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MATCH AND MISMATCH: A FEW THOUGHTS ABOUT THE AVAILABLE BLUEFIN PREDICTION MODELS FOR THE MEDITERRANEAN AREA

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SUMMARY

Several efforts have been devoted to develop prediction or descriptive models for both bluefin spawning areas and larval distribution areas in the last ten years. The review of these papers shows matches and mismatches with the current knowledge, which are mostly the results of various approaches, the development of models on limited areas or the limitation in data availability. The complexity of the behaviour of bluefin tuna is clearly driven by many factors and the major problem is the limits we still have in our knowledge and understanding of the bluefin tuna, even in the Mediterranean Sea where this species is studied since many centuries. The good results obtained by models using real-time data iodes not necessarily imply that the same models can be extended to all Mediterranean areas, because bluefin tuna seems to use different strategies in different areas, possibly taking advantage of various suitable environmental conditions. The need to develop improved approaches for having more suitable models is the clear result of this overview.

RÉSUMÉ

Plusieurs efforts ont été déployés pour développer des prévisions ou des modèles descriptifs pour les deux zones de frai et zones de distribution des larves de thons rouges au cours de ces dix dernières années. L'examen de ces documents montre des compatibilités et des incompatibilités avec les connaissances actuelles, qui sont la plupart du temps les résultats des différentes approches, de l'élaboration de modèles sur des zones limitées ou la limitation de la disponibilité des données. La complexité du comportement du thon rouge est clairement influencée par de nombreux facteurs et le principal problème sont les limites que nous avons encore dans notre connaissance et notre compréhension du thon rouge, même dans la mer Méditerranée, où cette espèce est étudiée depuis plusieurs siècles. Les bons résultats obtenus par les modèles à l'aide de données en temps réel ne signifient pas nécessairement que les mêmes modèles peuvent être étendues à toutes les régions méditerranéennes, parce que le thon rouge semble utiliser différentes stratégies dans différentes zones, peut-être en profitant de diverses conditions environnementales appropriées. Cet examen est parvenu à la conclusion qu'il est nécessaire d'élaborer des approches améliorées pour disposer de modèles plus appropriés.

RESUMEN

En los últimos 10 años se han dedicado muchos esfuerzos a desarrollar modelos de predicción o descriptivos tanto para las zonas de desove del atún rojo como para las zonas de distribución de larvas. El examen de estos documentos muestra correspondencias y no correspondencias con los conocimientos actuales, que son principalmente resultado de varios enfoques, del desarrollo de modelos para zonas limitadas o de la limitación en la disponibilidad de datos. La complejidad del comportamiento del atún rojo está claramente provocada por diversos factores y el principal problema son los límites que aún existen en nuestros conocimientos y comprensión del atún rojo, incluso en el Mediterráneo, donde esta especie lleva estudiándose desde hace siglos. Los buenos resultados obtenidos por los modelos que usan datos en tiempo real no implican necesariamente que los mismos modelos puedan extenderse a todas las zonas del Mediterráneo porque el atún rojo parece utilizar diferentes estrategias en diferentes zonas, posiblemente aprovechando varias condiciones medioambientales adecuadas. El resultado claro de esta visión global es la necesidad de desarrollar enfoques mejorados para contar con modelos adecuados.

KEYWORDS

Bluefin tuna, Spawning areas, Larvae concentrations, Oceanographic data, Prediction models, Descriptive models

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1. Introduction

Trying to predict the presence of bluefin tuna (*Thunnus thynnus*) in the various parts of its distribution range was always one of the dreams of scientists, managers and fishers, for various reasons. Trying to predict the bluefin tuna distribution during its life stages in the Mediterranean Sea was another challenging dream, which induced several scientists to spend effort, capabilities, knowledge and imagination, trying to get as close as possible to the reality.

