THE DISAPPERANCE OF YOUNG-OF-THE YEAR BLUEFIN TUNA FROM THE MEDITERRANEAN COAST IN 2016: IS IT AN EFFECT OF THE CLIMATE CHANGE?

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SUMMARY

The year 2016 was the hottest so far on the Earth and in the Mediterranean Sea and this is a fact. YOY of an unusual great size were noticed in September. The other fact is that, for the first time in living memory, the presence of Bluefin tuna YOY was completely different from the usual, with a regular but anticipated presence along all coasts in August, for then quickly disappearing in deeper and off-shore waters. The behaviour afterwards was also unusual. Even after cross-checking the oceanographic data, it is not clear which assemblage of factors had affected the distribution, but certainly the climate change had a still undefined role, because the situation was Mediterranean-wide spread.

RÉSUMÉ

C'est un état de fait que 2016 a été l'année la plus chaude que la terre et la mer Méditerranée aient connu jusqu'à présent. Des jeunes de l'année (« YOY ») d'une taille inhabituellement grande ont été observés en septembre. D'autre part, pour la première fois de mémoire d'homme, la présence de jeunes thons rouges de l'année était complètement différente de ce qui avait été habituellement constaté, à savoir une présence régulière mais anticipée le long de toutes les côtes en août, et ces spécimens ont ensuite disparu rapidement dans les eaux plus profondes et hauturières. Le comportement observé par la suite était également inhabituel. Même après la vérification croisée des données océanographiques, on ne sait pas précisément quel ensemble de facteurs a affecté la distribution, mais le changement climatique a certainement joué un rôle qui n'a pas encore été défini, car la situation s'est présentée dans l'ensemble de la Méditerranée.

RESUMEN

El año 2016 fue el más cálido hasta la fecha en la tierra y en el Mediterráneo y esto es un hecho irrefutable. En septiembre se detectaron juveniles del año con una talla inusualmente grande.. Otro hecho es que, por primera vez en la memoria viva, la presencia de juveniles del año de atún rojo fue completamente diferente a lo que es habitual, con una presencia regular pero anticipada a lo largo de las costas en agosto, para desaparecer rápidamente después en aguas de alta mar y más profundas. El comportamiento posterior también fue poco usual. Incluso tras realizar una verificación cruzada de los datos oceanográficos, no está claro que combinación de factores ha afectado a la distribución, pero sin duda el cambio climático desempeña un papel aún no definido, ya que la situación se ha producido en todo el Mediterráneo.

KEYWORDS

Bluefin tuna, YOY, climate change, behavioural anomalies, Mediterranean Sea

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1. Foreword

As reported in 2015 (Di Natale *et al*., 2016), bluefin tuna (*Thunnus thynnus*) shows immediate reactions to any environmental change like many other pelagic species, particularly when these changes occur during or close its main spawning season. Some descriptions of these effects are provided by Piccinetti *et al*. (2013), a paper which includes also a summary of many other papers published in the last 150 years, but it is not so easy to have all necessary data for correlating the Bluefin tuna spawning behaviour, oceanography and therefore any possible effect on recruitment.

These effects are even further less known in terms of larval survival success at a basin scale and in terms of YOY recruitment, even if some local small-scale fisheries are usually good tools for monitoring the recruitment in real-time.

The complexity of the Mediterranean Sea, with its various oceanographic situations, has usually a direct effect on the spawning activity, which is partly differentiated between areas, with early spawning in the eastern part (Levantine Sea) and then quite often a prolonged spawning in the western part (Balearic Sea) or, more recently, even in the Tyrrhenian Sea. Anyway, the peak of the spawning season is usually mid-June, with small variations from year to year, depending on the climatology and the oceanography.

This peak usually implies that the Bluefin tuna young of the year (YOY) specimens have a well-known growth, at least up to December, something also well-known by several small-scale fishermen. The variability in size at time is usually quite reduced, smoothed at the end of December.

The distribution of Bluefin tuna YOY is also sufficiently known[2], particularly in the first 6 months, up to December, because small tunas between 40 to 60 gr usually show-up close to the coast in many parts of the Mediterranean Sea (Balearic Sea, Ligurian Sea, Strait of Messina, Gulf of Gabes, Levantine Sea) in the second part of August and from this period on the presence of YOY increases week after week in most of the Mediterranean coastal areas and in the main islands (except for the Adriatic Sea, the Gulf of Lions, the eastern Mediterranean islands and the northern Aegean Sea). When the oceanographic and meteorological conditions are the proper usual ones, the presence of Bluefin tuna YOY is almost constant, month after month till December, with peaks when the conditions are more favourable.

