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Research Article

Relationship Between Climate Change Driven Sea Surface Temperature, Chl-*a* Density and Distribution of Giant Devil Ray (*Mobula Mobular* Bonnaterre, 1788) in Eastern Mediterranean: A First Schooling by-Catch Record off Turkish Coasts

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Abstract

Every ecosystem of the Earth is influenced by altering of physical and chemical composition of the Earth's atmosphere. Climate and thus sea surface temperature changes in the marine ecosystems affects particularly the vulnerable and endangered species and their distribution areas. Possible climate change effect on one of the most endangered and endemic ray species i.e. *Mobulamobular*'smigration in the Mediterranean Sea. The migration of the species was probably forced due to warming of the sea temperature of their native environment in winter time. The warming of the Adriatic Sea affects, changes and shifts the primary production. This could also force the rays to find new feeding regions in the Mediterranean Sea. From 2003 to 2015, sea surface temperature in the Mediterranean Sea has averagely an increase about 1.5 ºC, however, the increase of the temperature in JFM (January, February, March) was much greater (about 2.5 ºC). This prefigure a reason for migration e.g. especially the low temperature tolerant species. The climate change impacts on ray's migration and also the correlation between Chl-*a* concentration in Mediterranean have to deeply investigate. This could answer more questions about the ecological behavior of the rays under climate change in the future.

Keywords: Climate change, sea surface temperature, remote sensing, ecology, Devil ray, fish migration.

Öz

İklimsel Değişikliklerin Deniz Suyu Yüzey Sıcaklığında ve Deniz Suyundaki Chl-A Yoğunluğunda Neden Olduğu Artışların Şeytan Vatozu'nun (*Mobula Mobular* Bonnaterre, 1788) Doğu Akdenize'e Doğru Yayılışı Arasındaki Muhtemel İlişkiler; Şeytan Vatozu'nun Grup Olarak Türkiye Kara Sularındaki İlk Kaydı

Dünyadaki bütün ekosistemler atmosferin fiziksel ve kimyasal bileşenlerindeki değişikliklerden etkilenmektedirler. İklim ve bununla birlikte deniz ekosistemlerindeki yüzey su sıcaklığındaki değişimler özellikle soyları tükenme tehlikesinde olan türleri ve onların yayılış alanlarını etkilemektedir. Bu çalışmamızda, iklim değişikliğinin*Myliobatidae* ailesine ait, nesli tükenme tehlikesinde olup Akdeniz'e özgü bir tür olan ve Şeytan vatozu'nun (*Mobulamobular*) göçü üzerindeki etkilerini inceledik. Kış mevsiminde su sıcaklığında meydana gelen anormal artışlar balıkları göç etmeye zorlayan başlıca sebeplerden biridir.Adriyatik Denizi ve çevresinde yüzey suyu sıcaklığının artması birincil üreticilerin miktar ve kompozisyonunu doğrudan etkilediği gibi, Şeytan vatoz'unun diyetinde bulunan zooplankton, küçük balık ve kabukluları da etkilemektedir. Bu değişim, Şeytan vatozu'nun Batı Akdeniz'de doğal yayılış alanlarını terk ederek yeni, beslenme alanları aramasına neden olduğu düşünülmektedir. Yaptığımız bu çalışmada, 2003-2015 yılları arasında Akdeniz'in yüzey suyu sıcaklığında ortalama 1,5 ºC'lik bir artış olduğu gözlenmiştir. Bununla birlikte kış aylarındaki- kış mevsimi (Ocak, Şubat, Mart) ve bahar başlangıcında, su yüzey sıcaklığındaki artış 2,5 ºC'yi bulmaktadır. Kış aylarında yüzey suyu sıcaklığındaki bu ciddi artış sıcaklık değişimine fazla toleransı olmayan türleri göçe zorlamaktadır. Ayrıca, çalışmamızda Şeytan vatozu'nun göç etmesinin iklim değişikliği ile ilişkisinin yanı sıra deniz suyundaki klorofil konsantrasyonlarındaki değişimlerle olan ilişkisi de incelenmiştir. Bu çalışmanın sonuçları, Şeytan vatozu'nunekolojik davranışları ve iklim değişikliğinin bu davranışlar üzerindeki etkilerinin açıklanmasında önemli rol alacaktır.

