
		chlor_semianalytic	0.5906	0.726	0.6191
		chlor_MODIS	0.6397	-0.9046	0.9675
SeaWIFS Algorithms	**SST**	sst	0.7366		0.6805
	CHLOR	chlor	-0.637	0.5383	-

In Table 3.3 first two columns in the charts indicate Julian dates of the images utilized in the analyses. Real Julian dates indicate the day imagery is collected. If the image is absent or the necessary part is covered with cloud, instead of that, the imagery collected on the next day, which is represented in used column is utilized. As it is seen from the table due to the absence of SeaWIFS imagery and high cloud ratio, most of the calculations are done within ± 1 day interval. This is also a disadvantage for the accurate comparison of the algorithms.

Table 3.3. Dates of Satellite Imagery Used for the Evaluation.

a) SEAWIFS imagery b)MODIS imagery

	SEAWIFS		
	Julian Date		Corresponding Date
	True	Used	
Cruise 1	185	186	3/7/2000
	186	186	4/7/2000
	187	186	5/7/2000
	189	189	6/7/2000
	190	190	7/7/2000
Cruise 3	280	280	6/10/2000
	281	280	7/10/2000
	288	290	14/10/2000
	289	290	15/10/2000
	290	290	16/10/2000
	291	290	17/10/2000
Cruise 5	298	299	24/10/2000
		299	25/10/2000
		300	26/10/2000
		301	27/10/2000
	303	304	29/10/2000

a)

	MODIS		
	Julian Date		Corresponding Date
	True	Used	
Cruise1	184	184	2/7/2000
	185	185	3/7/2000
	186	186	4/7/2000
	187	187	5/7/2000
	188	188	6/7/2000
	189	189	7/7/2000
Cruise 3	281	281	7/10/2000
	282	282	8/10/2000
	288	288	14/10/2000
	289	289	15/10/2000
	291	291	17/10/2000
Cruise5	298	298	24/10/2000
	299	299	25/10/2000
	300	300	26/10/2000
	301	301	27/10/2000
	302	302	28/10/2000
	303	303	29/10/2000

b)

CHAPTER 4

ANALYSES

4.1. Description of Interannual Environmental Variability in Black Sea

Black Sea is the largest landlocked basin in the world. It is connected to the Azov Sea through the Kerch Straits and to the Marmara Sea with a restricted exchange through the Bosphorous and Dardanellas Straits (Beşiktepe et al., 2001; Özsoy and Ünlüata, 1997).

Due to the increased nutrient input via major rivers during the last few decades, Black Sea ecosystem has been subject to changes in recent years. Intrusion of new species (a lobate ctenophore, Mnemiopsis sp.) into the Black Sea, which competes with Anchovy for the zooplankton and morever consuming anchovy eggs and larvae in the Black Sea has resulted a decline in the Anchovy and other pelagic fish stocks (Kıdeys, 1994).

The major rivers discharging into the Black Sea are Danube, Dpener and Dnester. Danube alone holds the 50 % of the river run-off, which is 3 times higher than the total discharge of the Dneper and Dnester (Özsoy and Ünlüata, 1997).

Due to the sediment and nutrient load, river discharges has distinct effects on the Black Sea, which are sediment load directly affecting the water properties, whereas the nutrients have an indirect effect by inducing the planktonic flora. Both processes can be evaluated via the satellite imagery (Barale et al., 2002).

Besides the freshwater inputs from the rivers, Black Sea is also influenced by atmospheric effects, fluxes through straits and changes in topography. The circulation of the Black Sea need to be observed for understanding of primary production, growth and migration of the pelagic marine organisms (Özsoy and Ünlüata, 1997).

According to Besiktepe et al., (2001), the upper layer circulation is characterized by a cyclonic circulation in the center of the basin, which is stronger over the continental slope. Center region circulation is composed of weak cyclonic eddies and smaller and weaker anticyclones. In the outer boundary of the central cyclonic region and over the continental slope, there is a strong current called the Rim Current. On the coastal side of the Rim Current there are a series of anticyclonic eddies and the largest anticyclonic gyre is the Batumi gyre. It is often possible to identify eddies with their temperature pattern, since center of the anticyclones are usually cooler than their surroundings. Rim current can be divided into segments according to the different structural characteristics. Figure 4.1 represents the general circulation pattern of the Black Sea.

Northwest Shelfbreak Current, starts from Crimea Peninsula and reaches Bosphorous Strait in the North. It consists of two semi-permanent anticyclonic eddies, Sevastopol Eddy in the North and Kaliakra Eddy in the South.The driving mechanism is influenced by fresh water entrance and wind effect respectively.

Anatolian current, lies along the anatolian coast. Three to five anticyclonic cells with different strenghts are present on the shoreward side of the current. One of which is the Sakarya Eddy. Caucasian-Kerch Current, covers the rest of the Black Sea from the Battumi Gyre to the Crimea Peninsula and leads the formation of the caucasian eddy.

MODIS 8 day composite Level 3 Chlorophyll concentration and SST images starting from the end of February 2000 and continues to the middle of March 2001 are given in Appendix I. The given imagery might be used for visual interpretation of upper layer circulation pattern and the interannual variability in terms of change in chlorophyll concentration and SST.

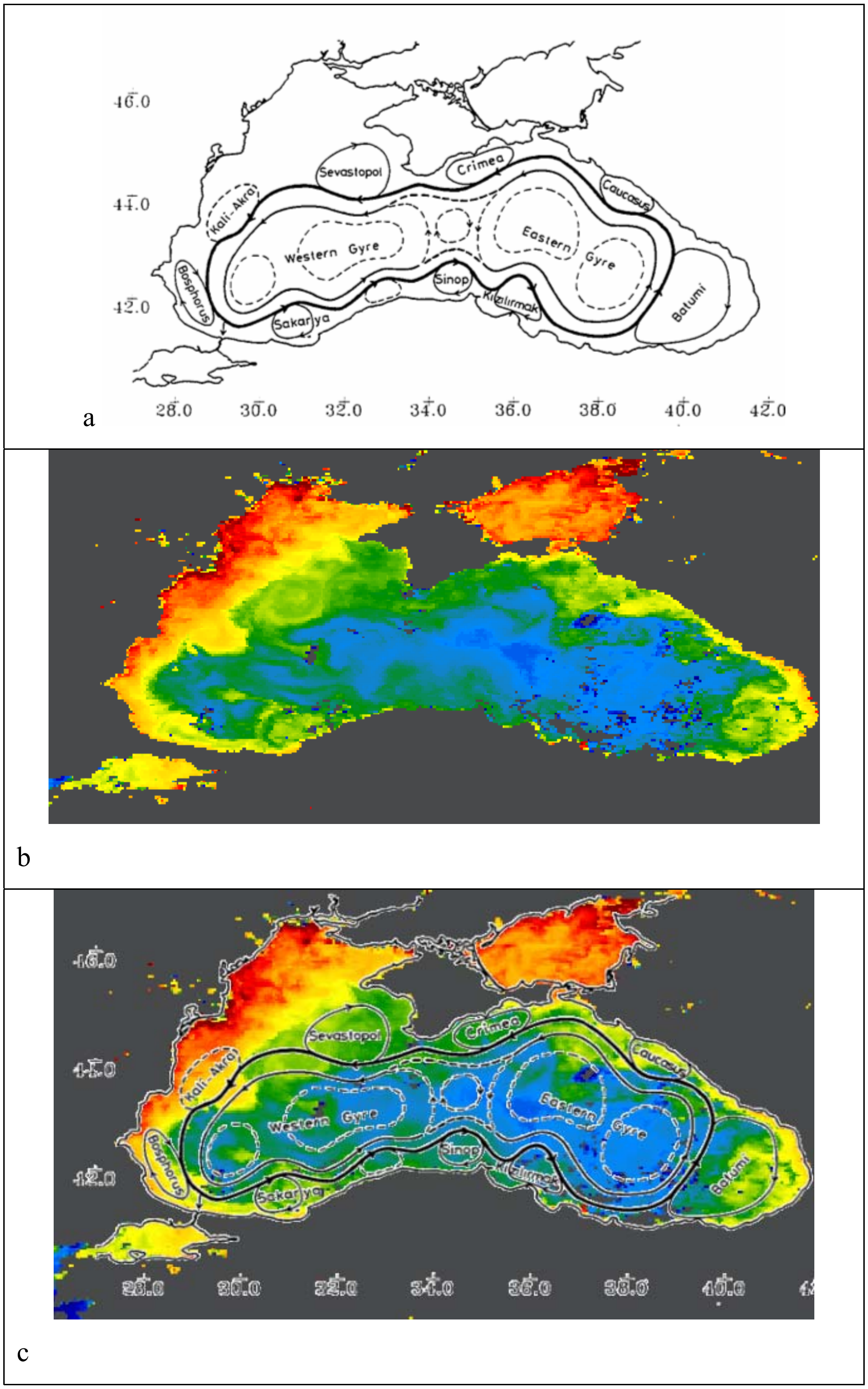


Figure 4.1. a) Representation of the upper layer general circulation pattern of the Black Sea. After Oğuz et al. (1993). b) MODIS L3 chlorophyll concentration imagery (24May-31May) c) MODIS L3 chlorophyll conc. imagery overlaid by circulation pattern

Depending on expert knowledge 6 sub-regions with specific characteristics were identified to examine spatial variability in the Black Sea. The 8 day composite MODIS Level 3 chlorophyll concentration and SST imagery dataset is divided into subregions as represented in Figure 4.2.

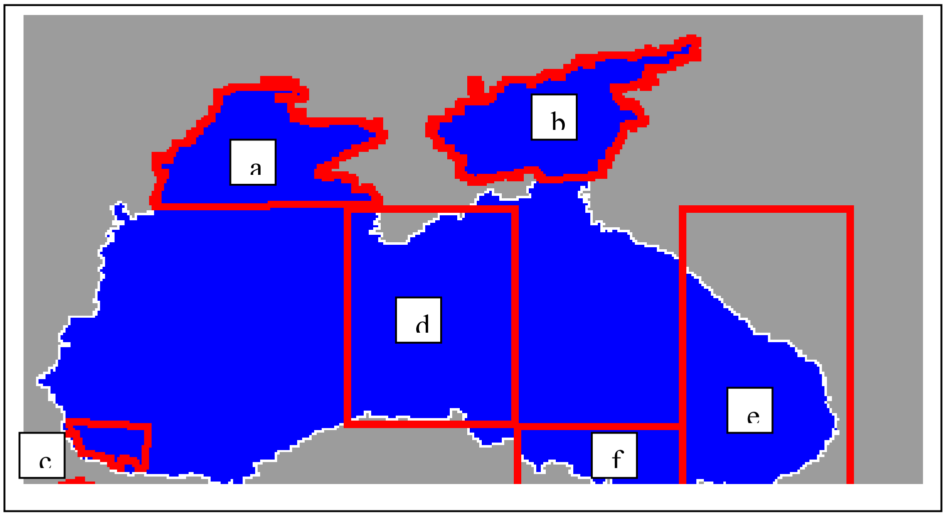


Figure 4.2. Thematic Map indicating the sub-regions in Blacksea (a- North Western Black Sea, b-Azov Sea, c-Pre-Bosphorous, d-Central Black Sea, e-Battumi Gyre, f-South Eastern Black Sea)

Mean pixel value of the sub-regions is calculated for each composite and assigned as the representative value for that time interval. These values are graphically represented and given in Figure 4.4 to Figure 4.8. Temporal distribution and the variability of the parameters for each sub-region were analyzed.

SST values in the Anatolian coasts are higher than the northern part of the Black Sea. Although some composites show erroneous results due to cloud coverage in general the mean SST distribution show a smooth variation within the year. The maximum temperature within the basin is in summer period and around 25 ºC in each sub-region. On the contrary the winter SST values vary inside the Black Sea.

Mean chlorophyll concentration in the sub-regions, show both spatial and temporal variations. According to Yunev et al. (2002), the chlorophyll concentration in the

Black Sea reaches peak values in winter and spring, the maximum occurs in January and March and a less marked peak is seen in November. However the values gathered from MODIS imagery reveals that the peak concentrations are in spring, or summer and autumn mainly in March, June and November.

Daskalov (1998), states that due to the impact of low temperatures and strong winds in winter time, the shelf zone is subject to intensive vertical mixing. Thus the phytoplankton bloom begins in the open sea in February-March accompanied by a zooplankton bloom in spring. The plankton bloom in the shallow North Western Shelf is generally delayed to the warmer season because of the more intensive winter cooling. It is also strengthened by the high river discharge in May and June.

i- North-western shelf

Although the outcome of the MODIS imagery interpretation gives similar results as Daskalov, unfortunately the chlorophyll concentration values in the North Western Shelf (Figure 4.3) and Azov Sea (Figure 4.4) are highly overestimated. The results might be influenced by the high freshwater inflow carrying both sediment and nutrients into these regions. In the shelf area SST ranges between 5 to 11 ºC (Figure 4.4).

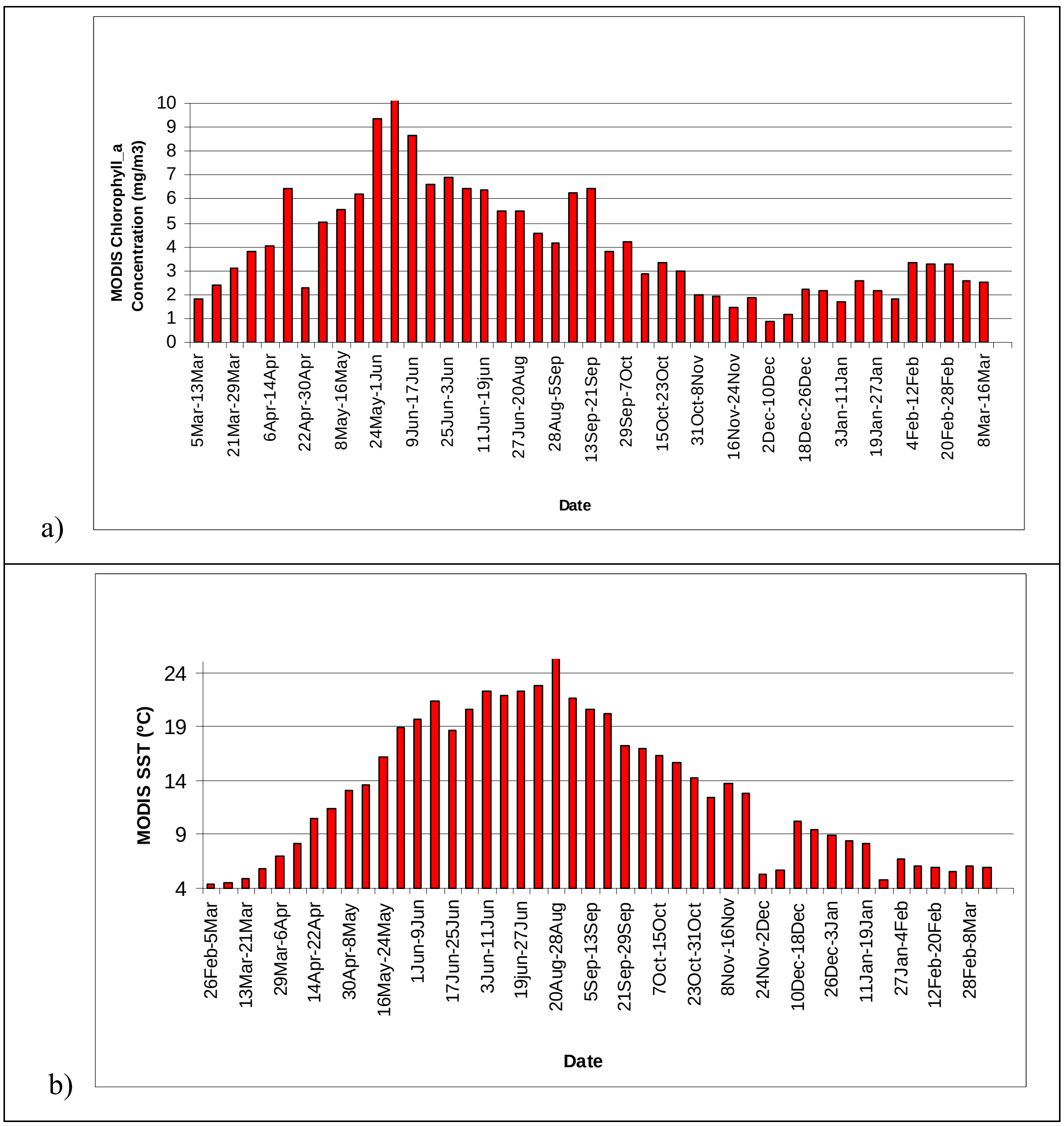


Figure 4.3. a) Annual Mean Chlorophyll-a Distribution of North Western Shelf b)Annual Mean SST Distribution of North Western Shelf

ii- Azov Sea

The overestimation of chlorophyll concentration values is higher in the Azov Sea due to the enclosed coverage, which increases the source of error due to ground reflectance. Azov Sea has the coldest SST values, which is less than 5 ºC through the winter (Figure 4.4), which might be due to the high fresh water inflow into the closed basin.

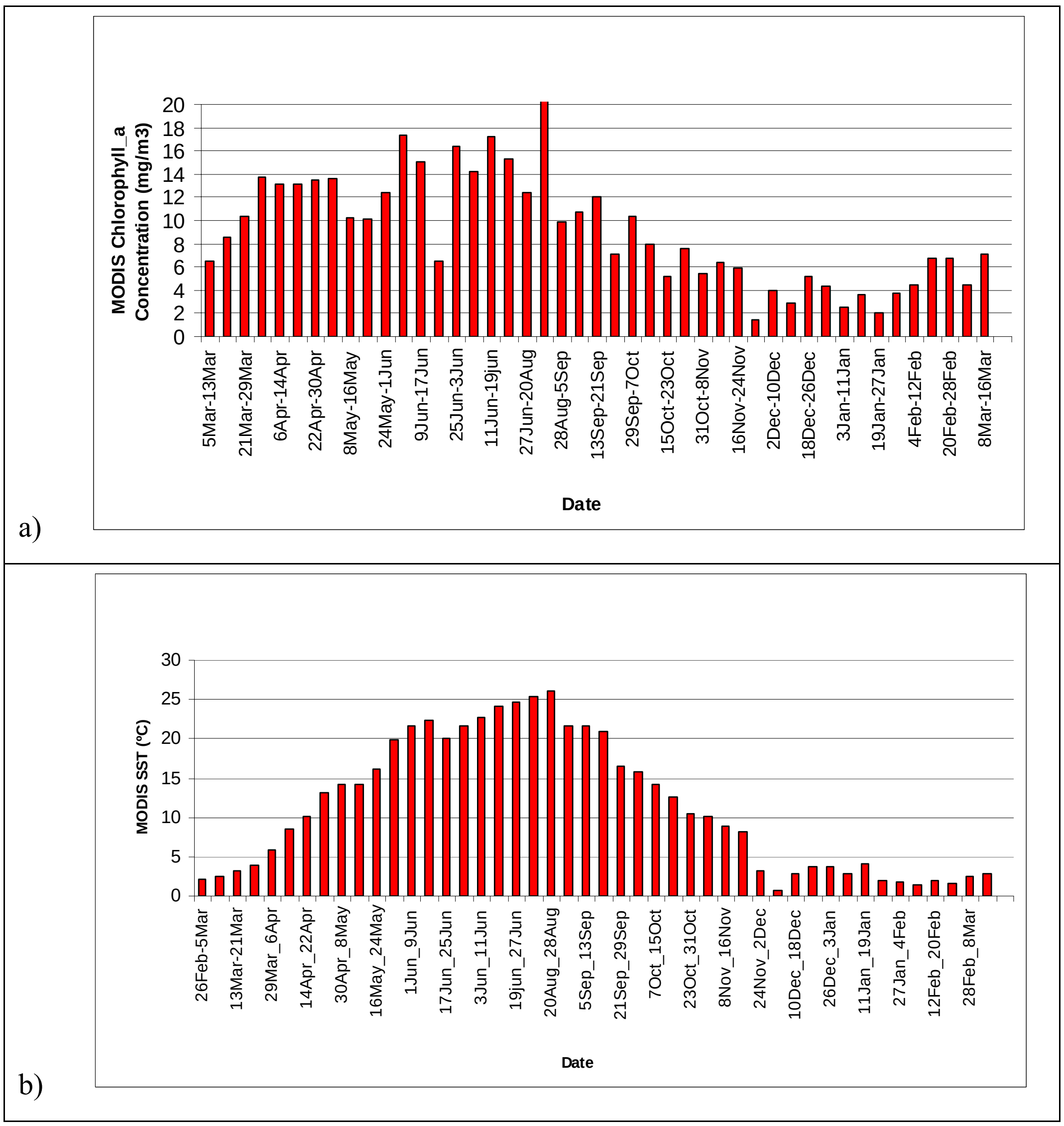
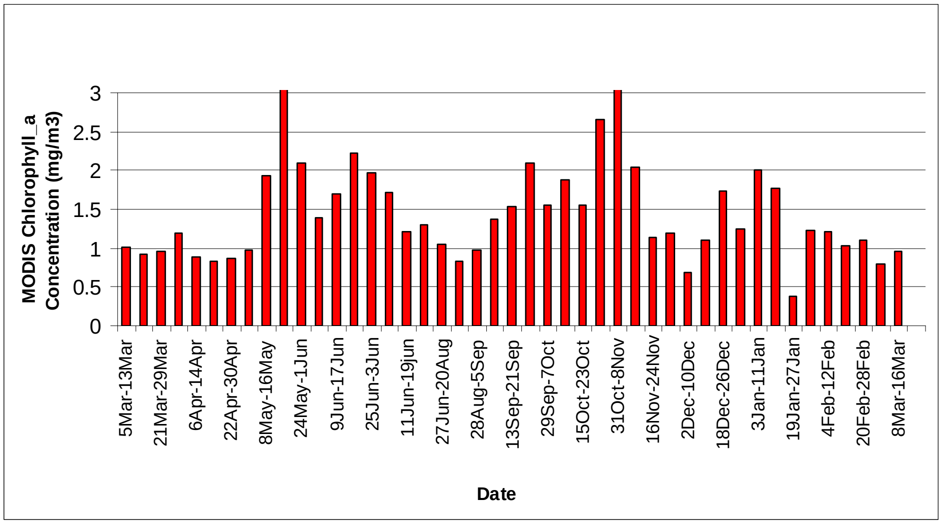


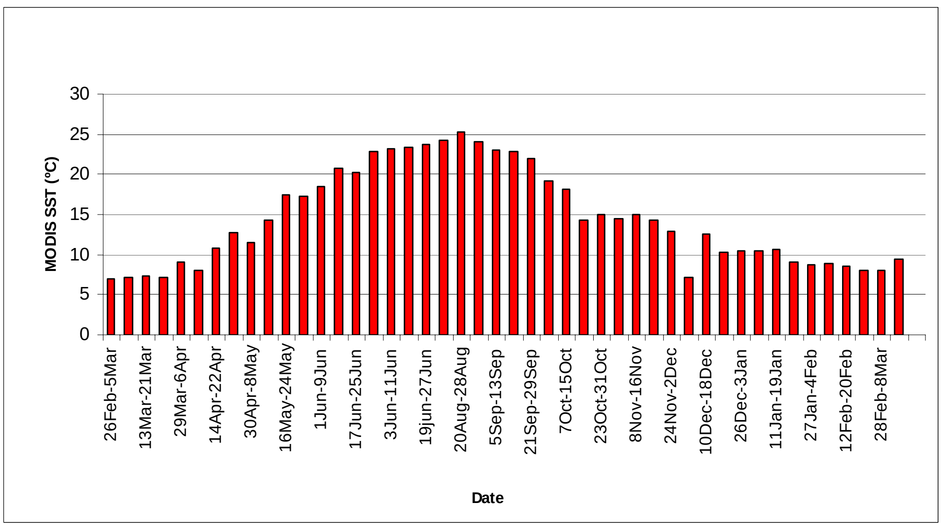
Figure 4.4. a) Annual Mean Chlorophyll-a Distribution of Azov Sea b) Annual Mean SST Distribution of Azov Sea

iii- Pre-Bosphorous

The rest of the sub-regions are mostly free from strong outer effects. Pre-bosphorous (Figure 4.5) show peak concentrations in late-spring/summer (May-June) and autumn (November). The area is warmer relative to the Northern Part, and the temperature varies between 7 to 11ºC.



a)



b)

Figure 4.5. a) Annual Mean Chlorophyll-a Distribution of Pre_Bosphorous b) Annual Mean SST Distribution of Pre_Bosphorous

iv- Central Black Sea

Central Black Sea shows similarity with the Pre-bosphorous. As represented in Figure 4.6, peak concentrations are in late-spring/summer (May-June) and autumn (November) and the temperature varies between 7 to 11ºC .

