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Research article

Preliminary assessment of the relationship between CPUEs and large-scale climate indices on the south coast of Turkey

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Abstract: The Mediterranean, particularly the east side, is considered one of the most susceptible regions to climate change. The marine fauna, including fish, has already been reported to respond to changing conditions. It is fundamental to understand which changes in the fish stocks are related to varying temperatures to design sustainable fishing practices. On the Turkish coast of the Mediterranean Sea, fluctuations in the fish stocks are attributed primarily to overfishing, pollution, and the Lessepsian invasion. As the region is listed among the fastest-warming areas, enlightening the impact of rising temperature on fish populations is essential. Within this context, we hypothesized that the large-scale climate indices might explain the changes in the abundance of exploited fish populations on the south coast of Turkey. We aimed to measure the responsiveness of catch per unit effort (CPUE) to North Atlantic Oscillation Winter Index (NAO DJFM) and East Atlantic-West Russia (EA/WR) seasonal indices. For that purpose, official landing and fishing fleet statistics reported by the Turkish Statistical Institute (TUİK) compiled for 1987 and 2020. Landings of fish species are categorized regarding the fishing practice targeting them. The total number of fishing vessels is used to calculate the annual CPUEs of trawlers and purse seiners. To investigate the relationship between climate indices and variations in CPUEs, cross-correlation analysis incorporating the differencing and pre-whitening methods has been performed. In general, CPUE of trawlers was significantly affected by NAO DJFM and EA/WR indices, while CPUE of purse seiners was significantly correlated only with EA/WR Winter Index. Considering the role of the EA/WR pattern on precipitation and NAO teleconnection on temperatures, the large-scale climate indices seem to impact the reproductive success and growth of the fish populations. Our results indicated that the large-scale climate indices have great potential to explain particular patterns of CPUEs. However, other, drivers such as fisheries and eutrophication that are probably acting in combination with climate must be included in the future studies.

Keywords: Catch per unit effort, Fisheries, Marine climate change, Northeastern Mediterranean Sea, Climate indices.

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Introduction

Climate warming has become noticeable, particularly in recent decades (MedECC, 2019). According to the latest assessment report of IPCC (2021), the warming will become more pronounced during the 21st century. Currently, it is considered to be the most widespread anthropogenic threat to marine ecosystems due to its impact both on oceanographic conditions and on the biology of the marine organisms (Brown et al., 2010; Dulvy et al., 2008; Engelhard et al., 2014; Gamito et al., 2015; Halpern et al., 2008). The aquatic organisms adapt to prevailing conditions to fulfill requirements to complete their life cycles (Beugrand et al., 2002; Chefaoui et al., 2018; Fry, 1971). Fry (1971) suggested that the fish can respond to variations in the temperature long before their thermal limits. The response to prevailing temperatures can be either directly through physiological and behavioral changes or indirectly due to the changes in productivity, the structure, and composition of the ecosystems on which fish rely on (Cochrane et al., 2009; Gamito et al., 2015; Hare et at., 2010; MacKenzie et al., 2007; Perry et al., 2005). The changes in growth and recruitment as a response to warming can, in turn, cause multiyear trends in the abundance and biomass of fish populations (MacKenzie et al., 2007; Vargas-Yáñez et al., 2008). Consequently, this affects the region's productive capacity and may ultimately change the nature and value of commercial fisheries (MacKenzie et al., 2007; Perry et al., 2005).

However, the warming process is geographically heterogeneous worldwide (IPCC, 2007). In the Mediterranean region, average annual temperatures rise 20% faster than the global average, which corresponds to a temperature approximately 1.5 °C higher than the pre-industrial period (1880-1899) (MedECC, 2019). The warming of shallow and deep waters has already been documented in the Mediterranean Sea (Nykjaer, 2009; Raitsos et al., 2010; Vargas-Yáñez et al., 2008). Future projections predicted temperature increases up to 5.1°C in some parts of the region, whereas sea surface temperature predictions ranged between 1.8°C and 3.5°C (MedECC, 2019). Among the basin parts, the Northeastern Mediterranean Sea, including Turkey's south coast, is projected as one of the most sensitive parts to the warming (MedECC, 2019).