Anahtar Kelimeler: İklim değişikliği, su yüzey sıcaklığı, uzaktan algılama, ekoloji, Şeytan vatozu, balık göçü.

Introduction

The devil rays (*Mobula spp.*) are in offshore living pelagic filter feeder fishes that distribute in sub-tropical, tropical and temperate climate zones around the World. Their biological characteristics (low reproductive rates, late maturity) and aggregating behavior make these species particularly vulnerable and endangered species due to over exploitation in fisheries. Notarbartolo di Sciara (1987) identified the devil ray fish (*Mobulamobular*) as an endemic ray species in the Mediterranean Sea, however the distribution of the species recorded not only in the Mediterranean Sea but also in the Atlantic Ocean. Since 2006, status of the species has been upgraded from vulnerable to endangered species by the International Union for Conservation of Nature (IUCN) red list, and the species is highly protected in the Mediterranean Sea. The Genus *Mobula* includes 10 species and the species *Mobulamobular* Bonnaterre, 1788 distributes mainly in offshore waters of the Mediterranean Sea (Poortvliet *et al.,* 2015). Some records also published in Atlantic and Pacific oceans. Members of the species have typical dorsaventrally flattened body, a long whip as a tail and also large pectoral fins. They can grow up to 5.2 m and weight up to 1000 kg (McEachran and Séret, 1990). The species was first recorded in Adriatic Sea by Bonnaterre in 1788. In Turkey coastal areas, Akyüz (1957) in Mediterranean and Geldiay (1969) in Aegean seas published some observed data of single specimen in fishing net and open water. Yaglioglu et al. (2013) have also documented a catch-release results about a single specimen of a giant devil ray in Iskenderun bay. The migration of fish species (except the migration for breeding) is mainly depended on changing the environmental factors (e.g. sea surface temperature, salinity, pH of the sea water, current directions etc.) and also on prey population in the native regions (O'Brien, 1979; Hansson *et al.,* 2007; Landsmann *et al.,* 2011; Afonso *et al.,* 2014).*M. mobular* is well known as zooplankton and small fish feeder. The prey of the species are highly depending on phytoplankton composition in offshore waters (Notarbartolo di Sciara, 1987). The changes in climatic conditions and thereby in physical conditions of the seas and the oceans can have quite important impacts on phyto- and zooplankton communities in marine ecosystems (Sommer and Lengfellner, 2008). Hallegraeff (2010) studied the prediction of the impact of global climate change on marine phytoplankton community, and pointed out to a direct relationship between climate change and algal bloom in marine ecosystems. The main preys of filter feeders are often the zooplanktons of the marine ecosystems. The zooplankton-phytoplankton interactions have been well studied and documented in the last decades (Deason and Smayda, 1982; Greer *et al.,* 2013; Vallina *et al.,* 2014).

In many studies, remote sensed Chlorophyll-a distribution (Chl-*a*) uses as an indicator for phytoplankton activities (biomass, primary production, eutrophication, zooplankton activities etc.) (Hemsley *et al.,* 2015; Lee *et al.,* 2015; Tilstone *et al.,* 2015; Schine *et al.,* 2016). Platt *et al.*, (2003) investigated the interaction between algal bloom and larval fish survival by using remote sensing satellite data of 5604 pixels (i.e. 1.5x1.5 km each) in spring time. They pointed out that the fish larva density increase with increasing the Chl-*a* concentration and primary production with some days shifting, respectively. In general, a high concentration of Chl-*a* is indicative of high phytoplankton cell concentration and Higher primary productivity. Because zooplankton feed on phytoplankton, the numbers of zooplankton increase in response during mainly starting of phytoplankton increase, which causes migration of filter feeder of marine or fresh water ecosystems (Zaret and Suffern, 1976; Suzuki *et al.,* 2008, Pasquaud *et al.,* 2008; Whitlock *et al.,* 2015).