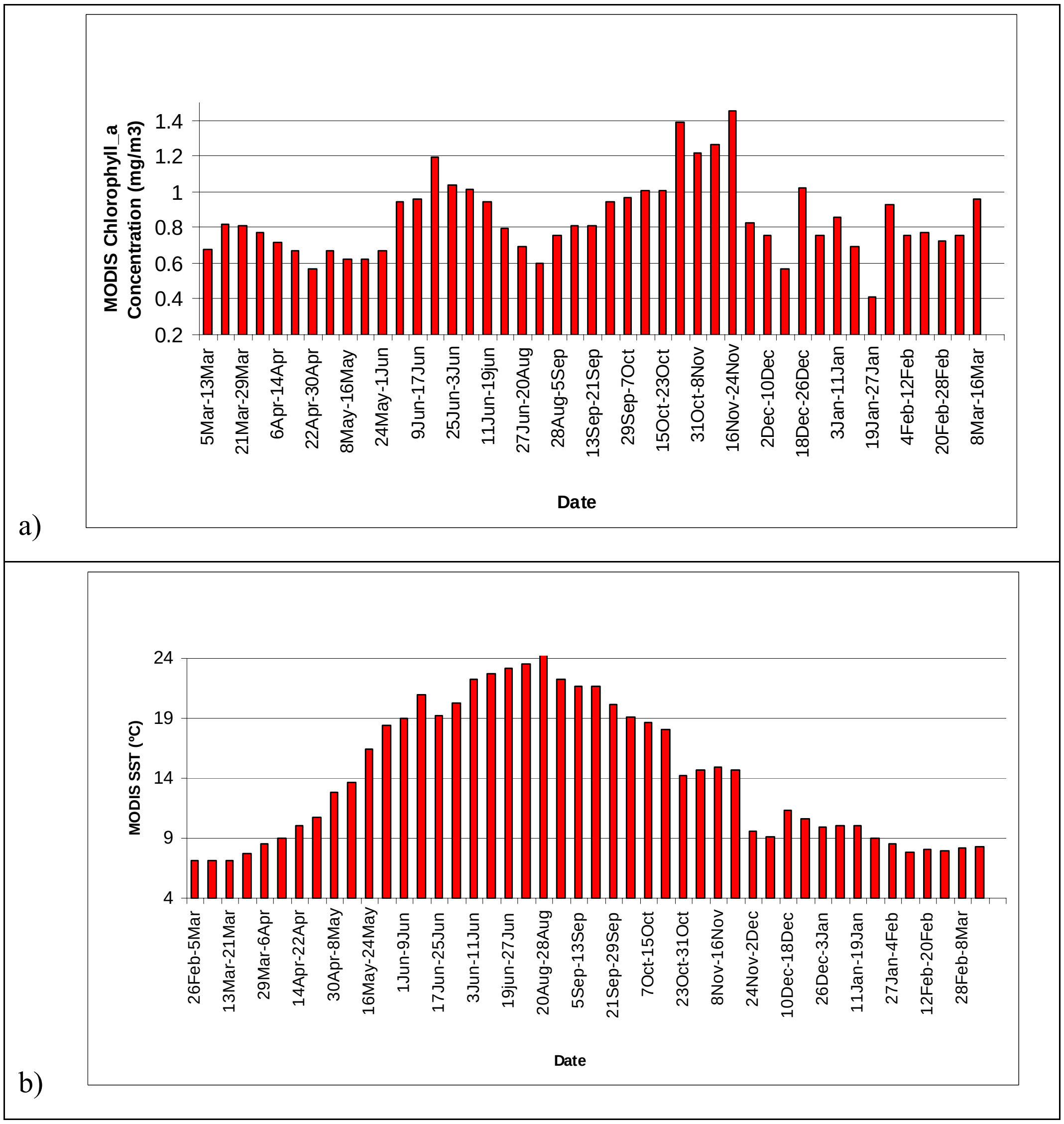
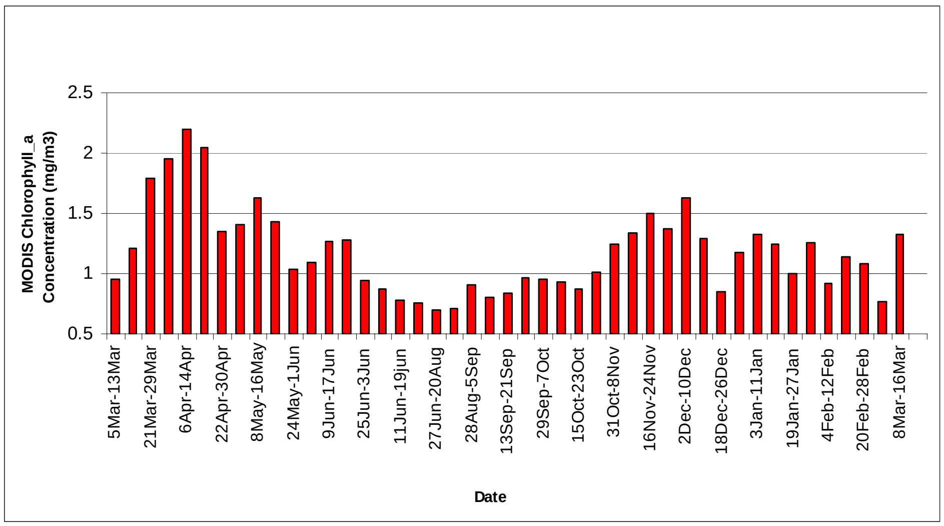


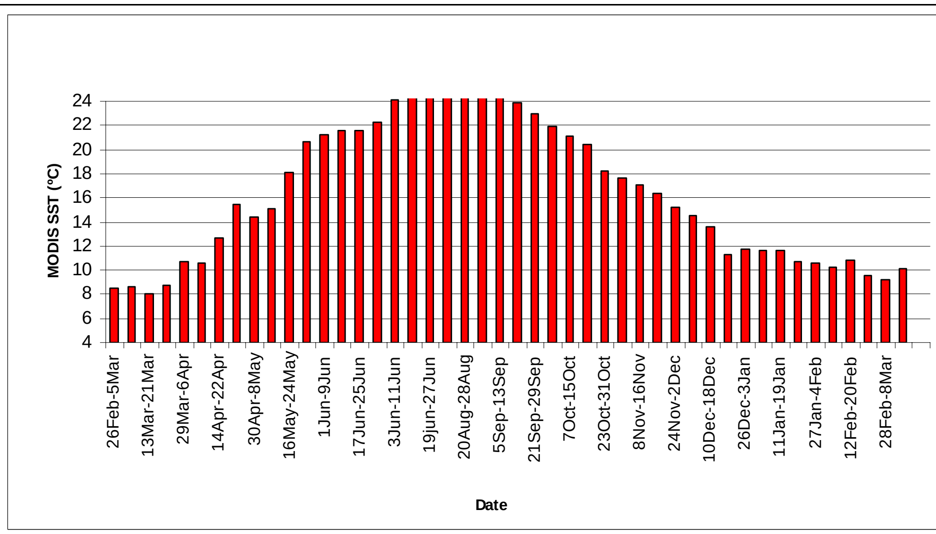
Figure 4.6. a) Annual Mean Chlorophyll-a Distribution of Central Black Sea
b) Annual Mean SST Distribution of Central Black Sea

v- Battumi Gyre

The Eastern part of the Black Sea, Battumi gyre (Figure 4.7) has the highest concentration values in spring (March) and autumn (November). Also the Eastern part is the warmest during the winter period is where the SST is around 8 to 12 º C SST.



a)

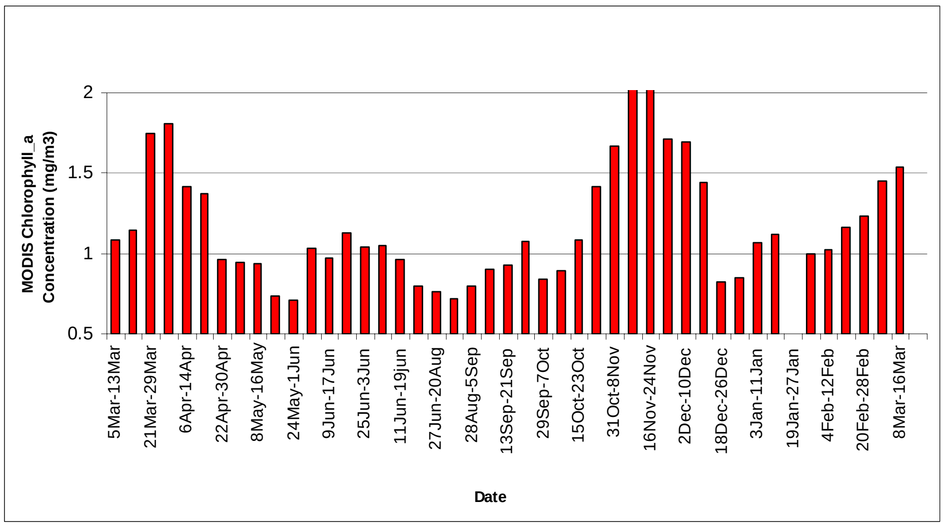


b)

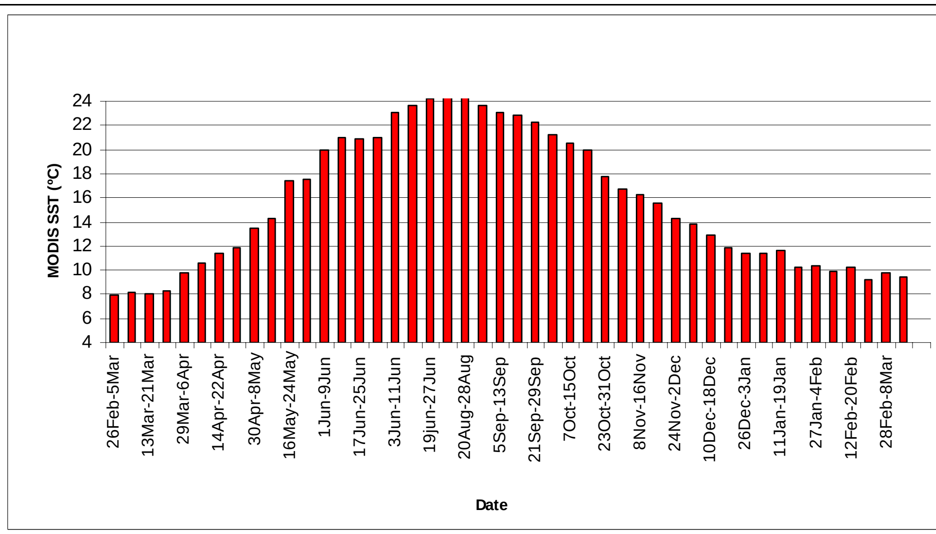
Figure 4.7. a) Annual Mean Chlorophyll-a Distribution of Battumi Gyre b) Annual Mean SST Distribution of Battumi Gyre

vi- South-Eastern Blacksea

South-Eastern Blacksea is similar to the Battumi gyre, the area shows the highest concentration values in spring (March) and autumn (November) as given in Figure 4.8. During the winter period the SST is around 8 to 12 º C SST in South Eastern Black Sea (4.8) similar to the the Battumi gyre (Figure 4.7).



a)



b)

Figure 4.8. a) Annual Mean Chlorophyll_a Distribution of South Eastern Blacksea b) Annual Mean SST Distribution of South Eastern Blacksea

4.2. Determination of Potential Favorable Zones for Pelagic Fish Stocks in the Black Sea

The capabilities of GIS, like managing large amounts of spatial data and also the ability to integrate multiple layers and ancillary data, have made GIS an effective tool in defining potential favorable zones for fish stocks. However for the integration of decision maker's preferences and the geographical data, a combination of GIS and MCDA is needed.

Two different decision rules are employed to generate fish stock maps, simple additive weigthing (SAW) and fuzzy additive weigthing (FSAW). These methods are similar, such that they both use the weighted average as the aggregation operator. However FSAW methods utilizes fuzzy data (Malczewski, 1999).

4.2.1. Determination of Potential Favorable Zones using SAW

A weight value that indicates the criterion importance relative to the other criteria is assigned to each criterion. Each criterion is ranked according to the decision maker's preferences. This criterion weighting method is called the ranking method and preferred due to its simplicity to apply (Malczewski, 1999).

Two criteria of equal importance (SST and chlorophyll concentration) are defined for this application. Each layer representing the criteria is divided into classes and given rank values according to their importance. Images are then reclassified upon the assigned rank values. The preferred temperature interval and the chlorophyll concentration for the anchovy are obtained from the literature.

In the literature there are only a few sea surface temperature measurements for the Black Sea Anchovy. Using the definitions in the literature, different temperature intervals are defined for different seasonal periods. During the spawning period for Anchovy starting from the end of April till the beginning of September fishing is prohibited in Black Sea. Thus this period is neglected in the analyses. Each temperature interval that is defined covers 3 ºC and has a 1ºC overlap with the neighbouring intervals. These intervals are assumed to be the best potential temperatures for the assigned seasonal periods and they are used as basis in the further analyses.

Weight assigned for each layer is multiplied by the rank value given to each class and all the overall scores are calculated. The zone with the highest score is chosen to be the best potential area. This method is named as SAW in the literature (Thill, 1999).

4.2.1.1. Sea Surface Temperature Images

Five different temperature intervals are defined according to the temperature preferences of Anchovy in the literature and expert knowledge as it is shown in the Figure 4.9. Each temperature interval is given the highest rank values in the assigned seasonal periods. For example SST imagery captured on 3rd of January 2001 belongs to 11-14 ºC temperature interval group. Pixel values within this range take 5 points out of 5. The neighbouring temperature intervals 14-16 ºC and 9-11 ºC are given 4 as rank value. Successive intervals take the lower values as they diverge from the prefered temperature values.

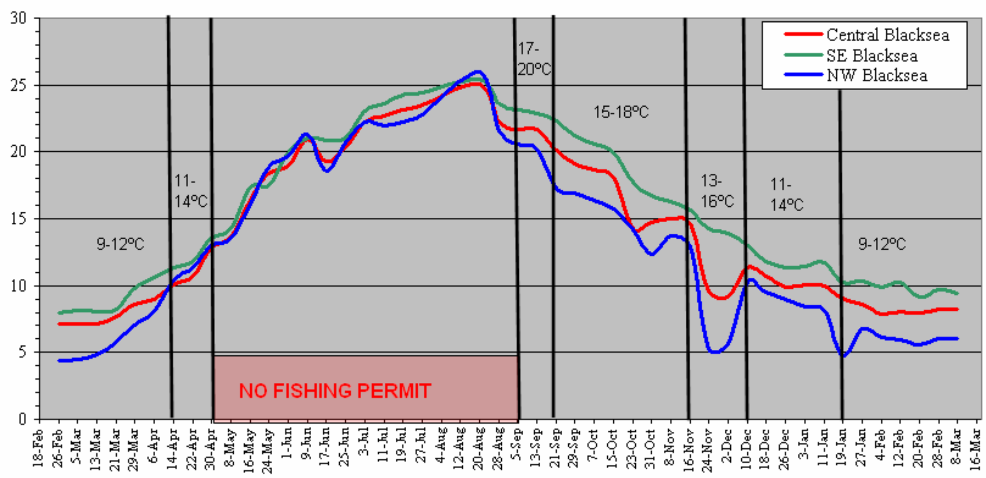


Figure 4.9. Mean SST Distribution Throughout the Black Sea and the Temperature Intervals

It should also be considered that although the Level 3 products are 8 day composite, the imagery captured especially on winter may contain inaccurate results or null values due to cloud coverage.

The reclassification results are given in the Figure 4.10. Prefered temperature interval having highest rank value is indicated in red color and the areas having lowest rank value are indicated in dark blue color.