At the same time, the region has an important place for the economy of coastal communities with a valuable contribution to trawl and purse seine fishery production (Bingel et al., 1993), which has been subjected to spatial distributional changes and fluctuations since the 1980s (Gücü & Bingel, 2011; Gücü et al., 2010; Gücü & Gücü, 2002; Mavruk, 2020). Previous studies conducted in the region mainly focused on the influence of overfishing, the impact of invasive species, the relationship between the temperatures and invaders or local hydrographic conditions to explain fluctuations in the fish populations (Ben Rais Lasram et al. 2010; Ben-Tuvia, 1966; Ben-Yami & Glaser 1974; Gücü & Bingel, 2011; Gücü et al., 2010; Mavruk et al., 2017; Gücü, 2021; Por, 2009). The response of fish populations to climate or climate indicators is evident in the trends of recruitment (Abella et al., 2008; Brunel & Boucher, 2007), distribution (Engelhard, 2014; Perry et al., 2005), and landings (Teixeira et al., 2014) at different parts of the world oceans.

Within the same context, considering the very fast warming trend of the Northeastern Mediterranean Sea, we hypothesized that the large-scale climate indices could be used to explain the changes in the CPUE of exploited fish populations on the Turkish coast of the Mediterranean Sea. Given that designing sustainable management practices requires a sound understanding of the relationship between the cause and the response (Probst et al., 2012), we aimed to elucidate the relationship between the large-scale climate indices and CPUE over time.

Material and Methods

Fishery Data

In the framework of the study, firstly, landing and fishing fleet data sets were collected to calculate annual CPUEs over time. For this purpose, although its reliability is questioned, officially reported landing and fleet statistics that have been collected systematically with a constant method for years by the Turkish Statistical Institute (TUİK) are compiled for the years between1987 and 2020. The fishing fleet categorized as “trawl” and “purse seine” boats. As the fishing fleet in the region targets multispecies, a holistic approach was taken to categorize fish species in the landing data. Two groups have been established considering the gear type used to catch fish: trawl catch and purse seine catch. Consequently, some pelagic species such as "horse mackerel" which are usually targeted by purse seiners in other regions have been included in the "trawl catch" category because they are targeted by trawlers in the study area. Total biomass of fish species of each group and fishing effort (number of fishing vessels) used to calculate annual CPUE values of trawlers and purse seiners. Later, linear regressions of CPUEs against fishing effort were fitted to relate the impact of fisheries.

Climate Indices

Large-scale climate indices reduce complexity in time and space variability (Massuti et al., 2008) and have been used in fishery research (Abella et al., 2008; Brunel & Boucher, 2007; Van Beveren et al., 2016). In order to elicit the impact of warming, instead of regional temperatures, large-scale climate indices, namely the North Atlantic Oscillation Winter index (DJFM) and East-Atlantic West-Russia (EA/WR) index, were used as an indicator of climatic conditions.

The North Atlantic Oscillation (NAO) is the most prominent atmospheric circulation mode that affects the climate of the Mediterranean region (Hurrell et al., 2003).

It is calculated as the difference in normalized sea level pressure (SLP) between Lisbon, Portugal, and Stykkisholmur/Reykjavik. Oscillations between its positive and negative phases affect the strength of the westerly winds hence regulating the air carried to Europe, leading to significant changes in weather conditions and having a substantial impact on oceanic conditions (Hurrell et al., 2003). Therefore, it is an excellent proxy for long-term environmental variables (Maynou, 2008).

As the NAO variability is most substantial in the winter, the NAO winter index (DJFM) is used for analysis (Hurrell et al., 2003). DJFM index was compiled from the National Center of Atmospheric Research https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based for the period between 1987 and 2020 (Schneider et al., 2013).
The East Atlantic-West Russian (EA/WR) is used as a second index due to its correlation to extreme precipitation frequency (de Vries et al., 2013; Krichak & Alpert, 2005; Krichak et al., 2002). It is one of the prominent teleconnection patterns that impact Eurasia (Barnston & Livezey, 1987). It consists of four anomaly centers associated with the height anomalies over Europe, Northern China, North Atlantic, and North of the Caspian Sea (Lim, 2015). Its data was compiled from National Oceanic and Atmospheric Administration (https://www.noaa.gov/) between 1987 and 2020. The data set included monthly EA/WR values. Because the index fluctuates between different seasons, it is categorized into seasons (winter, spring, summer, autumn) and seasonal indices calculated by using the means of four months.

Data exploration Statistical Analysis

The response to anthropogenic pressures on the ecosystem can be confounded by temporal lags (Probst et al., 2012). Therefore, cross-correlation analysis was used to measure parallelism between the main patterns of CPUE variations and large-scale climate indices. First, differencing and pre-whitening were applied to the data set to remove autocorrelation (Cryer & Chan, 2008; Probst et al., 2012). ARIMA models were fitted for each climate indices, and the best model was selected based on Akaike's Information Criterion (AIC) (Takane & Bozdogan, 1987). All analyses are carried out in the R environment (R Core Team, 2020).