Climate change has a clear impact on marine environment and marine species in the Earth oceans and seas (Sims *et al.,* 2004). Furthermore, effects of sea surface temperature (SST) change on migration of marine fish species have been shown in various studies (Southward *et al.,* 1975; Beamish, 1995; Carscadden *et al.,* 1997; Lea *et al.,* 2015). Whitlock *et al.,* (2015) released recently important data about the correlation of SST and migration of blue tuna fish in the Pacific Ocean.

The aims of this study is to identify the suitable SST range, main feeding zones of *M. mobular* in Mediterranean Sea, and illustrate the possible correlations between food resource change i.e. due to change in Chl-*a* distribution in trophic zones and climate change (i.e. change in SST) in the distribution zones of the species member.

Materials and Methods

In Feb. 12 2016, a giant devil ray group that was collected approx. 300 specimens were caught by purse seines of two vessels off Samandağ town coastal area in Southeastern Turkey (36º8'3.86" N, 35º48'33.34" E) close to the surface of the water at night time ($23^{\underline{00}}$ pm). Some of those specimens were presented in figure 1.

Figure 1. Some caught specimens of M. mobular on the vessels.

Figure 2. The specimen was presented at the fishmarket for local fishermen and domestic people.

After getting the rays on the vessels, they were immediately released. Unfortunately, some of them were dead during the catch-release time range. Afterwards, one of the dead specimen was presented in the fish market to inform the domestic fishermen and inhabitants about the endangered species as *M. mobular* in the Mediterranean Sea (see Fig. 2).

The coordinate, depth and time of the by-catch in the region was taken from the vessels. Monthly averaged SST and Chl-*a* were collected from MODIS-aqua mapped data (MODIS, 2016). The quality of the remote sensed data was globally investigated in various studies (Donlon *et al.,* 2007; Castillo and Lima, 2010; Banzon *et al.,* 2016). The Climate Data Operator (CDO) software were used to extract and analyze the collected remote sensed data for the Mediterranean Sea. The obtained remote sensed SST and Chl-*a* have 4x4 km spatial resolution. The analyze of the SST anomaly in JMF (January, February, March), when the most of the *M. mobular* specimens were observed in Eastern Mediterranean, was done by using the eq. (1)

$$SST_{anom} = SST_p - \overline{SST}_t \qquad (1)$$

Where SST_{anom} is the SST anomaly, $\overline{SST}_p$ the averaged SST for the JFM period, and SST_t for the 13 years average of SST (i.e. from 2003 to 2015), respectively.The relative differences (Δ) between 2015 and 2003 are computed for the climatic variables by using the eq. (2 and 3), and illustrated on the figures.

$$\Delta_{SST} = SST_{2015} - SST_{2003} \qquad (2)$$

$$\Delta_{Chl\text{-}a} = Chla_{2015} - Chla_{2003} \qquad (3)$$

Results

The specimen had approx. 263 cm disk width (DW) and 157 cm disk length (DL) (see Fig. 3). It had also 211 cm long spiny and prickles tail, 32 cm long vertical lobes in front of the head (cephalic fins), and 54 cm space between the two cephalic fins. The total weight of the specimen was approx. 144.5 kg.

