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Exploring the dynamics of small pelagic fish catches in the Marmara Sea in relation to changing environmental and bio-optical parameters

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Abstract: The Marmara Sea has a large drainage basin that includes cities with heavy industrialisation and agricultural land use. Therefore, it is under the influence of significant anthropogenic activities that adversely affect the well-being of its ecosystem. The Marmara Sea is also an important fishing ground with many commercially important fish species. These fish species are also under the influence of the adverse impacts of anthropogenic activities. Fisheries catches in the Marmara Sea had experienced severe fluctuations since the onset of the 2000s. In this study, possible underlying reasons for these fluctuations were investigated between 2000 and 2019 using remotely-sensed environmental and environmentally-influenced bio-optical parameters and fishery statistics. First, long-term inter-annual changes in the time series of sea surface temperature (SST), chlorophyll-a (Chl-a) concentration, net primary productivity (NPP), fishing effort, and catches of commercially important fish species, i.e. anchovy, sprat, Mediterranean and Atlantic horse mackerels and sardine, were scrutinised using trend analysis. Then, relationships between species' catches and the changes in the SST, Chl-a concentration, NPP, and fishing effort were investigated using correlation analysis. The results of the trend analysis showed that there were statistically significant declines in the catches of Mediterranean horse mackerel, sprat, and the total catch of the investigated species, although the decrease in the fishing effort was statistically not significant. The analysis of relationships between the environmental and bio-optical parameters and fishery statistics indicated that SST had statistically significant negative and NPP had statistically significant positive correlations with the catches of anchovy, sprat, and Mediterranean horse mackerel. Overall, the results indicated that the decreases in the fisheries catches were strongly correlated with the environmental and environmentally-influenced bio-optical parameters and fisheries management practices should consider environmental aspects of the ecosystem in addition to conventional fisheries regulations.

Key words: The Marmara Sea, fisheries, fish stocks, remote sensing, chlorophyll-a, primary production

1. Introduction

The Marmara Sea has a semi-enclosed basin with connections to the Aegean and Black Seas through the Dardanelles (Çanakkale) and Bosphorus (İstanbul) Straits, respectively. The sea has a two-layer circulation: At the bottom, the saline Mediterranean waters enter through the Dardanelles Strait and travel to the Black Sea and at the surface; the Black Sea waters enter through the Bosphorus Strait and travel to the Aegean Sea (Beşiktepe et al., 1994). The residence time is three months for the surface waters and five years for the deep waters (Ünlüata et al., 1990). These residence times enable a rapid turnover rate for the Marmara Sea. The Sea of Marmara has a drainage basin of 35000 km^2 (Okay and Ergün, 2005). The drainage basin includes big cities with heavy industrialisation and agricultural land use that are located by major rivers draining to the Marmara Sea. Therefore, although there is a considerable rapid renewal of its waters, the Marmara Sea is under constant stress due to the point and diffuse sources of pollution through rivers and their related plains (Ayaz et al., 2012). This has led to deteriorating ecological conditions in the Marmara Sea with frequent harmful algal blooms and mucilage formation events (Taş et al., 2016), possibly with adverse impacts on fish communities.

The deteriorating ecological conditions in the Marmara Sea may have also contributed to the decreases in fisheries catches. The total annual fisheries catches in the Marmara Sea declined 41% over twenty years, from 46137 tons in 2000 to 27157 tons in 2019; however, during the same period, the number of fishing vessels in the Sea of Marmara decreased only by 9% from 3006 vessels in 2000 to 2735 vessels in 2019.[1] Further, there has been a constant overall trend of decline in the catches of small pelagic fish species since 2000. Therefore, there must be more to the decreases

[1] Turkish Statistical Institute (2020). Fishery Statistics [online]. Website https://biruni.tuik.gov.tr/medas/?kn=97&locale=tr [accessed 16 November 2020].

