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SINAN MAVRUK

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Trends of white grouper landings in the Northeastern Mediterranean: reliability and potential use for monitoring

Sinan MAVRUK

Corresponding author: smavruk@cu.edu.tr

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Abstract

As a consequence of national fishery statistics showing a sharp decline in the landings of white groupers (WG) – *Epinephelus aeneus* (Geoffroy Saint-Hilaire, 1817) – after 2010, the decision to ban any further fishing of the species was taken by the Turkish management authority in 2016. Stakeholders have since strongly objected to this decision claiming that the trends of landing statistics are unreliable. Here, this assertion is questioned using multiple sources of data comprising the catch per unit effort (CPUE) from the fishery independent bottom trawl survey (2004-2018), officially reported landing statistics (2002-2017) and the microdata set of landings (2012-2016) gathered by the Turkish Statistical Institute (TUIK). Based on the results of this study, there were clear correlations among the datasets. Landing records and the CPUE time series revealed unimodal non-linear patterns over time ($p<0.001$). Landings increased until 2010 and decreased thereafter, whereas CPUE values started to decrease after 2009. In the segmented time series, there were no statistically significant differences between the direction and magnitude of slopes calculated from landings and fishery independent data. Cross-correlations between landings and CPUE were statistically significant with one and two-year time lags. This was because the earlier age groups were sampled with coastal bottom trawl operations. Combined with further efforts, these findings may help to develop a monitoring program for the status of white grouper populations in the northeastern Mediterranean and contribute to a better management strategy.

Keywords: *Epinephelus aeneus;* False cod; Levant Basin; fishery statistics; fishery management.

Introduction

The white grouper (WG), *Epinephelus aeneus* (Geoffroy Saint-Hilaire, 1817), is one of the most commercially valuable fish for coastal fisheries all along its distribution range from the eastern Atlantic to the southern and eastern Mediterranean (Heemstra & Randall, 1993). In addition, the WG is a predator species with considerable ecological importance to the structure and functioning of the coastal ecosystems (Sadovy de Mitcheson *et al.*, 2013). According to records of the International Union for Conservation of Nature (IUCN), its conservation status is "Near Threatened" (Pollard *et al.*, 2018) meaning that it may be allocated to one of the threatened categories in the near future (IUCN, 2012).

White groupers inhabit the Mediterranean and Aegean coasts of Turkey (Bilecenoglu *et al.*, 2014); however, the major part of their catch is recorded as coming from the Mediterranean (TUIK, 2019). By virtue of having extensive soft bottoms (Avsar, 1999), Iskenderun Bay is the main fishery ground (Mavruk *et al.*, 2018) providing an appropriate habitat for WG populations (Heemstra & Randall, 1993).

In spite of its huge economic importance for the local community (Ünal *et al.*, 2009), a scientific baseline has not yet been established to regulate WG fishery. Our current knowledge about its inter-annual variability is only based on the fishery landing statistics that have been collected since 2002. After 2010, these records revealed a sharp decline in the amounts of WG catches around the Mediterranean coasts of Turkey (TUIK, 2019). Based on this information, WG fishing was completely banned in 2016 (Official Gazette, 2016), causing strong protests from the fishers' community (Mavruk *et al.*, 2018). The main assertion of this opposition was that "the fishery landing records do not reliably represent the total catch or the population status of WGs". This assertion seems plausible scientifically, as recent studies have clearly revealed that a significant amount of the total landings are not recorded in the landing statistics (Pauly *et al.*, 2014; Pauly & Zeller, 2016). Thus, these records underestimate actual catch amounts around the world as well as in Turkey. According to Ulman *et al.* (2013), 37% of total landings are not recorded in the fishery statistics of Turkey, and unreported amounts are particularly apparent in artisanal fishery, which puts the highest pressure on the grouper populations (Mavruk *et al.*, 2018).

