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NOTE

# Mean temperature of the catch index can be masked by changes in catch composition unrelated to ocean warming

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## Abstract

Oceans are increasingly warming through climate change. Fish and invertebrate ectotherms respond to ocean warming through poleward and depth-related migrations, a consequence of which is disruption of fisheries catch compositions. Mean temperature of the catch (MTC) is an index of change in catch composition, from colder to warmer water species. MTC is widely applied as an easily parameterised variable using readily available data (catch and species preferred temperature), but few studies underscore situations that might mask the "true" MTC trend. Here, we use fisheries catch in the Arabian-Persian Gulf ("Gulf") to highlight, for the first time, how abrupt changes in market demand can strongly influence catch composition and thereby mask a trend in MTC, and discuss the implications of the unmasked MTC trend to fisheries in the region. We found that a recent sharp decline in MTC from 27 to 26°C, despite a gradual increase in sea surface temperature, coincided with an escalated demand for the largehead hairtail (*Trichiurus lepturus*), a relatively cold-water species in the Gulf, that caused catch to dramatically increase for export to overseas markets. Our findings suggest that the change in MTC reflected a fishery response to satisfy increased international market demand, rather than reflecting warming-driven changes in catch composition. When excluding the effect of *T. lepturus* catch, the Gulf MTC trend was stable over time and consistent with a trend in many tropical and subtropical waters. Our findings highlight that an MTC change can be masked by factors unrelated to warming-driven changes in catch composition, and that catch-only MTC trends should be examined cautiously.

**KEYWORDS**
Arabian/Persian Gulf, catch composition, MTC, ocean warming

## 1 | INTRODUCTION

Considerable evidence suggests that ocean warming is driving fish and invertebrate ectotherms to migrate poleward or to deeper, colder waters in ecosystems around the world (Engelhard et al., 2014; Perry et al., 2005; Pinsky et al., 2018, 2021). A main consequence of these warming-driven shifts is disruption of fisheries through changing the amount and composition of the catch (Free et al., 2019; Pinsky et al., 2018, 2021). For example, the proportion of warmer-water species caught in most states increased over time in the distribution and landings of fish and invertebrates in the northeastern United States (Pinsky &

  

Fogarty, 2012). Because such shifts are widespread and will likely persist in the future, indices have been developed to index warming-driven changes in catch composition (Cheung et al., 2013; Hare et al., 2010; Lenoir et al., 2010).

Mean temperature of the catch (MTC) is an index that measures temporal shifts in catch composition (Cheung et al., 2013). An increase in MTC over time implies that catches of warm-water species increased, whereas catches of cold-water species declined (Cheung et al., 2013). The MTC index has been widely applied to examine warming-driven changes in catch composition in many regions around the world, including the Mediterranean Sea, Black Sea, Yellow, and East China Seas, and large marine ecosystems such as the northeast Pacific Ocean and northeast Atlantic Ocean (Cheung et al., 2013; Keskin & Pauly, 2018; Liang et al., 2018; Tsikliras & Stergiou, 2014). Wide application of MTC is partly due to easy parameterisation of MTC and readily available data, most notably catch data and information on ectotherm preferred environmental temperature.

The MTC index has been validated as a proxy for warming-driven changes in catch composition. For example, in the North Sea, catch data did not differ significantly from trawl survey data when calculating the rate of change in MTC (Cheung et al., 2013). However, validation of MTC in the North Sea may not apply to other regions, because many global fisheries lack fisheries-independent data for testing if MTC is reflected only by catch data (Pauly & Zeller, 2016). Catch amount and composition can be influenced by factors other than warming, such as local oceanographic and fisheries-related changes, which in turn may mask MTC signals (Gianelli et al., 2019; Keskin & Pauly, 2018). Indeed, such masking distorted other commonly applied catch-based indices, notably the mean trophic level index, which quantifies fishing-down (Pauly et al., 1998). For example, geographical expansion of fisheries into new fishing grounds increased or maintained high catch trends of large exploited species over time, which masked a decline in high-trophic species (i.e., fishing down phenomenon) and consequently the decline in the mean trophic level index (Bhathal & Pauly, 2008; Kleisner et al., 2014; Liang & Pauly, 2017; Pauly et al., 1998). Recognition of the effect of geographical expansion on the mean trophic level index facilitated development of new approaches to account for this masking (Kleisner et al., 2014). Nevertheless, few studies have explicitly underscored situations that mask the "true" MTC trend.