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in the catches of small pelagic fish species in the Marmara Sea than just fisheries overexploitation. Environmental and environmentally-influenced biotic factors, such as sea surface temperatures, phytoplankton biomass, and primary productivity, play crucial roles in the dynamics of small pelagic fish species in the Mediterranean and the Black Seas (Brosset et al., 2015; Pennino et al., 2020, Niermann et al., 1999). Further, primary productivity influences fisheries production (Chassot et al., 2007). Hence, although coupled assessment of fishing effort and catches is necessary, changes in the environmental and environmentally-influenced biotic factors and related processes in the ecosystem should not be overlooked. Therefore, the aim of this study is to seek answers to three questions with respect to the fisheries resources of the Sea of Marmara: i) What could be the reason for the decreasing catch of the fishing fleet in the Marmara Sea? ii) Could the changes in the fishing effort be the only reason behind the decreasing catches? and iii) Could environmental and environmentally-influenced bio-optical factors be associated with the decreasing catches? The answers to these three questions were sought by analysing twenty-year time series of satellite-derived environmental (SST) and bio-optical (Chl-a and NPP), and fishery statistical data between the years 2000 and 2019.

2. Materials and methods

2.1. Data set

Inter-annual changes of spatially averaged annual mean sea surface temperature (SST), Chl-a, NPP and fishing effort, and their relation to the inter-annual fluctuations in fisheries catches of commercially important small pelagic fish species were investigated for the years between 2000 and 2019. The fish species included in the analysis consisted of anchovy (*Engraulis encrasicolus*, Linnaeus, 1758), sprat (*Sprattus sprattus*, Linnaeus, 1758), sardine (*Sardina pilchardus*, Walbaum, 1792), and Mediterranean (*Trachurus mediterraneus*, Steindachner, 1868), and Atlantic (*Trachurus trachurus*, Linnaeus, 1758) horse mackerels. Chl-a was chosen as a proxy of phytoplankton biomass and could be considered a predictor of the zooplankton availability that constituted a significant proportion of the diet of small pelagic fish. Primary productivity was chosen as a proxy of the carrying capacity of the Sea of Marmara ecosystem. SST was chosen as a limiting factor for the productive capacity of the system. As SST increases, the stratification in the water column increases, and the nutrient entrainment to the euphotic zone from the deeper layers of the water column is impaired (Dave and Lozier, 2010). Therefore, generally, negative relationships between SST and primary productivity; hence, fisheries catches are expected.

GlobColour monthly reprocessed Chl-a and NPP data products provided by ACRI-ST were obtained from Copernicus Marine Environmental Monitoring Service (CMEMS) for the years 2000-2019. The products had a 4-km spatial resolution and were space-time interpolated with calibration, merging, and validation. The Chl-a product included merged data from multiple satellite sensors SeaWiFS, MODIS-Aqua, MODIS-Terra, MERIS, VIIRS-SNPP, OLCI-S3A, and S3B (Garnesson et al., 2020). NPP was a derived product calculated based on the depth-integrated chlorophyll content, photosynthetically active radiation (PAR), and cross-section for photosynthesis per chlorophyll content following the algorithm by Antoine and Morel (1996). The SST product was a merged satellite multisensor product provided by The Group for High Resolution Sea Surface Temperature (GHRSST), Met Office (National Meteorological Service for the UK), and CMEMS, and obtained from Copernicus Marine Environmental Monitoring Service for the same period. For the fishing effort in terms of the number of vessels and fisheries catches, fishery statistical data from the Turkish Statistical Institute for the years 2000-2019 were used. Fisheries catches of individual species and species grouped as "small pelagic fish" that consisted of anchovy, sprat and sardine, and "all fish" that consisted of Mediterranean and Atlantic horse mackerels in addition to the species in the "small pelagic group" were analysed. Although horse mackerels are generally considered small pelagic fish species, they were not pooled in the combined small pelagic fish group in the analyses as they can attain much larger sizes than other small pelagic fish and feed on small pelagic fish species, and besides, Atlantic mackerel has a much longer life span.

2.2. Statistical analysis

Time series data, especially remote-sensing data products that rely on mathematical modelling algorithms, generally have serial dependence; hence, they often violate the principle of "independence of data points", or in other words, "independence of errors" required for the application of linear and generalised linear models (Smith and Warren, 2019). Therefore, the application of general and generalised linear models is not suggested for time series data produced by model applications. Further, linear models are utilised for predicting a response variable based on a set of explanatory variables. However, our study aims not to predict fisheries yield based on a set of explanatory variables but rather to explore any possible linkages between environmental and bio-optical parameters, and fisheries catches. Therefore, the application of a time series trend analysis followed by a correlation analysis was chosen as this approach has frequently been practised in similar kind of studies (e.g. Conti and Scardi, 2010; Chassot et al., 2007; Bengil and Mavruk, 2018).