Nonetheless, fishery management authorities are aware of this bias and assume that it is constant throughout time (Sullivan, 2003), thereby suggesting that fishery statistics provide reliable indications of both regional and local trends in populations (Garibaldi, 2012). Based on this assumption, catch-based stock assessment (CBSA) methods are developed (Froese & Kesner-Reyes, 2002) and employed (Pauly, 2007; Zeller *et al.*, 2009; Tsikliras *et al.*, 2013).

CBSA methods obviously require reliable estimates of catch trends rather than the actual catch amounts. The aforementioned controversy between the fishery community and the management authority; therefore, turns into the simple and testable question: "do official landing records reliably represent the trend of abundance in WG populations?" In order to find an answer to this question, we compared the trends of WGs from two fishery dependent and one fishery independent sources of data. The fishery dependent datasets included: (1) the officially reported national fishery landing statistics and (2) its microdata set gathered by the Turkish Statistical Institute (TUIK). The fishery independent data was (3) the catch per unit effort (CPUE) values of WGs that were provided from a scientific bottom trawl survey seasonally performed between 2004 and 2018 in the northeastern Mediterranean. Additionally, the use of coastal bottom trawl operations for the monitoring of WG populations was investigated.

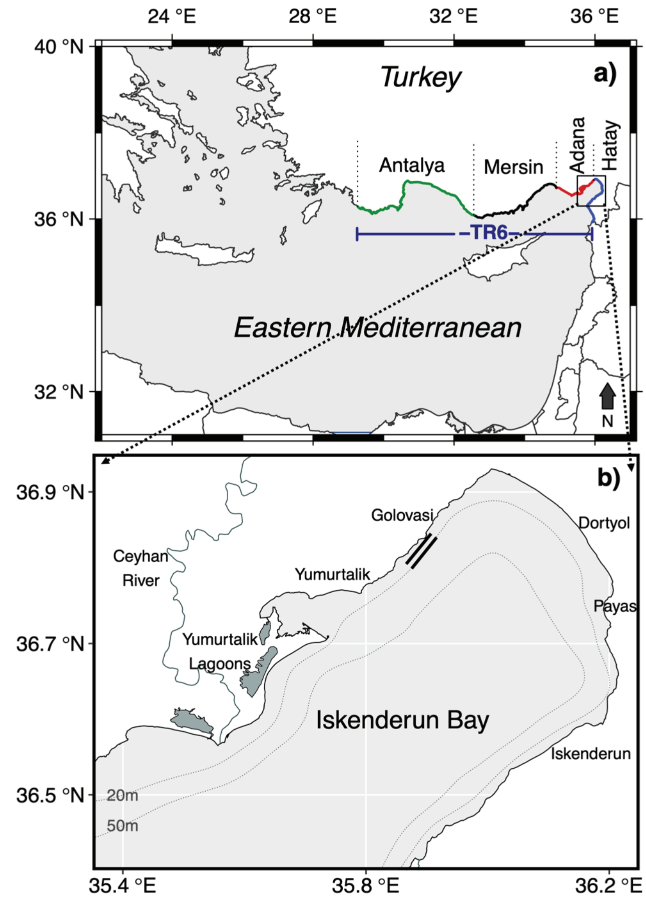

Fig. 1: (a) Map of the eastern Mediterranean and the study area. On the map, TR6 shows the coastline where the landings are recorded. The microdata was aggregated by cities. The coastline of each of the cities is marked with different colors and their borders are separated with dashed lines (b) The map of Iskenderun Bay where the fishery independent bottom trawl survey was performed. Straight lines on the map show bottom trawl transects (35.87°E, 36.82°N to 35.91°E, 36.86°N and 35.89°E, 36.80°N).