The major problem is that nobody really knows so far both the real distribution of bluefin tuna within the Mediterranean Sea at the different life stages and the list of factors which might drive its distribution. It is a matter of fact that, after more than 23 centuries of various studies and observations, bluefin tuna is still keeping many of the secrets about its life, even if nowadays we know much more details compared to ancient knowledge, but we are still missing several important parts of the bluefin tuna natural history puzzle. Every year we find new pieces of the puzzle, thanks to the many efforts made by several scientists and research teams in many countries, using the most sophisticated technologies and techniques but, it is a matter of fact, every time we find another piece of the puzzle, we realize that many other new pieces are missing, because research is able to find answers to some questions with a lot of efforts, but every time the same research discovers new questions, showing us again all limits we have in our knowledge about bluefin tuna.

The Atlantic-wide Research Programme for Bluefin Tuna has, as its main object, “improving understanding of Atlantic bluefin tuna key biological and ecological processes”.

2. The first trials

Some trials of bluefin tuna mapping predicting models have been tentatively proposed during the very recent years and all of them are interesting but all are showing important limits or biases, which are usually linked to our partial and imprecise knowledge of the natural history of bluefin tuna in the Mediterranean Sea (but not only in this sea!).

Fully analysing each of them is not the purpose of this short paper and would require diving deeper into the model, entering into complex mathematical approaches. On the contrary, a very quick and limited analysis might be useful for trying to understand their problems, limits or opportunities, with the only purpose of improving the situation in the future.

2.1 The habitat mapping for bluefin tuna spawning and feeding areas

Since many years various scientists are trying to identify the reasons and the conditions which drive the bluefin tuna to spawn in certain areas of the ocean; Mathers *at al.*, (1995) provided a good overview of the knowledge at that time, but without identifying specific conditions. Garcia *et al*. (2003a, 2005) and Alemany *et al.* (2010) reported about the environmental and oceanographic conditions observed driving the bluefin tuna spawning activity in the Balearic area. Arena (1963, 1964, 1980, 1982, 1988a, 1988b, 1990), taking advantage of many survey campaigns during the spawning season in the southern Tyrrhenian Sea, for several years supported also by aerial studies, provided extremely useful and detailed descriptions of the spawners behaviours and their environmental choices.

Many studies on this subject have been devoted in the last 150 year in the Mediterranean Sea and Piccinetti *et al.* (2013) provided a synthesis, although without a precise identification of the suitable conditions but discussing about the need to have 3-D data instead of the 1-D usual approach. According to the environmental and behaviour observations at sea, particularly during the aerial surveys carried out in the ‘80s and the ‘90s in the southern Tyrrhenian Sea, a stable warm (at least >20°C) sea upper layer having a proper minimum depth (over 10 m) and a well-established thermocline having a negative gradient of at least 3°C, seem all together some of the useful environmental factors for allowing bluefin tuna spawning. Strong or time-prolonged winds prevent some of these factors to be established. A specific behaviour, observed several times, is the fast vertical or diagonal swimming from the surface to deeper areas, crossing the thermocline up and down. It supposed that this behaviour may help in activating some physiological factors linked to the spawning activity.

Dr. Jean-Noël Druon, who works at the EC Joint Research Centre (JRC) in Ispra, published a first habitat modelling for bluefin tuna, having the objective of a sustainable management of the related fisheries (Druon, 2010). Besides the objective of the paper, which was quite ambitious for a first tentative modelling, the results showed several limits, with some positive matches with the available knowledge about spawners and feeders and some important mismatches: i.e., the only map (**Figure 1**) was referred to the period 7-9 May 2005, quite an unusual period for showing a spawning habitat, because spawning in that days usually occurs only in the eastern Mediterranean sea, where waters became warmer before other Mediterranean areas (and this information partly match), while it is extremely rare that spawning can occur in other areas, because the water masses are not suitable for bluefin tuna spawning. The authors found that only 5% of the Mediterranean Sea was a suitable spawning habitat for bluefin tuna and this estimation appears very limited. The problem was the hypothesis behind the model, because it was based both on SST data and chlorophyll concentration, with quite complex correlation. SST is one of the parameters which are known to be partly useful for identifying a spawning habitat, but SST alone can be a misleading oceanographic factor.