As the first step, environmental and bio-optical data were averaged spatially. Then time-series analysis was applied to the environmental, bio-optical, and fisheries data to determine whether there were statistically significant trends. For the environmental and bio-optical data, the time series (Y_t) were decomposed into their seasonal (S_t), trend (T_t), and remainder (R_t) components using seasonal decomposition with local polynomial regression (Cleveland et al., 1990).

$$Y_t = T_t + S_t + R_t$$

After the decomposition, the time series were deseasonalised by subtracting the seasonal component. For the fishery statistical data, the decomposition and deseasonalisation were unnecessary because the data were annual and did not include a seasonal component. Following Bayazıt and Önöz (2007), only the seasonal Chl-a and fishery statistical data were prewhitened to eliminate autocorrelation before the trend analyses because the slope of the trend was low (< 0.01) in the seasonal Chl-a and STT time series data, and the length of the time series for fishery statistical data was fewer than 50 observations. Nonlinear trend analysis was done on the time series following the Yue and Pilon method (Yue et al., 2002) for the series that required prewhitening and Mann-Kendall trend test for the series that did not require prewhitening, i.e. SST and NPP. The time series were analysed based on Kendall's tau, and Sen's slope and intercept provided by the trend analysis, and the significance of trends was assessed based on the significance level (α) of 0.05.

Finally, the monthly time series of environmental and bio-optical parameters were averaged annually to investigate their possible correlations with annual fishery statistical data, i.e. catches of fish species. The correlations between fishing effort in terms of the number of vessels and the catches of fish species were also tested. Correlation tests require a normal distribution of samples; therefore, before the tests, the environmental, bio-optical and statistical data were tested for normality (Shapiro and Wilk, 1965). For data showing nonnormal distributions, a natural log transformation was applied before the correlation test. The impact of environmental and environmentally-influenced bio-optical parameters on fish species can take a few years to materialise, considering the dynamics of larval survival and spawning (Chassot et al., 2007). Therefore, a time lag ranging from 0 to 2 years was tested using a cross-correlation analysis to investigate the relationships between the time series of catches and environmental and bio-optical parameters to detect any possible lagged correlations. Afterwards, Pearson's product-moment correlation test is performed between the time series of the two variables that had a statistically significant correlation at the significance level (α) of 0.05. The Pearson product-moment correlation test was chosen for correlation analysis because it is the most appropriate test for interval data, e.g. time series (Carroll, 1981). All the statistical analyses were done in R (R Core Team, 2020), and "zyp" (Bronaugh and Werner, 2019) and "trend" (Thorsten, 2020) libraries were used for the trend analyses.

3. Results

The trend analysis showed that there were statistically significant negative trends in monthly and annual mean NPP values ($p < 0.05$), and the trends in monthly and annual mean Chl-a values were not statistically significant (Figure 1, Table 1). The monthly and annual mean SST values had statistically significant positive trends ($p < 0.001$ and $p < 0.01$, respectively).

The trend in the time series of fishing effort in terms of the number of vessels was statistically not significant ($p > 0.05$, Figure 2 and Table 1). However, there were statistically significant negative trends in the catches of sprat ($p < 0.001$), Mediterranean horse mackerel ($p < 0.01$), and the combined all fish group ($p < 0.05$) (Figure 2 and Table 1). The trends in the catches per species of anchovy, sardine, Atlantic horse mackerel, and the combined small pelagic fish group that comprised anchovy, sardine, and sprat were statistically not significant. The details of the trend analyses for the environmental and bio-optical parameters and fisheries-related data are given in Table 1.

The correlations between the time series of fishing effort, the catches of fish species, and the environmental and bio-optical parameters were also investigated (Table 2). SST had statistically significant negative correlations with the catches of sprat ($p < 0.001$), anchovy with a one-year time lag ($p < 0.01$), Mediterranean horse mackerel with a two-year time lag ($p < 0.05$), the combined small pelagic fish group with a one-year time lag ($p < 0.05$), and the combined all fish group with a one-year time lag ($p < 0.01$). NPP had a statistically significant positive correlation with the sprat catch ($p < 0.05$). Further, NPP had statistically significant positive correlations with the combined small pelagic fish group ($p < 0.01$), the combined all fish group ($p < 0.01$), anchovy ($p < 0.01$), and Mediterranean horse mackerel ($p < 0.05$) with two-year time lags. These results indicated that the environmental and bio-optical parameters had strong associations with the catches of the majority of the fish species and groups of species, and the significant negative trends observed in the catches were related to the significant trends observed in the time series of SST and NPP. Chl-a was not correlated significantly with any of the species' catches.

