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Influence of some physico-chemical variables on wild fish richness beneath sea-cage fish farms in the Aegean Sea, Turkey

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Abstract

This study aims to determine the relationship between physico-chemical variables on a seasonal basis and wild fish assemblages beneath sea-cage fish farms. Assemblages of wild fish were counted monthly on two separate days at each of six fish farms between August 2015 and July 2017, by six rapid visual counts (RVC) in 5 minutes with scuba by two divers. Seawater samples were simultaneously taken by a Nansen bottle during the RVC from the fish farm barge. SST (°C), salinity (ppm), dissolved oxygen (mg l^{-1}) and pH were measured by YSI multiparameter, while Secchi disk was also used for light transmittance. Wild fish species richness went up with increasing temperature and salinity in the Izmir region, however, this stopped at about 26°C and about 39 ppm. Wild fish richness increased when the DO was at a level of 7 mg l^{-1} and the pH at about 7.9 in Izmir. Between 10 and 20 m, light transmittance showed greater wild fish species richness in Izmir region. In contrast, the wild fish species richness of the Muğla region fluctuated more. In terms of wild fish species richness, these fluctuations increased with salinity and DO, while they decreased with SST, pH and light transmittance. However, the range of variation of the recorded physico-chemical variables is rather narrow. The results of the correlation matrix indicate that the relationship between wild fish species richness and pH and SST was statistically significant in Izmir region ($P < 0.05$).

Introduction

Water quality in an aquaculture area is an essential factor leading to success or failure. A water quality variable can be considered as any characteristic of water that affects survival, reproduction, growth and production of fish species, influences management decisions, causes environmental impacts, or reduces product quality and safety (Boyd & Tucker, 1998). In general, the metabolic rates of fish are governed by controlling (e.g. temperature) and limiting (e.g. metabolites, food, water and respiratory gases) factors (Oppedal *et al.*, 2011). For instance, water temperature affects the natural productivity of aquatic ecosystems, all other water quality variables directly or indirectly, and seasonal changes in temperature, like the other environmental conditions, may also exert primary control over the vital cycles of aquatic animals (Boyd & Tucker, 1998). In fact, each physico-chemical variable has greater or lesser such effects on fish.

The natural environment is rarely stable and fish have to adapt constantly to environmental changes. If change limits and rates are exceeded or the normal physiological functions and controls become damaged, then stress occurs (Svobodová *et al.*, 1993). Furthermore, wild fish assemblages are also related to the water mass, with requirements of rich nutrients, correct temperature, dissolved oxygen and other suitable conditions (Svobodová *et al.*, 1993). Wild fish species can thus be affected by physico-chemical parameters, where they are found around sea-cage fish farms. Wu *et al.* (1999) stated that the main physico-chemical parameters that need to be considered in aquaculture systems include water temperature, salinity, dissolved oxygen, pH and ammonia levels. Also, Perez *et al.* (2003) indicated that enrichment of the water column with dissolved nutrients and bottom sediments with organic matter as a result of culturing finfish in sea-cages have been identified as real and potential environmental impacts of fish culture. It is obvious that marine aquaculture will influence waters near them via waste production and organic matter release that causes degraded water quality. However, these small-scale effects of water quality are quite limited and temporary, and normally do not exceed 25–30 m from sea-cages in terms of impact on the benthic environment (Machias *et al.*, 2004, 2006). Although any effect on water quality is likely to occur over short spatial scales, fish farming zones in the oligotrophic waters of the eastern Mediterranean attract a higher abundance and biomass of wild fish which could be attributed to a local increase in productivity (Pitta *et al.*, 2006). Abundance of wild fish is known to be greater around sea-cage fish farms in the Mediterranean, especially Spanish coasts (Dempster *et al.*, 2002, 2004, 2005; Valle *et al.*, 2007; Fernandez-Jover *et al.*, 2008; Bacher *et al.*, 2012) and in the Adriatic (Segvic Bubic *et al.*, 2011). However, there is a gap in knowledge of wild fish