Results

Numbers of both trawlers and purse seiners were lower in the late 1980s. Although fluctuations occurred, the number of trawlers has not notably changed in the 1990s. In contrast, number of purse seiners exhibited an increasing trend in 1990s. Numbers of both trawler boats and purse seine boats displayed the highest values between the years 2001 and 2013 and decreased to a degree after that point (Figure 1-A, -B).
Landing of trawlers reached the highest point in 1993 and declined remarkably after that year. It remained fairly stable after 1998. Whereas landing of purse seiners was lower in the first 20 years of the study period and reached its peak in 2011 and dropped after that year (Figure 1-C, -D).

Generally, the CPUE of both trawlers and purse seiners rapidly increased after the 1990s and reached the highest records, and started to decline after 1993 (Figure 2-A, -B). The lowest values were observed in the 2000s for trawl CPUEs and have not changed significantly. A slight increase has been observed in CPUE of purse seiners after the year 2008 until 2011. However, it declined after that period.

The response of the stocks to the fishing pressure was depicted in Figure 3, which indicated that the fishing effort explains some of the variations in the CPUEs. Both models produced significant p-values. Summary of the linear regression model of CPUE of trawlers and effort (Figure 3-A) was F-statistic: 13.18 on 1 and 32 DF, p-value: 0.0009752 and CPUE of seiners and effort (Figure 3-C) was: F-statistic: 18.79 on 1 and 32 DF, p-value: 0.0001355). Nevertheless, there are fluctuations in the CPUEs that cannot be explained by fishing effort. We tried to explain departures from the models with prevailing climatic conditions.

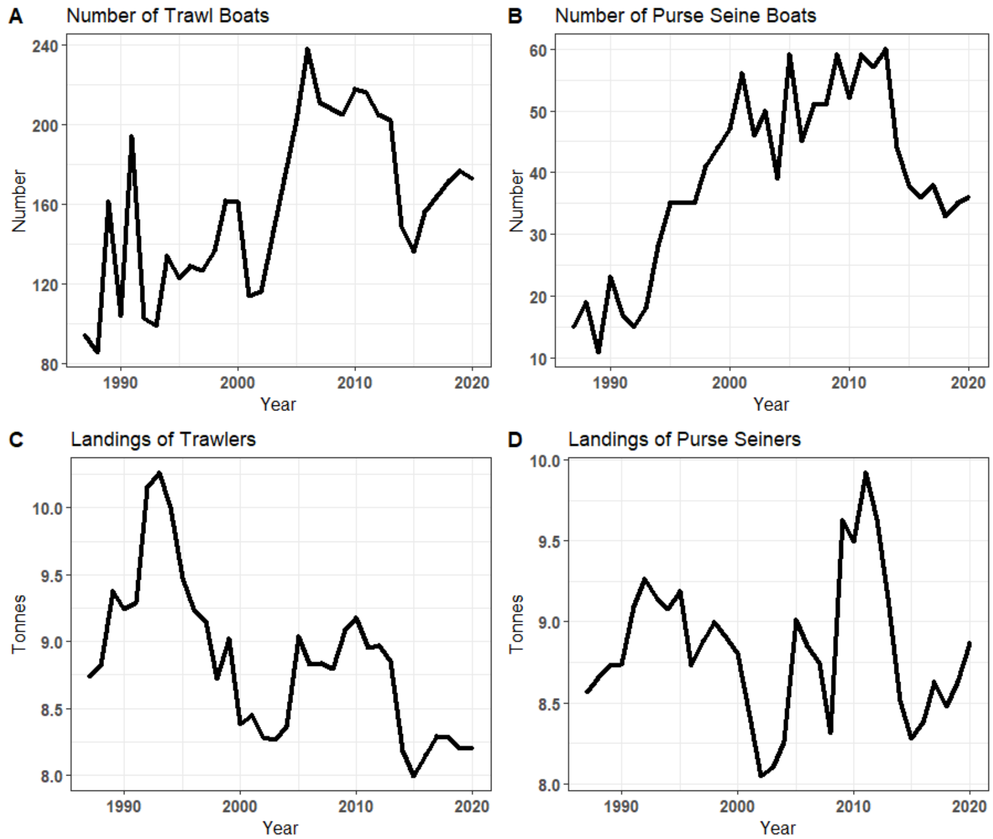

Figure 1. Time series of fishing fleet (A, B) and landing (C, D) data.

