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RAPID COMMUNICATION

Climate impact on Italian fisheries (Mediterranean Sea)

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Abstract Global warming is increasingly affecting marine ecosystems and ecological services they provide. One of the major consequences is a shift in species geographical distribution, which may affect resources availability to fisheries. We computed the mean temperature of the catch (MTC) for Italian catches from 1972 to 2012 to test if an increase of warmer-water species against colder-water ones was observed. We further analysed the relationship among MTC, landings, fishing effort and climatic factors through a Linear Mixed Models approach. Global MTC increased at a rate of 0.12 °C per decade. Though, by considering the influence of sea surface temperature (SST), a strongest increase (0.31 °C) was estimated in southernmost areas, while in the northernmost basin (Northern Adriatic Sea) a decrease of 0.14 °C was observed. SST resulted the most relevant driver, and the relationship between MTC and SST showed a high spatial variability both in terms of strength and sign, being positively stronger in southernmost areas while negative in the northernmost basin. The result is probably underestimated since several psychrophilous and thermophilous species were not included in the analysis. However, it seems that a change towards warmer-water species has already occurred in Italian marine ecosystems. Conversely, total landings temporal dynamics seem mostly driven by changes in fishing effort rather than by MTC and climatic factors. Consequently, fishery management strategies need to focalize primarily on fishing effort reduction, in order to reduce the pressure on the stocks while increasing their resilience to other stressors, among which global warming.

Keywords Climate change · MTC · SST · NAO · Linear Mixed Models · Mediterranean Sea

Introduction

Climate variability has always occurred throughout geological times and ecosystems have evolved consequently. However, the actual rate of climate change is more rapid than previous natural changes (Brander 2013), human influence on the climate system is clear (IPCC 2013), and the resilience of species and systems has being already compromised by concurrent pressures (Brander 2010). As a

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result, ocean warming is currently considered one of the main driving forces causing changes in the marine communities' structure (Portner and Peck 2010).

These changes affect marine species in terms of distribution shifts, growth rates, spawning period, size at maturity, recruitment and mortality (Pecl et al. 2014). Thus, such changes are expected to affect ecosystem services (e.g. fisheries; Gamito et al. 2015) all around the world. In particular, the vulnerability of a fishery to climate depends on induced changes in fish stocks that affect species composition and thus abundance in commercial catches. Fisheries should be affected by "meridionalization" (Azzurro et al. 2011) and "tropicalization" (Bianchi 2007) of catch, i.e. an increase of warmer-water species in relation to colder-water ones, since shifts in distribution are expected to affect their availability to fisheries (Rijnsdorp et al. 2009; Cheung et al. 2013). Landings may change in relation to global warming (Teixeira et al. 2014), and this may induce changes in the intensity and spatial distribution of fishing effort (Haynie and Pfeiffer 2012). The exposure of a fishing community will be greatest where other pressures, such as overfishing, are already stressing the social-ecological system (Miller et al. 2010). Also fish stocks, if already overexploited, are more strongly affected by climate change. This is due to reduced age structure, restriction of geographic distribution, loss of diversity etc. (Rijnsdorp et al. 2009; Perry et al. 2010; Planque et al. 2010).

Unfortunately, most of the Mediterranean fish stocks are currently overexploited (Colloca et al. 2011), making them particularly vulnerable to climate change, as observed, for instance, for the Northern Adriatic Sea (Pranovi et al. 2013). In that fishery, commercial catch is entirely composed of species from cold and temperate latitudes that have decreased during the past decade as a consequence of global warming.

Each species has individual characteristics which govern responses to environmental changes, thus the complexity of these processes and their interaction makes the task of understanding and predicting the impacts of climate on fisheries production tricky (Brander 2010). One possible solution is to look at the behaviour at a higher level, for instance community. We applied the mean temperature of the catch (MTC) index (Cheung et al. 2013) to Italian landings for the period 1972–2012 to test if an increase of warmer-water species against colder-water ones was observed. In order to disentangle the role of different driving forces on MTC changes, we used Linear Mixed Models (LMM) with an ensemble of different combination of predictors, i.e. the mean sea surface temperature (SST), the North Atlantic Oscillation index (NAO), landings and fishing effort. Moreover, we investigated if total landings are actually quantitatively affected by MTC dynamics, since climate and exploitation may likely interact in their effects (Planque et al. 2010).