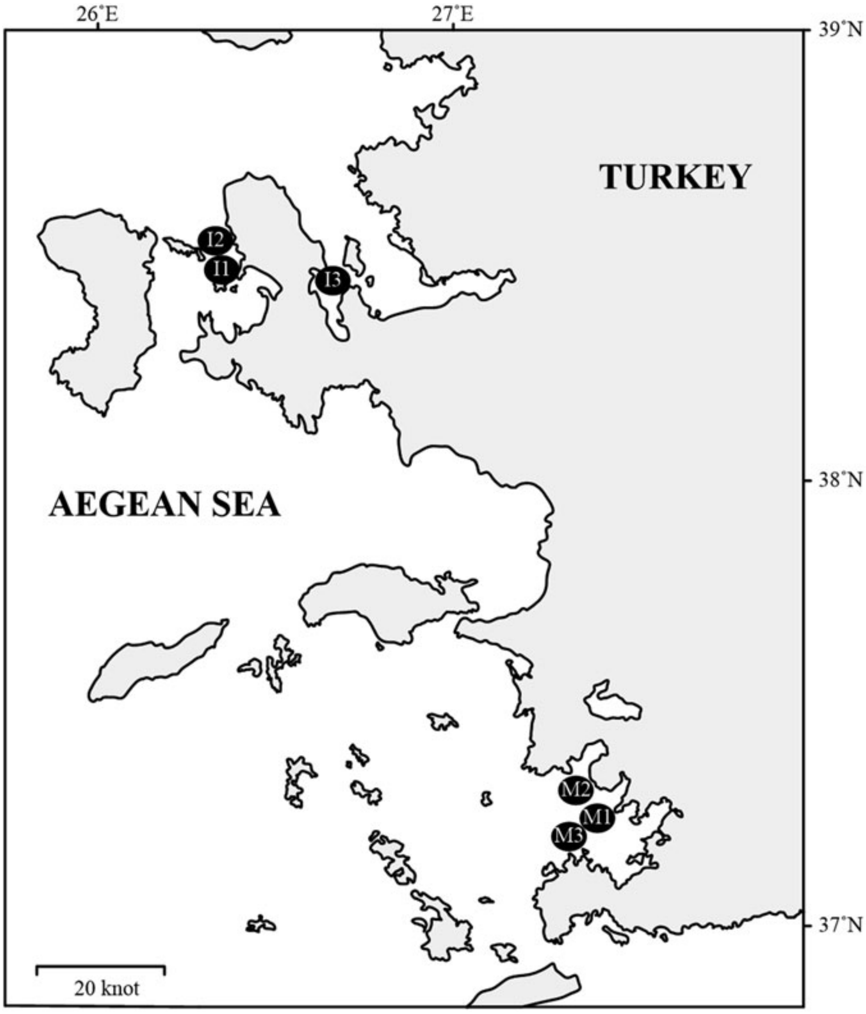

Fig. 1. The fish farms studied in the Aegean Sea. M1, M2 and M3 = southern Aegean Sea (SAS); I1, I2 and I3 = northern Aegean Sea (NAS).

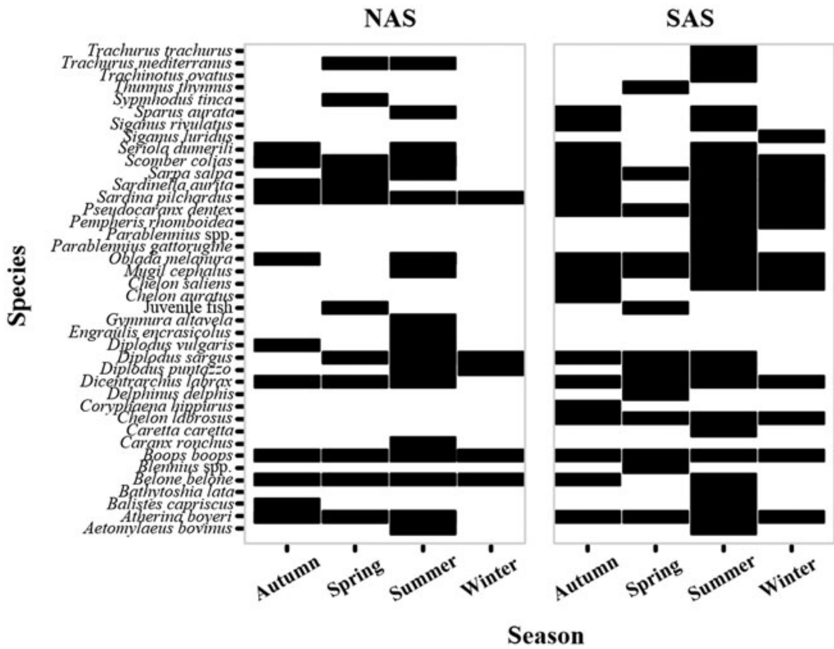

Fig. 2. Fish species, observed beneath sea-cage fish farms on a seasonal basis during the sampling periods in the Aegean Sea. SAS = southern Aegean Sea; NAS northern Aegean Sea.

communities beneath sea-cage farms and relationships between some physico-chemical variables and wild fish richness in the eastern Mediterranean.

Svobodová *et al.* (1993) concluded that substances which contaminate the aquatic environment could be harmful, not only by their direct effects on the organisms there. However, there was only a limited amount of information on this association, which was mainly related to experiences with farmed fish. The authors stated that the limited number of environmental stressors involved – low dissolved oxygen, extremes of temperature and pH, and ammonia – were probably due to the siting of fish farms in relatively unpolluted waters.