From the perspective of the fishing fleet, fishing effort in terms of the number of vessels had statistically significant correlations with the catches of sprat ($p < 0.05$), Mediterranean horse mackerel ($p < 0.05$) and Atlantic horse mackerel ($p < 0.01$) (Table 2). However,

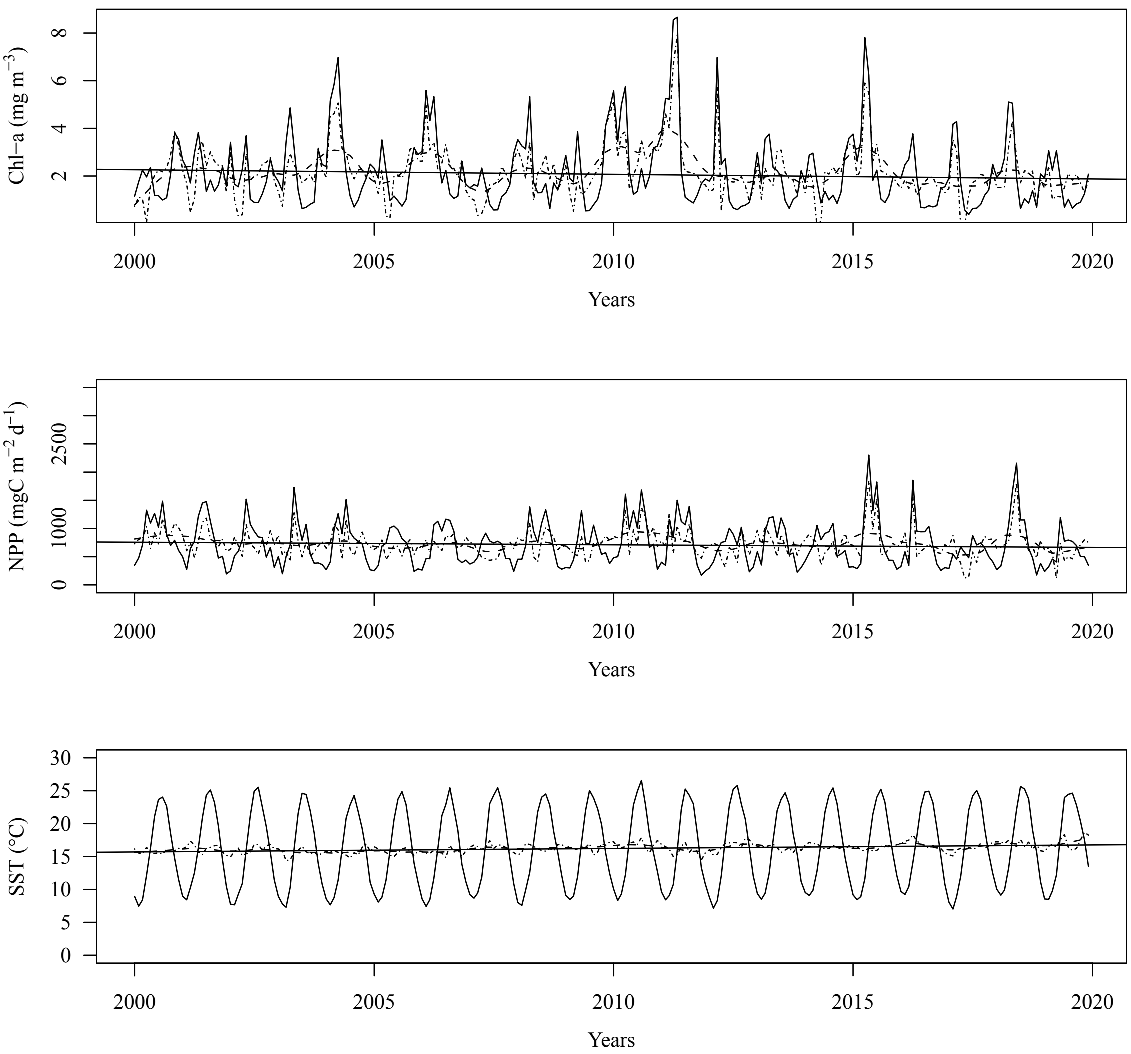

Figure 1. Time series of deseasonalised Chl-a, net primary productivity (NPP), and sea surface temperature (SST). Solid lines show the time series, dash-dot lines show the deseasonalised time series, dashed lines indicate their respective nonlinear trends, and flat solid lines show linear trend components.