The concentrations are usually organised by size range, in feeding aggregations that can be quite important in number of specimens, that can remain in the same area for several days. Usually, after December, the Bluefin tuna YOY aggregations leave the Mediterranean coastal surface waters, moving quite offshore, sometimes in deeper waters (> 50 m). This latter stage of the YOY Bluefin tuna behaviour is poorly known and documented.

2. Oceanography and climate in the Mediterranean Sea in 2016

Since the beginning of February 2016 it has been clear that an unusual situation would occur again in the Mediterranean, but we were not sure if the situation would be similar to the anomaly in 2015 or not. External temperatures were increasing almost everywhere (see NOAA monthly average charts in **Figure 1**), 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 the 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.

With the contribution of eight consecutive high monthly temperature records set from January to August, and the remainder of the months ranking among their five warmest, 2016 became the warmest year in NOAA's 137-year series (https://www.ncdc.noaa.gov/sotc/global/201613), possibly the hottest year after the XVI century. In global average, the marine and land temperature in 2016 was 0.94°C above the 20th century average, while the SST

[2] There is the exception of those Bluefin tuna YOY that migrate outside the Mediterranean, because their behaviour is poorly known. In the past, but also in recent years, Bluefin tuna YOY were found in the Bay of Cadiz and even close to the most extreme south-western part of the Spanish peninsula, but also along the Atlantic Moroccan coast and in the Canary Islands; it is not known if these aggregations were migrating from the Mediterranean Sea or if they were born somewhere in the eastern Atlantic.

temperature was 0.75°C above the 20th century average. The SST Mediterranean temperatures at the early beginning of the year (late January and February) were quite high compared to usual average, particularly in the southern and eastern Mediterranean area.

This year the situation was different, because the sea surface temperature reached the 20°C even in the second part of February, quite too early compared to a "normal" SST. This very anomalous situation remained until about the end of February, with temperatures around 20°C in the eastern and the central-southern part of the Mediterranean. **Figure 2** and **Figure 3** show the daily SST situation at intervals of about 15 days (source: http://medforecast.bo.ingv.it/mfs-copernicus/). The figures show quite clearly the high temperatures up to the end of the year.

At the same time, the salinity (**Figure 4** and **Figure 5**) showed some anomalies, being higher than usual in average, particularly at the early beginning of the year and in autumn (source: http://medforecast.bo.ingv.it/mfs-copernicus/). The effect of these salinity anomalies on the behaviour of Bluefin tuna are still under evaluation by a team of oceanographers and the results will be made available at a later stage.

3. Anomalies of Atlantic Bluefin tuna behaviour in the Mediterranean Sea in 2016

The general knowledge about the "usual" behaviour of the Atlantic in the Mediterranean Sea is quite good even if limited, being this species studied and observed by both scientists and fishermen since over 2,600 years.

We still have to know and understand what is the behaviour in the Mediterranean Sea of an undefined fraction of the EBFT stock of adults after the spawning season, when usually several tunas stay overwintering in the Mediterranean Sea, while most of the young-of-the-year starts swimming along many Mediterranean coasts in feeding aggregations up to December. At the same time, aggregations of juveniles and young mature tunas find the right trophic chain quite offshore (i.e.: in the Gulf of Lions, off the western Balearic Sea, in the Ligurian Sea, in the Strait of Sicily and off the island of Lampedusa). Small changes are within the normality, being a real-time response of the species to environmental opportunities, constraints or modifications.

In 2016 we noticed several anomalies, thanks to the very refined information network that was created along with the GBYP, a sort of Bluefin tuna real-time observatory, where both field scientists and fishermen kindly provide punctual information based on direct observations.

The first one was the early presence of Bluefin tuna YOY, similar but even further anticipated to what was noticed also in 2015. This happened in the second part of July, more than one month in advance compared to a "normal" situation. The YOY showed-up at fist in the Levantine Sea (where this anticipated presence is more usual, due to the early warming of the surface waters in the area), then, at the very early beginning of August in the Ligurian Sea (and there is very unusual) and then, in mid-August, in the southern Tyrrhenian Sea. Later, at the beginning of September, the YOY showed-up in the western Mediterranean and finally in the Ionian Sea.

The main specific anomaly was not only the very anticipated presence of YOY, but the contemporary presence of several cohorts in all areas at the same time. This anomaly is discussed in detail in another paper (Di Natale *et al*., in press b), but it was noticed, at a minor extend, also in 2015 (Di Natale *et al*., in press a).