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Table 1. Minimum, maximum and average values of measured physico-chemical parameters at the sea-cage fish farms, studied in the Aegean Sea. M1, M2 and M3 = southern Aegean Sea (SAS); I1, I2 and I3 = northern Aegean Sea (NAS)

	Stations	M1	M2	M3	I1	I2	I3
SST	Minimum	14.6	15.8	14.1	14.0	15.0	13.3
	Maximum	27.5	28.0	28.0	23.6	23.9	25.5
	Mean ± SE	21.7 ± 1.4	21.4 ± 1.4	20.9 ± 1.3	19.4 ± 1.0	19.5 ± 0.9	19.7 ± 1.3
Salinity	Minimum	38.5	35.1	35.7	33.1	36.1	34.0
	Maximum	40.5	39,3	41.1	39.5	39.8	40.9
	Mean ± SE	38.5 ± 0.5	38.3 ± 0.5	38.9 ± 0.4	37.9 ± 0.6	38.9 ± 0.3	38.7 ± 0.5
DO	Minimum	4.7	5.1	4.7	5.6	4.8	5.7
	Maximum	8.4	8.5	8.2	8.2	9.3	9.7
	Mean ± SE	6.2 ± 0.3	6.4 ± 0.3	6.6 ± 0.3	7.0 ± 0.2	6.9 ± 0.4	7.5 ± 0.4
pH	Minimum	7.7	7.8	7.5	7.2	7.8	7.9
	Maximum	8.3	8.2	8.1	8.1	8.0	8.1
	Mean ± SE	7.9 ± 0.04	7.9 ± 0.03	7.8 ± 0.04	7.8 ± 0.08	7.9 ± 0.08	7.9 ± 0.08
Secchi disk	Minimum	5.8	4.3	6.9	13.8	10.4	6.3
	Maximum	11.5	20.7	28.2	26.5	16.1	15.5
	Mean ± SE	8.3 ± 0.5	10.0 ± 1.5	16.0 ± 1.8	17.8 ± 1.4	14.3 ± 0.6	10.3 ± 0.8

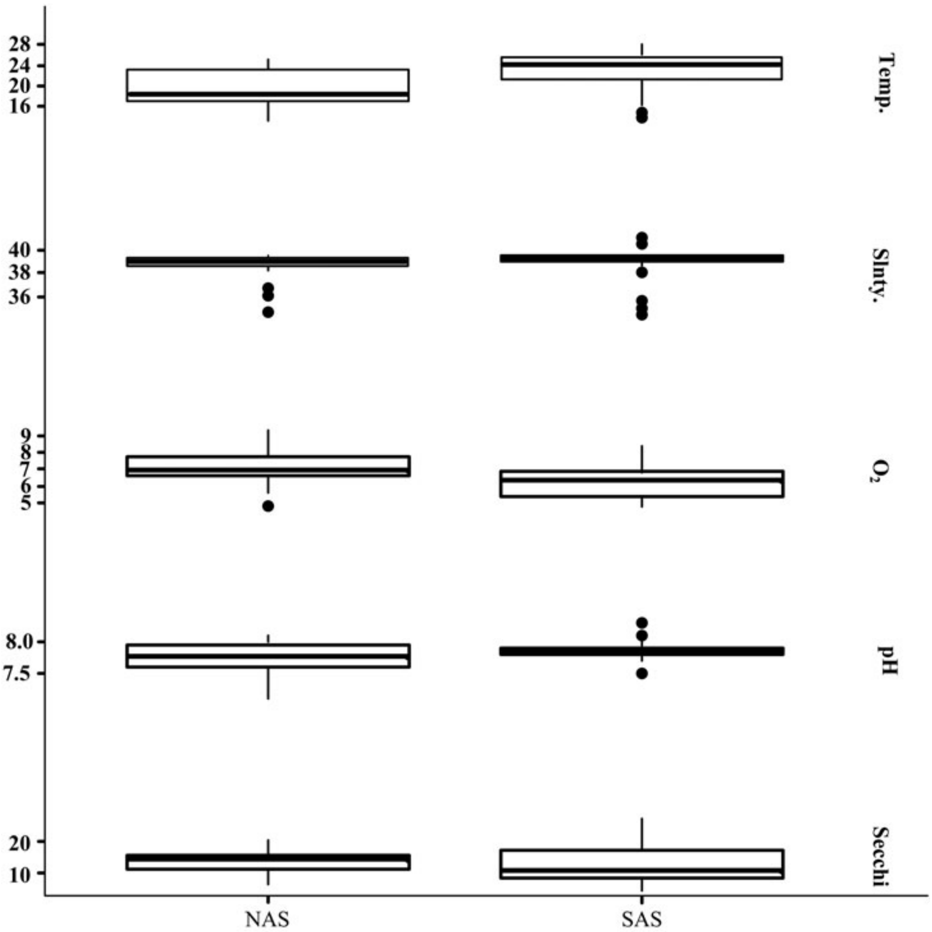

Fig. 3. Range of variation of recorded physico-chemical variables by region at the sea-cage fish farms in the Aegean Sea. Temp., sea surface temperature (°C); Slnty., surface salinity (ppm); O_2, surface DO (mg l^{-1}); pH, surface pH; Secchi, water transparency or turbidity (m).