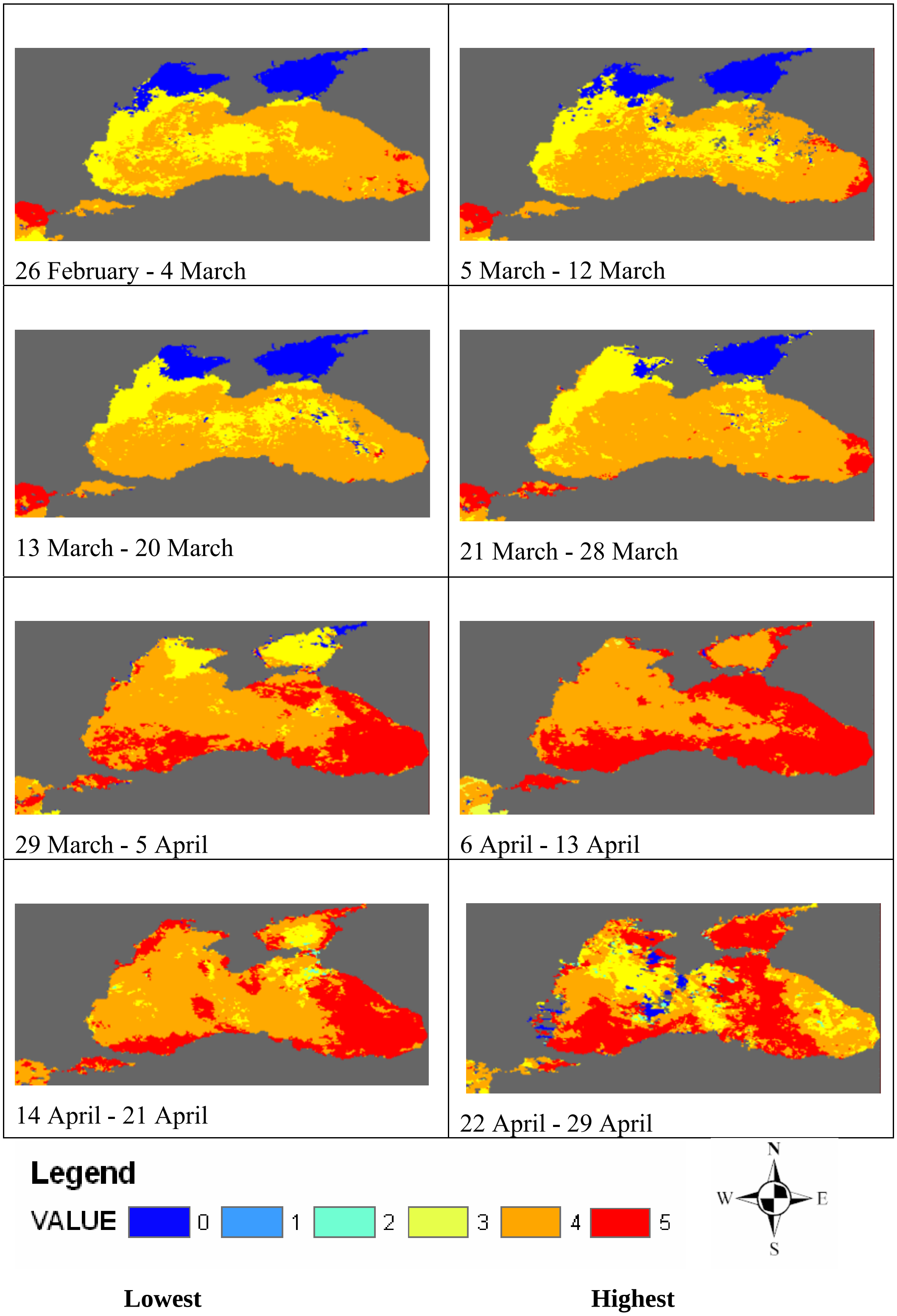


Figure 4.10. Reclassified SST Distribution in Black Sea

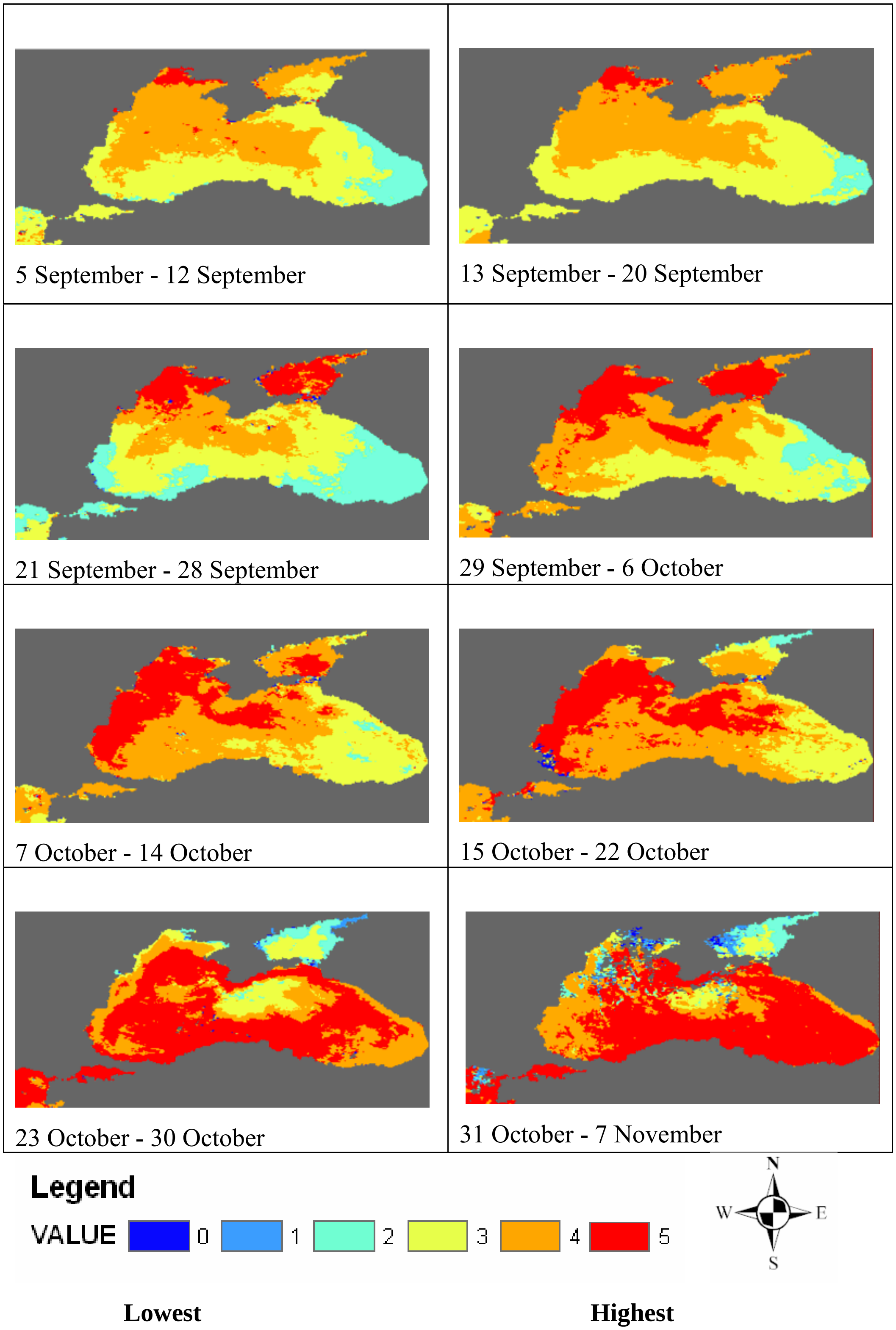


Figure 4.10. (continued). Reclassified SST Distribution in Black Sea

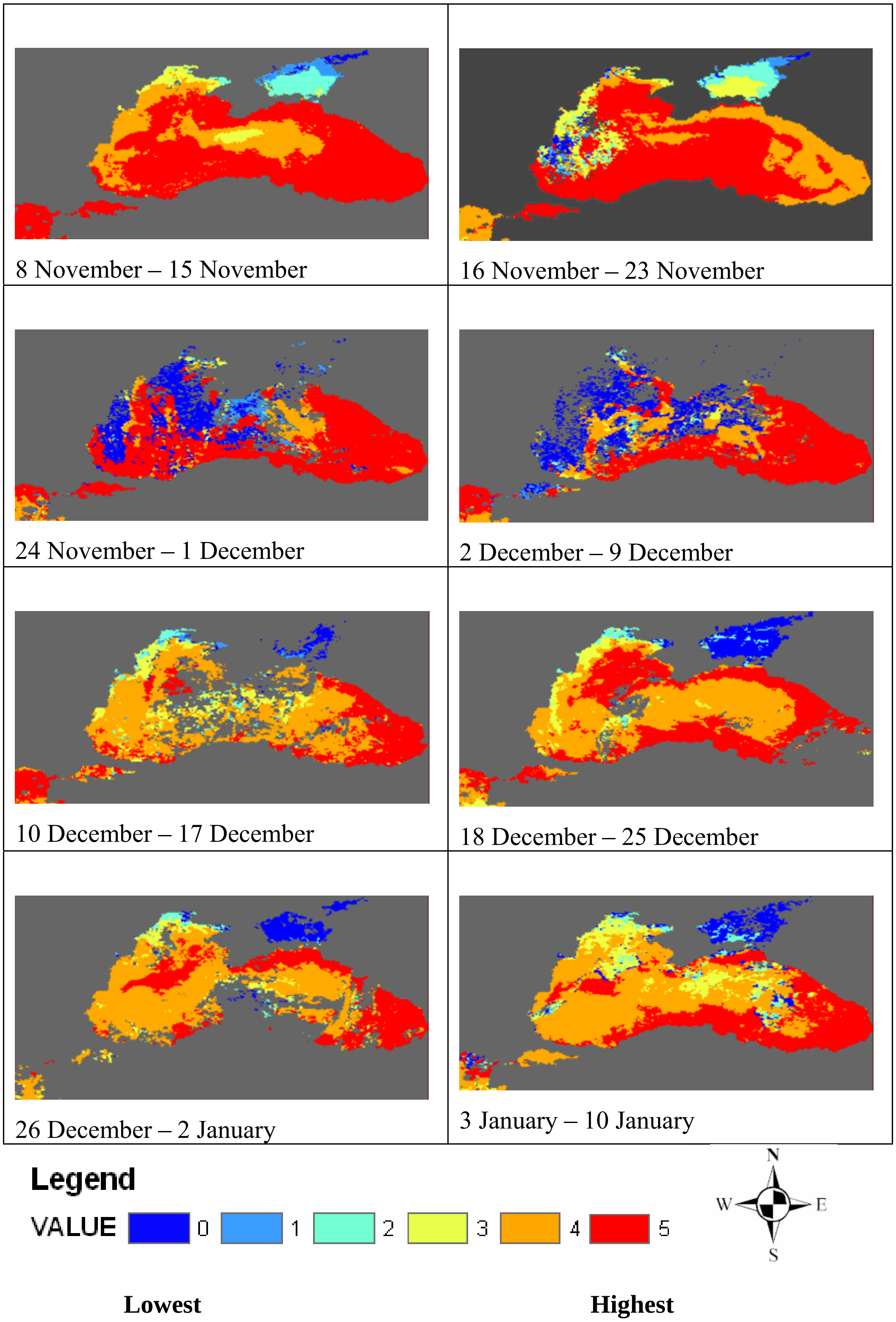


Figure 4.10. (continued). Reclassified SST Distribution in Black Sea

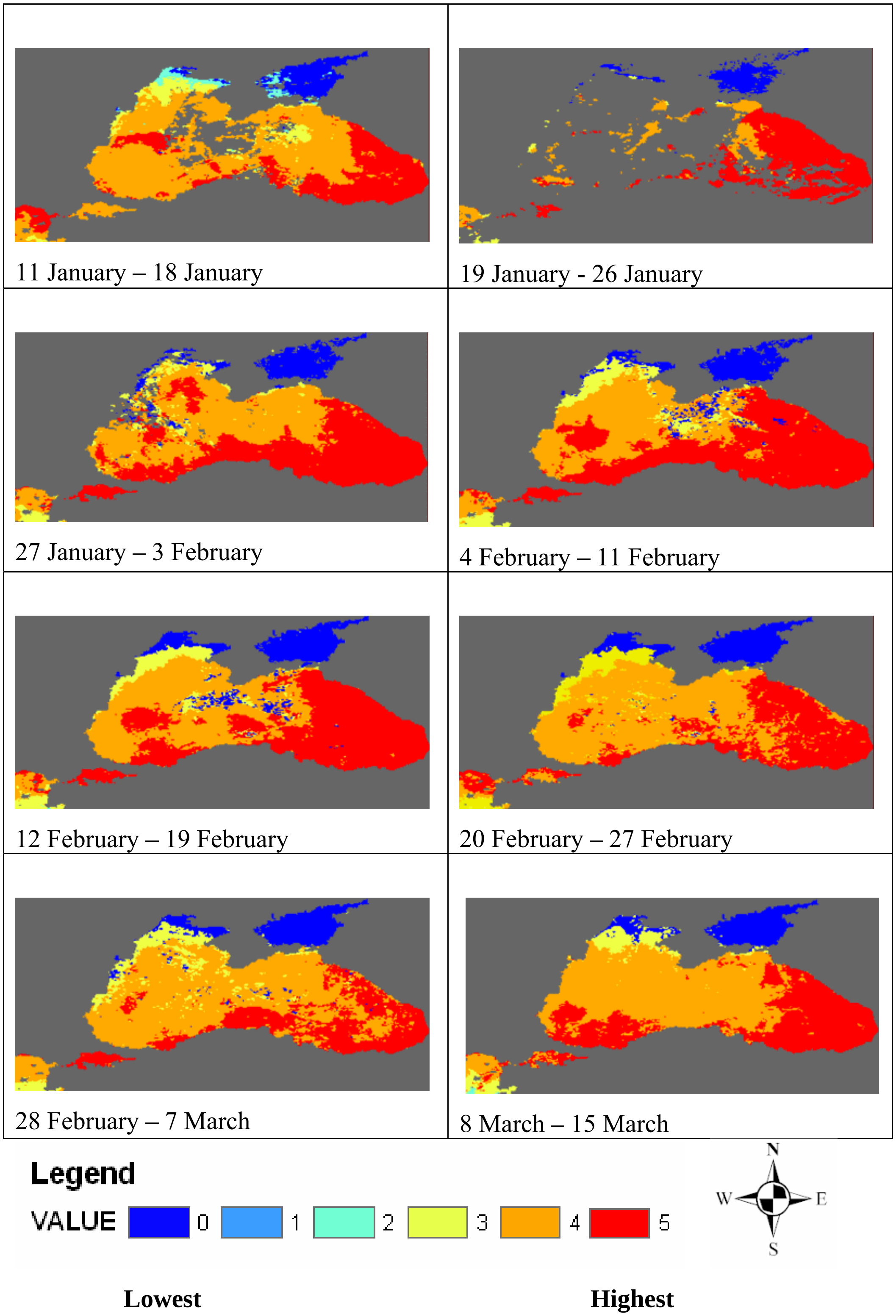


Figure 4.10. (continued). Reclassified SST Distribution in Black Sea

4.2.1.2. Chlorophyll Concentration Images

MODIS Level 3 Chlorophyll concentration images are reclassified according to the availability of nutrient. As it it clearly seen from the reclassified chlorophyll concentration imagery in Figure 4.11, rivers flowing into the Black Sea are important source of nutrient. Especially the large rivers in the North West keep the concentration values high in the coast throughout the year. Also Azov Sea has high concentration during the year without exception, due to inflow of the river Don and its enclosed coverage.

Assuming that the anchovy would prefer to be in the zones having nutrient, the imagery is reclassified according to the chlorophyll concentration values. The concentration between 20-5 mg/m3 is given the highest rank value and as the concentration decreases, the rank values decreases sucessively. Whereas Chlorophyll concentrations more than 20 mg/m3 is assumed to be too much and/or erroneous values (Yunev, 2002) so concentrations more than this value is given the lowest rank value. As an example, a pixel having a concentration value of 6 mg/m3 takes the highest rank value 5 out of 5, and if the value is between 3 to 5 mg/m3 the corresponding rank value is 4.

In reclassified chlorophyll concentration images red areas indicates highest rank value and the lowest rank value areas are represented by dark blue color.

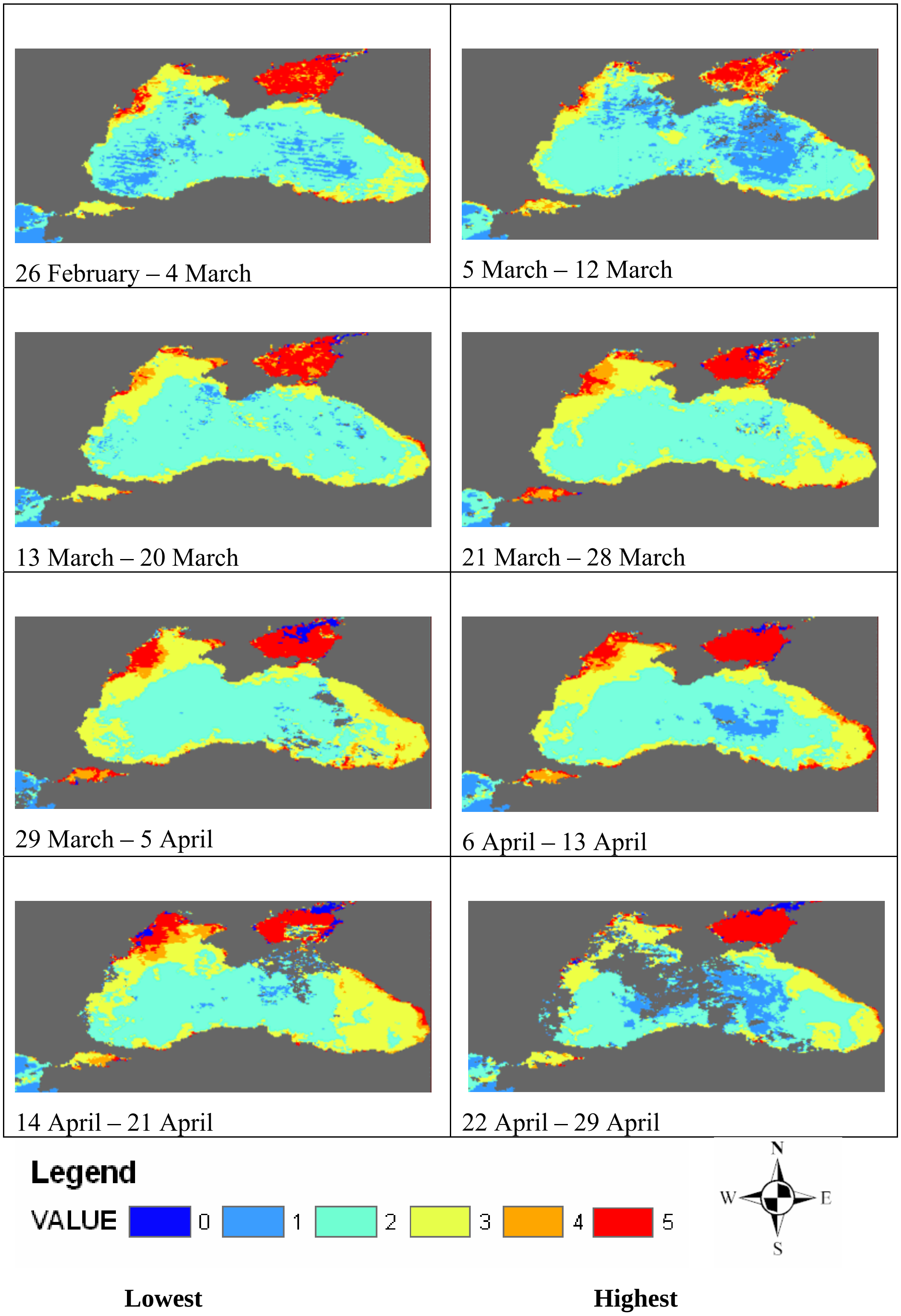
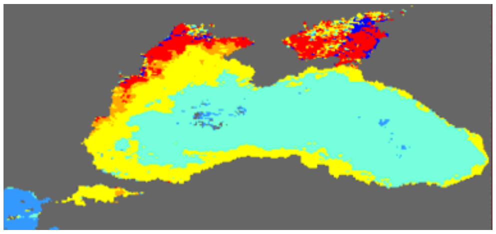
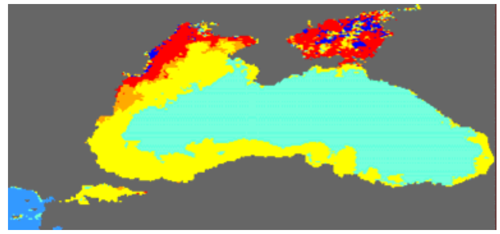


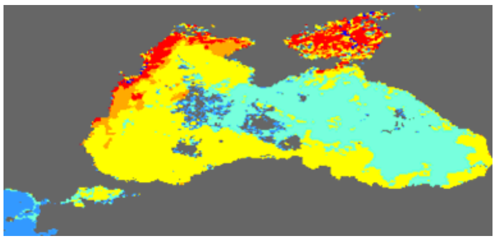
Figure 4.11. Reclassified Chlorophyll Concentration Distribution in Black Sea



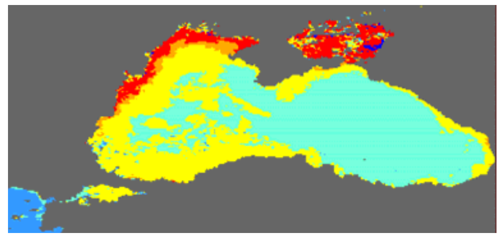
5 September – 12 September



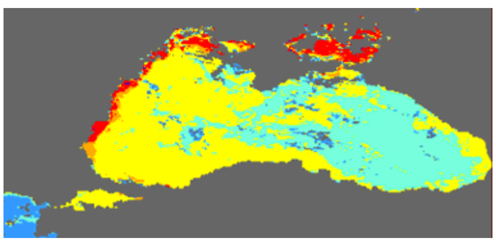
13 September – 20 September



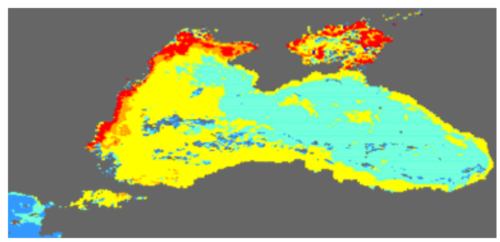
21 September – 28 September



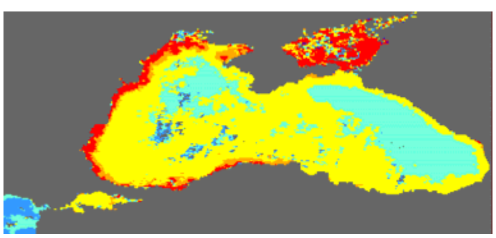
29 September – 6 October



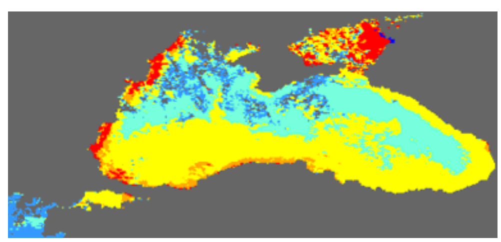
7 October – 14 October



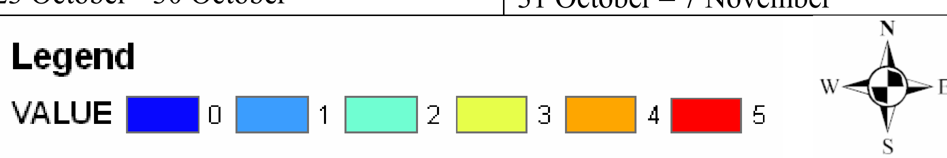
15 October – 22 October



23 October - 30 October



31 October – 7 November



Lowest **Highest**

Figure 4.11. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea

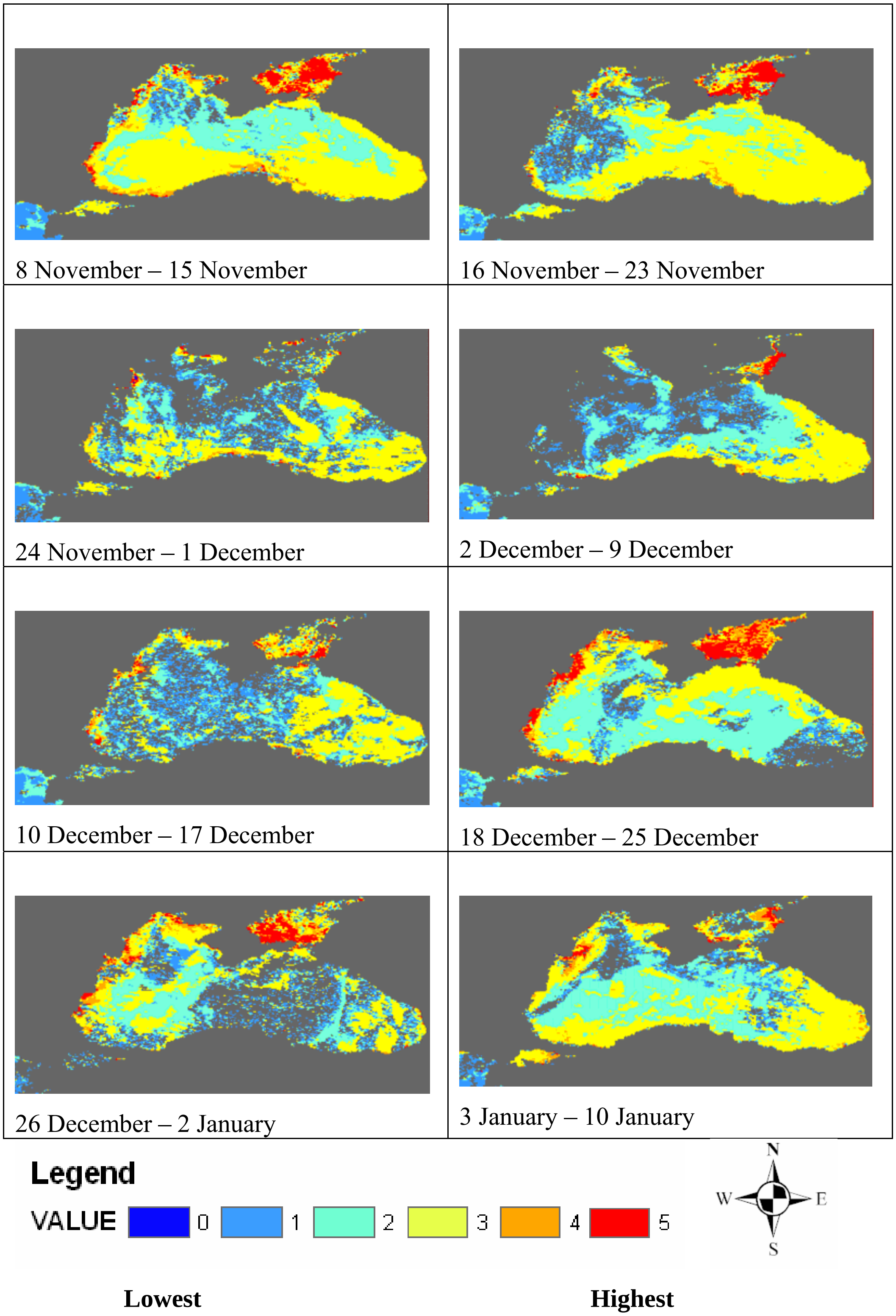


Figure 4.11. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea

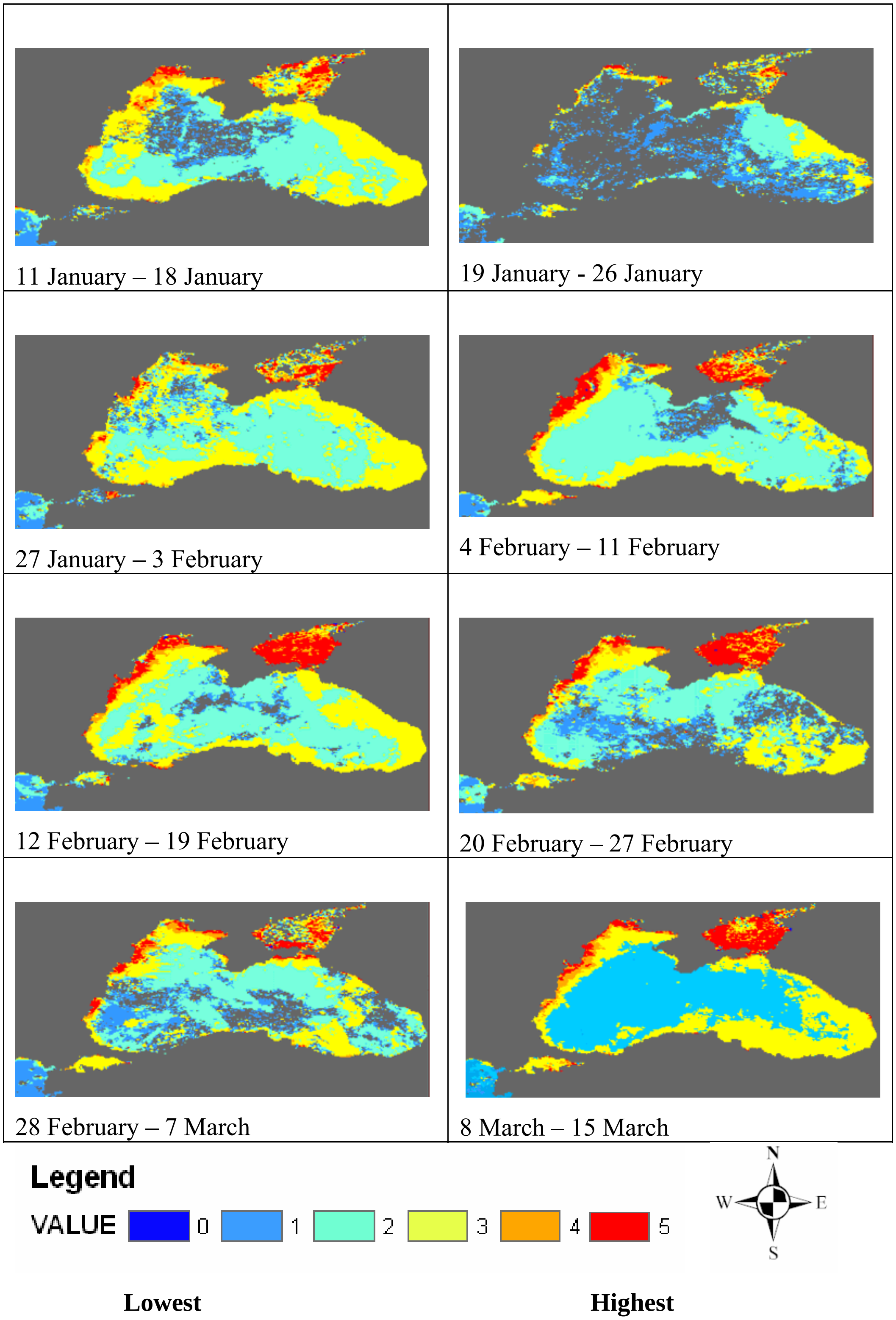


Figure 4.11. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea

4.2.1.3. Resultant Thematic Fish Stock Maps Generated by SAW

Reclassified images of SST and chlorophyll concentration are assigned equal weight values due to assumption that each layer has equal contribution to define fish stock maps. SST is known be the most significant parameter which defines the fish habitat, and the accuracy of satellite derived SST values are higher with respect to the cholorophyll concentration values. Yet still it is assumed that both the temperature and nutrient availabilty affect the habitat of fish and equal weight values are used to overcome the domination of SST values over cholorophyll concentration values.

The reclassified layers are summed and the zone with the highest score is chosen to be the potential favorable zones.

The resultant maps are given in the 4.12. Parallel to the literature, potential favorable zones for anchovy are located on the Northern part of the Black Sea in the end of summer and the beginning of autumn. As the winter approaches the potential sites start to approach south to warmer waters and reach Turkish coasts.