The most curious YOY situation was those of very large fish (more than 2.8 kg in late August, a weight that is usually reached at the very end of December for fish which were born in the first part of June), which was the indication of a very anticipated spawning event. These anomalous YOY were found in the southern Tyrrhenian Sea from mid to the end of August and then in the Ionian Sea in the second half of September.

The other important anomaly was the distribution and behaviour of the YOY. Usually, as previously mentioned, YOY are present along most of the Mediterranean coasts from late August to December. Their presence can be sometimes massive, with various feeding aggregations that came close to the surface or anyway in the upper stratum for finding the proper food chain. Usually the main aggregations are not far from the coast and they are particularly visible in areas like the Strait of Messina, where they are spot by small scale fishermen using hand lines form very small vessels.

In 2016 the situation was fully different. The Bluefin tuna YOY suddenly disappeared from most of the coasts, beginning from the Levantine Sea and then from other areas (Ionian Sea, Tyrrhenian Sea, Strait of Messina, Ligurian Sea, Malta, Lampedusa, Gulf of Gabes, Strait of Sicily). This happened since mid-September. The latest

area where this anomaly was noticed was the western Mediterranean Sea, along the Spanish coast and the Balearic Sea, in mid-October. After these dates, YOY showed-up close to the surface only occasionally, sometimes with very small aggregations or even with individual fish, and also in these cases it was possible to notice many cohorts in the same area in the same period.

Thanks to the information provided by some scientists and fishermen, it was noticed that, in those periods, YOY aggregations moved quite offshore in all Mediterranean areas, at a depth greater than 50 m (80 m in the Spanish waters).

This extremely unusual behaviour resulted in an apparent lack of Bluefin tuna YOY in the last part of the year and in many difficulties for the various scientists engaged in the GBYP YOY sampling in many Mediterranean areas.

4. Discussion

As we had already written in a previous paper (Di Natale *et al*., 2017, in press *a*), our understanding and knowledge of Bluefin tuna (*Thunnus thynnus*, L.) behaviour and biology is still very limited. This is a species with a complex and sophisticated behaviour, which easily crosses the oceans from side to side in a short time, it has migrations which can change 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 the Bluefin tuna is able to "read the ocean" in real time, making individual or collective decisions that we sometimes can only partly understand. Furthermore, being an oceanic 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, fitting the principle established by Spencer (1864) about the "survival of the fittest". The Atlantic Bluefin tuna is one of the fittest species in the oceans. Trying to reduce our knowledge gaps concerning the Atlantic 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 or detect.

According to the analyses carried out by the NOAA, 2016 was the hottest year in the 1880-2016 records (https://www.ncdc.noaa.gov/sotc/global/201613), possibly the hottest since the XVI century, while both January (https://www.ncdc.noaa.gov/sotc/global/201601) and February 2016 (https://www.ncdc.noaa.gov/sotc/global/201602) were the hottest months in the same series of records. The same record, at global scale, was attained in March, April, May, June, July and August 2016.

For the Mediterranean Sea, the data are still not available on the Copernicus web site (http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004), but according to the daily SST records, late January and particularly February were quite hot compared to previous years, as well as the months from the last part of the summer till December. Specifically, most of the Levantine Sea and most of the southern central Mediterranean Sea never went below 21°C even in December, something that is certainly unusual.

The salinity was also quite different from usual values, even in the very first part of the year, but the studies on recent data are still undergoing and will be available at a later stage.

How can all these (plus others not listed here, partly unknown) oceanographic and environmental anomalies affect the Atlantic Bluefin tuna reproductive biology and the behaviour of the YOY can be only supposed.

As concerns the anomalous big YOY individuals sampled in the Tyrrhenian Sea and in the Ionian sea (Di Natale *et al*., in press b), considering that these weights and size can be usually attained at the end of December for YOY that were born in the first part of June (equal to at least 6 and ½ months), it is therefore logical to imagine that this first cohort sampled in August was born in February somewhere in the Mediterranean, possibly in the Levantine Sea or in the southern-central Mediterranean, originated only from Bluefin tuna adults that overwintered in the Mediterranean Sea. Can we imagine that some Bluefin tuna adults can begin their sexual maturation in late January and then spawn in February? From a physiological point of view, potentially yes, even if an event like this is very far from the normality. According to Corriero *et al*. (2003), the ovary development needs less than two months between the very initial state with the appearance of oocytes at the lipid stage and the spawning, therefore the observation concerning these anomalous YOY might reflect an extreme but possible early anomalous maturation and spawning.