There are some studies on seasonal changes in environmental variables (especially on nutrients and plankton) related to Mediterranean aquaculture (Pitta *et al.*, 1999; Karakassis *et al.*, 2001; La Rosa *et al.*, 2002; Aksu & Kocataş, 2007; Neofitou & Klaoudatos, 2008; Kaymakci Basaran *et al.*, 2010; Gürses *et al.*, 2019), but there is a lack of research on wild fish species richness. Thus, this study aims to determine the influence of some physico-chemical variables, i.e. sea surface temperature (SST), salinity, dissolved oxygen (DO or O_2), pH, and light transmittance, on wild fish species richness beneath

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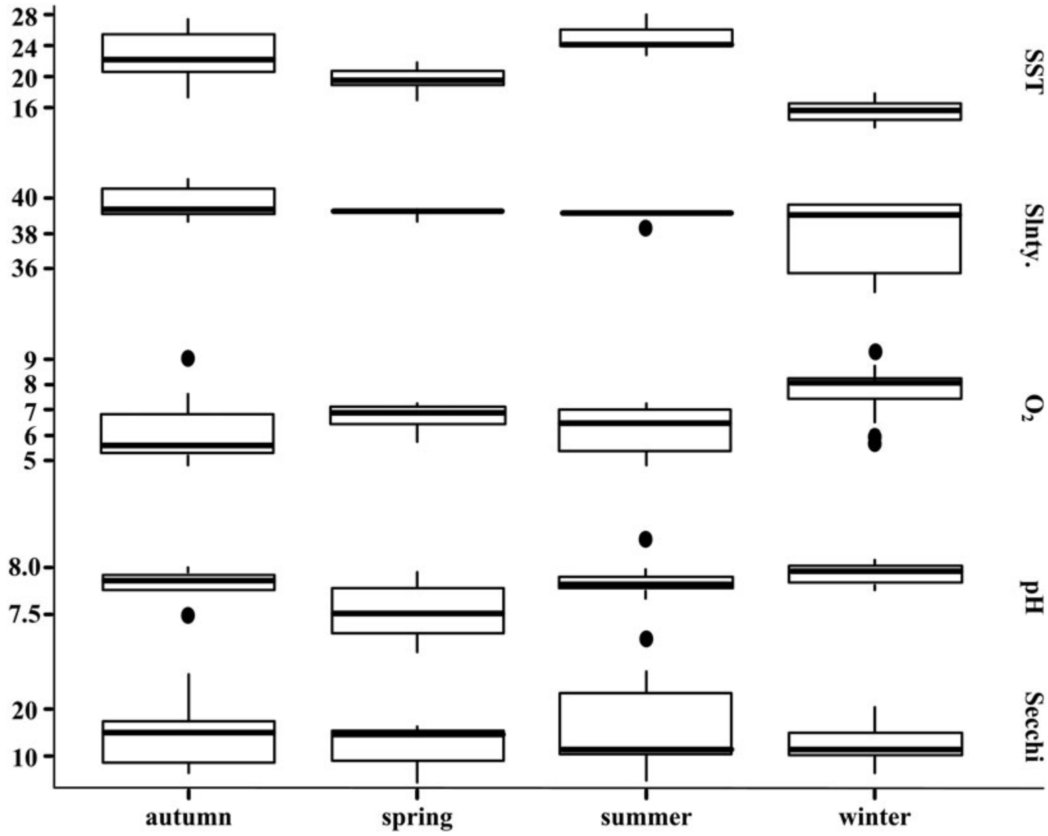

Fig. 4. Range of variation of recorded physico-chemical variables by season at the sea-cage fish farms in the Aegean Sea. SST, sea surface temperature (°C); Salinity, surface salinity (ppm); O_2, surface DO (mg l^{-1}); pH, surface pH; Secchi, water transparency or turbidity (m).

sea-cage fish farms in two zones (northern and southern) of the Turkish Aegean Sea.

Materials and methods

Study site

The selected fish farms are located in the northern Aegean Sea (NAS) and the southern Aegean Sea (SAS) (Figure 1). Each fish farm was coded as I1, I2, I3 (i.e. İzmir) for NAS and M1, M2, M3 (i.e. Muğla) for SAS. All fish farms were cultivating *Sparus aurata* and *Dicentrarchus labrax*. They were deployed between 720 m and 3 km away from the coast. Area usage of the farms ranged from 1200 and 70,000 m^2, off-shore type cage diameters were between 12 and 50 m, and fish cages were deployed at depths of 35–60 m.