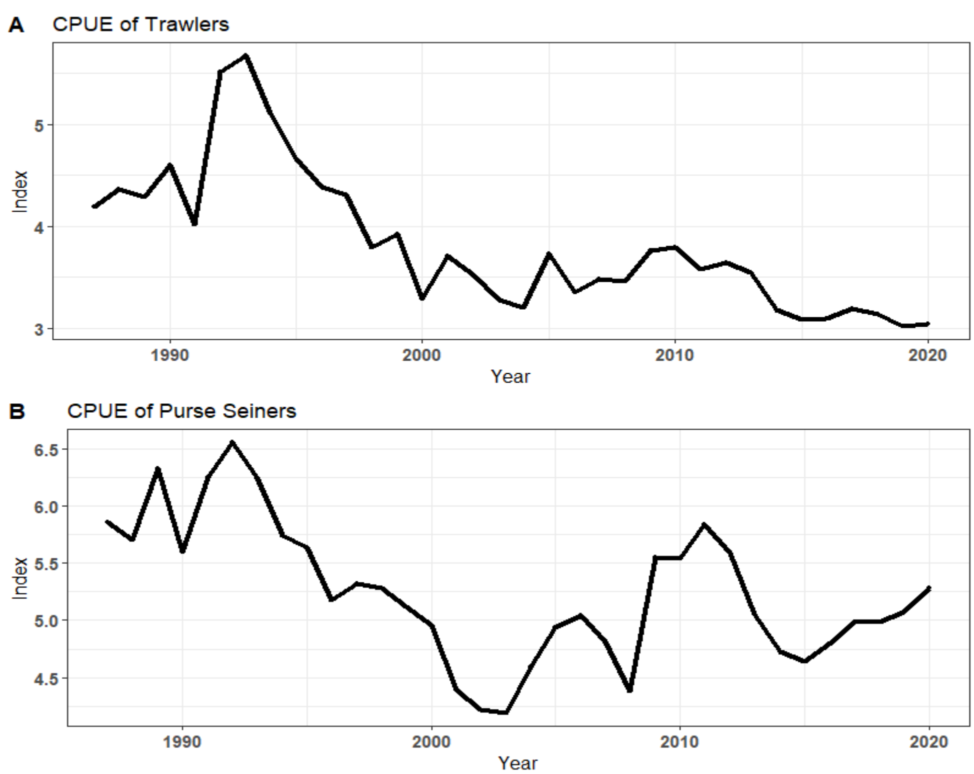

Figure 2. CPUE index of trawlers (A) and purse seiners (B) from 1987 to 2020. CPUEs are log transformed to make patterns more interpretable.

