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RESEARCH ARTICLE **ARAŞTIRMA MAKALESİ**

Fish diversity and community structure of a wetland system of the western Mediterranean Basin of Türkiye: Lake Koca (Dalaman)

Türkiye'nin Batı Akdeniz Havzası'ndaki bir sulak alan sisteminin balık çeşitliliği ve topluluk yapısı: Koca Göl (Dalaman)

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Abstract: Lake Koca (Dalaman), a wetland in the western Mediterranean basin of Türkiye, is an extraordinary lake with salty, fresh, and sulfurous waters and is home to high biodiversity. The present study examines the spatial and seasonal variation in fish communities and assesses the influence of environmental parameters on the community structure of Lake Koca. A total of 1.530 specimens were captured, representing seven families and 11 species (2 non-native, 1 introduced, and 8 native species). Total fish abundance and richness were higher at the littoral than at the limnetic zone, but no seasonal variation was observed. Non-native fish species, *Coptodon zillii*, was the most abundant in the littoral zone, followed by species of Mugilidae. The abundance of the two endemic fish species (*Capoeta aydinensis* and *Ladigesocypris irideus*) was relatively low in both habitats. Shannon-Wiener diversity index and evenness did not vary seasonally and spatially. Fish abundance and richness were significantly and positively correlated with chlorophyll-a and macrophyte coverage while negatively correlated with depth. Spearmen's Correlation analysis revealed that native fish species show a relationship with the chemical parameters of the water, while *C. zillii* showed a distribution related to depth and macrophyte density. Both anthropogenic activities and the presence of non-native fish may affect the distribution and abundance of endemic fishes.

Keywords: Fish biodiversity, seasonal variation, assemblage structure, environmental parameters, non-native fish, Lake Koca

Öz: Türkiye'nin Batı Akdeniz havzasında bir sulak alan olan Koca Göl, tuzlu, tatlı ve kükürtlü suları ile sıradışı bir sistem olup, yüksek biyolojik çeşitliliğe ev sahipliği yapmaktadır. Bu çalışma, balık topluluklarındaki mekansal ve mevsimsel değişimi incelemekte ve çevresel parametrelerin Koca Gölü'nün balık toplulukları üzerindeki etkisini değerlendirmektedir. Çalışmada yedi familya ve 11 türü (2 yabancı, 1 taşınmış ve 8 yerli tür) temsil eden toplam 1.530 örnek yakalanmıştır. Toplam balık bolluğu ve zenginliği littoral bölgede limnetik bölgeye göre daha yüksek bulunmuş, ancak mevsimsel bir değişiklik göstermemiştir. Yabancı balık türlerinden, *Coptodon zillii*, littoral bölgede en bol bulunan türdür ve bunu Mugilidae'ye ait türler izlemiştir. İki endemik balık türünün (*Capoeta aydinensis* ve *Ladigesocypris irideus*) bolluğu her iki habitatta da nispeten düşük bulunmuştur. Shannon-Wiener çeşitlilik indeksi ve düzgünlüğü mevsimsel ve mekansal farklılık göstermemiştir. Balık bolluğu ve zenginliği, klorofil-a ve makrofit kapatıcılığı ile anlamlı ve pozitif bir şekilde ilişkiliyken, derinlik ile negatif bir şekilde ilişkilidir. Spearmen Korelasyon analizi, yerli balık türlerinin suyun kimyasal parametreleri ile ilişki olduğunu, *C. zillii*'nin ise derinlik ve makrofit yoğunluğuna bağlı bir dağılım gösterdiğini ortaya koymuştur. Bu sulak alanda hem antropojenik faaliyetler hem de yabancı balıkların varlığı, endemik balıkların dağılımını ve bolluğunu etkilemiş olabilir.

Anahtar kelimeler: Balık biyoçeşitliliği, mevsimsel varyasyon, topluluk yapısı, çevresel parametreler, yabancı balıklar, Koca Göl

INTRODUCTION

Among ecosystems with high biodiversity, wetlands cover only about 1% of the Earth's surface but provide habitat for about 20% of the world's species (Cheng et al., 2012). Species community structures of highly biodiverse wetland lakes exhibit spatial and seasonal variations (Fitzgerald et al., 2017; Jin et al., 2019). Wetland hydrology affects organisms' population and community dynamics by affecting abiotic factors (Winemiller et al., 2000). In summer, when the depth of wetland is low, high temperature, hypoxia, and predation can cause a decrease in fish species diversity and abundance, while an increase in depth can increase fish diversity as it causes habitat stability (Cvetkovic et al., 2010; Grubh and Winemiller, 2018). In addition, most fish species in a wetland system use coastal areas as seasonal or ontogenetic stages of development (Westrelin et al., 2018) for feeding, spawning, nursery, or shelter habitat (Lewin et al., 2004; Matern et al., 2021). The aquatic vegetation in wetlands increases the spatial complexity and heterogeneity of these ecosystems (Marin Avendaño and Aguirre Ramírez, 2017), supporting production, high species diversity (Dustin and Vondracek, 2017), and consequently, food web complexity (Carey et al., 2010; Ziegler et al., 2015).