Sampling design

Between August 2015 and July 2017, assemblages of wild fish were counted monthly on two separate days at each of these farms. A total of 12 dives in the NAS, and 12 dives in the SAS were done for each station. Data were pooled according to the season. In terms of seasons, winter consists of December, January and February; spring is March, April and May, summer is June, July and August, autumn is September, October and November. Six Rapid Visual Counts (RVC; Dempster *et al.*, 2004) over 5 minutes carried out with scuba by two divers, covering 11,250 m^3 were performed at each fish farm. Fish farms at least 5–10 km away from each other. The bottoms underneath the sea-cages were sandy or muddy without sea meadows. Seawater samples were simultaneously taken by a Nansen bottle during the RVC from the barge of each fish farm. All diving and sea surface water sampling was carried out at midday (10.00–14.00). SST (°C), salinity (ppm), dissolved oxygen (mg l^{-1}) and pH were measured by YSI multiparameter (YSI Incorporated, USA), while a Secchi disk was used for light transmittance.

Statistical analysis

Multiple linear regressions were used to explore the relationship between wild fish species richness and recorded physico-chemical variables. In order to assess the dependence between recorded variables, a correlation matrix (correlation coefficients between each variable and the others) was computed. Since linear models are quite restrictive in terms of the trends they can fit, local polynomial regression fit was used to explore more complex trends in the relationship between species richness and the recorded physico-chemical variables. Given that species richness increases with sample size, and differences in richness actually may be caused by differences in sample size, prior to any analysis, the response variable, species richness, was rarefied to the minimum sample numbers (Hurlbert, 1971). All univariate and multivariate statistical analyses were carried out by using R statistical software (R Core Team, 2017).

Results

A total of 40 species including juvenile fish, belonging to 22 families were recorded at six fish farms. In the autumn, 11 species in the NAS (Izmir) and 19 species in the SAS (Muğla) were found (Figure 2). The total number of taxa seen per season and area, Izmir and Muğla varied between 5 and 28, respectively, with lowest taxa for winter in the NAS.

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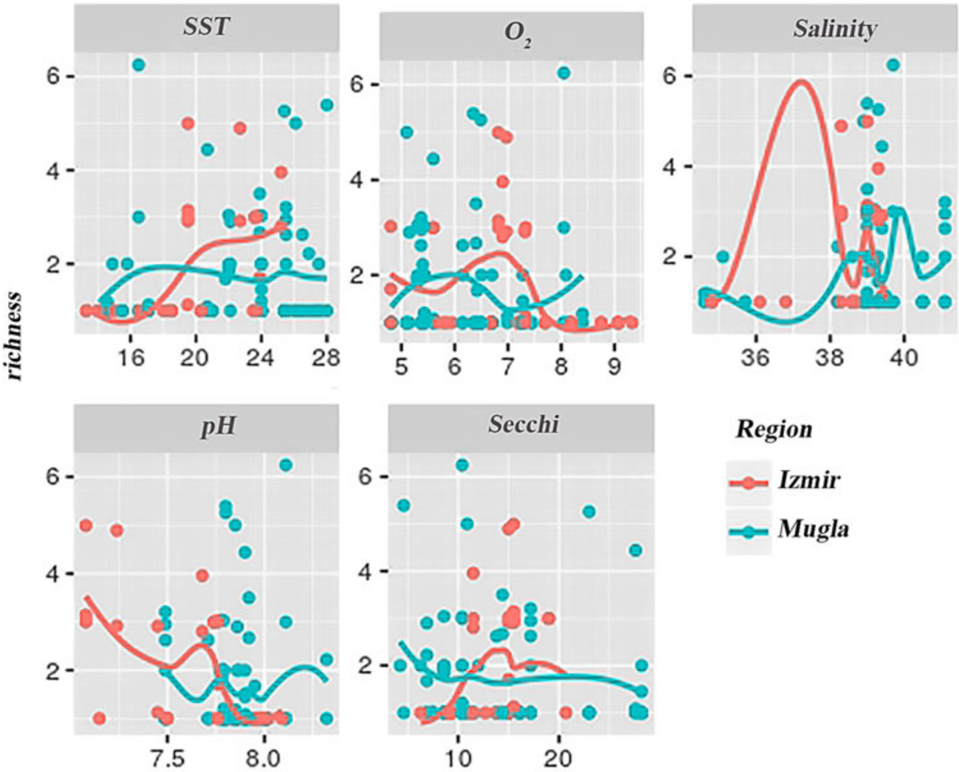

Fig. 5. Relationship between wild fish species richness and some physicochemical variables by region at the sea-cage fish farms in the Aegean Sea. SST, sea surface temperature (°C); Salinity, surface salinity (ppm); O_2, surface DO (mg l^{-1}); pH, surface pH; Secchi, water transparency or turbidity (m).

During the survey, measured values of some physico-chemical parameters at the sea-cage fish farms (i.e. M1, M2, M3, I1, I2, I3 stations) are indicated in Table 1. According to box plots, means of SST, salinity and pH values in the SAS were higher and light transmittance and DO were higher in the NAS (Figure 3). Seasonally, SST in summer, salinity in autumn, DO and pH in winter and light transmittance (Secchi disk) in autumn had the highest average value, whereas, salinity in winter, SST in autumn, DO in autumn and summer, pH in spring, and light transmittance in summer and autumn had the wider range (Figure 4).

