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Reconciling Trends of Mean Trophic Index and Mean Temperature of the Catch in the Eastern Mediterranean and Black Seas

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Abstract

The mean trophic level, i.e., the Mean Trophic Index (MTI) and Mean Temperature of the Catch (MTC) were estimated for Turkish waters in the Eastern Mediterranean and the Black Sea based on the reconstructed marine fisheries catches (consisting of N = 88 species and/or higher taxa) in Turkish waters for the year 1950 to 2010. The MTI decreased in both regions of Turkey, following expectations, but the MTC showed different trends in these two regions. It increased (by 0.48 °C·decade⁻¹), along with the SST in the Eastern Mediterranean, while it fluctuated in the Black Sea. This fluctuating behaviour, however, was similar to the fluctuating tendency of SST in the Black Sea. This suggests that the MTI and MTC can be relied upon as indicators of fisheries impacts on ecosystems, and of the impact of changing temperatures on fisheries, respectively.

Keywords: Catch composition, ecological indicators, climate change, Eastern Mediterranean Sea, Black Sea.

Introduction

The last decades, which saw an intensification of the impact of fisheries on marine ecosystems worldwide (Pauly *et al.*, 1998; Jackson *et al.*, 2001; Watson *et al.*, 2013), also exhibited the first sign of the impact of global warming on marine ecosystems (Cheung *et al.*, 2013). This is particularly true in the Eastern Mediterranean and the Black Seas, where fishing intensity has been intense (Daskalov *et al.*, 2007; Vasilakopoulos *et al.*, 2014), as have been the impact of climate change (Ludwig *et al.*, 2009; Raitsos *et al.*, 2010). However, the trends of indicators reflecting these two types of impacts differ in their behaviour. The Marine Trophic Index (MTI; Pauly & Watson, 2005), reflecting the depletion of large, high-trophic level fishes relative to small fishes is declining in these two ecosystems, as expected, but the Mean Temperature of the Catch (MTC; Cheung *et al.*, 2013), an indicator of global warming, which is increasing in the Eastern Mediterranean, as expected (Tsikliras & Stergiou, 2014; Keskin & Pauly, 2014), fluctuates in the Black Sea, which is contrary to expectations, at least when these expectations are not informed by the peculiar thermal history of the Black Sea. Thus, account must be taken, when using with the MTC, of the spatial and temporal scales of the changes in distribution induced by change in SST, as these changes, in some areas, can run counter to the generally observed poleward direction of fish migrations

(Pinsky *et al.*, 2013). This contribution presents the data, concepts and methods which allow resolving this apparent mismatch.

Materials and Methods

The marine fisheries catches of Turkey for the year 1970 to 2010 in the Eastern Mediterranean and the Black Sea (i.e., excluding the Bosphorus, Sea of Marmara and Dardanelles), as 'reconstructed' by Ulman *et al.* (2013), were used for this study. Reconstructed catches include, in addition to official data, previously unreported industrial, artisanal, recreational, and subsistence catches, along with discards (see also Pauly & Zeller 2016 and www.seaaroundus.org). The reconstructed catches exclude the substantial take of Turkish vessels operating outside the Exclusive Economic Zone (EEZ) of Turkey in the Black Sea. However, catches of sprat (*Spattus sprattus*) covering the years 1992 to 2010 were excluded, as this species was not identified as such in Turkish catch statistics prior to 1992. Also, the huge 2005 catch of Atlantic bonito (*Sarda sarda*), a fish which, depending on environmental conditions, spawns in the Black, Marmara or Mediterranean Seas (Demir, 1957), was considered to be an outlier and omitted from the MTI and MTC computation.

For the Mediterranean, the catches that were included were as reconstructed by Ulman *et al.* (2013) for the coastal waters of Turkey. The areas thus covered are shown on Figure 1.



Fig. 1: Regions from which the fishery catches used in this study originated. The 3 dots in the Southeast Black Sea document the three points whose SST values were averaged to obtain a SST trend characterizing the core area of Turkish fisheries in the Black Sea. The dotted line separates what Shapiro *et al.* (2010) call the colder “deep Black Sea” from the warmer “Western shelf” of the Black Sea.

The Turkish catches from these two areas consisted of $N = 88$ species and/or higher taxa (henceforth ‘species’) for which trophic levels and preferred temperatures were available or could be inferred (Table 1a for fishes and Table 1b for invertebrates in Supplementary Material), as required for the calculation of the MTI and MTC indices.

The MTI was calculated from:

$$MTI_i = \frac{\sum_i^n TL_i \cdot Y_{i,k}}{\sum_i^n Y_{i,k}} \quad \dots 1)$$

where $Y_{i,k}$ is the catch of the n species i in year k in a specific region, TL_i the trophic level of species i and TL_i values were obtained from FishBase (www.fishbase.org; Froese & Pauly 2014) for fish species and higher taxa, and from SeaLifeBase (www.sealifebase.org; Palomares & Pauly 2014) for invertebrates species.