Lake Koca is a wetland under a special environmental protection zone with 395.03 ha. It is located in the western Mediterranean basin of Türkiye, within the borders of the Dalaman district of Muğla in Türkiye (Ayaz et al., 2013). This area is surrounded by mountains and seas and is connected to the Mediterranean Sea by a natural channel covered with reeds. Lake water is slightly sulfurous due to the hot springs around the lake (Ayaz et al., 2013). In the past, the lake was fed by floodwaters coming from Tersakan Stream. However, when the direction of the stream was changed due to flood prevention in 1974, it caused the natural seasonal hydrological cycles to change. In addition, the high reinforced concrete bridge built on the canal connecting the Tersakan stream channel and Lake Koca caused the reinforcement to narrow and shallow with reeds, and as a result, migrating fish species such as Mugilidae species and *Anguilla anguilla*, etc. were prevented easy entry and exit between the sea and the lake (Şahin, 2019a). Some practices such as tourism, agriculture, and animal husbandry are significant threats to the area. In addition, it has been reported that some parts of the area are dried due to the existing airport and the agricultural fields (Şahin 2019b), and invasive fish species (*Carassius gibelio, Gambusia* sp.) were introduced into the lake several times (Şahin, 2019b).

Koca Lake wetland is one of Türkiye's richest and most sensitive in terms of ecosystem and species diversity due to its geographical location. Because it is an essential habitat for two endemic freshwater fish, *Capoeta aydinensis*, *Ladigesocypris irideus*, a butterfly species called Ottoman fire (*Lycaena ottomana*), Mediterranean monk seal (*Monachus monachus*), otter (*Lutra lutra*), the sea turtle (*Caretta caretta*), and many aquatic avian species, which are endangered on a world scale (Kıraç and Suseven, 2021), despite its national and global importance as a significant wetland supporting a wide diversity of animal taxa, but little information has been gathered about fish fauna. Yılmaz et al., (2006) conducted a taxonomic study on fish species in some inland waters of Muğla, including Lake Koca. There is no published article on the fish fauna of Lake Koca and its physicochemical properties. Research is urgently needed to understand sustaining biodiversity and ecosystem services and the value of floodplain lakes. The overall goal of this study is to describe spatial and seasonal variation in fish community structure (species richness, diversity, abundance, and evenness) in a wetland lake (Lake Koca) to investigate relationships between local environmental conditions and fish community structure. It is very important to reveal the current status of fish community in such a wetland system which is under anthropogenic pressure. This article presents the first detailed study of fish community structure in the Koca Lake.

MATERIALS AND METHODS

Study site

This study was carried out in the northwestern part of Lake Koca, a wetland lake in Türkiye. The lake is located within the borders of Kapukargın Village in southwest Türkiye and has hydrological connections to the Tersakan Stream and the Mediterranean Sea (Figure 1). While Tersakan Stream had a direct connection with the sea in the past, but today this connection is provided by narrow drainage channels. The lake's depth varies between 1 to 20m (Ayaz et al., 2013). The northwestern area of the lake is flat, and its depth is less than the southeastern part of the lake. There are Kargın and Sulfur lakes around Lake Koca. The characteristic Mediterranean climate prevails, summers are hot and dry, and winters are cool and rainy. The average annual temperature in the region is 18.3 °C. The hottest month is July with an average of 27.8°C and the coldest month is January with 10.1°C (Çınar and Ardahanlıoğlu, 2015). The annual average total precipitation is relatively high with 853 mm, of which 55% in winter, 19% in spring, 25% in autumn, and 1% in summer.