Herein, we sought to determine if Arabian-Persian Gulf (Gulf) MTC trend was masked by abrupt changes in international market demand that strongly influenced fisheries catch composition. Fishery resources are the most important renewable resources in the region (Grandcourt, 2012; Sale et al., 2011). Fisheries' catches expanded dramatically in recent years. Yield of the artisanal sector, for example, increased 167% since 1950 to 0.5 million tons in 2018 (Ben-Hasan & Daliri, 2022). In addition to strengthening food security in the region, fisheries employ at least tens of thousands of people. In one of Iran's coastal provinces, ~22,500 fishers depend on the sea for food and income (Daliri et al., 2016). Therefore, unmasking the MTC trend in the Gulf would enable discussion of the implications of the MTC for fisheries in the region where the rate of warming is faster than the global average.

## 2 | METHODS

Total catch of 142 fish and invertebrate species in the Gulf was obtained from the Sea Around Us database (Pauly et al., 2020), in addition to the mean and maximum preferred temperature of each species from FishBase and SeaLifeBase databases (Table S1) (Froese, 2023; Palomares, 2023). Mean preferred temperatures in these databases were estimated from overlapping biological probability distributions for each species with an atlas of sea surface temperature (SST) (Belkin, 2009; Palomares et al., 2021). MTC was calculated using the following equation (Cheung et al., 2013):

$$\mathrm{MTC} = \frac{\sum_{i}^{n} \mathrm{TC}}{\sum_{i}^{n} \mathrm{C}} \quad (1)$$

Where $T$ was the mean temperature preference of species $i$, $C$ was the catch of species $i$, and $n$ was the total number of species in annual catch. Besides calculating the MTC using species mean preferred temperature, we calculated it using the maximum preferred temperatures (Table S1). To compare trends of MTC and SST in the Gulf, SST time-series were obtained from the 5th generation European Centre for Medium-Range Weather Forecasts with a spatial resolution of 0.25° (Hersbach et al., 2023). SST data were aggregated to a temporal resolution by selecting daily time steps and later averaged to annual values (Table S2).

## 3 | RESULTS AND DISCUSSION

Total catch in the Gulf generally increased since 2009, but levelled off in recent years for some major species (Figure 1a). The mean preferred temperature ranged 21.4–28.8°C for most exploited species in the Gulf, with an overall mean preferred temperature of 27.4°C (Figure S2), consistent with the relatively high mean water temperature of the Gulf, which is considered the world's hottest sea in summer (Howells et al., 2020; Hume et al., 2015; Vaughan et al., 2019). Preferred temperatures ranged 24.7–28.3°C for nine of the top 10 caught species, but the mean preferred temperature for *Trichiurus lepturus* was 15.2°C (Figure 1b).

The MTC was stable at ~27°C and then sharply declined to 26°C during 2007–2019 (Figure 2, "masked MTC" trend). Two possible explanations for the decline in MTC trend include: (i) more cold-water species entered and were increasingly caught in the Gulf, thereby shifting the MTC trend downward; and (ii) more warm-water species migrated out or were driven toward