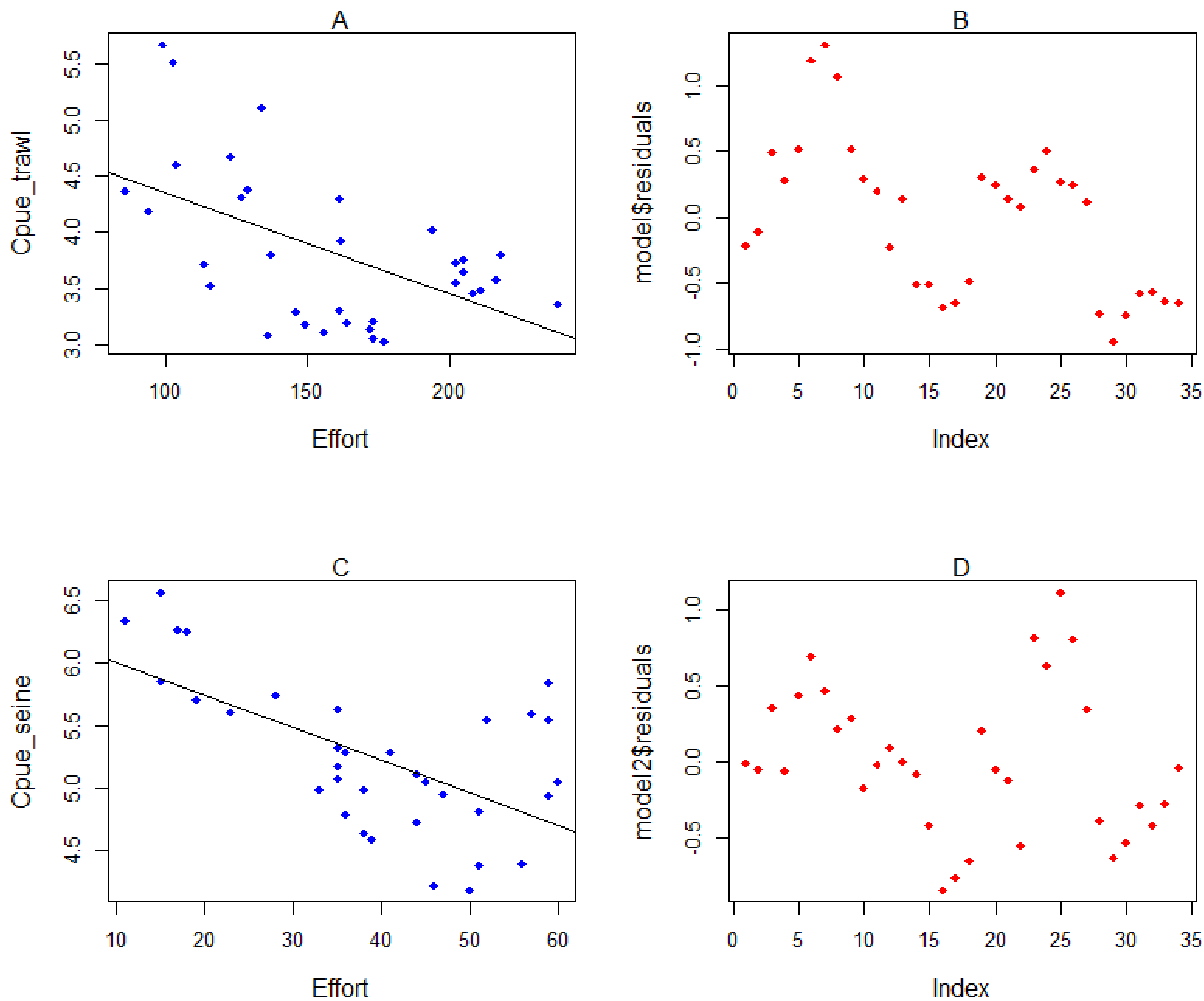

Figure 3. Linear regression between CPUE of trawlers and fishing effort of trawlers (A), CPUE of purse seiners and fishing effort of purse seiners (C), residuals of the linear regression model between CPUE of trawlers and fishing effort of trawlers (B), residuals of the linear regression model between CPUE of purse seiners and fishing effort of seiners (D). Filled blue diamonds are data points of original data set. Filled red diamonds are residuals of Linear regression models. Solid black line is the perfect fit line.

Between 1990 and 1995, the NAO DJFM index and EA-WR Winter-Summer-Autumn indices were positive, whereas EA-WR spring oscillated between the positive and negative phases (Figure 4-A). NAO DJFM index exhibited a positive pattern between the years 1987 and 1996. The transition occurs between 1996 and 2006. The negative phase became dominant between 2006 and 2010, with the lowest values in 2010. After this year, the index becomes positive. Autumn EA-WR index constantly oscillated in the positive phase during the study period, with higher values before the 1990s. The period between 1987 and 2010 seems to be the transition years between the high positive and low negative values for spring and summer indices. EA-WR Winter index oscillates between negative and positive phases. However, the negative phase becomes dominant after 2010 (Figure 4-B, -C, -D, -E).

Cross-correlation

Results of whitened cross-correlations showed the significant positive impact of the NAO DJFM index on the CPUE of trawlers (Figure 5.). Based on this model, the NAO DJFM index predicts the CPUE of trawlers by a lag of 4 years.

