Recreational fishers consistently inform about different meridionalization dynamics of two Mediterranean subregions

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ABSTRACT

Marine recreational fishers accumulate a vast amount of Local Ecological Knowledge (LEK) during their fishing activity that can be of paramount importance for monitoring how climate change affects the structure of biological communities. Here, we accessed the LEK of recreational anglers and recreational spearfishers to investigate the increase in the abundance of five northward expanding indigenous thermophilic fish species in two subregions of the Mediterranean Sea: the Adriatic/Ionian Seas and the Tyrrhenian/Ligurian Seas. We used an online survey administered through Twitter and Facebook between 2017 and 2018 to both Italian and Croatian recreational fishers. A total of 794 respondents completed the questionnaire (386 from the Adriatic/Ionian subregion and 408 from the Tyrrhenian/Ligurian one). Overall, the species perceived as most increasing in abundance were *Pomatomus saltatrix* (71% of replies) followed by *Sphyrna viridensis* (58%). The rest of species (*Coryphaena hippurus*, *Balistes capriscus* and *Sparisoma cretense*) ranged between 17% and 25%. We showed that recreational fishers have a stable system of beliefs about meridionalization, which is perceived homogeneously between recreational anglers and spearfishers. Moreover, our results indicate that latitude is negatively correlated with meridionalization in the Adriatic/Ionian, but not in the Tyrrhenian/Ligurian Seas, suggesting that meridionalization of the Adriatic/Ionian Seas could be a process that is temporally lagged with respect to the Tyrrhenian/Ligurian Seas. Our study

demonstrate that LEK of specific target groups such as recreational fishers can be easily accessed on large geographical scale and it can be useful to identify those fish species who are regarded as indicators of climate change.

KEYWORDS: angling; spearfishing; Adriatic; Tyrrhenian; climate change; local ecological knowledge; biological invasions

INTRODUCTION

Climate change is rapidly affecting the structure of biological communities through large-scale shifts in the geographical distribution of many species (Parmesan and Yohe 2003, Parmesan 2006). In particular a poleward expansion (or latitudinal ranges shift) of marine fishes has been indicated as the main response to increasing sea water temperature (Hiddink and Ter Hofstede 2008, Cheung et al. 2009, Pinsky et al. 2013). This poleward expansion may have profound effects on ecosystems, even triggering local extinctions in sensitive areas such as semi-enclosed seas (Cheung et al. 2009). Therefore, monitoring such phenomena is of paramount importance for adaptive management of the Mediterranean Sea, which is warming faster than any other region in the world (Bianchi 2007, Giorgi and Lionello 2008, Lejeusne et al. 2010, de Madron et al. 2011). In the Mediterranean Sea, increasing seawater temperature is rapidly changing the distribution of marine biota (Sabatés et al. 2006, Bianchi 2007, Coll et al. 2010, Lejeusne et al. 2010, Bianchi et al. 2012, Givan et al. 2018) and a northward expansion of indigenous thermophilic species (i.e., species that require temperatures high enough for the reproductive processes and development of eggs, and minimum winter temperatures above their lethal limits; Occhipinti-Ambrogi and Galil 2010) has been repeatedly documented (Francour et al. 1994, Bianchi 2007, Lejeusne et al. 2010). Notably, many species that were previously confined to the South are now expanding their geographical distribution northwards, a phenomenon also addressed to as “meridionalization” (Riera et al. 1995, Azzurro 2008, Azzurro et al. 2011, Bianchi et al. 2018). These species include thermophilic fish such as the bluefish (*Pomatomus saltatrix*), the yellowmouth barracuda (*Sphyrna viridensis*), the grey triggerfish (*Balistes capriscus*), the common dolphinfish (*Coryphaena hippurus*) and the Mediterranean parrotfish (*Sparisoma cretense*), which are increasingly observed at higher latitudes than those in their native geographical distribution (Dulčić 1999, Dulčić et al. 1999, Dulčić and Pallaoro 2001, Dulčić and Soldo 2004, 2005, Bianchi 2007, Dulčić et al. 2009, Azzurro et al. 2011, Bianchi et al. 2012, Villegas-Hernández et al. 2015, Bianchi et al. 2018, Azzurro et al. 2019). Nevertheless, there is limited knowledge about the specific local dynamics acting at the different mediterranean subregional levels.