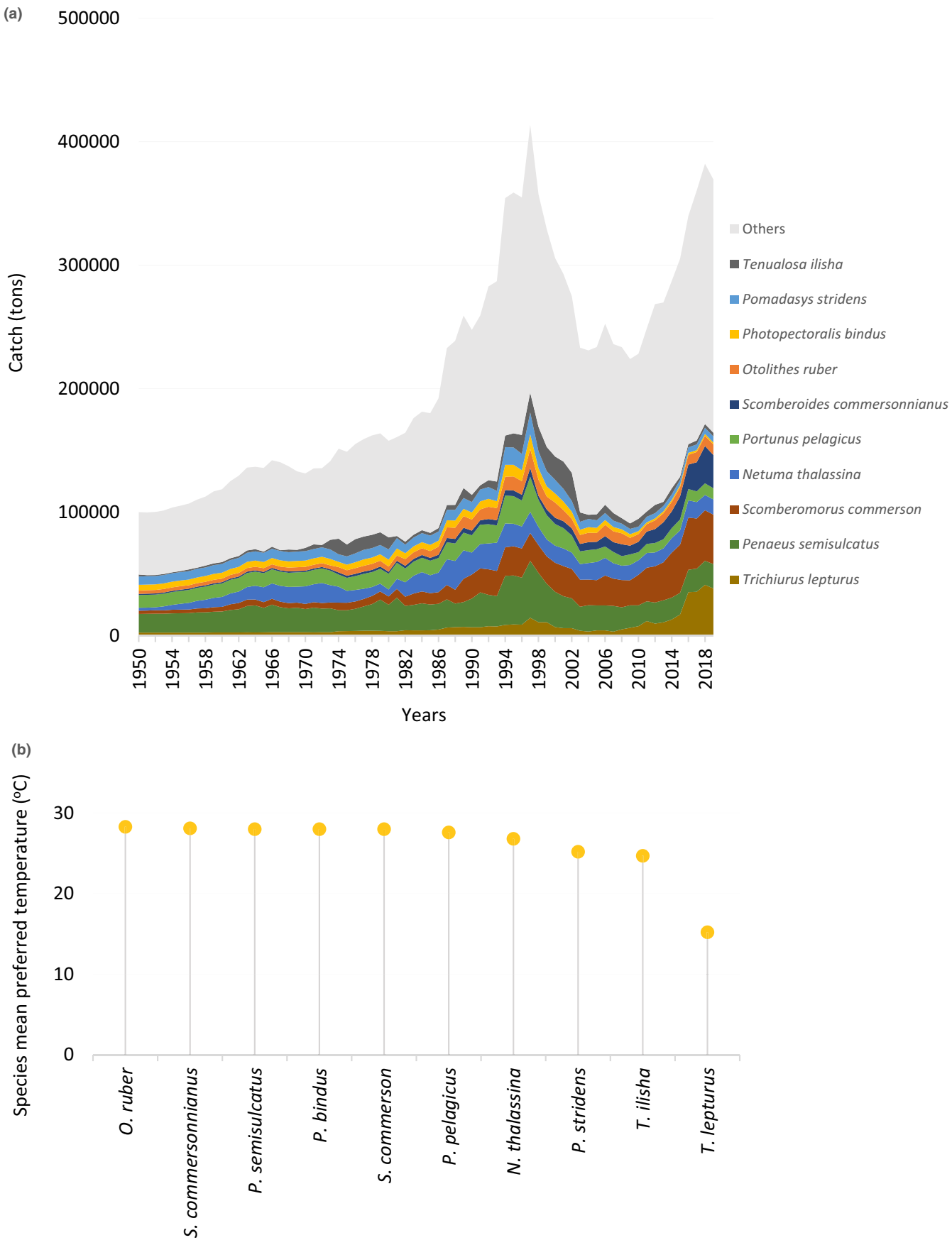


FIGURE 1 Fisheries catch and mean preferred temperature for exploited species in the Arabian-Persian Gulf (Gulf). (a) The Gulf catch (excluding fish or invertebrates that are not identified to species) from 1950 to 2019, which highlights the top 10 caught species; the category "Others" includes all other species. (b) Mean preferred temperature for the top 10 species caught in the Gulf.

extinction, perhaps due to excessive water temperature. Both explanations are unlikely because catches of warm-water species that comprised the bulk of the catch generally increased, rather than decreased (Figure 1a). More likely, catch of the relatively cold-water species, *T. lepturus*, increased dramatically in the same period of declining MTC (Figure 3). Therefore, the MTC was generally stable after removing the effect of *T. lepturus* (Figure 2, "unmasked MTC" trend).