According to the region, in the NAS, species richness went up with increasing temperature and salinity, however, this trend stopped at ~26°C and ~39 ppm. Also, species richness increased when DO was at a level of 7 mg l^{-1} and pH was ~7.9 and between 10–20 m, the light transmittance had shown the richness decreasing with depth in the SAS. These fluctuations increased with salinity and DO, and decreased with SST, pH and light transmittance (Figure 5). Seasonally, species richness tended to increase with SST, salinity and light transmittance during the summer and autumn (Figure 6). The correlation matrix between species richness and some physico-chemical variables is indicated in Table 2 and Figure 7. In general, the range of variation of the recorded physico-chemical variables is rather limited. According to region, statistical significance of the results of the correlation matrix between physico-chemical variables and species richness are shown in Table 3. The correlations of SST and pH between species richness were statistically significant in the NAS ($P <$ 0.05). Most of the physico-chemical variables (except SST and salinity) have negative correlations with species richness in the SAS, however, there was no statistically strong evidence to reject the null hypothesis.

Discussion

In general, the mean values of physico-chemical parameters herein were within the normal range for fish tolerance. The average value of SST in the SAS was higher by at least 1.5–2.3°C than that recorded in the NAS. The annual temperature in the SAS seemed to be the most important physico-chemical parameter for wild fish aggregations. The identified mean SST thresholds (between 19.4°C in I1 and 21.7°C in M1) may appear relatively close to each other, however, fish are poikilotherms and are sensitive to changes in thermal conditions of their environment (Roubeix *et al*., 2017). Hence, some Lessepsian migrant fish and

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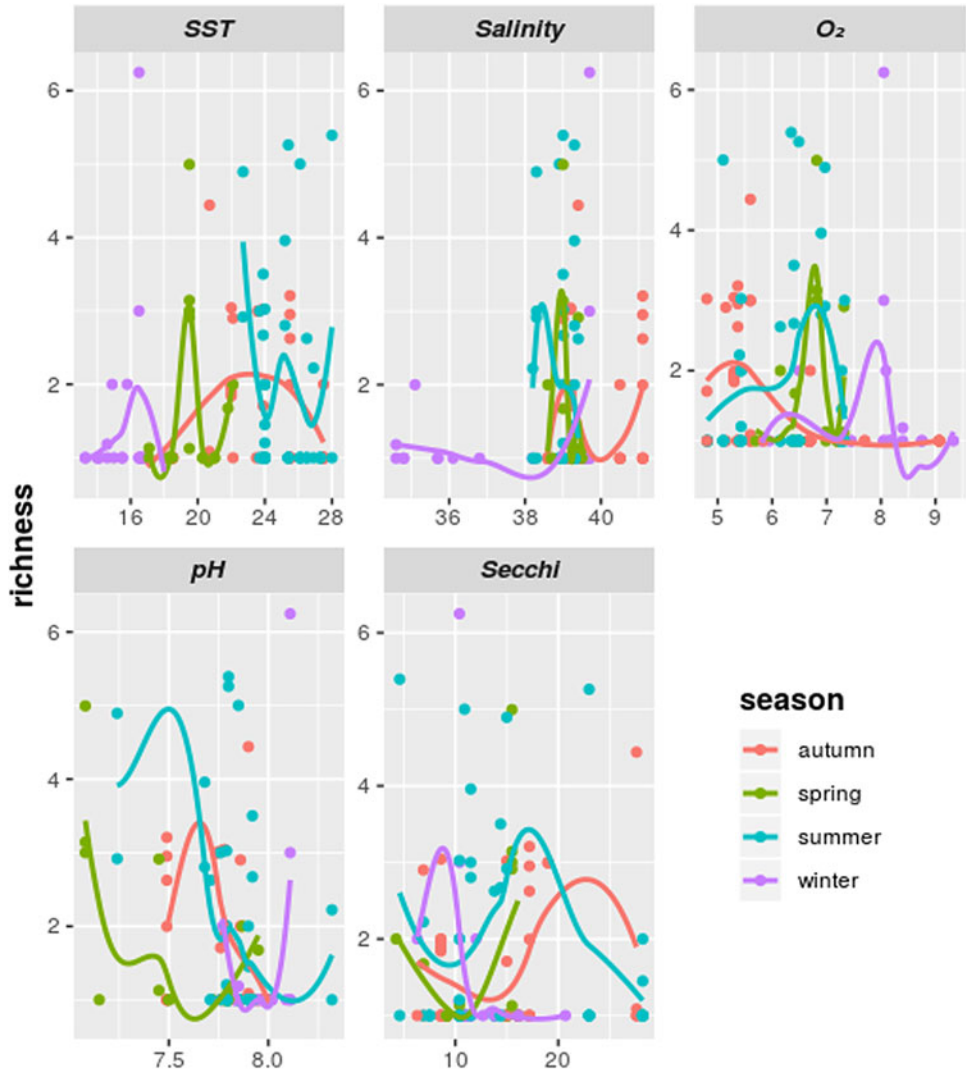

Fig. 6. Relationship between wild fish species richness and some physico-chemical variables by season at the sea-cage fish farms in the Aegean Sea. SST, sea surface temperature (°C); Salinity, surface salinity (ppm); O_2, surface DO (mg l^{-1}); pH, surface pH; Secchi, water transparency or turbidity (m).