Material and Methods

Description of Fishery Landing Data

Fishery landing data is gathered by the Turkish Statistical Institute (TUIK) by way of conducting face-to-face structured interviews with a representative sample of small-scale fishers (boat size < 10m) and all of the large-scale fishers (boat size > 10m) in each fishery port all over Turkey. The raw data is called microdata, which is not accessible. TUIK makes the data publicly available via the Biruni database (TUIK, 2019) after it is aggregated by years and by the main fishery areas (Mediterranean, Aegean Sea, the Marmara Sea and Black Sea) (TUIK, 2019). These records are also shared with the United Nations Food and Agriculture Organization (FAO) with some taxonomic deformities, which are explained in detail by Avsar *et al.* (2016). TUIK recorded white grouper (TUIK code: 741-Lahoz) landings after 2002 as a separate species (Avsar *et al.*, 2016). Its total annual landing data (tonnes/year) spanning from 2002 to 2016 from the Mediterranean coasts of Turkey (TUIK code: TR6, Fig. 1) were accessed using the publicly available Biruni database (TUIK, 2019).

The microdata set of national fishery statistics recorded from 2012 to 2016 were accessed at the Data Research Center in the Regional Office of TUIK in Adana, with a bilateral protocol declaring that "all responsibility arising from the analyzing and interpreting of the data belongs to the author of the study". In accordance with data confidentiality requirements, all personal details of informants were deleted by TUIK before being accessed. In the microdata set, species level information on the total landings (kg) of fishing vessels were recorded seasonally until 2013, and monthly thereafter. The total WG landing from large-scale fishery was calculated by cities using a total of 1467 records (TUIK, 2018).

Bottom trawl survey

A fishery independent survey based on bottom trawl operations was carried out seasonally (April, July, October and December) between summer 2004 and autumn 2018 at two transects located at 10 and 20 m depth contours in Iskenderun Bay in the northeastern Mediterranean (Fig. 1). Within the context of 56 fieldworks, a total of 112 operations were performed in the morning over a one-hour period at an average speed of 2.5 knots. The vessel length was 19.2 m and was powered by a 422 hp engine. A Mediterranean type bottom trawl net with a 10 m head rope and a mesh size of 44 mm was used in these operations

(Brandt, 1969; Mavruk *et al.*, 2017). The fraction of head rope was assumed to be 0.5 according to Pauly (1980). During the operations, groupers caught alive were immediately released after measuring and weighing. In order to obtain comparable results with previous studies, catch per unit area (CPUA) values were also calculated using the speed and towing duration (Sparre & Venema, 1998).

Statistical analyses

Because the landing (tonnes/year) and CPUE (gr/hour) time series were in different units, both were standardized in order for comparable measures to be obtained (Sokal & Rohlf, 2012). The standard Z scores were calculated using the following formula:

$$Z = \frac{x - \bar{x}}{sd} \ldots \quad (1)$$

Here, x denotes the original value, $\bar{x}$ and *sd* denote the overall average and standard deviation of CPUE or landing data (Table 1).

General linear mixed models (lmms) and additive mixed models (gams) were fitted to analyze linear and non-linear trends in the Z scores (Wood, 2006). Before the models were fitted, data exploration procedures were applied by using the protocol suggested by Zuur *et al.* (2010) to avoid common statistical problems. Then, the lmms were fitted using the restricted maximum likelihood estimation with Gaussian distribution, identity link function and autoregressive error structures. Based on likelihood ratio tests, autocorrelated error structures did not improve the models. Thus, the final model was refitted using the ordinary least square approximation. The effect of seasons and depth contours were investigated for CPUE data. Both variables were not found to be significant and dropped from the models based on Akaike Information Criteria (AIC). Model validation was then performed by checking the residuals against normality, homoscedasticity, autocorrelation and independence from the dropped variables (Zuur *et al.*, 2009). The final equation for the lmm was as follows:

$$Z_i = \alpha_1 + \beta_1 Y_i + \alpha_2 D + \beta_2 D Y_i + \epsilon_i \ldots \quad (2)$$

Here, Y_i refers to the i^{th} year. D is a dummy variable which is zero for CPUE and one for landings. The terms α_1 and β_1 are the intercept and slope for the CPUE, respectively. The terms α_2 and β_2 are the differences for intercept and slope for landings, respectively. The term ε indicates normally distributed residuals with zero mean and σ^2 variance. The final equation for the gam was as follows:

$$Z_i = \alpha + cr(Y_i) + \varepsilon_i \ldots \quad (3)$$

Where α is the intercept and $cr(Y_i)$ is the cubic regression spline function. The linear and additive models were fitted using R libraries *nlme* and *mgcv* (Wood, 2001; Pinheiro *et al.*, 2015).

