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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Spatial Variation of the Body Condition and Growth Type of Endemic and Introduced Fish Species in the Düden Stream (Antalya, Türkiye)

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Abstract: In this study, we evaluated the parameters of the length-weight relationship and the relative condition factor of endemic *Pseudophoxinus antalyae* and introduced fish species, *Carassius gibelio* and *Cyprinus carpio* in the Kırkgöz Spring-Düden Stream basin. A total of 269 fish were captured from three different sites of the basin from May to September 2022. There were differences in mean length and weight were observed between populations from sites 1 to 3 for three fish species. Negative allometric growth was observed at the site 2 population of *P. antalyae*, whilst sites 1 and 3 showed positive allometric growth, and the condition factor (K) for only site 1 was above 1. The populations of *C. carpio* from sites 2 and 3 showed positive allometric growth, while *C. giebelio* was negative allometry. K >1 for *C. carpio* at site 3 and for *C. gibelio* at site 2. This study can inform fisheries biology and environmental management for developing and conserving endemic fish stock.

Keywords: *Pseudophoxinus antalyae*, *C. gibelio*, *C. carpio*, condition factor, length-weight relationship.

Düden Çayı'ndaki (Antalya, Türkiye) Endemik ve Aşılanmış Balık Türlerinin Vücut Kondisyonu ve Büyüme Tiplerinin Mekansal Değişimi

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Öz: Bu çalışmada, Kırkgöz Çayı-Düden Çayı havzasında endemik *Pseudophoxinus antalyae* ve aşılanmış balık türleri, *Carassius gibelio* ve *Cyprinus carpio*'nun boy-ağırlık ilişkisi parametrelerini ve bağıl kondisyon faktörünü değerlendirdik. Mayıs-Eylül 2022 arasında havzanın üç farklı bölgesinden toplam 269 balık yakalanmıştır. Üç balık türü için 1. ve 3. istasyonlardaki popülasyonlar arasında ortalama uzunluk ve ağırlık farklılıkları gözlemlenmiştir. *P. antalyae*'nin 2. istasyondaki popülasyonunda negatif allometrik büyüme gözlenirken, 1. ve 3. istasyonda pozitif allometrik büyüme göstermiş ve sadece 1. bölge için kondisyon faktörü (K) 1'in üzerinde hesaplanmıştır. *C. carpio*'nun 2. ve 3. Istasyonlardaki popülasyonları pozitif allometrik büyüme gösterirken, *C. giebelio* negatif allometri göstermiştir. 3. istasyonda *C. carpio* ve 2. istasyonda *C. gibelio* için K >1. Bu çalışma, endemik balık populasyonlarının büyümesi ve korunması için hem balıkçılık biyolojisi hem de çevre yönetimi için bilgiler sağlayabilir.

Anahtar kelimeler: *Pseudophoxinus antalyae*, *C. gibelio*, *C. carpio*, kondisyon faktörü, boy-ağırlık ilişkisi.

INTRODUCTION

Somatic indices are important tools for biological monitoring of fisheries management, conservation and environmental stress on fish health (Anzueto-Calvo et al. 2022). Measuring these indices facilitates understanding of the biological, physiological, and ecological aspects of organisms (dos Reis et al. 2020). The most commonly used somatic indexes; condition factor (*K*) and length-weight relationship (LWR). Length-Weight relationships are a response to the physiological conditions of fish (Adite et al., 2017), which depend on habitat conditions, and provide

information about the population dynamics (Santos et al., 2019), welfare, and health status of the species in a given environment. The condition factor, on the other hand, makes it possible to understand the individual physiological states of organisms and relate them to environmental conditions and behavioral aspects of the species (dos Reis et al., 2020). These two parameters are actually used as indicators to evaluate the productivity, status, and especially the "ecological health" of aquatic ecosystems (Deekae and Abowei, 2010; Adite et al., 2017).

Düden Stream, located in the city center of Antalya, is an ecologically important location in terms of hosting endemic fish species (such as *Pseudophoxinus antalyae* Bogutskaya, 1992, *Paraphanius mentoides* Akşiray, 1948) (Çicek et al., 2018, Kuyumcu et al., 2021). The Düden Stream and its biodiversity has been heavily threatened by anthropogenic disturbance such as pollutants from agricultural activities, and domestic and industrial wastewater discharges for a long time (Ayaz et al. 2013). Besides, the natural flow of the stream has been altered by the operation of two hydroelectric power plants in the upper basin of the stream. *Carassius gibelio* and *Cyprinus carpio* have been stocked in the Düden Stream. Although *C. carpio* is a native species for some regions of Turkey (Atalay et al., 2017), it has been transported to almost all parts of Turkey due to aquaculture production and stocking programs and has subsequently been reported as an introduced fish (Tarkan et al., 2015). *C. gibelio* was also unintentionally and/or accidentally introduced as contaminants in *C. carpio* consignments for stocking (Tarkan et al., 2015).

