2015: IS THE BLUEFIN TUNA FACING ANOTHER 2003?

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SUMMARY

In 2003, due to a peculiar climate and oceanographic situation on both sides of the Atlantic Ocean and in the Mediterranean Sea, bluefin tuna had a huge recruitment that was noticed very clearly in the following years. According to the first information in 2015, the oceanographic conditions in the Mediterranean were very unusual, while for sure 2015 (up to August) has been the hottest year comparing the same period in the last 186 years. Even if recruitment information will be available only in the following months or next year at the best, for sure it will be important to follow the evolution of this year class, because it may be another unusual one, even if it is difficult, now, to understand in which way. The first information included in this paper reports about the presence of very small juveniles in several areas, a couple of weeks before the usual dates. This paper describes the unusual oceanographic conditions noticed in late spring and early summer 2015 in correlation with some very first observations reported on bluefin tuna in the Mediterranean Sea.

RÉSUMÉ

En 2003, en raison d'un climat particulier et de la situation océanographique des deux côtés de l'océan Atlantique et en mer Méditerranée, le thon rouge avait connu un recrutement très fort qui a été remarqué très clairement dans les années suivantes. Selon les premières informations obtenues en 2015, les conditions océanographiques en Méditerranée ont été très inhabituelles, l'année 2015 (jusqu'au mois d'août) ayant été l'année la plus chaude par rapport à la même période au cours des 186 dernières années. Même si les informations de recrutement ne seront disponibles qu'au cours des mois suivants ou de l'année prochaine au mieux, il sera à coup sûr important de suivre l'évolution de cette classe d'âge, car il pourrait s'agir d'une autre classe insolite, même s'il est difficile à ce stade de comprendre de quelle manière. Les premières informations contenues dans ce document se rapportent à la présence de jeunes de très petite taille dans plusieurs zones, deux semaines environ avant les dates habituelles. Ce document décrit les conditions océanographiques inhabituelles remarquées à la fin du printemps et début de l'été 2015 en corrélation avec de toutes premières constatations signalées sur le thon rouge en Méditerranée.

RESUMEN

En 2003, debido a una situación oceanográfica y climática peculiar en ambos lados del Atlántico y en el Mediterráneo, el atún rojo tuvo un enorme reclutamiento que se observó muy claramente en los siguientes años. De acuerdo con la primera información de 2015, las condiciones oceanográficas en el Mediterráneo eran muy inusuales, mientras que 2015 (hasta agosto) ha sido el año más caluroso en comparación con el mismo periodo de los últimos 186 años. Incluso aunque la información sobre reclutamiento estará disponible solo en los próximos meses o, como mucho, el año próximo, seguro que será importante seguir la evolución de esta clase anual, porque podría ser otra clase anual inusual, aunque es difícil, ahora, entender de qué manera. La primera información incluida en este documento trata sobre la presencia de juveniles muy pequeños en varias zonas, un par de semanas antes de las fechas habituales. Este documento describe las inusuales condiciones oceanográficas observadas a finales de la primavera y principios del verano de 2015 en correlación con algunas observaciones comunicadas sobre el atún rojo en el Mediterráneo.

KEYWORDS

Bluefin tuna, Oceanography, Climate,
Atlantic Ocean, Mediterranean Sea, Reproduction, Recruitment

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1. Foreword

Bluefin tuna (*Thunnus thynnus*) like many other pelagic species, shows immediate reactions to any environmental change, which induces modifications in any oceanographic situation, particularly during its spawning period. Some descriptions are provided by Piccinetti *et al.* (2013), while a first tentative of prediction model was developed by GBYP using both aerial survey data and SST (Cañadas *et al*., 2010, 2011), but it is not so easy to correlate bluefin tuna spawning behaviour, oceanography and therefore any possible effect on recruitment.

Data and detailed (even if still incomplete) information about eastern bluefin tuna exist since more than 22 centuries (Di Natale, 2010), and the total number of papers concerning various details of the reproductive biology of this important species are included in many hundreds of papers, published in several countries on both sides of the Atlantic Ocean and in the Mediterranean Sea (Corwin, 1929; Mather *et al*., 1995; Aguilar & Lastra, 2009; Di Natale, 2012). Besides this mass of information, several aspects are still to be further investigated and understood, because this species has a very complex behaviour and it is distributed in a very large area, in various environments.

The major spawning areas in the Mediterranean Sea are around the Balearic Islands, in the southern Tyrrhenian Sea, in the central-southern Mediterranean (a large area from south of Sicily, Malta and possibly a part of the Gulf of Sirte) and in the eastern Mediterranean Sea (Di Natale, 2006; Piccinetti *et al*., 2013). Some recent papers (Fromentin and Powers, 2005; Gabrié *et al*., 2012) are still not including the southern Tyrrhenian as a spawning area, even though it is possibly the most documented one.

Researches carried out with a daily ichthyoplankton sampling (Sanzo, 1932), with histological analyses of the gonads or with examinations of the bluefin tuna ovaries in tuna traps show that normally spawning in the Mediterranean Sea occurs from the second part of May to July, but in some years mature eggs and larvae were found also in August, demonstrating that the reproductive season might be extended in some years. The spawning period in the various areas of the Mediterranean Sea is also confirmed by the comprehensive review by Aguilar & Lastra (2009).

The extensive studies conducted on purse-seine fishery in the Tyrrhenian Sea (Arena, 1964, 1980, 1981, 1982a, 1982b, 1982c, 1985, 1986a, 1986b, 1988a, 1988b, 1990; Arena *et al*., 1979; Arena & Cefali, 2002), showed that the main reproductive season in this area is mostly between mid-May to mid-July, with a peak in June, usually showing a limited variability, before or after this period, each year, depending mostly on the oceanographic and environmental conditions. This period was confirmed also by De Metrio *et al*., (1988, 2003a, 2003b), Block *et al*., (2001) and Rooker *et al*. (2007) for the central Mediterranean Sea.

Spawning in the eastern Mediterranean and in the Levantine sea usually occurs slightly earlier, starting in the first part of May (Oray, 1998; De Metrio *et al*., 2003b), when the sea temperature in this area increases well earlier than in all other parts of the Mediterranean Sea and when favourable weather situations allow the formation of an upper stratum with relatively high temperature and a stable thermocline at the proper depth. According to the earlier evolution of the hot water masses, this situation possibly occurs also along the south-eastern part of the Mediterranean Sea, between eastern Cirenaica (Libya) and the eastern part of the Nile delta (Egypt).

The beginning of the bluefin tuna reproduction season in the western Mediterranean area and particularly in the Balearic Sea is usually delayed by one or two weeks compared to the central Mediterranean Sea. In very recent years and particularly in 2011, spawning occurred also at the very beginning of May, due to very particular oceanographic event, but this fact can be regarded as an anomaly, because the situation returned to the normality after about 10 days.