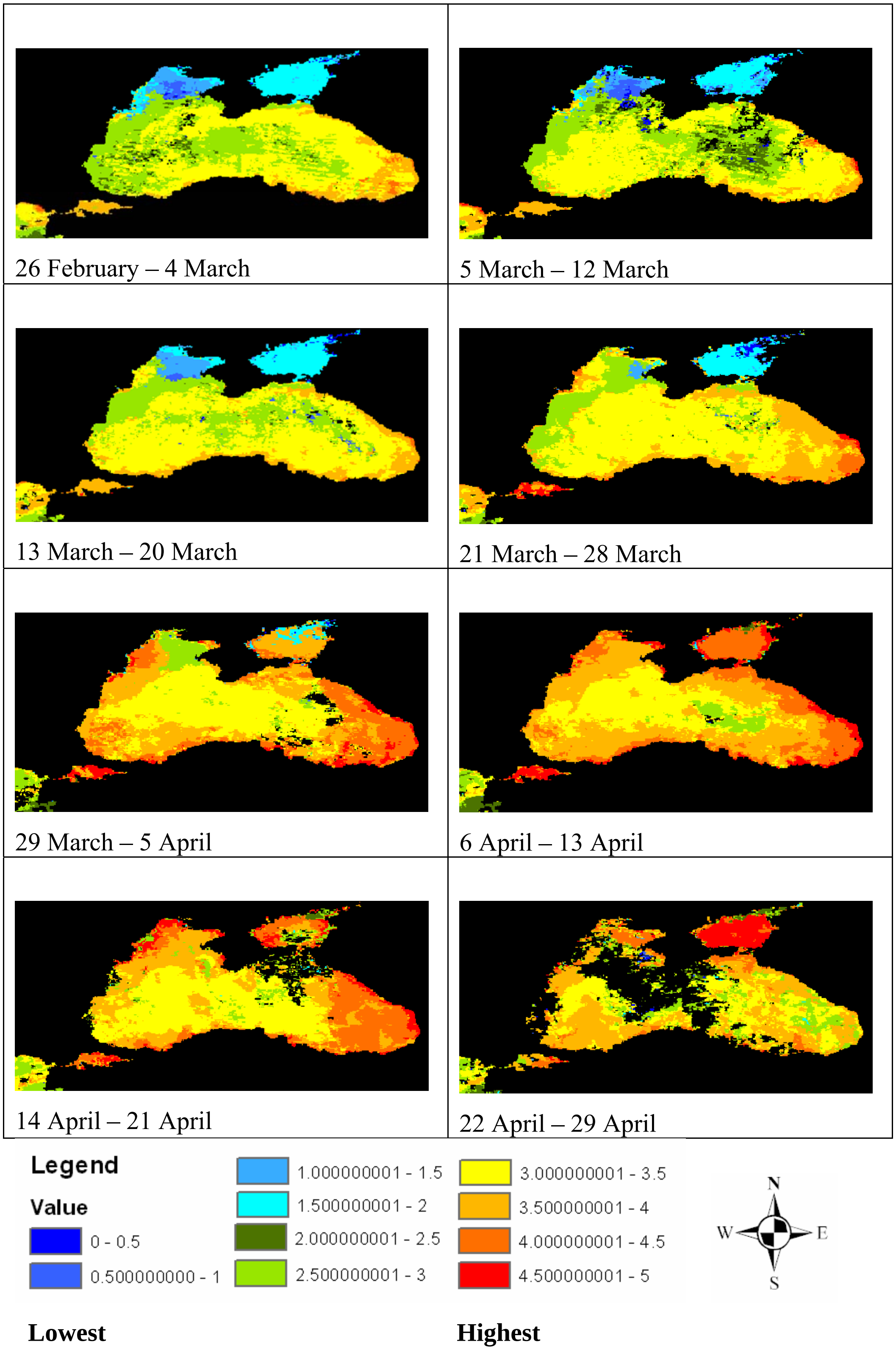


Figure 4.12. Resultant Thematic Fish Stock Maps Generated by SAW in Black Sea

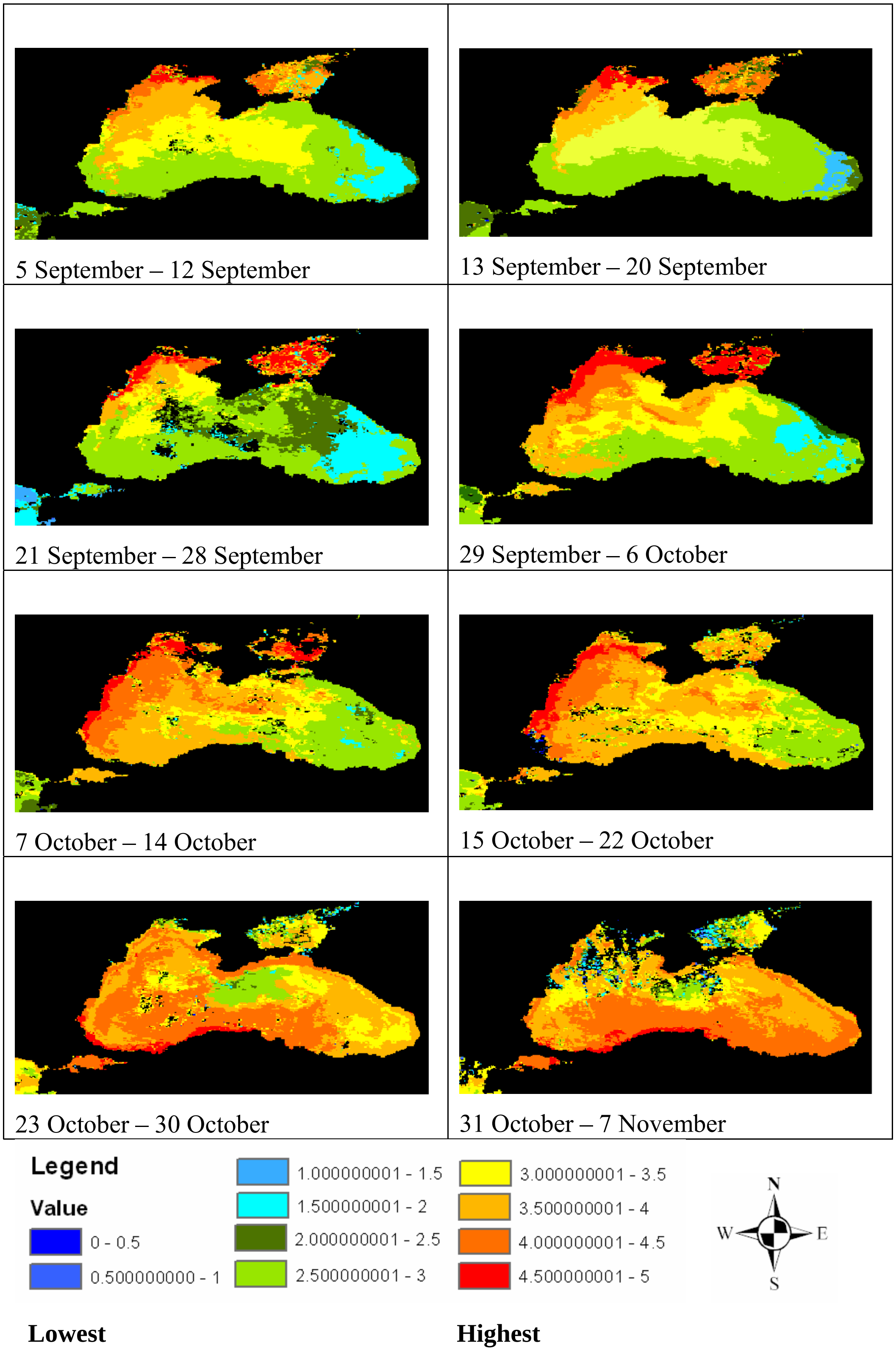


Figure 4.12. (continued). Resultant Thematic Fish Stock Maps Generated by SAW

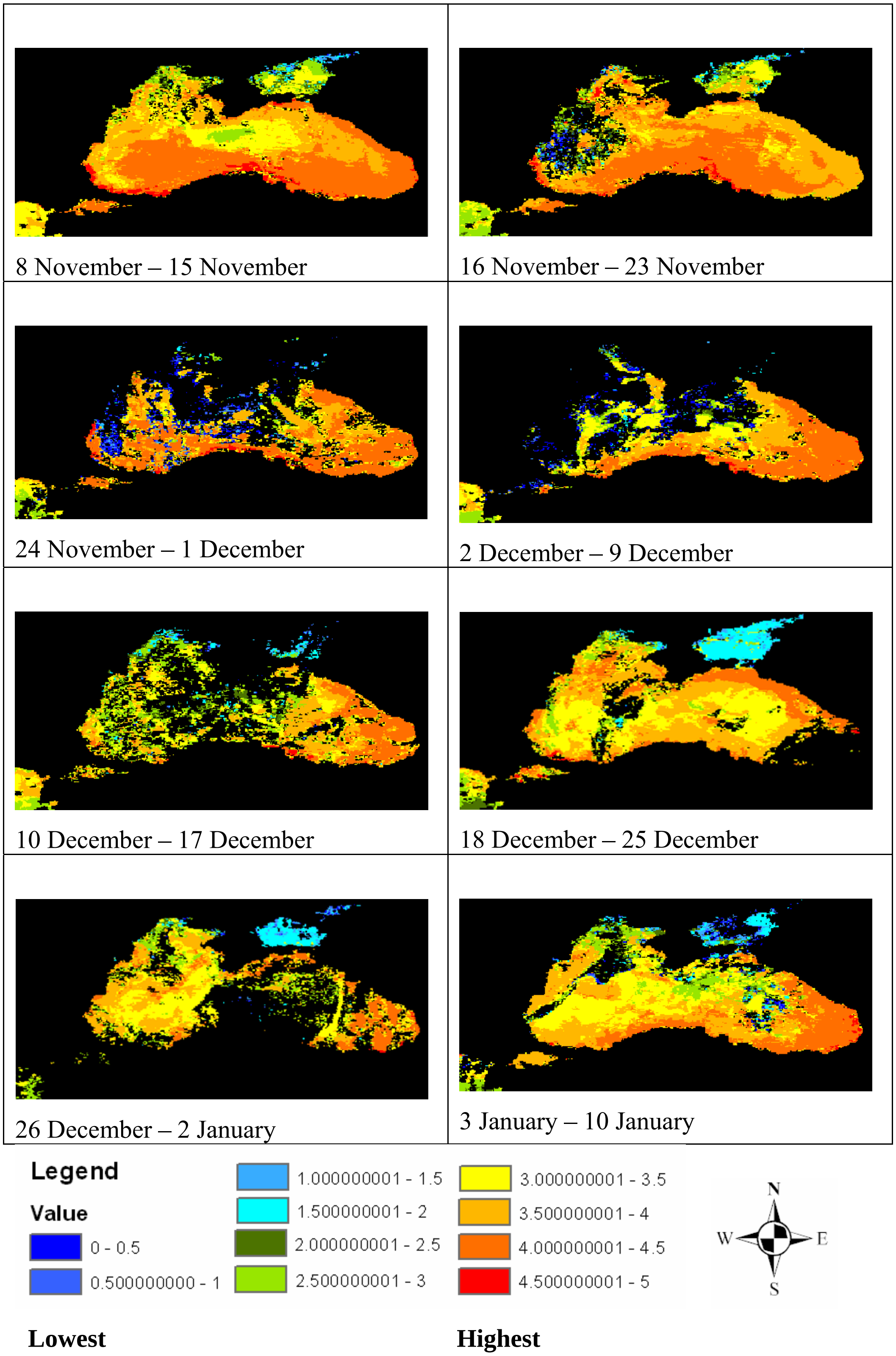


Figure 4.12. (continued). Resultant Thematic Fish Stock Maps Generated by SAW

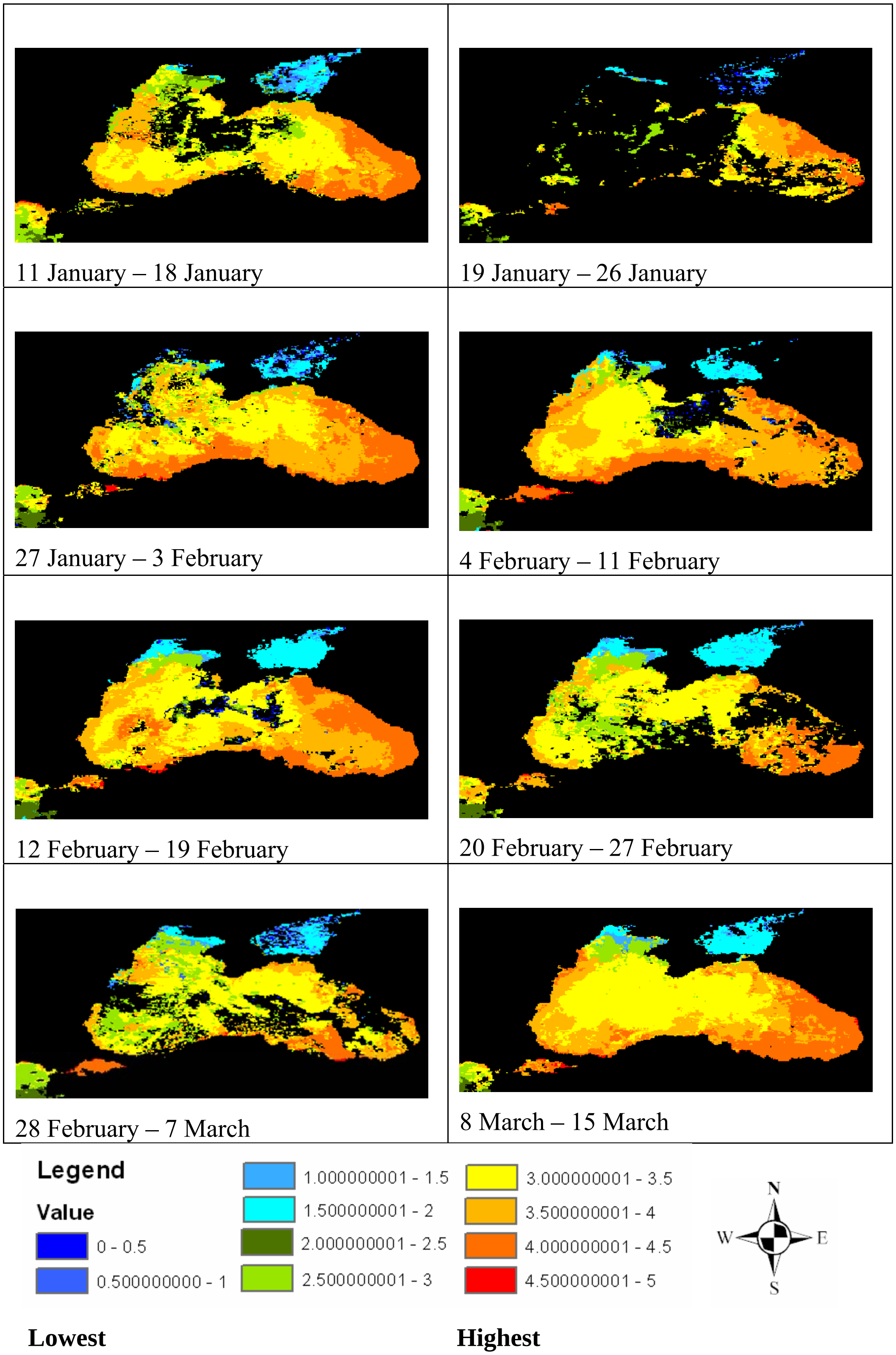


Figure 4.12. (continued). Resultant Thematic Fish Stock Maps Generated by SAW

4.2.2. Determination of Potential Favorable Zones using FSAW

The capability of SAW and GIS application combination which utilize classical set theory are inadequate to interpret the natural variability in the environment. The other method applied to generate fish stock maps is the integration of FSAW and GIS.

Fuzzy sets provides powerful representation of critical components of spatial decision making and furthermore a meaningful representation of vague or imprecise concepts (Malczewski,1999).

Through the use of linguistic variables, experts experiences involving imprecision, are converted to fuzzy rules. In this thesis, the fuzzy analyses are implemented on FuzzyCell software, which is developed on a commercial GIS software called ArcMap. This is free software and developed at METU Geodetic and Geographic Information Technologies Department. FuzzyCell allows users to handle imprecision in the decision making process (Yanar and Akyürek, 2005).

4.2.2.1. Sea Surface Temperature Images

MODIS Level 3 images and the previously defined temperature intervals are used in the analyses. As each temperature interval is given the highest rank values in the reclassification process, again in the membership function of fuzzy logic analyses prefered temperature interval is given the peak values for the assigned seasonal period. Bell shaped membership function, which is believed to define the smooth transition between the class values as given in the Figure 4.13, is selected to define the SST.

The areas, which suits the habitat preferences of anchovy are indicated in red and the least prefered areas are shown in dark blue color as given in Figure 4.14.

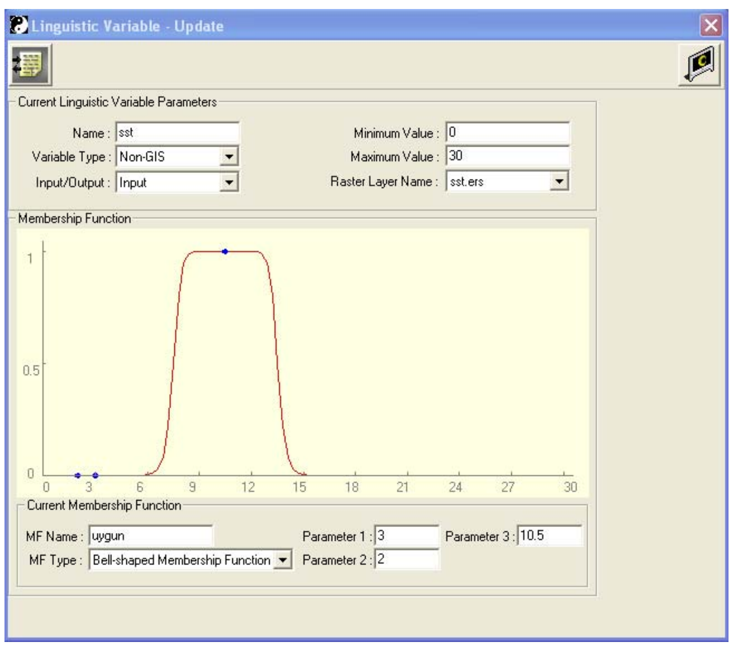


Figure 4.13. Bell Shaped Membership Function Defining the SST Distribution in Black Sea.

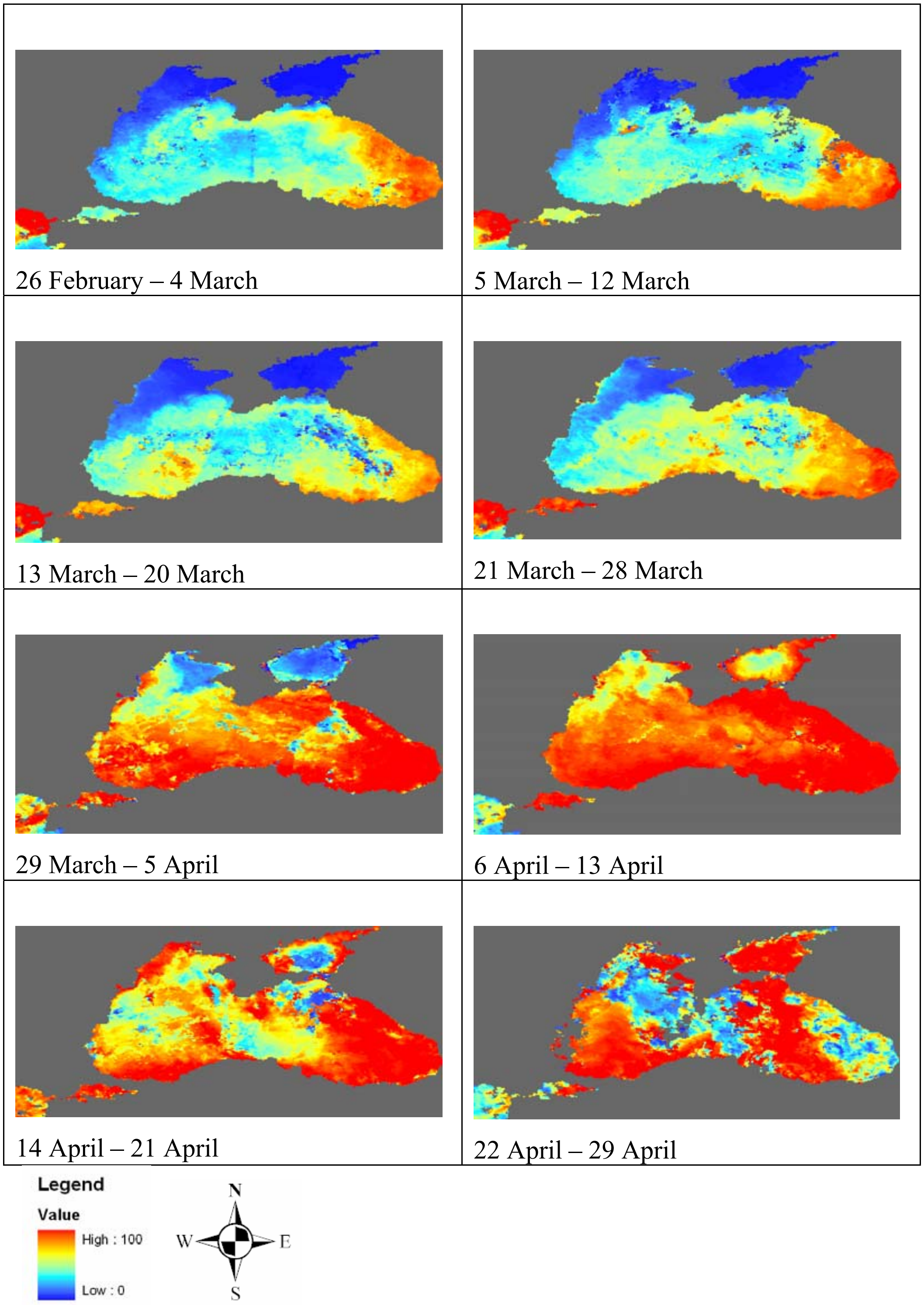


Figure 4.14. Reclassified SST Distribution in Black Sea with Bell Shaped Membership Function