The Western basin of the Mediterranean Sea is characterized by colder temperatures compared to the Eastern basin (Lejeusne et al. 2010, Sicre et al. 2016) and it has been reported as the most impacted area by the northward expansion of indigenous thermophilic species (Lejeusne et al. 2010). On the contrary, the Adriatic Sea is a peculiar area with a strong latitudinal gradient characterized by very low winter temperatures in the northern part and very hot summers in the southern part (Buljan 1976, Zore-Armanda et al. 1991, Civitarese et al. 2010) and local information on the dynamic of thermophilic species is scarce. The North Adriatic, represents one of the coldest sectors of the Mediterranean Sea and although it is considered to have biological features typical of boreal areas (Jardas 1996) and an ongoing process of meridionalization has been already observed (Azzurro 2008).

It is conceivable that the expansion dynamics of indigenous thermophilic fish species followed different patterns in the Western basin with respect to the Adriatic Sea. However, there is a gap of knowledge on such dynamics mainly due to the lack of high resolution data both in space and time; in this study we provide a contribution to fill this gap. Comprehensive information about the northward expansion of the species investigated in this study, hereafter referred to as target species (*P. saltatrix*, *S. viridensis*, *B. capriscaus*, *C. hippurus* and *S. cretense*) is difficult to obtain and available data is usually fragmented in space and time. Most scientific knowledge is limited to published records of the first occurrence of such species in new areas and long-term data series are usually lacking. Moreover in the study area, target species are seldom captured by professional fishers and fishery-dependent data are consequently really scarce or unavailable, motivating the development of complementary methods of research and monitoring.

Local Ecological Knowledge (LEK), defined as the cumulative body of knowledge (practice and beliefs) of individuals during their lifetimes (Berkes et al. 2000, Gilchrist et al. 2005), has been long recognized as a tool for environmental monitoring and natural resources management (Berkes et al. 2000, Sagarin and Pauchard 2010). LEK can be used for sampling the quantitative abundance of wild population with the advantage of being cheap, feasible and extremely useful to complement traditional sampling surveys (Anadón et al. 2009, Azzurro et al. 2011, Coll et al. 2014, Azzurro et al. 2018), also on the large geographical scale (Azzurro et al. 2019).

In this study we accessed the LEK of recreational fishers to explore how they perceived the northward expansion of Mediterranean thermophilic fishes and whether recreational fishers embedded them into coherent belief networks. Marine recreational angling and spearfishing have been estimated to be practiced by 2.8 million of people in the European Mediterranean coasts for a total of 20,855 fishing days every year (Hyder et al. 2018). Therefore, recreational fishers represent a huge and widespread network of observers with a great potential source of information to investigate local changes on fish communities (e.g., Boada et al. 2017). However LEK can significantly vary according to the different forms of recreational fishing (e.g., angling and spearfishing) due to differences in individual experiences, exploited habitats and catchability of the various species. For example, recreational anglers need to capture the fish to be aware of its presence, while spearfishers can also observe the species underwater.

Here we used an online survey to access the LEK of recreational fishers in the Adriatic/Ionian and Tyrrhenian/Ligurian Seas. We assessed whether five target fish species (*P. saltatrix*, *S. viridensis*, *B. capriscus*, *C. hippurus* and *S. cretense*): i) were perceived as indicators of an underlying common latent process of meridionalization, ii) whether this perception was similar between recreational spearfishers and anglers, iii) whether respondents showed latitudinal patterns in their perception of meridionalization, between the Tyrrhenian/Ligurian and the Ionian/Adriatic Seas.

MATERIALS AND METHODS

Survey methodology and data analysis

Between 2017 and 2018 we administered an online survey on some popular Facebook groups about recreational angling and spearfishing in Italy and Croatia, as well as on Twitter. We shared an online link to access the questionnaire on Google Forms. The questionnaire aimed to measure recreational fishers' perception about recent changes in fish species distribution in two Mediterranean subregions: the Adriatic/Ionian and the Tyrrhenian/Ligurian Seas (hereafter refers to as "Adriatic" and "Tyrrhenian", respectively; Fig. 1). Data collection was confidential, as we did not record any sensitive personal information about respondents, who were informed about the purposes of the study.

Figure 1. The geographical area of the study. Circles represent the locations where recreational fishers were used to go fishing most of the times. The size of the circles represents the number of respondents for each location subdivided according to the mediterranean subregions (Adriatic/Ionian Seas = “Adriatic”; Tyrrhenian/Ligurian Seas = “Tyrrhennian”).