The non-linear trend of standardized catch per unit effort values (Z_{CPUE}) was then predicted from equation 3. The parallelism between fluctuations of non-linear trends of standardized landing (Z_L) and CPUE (Z_{CPUE}) time series were evaluated by using cross-correlation coefficients (Zuur *et al.*, 2007) with time lags of up to five years. Based on cross-correlation analyses, the one-year lag values of the standard scores for CPUE ($Z_{CPUE\ i-1}$) were used in segmented linear models (slm). To determine the segments, a hierarchical clustering algorithm-based change point detection analysis was employed using R library *ecp* (James & Matteson, 2014). This analysis revealed that the directions of the common trend of both time series changed in 2010. Then, by way of adding a dummy variable (S) to the models' design matrix, both time series were divided into two tangential periods, which were from 2004 to 2010 (S = 0) and from 2010 to 2016 (S = 1). Then the segmented linear model (Taljaard *et al.*, 2014)was fitted using the same modeling and validation procedures with equations 2 and 3 (Zuur *et al.*, 2009). The final equation for the segmented linear model was as follows:

$$Z_j = \alpha_1 + \alpha_2 S + \alpha_3 D + \alpha_4 SD + \beta_1 Y_i + \beta_2 S Y_i + \beta_3 D Y_i + \beta_4 SD Y_i + \epsilon_i .. \quad (4)$$

Here, $j = i$ for $D = 1$ and $j = i-1$ for D = 0, α_1 and β_1 are the intercept and slope of the regression line for CPUE values in the first segment (2004 to 2010), $\alpha_{2,3,4}$ and $\beta_{2,3,4}$ are regression parameters for the differences of intercept and slope for the second segment (2010 to 2016) and landing data, respectively.

Table 1. Overall mean $\bar{x}$, standard deviation (sd), number of observations (n), 0.95 confidence intervals (0.95 ci), minimum and maximum values of white grouper (*Epinephelus aeneus*) landings, catch per unit effort (CPUE) and area (CPUA) in weight (W) and in numbers of individuals (N).

	Landings (t)	**CPUE-W (kg/h)**	**CPUE-N (ind/h)**	**CPUA-W (kg/km²)**	**CPUA-N (ind/km²)**
$\bar{x}$	262.39	2.66	8.00	93.53	281.03
sd	127.41	4.51	11.42	158.50	401.27
n	15	112	112	112	112
0.95 ci	70.56	0.84	2.12	29.35	74.32
min	119.50	0.00	0.00	0.00	0.00
max	583.00	23.57	55.00	827.98	1932.06

Results

Between 2002 and 2016, officially reported landings ranged from 119.5 (2015) to 583 (2010) tonnes/year with an overall average of 262±70.56 (±0.95 confidence intervals-ci) tonnes/year (Fig. 2 a). Based on the microdata set, 94±4% (± standard deviation) of the catch was reported from the cities around the Iskenderun and Mersin Bay. Longline fishing was the primary source of fishery pressure. The inter-annual changes of spatially fractioned data were consistent among cities (Fig. 3).

In the bottom trawl survey conducted between 2004 and 2018, WGs were caught in 80 out of 112 tows (71%). Seasonal (χ^2= 3.70, df = 3, p = 0.30) and depth-related (χ^2 = 0, df = 1, p = 1) variations in frequency of occurrence were not significant. A total of 896 WG individuals were sampled during the survey. Overall average CPUE values were found to be 8.00±2.12 (±0.95 ci) individuals per hour and 2.66±0.84 kg per hour, and CPUA values were found to be 281.03±74.32 individuals per km^2 and 93.53±29.35 kg per km^2 (Table 1). In 2009 and 2010, CPUE values reached 6.20±2.52 kg/h (Fig 2 b). In the bottom trawl survey, the overall mean and median of the total length of individuals caught were 27.84±2.85 (±0.95 ci) cm and 24.58 cm (23.7 to 30.6; 95% confidence intervals based on the Wilcoxon test), respectively.