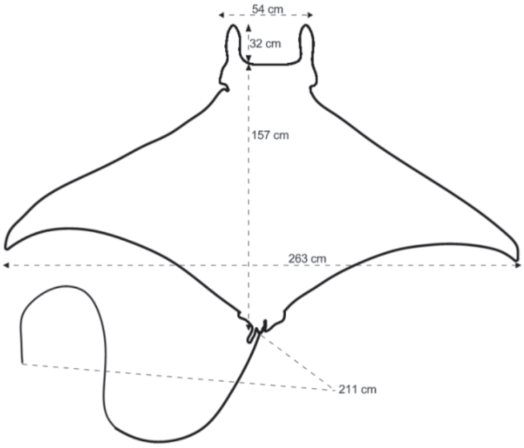
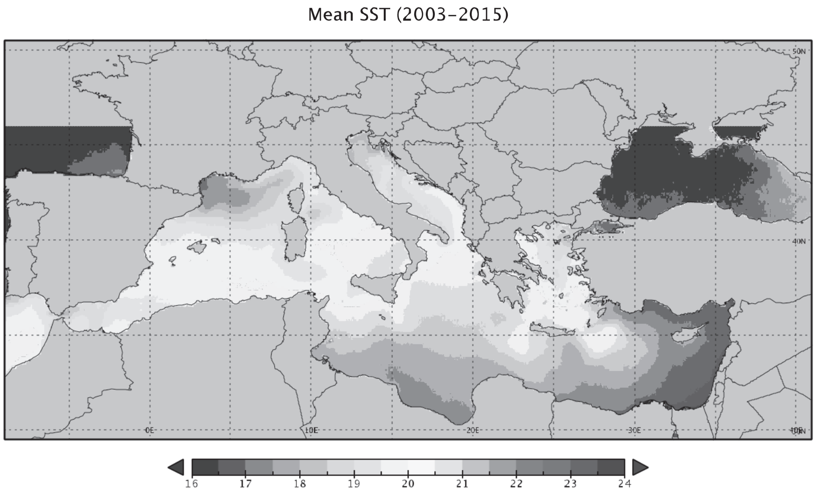


Figure 3. Data about morphological characters of the M. Mobular.

In this study, it is hypothesized that the giant devil ray migrates to find new territories for food resources, due to being suitable the sea temperature for the distribution of the species because of climate change, or to find new regions for breeding in the Mediterranean Sea. The change in Chl-*a*, which is an indicator for the change in primary production, and related to phyto-zooplankton community and SST are analyzed for 13 years.

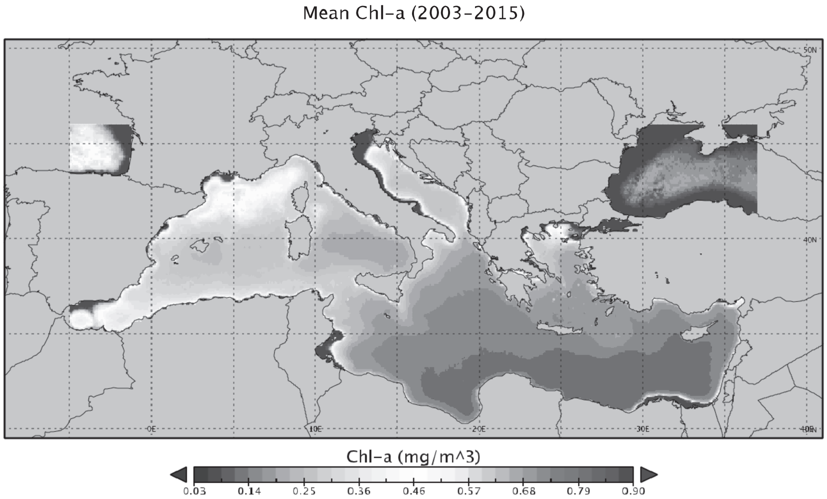
The 13 years mean of remote sensed SST and Chl-*a* by MODIS, and also absolute change (i.e. ΔSST (2015-2003) and ΔChl-*a* (2015-2003)) in SST and Chl-*a* were shown in the figures 4,5, 6 and 7.