Usually bluefin tuna (*Thunnus thynnus*)[2] in the Mediterranean Sea starts spawning at a temperature over 20.5°C, but this is not a lower limit, because occasional spawning has been reported at lower temperatures. Furthermore, this factor alone is necessary but not sufficient, because according to the current knowledge, bluefin tuna seems preferring that warm waters are there in a substantial layer (over 10 m depth minimum), able to host even a large school; this layer is usually limited at the lower part by a well-established thermocline having a minimum negative gradient of 3°C from the upper warm stratum. It is supposed that temperatures over 26°C in the upper sea water mass are not suitable for bluefin tuna spawning, but the possible upper temperature limit is not well

[2] In this case, we will examine the population currently defined as Eastern Atlantic Bluefin tuna by ICCAT.

defined. A specific spawning behaviour, observed several times mostly during aerials surveys conducted in the '80s and '90s, is the fast vertical or diagonal swimming from the surface to deeper areas, crossing the thermocline up and down (Arena, 1980, 1981, 1982a, 1982b, 1982c, 1985, 1986a, 1986b, 1988a, 1988b, 1990; Arena et al., 1979; Arena & Cefali, 2002). It is supposed that this behaviour may help in activating some physiological factors linked to the spawning activity.

The reproduction occurs in a fractionated manner in each bluefin tuna individual. Marino *et al*. (2005) demonstrated that the same bluefin tuna female individual is able to release mature eggs from the ovary several times, over a certain period, with spawning having one or more days distance one from the other. In the same individual, spawning may occur during more than one month in the same season. Each bluefin tuna ovary contains various million of oocytes, and a part of them having the biggest size can be hydratated and released in a very short time following hormonal stimuli, which some predators may also captate (Susca *et al*. 2000, 2001; Schaefer, 2001; Medina *et al.* 2002; Abascal *et al.* 2003, 2004; Corriero *et al*. 2003, 2005; Santamaria *et al*. 2003; Zupa *et al*. 2009). This spawning period can be much more extended under particular circumstances (Piccinetti *et al*., 2013). Logically, the same happens to male bluefin tunas, even if studies on males are much more limited (Santamaria *et al.*, 2003; Abascal *et al*., 2004).

Bluefin tuna spawning periods which have been more extended than usual were reported several times in the past (De Buen, 1923a, 1923b, 1923c; Biancalana, 1958; Scaccini, 1959; Arena, 1963, 1964; Sarà, 1983, 1998), and other evidences were provided like "anomalous" size frequencies of age 0 and 1 in some spring-summer fisheries. Other evidences for prolonged spawning season were also provided by Piccinetti *et al*. (2013) for the years 2003, 2006, 2006 and 2011.

The effects of a "special" year in terms of climate and oceanographic conditions were noticed several times by ICCAT SCRS and they refer mostly to 2003, when a long and hot spring and summer had many positive effects on bluefin tuna spawning success and the consequent recruitment on both sides of the Atlantic Ocean, including the Mediterranean Sea. This specific year class was noticed in several fisheries. Bluefin tuna spawning in some recent years was more intense and/or expanded in time (and maybe also in space) in the Mediterranean Sea, resulting in a higher recruitment, particularly in 2003, 2006, 2007, 2009, 2010 and 2011. All these year classes showed-up in the same years at very small sizes (200-600 g) late in August and up to early September in many areas (Piccinetti *et al*., 2013), while the very strong 2003 class is now evident in almost all fisheries in the Atlantic Ocean and in the Mediterranean Sea, as a result of the climate anomalies in that year.

Recent oceanographic anomalies in the Mediterranean Sea (like the variability in the Eastern Mediterranean Transient in 1996 and 2006) caused different concentrations of bluefin tuna spawners in some central Mediterranean areas, with a partial and temporary shifting of the major concentrations from the southern Tyrrhenian Sea to the southern Mediterranean Sea. More recently, in 2011, the presence of a stable warm water mass between eastern Libya and southern Italy and Greece, during the spawning period, coupled with the contemporary strong winds in the central Mediterranean south of Malta (which mixed-up the upper layer of the sea, thus preventing the establishment of a stable thermocline) caused eastward movements of bluefin tuna schools of spawners, noticed also by the ICCAT GBYP aerial survey for bluefin tuna spawning aggregations in 2011. This fact further confirms how bluefin tuna can opportunistically use most of the Mediterranean Sea for spawning. These considerations imply a need for extra caution when spatial models are developed, because variables can be many and important.

This year, following the usual day-by-day observations on the development of the oceanographic conditions in the Mediterranean Sea prior to and during the bluefin tuna spawning season in the Mediterranean Sea, we noticed since the beginning an unusual situation and therefore we proceeded with a strict monitoring of various oceanographic parameters and in several occasions we checked the data and exchanged and corroborated the information with several oceanographers. At the same time, we tried to obtain anecdotal real-time information on the fisheries in the various areas, especially on the specific behaviour of bluefin tuna in order to possibly correlate it with the particular oceanographic conditions noticed this year.

Oceanography[3] and waves[4] are monitored every year by GBYP since the beginning, usually from mid-April to August, trying to better understand the correlations among various factors and the behaviour of bluefin tuna in the Mediterranean. This monitoring is also useful for checking the best conditions for the GBYP aerial survey on spawning aggregations.

2. Oceanography and climate in late spring and early summer 2015

Since mid-April 2015 it has been clear that an unusual situation will occur in the Mediterranean. External temperatures were increasing almost everywhere, while sea-surface temperature (and the temperature in the upper layers) was showing various anomalous situations compared to averages in the last 20 years, and particularly compared to the recent years, since the beginning of the GBYP activities.

As a matter of fact, in these last years the temperature in the eastern part of the Mediterranean (Levantine Sea and are around the Nile delta) has usually started increasing in the last part of April, rapidly reaching over 21°C SST. This is the reason why bluefin tuna usually starts its spawning in the eastern Mediterranean, sometimes a couple of weeks before than in the other parts of the same Sea.

This year the situation was different: **Figure 1** shows daily SST situation at intervals of about 15 days, while **Figure 2** shows the situation of waves and wind, always at about 15 days intervals, from the last part of April to the first part of July.

At the end of April, most of the eastern Mediterranean and the Gulf of Sirte had the SST well below 18°C. The western Mediterranean and the central Mediterranean had temperatures several degrees below the average. The sea surface and the upper strata were mixed up by very strong winds in the western and central Mediterranean up to April 27.

At the early beginning of May, with the increasing air temperature, the hottest area was a large gyre in the Gulf of Sirte, while the eastern Mediterranean was largely below 20°C. An area of warm temperatures was slowly growing SW of the Balearic Sea, but no tunas were noticed at the surface in this area or in the eastern Mediterranean. The warm area SW of the Balearic Sea disappeared quite quickly.