Similarly, the MTC was calculated from:

$$MTC = \frac{\sum_i^n T_i \cdot Y_{i,k}}{\sum_i^n Y_{i,k}} \quad \dots 2)$$

where $Y_{i,k}$ is, as previously, the catch of the n species i in year k in a specific region, while T_i is the temperature preference of species i . Herein, T values were obtained from the supplementary online material of Cheung *et al.* (2013), as derived by superposing the distribution maps described in Palomares *et al.* (2016) onto sea temperature from the U.K. Meteorological Office observation dataset (<http://hadobs.metoffice.com/hadisst/>). This yielded Temperature Preference Profiles (TTP) which are generally Gaussian-shaped and whose mode can be assumed to be the preferred temperature of the species in question (Cheung *et al.*, 2008, 2013).

Given that a comprehensive account of the oceanog-

graphy of the Turkish EEZ in the Black Sea does not appear to exist, the temperatures we used to represent this body of water are the means SSTs at three points in the south-eastern part of the Turkish Black Sea EEZ (see Fig. 1), corresponding to its core area in term of fisheries (Ulman *et al.*, 2013). The SSTs were derived for the years 1970 to 2010 from the *COBE-SST2 data, provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA* (<http://www.esrl.noaa.gov/psd/>).

Results and Discussion

The reconstructed catch data used here, from Ulman *et al.*, (2013), are higher than the landings data Turkey reports to the Food and Agriculture Organization of the United Nation (FAO). The differences are due mainly to unreported landings (22 %), discards (9%), and recreational and subsistence catches (9%). However, as these additional catches are not well disaggregated taxonomically, they were not used here. Thus, our MTI and MTC indicators are based on a catch composition largely similar to that of the catches reported by FAO on behalf of Turkey.

The MTI, i.e., the mean trophic level of the catch, decreased in both regions of Turkey. In the Eastern Mediterranean, it decreased significantly ($p < 0.05$) at a low but ready rate of $0.018 \text{ TL} \cdot \text{decade}^{-1}$ (Fig. 2A). This confirms previous documentation of fishing down in the Eastern Mediterranean (Stergiou, 2005; Stergiou & Christensen, 2011). In the Black Sea, where ‘fishing down’ is well documented (Daskalov *et al.*, 2007), the MTI decreased significantly ($p < 0.01$), from 3.5 in the late 1970s/early 1980s to about 3.1 in the late 2000s and 2010, i.e., at the very high rate of $0.127 \text{ TL} \cdot \text{decade}^{-1}$ (Fig. 2B). This figure also confirms that massive ecosystem shifts occurred from the late 1970s to the mid-1990s in the Black Sea (Daskalov *et al.*, 2007), which induced strong biomass and hence catch oscillations (Knudsen, 2009), reflected in the wavy pattern of Figure 2B.

Given this match with expectations, we can conclude that the reconstructed catch data of Ulman *et al.* (2013) reflect, at least roughly, the relative abundance of the underlying resource species. Also, we can conclude that that these resources have been impacted by fisheries as described by Pauly *et al.* (1998), i.e., they have been ‘fished down’.