If something like this happened, looking at the cohorts (Di Natale *et al*., in press b) this happened possibly twice in early 2016, with a short delay between the two events or with some area differentiation, because these two first cohorts had different growth rates. Always on the same line, possibly both cohorts found food chains slightly different from the usual, and this therefore possibly affected their growth, but we are not able to say if this had a positive or a negative effect. Surely, this situation was well outside the extremes reported by Piccinetti *et al*. (2013) for anticipated or delayed Bluefin tuna spawning in the Mediterranean Sea.

Quite less understandable is the situation of the disappearance of YOY from the coasts in autumn-fall 2016. As a matter of fact, the presence of YOY along most of the Mediterranean coasts from late August to December represents a quite well established pattern, having no remarkable anomalies in living memory. In the past, in some years, the presence of Bluefin tuna YOY was lower or higher than the average, depending on the spawning success in the given year; in some years the YOY disappeared for short periods in some areas, depending on the local trophic chain, then coming back in the same season when the normal situation was re-established.

The anomaly encountered this year was indeed very remarkable, at first for the wide-spread diffusion of the anomalous behaviour and also for its duration in time. The fact that the Bluefin tuna YOY decided to leave the Mediterranean coastal waters, moving offshore and in much deep waters almost at the same time in all areas, must have a strong motivation that we are still searching for.

Unfortunately, even the data concerning the situation of the Eastern Mediterranean Transient (EMS)[3] in 2016 are still not yet analysed and therefore they are not available.

Surely, the temperature was higher in general and the salinity was higher as well. Possibly the salinity was partly higher due to a much higher evaporation caused by the high temperatures in the Mediterranean basin, but maybe even for other factors that we would like to understand. It is supposed that this important anomaly in the displacement of Bluefin tuna YOY in fall and winter 2016 was also possibly linked to a different distribution of their food chain, possibly displaced in off-shore deeper waters.

When similar displacements happen at a so large scale, usually they are linked to a chain of events and conditions, induced by some factors which could be possibly discovered only after difficult analyses and only if enough oceanographic data become available.

These real-time observations confirm again the importance of strictly monitoring several oceanographic and environmental data for possibly correlating them with the Bluefin tuna distribution and behaviour, trying to further improve our knowledge and understanding of this species. Furthermore, the provision in real time of this information to ICCAT SCRS BFT Species Group may allow for better understanding future data sets.

5. Acknowledgments

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[3] The EMS is the most important oceanographic anomaly in the Mediterranean Sea (Incarbona *et al*., 2016) and it is able to produce effects mostly in the central-eastern Mediterranean Sea, but also in the western part of the basin and in the near Atlantic area.

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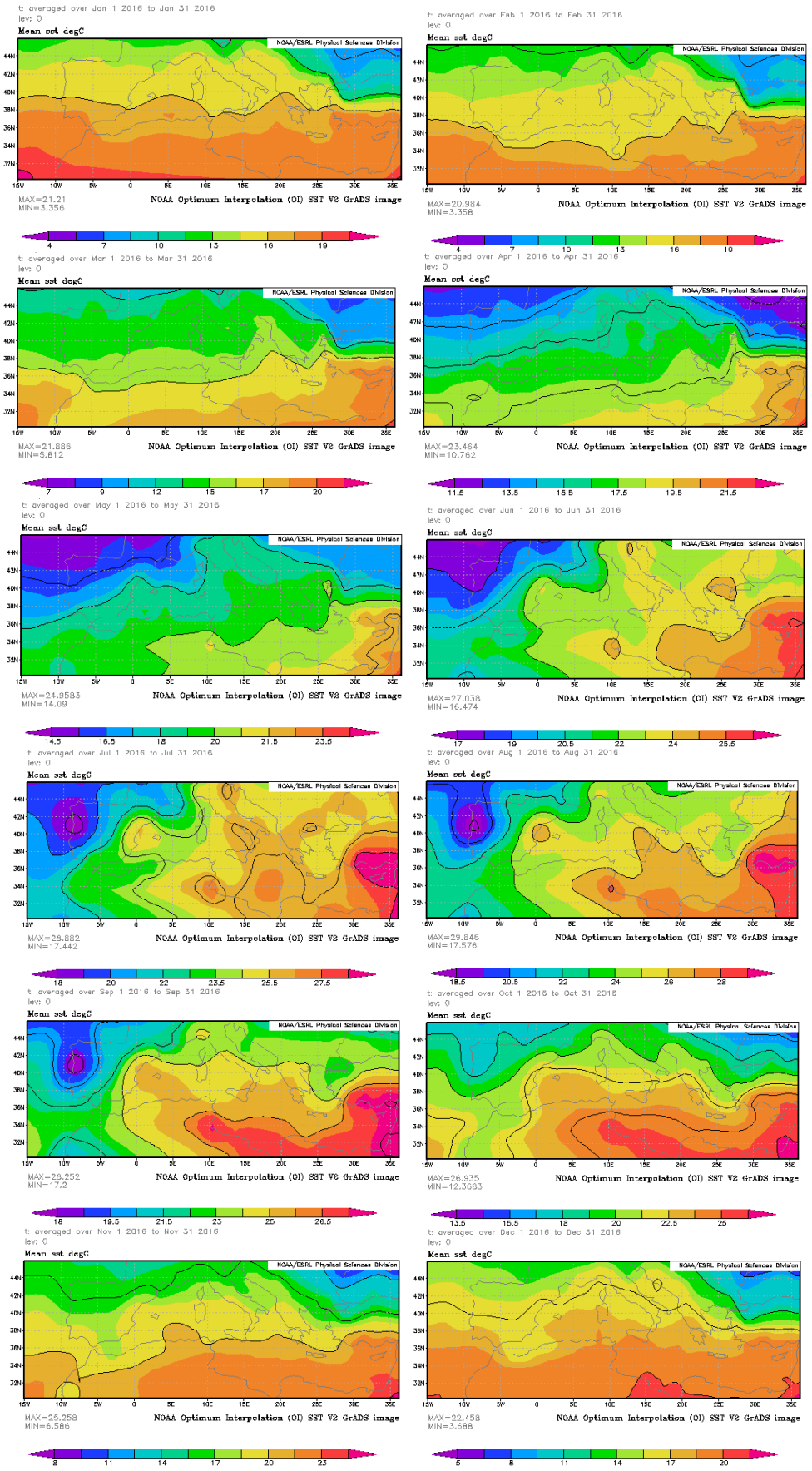