A further development of the model was published by Druon *et al*. in 2011, and there, having more map images available, it is easier to find match and mismatch areas. As a matter of fact, this work used complex inputs and more accurate reviews of available papers (**Figure 2**). In average, according to the outputs of the model, spawning suitable areas occurred where spawning was never noticed by fisherman trying to find spawners during the fishing season, while other suitable areas were much more fitting the current knowledge (**Figure 3**): i.e.: suitable spawning areas were identified all around Sardinia, or between the Balearic Islands and Sardinia, or in the Ligurian Sea, or in the Adriatic Sea, or in the northern Aegean Sea or offshore the Algerian coast and none of these areas is known to be a spawning areas at least in the last 150 years, besides of the intense fishing activities in all parts of the Mediterranean and the very spread distribution of various types of fishing vessels in all these areas; at the same time, the spawning habitats in the Balearic Islands, in the southern Tyrrhenian Sea, in some of the areas in the central Mediterranean Sea and in some parts of the eastern Mediterranean Sea for the first part of the period considered were all fitting the current knowledge. Some strange outputs, in both senses, are also noticed for the feeding habitats: while the some parts of the Catalan Sea, the Gulf of Lion, the Ligurian Sea, some parts of the Ionian Sea, some parts of the Adriatic Sea and a few Tunisian areas are fitting the current knowledge, other areas are mismatching, like areas where the feeding habitat is indicated as very important (i.e.: all the Alboran Sea and the north-western Aegean Sea) or where the feeding habitat is shown as not present (the southern and central Tyrrhenian Sea, the Gulf of Taranto, the Gulf of Gabes, the eastern part of the Levantine Sea). Some of these mismatches were correctly noted in the discussion part of the paper, as well as interannual variability. The authors also mentioned the limits of using only few oceanographic parameters.

A very first tentative of using real time presence of bluefin tuna spawners for developing a presence prediction model was made within the ICCAT GBYP framework, after the first Mediterranean aerial survey in 2010, for smoothing some of the possible problems induced by the ex-post use of indirect data. The model was described by Cañadas *et al*. (2010) and further developed in the following year using the aerial survey data in 2011 (Cañadas *et al*., 2011). In this case, due to the fine resolution of the real time sightings, it was possible to develop a weekly model, using also daily SST field compensated data with a resolution of 0.25°x0.25°. For evident reasons, in this experimental model the match was perfect, also because the trial was limited to the four areas where the survey was carried out. Even if the correlation was very high, the limit was the use of only the SST parameter, which was not enough for identifying alone a suitable spawning area.

In the same years, the GBYP staff tried to further improve the prediction of the suitable spawning habitat for bluefin tuna working tentatively and manually on a larger set of oceanographic and environmental parameters: SST real-time and forecasting data, vertical temperature profiles along some transects in the Mediterranean Sea, both provided by the Mediterranean Ocean Forecasting System of the Italian "Gruppo Nazionale di Oceanografia Operativa" (http://gnoo.bo.ingv.it/mfs/myocean/bulletin.html?mode=forecast), the Mediterranean wave and wind forecast provided by the Israel Oceanographic and Limnological Reasearch (http://isramar.ocean.org.il/isramar2009/wave_model/default.aspx?region=coarse&model=wam), and by the recent availability of surface currents, wave height and direction, wind strength and direction from the TESSA project (http://www.sea-conditions.com/en/). Due to the lack of numeric data, an excel spreadsheet was developed, transferring coded information by area and trying to detect possible correlations. In particular, a special attention was devoted for predicting areas where good weather and oceanographic conditions were allowing a stable and sufficient surface layer of warm waters, with a well-established thermocline. These rough trials, further supported by the real time aerial survey observations, demonstrated their utility for describing anomalies in the distribution of spawning areas in 2011 that were later detected by the genetic analyses, which were able to find a mixing deriving from the bluefin tuna spawners eastward massive and not-usual displacements in that year (Di Natale *et al.*, 2013).