The marsh vegetation is also well represented in the wetlands and marshy areas around the littoral zone of Lake Koca, which has extensive stands of aquatic emergent (*Schoenetum nigricantis, Phragmites australis, Juncus maritimus, Typha domingensis),* floating *(Lemna* sp., *Azolla* sp., etc.) and submerged aquatic macrophytes (*Ceratophyllum* sp.*, Myriophyllum* sp., *Potamogeton spp.,* etc.). The coverage percentage of littoral aquatic vegetation is 100% (Çınar and Ardahanlıoğlu, 2015). We determined two different regions in the lake: the first region was located in the littoral zone of the lake which had extensive and dense patches of submerged, floating, and emergent macrophytes; and the second was located in the limnetic zone of the lake which had characterized by mostly a mud bottom with little submerged vegetation, but no floating and emergent macrophytes (Figure 1).

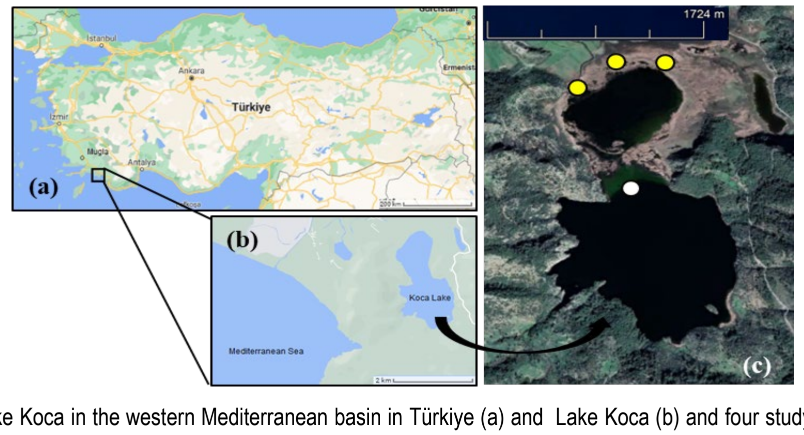

Figure 1. Location of Lake Koca in the western Mediterranean basin in Türkiye (a) and Lake Koca (b) and four study sites (c) within the lake. The yellow circles indicate the littoral sampling zone, and the white one indicates the limnetic zone

Sampling protocol

Two regions (littoral and limnetic sites) of Lake Koca were sampled for fish in winter, spring, summer, and autumn between February 2019 and December 2020. Three different locations were selected for fish sampling in the littoral site. The littoral site was sampled using overnight fyke-net sets with 17 mm mesh (mean soak time = 12 h/fyke net). Four traps for each littoral station were set as a pair with leads (15 m) facing each other and nets oriented parallel to the shoreline. Fish sampling was made from one station at the limnetic site (Figure 1). Fishes were caught using trammel nets with inner nets consisting of four 100 m long panels of 10, 25, 50, 80, and 100 -mm mesh. Trammel nets were set into the water at around 9:00 – 10:00 pm and retrieved at around 9:00 - 10:00 am the following day. After sampling, all fish individuals were treated in accordance with the guidelines of the local ethics committee (Reference number: 93773921). Captured fishes were anesthetized in MS-222 and then fixed in 4% formalin in the field. In the laboratory, samples were sorted, and identified into species (based on studies: Balık et al., 1992; Muus and Nielsen, 1999; Kottelat and Freyhof, 2007; Özuluğ and Freyhof, 2011; Güçlü et al., 2013; Turan et al., 2017; Güçlü et al., 2020), and counted.

Before trammel and fyke netting, temperature (T), dissolved oxygen concentration (DO), conductivity (Cond), and pH were measured at each survey site with a multiparameter probe (YSI Instruments). Depths (m) were measured with a meter stick at the mouth of each fyke and trammel net, and the percent macrophyte cover (MacCov) was assessed for the lead length between the wings for each net (Bhagat and Ruetz, 2011). Braun-Blanquet coverage categories were used to estimate densities from calculated percent macrophyte values (Barbour et al., 1987). For analysis of water quality parameters such as phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+), a one liter sample of surface water was collected within each study station and season. Water samples were immediately placed on ice. In the laboratory, each water sample was filtered through precombusted Whatman GF/F filters (Merck, Darmstadt, Germany). The filtrate was then used to measure soluble PO_4^{3-}, NO_3^-, NO_2^- and NH_4^+ using calorimetric kits and the WTW model Photo Flex Turb (Xylem Analytics Germany Sales GmbH & Co. KG, Weilheim, Germany). To measure chlorophyll (Chl-a), 1 L of water was collected at each site and placed in polyethylene bottles. After the water samples had been filtered through a Whatman GF/F filter, the filters were placed in 90% acetone for 24 h and measured absorbance using a spectrophotometer (at 665, 664, and 750 nm) (Wetzel and Likens, 1991).