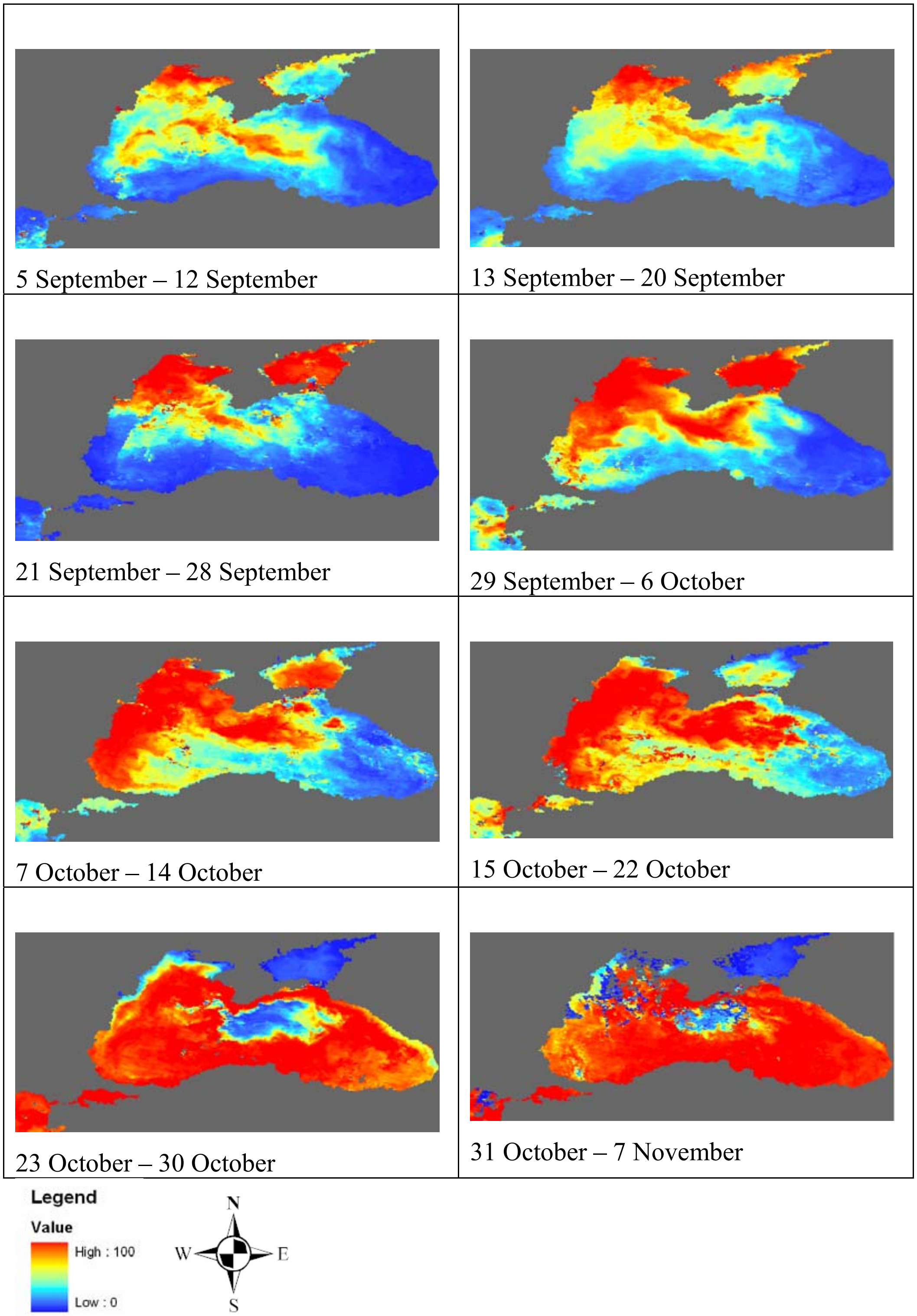
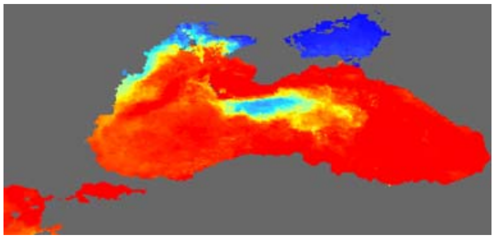
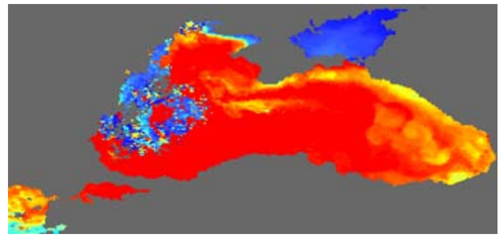


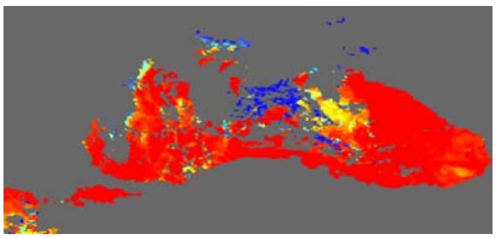
Figure 4.14. (continued). Reclassified SST Distribution in Black Sea with Bell Shaped Membership Function



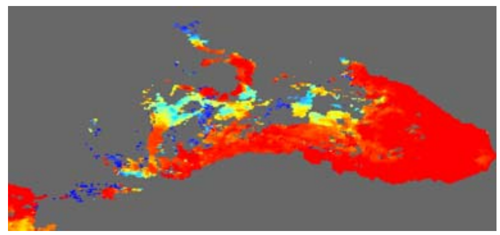
8 November – 15 November



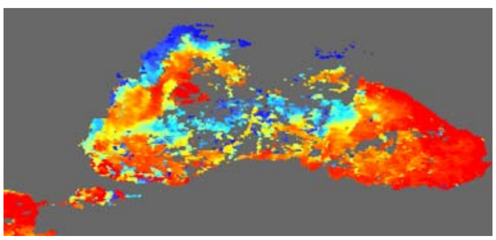
16 November – 23 November



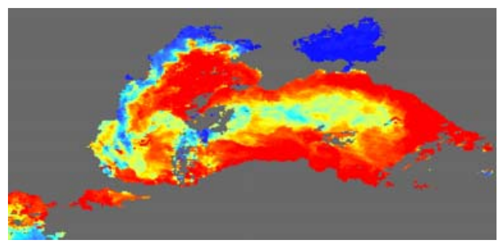
24 November – 1 December



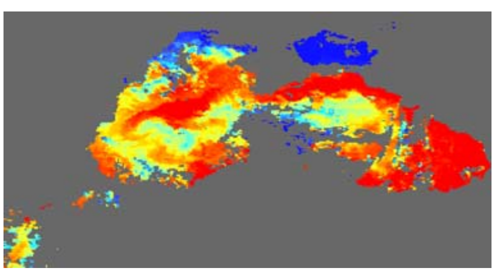
2 December – 9 December



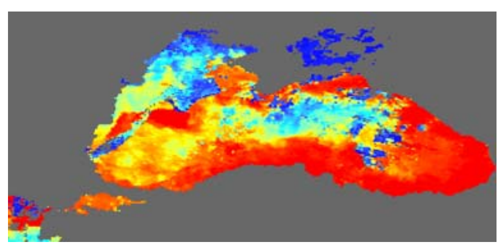
10 December – 17 December



18 December – 25 December



26 December – 2 January



3 January – 10 January

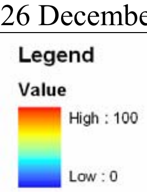


Figure 4.14. (continued). Reclassified SST Distribution in Black Sea with Bell Shaped Membership Function

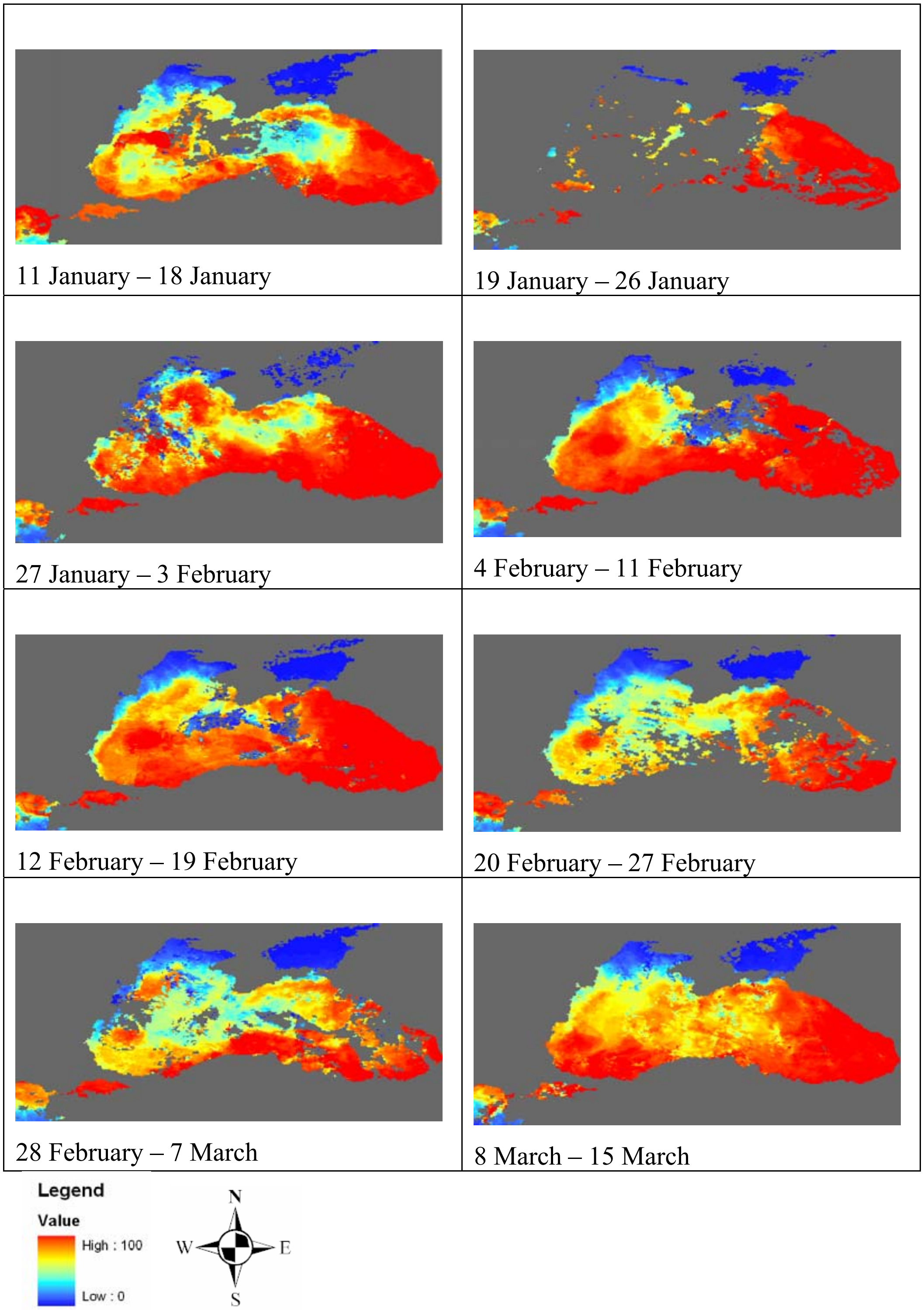


Figure 4.14. (continued). Reclassified SST Distribution in Black Sea with Bell Shaped Membership Function

4.2.2.2. Chlorophyll Concentration Images

Several trials are performed and finally trapezoidal membership function is believed to define the nutrient availability from MODIS Level 3 Chlorophyll concentration images. The concentration values between 5-20 mg/m3 is given the highest value in the function and the values decrease linearly as the concentration decreases. Chlorophyll concentrations more than 20 mg/m3 is assumed to be too much and/or erroneous values so concentrations more than this value are given lower values as the concentration increases.

The chlorophyll concentration having highest values are indicated in red color color and the lowest value areas are indicated in dark blue color. The reclassified chlorophyll concentration distribution in Black Sea in Figure 4.11 is mainly similar to the reclassified maps in Figure 4.16. The chlorophyll concentration in the North Eastern Black Sea and the Azov Sea are high throughout the year.

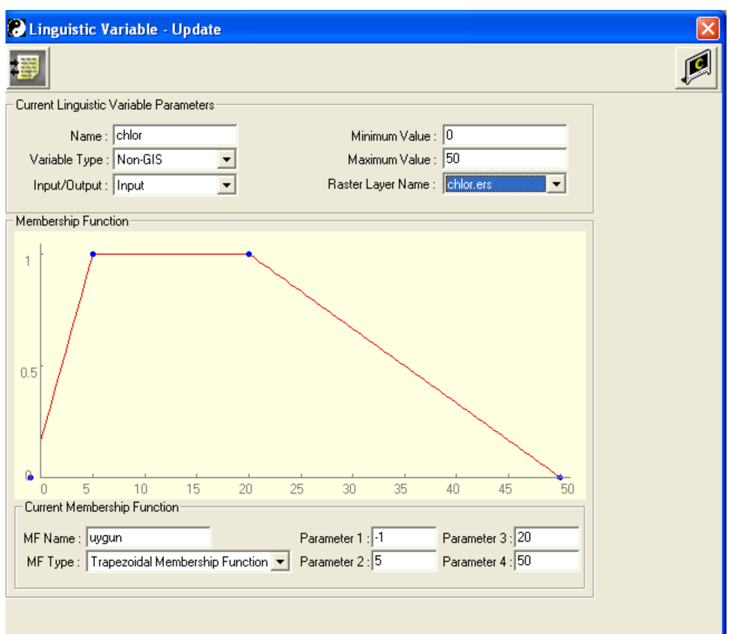


Figure 4.15. Trapezoidal Membership Function Defining the Chlorophyll Concentration Distribution in Black Sea.

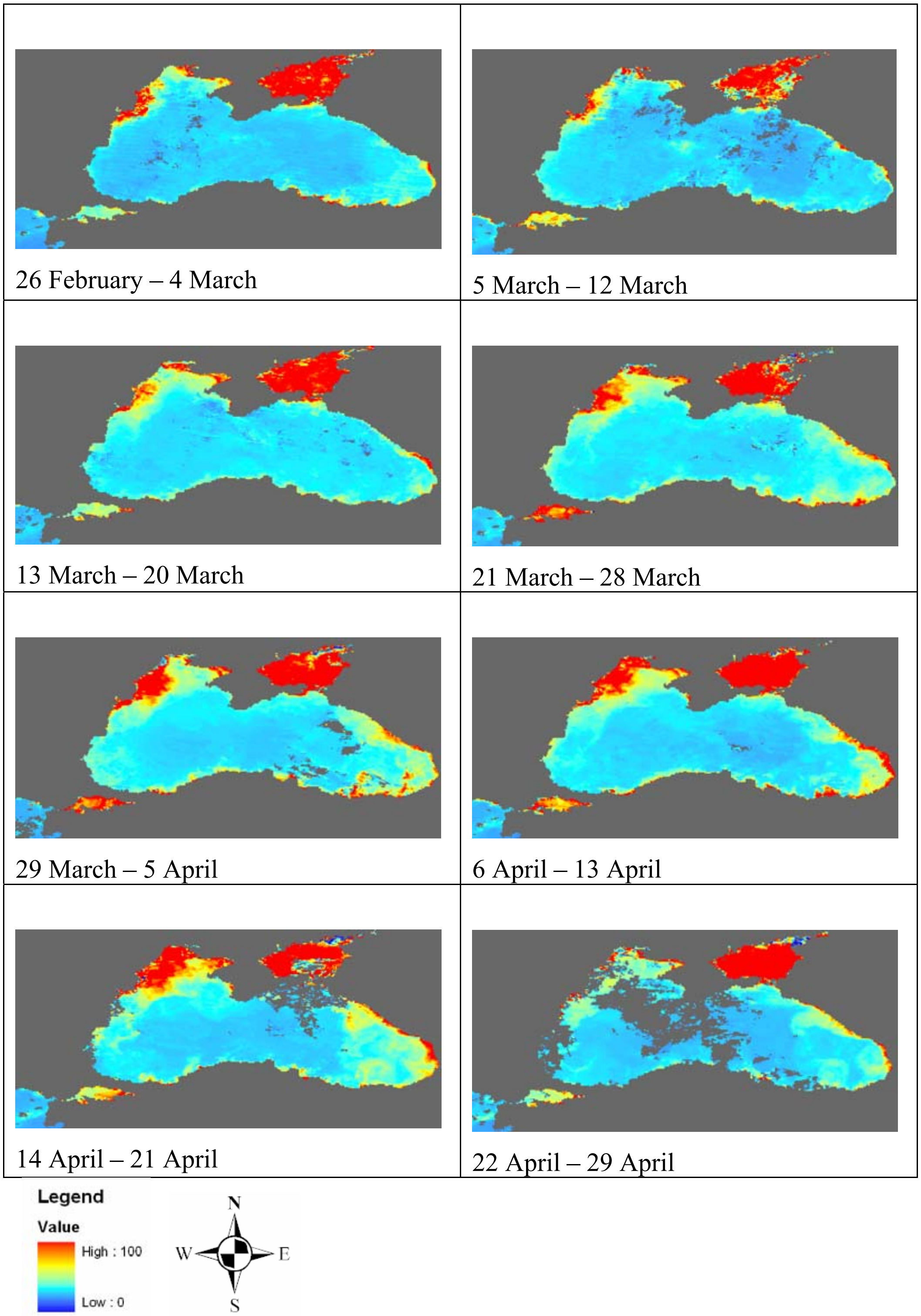


Figure 4.16. Chlorophyll Concentration Distribution in Black Sea

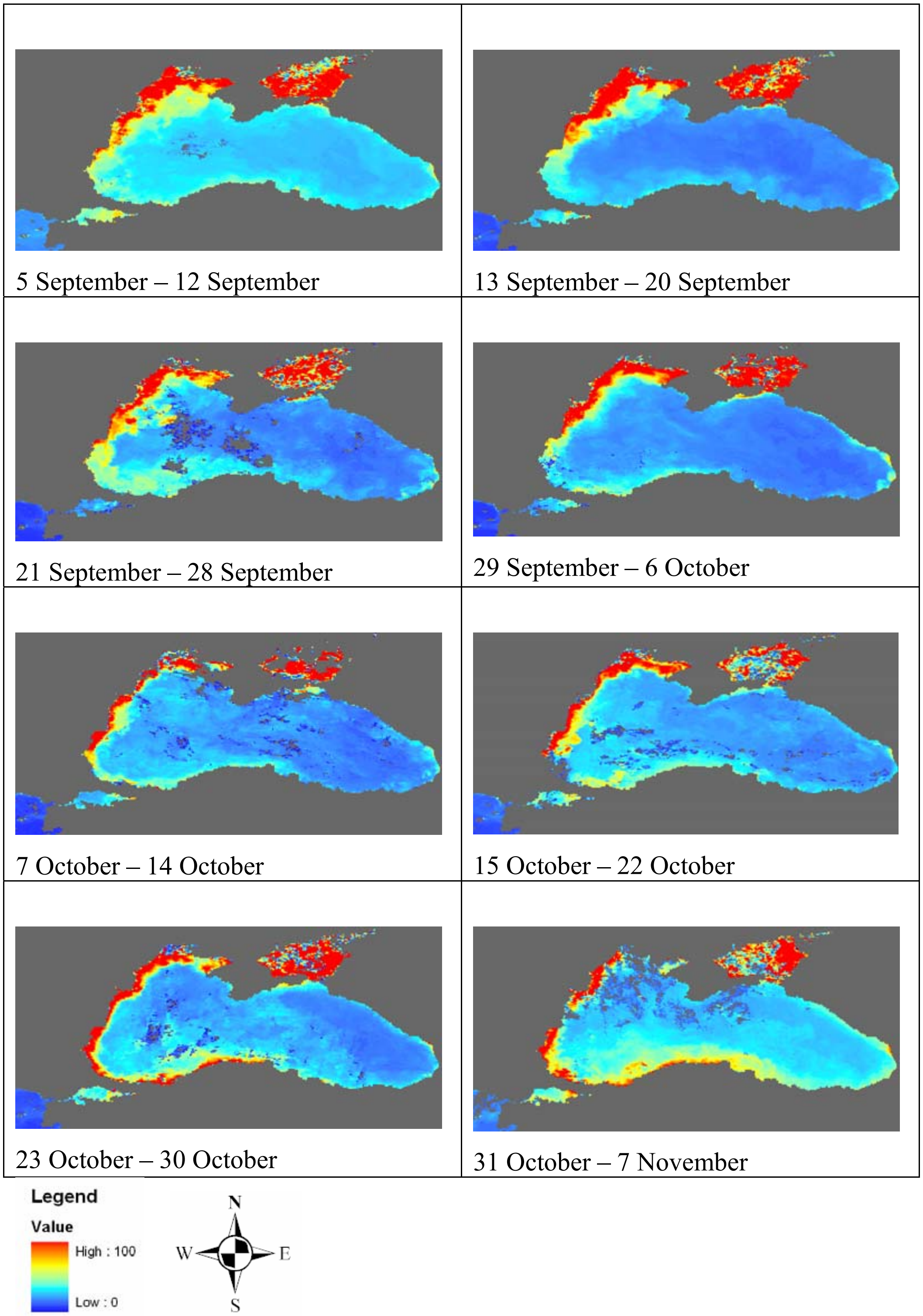
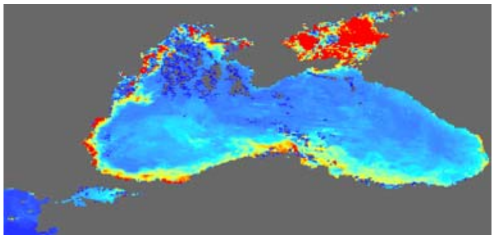
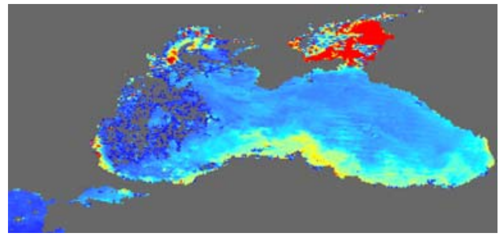
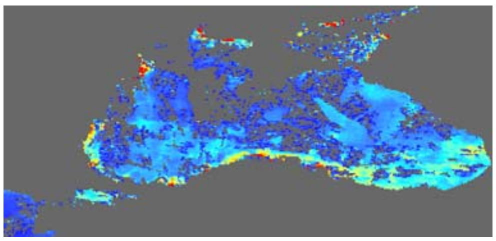
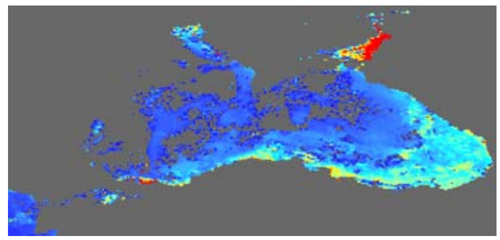
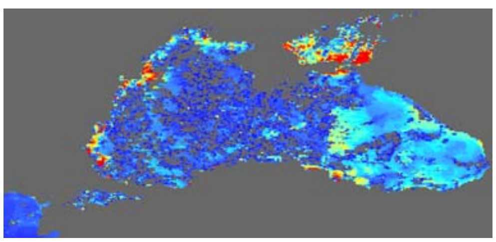
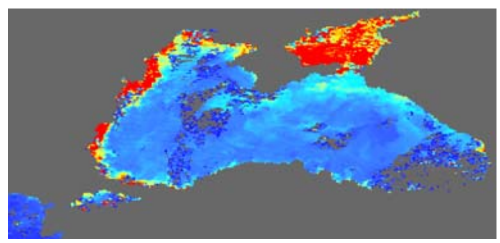
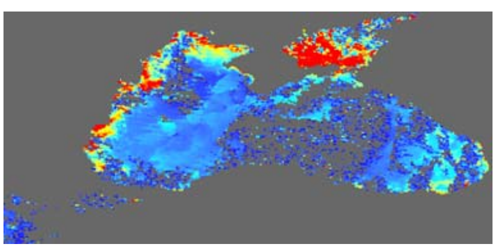
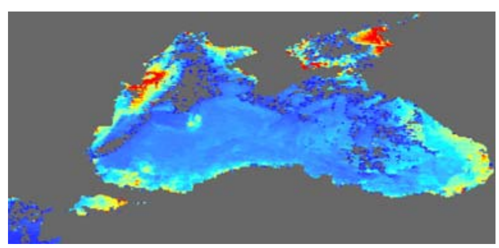


Figure 4.16. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea with Trapezoidal Membership Function.

 8 November – 15 November	 16 November – 23 November
 24 November – 1 December	 2 December – 9 December
 10 December – 17 December	 18 December – 25 December
 26 December – 2 January	 3 January – 10 January

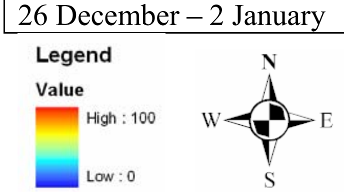


Figure 4.16. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea with Trapezoidal Membership Function.