The last tentative trial was carried out in 2014, in the absence of any aerial survey. In this last year a short-term forecast about the distribution of bluefin tuna spawning aggregation was and their behaviour was tried, thanks to the availability of several fishing vessels and one trap that were requested to inform in real time about the location of their catches and the fish behaviour. Two days in advance, the forecast was shared with few colleagues at the ICCAT Secretariat and kept strictly confidential. The real time information coming from the vessels or the trap was checked against the forecast and, surprisingly, this absolutely informal and not-formally modelled system was able to predict not only the very fine distribution of bluefin tuna aggregations in some areas, but also the fish behaviour and the depth of these groups. Furthermore, in April we made a forecast a probability forecast about the spawning period in 2014 in the Mediterranean and the possible delay in various areas and even in this case the forecast was correct. This was for us a clear demonstration that many more components (both oceanographic and meteorological) are necessary for improving the bluefin tuna habitat modelling system and this improvement will be not easy because of the complexity and variety of factors to be modelled and correlated, taking always into account that these factors will not be all components possibly taken into account by bluefin tuna spawners.

2.2 The habitat mapping for bluefin tuna larvae

Strictly and directly linked to the studies on bluefin tuna reproduction, studies on larval presence, distribution and related environmental conditions have been carried out in the last century in several Mediterranean areas. Mathers *et al*. (1995) and Piccinetti *et al*. (2013) provided both comprehensive syntheses of these studies. According to Piccinetti el al. (2013) bluefin tuna larvae have a distribution much larger than the spawning areas, because the complex Mediterranean circulation drive them sometimes far from the bulk of the main spawning sites; this different distribution might induce biases in correlating spawning areas with larval areas.

Habitat mapping studies for bluefin tuna larvae are carried out since several years mostly by a team headed by Dr. Alberto Garcia of the Instituto Español de Oceanografía (IEO, Malaga). Garcia *et al.* (2001, 2003a, 2005, 2007a, 2007b) and Alemany *et al*. (2006) deeply studied and explored observed correlations among many environmental factors (temperature at various depths, salinity, density, circulation, geopotential abnormalities, geostrophic velocity, chlorophyll at various depths and even lunar cycles), often assisted by aerial surveys and real-time fishery data for spawners, and the bluefin tuna larvae in the Balearic area, showing both the implicit complexity of the bluefin tuna choices and the need to consider all these factors in the modelling approach. Finally, Garcia *et al.* (2013) tested all data for understanding the annual variability of bluefin tuna larvae presence and growth induced by changes or anomalies in environmental conditions, even driven by climate. All these studies, carried out on the Balearic area, were showing good matches with the oceanographic factors which have been selected, because they were based on real-time observations. Extending these observations to other areas where bluefin tuna larvae distribution is known but where oceanographic conditions are different from the Balearic area will be a non-obvious exercise.

In the same year, Kocked *et al.* (2013) used a similar methodological approach in the Gulf of Gabes, successfully correlating a series of environmental and oceanographic parameters to the bluefin tuna larval distribution.

A first attempt to identify a suitable spawning habitat from larval growth was published by Nieblas *et al.* (2013), correlating biogeochemical models, dynamic energy budget and Lagrangian dispersal, but this trial had some partial matches for the area south of the Balearic isles, the Ionian Sea and the southern-eastern Mediterranean Sea, and several mismatches (in both senses) in the Alboran Sea, in the southern Tyrrhenian Sea, in the central Mediterranean Sea, in the NW Aegean Sea and in the Levantine Sea (**Figure 4**). Problems were possibly induced by larval growth data inputs and by the use of some prevalent oceanographic inputs (mostly SST).

3. Discussion

A recent book (Würtz, 2010) provided a general overview of the Mediterranean pelagic habitat and described the biological and oceanographic processes driving the presence, distribution, biology and abundance of the various pelagic species. This extremely difficult exercise was clearly limited by the enormous amount of information required, the immense literature and the biases induced by the papers published by some authors for several species. In the case of bluefin tuna, the maps showed on this book are mostly referred to the western and central Mediterranean, and then are partial. Even in this case, SST <24°C was the factors mentioned as the most important for the spawning, while correlation with anticyclones eddy structure was the main factor for larval presence and growth, which are partial matches for limited areas in the Mediterranean Sea.