Figure 1. Monthly surface temperature averages in 2016 from NOAA Optimum Interpolation SST V2 Data (Source: www.esrl.noaa.gov/psd/). The variable temperature scales are below each map.

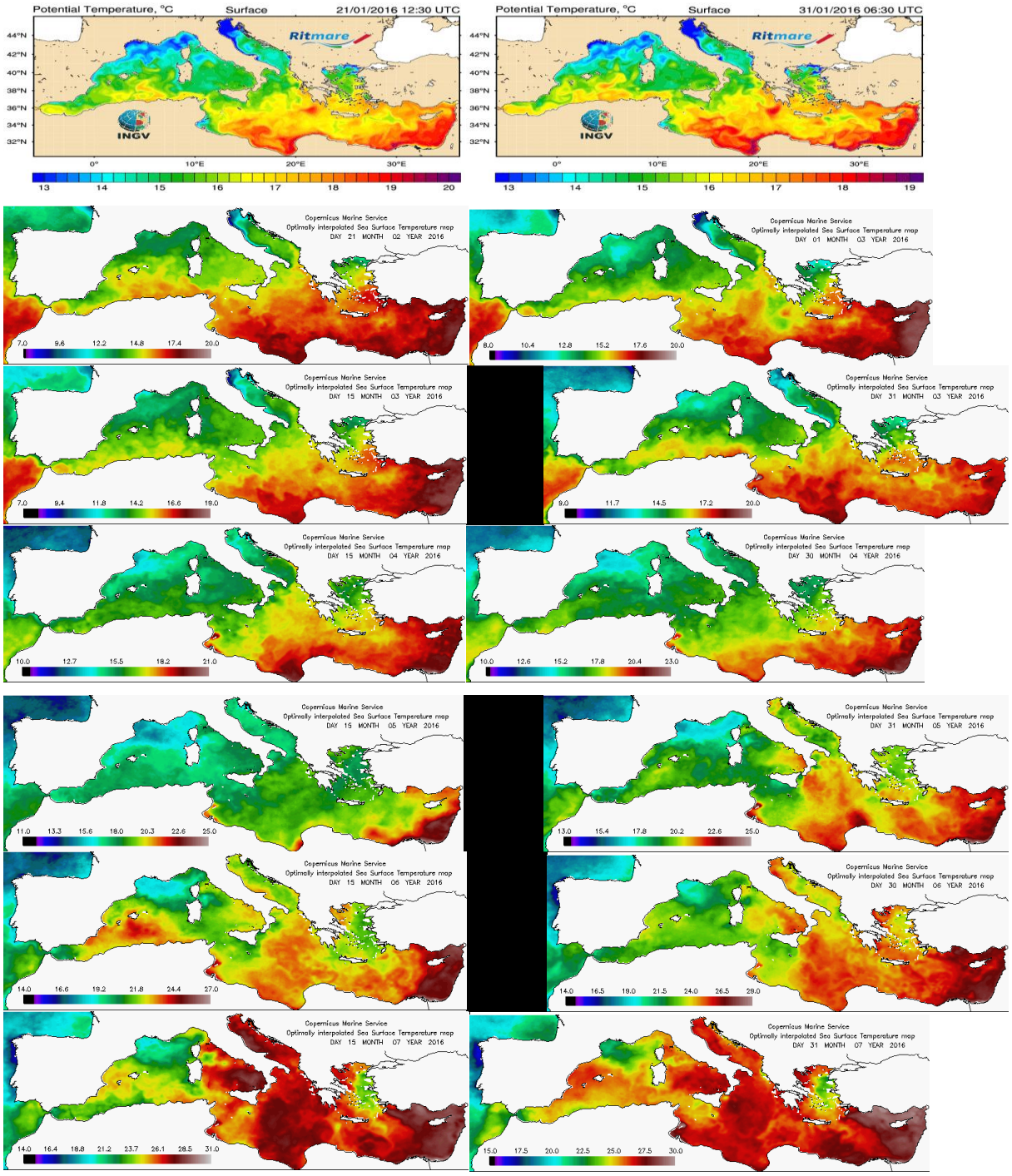

Figure 2. Graphic presentation of SST daily evolution in the Mediterranean Sea in 2016, at intervals of about 15 days, from 21 January to 31 July. The variable temperature scales are below each map and they are not constant. (Source: http://medforecast.bo.ingv.it/mfs-ritmare/ and http://gosweb.artov.isac.cnr.it/viewer/viewer.php)