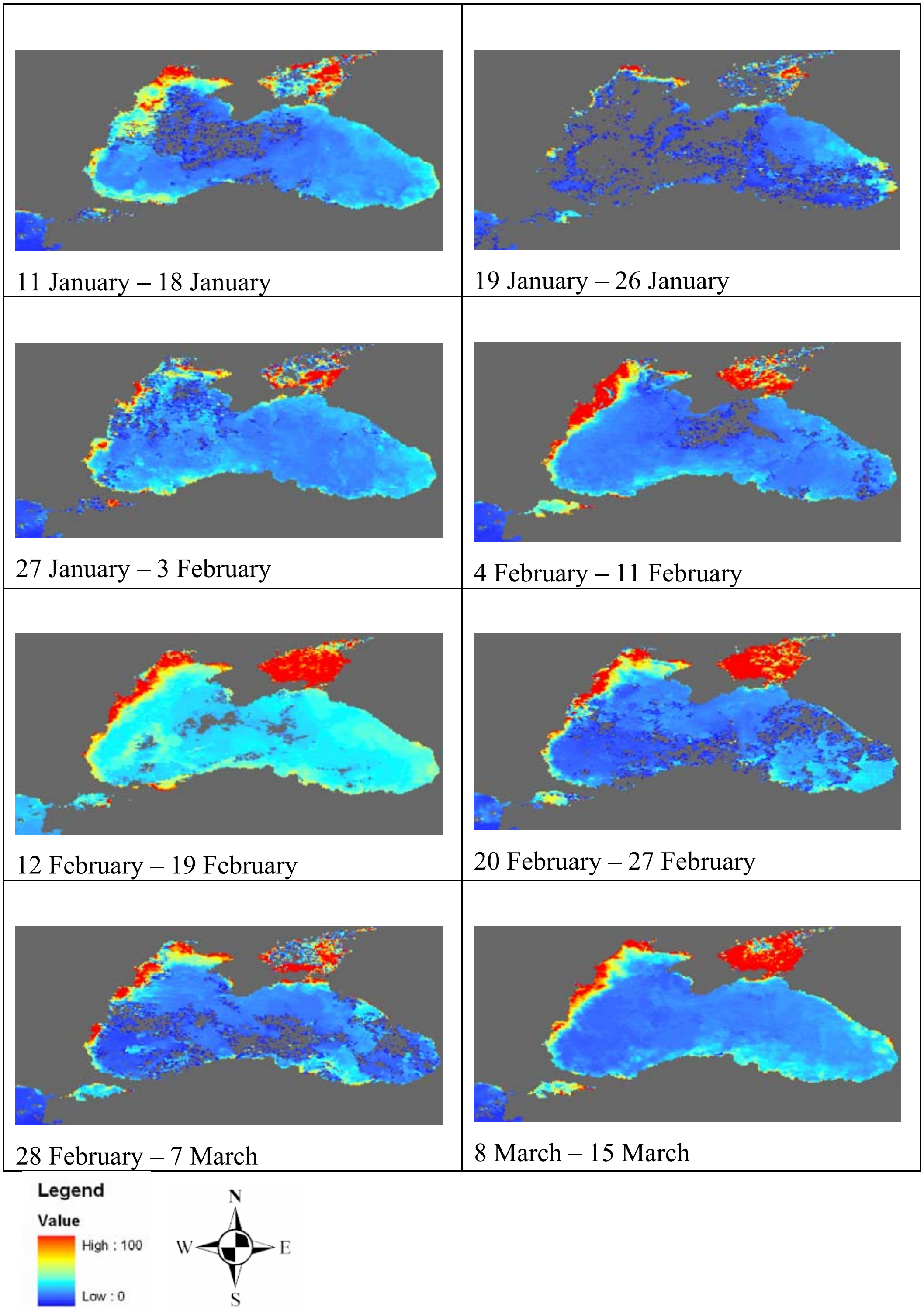


Figure 4.16. (continued). Reclassified Chlorophyll Concentration Distribution in Black Sea with Trapezoidal Membership Function.

4.2.2.3. Resultant Thematic Fish Stock Maps Generated by FSAW

Processed SST and chlorophyll concentration images are evaluated with equal contribution. In this thesis depended on expert knowledge maximum aggregation method is used with smallest of maximum defuzzication. However variety of results can be obtained using different membership functions, different membership function parameters and aggregation methods.

Due to the fact that the same temperature intervals and chlorophyll concentration intervals are utilized in both SAW and FSAW analysis, the final thematic maps give approximate results. However the resultant thematic fish stock maps generated by FSAW (Figure 4.18) analysis represents the uncertainity in the environment better than the ones generated by SAW analysis (Figure 4.12).

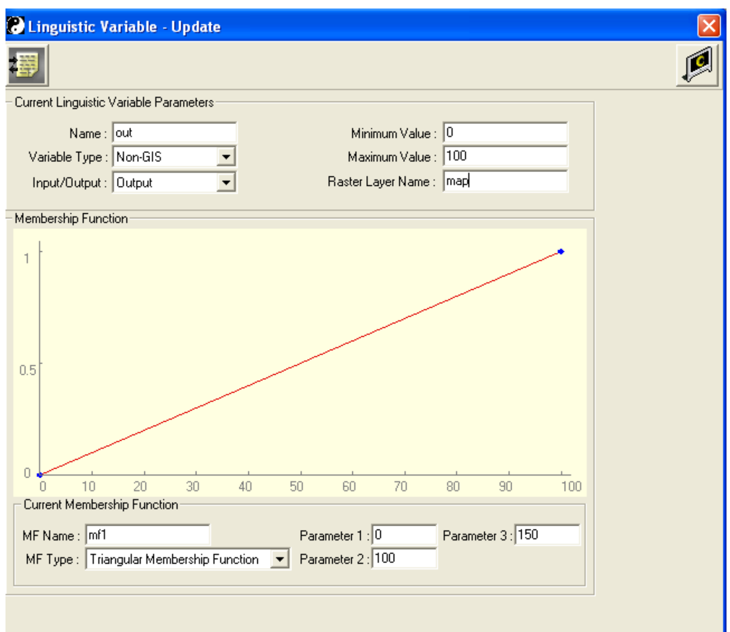


Figure 4.17. Liner Membership Function for Generation of Thematic Fish Stock Maps

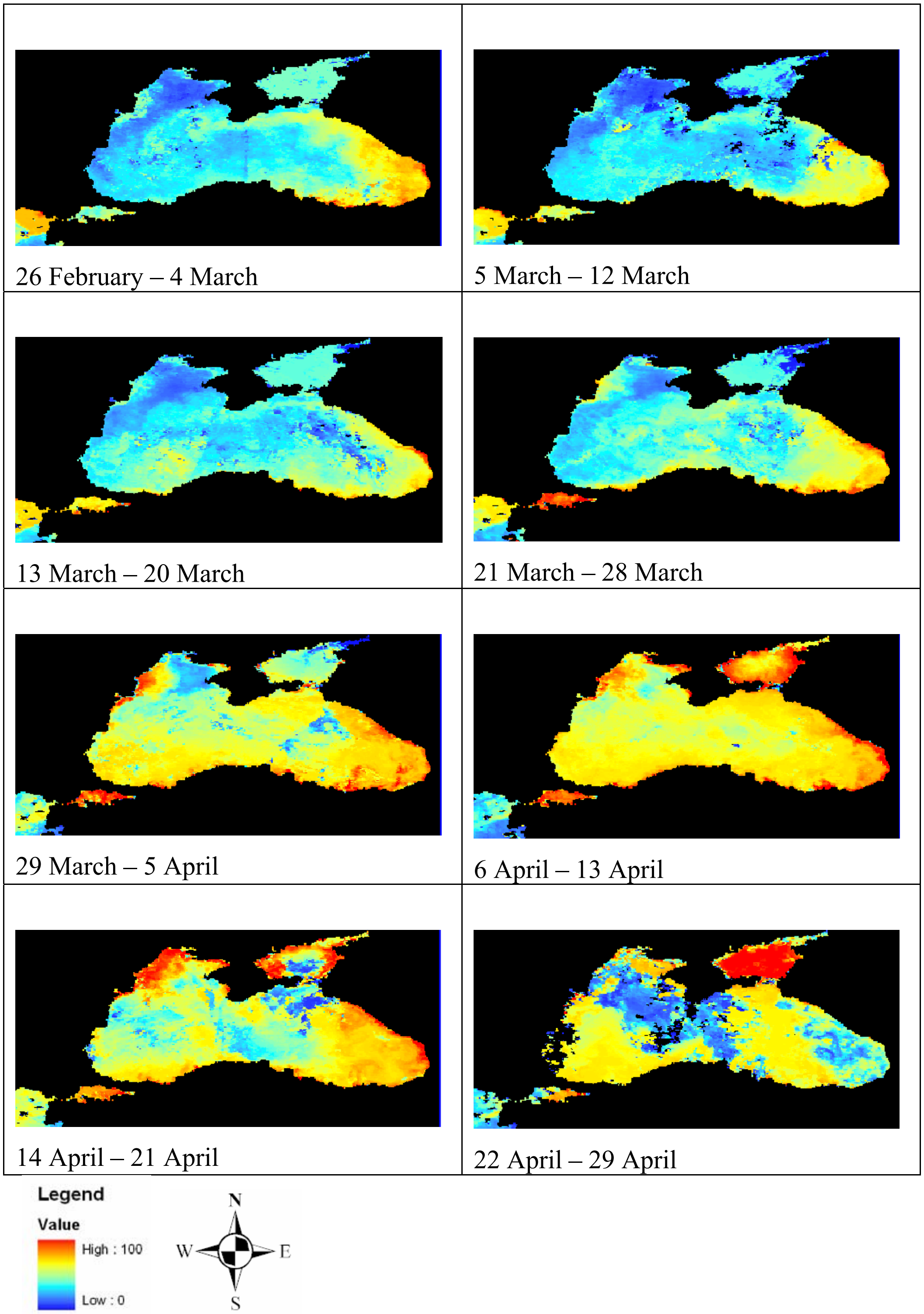


Figure 4.18. Distribution of Potential Favorable Zones for Pelagic Fish Stocks in Black Sea Through FSAW

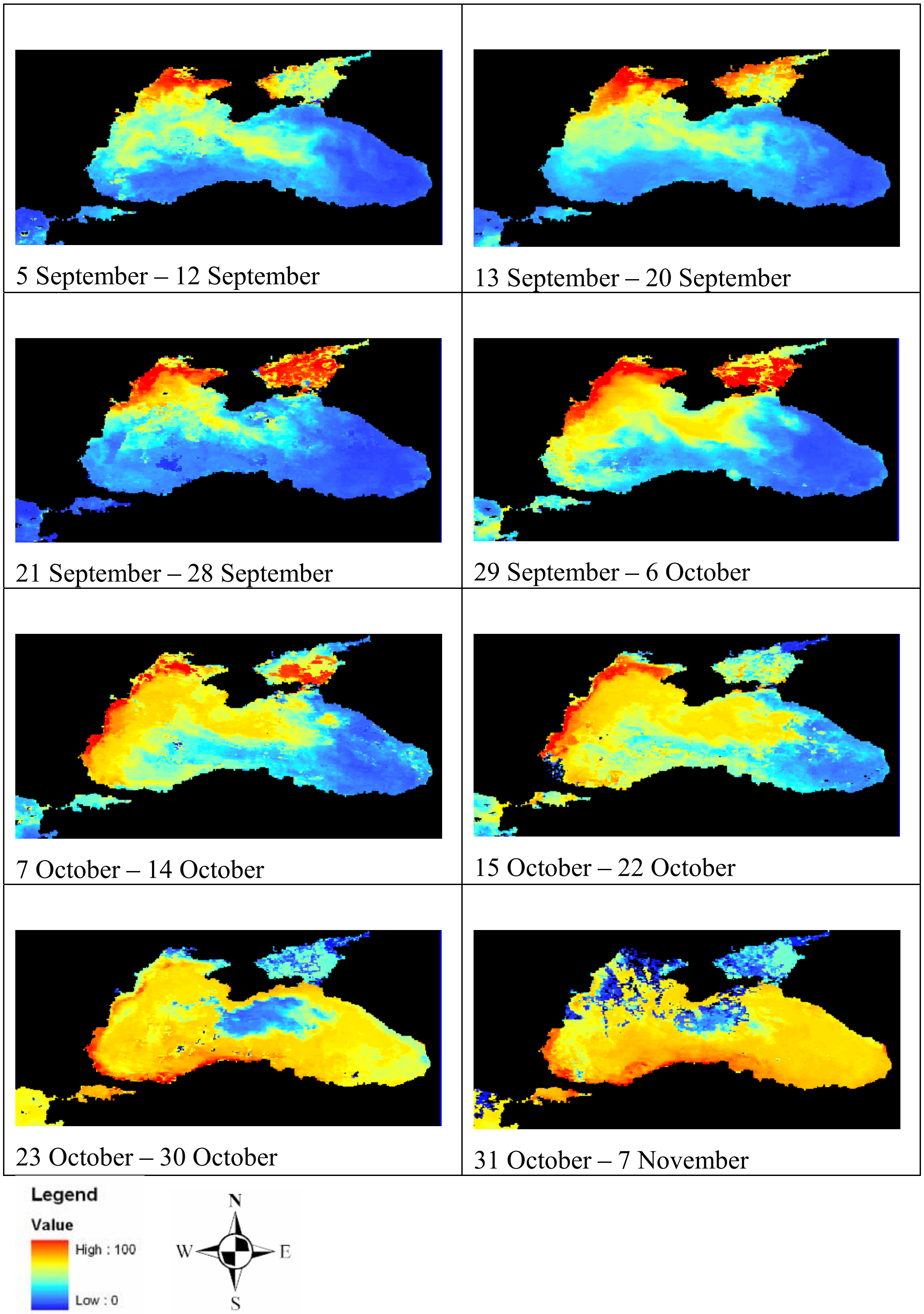


Figure 4.18. (continued). Distribution of Potential Favorable Zones for Pelagic Fish Stocks in Black Sea Through FSAW

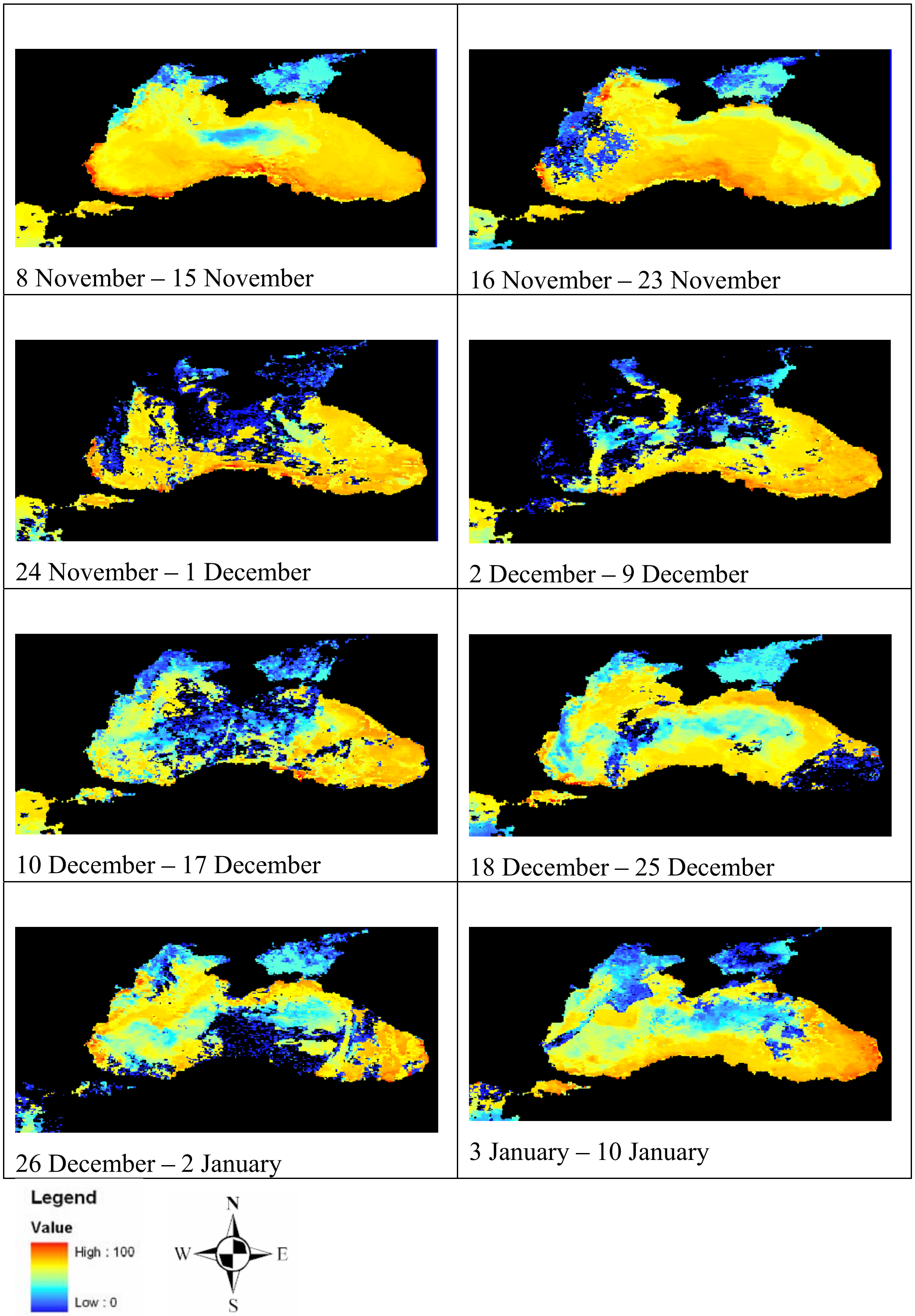
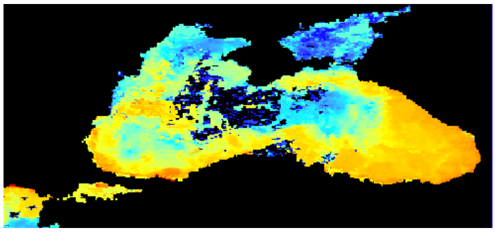
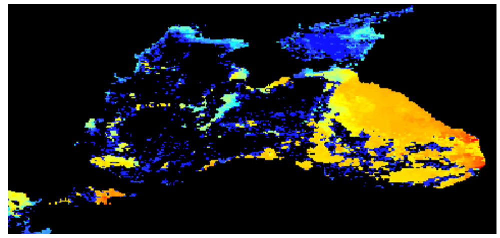
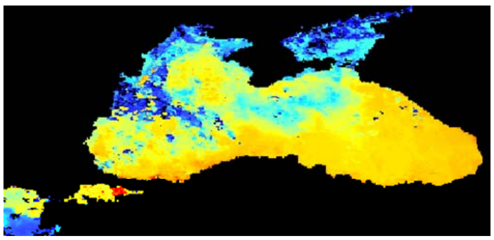
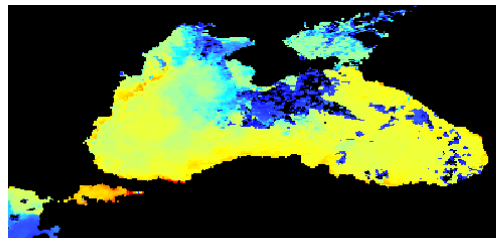
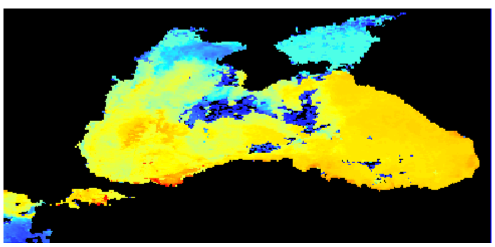
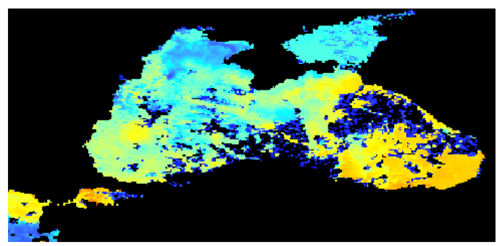
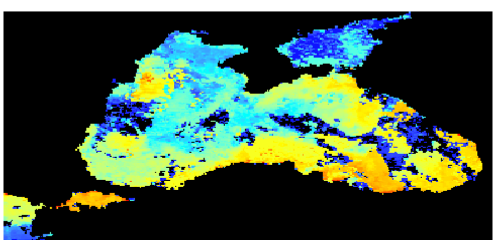
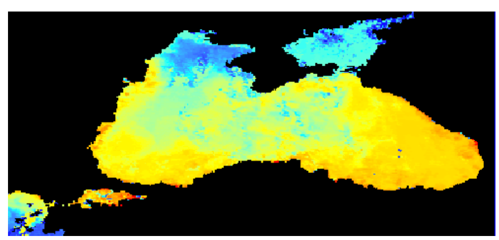


Figure 4.18. (continued). Distribution of Potential Favorable Zones for Pelagic Fish Stocks in Black Sea Through FSAW

 11 January – 18 January	 19 January – 26 January
 27 January – 3 February	 4 February – 11 February
 12 February – 19 February	 20 February – 27 February
 28 February – 7 March	 8 March – 15 March

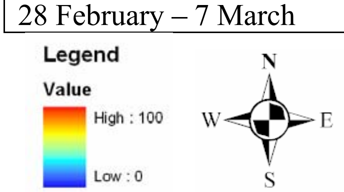


Figure 4.18. (continued). Distribution of Potential Favorable Zones for Pelagic Fish Stocks in Black Sea Through FSAW

CHAPTER 5

DISCUSSION

5.1. Data

The recent technological improvements lead the availability of better geospatial information. Starting from 1970s sensors providing information about the ocean color are operational. First launched CZCS had only 6 channels but now MODIS has 36 identical channels specialized for marine applications. Today the sensors are capable of interpreting the variability of various parameters. It is also important that most of the data is available through the internet free from charge and with no restrictions. Even in this thesis local coverage, daily and global coverage, weekly composites of many parameters are downloaded from NASA DAAC. It would be impossible to realize this study if the satellite imagery was not available.

Furthermore marine applications have a disadvantage that gathering in-situ data from the field is not inexpensive. Research vessel expenses are so high that it is not possible to go on cruise frequently. As a result not too many in-situ datasets are available. In-situ data is provided by METU IMS for a certain time period which limits the accuracy analyses within a year. Time series of information plays an important role in defining the variations in marine environment. The analyses would yield more reliable results if time series of in-situ data was available.

5.2. Evaluation of the Satellite Imagery

The satellite algorithms are global. Although the Mediterranean and the Black Sea has extremely different optical properties, the algorithms used to evaluate both Seas are the same. Local algorithms need to be generated for our seas in order to confidently utilize the ocean color sensors. Because the accuracy of the algorithms directly affect the accuracy of the satellite driven data and the validity of our study.

Seas, besides pure water contains various constitutes. Even the same sea might show distinct optical properties within different seasons due the biological activity and environmental effects. It is evident in Figure 3.11 that there are three sub-groups within the graphic indicating different seas and/or different seasons.

When the data is divided into sub-groups it can be observed that both satellites overestimate the chlorophyll concentration values in Black Sea; 7 times in summer period and 2 times in autumn. It is stated in the literature that the absorption coefficient of phytoplankton, which the chlorophyll algorithms rely on, changes with species type, size and nutrient and available light in the environment (Morel and Bricaud 1981; Kirk,1983). The cause of the different overestimation rates is believed to depend on increase of different species in summer and autumn respectively. However, since algorithms are affected by solar contamination, the difference also may occur due to the different illumination conditions in different seasons.

MODIS products give relatively better accuracy than SeaWIFS products. Yet it should be considered that the number of the satellite imagery used in the accuracy analyses for each sensor was not identical due to the availability and cloud coverage in the satellite imagery and the number of in-situ data was not enough in some cases for evaluation purposes. In spite of the stated reasons, an overall accuracy analyses was done to evaluate the validity of MODIS products in the Black Sea.

SST parameter derived from MODIS has overestimated the in-situ values in Black Sea during summer but underestimate in winter. When the Black Sea cruises further divided into groups, it is seen that the correlation coefficient fails in summer but still gives good results in winter. This might be the effect of solar contamination as indicated in MODIS documentation. Yet still the correlation of MODIS SST values are high enough to be used in the analyses.

5.3. Description of Interannual Environmental Variablity in the Black Sea

Spatial and temporal variations in the SST and the chloropyhll concentration in the Black Sea for 6 sub-regions are examined. SST values in the Anatolian coasts are found to be higher than the northern part of the Black Sea. The high fresh water inflow into the Northern Black Sea is thought to be the reason of this temperature difference.

The time period when there is an important increase in chlorophyll concentration gives similar results both in the literature and the results observed from the MODIS imagery. However the chlorophyll concentration values in the North Western Shelf (Figure 4.3) and Azov Sea (Figure 4.4) are highly overestimated. The results might be influenced by the high freshwater inflow carrying both sediment and nutrients into these regions. Furthermore the enclosed coverage of Azov Sea might increase the source of error due to ground reflectance.

In general the physical effects of the upper layer circulation patterns like cyclonic circulation, cyclonic and anticyclonic gyres can be observed from the satellite imagery. Marine satellites have large coverage, favorable to observe the large scale changes in the marine environment. Also the availability of data in time series is another advantage that supports the interpretation of variation.

5.4. Determination of Potential Favorable Zones for Pelagic Fish Stocks

The satellite measurements can only penetrate few meters into sea surface. Thus the techniques used in defining the potential locations of fish stocks using satellite data are valid for pelagic species only, which live near surface waters.

Due to the large scale required to determine the potential locations and migration routes of the stock, integration of RS and GIS is an effective tool in fisheries applications. Furthermore a combination of GIS and MCDA is needed for the integration of decision maker's preferences and the geographical data.