It is to see that most of the regions in Mediterranean Sea became warmer (up to 2ºC) and more trophic (up to 0.5 mgm^{-3}) in 2015. It is also to mention that northwest (southern France and northwest of Sardinia and Corsica islands) and south Mediterranean Sea show up to 1.5 ºC decrease in sea surface temperature (see Fig. 6). In general, south and southeastern Mediterranean Sea are warmer than north and west Medi-



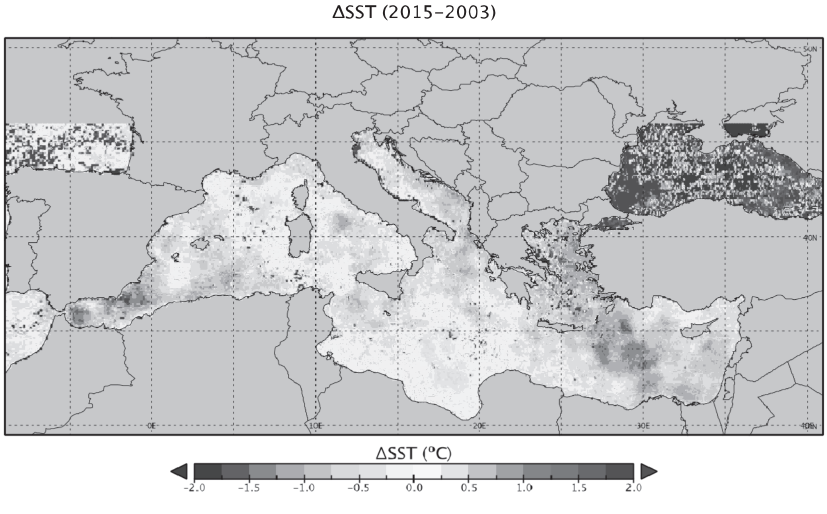
Mean SST (2003–2015)

Figure 4. The 13 years mean of the SST by MODIS Aqua satellite.



Mean Chl–a (2003–2015)

Figure 5. The 13 years mean of Chl-a by MODIS Aqua satellite



ΔSST (2015–2003)

Figure 6. The relative differences for SST between 2015 and 2003.

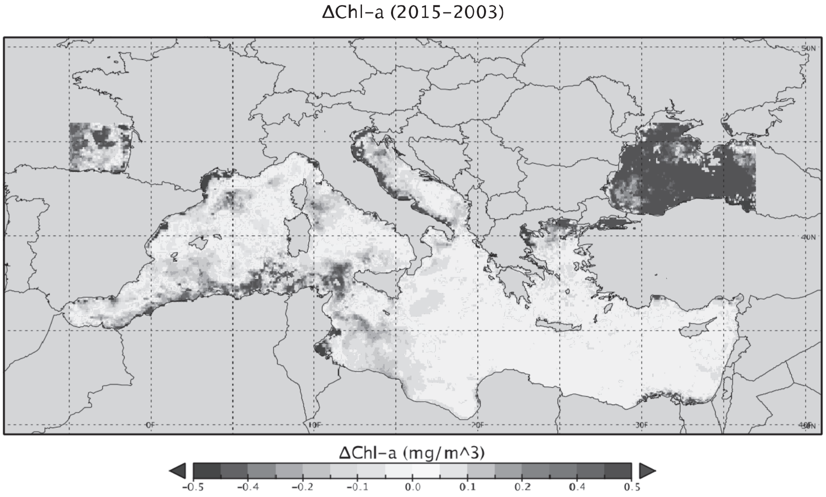


Figure 7. The relative differences for Chl-a between 2015 and 2003.