Around the 11th of May, the SST started increasing in the eastern Mediterranean, particularly north of Cyprus, going over 21°C for the first time in the season. A warm water mass started to develop between the Cirenaica (eastern Libya) and Greece, giving the impression that we were going to face the same situation noticed in 2011, when this area was one of the hottest in June, creating problems for detecting the spawners in the main areas by the aerial survey. The temperature of this water mass decreased in the following days, while the central and western Mediterranean showed SST lower than usual. Strong winds mixed up the upper sea stratum in the central Mediterranean on the 11th and 12th May. Another wind storm arrived on the 15th and continued up to the 17th May. There wasn't any bluefin tuna school reported at the surface in any area, while they were noticed by sonar in various places and catches by longliners started to increase, particularly the by-catch.

After the 20th of May, most of the Mediterranean was colder than usual and the only suitable water masses for spawning were between Cyprus and Lebanon and along a part of the Turkish area (Gulf of Mersin and, in the following days, even in the Gulf of Antalya). Few sightings of tunas at the surface were reported in Turkey, all for short time, while no information is available from Cyprus. A storm arrived in the western Mediterranean on the 19th and mixed up the upper strata up to the 23rd of May. In the large remaining part of the Mediterranean, tuna schools were apparently abundant, but always travelling below the surface.

A large warm water mass slowly grew in most of the eastern Mediterranean in the following days, but not homogenously, keeping some parts colder than usual (i.e.: N and SW of Cyprus), but with instable situations. The central and eastern Mediterranean, despite of the hot air temperatures, remained much colder than usual, due to a further storm from the 26th to the 28th. Only at the end of the month a few schools of tuna were noticed at the surface, but for a short time and in very few areas.

[3] Oceanographic data are provided by http://medforecast.bo.ingv.it/

[4] The daily situation of waves and winds is provided by http://isramar.ocean.org.il/isramar2009/wave_model/default.aspx?region=coarse&model=wam

At the early beginning of June, the eastern Mediterranean showed an even less stable hot water mass, with hottest areas along the E-SE coast, which was potentially suitable for the bluefin tuna spawning, while the other parts were keeping colder than usual, despite the low intensity of the wind. Many bluefin tuna schools were found by sonar only in the depth and not at the surface as usual.

Starting from the 7th of June, thanks to the hot air temperatures, a very hot water mass was noticed in the Tyrrhenian Sea (including also the usually cold Ligurian Sea) and in the NW part of the Balearic Sea, reaching SST of even above 24°C, while SST in the eastern Mediterranean was lower than usual in those days, although quite suitable for spawning. The bluefin tuna seems to prefer the coldest part of the hot water mass in the Tyrrhenian Sea rather than going to the surface, and the fishermen got the quota close to the coast, detecting the schools by sonar. The same happened in the eastern Mediterranean Sea and NW of Balearic Sea. The bluefin tuna was apparently abundant in many areas and it was caught by many longlines at various depths. It seems that in all areas the bluefin tuna schools avoided the hottest parts, but the information is largely incomplete. According to some fishermen's information, some bluefin tuna schools were noticed at the surface late at night or just close to the dawn, when the surface waters were slightly colder.

Around the 10th of June, the Tyrrhenian Sea showed the hottest SST in the Mediterranean, going over 25°C, something really unusual, while the eastern Mediterranean had lower temperatures and a thin colder water mass separated its waters from the central Mediterranean ones. The SST in the water around the Balearic Sea started to decrease, particularly in the SE area, due to a further storm arriving in the area on the 11th and lasting for few days.

Starting from the 13th of June, a hot water mass started to distribute from the Tyrrhenian to the western Ionian Sea, an area usually cold, due to the combined effect of both currents and upwelling from deep zones. Many parts of the central and western Mediterranean had SST decreasing rapidly to about 20°C, possibly due to very strong winds coming from N-NW which lasted for various days. The SST in the eastern Mediterranean waters increased again, reaching more than 26°C. The huge hot water mass, which resembles to the conditions we had in 2011, was distributed from Cyrenaica to the Gulf of Taranto and western Greece, staying there up to the June 18th and then again from the 20th. Currents going in unusual directions were noticed in most of the Mediterranean Sea on June 20th and in the following days they got stronger and were also followed by marked sea fronts.

From the 22nd of June, always having very hot air temperatures, the SST started to increase even in the Balearic area, with a large hot water mass all around the islands, which reached 25°C on the 26th; this water mass, with small changes, remained there up to the July 12th, thanks also to very low winds. The southern Tyrrhenian Sea was quite hot as well, with an expanding water mass in all the area, which rapidly extended throughout the Tyrrhenian and reached 31°C on the July 17th; this high temperature remained there for a couple of weeks. Starting from the same day, even the eastern Ionian Sea and the area SE of Malta had hot SST, reaching about 31°C on July 24th; this unusual temperature further expanded up to August 4th, 2015, reaching the full central Mediterranean Sea. Two very hot water masses were also in the Gulf of Antalya and in the Gulf of Mersin (Turkey), but many parts of the eastern Mediterranean had again strong winds.

Finally, the temperatures in the hottest parts started to decrease after August 15th, when colder water masses invaded most of the western basin.

The temperatures on land, in the last part of spring and the first part of summer 2015 in the Mediterranean Sea, were quite often over 40°C, due to a heat wave. According to a very recent NOAA report (https://www.climate.gov/news-features/event-tracker/summer-heat-wave-arrives-europe), this period was the second hottest in Europe after 2003, the hottest year after the XVI century.

3. Discussion

Our understanding and knowledge of bluefin tuna (*Thunnus thynnus*, L.) behaviour and biology is still very partial. Surely, this is a species with a complex and sophisticated behaviour, which easily crosses the ocean from one side to the other, it has migrations which can be partly modified from year to year, it is able to get the best opportunities as soon as they are there, but at the same time it is quite clear that it is able to "read the ocean" in real time, making individual or collective decisions that we sometimes only partly understand. Furthermore, being a top-predator, its behaviour is in correlation with many other ecosystem factors which induce further choices (Ferrari, 2015). This is clearly the result of a complex and on-going evolution process, possibly fitting

the principle established by Spencer (1864) about the "survival of the fittest". Bluefin tuna is one of the fittest species in the oceans. Trying to reduce our knowledge gap concerning bluefin tuna, we are working to find all possible correlations between behaviour and some environmental factors, always considering that correlations are surely much more complex than those we can consider.

According to the analyses carried out by the Cornell University for the first part of 2015 (www.change.cornell.edu/2015-a-high-temperature-record-breaker-like-none-before-it/), "2015 is on track to break that 2014 record and might even create a new high-temperature bar that lifts itself above all past contenders from the period of instrumental records" (**Figure 3**). Taking into account the temperature record-breaker month of July in the Mediterranean area, reported as the hottest in the last 180 years, it is supposed that 2015 spring-summer will strongly characterise this year.