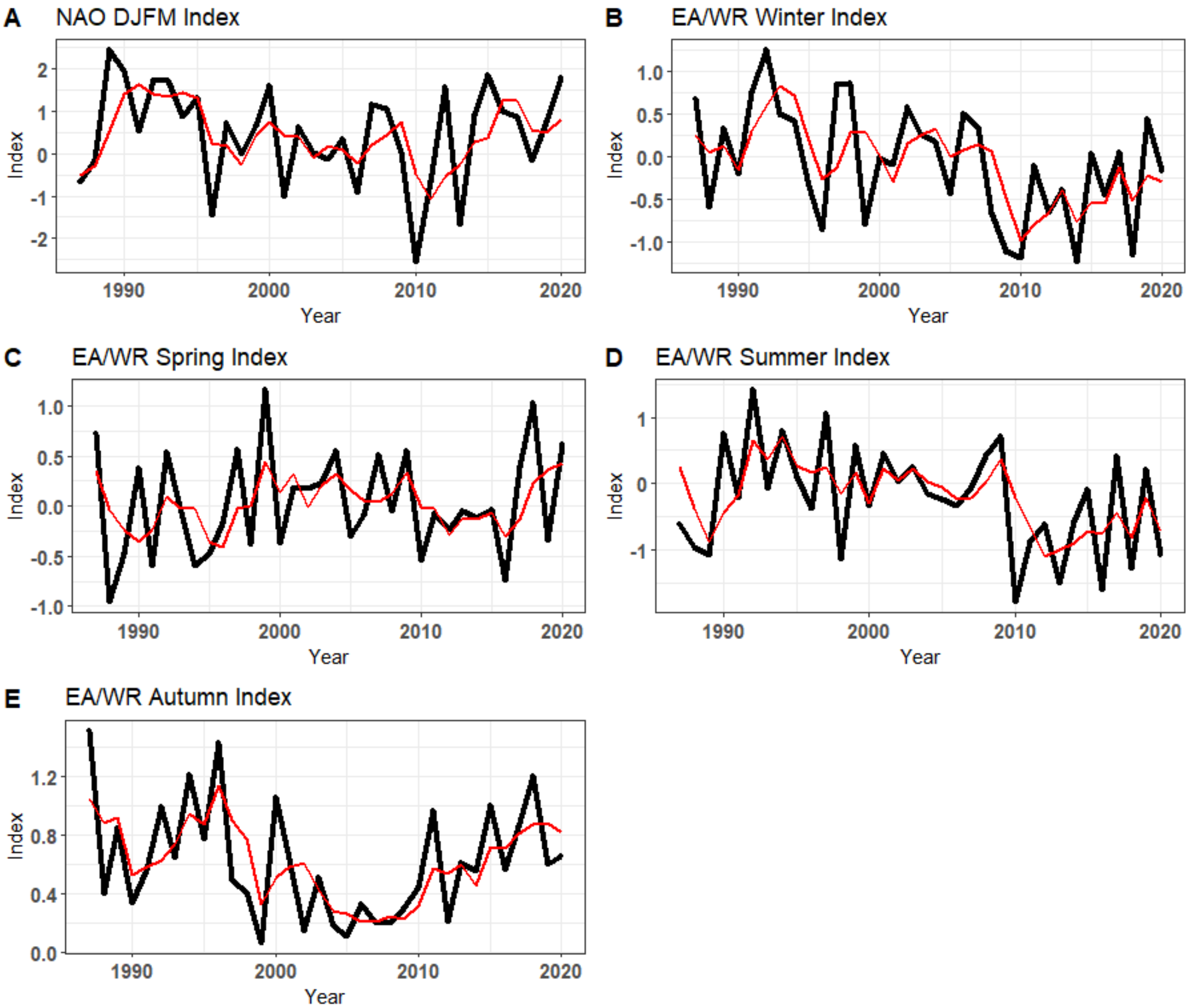

Figure 4. Large-scale climate indices: the NAO DJFM(A), EA/WR Winter(B), EA/WR Spring(C), EA/WR Summer (C), and EA/WR Autumn (C). Red line indicates 3-year running mean.

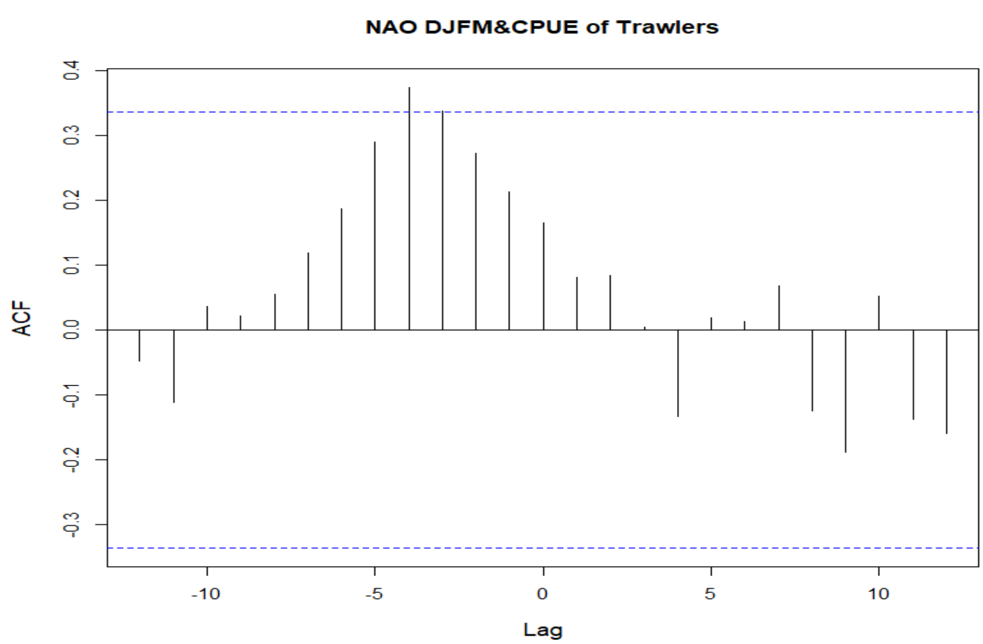

Figure 5. Cross-correlation analysis between the NAO DJFM Index and CPUE of trawlers.