the decreasing trend in the fishing effort over the study period was statistically not significant ($p > 0.05$, Table 1). Therefore, the significant negative trends in the catches of sprat and Mediterranean horse mackerel were not related to the fishing effort. There was a significant negative trend in NPP and a significant positive trend in SST, and NPP and SST were significantly correlated with the catches of sprat and Mediterranean horse mackerel. Hence, the significant negative trends in the catches of these two fish species could only be associated with the decreases in these two environmental and bio-optical parameters. Further, the trends in Atlantic horse mackerel catch and fishing effort were statistically not significant, although the correlation between the two variables was statistically significant ($p < 0.01$). These aspects indicated that inter-annual variations in the Atlantic horse mackerel catch were correlated with the inter-annual variations in the fishing effort. However, the overall change in the Atlantic horse mackerel catch over the twenty years could not be attributed to the variability in the fishing effort because both of the trends in the time series of fishing effort and Atlantic horse mackerel catch were statistically not significant. The sardine catch was not correlated with any of the environmental and bio-optical parameters or the fishing effort.

4. Discussion

In this study, catches as proxies for the dynamics of small pelagic fish species and their relation to fishing effort, environmental and environmentally-influenced bio-optical parameters were investigated. Overall, the results showed that catches of all fish species except sardine in the Marmara Sea decreased, although fishing effort did not

Table 1. Results of trend analyses of fisheries catches by species and groups, fishing effort, and spatially-averaged Chl-a, net primary productivity (NPP), and sea surface temperature (SST).

Species/Group/Variable	Slope	Intercept	Kendall's tau
Anchovy	-0.598	27662.60	-0.16 ns
Sprat	-0.049	839.08	-0.59 ***
Mediterranean H. mackerel	-0.812	15761.73	-0.56 **
Atlantic H. mackerel	-0.386	8177.12	-0.32 ns
Sardine	0.435	-1664.65	0.08 ns
Small pelagic fish	-0.423	29863.33	-0.10 ns
All fish	-1.764	56425.82	-0.37 *
Fishing effort	-0.072	3907.37	-0.30 ns
Chl-a (deseasonalised monthly)	-0.00001	3.12	-0.02 ns
Chl-a (annual)	0.002	2.96	0.041ns
NPP (deseasonalised monthly)	-0.013	895.04	-0.95 *
NPP (annual)	-9.357	776.26	-0.42 *
SST (deseasonalised monthly)	0.0001	14.09	0.19***
SST (annual)	0.08	15.24	0.46**

ns: nonsignificant
* Significant at $\alpha = 0.05$
** Significant at $\alpha = 0.01$
*** Significant at $\alpha = 0.001$

change significantly over the study period. Environmental (SST) and bio-optical (NPP) parameters were influential on the decreasing catches. However, the impact of overexploitation by fisheries should not be ruled out, considering that the majority of fish stocks in the Marmara Sea have already been overexploited (Demirel et al., 2020).

NPP had a significant negative trend, and SST had a significant positive trend over the study period. The catches of sprat, Mediterranean horse mackerel, and the combined all fish group had significant negative trends and were significantly correlated with either one or both of NPP and SST. Therefore, the decreases in the catches of these fish species and groups could be related to the decrease in the NPP and increase in the SST in the Marmara Sea. Primary productivity directly affects the living resources in a marine environment and influences the fisheries catches via a direct positive relationship (Chassot et al., 2007). Sea surface temperatures also have an influence on marine environments, and increasing SST values usually negatively affect the primary productivity by impairing nutrient entrainment via convective mixing from the deeper water layers due to increased stratification in the water column (Dave and Lozier, 2010). Further, some species, such as sardine, may prefer colder waters for their reproductive and feeding dynamics (Sabatés et al., 2006), and increase in SST values could favour species associated with warmer waters. Hence, a general increase in SST can negatively affect fisheries catches by changing the catch composition (Leitão et al., 2018). The results of our study showed similar associations between NPP, SST, and the catches of the investigated fish species.