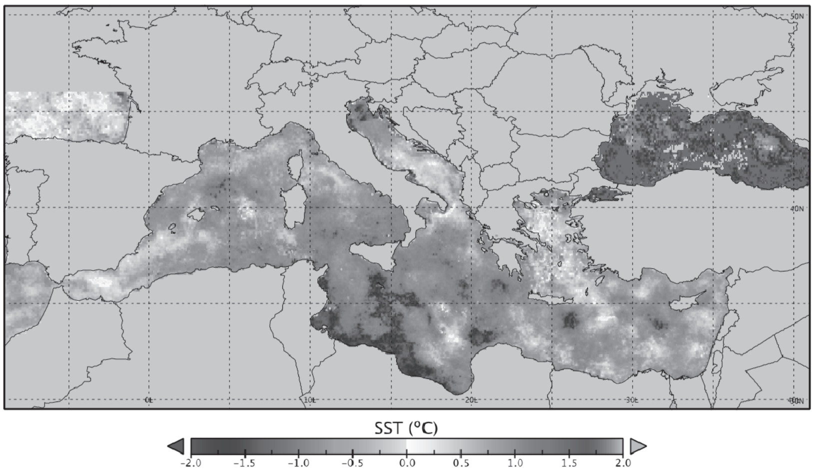


Figure 8. Anomaly in SST for the JFM period in 2003.

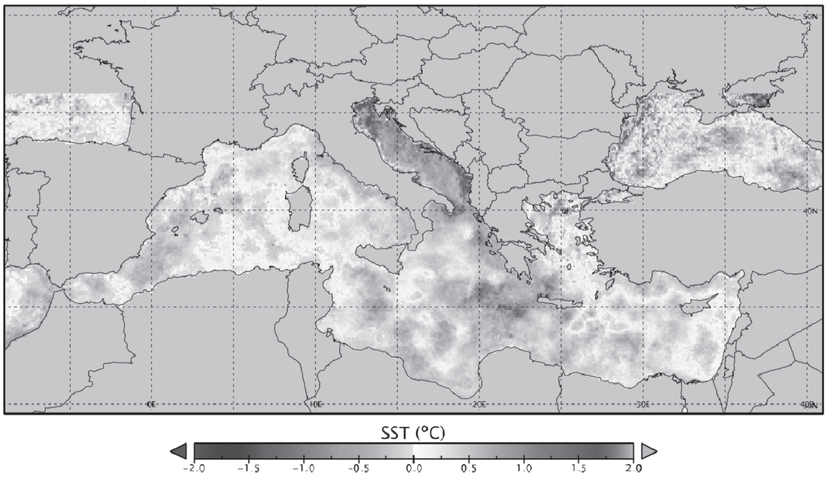


Figure 9. Anomaly in SST for the JFM period in 2015.

terranean Sea (ca. 5-9 ºC) (see Fig. 4).

On the other hand, north and west Mediterranean Sea more trophic than the south and southeast Mediterranean Sea (see Fig. 5).

That points to a higher primer production in the regions due to the high Chl-*a* concentration. An interesting result about the anomalies of mean of SST in JFM season is shown in the figures 8 and 9. Comparing the figures shows that the anomaly of sea surface temperature in JFM season much greater in 2015 than 2003. Furthermore, SST anomaly in the Adriatic Sea becomes greater (ca. 2.5 ºC) than the Levantine basin (about 0.5 ºC) from 2003 to 2015 (see figures 8 and 9).

Discussion

The species was first observed by Akyüz (1957) in Turkish coastal sites of the Mediterranean Sea. Fortuna *et al.*, (2014) published that the main distributed region of the species is probably the central-southern Adriatic Sea. Ca. 25% of the total species member distribute and breed in the region. Although all the species members were observed in the Eastern Mediterranean Sea in winter season between February and April (Akyüz, 1957; Bradai and Capapé, 2001; Golani and Levy, 2005; Yaglıoglu *et al.,* 2013), the species is even observed in the central-southern Adriatic Sea in summer season (Fortuna *et al.,* 2014).In the northern Mediterranean, the species gives birth in summer and the gestation period is still largely conjectural (Notarbartolo di Sciara, 1989). On the other hand, Storai *et al.,* (2011) also observed and recorded a 36 percent of the total by-catch species around Sardinia Island from *M. mobular* during the fishing season from 1990 to 2009. Among other inexperienced information about the ecological and biological characteristics of the species, the migration distance of the giant devil ray is still not well understood. The knowing longest migration distance of *M. mobular* specimen is about 337 km in 120 days (Canese *et al.,* 2011).