Table 2. Correlation matrix between physico-chemical variables and richness

	SST	Salinity	DO	pH	Secchi	Richness
SST		0.47	−0.65*	−0.13	0.05	0.15
Salinity	0.47*		−0.41*	−0.18	0.14	0.09
DO	−0.65*	−0.41*		0.19*	0.04	−0.13
pH	−0.13	−0.18	0.19*		−0.10	−0.30*
Secchi	0.05	0.14	0.04	−0.10		−0.02
Richness	0.15	0.09	−0.13	−0.30*	−0.02	

*Statistically significant ($P < 0.05$).

thermophilic fish such as *Pseudocaranx dentex* were only observed around the sea-cage fish farms in the SAS.

In terms of salinity, this fluctuated more in the Izmir region. Salinity peaked between August and September with slightly higher values in M3 (max. 41.1 psu) and I3 (max. 40.9 psu) stations. This was expected due to increasing horizontal surface salinity with >38 psu towards to northern Lesvos Island in the Aegean Sea (Oğuz, 2015). In contrast DO increased during the winter season (i.e. December, January and February), and decreased during the spring (i.e. March, April and May) and summer season (i.e. June, July and August). DO has a lower value in the SAS owing to the warmer waters. There is an inverse relationship between temperature and DO, and DO in the Aegean Sea has low saturation values due to high salinities and temperatures (Izdar *et al*., 2015, Kadak & Aras, 2017). In other words, the solubility of oxygen decreases as water temperature increases. Furthermore, the factor most frequently responsible for notable reductions in the oxygen concentration of the water (oxygen deficiency) is pollution by biodegradable organic substances (Svobodová *et al*., 1993). Namely, DO may fall to unhealthy levels

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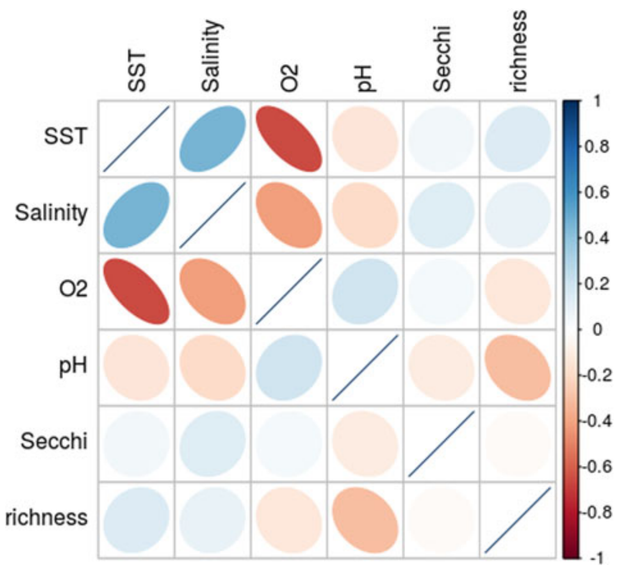

Fig. 7. Correlation matrix between physico-chemical variables and wild fish species richness (the colour codes on the right side shows the correlation coefficient as r^2). SST, sea surface temperature (°C); Salinity, surface salinity (ppm); O_2, surface DO (mg l^{-1}); pH, surface pH; Secchi, water transparency or turbidity (m).

if water is polluted. Relatively high presence of organic matter (personal observation and Secchi disk measurements) around the sea-cage fish farms in the SAS sites explains the lower DO levels than those of the NAS sites. We observed that the sea-cage fish farms in the SAS were at a higher stocking density than in the NAS, and cages were closer to each other. It is obvious that fish diversity increases in the warmer season (i.e. from June to September) that has lower DO values and probably, this phenomenon causes the negative correlation with DO in Table 3.

In terms of pH, all stations have optimal pH range (7–8.5; see Bhatnagar & Devi, 2013) for fish, and the previously measured pH range in the Aegean Sea is between 7.0 and 8.4 (Izdar *et al*., 2015). Levels below 6.5 pH lead to a decrease in reproduction of fish (Stone *et al*., 2013), conversely, alkaline pH higher than 8.8 could cause gill irritation and death of the fish (Dastagir *et al*., 2014). In this study, mean pH with 7.9 ± 0.08 was close to alkaline and high alkaline pH can occur in eutrophic reservoirs (Svobodová *et al*., 1993). There is also an inverse relationship between CO_2 and pH level, therefore, CO_2 decreases with warmer seasons and pH increases or vice versa (Izdar *et al*., 2015; Kadak & Aras, 2017). So, the higher means of pH as measured in SAS were as expected (Figure 3).