However, the NAO DJFM index and CPUE of purse seiners were uncorrelated and did not exhibit any significant relationship. EA/WR Autumn index showed a significant negative relationship with CPUE of trawlers. Responsiveness occurred in year four after pre-whitening (Figure 6.). EA/WR Summer index was positively correlated with CPUE of trawlers with a lag of 2 years.

On the other hand, no relationship has been found between the EA/WR Autumn Index and CPUE of purse seiners. The only significant relationship between the CPUE of purse seiners and climate indices was observed at EA/WR Winter Index, which displayed a significant negative correlation at lag 10 (Figure 7.).

Other cross-correlations provided insignificant results between the climate indices and CPUE trawlers and purse seiners.

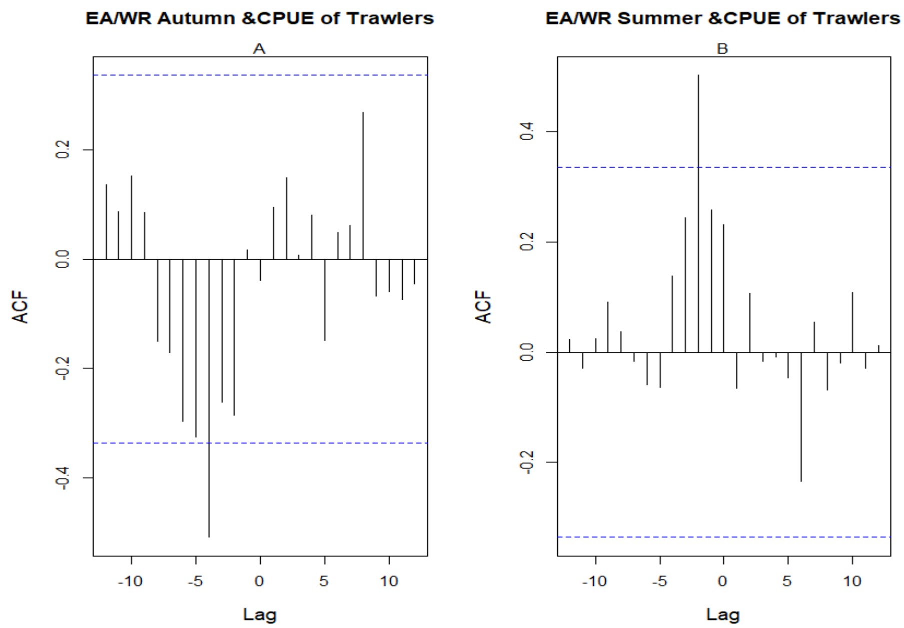

Figure 6. Cross-correlation analysis between the EA/WR Autumn Index and CPUE of trawlers (A) and the EA/WR Summer Index and CPUE of Trawlers (B).