Increased catch of *T. lepturus* was unlikely due to increased abundance driven by more fish coming into the Gulf. For example, the catch rate of *T. lepturus* escalated sevenfold in the Gulf and Oman Sea over a 10-year period, with indications that the level of fishing pressure may be unsustainable (Khervi et al., 2021; Taghavi Motlagh et al., 2021). Rather, the main driver behind the increased catch of *T. lepturus* was international demand for this species (Khervi et al., 2021), as supported by export data, which mimicked catch over the same period of declining MTC in 2007–2019 (Figures 2 and 3).

The unmasked MTC pattern shows that average temperature of the species composition of the catch was stable at ~27.4°C. A stable MTC trend suggests that warmer-water species were not entering the Gulf, perhaps because further tropicalisation of catches is limited for many tropical and subtropical water bodies around the world (Cheung et al., 2013; Dimarchopoulou et al., 2022; Keskin & Pauly, 2018; Liang et al., 2018; Tsikliras & Stergiou, 2014).

The Gulf marine fauna experiences extreme thermal differences, with water temperature exceeding 35°C in summer and decreasing rapidly to less than 15°C in winter (Vaughan et al., 2019). This difference in water temperature far exceeds that in many other subtropical or tropical waters (Figure S3). Further, the mean SST in the Gulf has been steadily increasing since 1990, and, on average, heading toward the maximum MTC trend (Figure 4). This

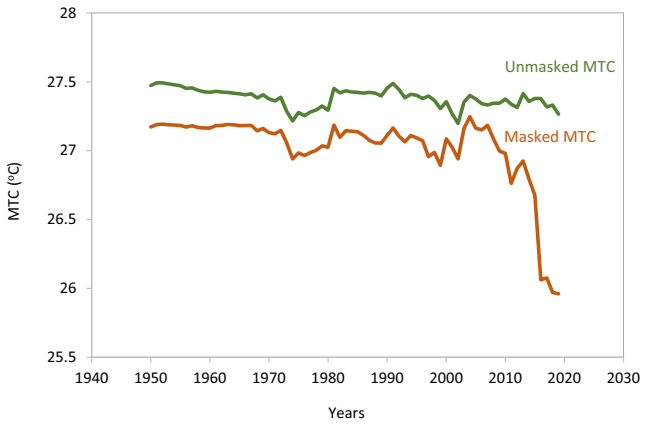


**FIGURE 2** Mean temperature of the catch (MTC) in the Arabian-Persian Gulf from 1950 to 2019. The "Masked MTC" includes catches of all exploited species, whereas the "Unmasked MTC" excludes the catch of *Trichiurus lepturus*.

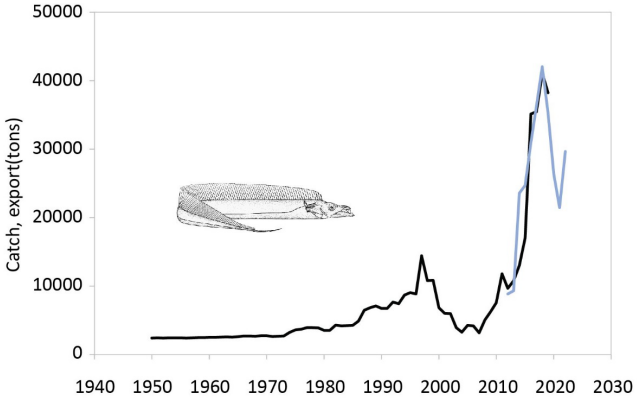


**FIGURE 3** Catch (black line) and export (blue line) of *Trichiurus lepturus* in the Arabian-Persian Gulf. Catch of *T. lepturus* in the Gulf (1950–2019), harvested primarily by Iran fisheries (Figure S1). Export of *T. lepturus* (2010–2022) obtained from the Iranian Veterinary Organization (exports not recorded for species prior to 2010).