In particular, the aims of this study were to analyze MTC temporal changes in different areas belonging to Italian seas in relation to climatic factors and fishing effort, and to investigate how changes in MTC contributed, in space and time, to changes in landings.

Materials and methods

Landings and mean temperature of the catch

Annual landings (1972–2012) originated from official Italian statistics on fishery, reported by the Italian National Institute of Statistics (ISTAT) from 1972 to 2004, and by the Institute for Economic Research in Fishery and Aquaculture (IREPA) from 2005 to 2012.

Landings were expressed in terms of species or groups of species wet weight (kg/year) per region, and do not include discarded, illegal and unreported catches. To take into account possible geographical differences in variables relationships and trends, regional data were grouped in six areas (Fig. 1).

The taxonomic resolution of landings changed over time, so only species clearly recognizable across the entire time-series were included in the analysis. The final database resulted to be composed by 25 species in each region (35 species in total, since some species were different according to the region). For each species the thermal preference (median temperature preference, *T*) was assigned according to Cheung et al. 2013 (Table S1).

The yearly MTC was calculated for each region from the average inferred temperature preference of exploited species, weighted by their annual landing (Cheung et al. 2013), according to the following formula:

$$\mathrm{MTC}_{\mathrm{yr}} = \sum_{i}^{n} c_{i,\mathrm{yr}} \cdot T_i \Big/ \sum_{i}^{n} c_{i,\mathrm{yr}} \tag{1}$$

where $c_{i,\mathrm{yr}}$ is the landing of species i in a specific region in year yr, T_i is the median temperature preference of species i and n is the total number of species.

Trawl-survey data

Biomass data were obtained from the Mediterranean International Trawl Survey program (MEDITS) for the years 1994–2011 (for further details see Bertrand et al. 2002). These data were used to calculate the MTC in the FAO Geographical Sub Area 17 (GSA 17, corresponding to Area 1 and 2 in Fig. 1) for the period 1994–2011 to test the effect of the use of landings or survey data in estimating

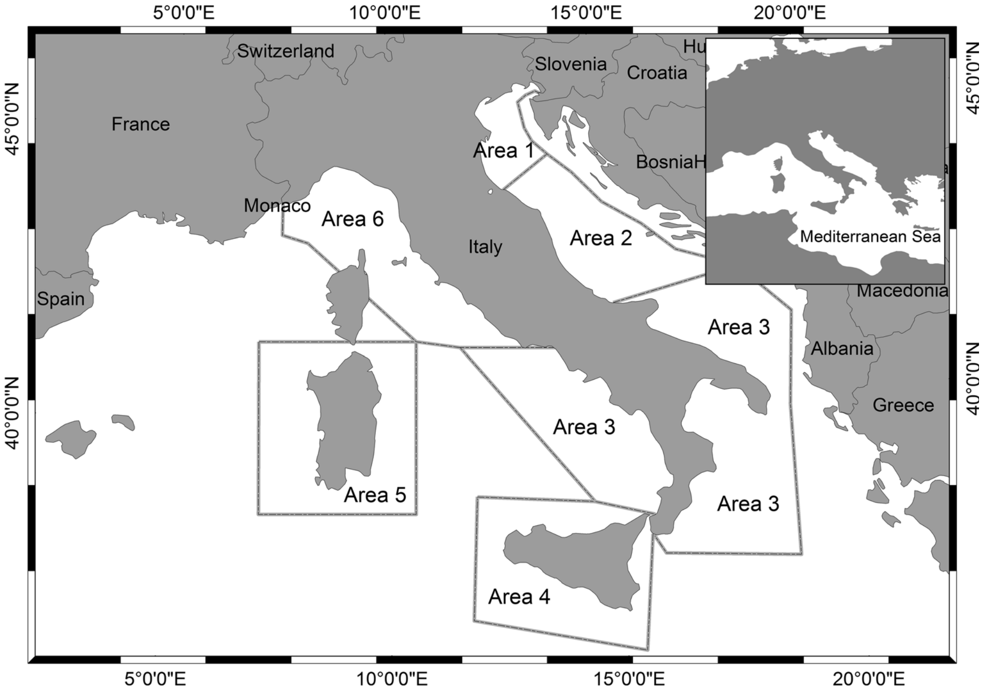

Fig. 1 The area of study. *Dashed lines* indicate different areas into which regional landings were grouped

changes in MTC over time through the analysis of covariance (ANCOVA).