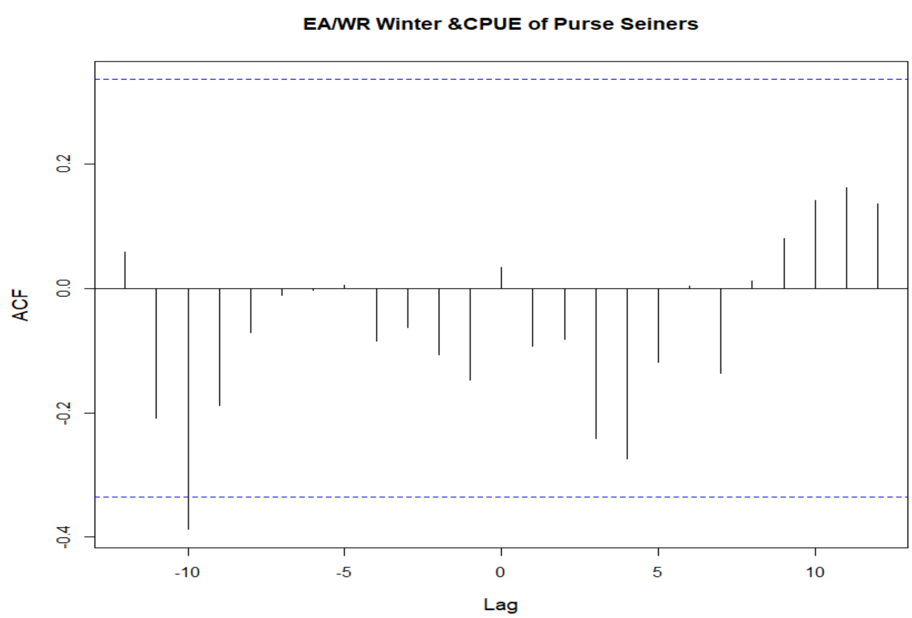

Figure 7. Cross-correlation analysis between EA/WR Winter Index and CPUE of purse seiners.

Discussion

In general, the results indicated the significant influence of both NAO and EA/WR climate indices on the CPUE of trawlers. The positive phase of NAO is mainly associated with colder conditions in the eastern Mediterranean regions, while the contrary is observed during the negative NAO phase (Baltaci et al., 2018; Skliris et al., 2012). Due to the negative relationship between climate and NAO in the eastern Mediterranean (Skliris et al., 2012), a significant positive correlation with a lag of 4 years between CPUE of trawlers and NAO DJFM index indicates a negative impact of the warm temperatures and positive impact of cooler temperatures on the fish stocks targeted by the trawl fleet. Demersal fishing ban applied from mid-April to May secures the spawning period of commercially valuable fish species in the region. Considering the influence of the NAO DJFM winter index on temperatures, changes in the ambient water conditions may impact both the physiology of fish and the hydrology of the environment prior to the spawning period. This, in turn, can favor reproductive success in the no-fishing season.

The positive phases of EA/WR enhance the northerly flow of cold and dry air over the Eastern Mediterranean and play a role in the precipitation variations (Criado-Aldeanueva & Navarro, 2020; Krichak et al., 2002). Due to its influence on rainfall, it can be suggested that EA/WR indirectly impacts the growth of fish by changing the region's primary production.

Lemus-Canovas (2022) represented significant correlations between EA/WR pattern and Wet-Cold extremes, particularly in autumn, winter, and moderately in summer months on the south coast of Turkey for the 1951-2021 period. Indeed, our findings demonstrating significant impacts of EA/WR Autumn, Summer, and Winter indices on CPUEs were consistent with the study of Lemus-Canovas (2022). However, the lag of 10 years between the CPUE of purse seiners EA/WR Winter Index and the lack of relationship between the other climate indices may not reflect the whole picture of the situation.

On the other hand, impacts of both climate modes, particularly NAO, reduce towards the Northeastern Mediterranean Sea (de Vries et al., 2013). Similar to our findings, Tsikliras et al. (2019) demonstrated that the impact of NAO on the pelagic fishes in the eastern Mediterranean was not significant. The impact of NAO and EA/WR on the climate of the Northeastern Mediterranean is a debated topic (Baltaci et al., 2018; Criado-Aldeanueva and Navarro, 2020; Lemus-Canovas, 2022). They may not be straightforwardly related to local weather patterns. In such cases, besides large-scale climate indices, Stenseth et al. (2004) suggested using the traditional approach which incorporates local temperature conditions of the study area as an indicator of climate.

It is also worth mentioning that the variable relationships between both CPUEs and climate indices might be caused by removing auto-correlation (Pyper, 1998). In such cases, instead of pre-whitening and differencing, one can choose to adjust the hypothesis and smooth the data set (Pyper, 2011). Nevertheless, removing auto-correlation before the analyses have increased fisheries and ecological studies (Mellin et al., 2010; Milicich et al., 1992; Probst et al., 2012; Tsikliras et al., 2019).

The results indicate that variability in the large-scale climate indices significantly impacts CPUEs of particular seasons. Although they cannot explain the abrupt changes in CPUEs in the 1990s, we demonstrated their potential to be used as a proxy for regional climate. However, assessing the influence of climate variability on fish stocks is challenging in complex environments such as the Mediterranean. The effects of climate change on marine fauna can have an additive, synergistic or antagonistic with the anthropogenic impacts (Rose, 2004; Sala & Knowlton, 2006). Given the region's predicted temperature increments in the future, other environmental drivers should be incorporated into models to develop a comprehensive picture.

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Conflicts of Interest

No potential conflict of interest was reported by the authors.

Ethical approval

All applicable national guidelines for the care and use of animals were followed.

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