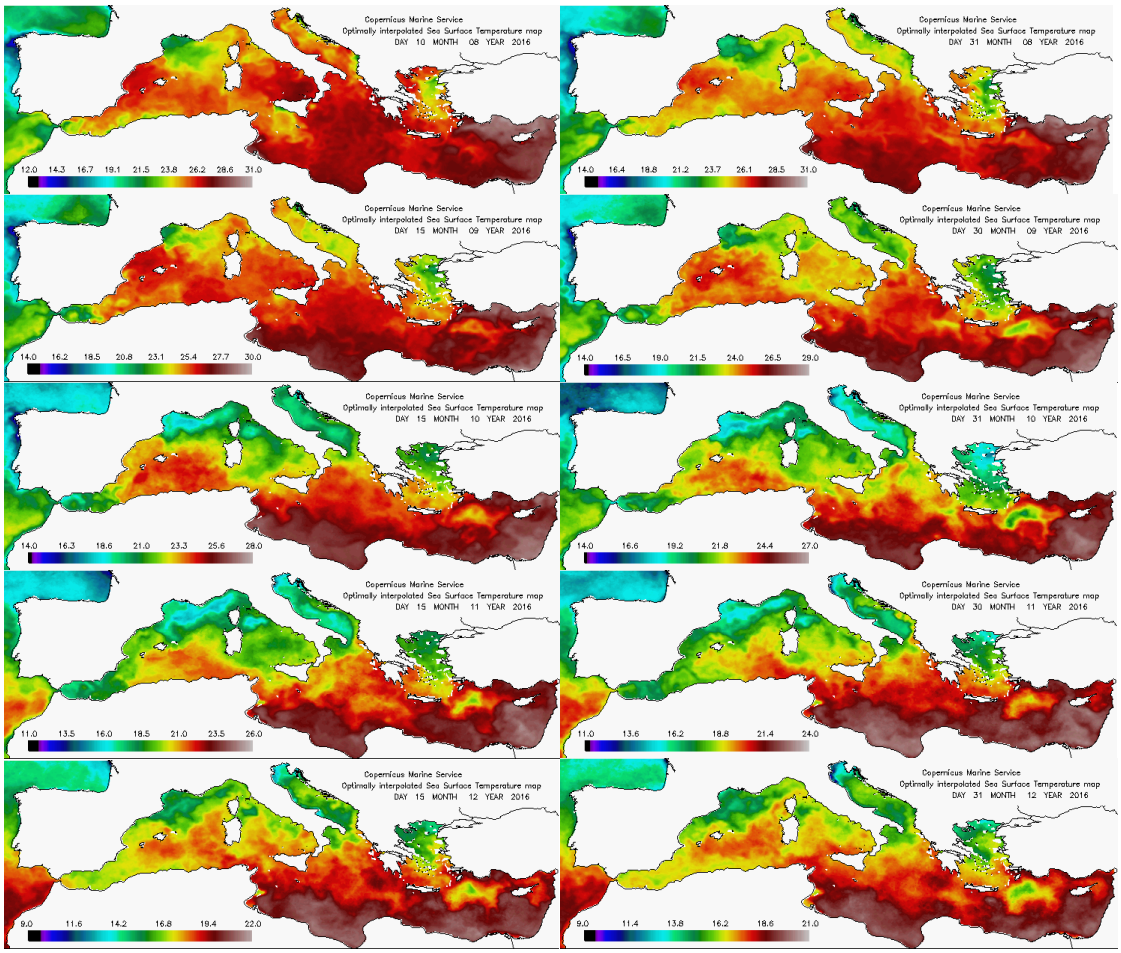

Figure 3. Graphic presentation of SST daily evolution in the Mediterranean Sea in 2016, at intervals of about 15 days (left to right), from 10 August to 31 December. The temperature scales are below each map and they are not constant. (Source: http://gosweb.artov.isac.cnr.it/viewer/viewer.php)