The documentation of the alien species of the Turkish coastal waters has been intensively driven particularly since last decades. The observations of single specimen (i.e. *M. mobular*) were recorded three times in the off Turkish coastal sides (Akyüz, 1957; Geldiay, 1966; Yaglioglu *et al.,* 2013; Bilecenoğlu *et al.,* 2014) moreover in the northeastern Mediterranean coasts (East Med, 2010; Yaglioglu *et al.,* 2013). In the table, the observation records of the *M. mobular* were collected (see Tab. 1), and the observation locations were also illustrated on figure 10.

Only records with observation time and location name were taken in consideration by literature reviews. In Turkish coastal waters, the observation regions with the species have been fishing regularly between 1st of September and 15th of April (i.e. fishing season in Turkey), and during also offshore fishing season (from 15th of April to 31st of August). By consideration of the density of the fishing regions and seasons in Turkish coastal waters, it is certainly assumed that members of this species do not frequently distribute in the by-catch regions of Turkish coastal waters, and not in a large schooling.

In this paper, the first documentation of the species was documented in a large schooling in the Turkish coastal water. A similar large population in Eastern Mediterranean Sea had been also published in Gaza Strip coasts of Palestine in February 2013 (Couturier *et al.,* 2013). The causes of the giant devil ray migration are still an unknown issue in ichthyology. The extraordinary warming of the Adriatic Sea in JFM season (see Fig. 8 and 9)

Table 1.Records of the M. mobular distribution in non-native regions in the Mediterranean Sea. The records were sorted after the record year in the locations

Source	**Record Year**	**Month/Season**	**Location**
Ben-Tuvia (1971)	1960	May	Haifa Bay, Israel
Capapé&Zaouali (1976)	1976	Winter	Off SidiDaoud, Tunisia
Golani (1996)	1987	February	Akhziv at the northern coast of Israel
Hemida et al. (2002)	1996	December	Eastern Algerian Coasts
Hemida et al. (2002)	1996	December	Central Algerian Coasts between Dellys and Zemmouri
Bradai&Capapé (2001)	1999	March	Golf of Gabes, Tunisia
Hemida et al. (2002)	1999	November	Eastern Algerian Coasts
Hemida et al. (2002)	1999	December	Eastern Algerian Coasts
Hemida et al. (2002)	1999	December	Central Algerian Coasts
Bradai&Capapé (2001)	2000	May	Golf of Gabes, Tunisia
Akyol et al. (2005)	2001	Winter	Sivrice, Muğla, Turkey
Hemida et al. (2002)	2001	December	Eastern Algerian Coasts
Akyol et al. (2005)	2002	Winter	Fethiye, Muğla, Turkey
Yaglioglu et al. (2013)	2012	March	Iskenderun Bay, Turkey
Couturier et al. (2013)	2013	February	Gaza Strip, Palestine
Akyol& Ceyhan (2011)	2008-2010	Winter	Aegean Sea, Turkey