One other important aspect of our study was that the inter-annual fluctuations in the catches of sprat and Mediterranean horse mackerel were significantly correlated with NPP, SST, and the fishing effort. However, the significant correlations between the fishing effort and the catches of sprat and Mediterranean horse mackerel did not imply that the significant decreasing trends in the catches of these two species were related to the fisheries exploitation because the change in the fishing effort over the study period was statistically not significant (Table 1). The fishing effort could only be considered related to the decrease in the catch of a given species if both the decrease in the fishing effort and the decrease in the catch of the species correlated with the fishing effort are statistically significant. However, according to the trend analysis, the change in the fishing effort was statistically not significant, but the negative trends in the catches of sprat and Mediterranean horse mackerel were statistically significant. Further, the catches of these two species

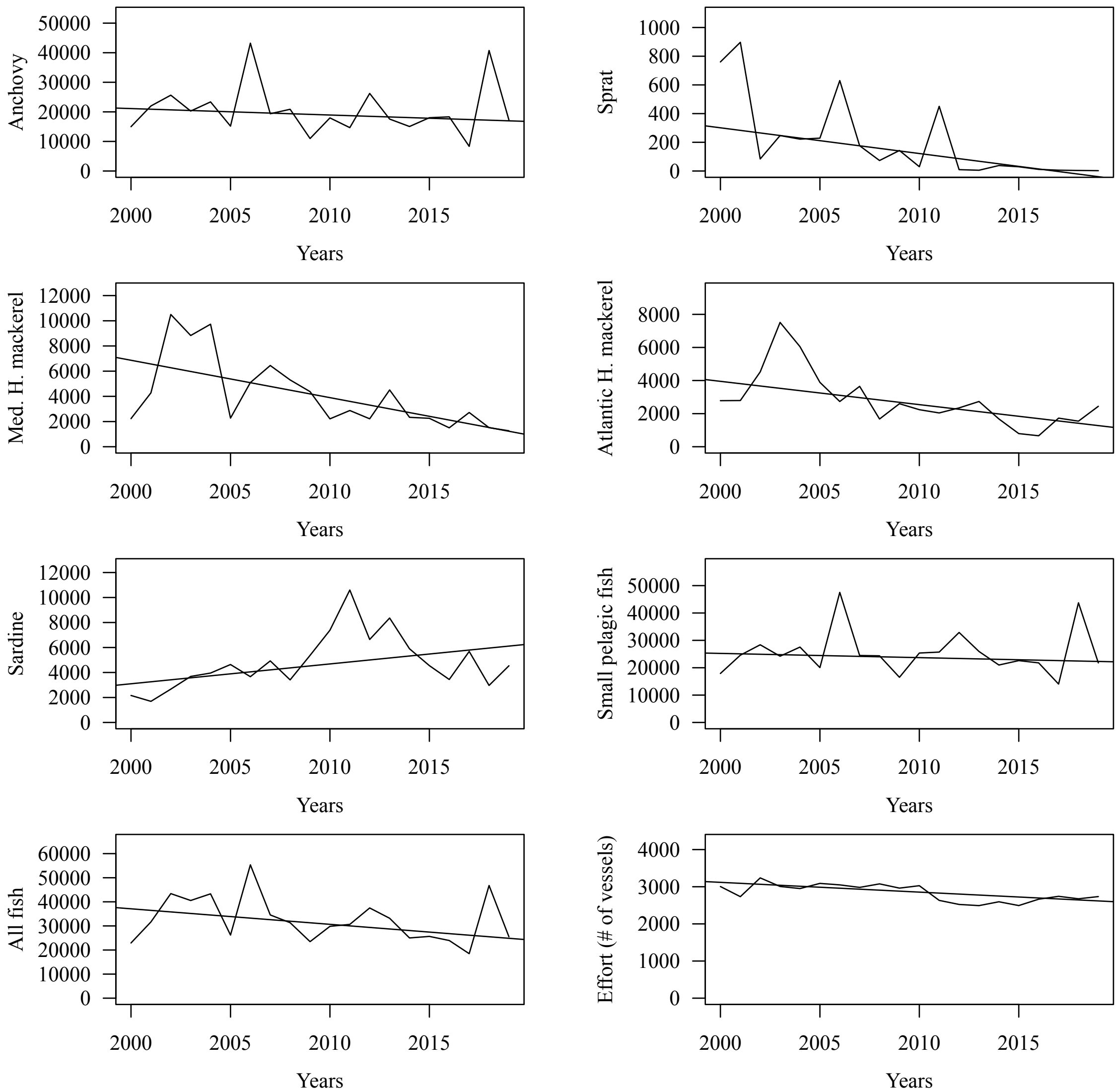

Figure 2. Time series of fisheries catches (tons) and fishing effort in the Marmara Sea between 2000 and 2019. Flat solid lines indicate linear trends.