The NOAA had just published its most recent report about the situation in 2015, up to July (http://www.ncdc.noaa.gov/sotc/). The July average temperature across global land and ocean surfaces was 0.81°C above the 20th century average. As July is climatologically the warmest month for the year, this was also the all-time highest monthly temperature in the 1880–2015 record, at 16.61°C, surpassing the previous record set in 1998 by 0.08°C. The July globally-averaged sea surface temperature was 0.75°C above the 20th century average. This was the highest temperature for any month in the 1880–2015 record, surpassing the previous record set in July 2014 by 0.07°C. The year-to-date temperature combined across global land and ocean surfaces was 0.85°C above the 20th century average. This was the highest for January–July in the 1880–2015 record, surpassing the previous record set in 2010 by 0.09°C. The year-to-date globally-averaged sea surface temperature was 0.67°C above the 20th century average. This was also the highest for January-July in the 1880-2015 record, surpassing the previous record of 2010 by 0.06°C. Every major ocean basin observed records warmth in some areas (**Figure 4**).

At the moment, it is almost impossible to have any reliable data about the bluefin tuna SSB level in 2015, its reproduction success in the spawning season 2015 and therefore any possible recruitment level, but very recent observations at sea reported the following:

- small YOY bluefin tunas (having a FL of about 28 cm) were noticed on August 8th off Calafell (close to Tarragona, western Mediterranean Sea); this size is extremely unusual at that time of the year and might imply a spawning activity at the very early beginning of May (theoretical suitable spawning conditions were detected much southern of this location on May 3rd, 2015, off Cabo de Gata), while other suitable conditions were reported SW of the Balearic area from the same day and up to May 5.
- Several very small YOYs were present in the Gulf of Genoa between August 15th and August 21st, 2015; on August 15th, the YOY had a FL between 19.5 (99 g) and 23.9 cm (232 g); usually the Ligurian Sea is not a spawning area but it is a distribution area for the YOY; the eastern Ligurian Sea and the northern Tyrrhenian Sea had potentially suitable spawning conditions from the 1st of June 2015.
- several feeding aggregations of very small YOY bluefin tuna (with individuals weighting between 150 and 160 g each, between 21 and 22 cm FL) were noticed in the southern Tyrrhenian Sea from August 22nd[5], confirming that spawning possibly occurred even in late May in this area.

Taking into account the early growth rate in normal oceanographic conditions (Orsi Relini *et al*., 1997; La Mesa *et al*., 2005), a bluefin tuna having a length of 19 cm should have an age between 75 to 90 days, at 24 cm should be between 80 to 110 days old, and at 28 cm should be between 90 and 110 days old. These growth rates are supposed to increase whenever warmer temperatures are there.

Surely, the behaviour of bluefin tuna in this period was quite different than usual, due to the very unusual oceanographic conditions, especially the weather. Bluefin tuna schools were frequently noticed in many areas, quite often not at the surface, but immediately below. It seems that the thermocline was quite instable or reduced in most of the areas up to the end of May. This fact possibly prevented any extended or massive bluefin tuna spawning in many areas during this period but not scattered spawning activities. Anecdotal information coming from various fisheries in 2015 always reported catches with mature gonads in May, but very few fish with "fluent" gonads.

[5] These feeding aggregations of bluefin tuna YOY were swimming at 10-15 m depth over a large area.

Since the end of the first week of June, fishermen started reporting fluent gonads in almost all parts of the Mediterranean Sea and it seems that the thermocline was properly present in several parts (with a high instability, locally depending from the wind intensity), even if bluefin tuna schools were swimming for very short time at the surface. Most of the purse-seine fleets got their full quota in very few days during this period, sometimes not far from the coasts.

In the second part of June, huge schools of bluefin tunas (sometimes estimated at over 15,000 tons in one single school) were noticed at the surface in several parts of the central-western Mediterranean, in areas where these events are not common, but spawners were reported both by the ICCAT GBYP aerial survey (SCRS/2015/147) and many fishermen. Unusual concentration of bluefin tuna spawners were noticed in areas between W-Sardinia and NE-Algeria and W-Sicily and NE-Tunisia, zones where bluefin tuna usually moves during its seasonal migrations to some of the usual spawning areas in the southern Tyrrhenian Sea or in the central Mediterranean Sea. Thanks to the real time analyses of the SST maps, the wind/wave situation, the aerials survey data and the data provided by some miniPATs implanted in Larache (Morocco), it was possible to better confirm this situation and detect the correlations, which are not common or easy to find. **Figure 5** shows the movement of a bluefin tuna which clearly stayed for several days in the same area NW of Tunisia, along with the SST maps in the same days, where is evident a warm water mass in the same area; due to the calm sea state on 24th and 25th June, it is possible that a suitable warm water stratum and thermocline were present when tuna spawners concentrated, where the biggest school was spotted. A strong thermocline was present in the Tyrrhenian Sea, in the Balearic Sea and in some eastern Mediterranean areas, where winds had low intensity.

Bluefin tuna spawners were reported up to mid-July in various areas, but the hot temperature induced the fish not to stay often at the surface and many were reported again just below it. Fishermen reported that gonads were fluent in the very first week of July, getting less tense shape in the following days. In this last period, some fish were caught with almost empty gonads, only with a not mature fraction (possibly to be reabsorbed in the following weeks). Others were still with full mature gonads.

Anecdotal information obtained from several longline fleets (mostly targeting swordfish) reported that bluefin tunas were distributed almost everywhere, mostly from 20 to 250 m depth.

The unusual high temperatures, the variable thermocline, the strong winds in many areas which contributed to the mixing of the upper layer, the wide distribution of adult bluefin tuna in most of the Mediterranean areas, possibly induced it in adopting a different spawning strategy in 2015, opting for a fractioned spawning and taking advantage of appropriate oceanographic conditions and opportunities whenever they were present and moving quickly within various areas of the Mediterranean for catching them. This behaviour, supported by a considerable information, possibly negatively affected the ICCAT GBYP aerial survey for spawning aggregations, increasing the additional variance and making more difficult the encountering of bluefin tuna spawners at the surface, even though most of the areas were surveyed and with various aircrafts.

Thanks to the availability of several SST data elaborations, mostly on http://marine.copernicus.eu/web/69-myocean-interactive-catalogue.php?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004 it was possible to examine the average monthly SST data for the Mediterranean Sea from 1987 to 2015, and we selected the months of May and June, those when the bluefin tuna spawning activity is usually the most intense. Looking at the images (where the temperature scale was kept constant, setting the lower limit at 20.5°C and the upper limit at 26°C), it is quite clear that there were important differences in some years.

Figure 6 shows the yearly variability of average monthly SST in the Mediterranean Sea in May, from 1987 to 2015. According to the various images, it is confirmed that usually the temperature starts increasing already in May and first in the eastern Mediterranean, but in some years (1987, 1992, and 1993) there was a clear delay and this possibly affected the spawning in this month. In some years (1999, 2000, 2003, 2003, 2013 and 2015), the temperature increase was noticed even in other areas, possibly contributing to more spawning opportunities.