Seasonal- and depth-related variations of CPUE were not significant, and both variables were dropped from the linear and additive models. Based on the gam results,

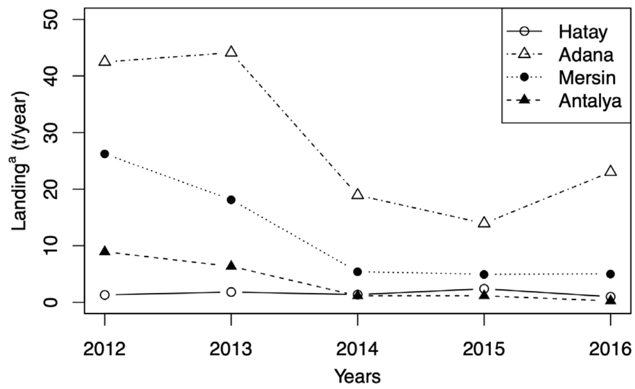

Fig. 3: Inter-annual changes of white grouper landings reported from Hatay, Adana, Mersin and Antalya.

Table 2. Details of generalized additive models (gams) for standardized catch per unit effort (Z_{CPUE}) and landing data (Z_L).

		Z_{CPUE}	Z_L
α	estimate	0.00^{ns}	0.00^{ns}
	std. error	0.08	0.07
cr(Year)	edf	7.00***	8.52***
	f-value	4.904	18.06
	n	112	15
	adj. r^2	0.20	0.92