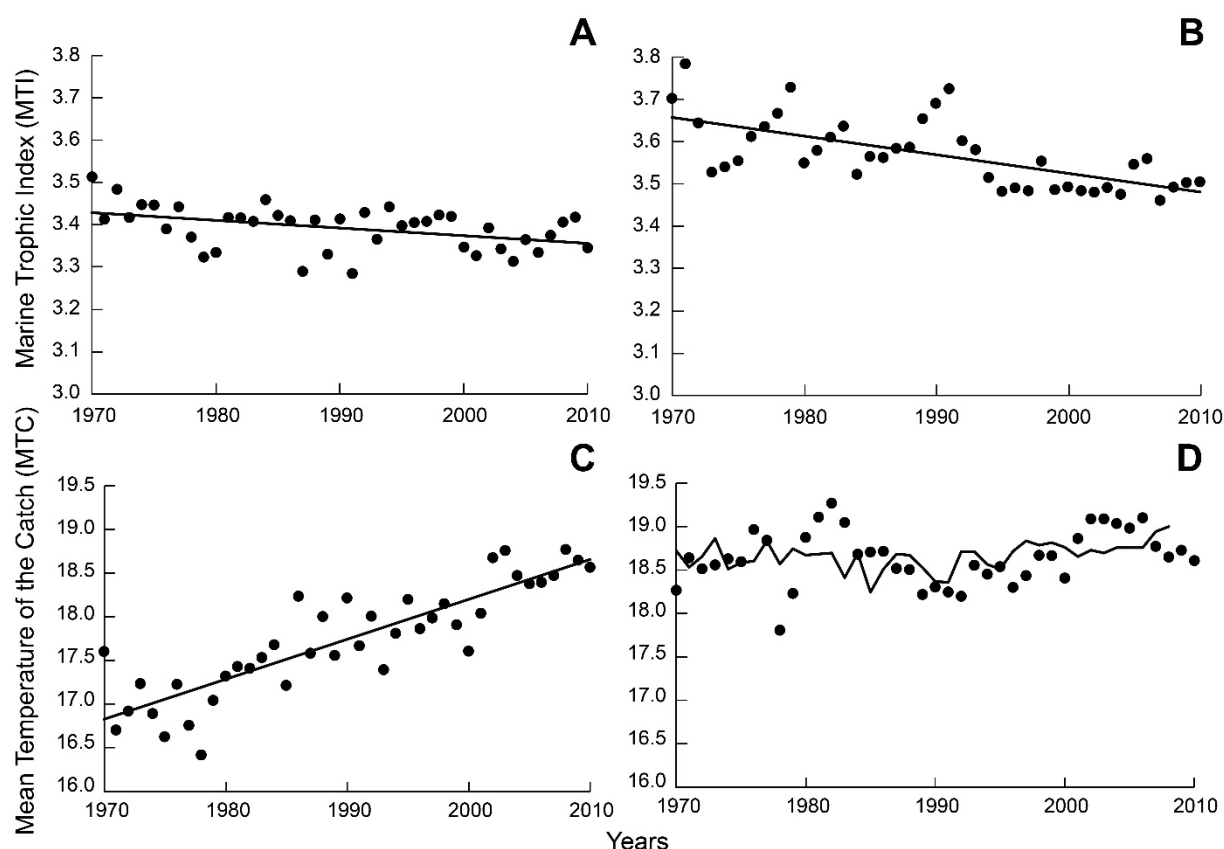


Fig. 2: Indicators of fisheries (MTI) and global warming (MTC) impacts on Turkish fishing grounds. In the Eastern Mediterranean (A, C), the MTI decreases because of ‘fishing down’ (A), and the MTC increases because of global warming; both indicators behave as expected. In the Black Sea (B, D), the MTI declines as expected (B), but the MTC fluctuates (D). However, SST also fluctuates; the regression in Fig. 3 (see Supplementary Material) enabled tentative predictions of MTC from SST, used here to generate the continuous, but fluctuating line linking the dots in D (see text).

The MTC of the Turkish Mediterranean (Fig. 2C) shows a significant increase ($p < 0.05$), of $0.457^{\circ}\text{C}\cdot\text{decade}^{-1}$, very close to the observed rate of increase in SST in the Eastern Mediterranean ($0.42^{\circ}\text{C}\cdot\text{decade}^{-1}$; Skliris *et al.*, 2011), which is nearly twice the average rate for the world ocean, of about $0.23^{\circ}\text{C}\cdot\text{decade}^{-1}$ (Levitus *et al.*, 2005, 2009).

On the other hand, this rate of MTC increase is almost double that estimated by Tsikliras & Stergiou (2014), of $0.29^{\circ}\text{C}\cdot\text{decade}^{-1}$, for the period from 1970 to 2010, based on catch data in the database of the General Council for the Fisheries of the Mediterranean (GCFM). These authors explained their low estimate with the underrepresentation, in the GCFM database, of the thermophilic Lessepsian species that have been colonising in the Eastern Mediterranean Sea since the opening the Suez Canal in 1869. We agree with this assessment.

The MTC of the Turkish Black Sea, in contrast, fluctuates strongly, but without any trend (Fig. 2D), as does the mean SSTs at three areas highlighted by dots in Fig. 1. However, the MTC and SST for the Turkish Black Sea are significantly correlated, once a lag of two years is introduced. (See Supplementary Material, Fig. 3). This is reasonable, as one would expect the (adult) fish biomass of a given species to increase after a year with favourable SSTs for the young of that species, and decrease after a year with unfavourable SSTs.

While SST and MTC in the Turkish Black Sea are weakly, if significantly correlated (Fig. 2D, and Fig. 3 in Supplementary Material), their overall behaviour requires some comments. First, we must recall, with Pinsky *et al.* (2013), that the movements of fish, given global warming, while generally poleward, are actually driven by local oceanographic conditions, i.e., temperature, and thus can run in opposite direction to the overall trend when examined at smaller scales.

In our case the best evidence we have, summarized in Shapiro *et al.* (2010), is that while the north-western Black Sea, which has extensive shelves and other shallow areas, has been warming in the last decades, the deeper central and south-eastern Black Sea region has generally been cooling. Shapiro *et al.* (2010) note that “there was a definite cooling trend in the deep Black Sea over the 20th century. [On the other hand,] there was neither cooling nor warming trend over the length of the 20th century on the Western shelf.” Or put differently: “[t]he long term variability in both deep and shelf areas of the Black Sea is at variance with many other parts of the world ocean (Levitus *et al.*, 2005, 2009)” (Shapiro *et al.*, 2010). These authors further explain that “[u]nusual temperature trends in the Black Sea could be attributed to the variations in the overlying weather pattern.” This is what produced the observed fluctuating SST patterns in the central part of the Turkish EEZ in the Black Sea.

Consequently, we can infer that the MTC of the south-east Black Sea, i.e., of the Turkish EEZ, did track the fluctuating temperatures occurring there. Also, Fig. 2D, rather than being an anomaly, requiring an *ad hoc* expla-

nation, fully support the notion that the MTC reflects local environmental temperatures, and thus can be used as a reliable indicator of climate change effects on exploited fishes and invertebrates.

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