were significantly correlated with NPP and SST that had statistically significant negative and positive trends, respectively, indicating that the significant decreasing trends in the catches of sprat and horse mackerel were related to the significant changes in NPP and SST. Therefore, the correlation between the catches of these two species and the fishing effort can only suggest that the inter-annual variability in the two species' catches were prone to fluctuate per the variations in the fishing effort; however, the significant decreases in their catches were linked to the significant decrease in the NPP and the significant increase in the SST. We hypothesised that the catches of sprat and Mediterranean horse mackerel may continue to decrease in the future if NPP continues to decrease and, possibly, SST continues to increase. Eventually, the catches of these two species may become decoupled from the fishing effort because the decreases in their catches were significantly correlated with the significant changes in the NPP and SST in the Marmara Sea.

The impacts of environmental and bio-optical parameters are the most influential in the early life stages of fish species by affecting larval survival and recruitment success (Teixeira et al., 2016). Considering that sexual maturity is attained at the age of 1 for anchovy (Lisovenko and Adrianov, 1996), sprat (Balık, 2018) and sardine (Tsikliras and Koutrakis, 2013) and 2+ for the Mediterranean horse mackerel (Kukul, 1987) and Atlantic horse mackerel (Abaunza et al., 2003), a one and/or two-year lag correlation with environmental and bio-optical parameters should be expected. In our study, similar

Table 2. The correlations between catches, fishing effort, and spatially-averaged annual mean environmental and bio-optical parameters.

Species/Group	Fishing effort	Chl-a	NPP	NPP (lag 1)	NPP (lag 2)	SST	SST (lag 1)	SST (lag 2)
Anchovy	0.11 ns	0.14 ns	0.11 ns	-0.13 ns	0.62 **	0.01 ns	-0.60 **	0.02 ns
Sprat	0.53 *	0.18 ns	0.46 *	0.55 *	0.18 ns	-0.82 ***	-0.42 ns	-0.24 ns
Mediterranean H. mackerel	0.53 *	0.05 ns	0.18 ns	0.13 ns	0.49 *	-0.42 ns	-0.43 ns	-0.54 *
Atlantic H. mackerel	0.58 **	-0.11 ns	0.22 ns	0.31 ns	0.21 ns	-0.36 ns	-0.34 ns	-0.44 ns
Sardine	-0.38 ns	0.36 ns	-0.01 ns	0.16 ns	-0.08 ns	0.10 ns	0.40 ns	0.15 ns
Small pelagic fish	-0.002 ns	0.27 ns	0.15 ns	-0.04 ns	0.63 **	-0.03 ns	-0.52 *	0.09 ns
All fish	0.27 ns	0.18 ns	0.14 ns	-0.03 ns	0.64 **	-0.20 ns	-0.62 **	-0.10 ns

ns: nonsignificant
* Significant at α = 0.05
** Significant at α = 0.01
*** Significant at α = 0.001

results were obtained as the majority of the fish species and groups had statistically significant correlations with NPP and SST with one-year or two-year time lags. Sardine and Atlantic horse mackerel did not significantly correlate with any of the environmental and bio-optical parameters. However, sardine was expected to have been impacted by the increasing SST as it prefers colder waters, especially for reproduction. The findings of this study could not explain the dynamics of these two species, given the extent of the analyses. However, we hypothesised that these two species could be under the influence of other important dynamics in play, for instance, trophic dynamics in the food web. This aspect needs further investigation in future studies.