Data analysis

Due to the different fishnets used in the lake, fish densities could not be calculated and compared in terms of catches per unit effort (CPUE). Instead, they were presented as the total number of fish obtained to indicate fish abundances roughly. Spatial (site with or without aquatic vegetation) and seasonal changes in fish community metrics were analyzed. Different community metrics were determined for each site and season, including species richness (total number of species (S)), species diversity (Shannon diversity index (H')), numerical abundance (N), species evenness index (E), and species richness index (D). Higher values represent greater diversity (Cheng et al., 2012). These standard indices for each survey were calculated using the following formula:

Shannon diversity indices (H') (Krebs, 1998):

$$H^{\iota} = -\sum_{i=1}^{S} Pi\ log_2\ Pi$$

where *Pi* = the proportion of individuals belonging to the *i*th fish species in the data set. Species richness (S) is the absolute number of species captured in a given area and time. Evenness was calculated to estimate the equitability of species abundances within each community. Species evenness index (J) (Pielou, 1966):

$$J^{\iota} = H^{\iota}/In\ (S)$$

Where *H'* = Shannon-Wiener diversity index and *S* = total number of species. Species richness index (D) (Menhinick, 1964):

$$D = S\ /\ \sqrt{N}$$

Where *S* = number of different species in the sample, *N* = total number of individuals.

A one-way analysis of variance (ANOVA), and a student's t-test were used to compare fish community metrics and environmental parameters among seasons, and sites (littoral vs. limnetic), respectively. Before the analysis of variance, all variables were tested for normality (Shapiro Wilk test), and the homogeneity of variances (Cochran tests). After macrophyte coverage was arcsine–square-root transformed and all environmental data were transformed by log_{10} (x+1), data showed normal distribution. Principal components analysis (PCA) was used to examine spatial and seasonal relationships among environmental parameters. The Pearson correlation coefficient was used to investigate relationships between environmental parameters and fish community metrics. In addition, the degree of association between fish species and environmental parameters was calculated by applying Spearmen's correlation since the abundance data of each fish species did not show normal distribution. All analyses were performed with SPSS version 23.

RESULTS

Spatial and temporal variation in environmental conditions

While seasonal variations in nitrite, nitrate, phosphate, temperature, and pH were statistically significant, depth, chlorophyll-*a,* and macrophyte cover were spatially different. Temperature was highest in summer ($F_{3,7}$=162.421; p=0.000), whereas pH and nitrite were in winter ($F_{3,7}$=17.66; p=0.009;

$F_{3,7}$=124.169, p=0.000, respectively) (Table 1). The nitrate was higher in summer but lower in winter and autumn ($F_{3,7}$=94.93, p=0.000). The phosphate concentration was the highest in autumn ($F_{3,7}$=21.86, p=0.006). The water depth was higher in the limnetic than littoral site (t_6 = -9.727, p=0.000), while chl-a concentration and macrophyte cover were greater in the littoral site (t_6 = 2.936, p=0.026; t_6 = 3.347, p=0.015, respectively) (Table 1, Figure 2).

Table 1. Seasonal and spatial variations in some environmental parameters of Lake Koca

	Winter		Spring		Summer		Autumn	
	Littoral	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**
NH_4^+(mg/l)	0.01	0.01	0.02	0.01	0.02	0.02	0.03	0.02
NO_2^-(mg/l)	1.53	0.97	-	-	0.03	0.02	0.11	0.06
NO_3^-(mg/l)	0.01	0.02	1.23	0.81	2.68	1.04	0.01	0.02
PO_4^{3-}(mg/l)	0.12	0.1	-	-	0.06	0.06	0.44	0.57
T (°C)	13.6	12.5	24.6	23.4	27.6	27	19.4	19
DO (mg/l)	9.01	9.96	10.14	11.16	9.89	10.32	6.18	8.21
pH	8.36	8.3	7.96	7.88	7.99	7.84	8	8.03
Cond (µS/cm)	418	425.63	401	419.87	448	487.6	410	400.65
Chl-a (µg/l)	3.04	1.01	5.81	2.31	6.74	3.01	7.23	3.21
MacCov	3	1	4	1	5	2	5	3
Depth (m)	3.25	11.54	1.8	9.22	1.05	6.45	2.6	10.15

The two PC axis explained 91.6% of the total variation in the season and site data (Table 2). The first PC axis described a gradient of decreasing macrophyte coverage and chlorophyll-a associated with increasing depth. The second PC axis was associated negatively with nitrite and positively with nitrate and temperature (Table 2; Figure 2).