The studies published by Block *et al*. (2001a, 2001b), by Rooker *et al*. (2007) and by Quílez-Badia *et al*. (2013), who used results obtained by electronic tagging (internal archival or pop-up tags) in areas including the Mediterranean Sea are quite useful for improving at least the correlation between spawning or feeding, water temperature, depth and position, which allows for further correlations. The advantage of these tags is that it is possible to collect observations over a wide space and a long time and this is certainly helpful.

According to what Aristoteles said more than 300 years b.C. (1635, also in Athaeneus, 1653) said, "*thynnum esse tradit gregalem ac locum mutare*", this species is a very migrant one, able to cross the ocean in a short time, and to carefully read the chemical and physical messages from the sea waters for various reasons, including for spawning. Its choices are complex like its behaviour and then difficult to understand even using the most sophisticated technology we can have available. Of course models are necessary simplifications of the system, but we need to use a 3-D approach, because a 1-D approach is able to create serious distortions and important biases and mismatches.

The main problem posed by some of the models and reports is that they could be potentially used for establishing open-sea protected areas for spawners (making no much sense for a species like the bluefin tuna which can easily move from one oceanic area to another one within the same basin, due to instantaneous choices linked to not-well known changes in some environmental conditions) or for driving management processes. As it is at the moment, we are still far from having any reliable model (and it should be clear that this is independent from the scientific value and capacity of the scientists who developed them), because of the extreme complexity of the factors to be taken into account, the very limited data availability, the very reduced number of real-time studies and our limited understanding and knowledge. If we would like to improve the models for the entire Mediterranean Sea (but we should include also some other nearest areas), we absolutely need to further improve our knowledge and devote much more resources for collecting various types of data, taking into account the value (both naturalistic and economic) of this species and the need to sustainable use it over the future years.

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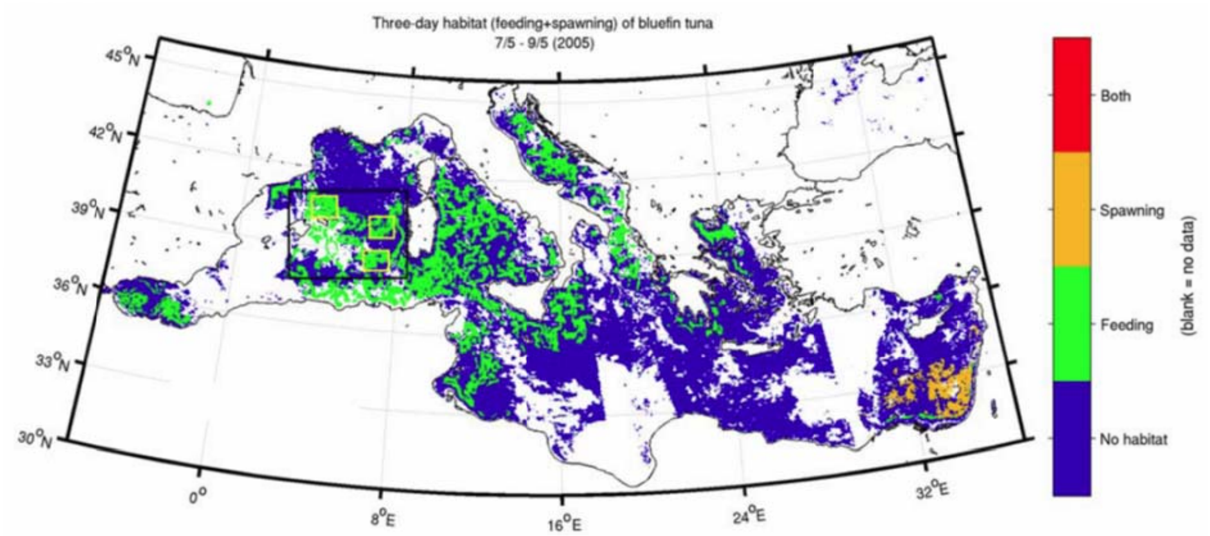

Figure 1. Habitat mapping on 7-9 May 2005: feeding habitat is in green, spawning habitat in orange and no favourable habitat is in blue (from Druon, 2010).