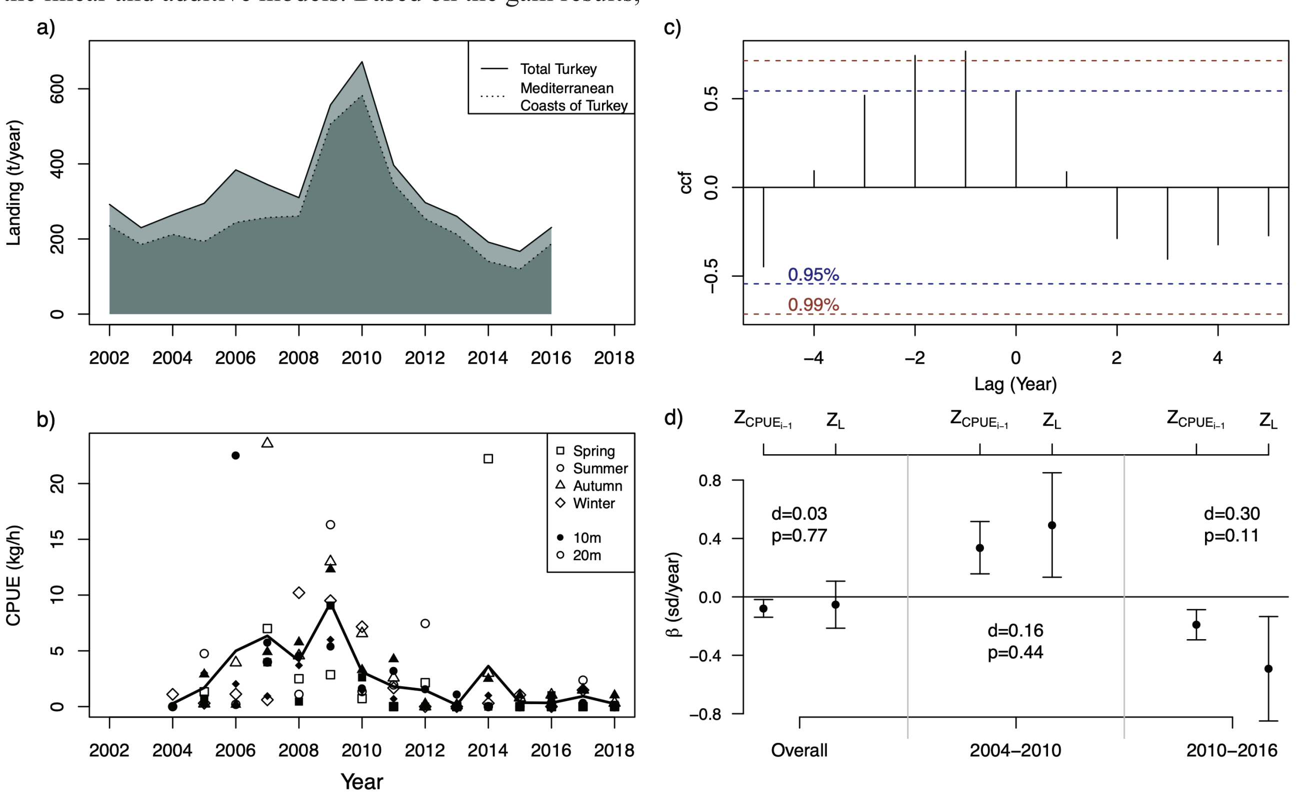

Fig. 2: Inter-annual changes of white groupers (*Epinephelus aeneus*) and consistency between multiple data sources. a) trends of landing statistics gathered along the Mediterranean coasts of Turkey (TR6). b) catch per unit effort (CPUE) values from bottom trawl survey (line shows annual average). c) cross correlations (ccf) between standard CPUE (Z_{CPUE}) and landings (Z_L) (Horizontal lines show thresholds of 0.95 and 0.99 significance levels). d) slopes of segmented regression lines (vertical bars show 0.95 confidence intervals of slope. sd: standard deviation, d: difference between two slopes and p shows significance level).

non-linear trends of both CPUE and landings were significant (Table 2; p<0.001). Moreover, non-linear trends of Z_{CPUE} and Z_L showed significant correlation with each other for one- and two-year lags (Fig. 2 c). The highest cross-correlation between two-time series was observed with a one-year lag (r = 0.77, p<0.01) indicating that the landings were strongly correlated with the CPUE of the previous year.

Ordinary linear regressions fitted to the unsegmented time series revealed that the monotonic decrement was statistically significant for the CPUE (p<0.05; −0.36 ± 28 kg/hour per year; ± 0.95 ci), whereas no significant change was detected in landings (Table 3). Based on segmented linear models (slms), CPUE increased 1.52 ± 0.81 kg/hour per year from 2004 to 2010 (p<0.001). It then decreased by 0.86 ± 0.47 kg/hour per year (p<0.001). Total landings of WGs also revealed the same pattern. Annual landings increased by 62.71 ± 45.57 tonnes per year from 2004 to 2010 (p<0.01) and decreased at the same rate afterwards (p<0.01). Slopes of regression lines of CPUE and landing time series were not significantly different from each other in the segmented linear models (Fig. 2 d).

Table 3. Details of linear regressions for overall and segmented time series of standard scores for catch per unit effort ($Z_{CPUE\ i-1}$) and landing data (Z_{L_1}).

Parameters	Overall	Segmented
α_1	0.739±0.487**	-1.125±0.902*
α_2	-0.127±1.358ns	3.096±1.430***
α_3	-	-0.374±1.836***
α_4	-	3.331±4.231ns
β_1	-0.079±0.061*	0.337±0.179***
β_2	0.025±0.172ns	-0.528±0.207 ns
β_3	-	0.155±0.400 ns
β_4	-	-0.457±0.546 ns
Adj. R^2	0.03	0.267
AIC	368.67	339.25
RSE	1.097 df = 116	0.955 df = 112

Significance codes: ns: not significant, * p<0.05, ** p<0.01, *** p<0.001. ± values show 0.95 confidence intervals of parameters. AIC: Akaike information criteria, RSE: residual standard error, df: degrees of freedom of the model. $\alpha_{1,2,3,4}$ and $\beta_{1,2,3,4}$ denotes the regression coefficients of Equation 2 for overall model and Equation 4 for segmented model.