Fishing effort

The engine power (kW) has been adopted as a proxy for fishing effort (Anticamara et al. 2011), since no estimates of the effective effort were available for the considered period. Data from 1972 to 2001 originated from the official statistics produced by ISTAT and IREPA. This database was integrated with data coming from the Community Fishing Fleet Register (2002–2012).

Climatic factors

Monthly data on SST were downloaded for the period 1972–2012 from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS). The spatial resolution of the dataset is 1° latitude × 1° longitude.

The NAO index (December thru March anomaly) was used as large scale climatic indicator for the period 1972–2012 (Hurrell et al. 2014). The winter NAO is based on the difference of normalized sea level pressure between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland).

Data analysis

A LMM approach (Pinhero and Bates 2000) was followed to assess the relationship among MTC, landings, fishing effort and climatic factors, fitting three models by using different response variables, namely MTC and landings.

The structure (i.e. the included predictors) of the models has been chosen evaluating different alternative combinations of formulations (Table S2). Model 1 uses MTC as response variable and year, fishing effort, SST and NAO as candidate predictors; Model 2 relates landings (response variable) to the same predictors of the first model; Model 3 is fitted to explore the role of MTC in influencing landings, and it considers landings as the response variable, the optimal structure—as defined by the model selection procedure—of Model 2 and MTC as candidate variables.

Different alternative correlations terms and random structures were evaluated following the protocol proposed by Zuur et al. (2009). After the choice of the optimal random structure, alternative formulations of the fixed part were fitted to explore different combinations of explanatory variables (see Table S2). The optimal structure of models was evaluated considering the Akaike Information Criterion, corrected for small samples (AICc; Grueber et al. 2011). In case of no strong support for one single 'best' model (ΔAICc smaller than four for the two models with the lower AICc values), inferences were carried out on an averaged model, built computing the weighted averages parameters for each independent variable, using AICc weights (W_{AICc}) (Burnham and Anderson 2002, Burnham et al. 2011) and considering the set of models whose cumulative weights (W_{AICc}) represent 95 % of the total ensemble. Calculations were carried out using the 'nlme' (model fitting; Pinhero and Bates 2000) and 'MuMIn' (model averaging; Barton 2014) packages, within the R statistical environment (v. 2.15.1; R Core Team 2012).

Results

No significant difference ($F = 2.634$, $p = 0.1144$) was found between using landings and scientific bottom trawl survey data in the rate of change in MTC in GSA 17.

The optimal structure for the LMM for MTC includes an autoregressive correlation structure (AR1) and a structure that allows a different variance for each region, in order to address to heteroschedasticity issues. The temporal correlation between years is high (phi = 0.76), and it is not possible to estimate a unique optimal structure of the fixed part, following the AICc criterion. The average model, obtained by using the three models, suggested the presence of a linear trend of MTC over time, with an increase rate of 0.12 °C per decade and an area-specific dependence of MTC from SST. This means that changes of MTC over time are composed by a fixed rate ($0.12\ ^{\circ}\text{C} \times 10\ \text{year}^{-1}$) plus a variable part that depends from the rate of change of SST in each area (Table 1). The relationship follows a latitudinal gradient, being strongest for Area 4 (Table 1) and increasingly weaker moving northward, with the Northern Adriatic area (Area 1) showing a negative relationship (i.e. MTC decreases with increasing water temperatures). Moreover, a high heterogeneity in terms of dependence of MTC from SST trend was observed among areas.