is concerning because some fish species are already under intense thermal pressure. For example, reef fish in the Gulf are already adapted to extreme conditions, but live close to their maximum thermal threshold in summer (Bouwmeester et al., 2021). In addition, some fish species in the Gulf are smaller in size, lower in diversity, and lower in abundance than in the adjacent and more benign Oman Sea, which is partly driven by a need to cope with Gulf environmental extremes (Brandl et al., 2020; D'Agostino et al., 2021; Pauly, 2021). Given a stable MTC trend, which implies that fish are not migrating inside the Gulf, a further increase in water temperature may affect performance of local fish, including growth, reproduction, and survival, thereby ultimately affecting catches in the region. Indeed, future projections (Wabnitz et al., 2018) indicated that local extinctions are expected throughout the Gulf, thereby reducing both the number of species and catch potential along the coast of the western side of the Gulf.

In conclusion, the recent sharp decline in the MTC in the Gulf was most likely influenced by an increase in the international market demand for *T. lepturus*, a relatively cold-water species in the Gulf, for which catch and export increased in the same period. This suggests that catch-only MTC trends were masked by changes unrelated to warming-driven migrations. After excluding the influence of *T. lepturus* catch, warming-driven shifts in catch composition indicated that: (i) MTC was stable, not decreasing, in the Gulf, so catch composition did not change dramatically since 1960; and (ii) the SST trend, on average, increased recently and will probably approach the maximum MTC in the future. Taken together, this suggests that if fish performance were to be impacted by increasing SST, it would unlikely be compensated by fish migrating into the Gulf.

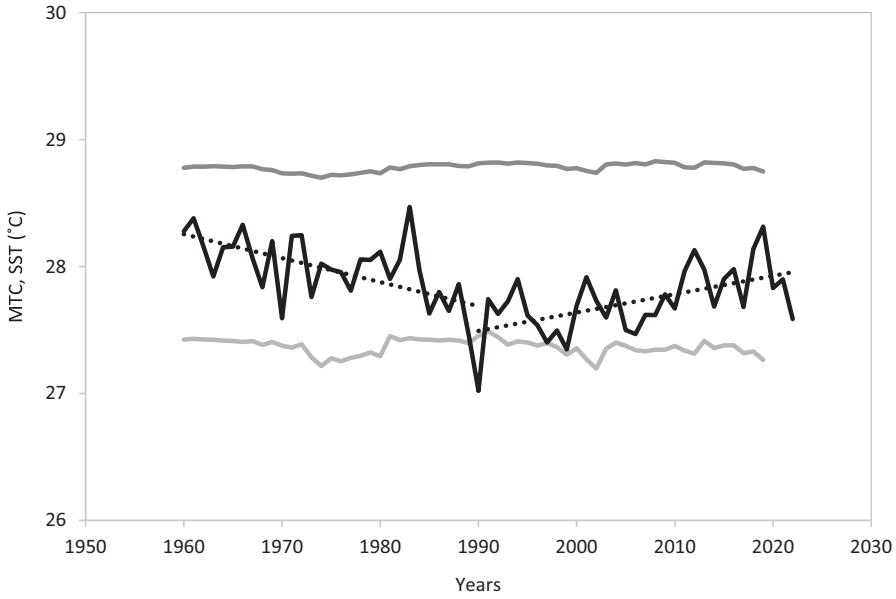


**FIGURE 4** Unmasked mean temperature of catch (MTC, light grey line calculated using species mean preferred temperature and dark grey line calculated using species maximum preferred temperature over the period 1960–2019) and annual sea surface temperature (SST, black line) in the Arabian-Persian Gulf, with linear trends in SST (dotted lines) during 1960–1990 and 1990–2022.

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## CONFLICT OF INTEREST STATEMENT

We confirm that this work is original and has not been published, nor is it currently under consideration for publication elsewhere. We have no conflicts of interest to disclose.

## DATA AVAILABILITY STATEMENT

We have obtained most of data from open access databases. Please refer to the Section 2.

## ETHICS STATEMENT

Not applicable.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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