A convex parabolic relationship exists between fishing effort and fishery catch per the Schaefer growth model (Schaefer, 1954). Fisheries catches may increase parallel to the increase in the fishing effort unless there is overfishing. However, the theory is based on the dynamics of a single unit stock with the assumption that growth of the stock is only influenced by the fishing mortality and excludes other factors that may influence the carrying capacity for the stock and its food web, e.g., resource availability, prey-predator and competitive interactions. Therefore, as practised in this study, the carrying capacity of the system and resource availability that directly affects the growth rate of the stock should be taken into account via environmental parameters. Such an approach is essential to delineate the fluctuations in fisheries catches under variable levels of fisheries exploitation. The results of our study indicated that, in addition to fishing effort, environmental and bio-optical parameters should be considered when assessing the dynamics of fish stocks in the Marmara Sea. Therefore, linking the dynamics of fishing effort and fisheries catches without considering the environmental dynamics would not suffice to manage the fish stocks in the Sea of Marmara sustainably. Hence, an ecosystem approach to fisheries management should be adopted.

The catches of sprat, Mediterranean horse mackerel, and the combined all fish group in the Marmara Sea had statistically significant negative trends, i.e. decreasing catches. Although statistically not significant, the catches of anchovy, Atlantic horse mackerel and the combined small pelagic fish group also declined. These declines could be considered an alarming situation considering that the fishing effort did not change significantly in the Marmara Sea. Contrary to the catches of all the other fish species and groups, the catch of sardine had an increasing trend, but this trend was statistically not significant. Further, the catch of sardine was not correlated with any of the variables investigated. Both sardine and anchovy depend on zooplankton as the primary food source, and sardine prefers cold waters for its reproductive processes. Therefore, under significantly decreasing primary productivity conditions and significantly increasing sea surface temperatures, the insignificant changes observed in the dynamics of sardine and anchovy catches in our analysis could be attributed to other factors such as changing conditions related to the trophic competition in the food web or their species-specific fisheries exploitation levels. These aspects were beyond the boundaries of this study, and possible reasons for this situation requires further investigation in future studies.

Demirel et al. (2020) showed that of the seventeen stocks assessed in the Marmara Sea, most of them were already overfished, and two of them, i.e., Mediterranean horse mackerel and sprat, were fished at their maximum mortality levels ($F = F_{MSY}$). According to the results of our study, the significant declines in the catches of Mediterranean horse mackerel and sprat were significantly correlated with the significant decrease in NPP in the

Marmara Sea over the study period. The negative changes in NPP could be enforcing a limit on the maximum biomasses that the stocks of these species could attain. Therefore, we hypothesised that sprat and Mediterranean horse mackerel might have already transitioned to the "overfished" stock status.

Similar to our study, Chassot et al. (2007) investigated the bottom-up control on the fisheries production in the European Seas, including the Marmara Sea, between 1998 and 2004. They related mean annual primary production to mean annual fisheries catch over the period from 1998 to 2004 in 14 large marine ecosystems across Europe and found that a significant linear relationship existed between marine productivity and fisheries production. Our study could be considered an advancement on their study because our study capitalised on time series of environmental and bio-optical parameters and statistical catches over a much longer and recent time and, unlike their study, did not use multiyear averaged values. Therefore, to the best of our knowledge, our study could be considered the first study investigating the relationship between the dynamics of fisheries production in terms of time series of catches and environmental and bio-optical parameters in the Marmara Sea.

One limitation of our study that may had implications on the results could be the capitalisation on fishing effort in terms of the number of vessels. The expression of fishing effort in terms of hours or number of days fished per gear/type per target species is the preferred method, but such an optimal level of detailed information on fishing effort was not statistically available. In such circumstances, the number of vessels could be considered a simple index that can be used (Ricker, 1975). Therefore, effort data, i.e. the number of vessels, were utilised under the assumption that all gears participated equally in the fishing effort in the Marmara Sea throughout the study period and peculiarities between the gears in terms of effort considering their target species were negligible.

In this study, the long-term variations in remotely-sensed SST, Chl-a and NPP, and catches of small pelagic fish species and fishing effort were analysed to determine existing trends in their time series. Further, the relationships between all the variables were investigated to understand if fishing effort and environmental and bio-optical parameters influenced the fisheries production in the Marmara Sea. Results showed that NPP and SST and the catches of all the fish species except sardine, anchovy and Atlantic horse mackerel had significant decreasing trends, and NPP and SST were significantly correlated with the catches of the majority of the species with a one-year or a two-year time lag. Further, fisheries catches continuously decreased since the beginning of the 2000s, although the changes in the fishing effort were statistically not significant. These findings indicated that immediate action should be taken for sustainable management of the fish resources in the Marmara Sea. An ecosystem approach to fisheries management that considers the dynamics of the fish stocks and at least the changes in the sea surface temperatures and primary productivity of the system should be implemented.

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