The first section of the questionnaire focused on demographic information, and it identified the geographical location where respondents were used to go fishing most of the times. Then, respondents were invited to indicate which fish they deemed to have increased over the last few years among those reported on a list of species. To clearly identify each species, each option was associated to a species picture, altogether with its common and scientific name. Options included five easy to recognize species, which are known to have expanded their distribution northward: (1) the bluefish, *P. saltatrix*; (2) the yellowmouth barracuda, *S. viridensis*; (3) the grey triggerfish, *B. capriscus*; (4) the common dolphinfish, *C. hippurus*; (5) the mediterranean parrotfish, *S. cretense*.

Statistical approach

Perceptions about the increase in the five target species over the last 10 years were coded as dummy variables, indicating whether respondents believed a certain species to have increased or not. To test for the hypothesis that respondents regarded species-specific increases as indicators of broader changes in fish assemblages, due to meridionalization, we fit a Confirmatory Factor Analysis (CFA). CFA treated the

increase in the five target species as five indicator variables reflecting a common latent variable (meridionalization, Fig. 2). We also tested whether meridionalization was perceived homogeneously across spearfishers, anglers and respondents practicing both, by adding fishing technique as a grouping variable in a multi-group CFA. We used chi-squared testing and alternative fit indexes to see whether our data supported our multi-group CFA.

We also tested whether the perceived increases in the five fish species were independent, or whether respondents had interdependent perceptions of species-specific increases. In case of independence, respondents would have been able to evaluate the numerical increase of each species independently, regardless of their evaluation of the other species. On the other hand, in case two or more error variances of the CFA were correlated, this would indicate that respondents anchored their evaluations together, for example due to priming. To test for this latter hypothesis we fit a CFA without any correlation between the indicator variables, then we explored the covariance matrix of its residuals and we compared this first model with another one accounting for correlation between two or more indicators. Then, we re-inspected the covariance matrix until we found values scarce correlation (less than 0.10) between the error terms (Beaujean 2014). To achieve model identification we standardized indicator and latent variables, estimating factor loadings and error variances (Fig. 2).

Once the fitness indexes indicated that the measurement model in the CFA was supported by the data, we estimated standardized latent variable scores and we compared their distribution between anglers, spearfishers and respondents practicing both. This comparison enabled us to estimate whether different forms of recreational fishing indicated a different perception of meridionalization. Moreover, we also explored how factor loadings, measuring the correlation between species-specific increases and the latent variable, differed between recreational fishers groups.

Finally, we tested whether perceived meridionalization decreased with latitude in the Adriatic and Tyrrhenian sectors. To test for this hypothesis, we fit a Bayesian Generalized Linear Model with a skewed-Gaussian distribution of the error term, modelling the effect of the latitude and its interaction with the sectors over perceived meridionalization. The model was fit with Stan (Carpenter et al. 2017) via RStan

Figure 2. A schematic view of the causal structure of the Confirmatory Factor Analysis used to assess the common latent variable: meridionalization. Latent variables are represented by circles (Meridionalization), indicator variables by squared boxes (one for each species). Relationships between latent and indicator variables are represented by an arrow, indicating the causal dependence between the two variables, and by a coefficient (from "a" to "e"). The model also contains error variances (the "epsilon" variables in small circles), representing the error term of each indicator variable. Latent variables are standardized.

(<http://mc-stan.org>) by selecting 4 MCMC with 5000 iterations each and a burn-in of 1000 iterations with diffuse uninformative Gaussian priors. We explored posterior distributions and MCMC to check for model convergence. We run all the analyses in R (<https://www.r-project.org/>; version 3.5.0) with the additional package “lavaan” for CFA (Rosseel 2012). A complete explanation of data analysis, with a reproducible software code, and model interpretation is available in the Supplementary Information.

RESULTS

We collected a total of 794 surveys (408 from the Tyrrhenian and 386 from the Adriatic; Fig. 1). Most respondents were spearfishers (Tyrrhenian = 60.5 %; Adriatic = 40.3%), followed by respondents practicing both spearfishing and angling (Tyrrhenian = 23.7%; Adriatic = 38.5%) and by recreational anglers (Tyrrhenian = 15.8%, Adriatic = 21.2%). Respondents were nearly all men (Tyrrhenian = 96.86%, Adriatic = 97.55%) and they showed similar distributions of age and experience between the two basins (more

details in supplementary material). The bluefish (*P. saltatrix*) was the species which was deemed to have increased the most over the last 10 years (Tyrrhenian = 61.9%, Adriatic = 83.6%), followed by the yellowmouth barracuda (*S. viridensis*; Tyrrhenian = 80.2%, Adriatic = 33.1%), the parrotfish (*S. cretense*; Tyrrhenian = 24.9%, Adriatic = 18.1%), the grey triggerfish (*B. capriscus*; Tyrrhenian = 16.4%, Adriatic = 20.4%) and the common dolphinfish (*C. hippurus*; Tyrrhenian = 12.7%, Adriatic = 22.9%).