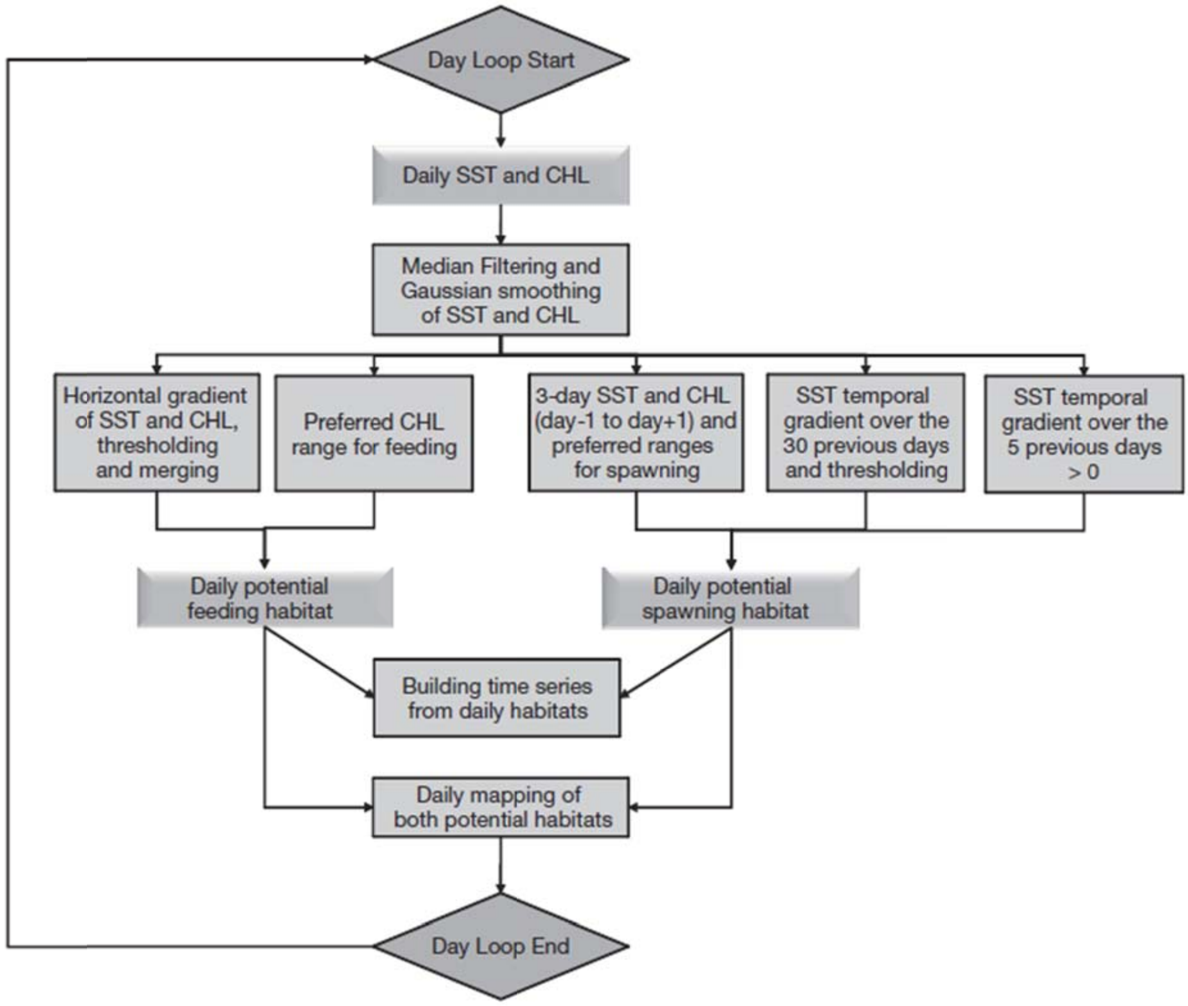

Figure 2. Bluefin tuna habitat modelling flowchart as it was developed by Druon *et al*., 2011.