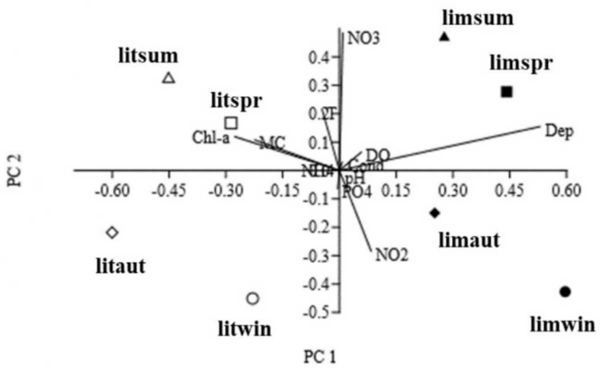

Figure 2. PCA ordination of environmental parameters (Lim: Limnetic site, Lit: Littoral site, win: winter, spr: spring, sum: summer, aut: autumn)

Table 2. PCA eigenvalues (in parentheses) and major axis loadings of environmental parameters

Environmental Parameters	PC 1 (0.198)	PC 2 (0.128)
Ammonium	0.00	0.00
Nitrite	0.13	**-0.44***
Nitrate	0.01	**0.75***
Phosphate	-0.01	-0.10
Temperature	-0.07	**0.33**
DO	0.09	0.10
pH	0.00	-0.02
Conductivity	0.01	0.05
Depth	**0.82***	0.24
Chl-a	**-0.43***	0.18
MacCov	**-0.34***	0.17

*High correlation coefficients

Fish Community Structure

A total of 12 fish taxa belonging to six families and 1.530 fish specimens were collected across four seasonal sampling events during the study. In general, the most dominant families, according to their numerical abundance, are Mugilidae (36.21%), Cichlidae (29.74%), Atherinidae (14.18%), and Cyprinidae (11.11%). Two fish species, *Capoeta aydinensis,* and *Ladigesocypris irideus* were endemic, and comprised 2.94%. In contrast, two non-native fish species (*Coptodon zillii* and *Carassius gibelio*) contributed 37.12% of the numerical abundance of the total catch. *Cyprinus carpio* comprised 3.27% of the total catch. The other fish species were the sole representatives of the Anguillidae: *Anguilla anguilla,* Siluridae: *Silurus glanis,* which comprised 6.08%, and 0.20% of the total catch, respectively.

There was no seasonal variation in the total abundance of fishes when data were pooled across all habitats ($F_{3,7}$=0.064, P= 0.976). It was determined that *C. zillii*, which was the most abundant fish species, had a very high abundance in the summer (49.61%) and autumn (38.10%) (Figure 3). When data were pooled across all seasons, the total abundance was higher in the littoral site compared to the limnetic site (t_6 = 7.132, p=0.000). Especially, *C. zillii* (39.1%) was the most abundant in the littoral site, followed by Mugilidae species (*Mugil cephalus*, *Chelon ramada* and *Chelon labrosus*) (28.4%). In the limnetic site, the most dominant species were Mugilidae species (48.98%), followed by *A. boyeri* (19.84%) and *C. zillii* (16.90%) (Figure 3).

During the study, species richness (S) and species richness index (D) varied from 6 (limnetic site during summer) to 11 (littoral site during autumn) and from 0.50 (limnetic site during summer) to 0.76 (littoral site during autumn), respectively (Figure 4). While there were no significant differences among seasons for species richness ($F_{3,7}$= 0.194, p=0.896) and D ($F_{3,7}$=0.535, p=0.683), species richness showed significant differences between sites with the highest in littoral site (t_6 = 4.127, p=0.006).