The model developed for landings has a different random structure, including a random intercept for the factor Area, in addition to the components already present in Model 1. The temporal correlation between years is stronger (phi = 0.85) than for MTC, and the uncertainty in the selection of the fixed structure is higher (ΔAICc among models is generally lower, and the average model was fitted considering 12 different models). There is a positive trend in landings, but the temporal dynamic is less strong than for MTC. The most influential variables are fishing effort, positively correlated with landings, and NAO, negatively correlated with landings. The dependence from SST is less important than for MTC, and it changes in the different areas. Specifically, this relationship is notably stronger in the southernmost area (Area 4; Table 1).

To understand the effects over time on landings of changes in MTC, a new set of models was considered: this is composed by the 12 models considered after the selection procedure for Model 2 (same fixed and random structure) and 12 additional models with the same random structure and considering the same covariates, but including also MTC among the predictors. The model selection procedure indicates that uncertainty increases, and the best combination of models is obtained considering 18 models, mixing some of the models including MTC with some models without this term among the predictors (Table S2). The role of the other variables are similar as for Model 2 (even if NAO is the most influential variable), and MTC is positively correlated with landings, even if it represents the less important variable and seems to contribute marginally on the prediction of landings (Table 1).

Discussion

Within the context of the Mediterranean basin, the Italian Seas can be considered an interesting case study to analyze possible effects of climate changes on fish communities and fisheries, due to the presence of a high environmental variability and a wide latitudinal gradient. The different

Table 1 Estimated parameters of the models

	Model for MTC			Model for landings			Model for landings (including MTC)		
	Estimate	Adjusted st. error	AICc weigths	Estimate	Adjusted st. error	AICc weigths	Estimate	Adjusted st. error	AICc weigths
Intercept	−4.477	7.459	–	57,650.88	219,402.60	–	50,063.78	221,098.48	–
kW	0.000	0.000	0.262	0.14	0.07	0.72	0.14	0.07	0.73
SST	–	–	–	561.19	344.15	0.53	552.20	340.62	0.52
YEAR	0.012	0.004	1.000	13.61	180.80	0.37	12.01	180.27	0.37
NAO	−0.002	0.006	0.194	−369.23	154.90	0.69	−375.64	153.75	0.74
Area 4:SST	0.019	0.015	1.000	10,462.14	3571.00	0.34	10,455.39	3570.29	0.35
Area 6:SST	0.015	0.014		−194.61	1391.88		−196.29	1388.17	
Area 5:SST	0.017	0.021		−274.45	1830.87		−317.88	1824.86	
Area 1:SST	−0.026	0.014		1449.23	1050.28		1446.96	1045.29	
Area 2:SST	0.002	0.013		572.58	372.25		554.93	368.33	
Area 3:SST	0.019	0.013		136.23	1015.35		121.45	1016.53	
MTC	–	–	–	–	–	–	1090.49	1043.85	0.33

The estimation refers to the averaged models areas surrounding the Italian peninsula and its isles are characterized, indeed, by different features, such as water temperature, hydrodynamic circulation, nutrients load, that all directly affect marine communities (Cataudella and Spagnolo 2011).

Although we are aware of the limitations inherent in the use of commercial data to infer changes at community level, MTC confirmed to be a robust proxy to examine changes in relation to ocean warming (Cheung et al. 2013), since the rate of change does not depend on the type of data used. Indeed, no significant difference was found between using landings and scientific bottom trawl survey data in the MTC rate of change.

Globally, the MTC in Italian waters increased at a rate of 0.12 °C per decade in the last 40 years, without considering the effect of SST. Thus, an increasing dominance of catches of warm affinity species occurred in the landings. This value resulted lower than those reported for the Western and Central Mediterranean (0.56 and 1.05 °C per decade, respectively) by Tsikliras and Stergiou (2014), but more similar to that reported for the Greek Seas (0.16 °C per decade) (Tsikliras and Stergiou 2013). These differences may derive from the different spatial scale at which MTC changes are analyzed in these works, but are also strongly influenced by the relationship with SST. Indeed, our model formulation considers also the influence of temperature whose signal should be added to the 0.12 °C rate of change. For instance, if we consider also SST effect the strongest increase of MTC was estimated (0.31 °C per decade and per °C of increase of SST) in southernmost areas (3 and 4), while in the northernmost basin (Area 1) a decrease of 0.14 °C (per decade and per °C of increase of SST) was estimated. In general, SST resulted the most influential variable in driving MTC temporal changes. This is not surprising, since temperature is recognized to be the main driving force causing shifts in the geographical distribution of species (Ben Rais Lasram et al. 2010; Portner and Peck 2010; Cheung et al. 2013; Tsikliras and Stergiou 2014).