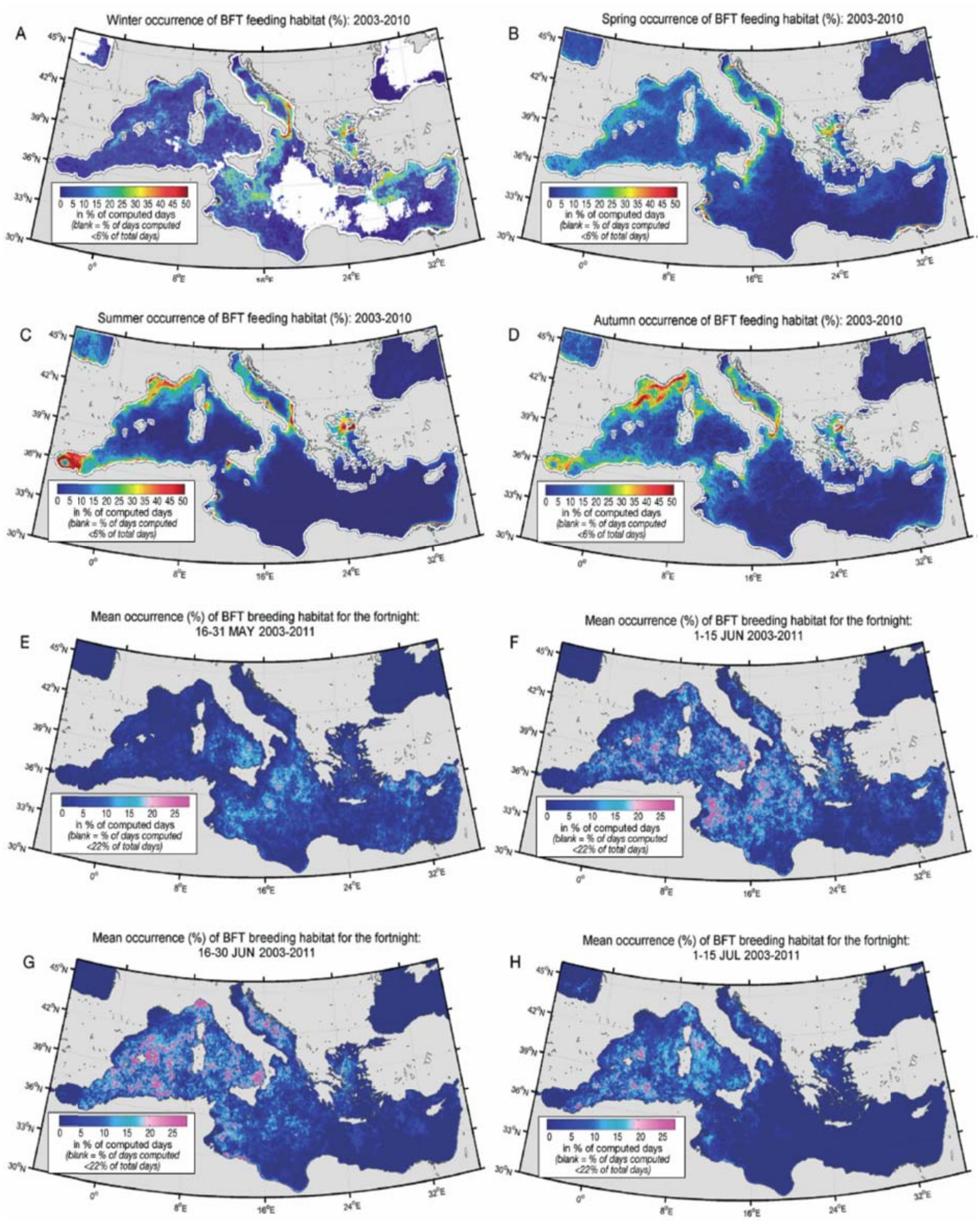

Figure 3. Seasonal composite of bluefin tuna feeding habitat in the Mediterranean Sea for the period 2003-2010: (A) winter, (B) spring, (C) summer and (D) autumn. Mean fortnight composite of bluefin tuna spawning habitat in the Mediterranean Sea for the period 2003-2010: (E) second half of May, (F) first half of June, (G) second half of June and (H) first half of July (from Druon *et al*., 2011).