Figure 7 shows the yearly variability of average monthly SST in the Mediterranean Sea in June, from 1987 to 2015. In June, the suitable temperatures for spawning are present in most of the Mediterranean, usually with highest temperatures in the eastern part. In just a few years (1997, 1991 and 1992) June was colder that other years and this possibly affected both spawning and recruitment. In all other years June was quite warm, particularly from 1993 to 2003, in 2005, from 2007 to 2012, in 2014 and 2015. The hottest June was clearly in 2003, but even June 2015 shows the second highest average. Taking into account the remarkable year class noticed in 2003, it is possible that a numerous year class will be reached also in 2015.

The first impression is that in 2015 there was a considerable delay in the initial spawning in many parts of the Mediterranean Sea (from 2 to 3 weeks in most areas), followed by scattered but very intense and massive spawning in many parts of the Mediterranean Sea, including some areas where spawning not always occurs. At the same time, there were anticipated potentially suitable spawning conditions in the Gulf of Sirte and, maybe, for a few days, even in few small areas in the western Mediterranean and in the far eastern Levantine Sea. How this spawning behaviour will result in a higher number of bluefin tuna larvae and then recruits will be detected later in the season and in the following years, but possibly young-of-the-year will provide a first indication in autumn 2015. According to the very first information available at the date, recruitment in 2015 was much anticipated than usual in some areas and possibly very extended over the season; this will possibly result in a broader range of size frequencies for age 0 fish. However, taking into account all data, it is possible that 2015 will not be so different from 2003 for bluefin tuna.

This real-time observations confirm again the importance of strictly monitoring several oceanographic and environmental data for possibly correlating them with bluefin tuna distribution and behaviour, trying to further improve our knowledge and understanding of this species.

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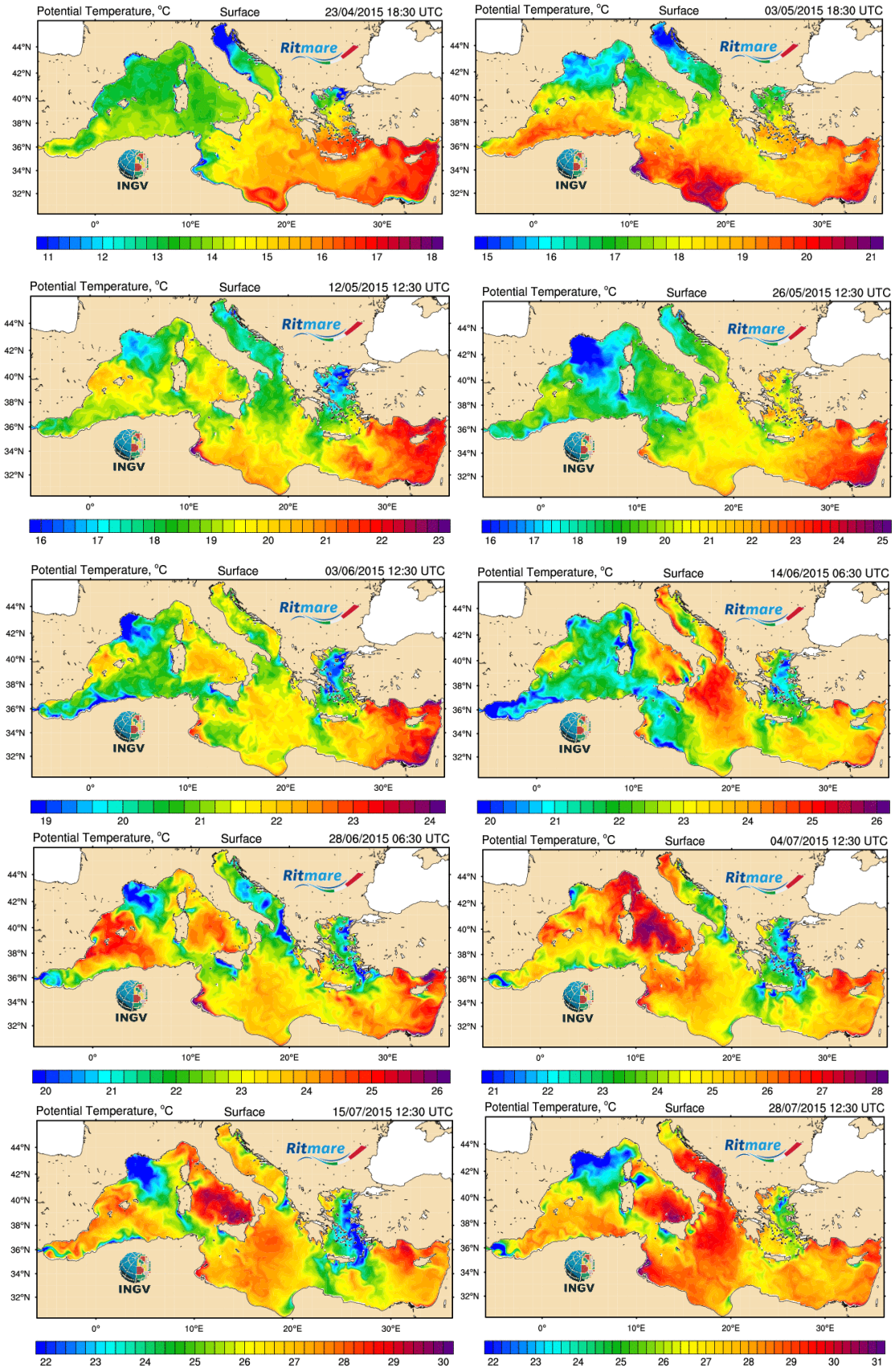

Figure 1. Graphic presentation of SST daily evolution in the Mediterranean Sea in 2015, at intervals of about 15 days, from 26 April to 28 July. The temperature scales are below each map and they are not constant.