Discussion

Reliable knowledge on the temporal changes in fish populations is important in order to advance successful conservation and management strategies. However, fishery independent estimations of trends are only available in a few areas and stocks in the eastern Mediterranean (Gucu *et al.*, 2010; Gucu & Bingel, 2011; Mavruk *et al.*, 2017). Landing statistics are therefore the only source of information on decision making – as throughout the world (Pauly *et al.*, 2013). On the other hand, it is well documented that landing statistics underestimate the actual landings particularly in grouper fishery because of the excessive illegal, unreported or under-reported catches (Sadovy de Mitcheson *et al.*, 2013; Ulman *et al.*, 2013; Pauly *et al.*, 2014). Nevertheless, this data can be utilized in stock assessment procedures, if the mentioned bias is stable throughout the years. Based on the results of this study, fluctuations of fishery landing records were in accordance with the fishery independent data. These two datasets were collected using different approaches and provided different kinds of information on the fish populations (Pennino *et al.*, 2016). Fishery independent data used in this study was collected for the purpose of monitoring the abundance of the coastal fish populations (Mavruk *et al.*, 2017), whereas the fishery dependent data (landing records) was collected to document the total catch amounts of commercial fish species (TUIK, 2019). Therefore, the parallelism between the two datasets is considered as a strong indication that the trend of landings reliably represents the trend of the white grouper population in the eastern Mediterranean coasts of Turkey. In accordance with this, there are other instances showing that the trends calculated from grouper landing statistics are validated by fishery independent data sources in the west African coasts (Thiao *et al.*, 2012; Ndiaye *et al.*, 2013).

This inference can be criticized in some respects. First of all, the catch is not just dependent on the status of the population but is also influenced by fishery related factors such as changes in effort and fishing behavior (Carruthers *et al.*, 2012; Pauly *et al.*, 2013). But, between 2002 and 2016, no apparent change occurred in the fishery fleet size operating throughout the Mediterranean coasts of Turkey (TUIK, 2019). Another concern about the reliability of making comparisons between two different data sources is that the spatial extents of landing (all along the Mediterranean coasts of Turkey) and fishery independent datasets (for the northwestern coasts of Iskenderun Bay) are quite different. Nonetheless, it is clear from the analysis of the microdata set that the largest fraction of landings was recorded from the ports around Iskenderun Bay, from which the fishery independent data was collected. As the assessment of Mavruk *et al.* (2018) revealed, this area is the major fishing ground for WGs along the Mediterranean coasts of Turkey.

The microdata set revealed that the trends of landings were consistent among cities along the Mediterranean coasts of Turkey. This can be considered as an indication that fluctuations in the grouper catches reflect large-scale variations in grouper populations because fishery related factors, such as gear types, are not different among cities (Demir, 2018). It is also important to note the decrease in grouper populations (from fishery independent data) and catches started in 2009 and 2010. In 2009, the annual average sea surface temperature (sst) was 0.7°C higher than the decade average in Iskenderun Bay (Mavruk *et al.*, 2017). Moreover, for the eastern Mediterranean, the highest maximum sst value for the last 30 years was recorded in August of 2010 (Bengil & Mavruk, 2019). In the following years, these climatic anomalies resulted in drastic changes to the fish communities of Iskenderun Bay in favor of invasive species (Mavruk *et al.*, 2017). In this regard, climate-related changes in the abiotic and/or biotic environment could have been major drivers of the observed fluctuations in the grouper populations. Further studies will inevitably be required in order to fully establish these connections.