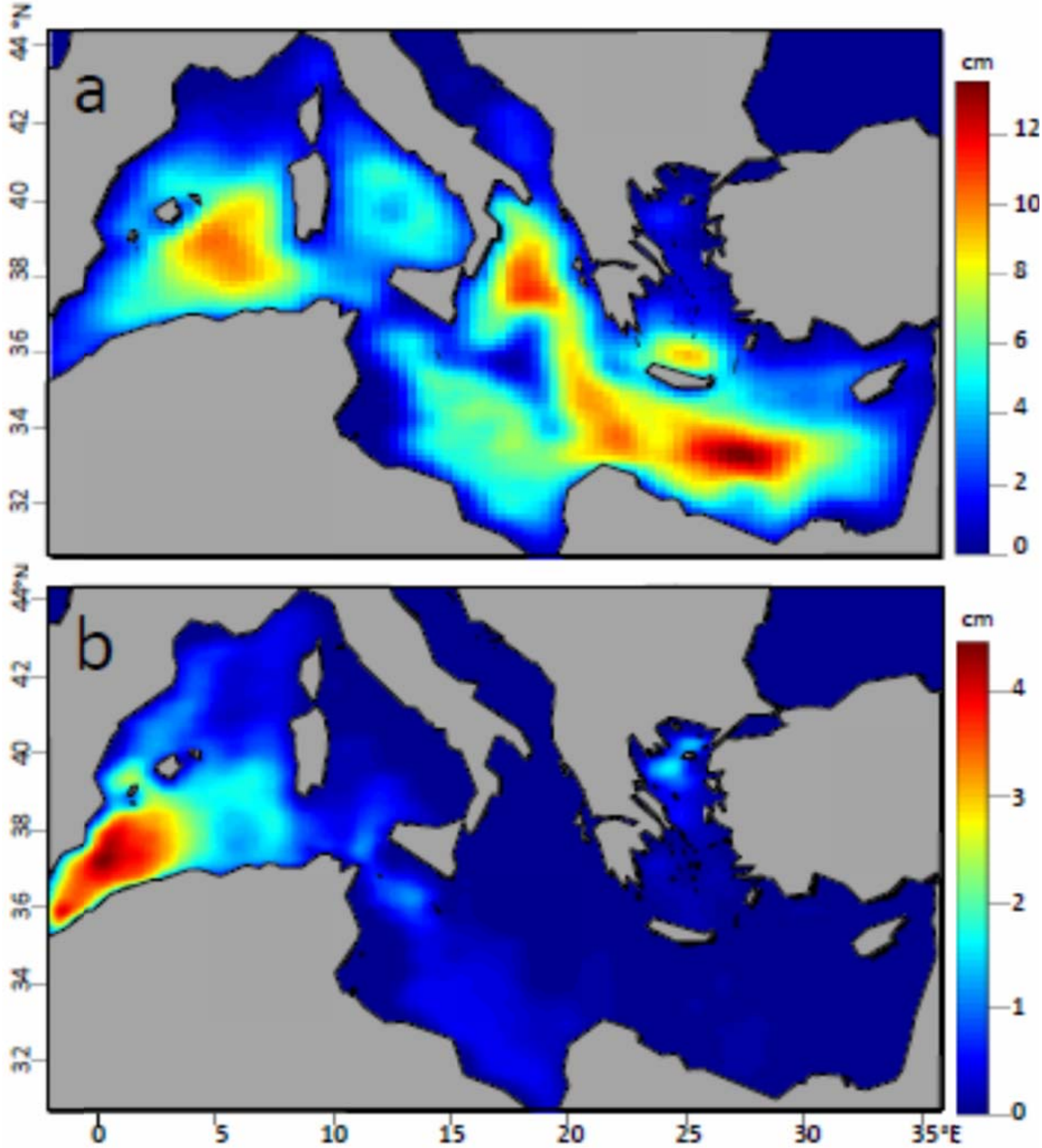

Figure 4. Climatological larval growth for (a) variable temperature and maximal food and, (b) variable food and temperature simulation (from Nieblas *et al*., 2013).