Fitness indexes provided support for our measurement model, a CFA where species-specific increases reflected an overall perception of meridionalization across different recreational fishers groups. Model selection indicated that a model accounting for correlation between the perceived increase in the bluefish (*P. saltatrix*) and in the dolphinfish (*C. hippurus*) outperformed a model with independent error terms and had no leftover correlation between indicator variables (Table 1; more details in supplementary material).

Table 1. Model fitness indexes between the two models

Parameters	Model without correlation	Model with correlation
chi-squared tests (p-value)	0.05	0.27
Comparative Fit Index (CFI)	0.92	0.98
Tucker-Lewis Index (TLI)	0.84	0.95
Root Mean Squared Error of Approximation (RMSEA)	0.05	0.03
RMSEA: lower limit of the confidence interval	0.00	0.00
RMSEA: upper limit of the confidence interval	0.08	0.07
Standardized Root Mean Residuals (SRMR)	0.08	0.05

Latent variable scores were similar between the different forms of recreational fishing (Fig. 3); anglers, spearfishers and respondents practicing both had similar perspectives about ongoing meridionalization, with minor differences in the factor loadings of the various species (Table 2). The grey triggerfish (*B. capriscus*) seemed to be the species with the highest correlation between its perceived increase and the overall perception of meridionalization, while this correlation was extremely low for the bluefish (*P. saltatrix*; Fig. 4).

Figure 3. The latent variable scores of the common latent process of meridionalization according to the different forms of recreational fishing: angling, spearfishing and respondents practicing both.

Figure 4. The factor loadings of the various species related to the common latent process of meridionalization according to the different forms of recreational fishing: angling, spearfishing and respondents practicing both.

Latitude showed a moderate negative correlation with the perceived meridionalization in the Adriatic, but not in the Tyrrhenian. Respondents from the northernmost sectors of the Adriatic basins believed the five species to have increased slightly less than respondents from the southernmost areas (Fig. 5).

Table 2. Factor loadings for all the indicator variables across the three groups of respondents

Group: anglers				
	Estimate	SE	z-value	p-value
<i>Pomatomus saltatrix</i>	0.012	0.193	0.064	0.949
<i>Sphyraena viridensis</i>	0.326	0.148	2.200	0.028
<i>Coryphaena hippurus</i>	0.390	0.154	2.543	0.011
<i>Sparisoma cretense</i>	0.899	0.199	4.521	0.000
<i>Balistes capriscus</i>	0.727	0.165	4.417	0.000
Group: spearfishers				
	Estimate	SE	z-value	p-value
<i>Pomatomus saltatrix</i>	0.247	0.099	2.488	0.013
<i>Sphyraena viridensis</i>	0.319	0.093	3.434	0.001
<i>Coryphaena hippurus</i>	0.420	0.160	2.627	0.009
<i>Sparisoma cretense</i>	0.273	0.107	2.552	0.011
<i>Balistes capriscus</i>	0.990	0.277	3.579	0.000
Group: both				
	Estimate	SE	z-value	p-value
<i>Pomatomus saltatrix</i>	0.348	0.128	2.709	0.007
<i>Sphyraena viridensis</i>	0.373	0.138	2.707	0.007
<i>Coryphaena hippurus</i>	0.065	0.149	0.435	0.664
<i>Sparisoma cretense</i>	0.548	0.173	3.176	0.001
<i>Balistes capriscus</i>	0.626	0.190	3.301	0.001

DISCUSSION

Our study shows that the LEK of specific target groups such as recreational fishers can be accessed over large geographical scales, providing new information about the meridionalization of the Mediterranean Sea. We also showed that both recreational spearfishers and anglers have a coherent system of beliefs about meridionalization. Moreover, our results indicate that latitude is slightly negatively correlated with the

perceived meridionalization in the Adriatic, but not in the Tyrrhenian Sea. This suggests that meridionalization of the Adriatic Sea could be a process that is temporally lagged compared to the Tyrrhenian Sea. As we will show below, such interpretation is supported by published records indicating that the species studied here arrived or increase in abundance more recently in the Adriatic than in the Tyrrhenian Sea.