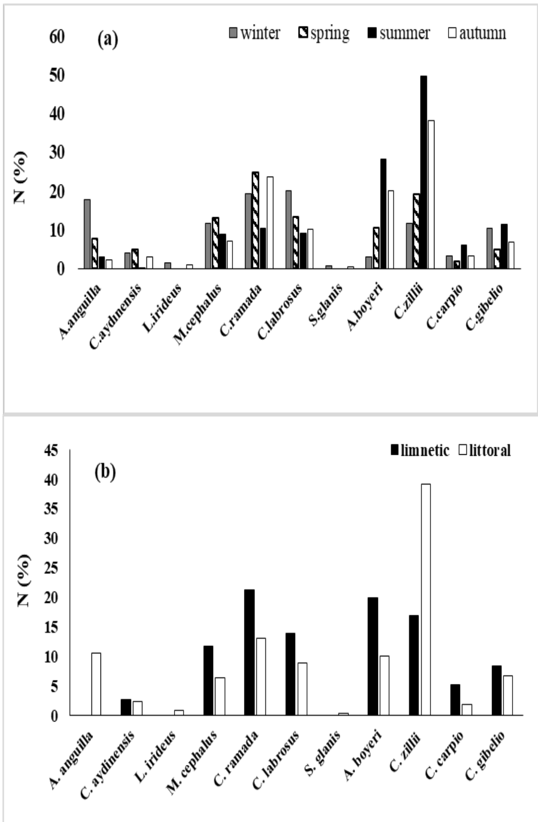

Figure 3. The temporal (a) and spatial (b) variations in the total fish abundance

Shannon-Wiener diversity index (H') and Evenness (J), which is a measure of whether the abundance of the species is evenly distributed, ranged from 1.34 (littoral, summer) to 1.98 (littoral, spring) and 0.58 (littoral, summer) to 0.96 (littoral, spring and limnetic, winter), respectively. Both H' and J did not vary seasonally ($F_{3,7}$=4.035, p=0.106; $F_{3,7}$=0.488, p=0.709, respectively) and spatially (t_6=0.48, p=0.964; t_6=1.263, p=0.253, respectively) (Figure 4).

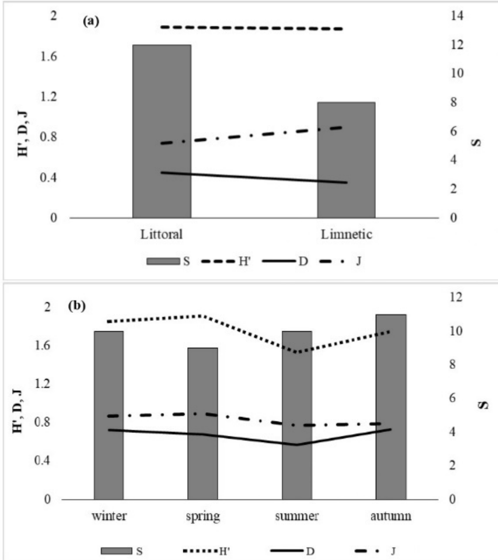

Figure 4. The spatial (a) and temporal (b) variations in mean community metrics of fishes

Water depth was negative (-0.713), but macrophyte coverage was positively (0.731) associated with species richness, whereas the opposite was true for the evenness index (0.718, -0.714, respectively). Total abundance was negatively associated with depth (-0.794) and positively correlated with chlorophyll-a concentration (0.738) and macrophyte coverage (0.765).

Spearman Correlation analysis between abundance and environmental parameters showed that *A. anguilla* had a significant negative correlation with depth. Both *S. glanis* and *L. irideus* were negatively associated with nitrate. *M. cephalus* abundance was correlated with nitrite, phosphate, and dissolved oxygen, but *C. ramada* with conductivity, *C. labrosus* with ammonium. The non-native fish species, *C. zillii,* was negatively associated with water depth while positively with chl-*a* and macrophyte coverage (Table 3).

Table 3. Spearman correlation coefficient between fish species and environmental parameters (*Aa: A. anguilla, Sg: S. glanis, Li: L. irideus, Ab: A. boyeri, Ca: C. aydinensis, Cc: C. carpio, Cg: C. gibelio, Cl: C. labrosus, Mc: M. cephalus, Cr: C. ramada, Cz: C. zillii*)

Parameters	Aa	Sg	Li	Ab	Ca	Cc	Cg	Cl	Mc	Cr	Cz
Ammonium	0.063	0.031	0.031	0.611	-0.156	-0.036	-0.548	**-0.833***	-0.419	0.419	0.405
Nitrite	0.254	0.655	0.655	-0.419	-0.228	-0.06	0.524	0.333	**-0.743***	-0.443	0.19
Nitrate	0.025	**-0.733***	**-0.733***	0.359	-0.108	0.299	-0.571	-0.19	0.551	-0.144	0.095
Phosphate	-0.076	0.483	0.483	0.012	-0.359	0.144	0.238	-0.19	**-0.766***	-0.108	0.095
T	0.101	-0.405	-0.405	**0.731***	-0.275	0.252	-0.524	-0.524	0.192	0.012	0.429
DO	-0.304	-0.592	-0.592	0.024	0.192	0.168	0	0.333	**0.886****	0.012	-0.429
pH	0.304	0.546	0.546	-0.611	0.024	-0.216	0.286	0.238	-0.575	-0.275	0.095
Cond	-0.228	-0.234	-0.234	0.311	-0.491	0.575	0.262	0.238	0.12	**-0.766***	0.024
Depth	**-0.761***	-0.234	-0.234	-0.24	0.012	0.335	0.429	0.429	0.323	0.036	**-0.881****
Chl-a	0.545	0.312	0.312	0.347	-0.06	-0.311	-0.5	-0.69	-0.599	0.216	**0.762***
MacCov	0.639	0.333	0.333	0.293	-0.11	-0.293	-0.473	-0.618	-0.64	0.073	**0.837****