Despite the potential errors in the magnitude and/or trends of grouper landing records, such as under-reported catch amounts (Pauly & Zeller, 2016) or presentist bias (Zeller & Pauly, 2018), the decline in WG landings apparently reflects the actual situation in the grouper populations of the northeastern Mediterranean. Therefore, from a statistical perspective, the official landing data for WG fishing can be considered as accurate for policymaking. However, this does not mean it provides enough information on policymaking from conservation and managerial perspectives. Catch-only stock assessment methods can give overprotective and misleading results (Carruthers *et al.*, 2012), particularly with short time series. The WG fishery ban in Turkey provides a good example of this. Based on the decrease in landing records, WG fishery was completely banned in 2016 (Official Gazette, 2016), and this measure was widely rejected by the fishers' community. Moreover, the regulation caused additional concerns about the other grouper species (Mavruk *et al.*, 2018), some of which are classed under data deficient or endangered categories in respect of their conservation status (IUCN, 2017). The ban was finally revoked in October 2018. In the new statute, the minimum landing size was declared to be 50 cm in total length, and WG fishing is seasonally closed from the 1st of June to the 31st of August (Official Gazette, 2018). Despite the frequent changes in legislations, the scientific baseline to manage WG populations is still lacking, and a better data collection and monitoring strategy is required.

Based on the results of this study, a monitoring program can be developed in Iskenderun Bay using scientific bottom trawl operations in the shallow coastal zone. In the fishery independent data, the abundance of WGs over the previous two years was strongly correlated with the total landings. However, this data was collected using bottom trawl operations, whereas the primary source of fishing pressure on WGs was from longline fishing instead (Mavruk *et al.*, 2018). In accordance with this, the majority of total landings were reported by longliners as a result of analysis of TUIKs' microdata set. Actually, these two types of fishing catch different length/age classes. Mavruk *et al.* (2018) report that the median length of WGs caught by trawlers is 32 cm. This value was close to that of the present study, which was from 23.7 to 30.6 cm (95% ci). On the other hand, the median length caught by longliners was reported to be 50 cm (Mavruk *et al.*, 2018), which is considerably larger than those of bottom trawlers. Using von Bertalanffy growth parameters given by Turan *et al.* (2017) for Iskenderun Bay, WGs caught by bottom trawlers are around three years old, whereas longliners mainly catch five-year old fish. This may explain why the highest correlation coefficients were found using one and two-year time lags between the bottom trawl survey and landing records. One implication of this could be that the status of WG cohorts can be monitored by using bottom trawl surveys one or two years before the pressure of longline fishing impacts the WGs.

The northwestern coast of Iskenderun Bay is a shallow area with prevailing soft bottoms (Avsar, 1999) that provide a proper habitat for juvenile WGs (Özbek *et al.*, 2013). In comparison with the adjacent areas, WG biomass was found to be at least twofold higher than the 0 to 30 m depth contours of Mersin Bay (Gucu & Bingel, 1994; Salihoglu & Mutlu, 2000) and Antalya Bay (Özbek *et al.*, 2013). In this study, the overall average WG biomass was 2.66 kg/h at 10 and 20 m depth contours, whereas Gucu & Bingel (1994) reported 1.19 kg/h at 7 to 17 m depth contours in Mersin Bay. In the same area, Salihoglu & Mutlu (2000) reported that the WG biomass ranged from 0.32 to 1.2 kg/h at 0 to 25 m depth contours. Moreover, both studies (Gucu & Bingel, 1994; Salihoglu & Mutlu, 2000) reported higher biomass values from Iskenderun Bay. Özbek *et al.* (2013) found that the white grouper biomass was 3.09 kg/h at the 25 m depth contour in Antalya Bay. Although this value is higher than the overall average of the present study, the study by Özbek *et al.* (2013) was performed between 2009 and 2010 when the average white grouper biomass was 6.20 kg/h in Iskenderun Bay.

In conclusion, the northwestern coast of Iskenderun Bay appears to be a good candidate for a regular monitoring program on juvenile WGs, with the resulting data possibly providing a useful precautionary management tool for WG fishery. Data currently available does not provide enough information to accomplish this objective, because it does not cover the necessary parameters on the biology of white groupers. Further efforts should therefore be focused on points such as inter-annual changes of age classes, maturity stages and reproduction parameters.

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