Light transmittance was higher at the M3 site, while lower at M1 and M2. The reason for this, was that M3 station has higher currents in the southern entrance of Gulluk Bay (i.e. open sea), while M1 and M2 stations have weak currents near coves in the north of the bay. Additionally, plenty of pellet foods have been used in this part of the bay, and intense suspended solids might be contributing to the turbidity. Price *et al*. (2015) suggested that the proper siting of sea-cages to ensure flushing and improvements in feed composition and feeding efficiency which reduces feed waste were general management guidelines recommended to minimize aquaculture effects on turbidity, and the use of fish feed with low fines (i.e. feed dust particulates) would further minimize turbidity effects. Regionally, average light transmittance in the NAS was higher by at least 0.3–9.5 m than that of the SAS. This can be attributed to the increase in organic matter (especially plankton) due to the high water temperature in the SAS. Vargas-Machuca *et al*. (2008) stated that when working with fish densities of 2500–3500 per cage and small quantities of food (60 ton year^{-1}), no impact was made on the water column quality in the floating cage culture systems, and long periods of cultivation might lead to variations in pH, transparency (or light transmittance) and DO. Namely, water quality deterioration can be connected with the long-term deployment of sea-cages, density of cages and quantity of pellet food. As stated by Vargas-Machuca *et al*. (2008), the scale of environmental impact would depend on the amount of waste generated by the sea-cages, which is driven by the stocking density, quantity and type of feed, feed composition, size of pellets and the hydrographic conditions where cages were located.

During the underwater observations, we detected remarkable aggregations of wild fish beneath the sea-cage farms; however, in the Muğla region in the SAS this was more intense and more diverse. In total, 40 fish species were identified during the study. The fish observed were typical Aegean Sea fish species. The fish diversity found in this study is one of the higher biodiversities found in western Mediterranean studies (Dempster *et al*., 2002, 2004; Valle *et al*., 2007; Fernandez-Jover *et al*., 2008; Arechavala-Lopez *et al*., 2011; Bacher *et al*., 2012). However, we identified just four Lessepsian immigrant fish (*Siganus luridus*, *S. rivulatus*, *Stephanolepis diaspros* and *Pempheris rhomboidea*) beneath the sea-cages. These thermophilic fish species must have come because of the increasing temperatures in the area. It is well known that fish abundance and diversity increase more towards the southern part of the Aegean Sea (Kocataş & Bilecik, 1992). The fish farms, which have less fish diversity and abundance in the NAS may be affected by the Black Sea water mass with cooler and fresher characteristics entering the Aegean Sea via the Çanakkale Strait (Oğuz, 2015). In other words, intense species richness in the SAS is due to warmer sea conditions (i.e. southern latitudes). Bilecenoğlu (2015) supports this hypothesis in that boreal and pontic forms concentrate in the NAS such as *Sprattus sprattus*, *Merlangius merlangus* and *Neogobius melanostomus*, and thermophilic/subtropical forms are more commonly found in the SAS. Additionally, Fernandez-Jover *et al*. (2008) demonstrated that fish communities around fish farms change depending on environmental conditions, such as coastal morphology, distance to the coast, currents and depth, farm characteristics, such as the quantity of feed being lost, and the composition of the fish fauna in surrounding waters. Moreover, Machias *et al*. (2006) analysed the data from time series of fish landings, fish farming production, fishing fleet, temperature and rainfall based on the minimum–maximum auto-correlation factor analysis (MAFA), and the results suggested that increased fish farming activity in enclosed, oligotrophic areas could mean an increase in fisheries landings. Thus, intensive fish farming could be an important explanatory factor regarding changes in fish production in certain areas. The parameters mentioned above should be considered separately in future studies.

In conclusion, linear models result in very poor fit to the data (confirmed by the almost total lack of statistically significant coefficients in the correlation matrix). It is clear from the exploratory analysis of the data that the fitted relationships between species richness and physico-chemical variables are non-linear functions. Wild fish species richness near sea-cages is affected variably by physico-chemical factors, region and seasons. It seems that SST, pH, salinity and DO are the main determinants. However, additional studies are needed on the effects of chlorophyll *a*, nutrients, sea currents, meteorological conditions (i.e. wind, waves, rain, etc.), pellet foods and benthic conditions for improved understanding of the reasons for wild fish aggregations beneath sea-cage farms.

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Table 3. Correlation matrix between physico-chemical variables and wild fish species richness near sea-cage farms according to region

	NAS		SAS	
Physico-chemical variables	Correlation	*P*-value	Correlation	*P*-value
SST	0.5464	0.0003*	0.0142	0.9016
Salinity	0.1501	0.3618	0.0763	0.5068
DO	−0.2736	0.0920	−0.0648	0.5730
pH	−0.6408	0.0000*	−0.0196	0.8651
Secchi	0.2694	0.0972	−0.0870	0.4491

*$P < 0.05$.

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