It is worth noting that, while the signal is well-defined, our result is rather conservative, given that several thermophilous species (e.g. Lessepsian migrants) and psychrophilous species (Atlantic relicts, such as *Platichthys flesus* and *Sprattus sprattus*) were not included in the analysis, since their catches were not recorded in available statistics. This means that probably the rate of warming-induced changes is higher than that here reported, as observed also by other authors (Tsikliras and Stergiou 2014).

The relationship between MTC and SST, even if significant in each of the analyzed areas, showed a high spatial variability both in terms of strength and sign. This could be related to the local environmental features characterizing each area and the structure of underlying communities. For example Area 4 (Sicilian Seas), due to its peculiar hydrodynamic conditions and being at the boundary between the West and East Mediterranean, is recognized as one of the most influenced by/exposed to climate change (Gasparini et al. 2005). In this area, the MTC–SST relationship revealed to be the strongest positive one. On the opposite, in the Northern Adriatic Sea (Area 1) a negative MTC–SST relationship was detected. The Northern Adriatic Sea is one of the coldest Mediterranean basins, hosting an endemic community mainly composed by cold/temperate affinity species (Pranovi et al. 2013). Within this context of ‘low’ temperature, the water warming is expected to, at least during a first phase, positively affect the biological cycles of endemic species, increasing their production (Norman-López et al. 2013). Thus, the Northern Adriatic Sea may be acting as a refuge for cold-water species (Ben Rais Lasram et al. 2010). This hypothesis is supported also by the positive relation between SST and landings in the area. However, in the long-term the area may become a ‘cul-de-sac’ for such species (Ben Rais Lasram et al. 2010), since Mediterranean surface waters are expected to warm by an average of 3.1 °C by the end of the twentyfirst century (Somot et al. 2006). A warming that exceeds the thermal tolerance of psychrophilous species may negatively impact catch potential in the region, with direct implications for fishing communities.

Conversely, the temporal trend resulted to be less important for landings, being the fishing effort the most important explaining variable. In general, the SST seems to play a less important role in affecting landings trend. However, significant differences among areas have been recorded, with a higher positive impact of warming in Area 4, suggesting that the increase in water temperature favoured fishery in the last 40 years, and confirming the hypothesis of a stronger effect on southernmost areas.

On the other hand, NAO’s role in determining MTC and landings trends resulted to be marginal and highly variable depending on the area. This result confirms that, even if it was expected the NAO to influence marine communities (Conversi et al. 2010), the effects on Mediterranean meteorological/climatic conditions are weak and sometimes controversial (Lionello and Galati 2008; Vicente-Serrano and Trigo 2011).

Finally, MTC resulted to be scarcely related to landings in all areas. This could mean that, even if in presence of clear changes in fish community structure due to ocean warming, actually such modifications do not deeply modify fishing activities.

In conclusion, MTC confirmed to be a good aggregated index useful to describe the effects of climate change on marine communities and fisheries. Thus, the index should be adopted to monitor how global warming is affecting marine ecosystem services in the framework of the EU

Strategy on adaptation to climate change. It is worth noting that the spatial scale of analysis plays a crucial role in determining the outputs, both in terms of the increasing rate and sign of the interaction with SST. However, the presence of a weak relationship between MTC and landings suggests that, at present, MTC cannot be used to inform fishery management strategies. Within the context of a general trend of change driven by increasing temperature, landings are mainly affected by other drivers, first of all fishing effort. Therefore, in order to cope with the effects of climate change, fishery management strategies need to focalize primarily on fishing effort reduction, in order to reduce the pressure on the stocks while increasing their resilience to other stressors, like global warming.

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