Figure 5. The correlation between latitude and perceived meridionalization in the Adriatic/Ionian (Adriatic) and Tyrrhenian/Ligurian (Tyrrhenian) areas. Shaded areas represent the confidence interval.

Recreational anglers and recreational spearfishers provided overall consistent information on the process of meridionalization. This might indicate that recreational fishers' beliefs about the temporal trends of fish species are embedded in complex networks due to their personal experience acquired during fishing trips, or to their exposure to common sources of information (e.g. fishing forums). An additional explanation could be related to the overall high trophic levels of the target species: *P. saltatrix*, 4.5; *S. viridensis*, 4.3; *C. hippurus*, 4.4; *B. caprisca*, 4.1; *S. cretense* 2.6 (Froese and Pauly 2010). Species of high trophic levels are intrinsically more vulnerable to passive fishing gears as the ones used by recreational anglers (e.g., Font and Lloret 2011) and are overall preferred preys of recreational spearfishers (e.g., Lloret et al. 2008). Consequently, the chances of these five species to be captured by recreational

anglers and recreational spearfishers are similar and this could explain why we have found consistent results in the LEK data provided by these two groups.

Our results also suggest that meridionalization of the Adriatic Sea could be a process that is temporally lagged with respect to the Tyrrhenian Sea. This idea is supported by the available scientific knowledge about three fish species that we considered in this study. An unusual catch of *P. saltatrix* at the extreme North of the Adriatic was reported in 2005 (Dulčić et al. 2005), while the species was already regularly fished, and reported as northward expanding, off the coast of Catalan coast in 1993 (Sabatés and Martin 1993). The first record of *S. viridensis* in the Adriatic was reported in 2004 (Dulčić and Soldo 2004), by contrast there were already records of *S. viridensis* in the Ligurian Sea in 1996 and professional fishers perceived an ongoing increase of abundance of the species (Relini and Orsi Relini 1997). Finally, in the last two decades, *C. hippurus* sporadically occurred in the northern Adriatic (Dulčić 1999, Dragičević et al. 2009, Lipej et al. 2009), however captures of *C. hippurus* by recreational fishers were reported in the Ligurian Sea since 1989 (Relini et al. 1994) and it was a common catch in professional fisheries off the Majorca coast since 1961 (Cabo 1961, Massutí et al. 1998). The scientific knowledge on the other two species does not allow a comparison between the Adriatic and Tyrrhenian. However, the abundance of *B. caprisus* in the Adriatic Sea has been reported as increasing (Dulčić et al. 1999), and it is reported to be found in the north Adriatic only during warm years (Dulčić and Soldo 2005) suggesting temperature-mediated migrations as already described for this species (Aggrey-Fynn 2007). Finally, the available scientific information about *S. cretense* indicated that the abundance fluctuated in the recent decades with a peak of increase for both southern Tyrrhenian and central Adriatic in 1999 (Azzurro et al. 2011).

We showed that the LEK of recreational fishers can also be a complementary tool for assessment and management of fishery resources and that LEK is not necessarily a black-box, but a testable source of information whose structure can be elicited and tested (e.g., Coll et al. 2014, Lopes et al. 2018). To the best of our knowledge, our study was the first where LEK was explicitly modeled in terms of causal relationships between overall perception of change and species-specific beliefs. Such approach enabled us to test for the existence of conjoint beliefs about species-specific

change, showing that recreational fishers anchor their beliefs about temporal changes across various fish species. In the near future, it would be absolutely interesting to explore where these conjoint beliefs stem from and how they are shaped by exposure on multiple sources of information (e.g. angling forums, fishing magazines, local fishing associations). We also believe that future studies should also replicate our approach by moving out from convenience samples, like our online sample, as recreational fishers is a heterogeneous group with diverse and complex behaviors (Johnston et al. 2010, Arlinghaus et al. 2019) that could create biases when exclusively sampled online.

From a general viewpoint, our study contributes to existing literature about the ongoing shifts in marine organisms towards high latitude in an era of climate change (Doney et al. 2012, Pauchard et al. 2016). Our approach provides easy to use indicators for tracking changes in the natural environment (Philippart et al. 2011, Simberloff et al. 2013). Specifically, researchers and managers can leverage on recreational fishers as local experts to obtain fine-grain information about large scale changes in the distribution of Mediterranean fishes. Collected information was consistent between two different recreational fishers groups, like anglers and spearfishers. Finally, our results support the idea of significant differences between the spatio-temporal dynamics of thermophilic fishes in the Adriatic/Ionian and in the Tyrrhenian/Ligurian Seas.

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