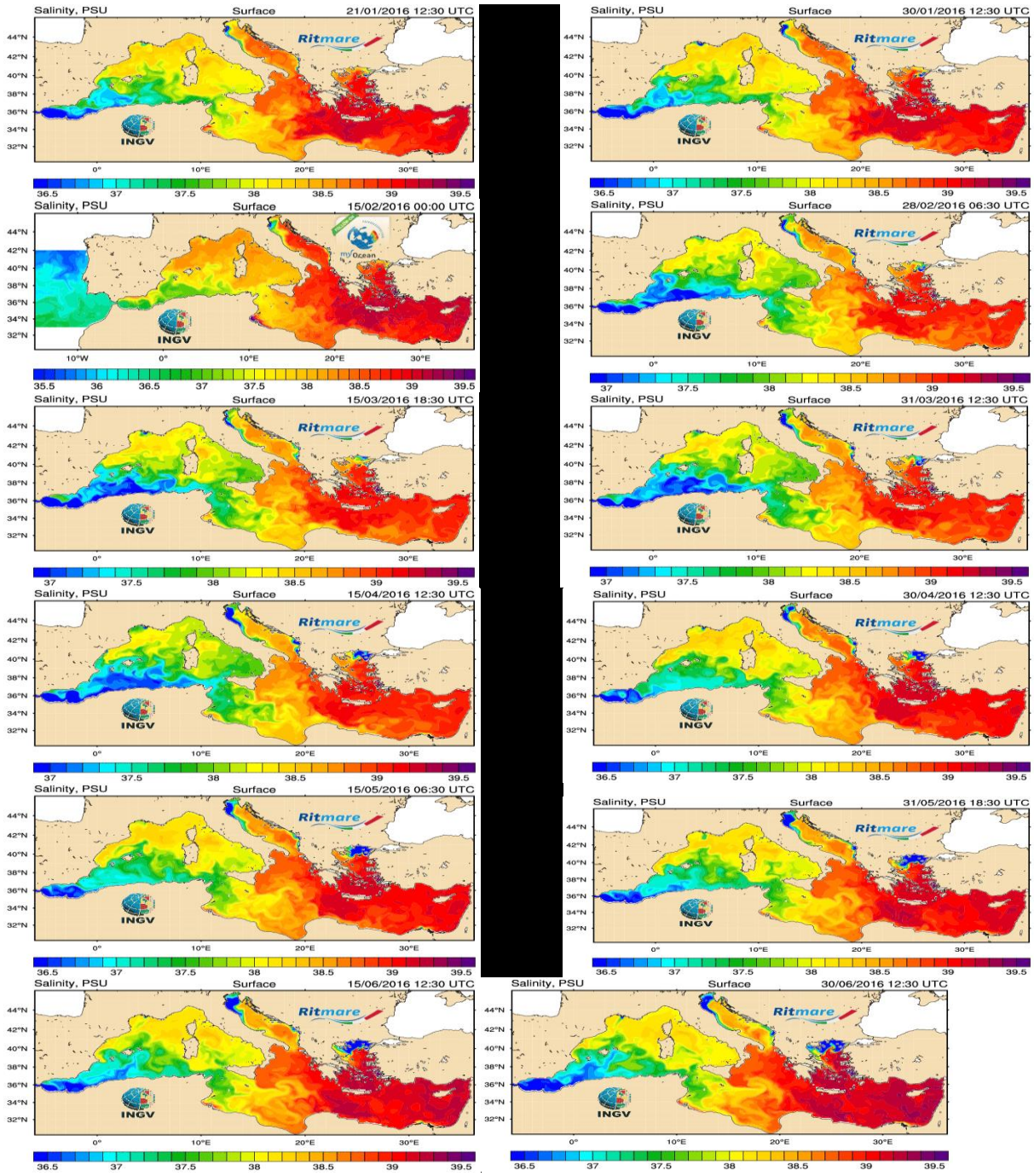

Figure 4. Graphic presentation of Salinity daily evolution in the Mediterranean Sea in 2016, at intervals of about 15 days (left to right), from 21 January to 30 June. The salinity scales are below each map and they are not constant. (Source: http://medforecast.bo.ingv.it/mfs-ritmare/)

