Species composition of ichthyoplankton assemblages: a response to seasonal temperature changes

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Species composition of ichthyoplankton assemblages: a response to seasonal temperature changes

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Abstract

The ‘mean temperature of the catch’ (MTC; Cheung et al. 2013, Nature 497: 365-368.) was computed for 59 ichthyoplankton surveys conducted in several regions of the Eastern Mediterranean (off the coasts of Greece and Turkey) and in the Black and Marmara Seas. This covered 162 fish species whose preferred temperatures (PTs) were derived mainly from the data used to derive Aquamaps (see www.aquamaps.org). The (geometric mean) MTCs estimates from these 59 surveys correlated strongly with observed sea surface temperatures (SSTs), once account of the sampling regions was taken. Here, this relationship is quantified using a Type II or ‘functional’ (multiple) regression. Overall, the results suggested that the MTC could be an important descriptor of the taxonomic composition and temperature affinities of ichthyoplankton assemblages.

Keywords: Ichthyoplankton; mean temperature of the catch; Eastern Mediterranean Sea; Black Sea.

Introduction

While their body temperature can fluctuate with that of their environment, which can vary seasonally by over 10 °C or more, fish have preferred temperatures (PTs) for which their enzyme systems are optimized, and at which they perform best. This is also true for their eggs and larvae (ichthyoplankton) which, however, have narrower ranges of tolerated temperature (Pauly, 2010).

Because the PTs of fish are relatively stable, and can change only over evolutionary time, the taxonomic composition of fisheries catches can be used to infer a mean PT weighted by the catch of the component species, and thus to obtain a Mean Temperature of the Catch (MTC), shown, for example, to correlate, outside the tropics, with the increasing temperature of the habitats of fishes (Cheung et al., 2013).

The principle at hand, i.e., the replacement in fisheries catches of fish with cold-water affinities, given increasing temperatures (in a given ecosystem) by fish from lower latitude regions (which cannot occur in the tropics, hence their exceptional situation), also applies to fish assemblages as obtained from surveys of juveniles and/or adults fish and invertebrates (Wichert & Lin, 1996; Collie et al., 2008; Pinsky & Fogarty, 2012; Keskin & Pauly, 2014; Tsikliras et al., 2015, 2018).

The MTC is tested here using a set of 59 ichthyoplankton surveys conducted in the Eastern Mediterranean, Marmara and Black Seas (Fig.1). We examine whether the taxonomic composition of ichthyoplankton assemblages, which largely reflects the timing of spawning in relation to the seasonal temperature cycle, can be summarized using MTCs. If species with cold/warm-water affinities spawn in colder/warmer waters, the MTCs of ichthyoplankton surveys would be expected to correlate with ambient water temperatures.

Material and Methods

Table 1 provides key information on the ichthyoplankton surveys included here and the sea surface temperatures (SST) recorded during these surveys. Altogether, the surveys recorded 162 species of fish (Table S1, Supplementary Material), whose preferred temperatures (PTs) were estimated mainly from the temperature data used to draw the distribution range map in Aquamaps (see www.aquamaps.org). Each MTC estimate was assigned to a sampling date (the survey midpoint) and a location: Aegean Sea (AS), Black and Marmara Seas (BS), Levant Sea (LS) (Table 1).

The MTC for each survey was computed twice: (i) as the (arithmetic) mean of the PTs of the species in a survey, weighted by the number of their egg and/or larvae
Fig. 1: Location of the 59 ichthyoplankton surveys performed in the Eastern Mediterranean (Levant and Aegean Seas) in the Black and Marmara Seas from 1989 to 2014 and further documented in Table 1.

Table 1. Basic information on the ichthyoplankton surveys analysed here by season (Winter, Spring, Summer and Autumn), with the number of species (SPP), sea surface temperature (SST, °C) and mean temperature of the community (MTCa and MTCg, °C) computed as explained in the text.