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

The fish community structure of the Koca Lake wetland can be characterized by relatively low species richness but an overabundance of some species. The fish community in Lake Koca was dominated by *A. anguilla, A. boyeri, M. cephalus, Chelon ramada*, and *C. labrosus* (42.29%), characteristic of other coastal lakes of the western Mediterranean basin (Akın et al., 2005). Non-native fish species (*C. zillii,* and *C. gibelio*) were dominant in the Koca Lake wetland and represented 37.12% of the fish community. Although *C. carpio* is a native species for some regions of Türkiye (Atalay et al., 2017), it was not recorded in a previous study from Lake Koca (Yılmaz et al., 2006). Tarkan et al. (2015) has been reported as an introduced fish because this fish has been transported to almost all parts of Türkiye due to aquaculture production and stocking programs. Therefore *C. carpio* is an introduced fish species for this lake and contributed more to the fish community than endemic species. On the other hand, freshwater-dependent endemic species (*C. aydinensis* and *L. irideus*) were at a very low density (2.94%). The abundance of non-native species and the decline of native fishes could reflect the high degree of human influence on the wetland, leading to the current semi-replacement of native species. There is no study on the fish community composition or biodiversity of this wetland and only a study provides information on the fish fauna (Yılmaz et al., 2006), and reported that no non-native species, but only catadromous species were recorded between 1999 and 2003.

Our results showed that the non-native cichlid *Coptodon zillii* was the most abundant species of the Lake Koca fish community. This species is evaluated as the high invasiveness in the USA (U.S. Fish and Wildlife Service, 2014) and is generally considered to be a greedy herbivore that depends on aquatic plants for feeding, protection, or spawning (Nico et al., 2014). High fertility (developed gonads even in 0-year-old) and ecological plasticity may have contributed to successful populations of *C. zillii* (Gu et al., 2016; Çoban, 2018). We found a high abundance of *C. zillii* in the littoral site during summer and autumn. For example, the littoral site was characterized by higher chl-a and macrophyte coverage, and lower depth. However, abundance of other non-native (*C. gibelio*) and introduced fish species (*C. carpio*) did not correlate with any of the abiotic environmental parameters we identified. In fact, this result can be explained by the fact that both fish species are opportunistic generalists (Balık et al., 2003; Gül et al., 2010). Seasonal or daily habitat use preferences may vary in both fish. For example, *C. carpio* shows a significant preference for shallow, vegetated habitats during all seasons, but they migrate to deep water during the day (Zhang et al., 2020). *C. gibelio* prefers shallow waters with dense aquatic plants for feeding and spawning in spring and summer, and deep waters in autumn and winter (Giosa et al., 2014).

Species of the Mugilidae family, which are among the native catadromous species, are marine-estuarine dependent and are commercially important fishes. These species are found in greater density in the limnetic site of Lake Koca in spring and summer. Similar results have been reported in other lagoon and wetland systems in the Mediterranean region (Akın et al., 2005; Franco et al., 2008; Scapin et al., 2018). The abundance and distribution of Mugilidae species were correlated with local abiotic factors. For example, *M. cephalus* and *C. labrosus* were negatively correlated with water nutrient parameters such as nitrite, phosphate, and ammonium, respectively. The abundance of *C. ramada* was negatively correlated with conductivity. It has been reported that *C. ramada* is more tolerant to organic pollution and eutrophication than *M. cephalus* (Boglione et al., 2006). Besides, the three sympatric mullet species show interspecies differences in breeding period, habitat, and resource use to reduce competition, which may lead to differences in abundance and distribution (Cardona, 2006; Akın et al., 2005).