Two different decision rules are employed to generate fish stock maps, SAW and FSAW. Utilizing fuzzy data, FSAW analysis represents the uncertainity in the environment better than SAW analysis.

The limitations of the avaliable in-situ data may yield some inconsistencies within the results. There are not many information about the habitat preferences of the anchovy, so the interpreted parameters are taken as a basis in the analyses. The results would have been more realistic if more information on the fish was available. The resultant fish stock maps reveal potential favorable zones rather than the exact locations of the stock.

The effect of bathymetry on the migration paths of the fisheries is stated in the literature. It is believed that the bottom topography has a certain influence on the environmental conditions and also the steep canyon areas are safe from predators. The effect of bathymetry is not used as an indicator in this study due to the deficiency of information. Knowledge about relations between the bathymetry and the anchovy stocks will increase the accuracy of the results.

It is also possible to improve the study with the support of fish catch data. The environmental parameters at the time of fishing and related location information might be a valuable dataset to examine the fish behavior. In this extent collaboration with the local fishermen might be an effective solution. Yet it should be considered that the reliability of the information is dependent on the declaration of the fishermen.

Estimation of the fish stock locations might be used to make fisheries operations more efficient, however they should not be used in the perspective of improving fishing effort if there is a danger of overfishing.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Due to the high cost of marine studies, usage of satellite data in defining environmental variability in the sea has a significant economic importance. The validity of the results is directly affected by the accuracy of the satellite information. According to the results obtained by evaluation of satellite derived chlorophyll and SST products with respect to in-situ measurements, the algorithms yield some inconsistencies within Turkish Seas. In order to acquire more reliable information, algorithms for our seas must be revised or new algorithms should be developed.

However the cost of cruise is extremely high for a single organization due to the expenditures of research vessel. A collaboration of governmental agencies, research institutes and universities will be wiser in terms of sharing both the expenditures and the knowledge.

Chlorophyll concentration and SST of the sea are believed to be the most effective parameters which define the fish habitat. These parameters for the Turkish Seas are examined from May 2000 to May 2001 and the interannual variability is observed. SST values in the Anatolian coasts are found to be higher than the northern part of the Black Sea. Chlorophyll concentration within the basin varies according to the different environmental conditions for each season. Central Black Sea and Pre-Bosporus show peak concentrations in late-spring/summer (May-June) and autumn (November). Whereas eastern part of the Black Sea Battumi gyre and South Eastern Black Sea has the highest concentration values in spring (March) and autumn (November).

As it is the responsibility of governmental organizations to support the sustainable development of marine resources. Before assigning a quota for the fish catch, the amount of the stock should be well defined. The determination of the stocks will lead the information of the species which are at risk and so that the Ministry of Agriculture and relevant organizations can take precautions before it is too late.

The results obtained from this thesis corresponding to the location of the potential favorable zones for pelagic fish stocks throughout the year can be used both to understand the relation of the fish stocks with the chlorophyll concentration and SST and also to predict the potential locations to reduce the time spend for searching stocks. Due to the fact that the liquid fuel and motor oil expenditure is over 27 trillion and holds the 60 % of the total expenditure, the forecast of the potential locations of fish stocks is highly important. Moreover this would lead the fleet to spend less days at sea, which would decrease the expenses with the crew and with ship maintenance.

Yet it should be considered that the results give only the potential favorable locations and it's possible to have misleading estimates. In order to minimize the error, this study might be improved with the support of in-situ fish catch data. Although it's beyond the scope of this thesis it's possible to collaborate with the local fishermen to obtain catch data, which is scarce in Turkey. Furthermore researches investigating the relation of the fish species with the environment and clarify their habitat would also increase the validity of this kind of studies.

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APPENDIX

MODIS LEVEL 3

CHLOROPHYLL CONCENTRATION AND SST PRODUCTS

In this chapter MODIS Level 3 raw chlorophyll concentration (Figure A.1.) and SST (Figure A.2) images are given to represent the variability within the Black Sea.

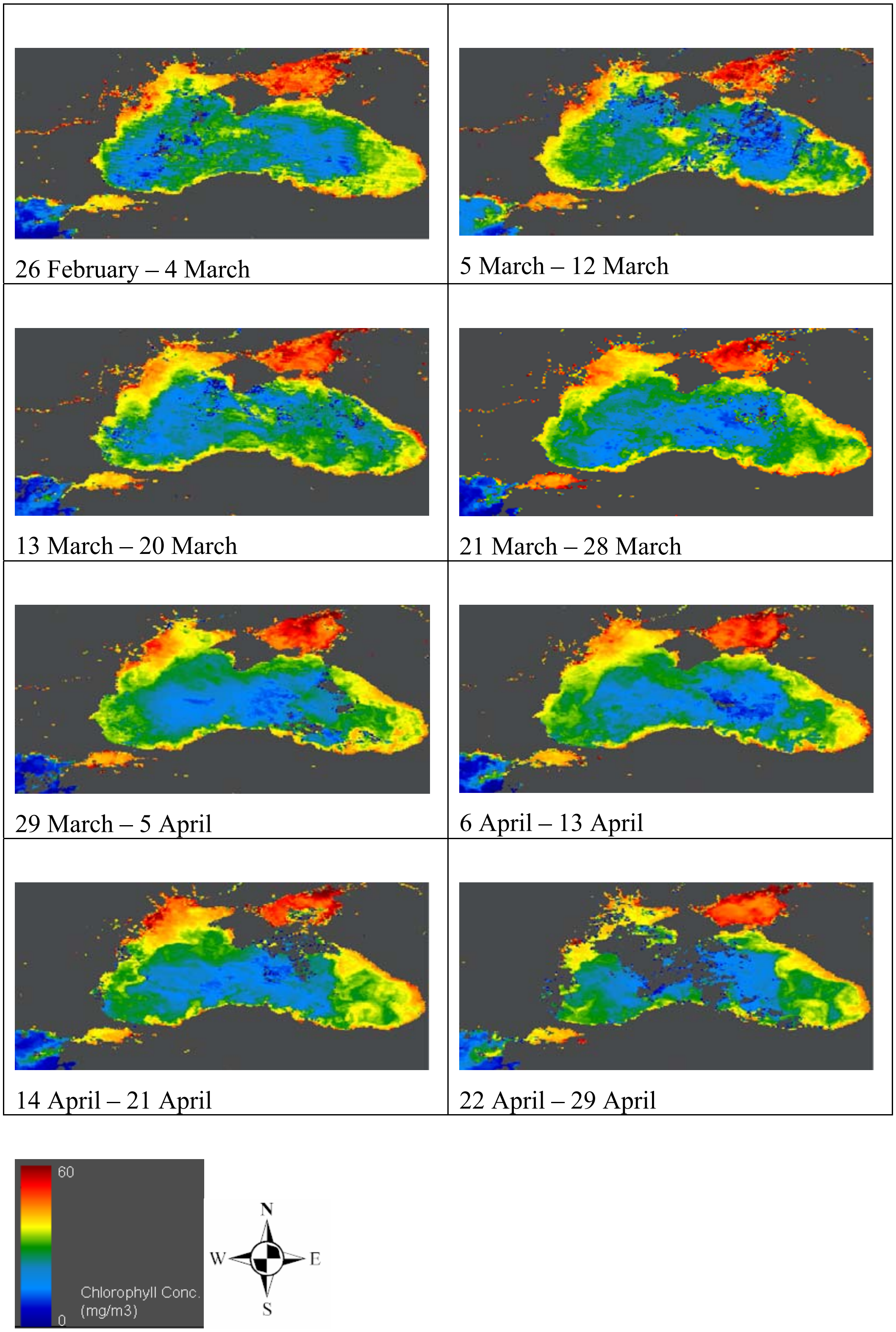
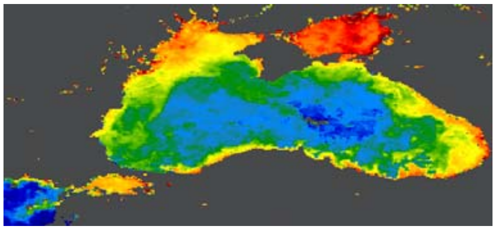
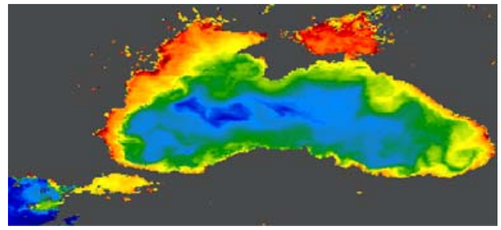
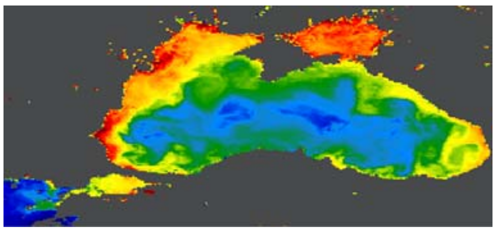
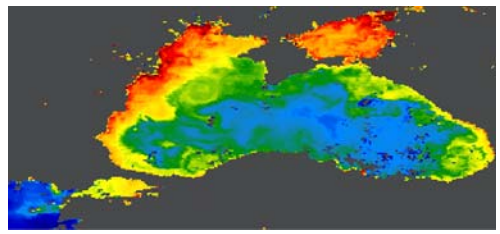
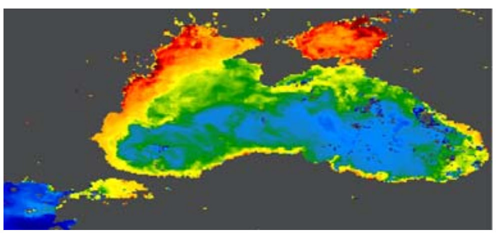
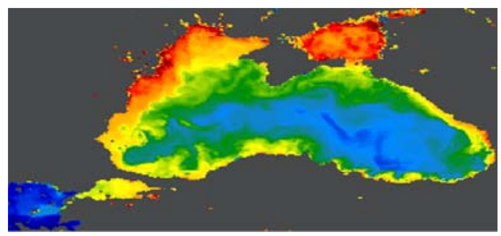
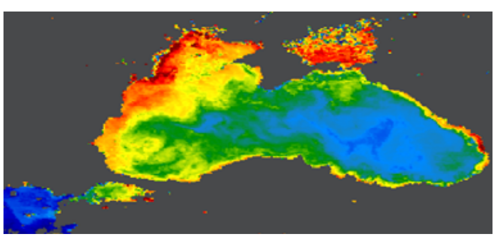
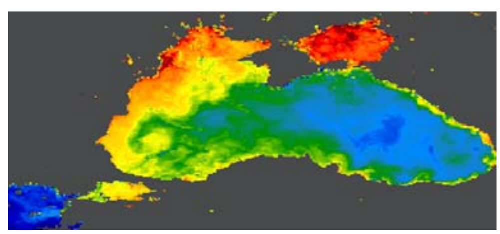
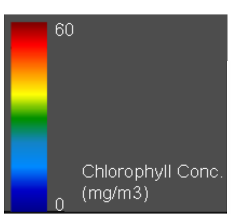


Figure A.1. Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

 30 April – 7 May	 8 May – 15 May
 16 May – 23 May	 24 May – 31 May
 1 June – 9 June	 9 June – 16 June
 17 June – 24 June	 25 June – 2 July



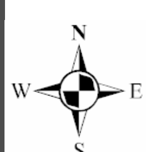
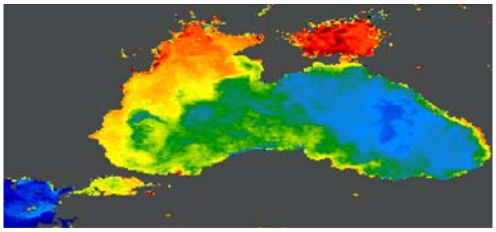
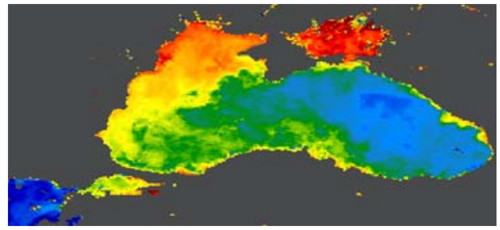
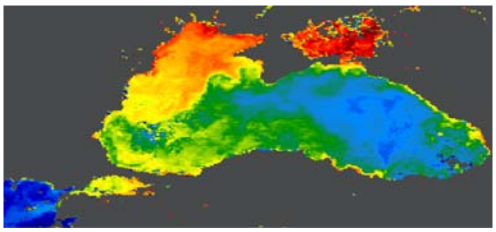
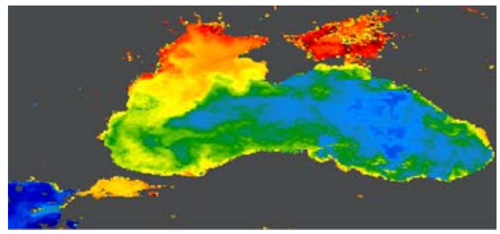
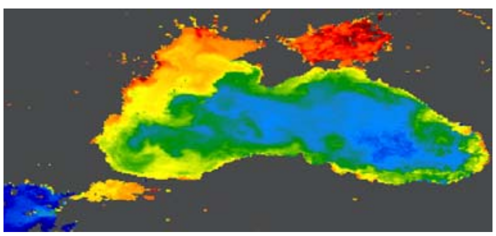
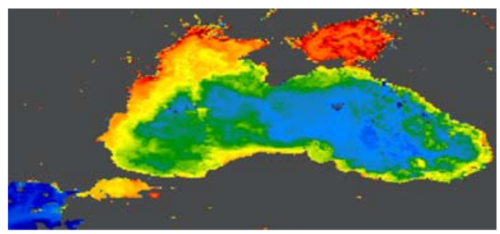
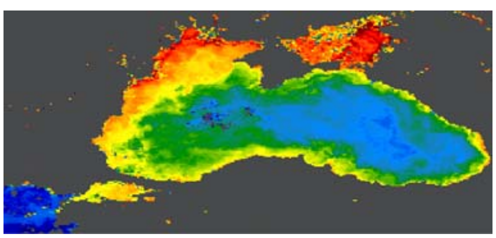
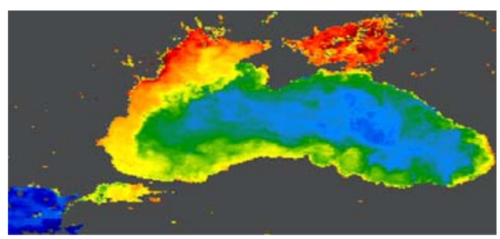


Figure A.1. (continued). Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

 3 July – 10 July	 11 July – 18 July
 19 July – 26 July	 27 July – 3 August
 20 August – 27 August	 28 August – 4 September
 5 September – 12 September	 13 September – 20 September

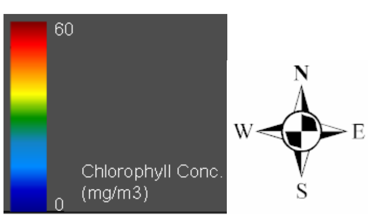
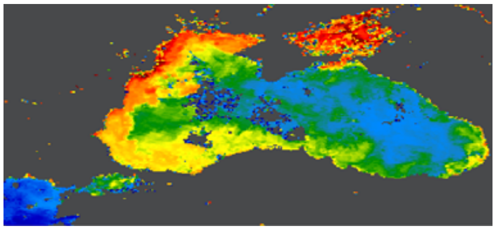
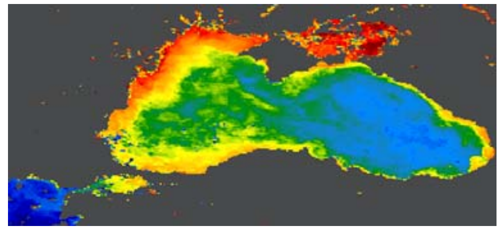
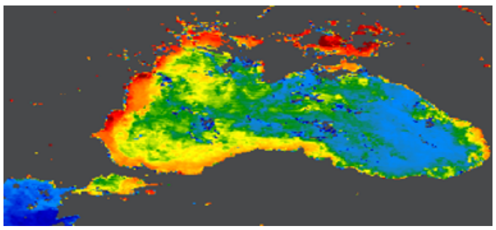
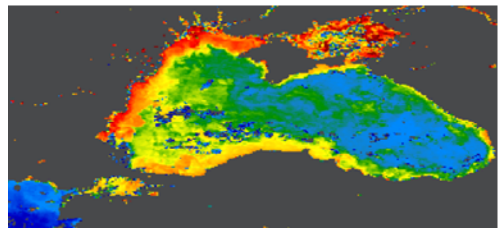
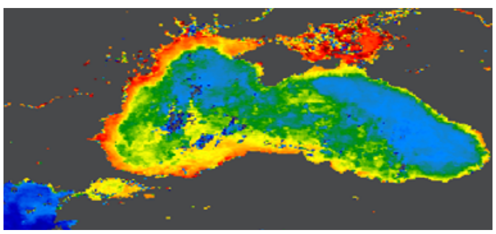
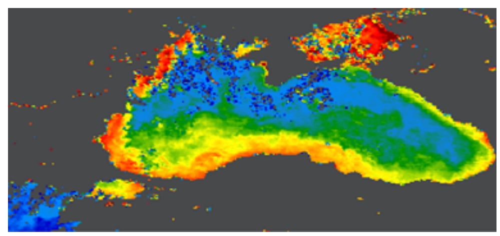
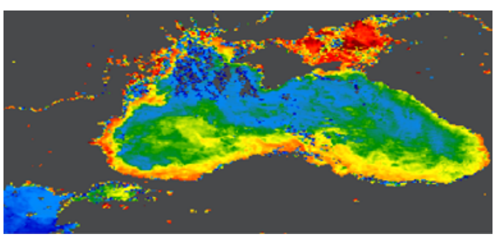
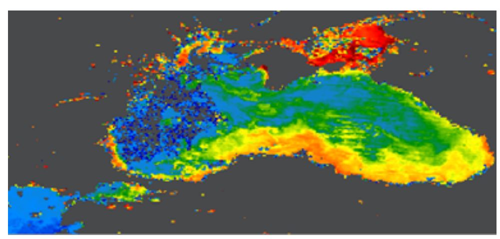
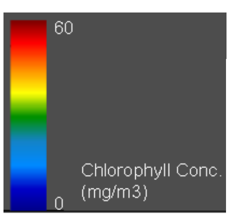


Figure A.1. (continued). Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

 21 September – 28 September	 29 September – 6 October
 7 October – 14 October	 15 October – 22 October
 23 October – 30 October	 31 October – 7 November
 8 November – 15 November	 16 November – 23 Novembe



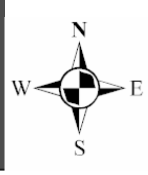
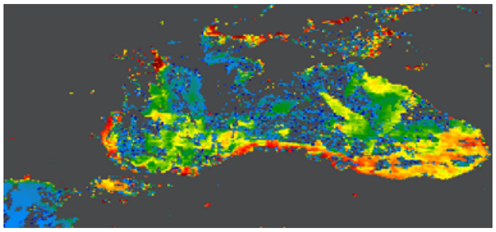
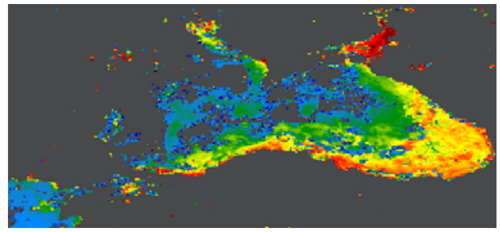
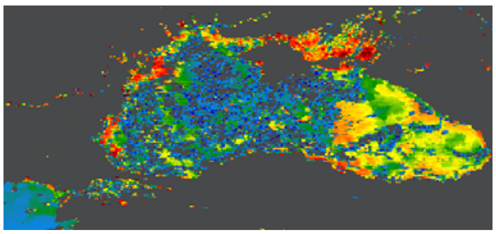
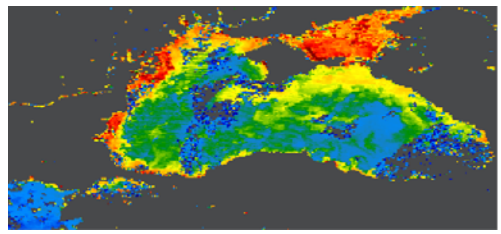
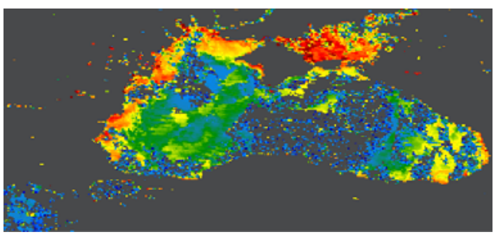
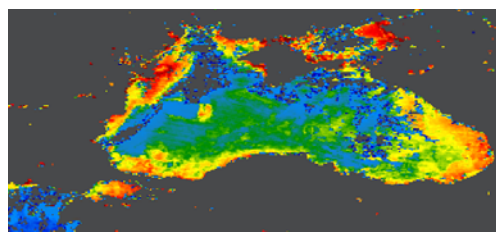
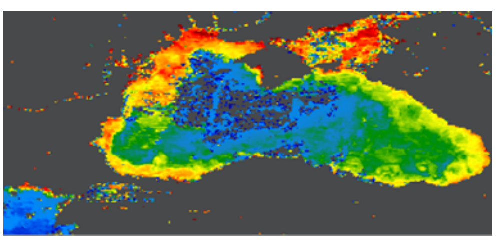
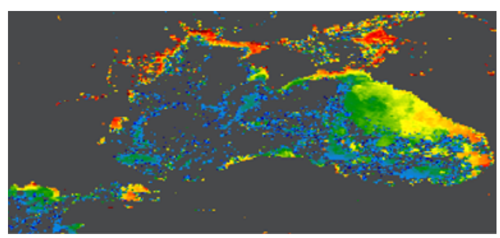


Figure A.1. (continued). Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

 24 November – 1 December	 2 December – 9 December
 10 December – 17 December	 18 December – 25 December
 26 December – 2 January	 3 January – 10 January
 11 January – 18 January	 19 January – 26 January

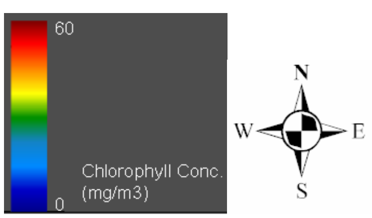


Figure A.1. (continued). Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

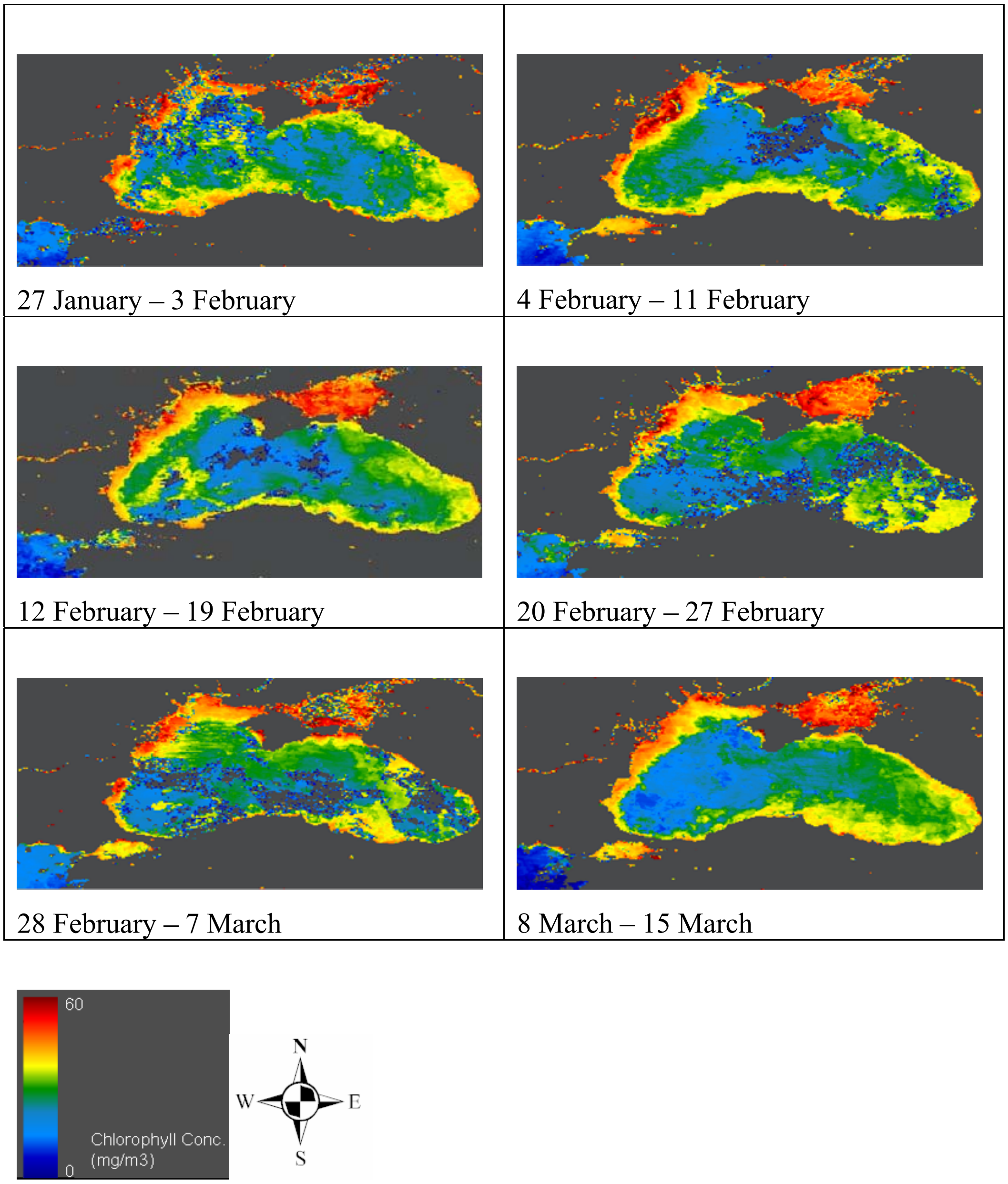


Figure A.1. (continued). Chlorophyll Concentration Distribution Gathered from MODIS Chlorophyll-a Parameter in Black Sea