| #  | Season      | Sea      | Haul type     | SPP | SST  | MTCa | MTCg | Reference                        |
|----|-------------|----------|---------------|-----|------|------|------|-----------------------------------|
| 1  | January 15, 1989 | Aegean   | horizontal   | 15  | 13.8 | 12.7 | 13.3 | Hoşşucu and Ak (2002)            |
| 2  | January 15, 1999 | Black    | vertical     | 2   | 10.2 | 9.5  | 9.4  | Satılmış et al. (2003)           |
| 3  | January 15, 2000 | Levant   | horizontal   | 11  | 17.0 | 17.9 | 18.4 | Avşar and Mavruk (2011)          |
| 4  | January 15, 2002 | Black    | vertical     | 2   | 10.2 | 9.6  | 9.8  | Satılmış et al. (2006)           |
| 5  | Dec. 21, 2006  | Black    | vertical     | 5   | 8.5  | 9.6  | 10.2 | Klimova et al. (2009)            |
| 6  | Dec. 15, 2008  | Levant   | horizontal   | 4   | 19.0 | 16.6 | 16.6 | Mavruk (2009)                    |
| 7  | Feb. 15, 2015  | Marmara  | horizontal   | 5   | 9.8  | 9.9  | 10.8 | Karademir (2015)                |
| 8  | Feb. 15, 2015  | Marmara  | vertical     | 6   | 9.8  | 10.1 | 11.8 | Karademir (2015)                |

Mean SPP, SST & MTC for all winter surveys

| #  | Season      | Sea      | Haul type     | SPP | SST  | MTCa | MTCg | Reference                        |
|----|-------------|----------|---------------|-----|------|------|------|-----------------------------------|
| 9  | May 15, 1999 | Black    | vertical     | 3   | 16.0 | 9.5  | 9.7  | Satılmış et al. (2003)           |
| 10 | May 15,1989 | Aegean   | horizontal   | 43  | 16.6 | 15.1 | 14.7 | Hoşşucu and Ak (2002)            |
| 11 | April 15, 1998 | Aegean  | oblique      | 23  | 22.6 | 12.0 | 14.3 | Koutrakis et al. (2004)          |
| 12 | May 15, 1999 | Black    | horizontal   | 13  | 16.0 | 11.5 | 12.7 | Satılmış et al. (2003)           |
| 13 | April 1, 1999 | Black   | horizontal   | 5   | 18.6 | 17.9 | 17.9 | Avşar and Mavruk (2011)          |
| 14 | May 15, 2000 | Levant   | horizontal   | 5   | 18.6 | 21.2 | 19.8 | Avşar and Mavruk (2011)          |
| 15 | May 15, 2002 | Black    | vertical     | 4   | 16.0 | 11.1 | 11.8 | Satılmış et al. (2006)           |
| 16 | April 15, 2008 | Levant | horizontal   | 25  | 20.9 | 17.0 | 17.6 | Mavruk (2009)                    |
| 17 | May 15, 2015 | Marmara  | horizontal   | 14  | 17.6 | 12.4 | 14.4 | Karademir (2015)                |
| 18 | May 15, 2015 | Marmara  | vertical     | 10  | 17.6 | 14.4 | 15.1 | Karademir (2015)                |

Mean SPP, SST & MTC for all spring surveys

| #  | Season      | Sea      | Haul type     | SPP | SST  | MTCa | MTCg | Reference                        |
|----|-------------|----------|---------------|-----|------|------|------|-----------------------------------|
| 19 | July 15, 1988 | Black    | vertical     | 13  | 23.0 | 11.9 | 13.3 | Klimova et al. (2014)            |
| 20 | July 15, 1989 | Aegean   | horizontal   | 37  | 22.8 | 17.2 | 17.0 | Hoşşucu and Ak (2002)            |
| 21 | July 15, 1989 | Black    | vertical     | 10  | 23.0 | 14.8 | 13.7 | Klimova et al. (2014)            |
| 22 | July 15, 1990 | Black    | vertical     | 15  | 23.0 | 11.6 | 12.1 | Klimova et al. (2014)            |
| 23 | July 15, 1992 | Black    | vertical     | 5   | 23.0 | 11.6 | 12.4 | Klimova et al. (2014)            |
| 24 | June 11, 1993 | Aegean   | vertical     | 40  | 22.0 | 12.0 | 14.1 | Somarakis et al. (2011)          |
| 25 | June 22, 1994 | Aegean   | vertical     | 44  | 22.2 | 13.4 | 14.9 | Somarakis et al. (2011)          |
| 26 | June 22, 1995 | Aegean   | oblique      | 61  | 24.1 | 13.8 | 14.7 | Somarakis et al. (2002)          |
| 27 | June 19, 1995 | Aegean   | vertical     | 48  | 24.1 | 13.9 | 14.9 | Somarakis et al. (2011)          |
| 28 | June 13, 1996 | Aegean   | oblique      | 56  | 21.8 | 12.3 | 13.3 | Somarakis et al. (2002)          |

continued
A Type I bivariate regression can be straightforwardly turned into a Type II regression by dividing its slope \( b \) by the correlation coefficient between the two variables \( (X \text{ and } Y) \), and re-computing an intercept that satisfies = \( a \ (b/r)^* \). This is equivalent to minimizing the squares of the deviations along both the abscissa and the ordinate (Ricker, 1973). With multiple regressions that include dummy variables, however, this procedure can be applied only to the continuous variables, as shown below.