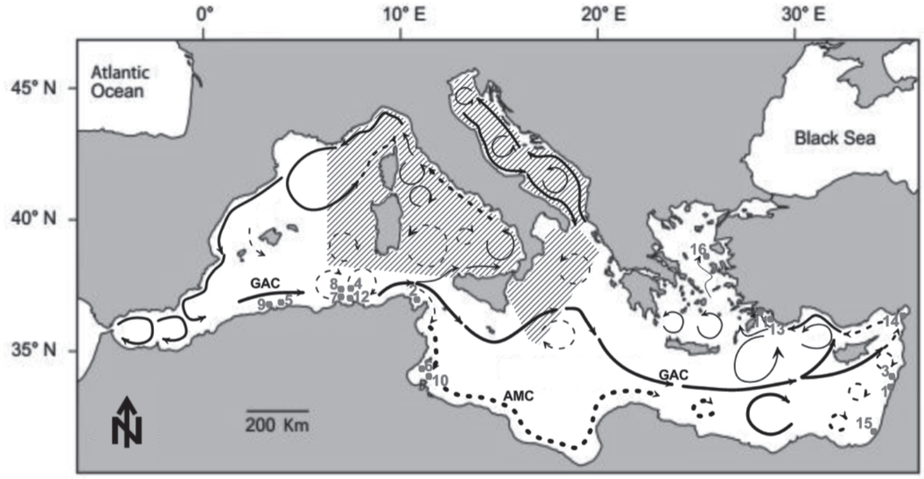


Figure 10. Modified main current system of the Mediterranean Sea. (AMC: African Modified Atlantic Current; GAC: Gibraltar Atlantic Current System. Sources: Pinardi et al.; 2005; Siokou-Frangou et al.; 2010). The observed locations of the M. mobular in non-nativeregions (see Tab. 1). The blue striped area is the native distribution regions of the M. mobular (Notarbartolo di Sciara et al.; 2015).

could force the species to migrate in direction regions with colder sea temperature (i.e. in direction to Levantine basin). Rose (2005) reported a similar ecological behavior of the fish species from temperate to Subarctic North Atlantic regions. Certainly, the change in temperature could not be the only reason for changing the native habitats of the marine species. Doney *et al.,* (2012) precisely studied the biological, physiological, and biogeochemical responses of the marine ecosystem under climate change by long term oceanic observations. The ecological behaviors of the marine species show differences due to their adaptation ability for physical and biochemical conditions of the marine environment (Doney *et al.,* 2012). It seems that the *M. mobular* is relatively sensitive to particularly the SST change in their native in the winter time.

Likewise, the surface current system of the Mediterranean Sea can be taken as an important indicator for migration of the marine species, particularly from the West to the East of Mediterranean (see Fig. 10). Fishes often make large migrations between their feeding and spawning grounds. Movements are associated with ocean/sea currents and with the availability of food (e.g. due to changing the food web) in different regions at different times of years (Barbaro *et al.,* 2009; Ueda and Tsukamoto, 2013). The revision of the literature for records of the *M. mobular* observation in non-native regions, where the species occurs only seasonally shows that the member of the species most probably follows the AMC (Atlantic Modified Current system) and GAC (Gibraltar Atlantic Current system) current systems in Mediterranean Sea to migrate to new regions (see Fig. 10).

The main outcomes of this study is: to understand of the alien species migration in/into the Mediterranean Sea, the seasonal change in sea surface temperature, change Chl-*a* density, current system and also maybe change in pH have to be taken in consideration. Due to lack of the long-term gridded salinity data with high spatial resolution in the regions, unfortunately the impact of salinity with sea surface temperature, current and Chl-*a* change on the migration of *M. mobular* could not be investigated. For the future studies, it is highly recommended to include the change in long-term salinity of the Mediterranean Sea for investigation the impact on the topic.

The impacts of climate change due to especially anthropogenic activities have been observed on all ecosystems at global and regional level since the increase of industrial activities. The ecological behavior of the living organisms is also highly depending on the synergy of environmental factors. For understanding and simulating of the ecological behaviors of species (i.e. marine species), the synergy and interaction between the marine ecosystems and atmospheric processes has to be considered. In this study, possible impact of the environmental factors (i.e. sea surface temperature (SST) and current system of the Mediterranean Sea) and change in Chl-*a* density on the migration of the giant devil ray (*M. mobular*) is investigated towards Eastern Mediterranean Sea. Comparing of the direction of the giant devil rays' migration with the change in SST, Chl-*a*, and direction of the main current systems between the domestic regions and migrated regions indicates to a hypothesis that the giant devil rays fallow the Atlantic Modified Current system (AMC) and Gibraltar Atlantic Current system (GAC) due to the increase of the SST in the domestic regions in winter time and decreasing the Chl-*a* concentration in particularly northwest Mediterranean Sea in last decades. It is also highly suggested to include investigation of the possible impact of salinity on migration of the alien species in the Mediterranean Sea.

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