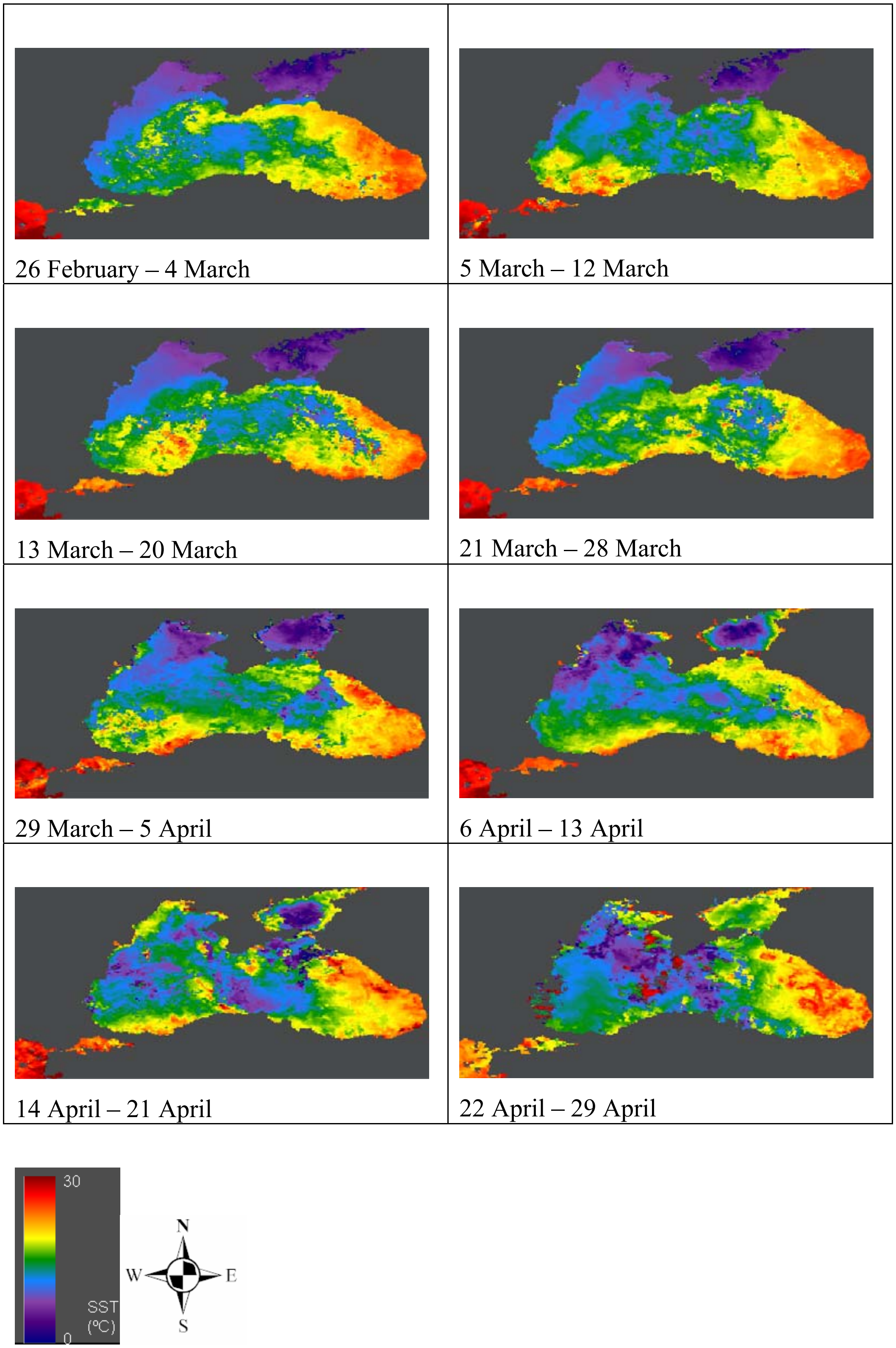
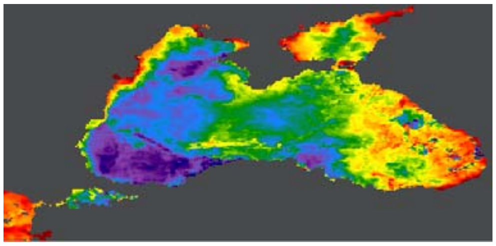
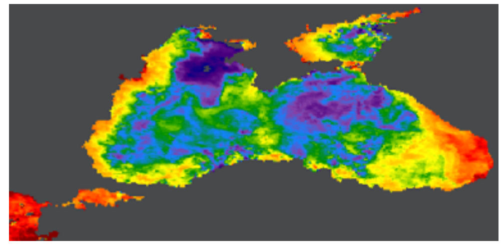
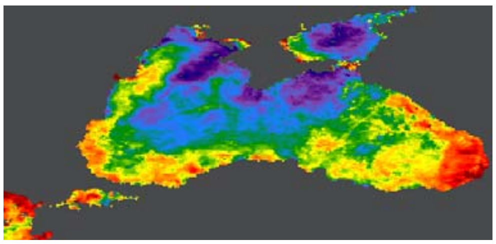
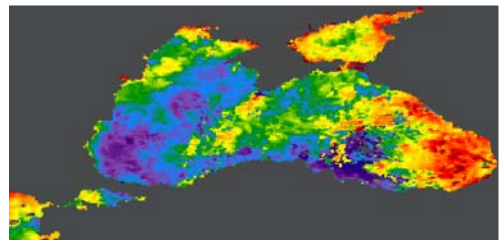
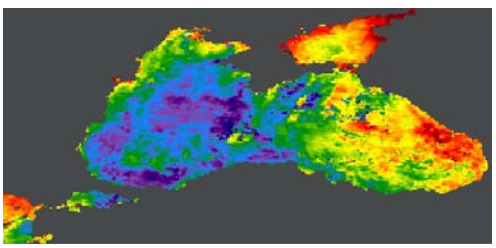
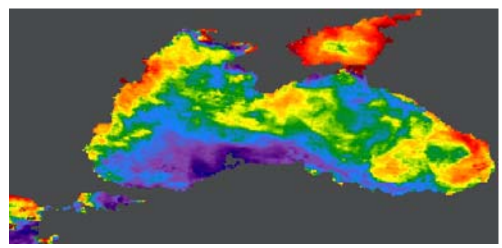
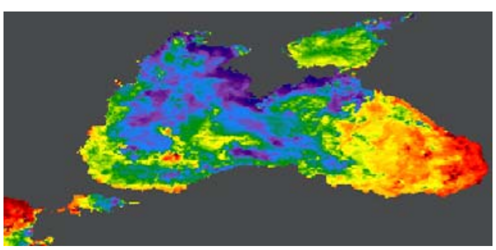
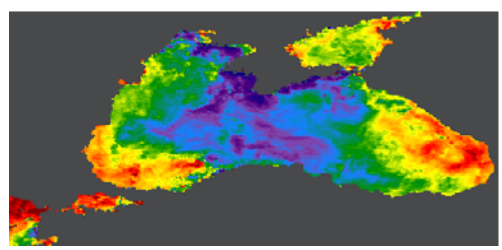


Figure A.2. SST Distribution Gathered from MODIS Sst4 Parameter in Black Sea

 30 April – 7 May	 8 May – 15 May
 16 May – 23 May	 24 May – 31 May
 1 June – 9 June	 9 June – 16 June
 17 June – 24 June	 25 June – 2 July

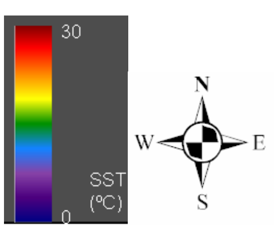
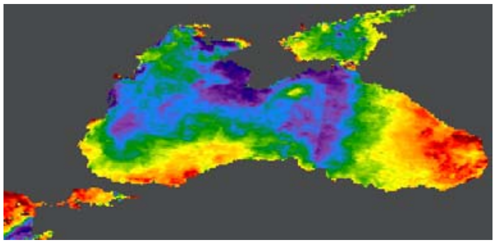
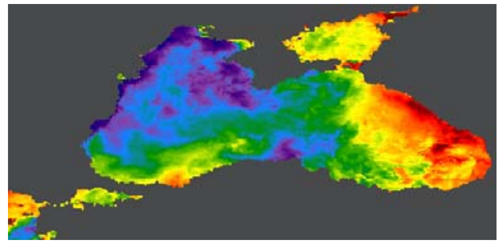


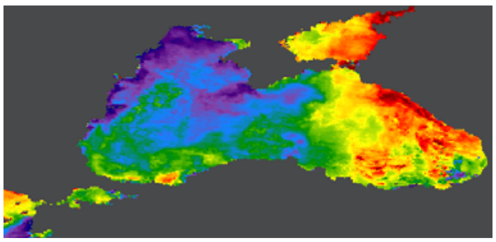
Figure A.2. (continued). SST Distribution Gathered from MODIS Sst4 Parameter in Black Sea



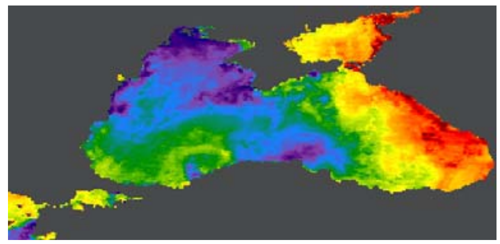
3 July – 10 July



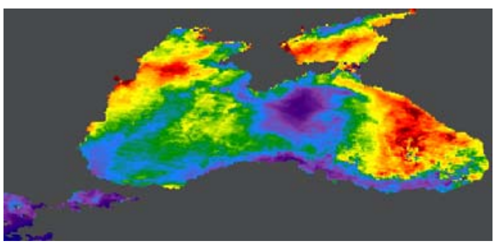
11 July – 18 July



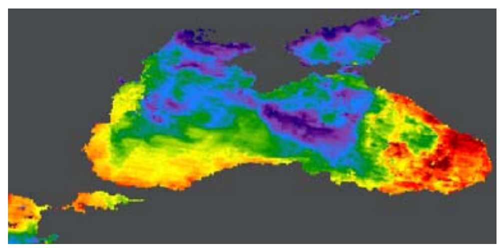
19 July – 26 July



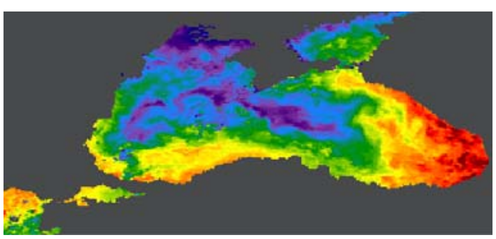
27 July – 3 August



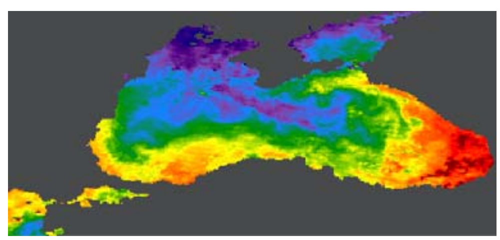
20 August – 27 August



28 August – 4 September



5 September – 12 September



13 September – 20 September

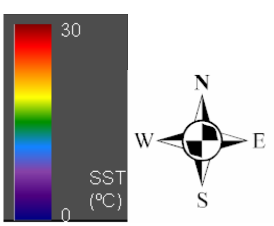
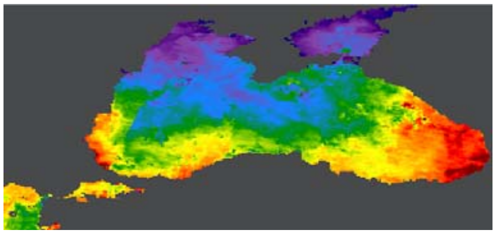
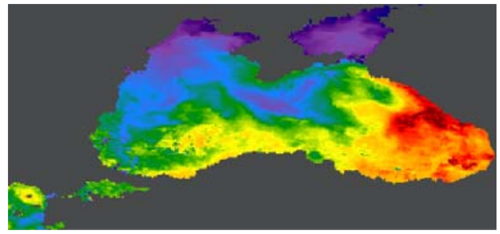
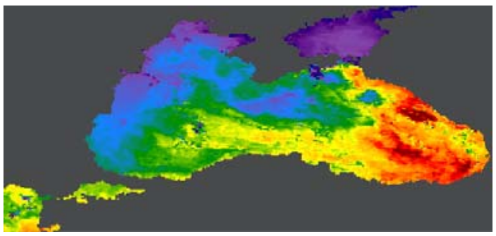
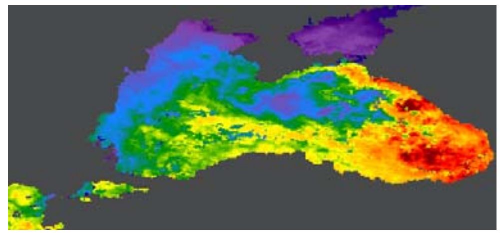
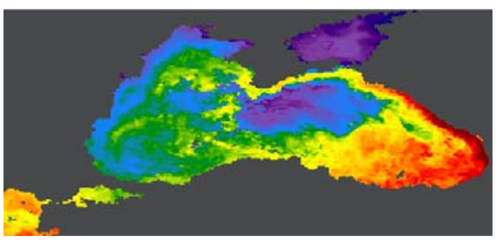
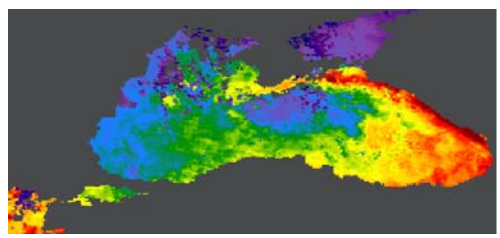
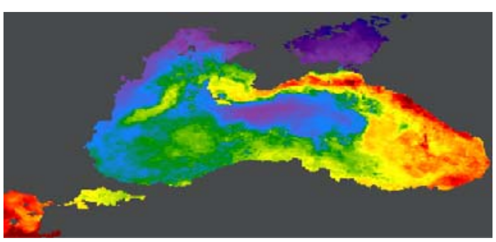
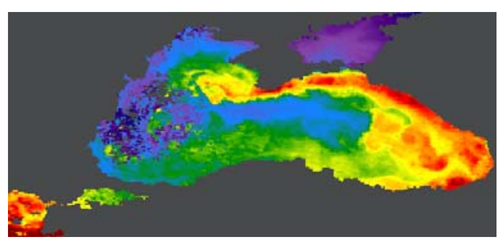


Figure A.2. (continued). SST Distribution Gathered from MODIS Sst4 Parameter

 21 September – 28 September	 29 September – 6 October
 7 October – 14 October	 15 October – 22 October
 23 October – 30 October	 31 October – 7 November
 8 November – 15 November	 16 November – 23 November

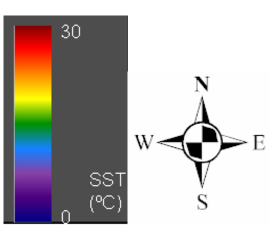
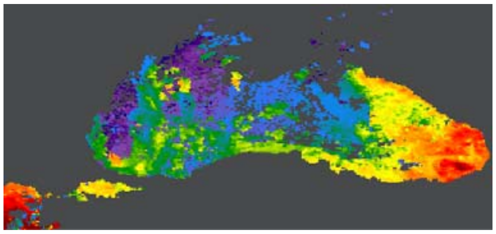
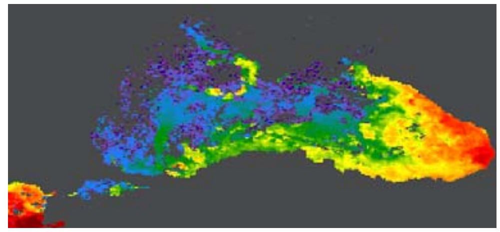
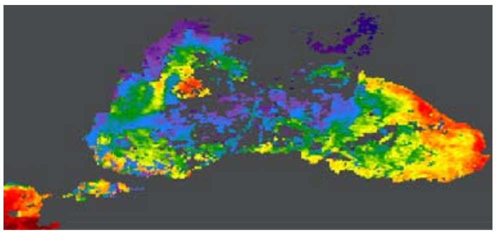
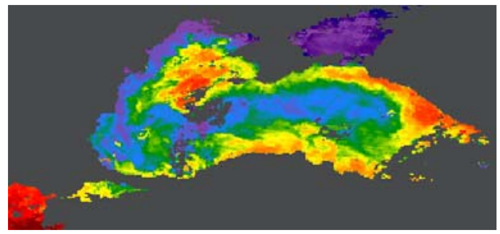
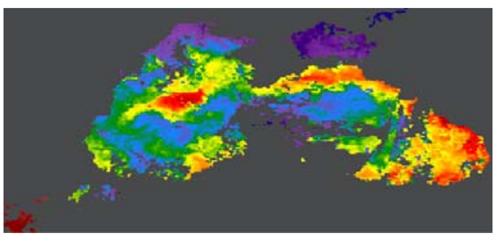
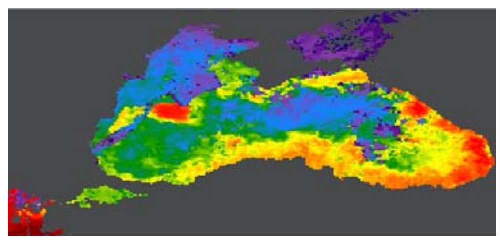
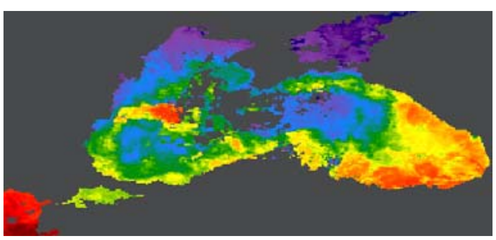
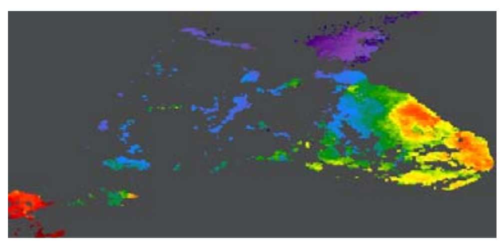


Figure A.2. (continued). SST Distribution Gathered from MODIS Sst4 Parameter in Black Sea

 24 November – 1 December	 2 December – 9 December
 10 December – 17 December	 18 December – 25 December
 26 December – 2 January	 3 January – 10 January
 11 January – 18 January	 19 January – 26 January

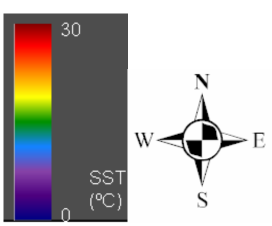


Figure A.2. (continued). SST Distribution Gathered from MODIS Sst4 Parameter

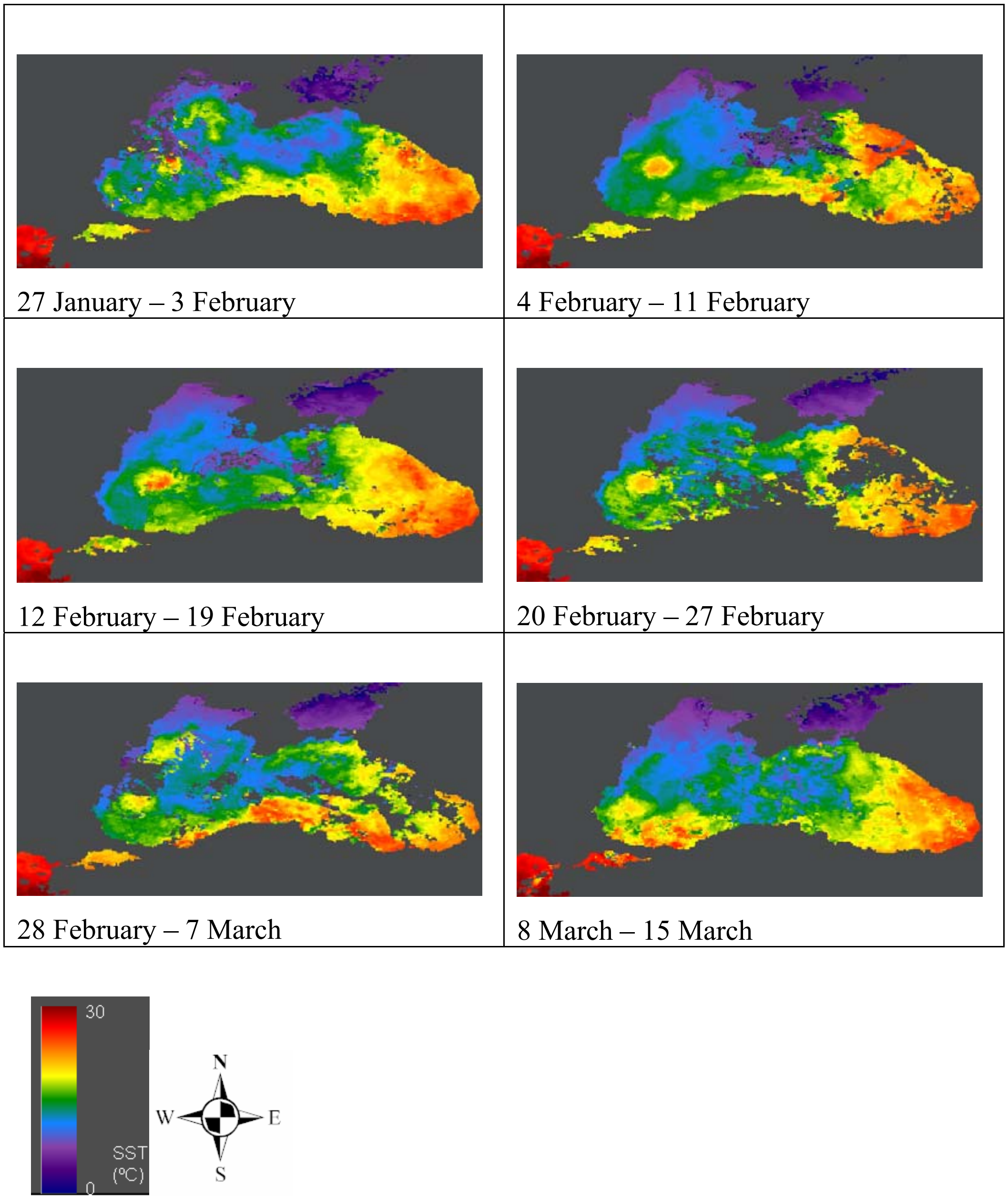


Figure A.2. (continued). SST Distribution Gathered from MODIS Sst4 Parameter in Black Sea