One of the endemic fish species, *L. irideus* has the lowest abundance (only 7 individuals) and was mainly caught in the marginal vegetation in the littoral site during winter and autumn. In addition, the abundance of *L. irideus* was found to be negatively associated with nitrate. *L. irideus* was assessed as “Near Threatened" according to the IUCN Red List 2014 (Freyhof, 2014). Although no precise data on population trends are available in the literature, the populations of this species are slowly declining due to the negative effects of anthropological activities (Yılmaz et al., 2015). Another endemic species, *C. aydinensis*, is a species that has a low tolerance to environmental changes and prefers specific habitats (Akbaş et al., 2019). *C. aydinensis* had a very low abundance and constituted 2.48% of the fish community of Lake Koca. It was determined that the abundance and distribution of this species were not correlated with the environmental variables of this wetland. Akbaş et al. (2019) also showed that this endemic fish from the Tersakan Stream which flows into the Lake Koca, was a slow-growing species, therefore the age of reaching sexual maturity is higher than other fish. The destruction of habitats by anthropogenic activities and the presence of non-native fish are critical to the survival of populations of such sensitive and slow-growing species.

Unlike species diversity, species abundance, richness, and evenness showed spatial patterns in Lake Koca. Fish sampling method and used fishing nets can explain spatial patterns (limnetic vs. littoral) in fish community structure. Besides, the fish community of Lake Koca is strongly associated with environmental parameters revealing spatial patterns. Evenness, richness, and abundance were highly correlated with macrophyte coverage and chlorophyll-a concentration. As a central component of the freshwater ecosystem, macrophytes are essential in providing resources and shelter to aquatic organisms (Silva et al., 2013). Aquatic macrophytes appear to play a powerful role in structuring the fish community in Lake Koca. Fish species richness and abundance were high in the littoral habitat, where macrophyte coverage and chlorophyll-a concentration were high. Similar trends have been identified in many wetland and lake ecosystems (Pelicice et al., 2008; Cvetkovic et al., 2010; Thomaz and Cunha, 2010; Bhagat and Ruetz, 2011). Macrophytes increase habitat structural complexity and productivity for aquatic macroinvertebrates which are important food resources for fish. Additionally, the increase in habitat complexity provides an increase in fish species richness and associated fauna, due to the diversification of possibilities in exploring different habitats (Dias et al., 2017).

In this study, none of the fish community structure parameters showed seasonal variation. However, seasonal patterns are quite common in fish communities from estuarine and lagoon systems (Nsor and Obodai, 2016; Jin et al., 2019; Grubh and Winemiller, 2018). The seasonal variation of communities within these systems is often due to the reproductive biology of fish (reproductive migrations between marine and freshwater and seasonal dynamics) (Akın et al., 2003). Fish that spend their trophic life in fresh water and then migrate to the sea to spawn, such as eels (*A. anguilla*), and marine-estuarine opportunist fish such as Mugilidae (were commonly found in Lake Koca. Estuarine migrant Mugilidae members regularly enter the estuary, especially when juveniles, and use them as nurseries to take advantage of higher nutrient input and structured habitats to develop rapidly in their first years of life. After that, they migrate to coastal seas, where reproduction usually takes place (Rangely et al., 2023). These migratory species, albeit small in size (N. Kaymak personal observation), may have been sampled during four seasons and may have affected the species richness. In addition, some species (*C. zilli, M. cephalus, C. ramada*, etc.) that were abundant in all seasons may have affected the species diversity patterns.

CONCLUSION

The contribution of non-native fish to the fish abundance of Lake Koca was quite high and the most dominant of non-native fish was *C. zillii*. Species diversity and abundance are higher in the littoral than in the limnetic habitat, and in the summer season. All biodiversity parameters showed correlations with environmental parameters such as chlorophyll-a and macrophyte density which are related to primary productivity in the lake. Water quality parameters such as nitrate, nitrite, and phosphate were negatively correlated with native fish distribution. The results of the analysis in this study showed that environmental parameters and non-native fish species in this wetland system affect both biodiversity and fish community structure.

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AUTHOR CONTRIBUTION

Nehir Kaymak wrote the main manuscript text, Yılmaz Emre designed the project and study, Şenol Akın reviewed the draft, Nehir Kaymak and Nesrin Emre analyzed the data.

CONFLICTS OF INTEREST

The authors declare that there is no known financial or personal conflict that may affect the research (article).

ETHICS APPROVAL

Approval was granted by the Ethics Committee of Burdur Mehmet Akif Ersoy University (Date: 19.07.2018 / Approval Number: 93773921).

DATA AVAILABILITY

For questions regarding datasets, the corresponding author should be contacted

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