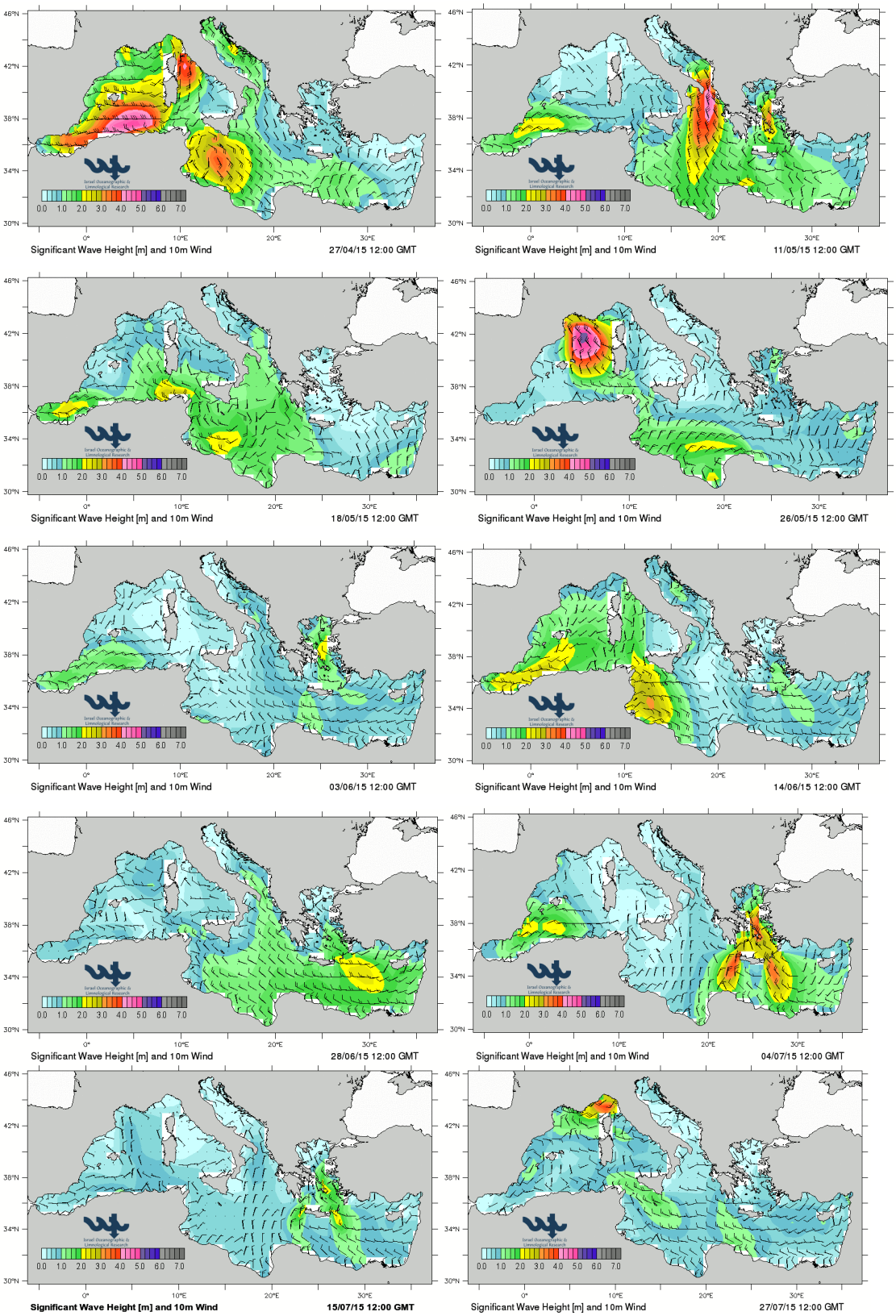

Figure 2. Graphic presentation of daily waves and wind direction and intensity in the Mediterranean Sea in 2015, at intervals of about 15 days, from 27 April to 27 July. The wave high scale is below each map.

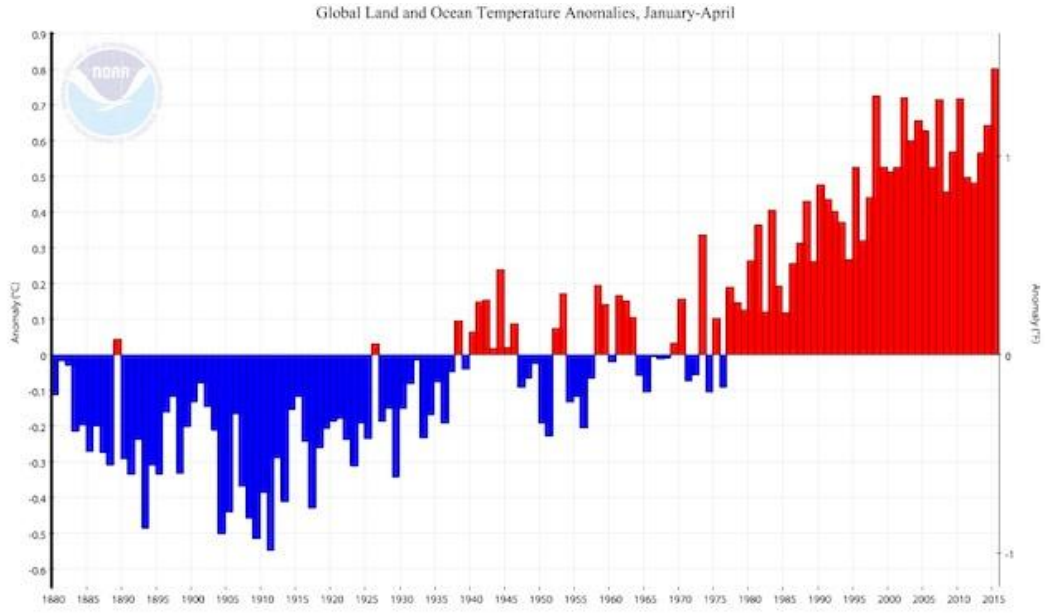

Figure 3. Graphic presentation of the global temperature anomalies from 1880 to 2015, for the first four months of each year, from January to April of each respective year. Looking only to the first trimester of the 2015, it has already set a new record as the hottest. Source: https://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/4/1880-2015.