### Results

A single multiple regression which summarizes the data in Table 1, and explains 59 % of the variance is:

\[
MTCa = 8.441 + 0.161 \times SST + 2.226 \times AS + 5.468 \times LS
\]

(1)

Where \( MTCa \) is the arithmetic mean temperature of the ichthyoplankton assemblages (in °C), \( SST \) the surface temperature at the time of sampling (in °C), and \( AS \) and \( LS \) are the dummy variables referring to the sampling locations (see Table S1 in Supplementary Material).

The corresponding equation for \( MTCg \) (see Table S2 in Supplementary Material) explains 75 % of the variance and has the form:

\[
MTCg = 10.161 + 0.172 \times SST + 1.160 \times AS + 4.578 \times LS
\]
MTCg = 9.000 + 0.188*SST + 1.669*AS + 5.027*LS  \hspace{1cm} (2)

The fit is much better than for Equation 1, and hence our further considerations refer only to Equation 2.

The partial correlation (see Table S3 in Supplementary Material) between MTCg and SST, i.e., their correlation after the effects of the variables AS and LS were accounted for, was 0.507 (df=57, p< 0.01).

The slope linking MTCg and SST in Equation 2 is 0.188 (see above and Table S1 in Supplementary Material); hence, the Type II slope is 0.188/0.578 = 0.330. Thus, we have:

\[ MTCg = 5.604 + 0.330*SST + 1.669*AS + 5.027*LS \quad (3) \]

as our best summary of the data in Table 1 (see also Fig. 2).

Discussion

The mean temperature of the catch (MTC) concept was defined, set on a rigorous footing and shown to apply widely by Cheung et al. (2013), and subsequently confirmed by local studies, e.g., Tsikiras & Stergiou (2014) or Liang et al. (2018). Moreover, the ‘C’ in MTC can also be extended to communities, i.e., assemblages that are sampled at various places and whose taxonomic composition can be expected to yield MTC values that correlate with local temperatures, as shown, e.g., for the eastern Mediterranean by Tsikiras et al. (2015, 2018) and Keskin & Pauly (2018).

This is the first demonstration of a significant relationship between the MTC of ichthyoplankton assemblages and the SST at the time when and where these assemblages were sampled. A first insight from this is that geometric MTCs (i.e., MTCg) may be more appropriate than arithmetic MTCs for ichthyoplankton surveys, where a single species that happens to have spawned just before the survey is conducted can swamp an estimate (of MTCa) with an an huge number of eggs and larvae, and similarly for a very few species.

The dummy variables used to account for location generated patterns that were straightforward to interpret (Fig. 2). Thus, there was, in the SST/MTC space, a zone that none of the surveys occupied, i.e., low SST combined with high MTC. This implies that, in the Black Sea (where the coldest temperatures occur), the eggs and larvae of fish with cold water affinities dominate ichthyoplankton assemblages when SSTs are low. Conversely, in the Levant Sea, the MTCs are the highest in absolute term, and for any SST level, as befits an area with higher SST, and hence home to fish with warm-water affinities.

The only feature of Equations (2) and (3) that is not fully matching expectations is the value of the slope linking MTC and SST which, even when corrected as in Equation (3), is significantly lower than unity (p< 0.05).

Visual inspection of the data in Table 1 suggests that for some groups of surveys, MTC and SST have the expected 1:1 relationship (see also Figure 2). Thus, we suggest that a combination of noise due to taxonomic misidentifications, measurement errors and/or hidden parameters is the reason for this slope being < 1. Future studies may be devoted to reducing measurement errors: for example, by estimating PTs using a more rigorous method, and/or identifying additional predictors for MTC.

In the meantime, however, we are pleased to be able to report a surprising coherence among the results of 59 ichthyoplankton surveys and, in the process, to have established the usefulness of MTC as an indicator of the taxonomic composition and temperature affinities of ichthyoplankton assemblages.

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