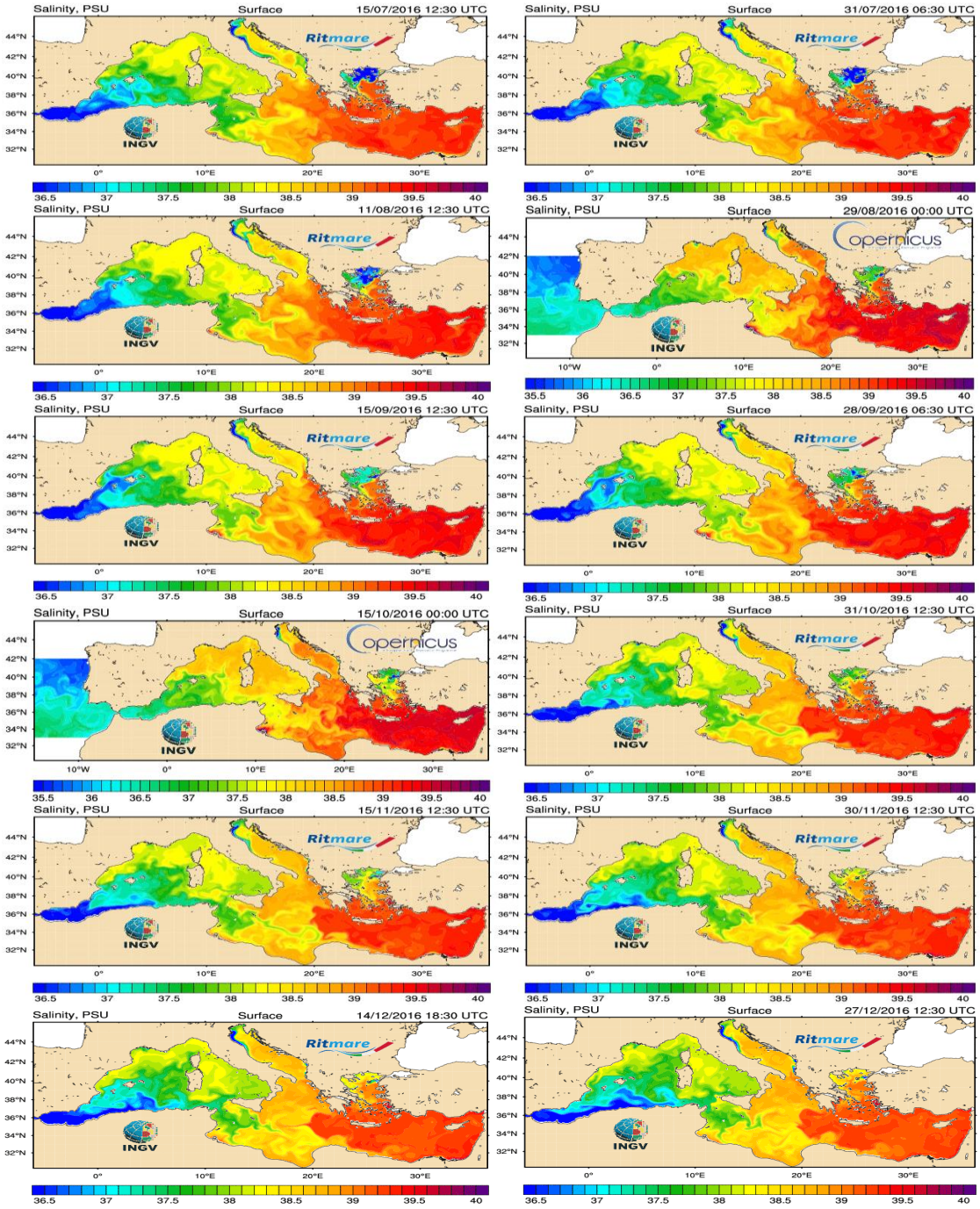

Figure 5. Graphic presentation of Salinity daily evolution in the Mediterranean Sea in 2016, at intervals of about 15 days (left to right, from 17 July to 27 December. The salinity scales are below each map and they are not constant. (Source: http://medforecast.bo.ingv.it/mfs-ritmare/)