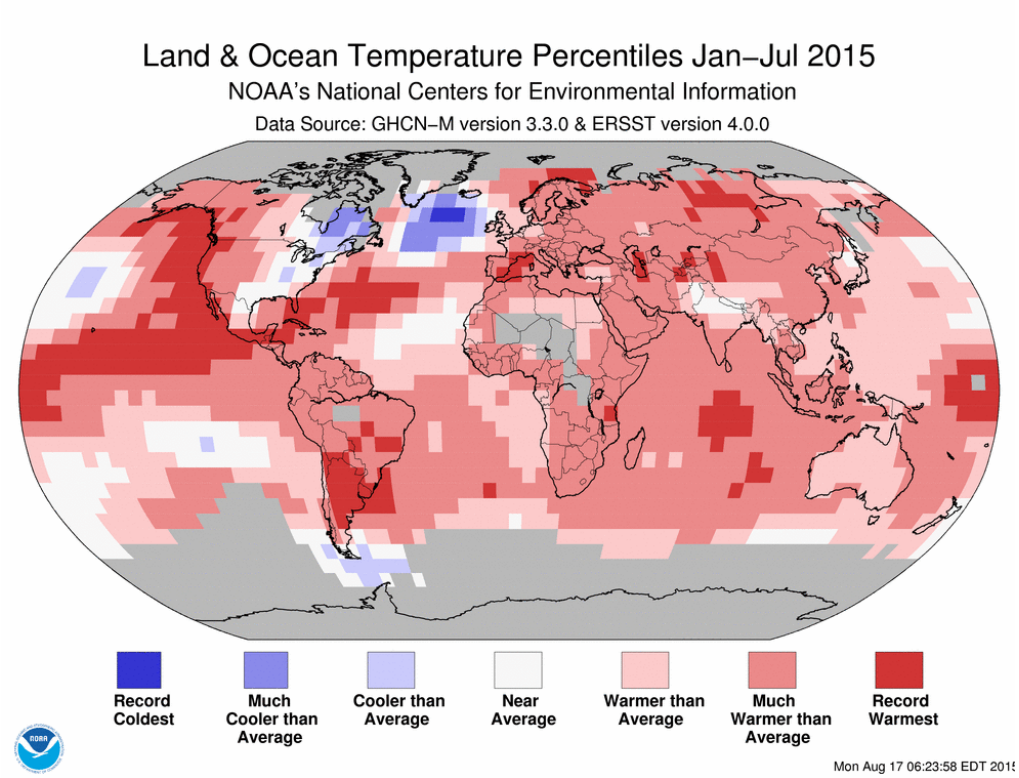

Figure 4. Graphic map of the global blended land and Sea Surface Temperature percentiles, for the first seven months of 2015, from January to July. The Mediterranean area was much warmer than average, a part of the eastern Mediterranean area was warmer than average, while the western Mediterranean area set the warmest record. Source: http://www.ncdc.noaa.gov/sotc/global/201507

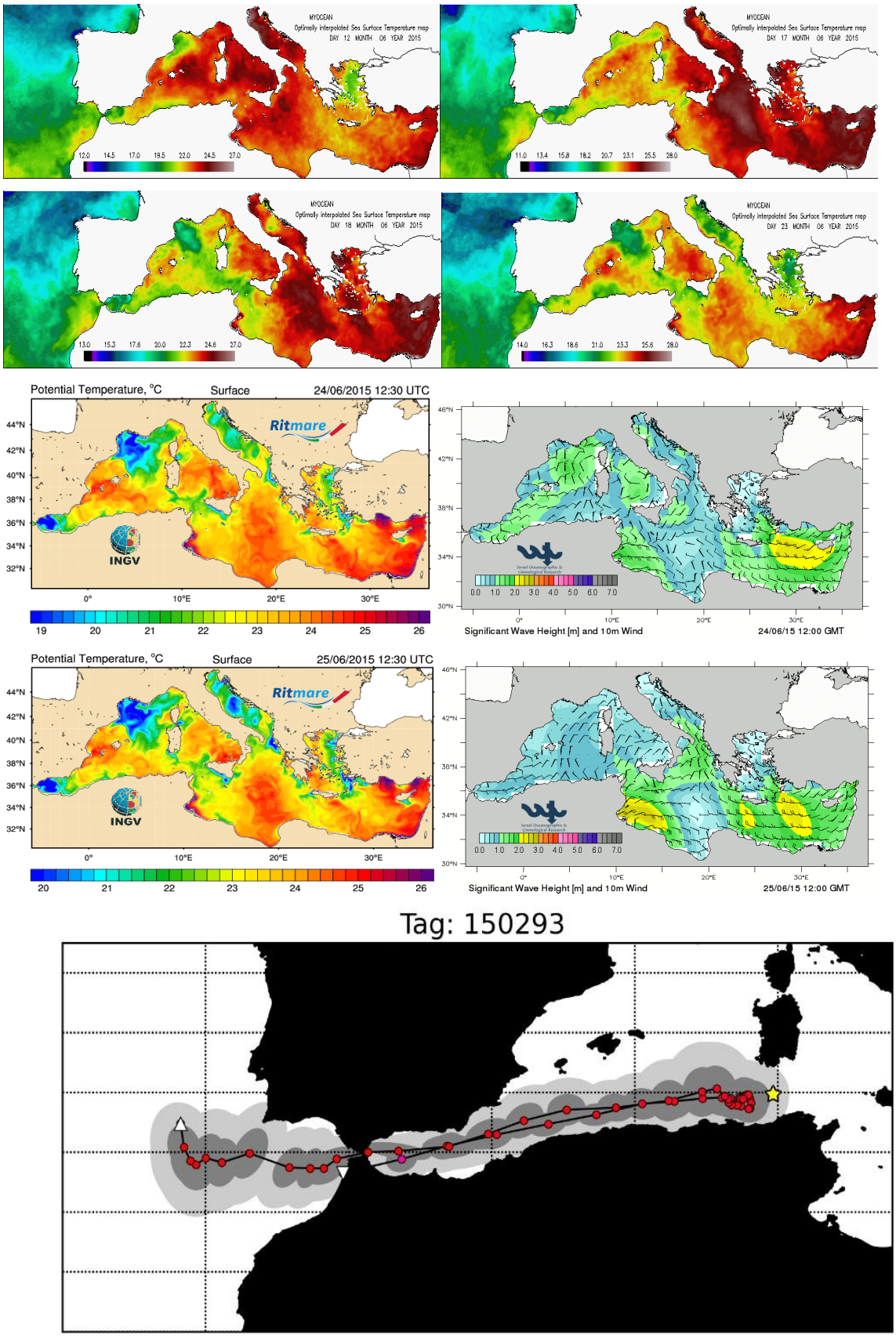

Figure 5. Displacement of a bluefin tuna tagged in Larache (Morocco), which moved to NW Tunisia, remaining in the area between June 12 and 25. SST on June 12, 17, 18 and 23 are in the upper part of the figure, while SST and winds/waves on June 24 and 25 are in the lower part. An aerial sighting of an enormous school (>15,000 tons) of bluefin tuna spawners (yellow star) in the area was reported on June 24, 2015.

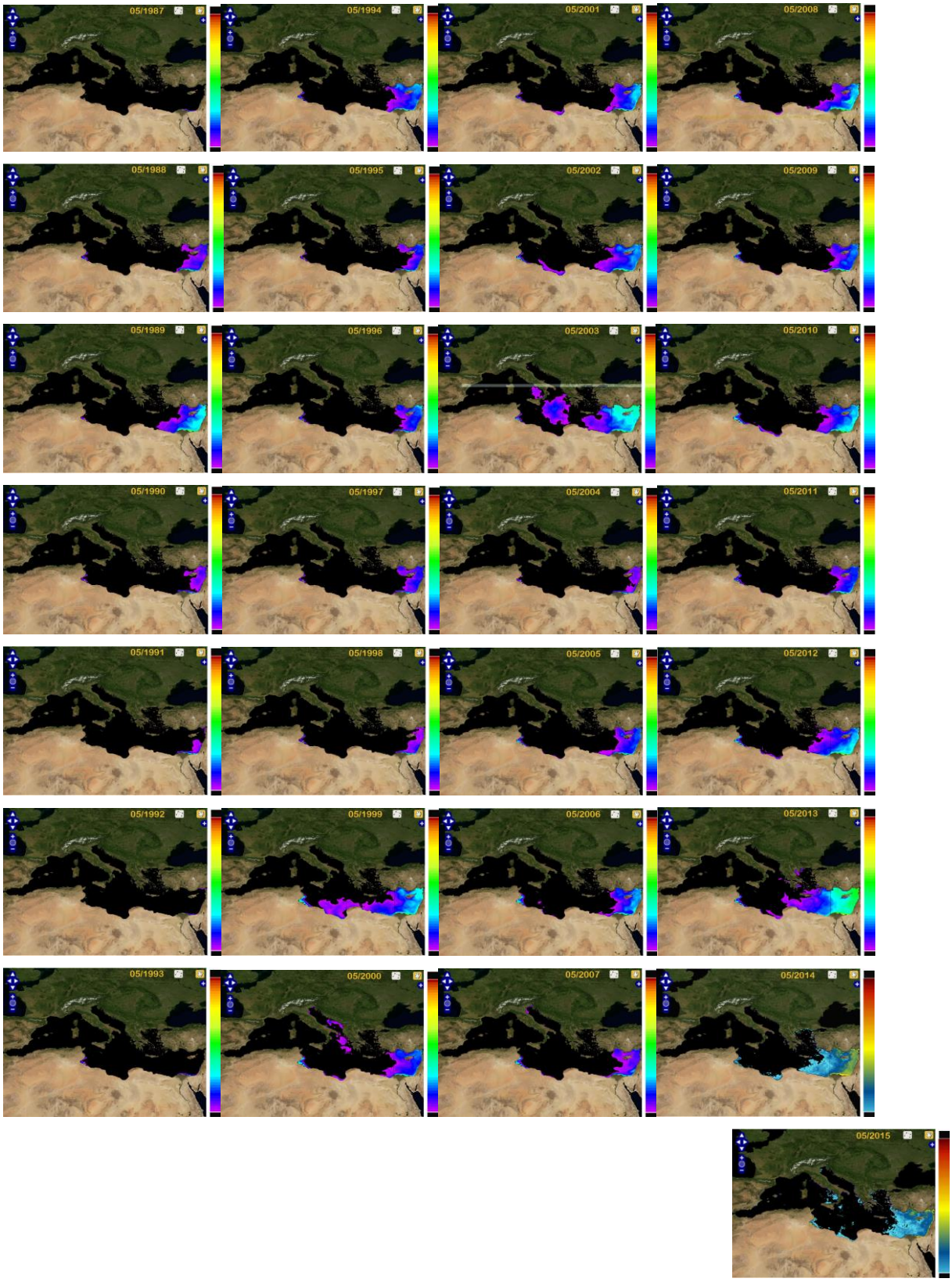

Figure 6. Monthly average SST in the Mediterranean Sea in May, from 1987 to 2015, from the top the bottom and from left to right. The temperature scale we used for these images is constant, ranging from a lower limit of 20.5°C to a maximum limit of 26°C, but the last two years (2014 and 2015) have a slightly different scale of colour.

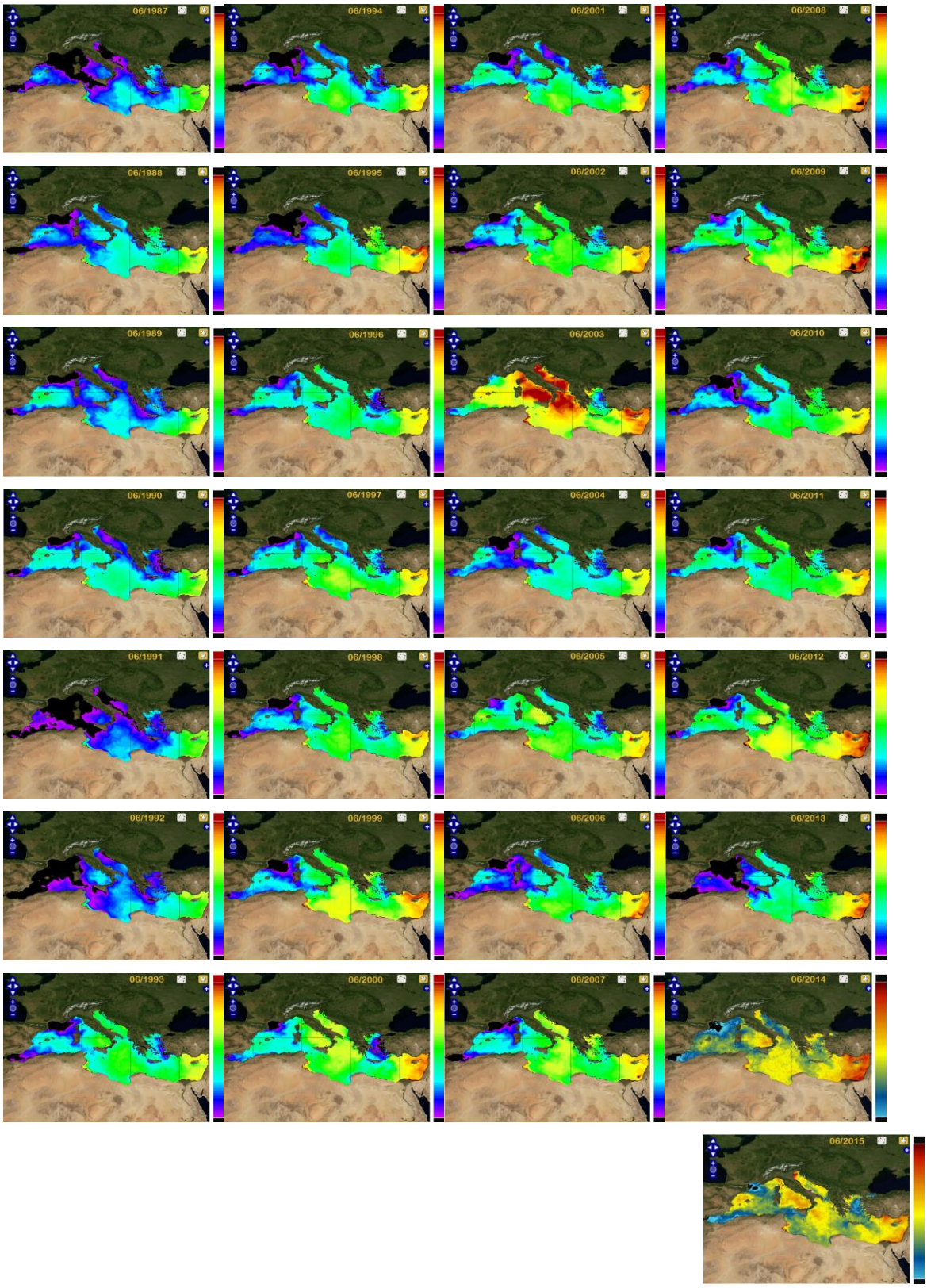

Figure 7. Monthly average SST in the Mediterranean Sea in June, from 1987 to 2015, from the top the bottom and from left to right. The temperature scale we used for these images is constant, ranging from a lower limit of 20.5°C to a maximum limit of 26°C, but the last two years (2014 and 2015) have a slightly different scale of colour.