Some previous studies examined the condition and growth parameters of *P. antalyae*. For example, Innal (2014) compared the length-weight parameters of *P. antalyae* and *C. antalyensis*, mostly caught from the lower basin of the Düden Stream. In addition, Erkakan et al (2012) and Ilhan and Gücer (2018) compared the length-weight relationships of ten fish species (*P. antalyae* was sampled from Kepez Dam Lake) and eight Pseudophoxinus species (*P. antalyae* was sampled from only Kırkgöz spring), respectively. It is very important to understand how body conditions and development change along the stream from the source to the sea at stations where local and introduced fish coexist or not. Therefore, we investigated spatial variations of condition factors and growth parameters in both endemic and introduced fishes along the Kırkgöz Spring-Düden Stream in this study.

MATERIAL AND METHOD

Düden Stream is 14 km long and originates from the karst Kırkgöz Springs (Dösemealtı (Antalya)) and falls into the Mediterranean Sea in Antalya. The stream mostly flows through Antalya city center. A large part of the water coming out of the spring is taken into the canal for Kepez Hydroelectric Power Plant which was built in the 1960s, and some of it goes underground through the karst waterways in the sinkhole and permeable travertine (TCAVCSİM, 2020). Annual precipitation is 856 mm, and the mean annual flow of the stream is 23.8 m^3/s (AKKYK, 2021; Ayaz et al. 2013). There are two hydroelectric power plants in the upper basin of the stream, and two waterfalls (the upper Düden and the lower Düden waterfall, where the stream pours into the sea from a height of 40 m) in the lower basin of the stream.

Fishes were captured from three different segments of the basin from May to September 2022 (Figure 1, this figure was taken from Ayaz et al. (2013)): the littoral zone of the Kırkgöz spring (site 1) (three different locations within the spring), one location in the water retention pond and stream channel located above the Hydroelectric Power Plant (HPP) (site 2), and one location in the main channel of the lower basin of the stream (site 3) (Figure 1).

Figure 1. Study area

Kırkgöz Spring (site 1) is located at an altitude of 250-300 m from the sea and covers an area of 45.000 m^2. This spring lake consists of swampy areas and is densely covered with riparian, emergent, and submerged plant species. Site 2 was located in the upper basin of the Düden Stream and in the site where the stream water leaving the spring connects to the HPP channel (average channel width 5.6m) and littoral site of water retention pond of HPP. Site 3 was located in the lower basin of the Düden Stream and the city center. This site is close to the waterfall which flows into the sea. The mean channel width of this site was 49 m and submerged and herbaceous plants dominated the riparian zone of this site. The stream substrate consists of rocks, sand, and mud. Site 3 was also under the influence of urbanization, agriculture, and industrial activities. We did not determine the environmental parameters of the stream sites, therefore we derived heavy metal pollution index (HPI) values from a

previous study (Leventeli et al., 2019) to define habitat characteristics and anthropogenic pressure. According to that study; site 1 was defined as "good" (HPI: 43.9), site 2 was "poor" (HPI: 72.54), and site 3 was "very poor" (HPI: 242.13).

Fishes from each of site were caught using fyke-nets with a mesh size of 12 – 35 mm. A trawl net (8 - 55mm mesh size) from the littoral zone of lakes at sites 1 and 2 were also used. Samples were taken using these nets operated for 24 h. The fish samples were first stunned with an anesthetic (MS222) and then placed in 10% formaldehyde solution in the field and brought to Akdeniz University, Biology Department, Hydrobiology Laboratory. Fish weights (W) and total lengths (TL) were measured to the nearest 0.01 g and 1.0 mm, respectively. The length-weight indices (Ricker, 1975) and relative condition factor (Le Cren, 1951) of the individuals in the fish population were compared spatially. The length-weight index (LWR) and relative condition mean were calculated from the weight and length of each fish: $\boldsymbol{K = Wt/Wt'}$, where *Wt* represents body weight and *Wt'* is the estimated weight based on the total length (TL) and weight relationship ($\boldsymbol{Wt' = aL^b}$) from the linear regression model. *a* expresses the Y-axis intersection point of the line in the exponential equation, and *b* is the slope of the regression line. The Ls × Wt relationship parameters required to estimate the condition factor were calculated separately for each species and site.

Statistical analysis: First of all, the condition factors of three fish species were compared, and then the spatial variations in condition factors of three fish populations were compared using a one-way analysis of variance (ANOVA). Pairwise differences were tested using Tukey's post hoc testing. Before starting the analysis, it was checked whether the data showed normal distribution with the Shapiro-Wilk test and it was determined that the normal distribution condition was met ($p>0.05$). Whether the b value in LWR was statistically different from "3" was tested with Student's t-test. Since only 2 small individuals of *C. gibelio* were caught in the Kırkgöz spring, they were not included in the analysis. All analyzes were conducted using the PAST 4.0.4 statistical program.

RESULTS

A total of 3 fish species, *Pseudophoxinus antalyae* (Leuciscidae), *Cyprinus carpio*, and *Carassius gibelio* (Cyprinidae), representatives of 2 families, were collected during the period of the study. A total of 269 specimens were sampled, 172 individuals were *P. antalyae*, 69 were *C. carpio*, and 28 were *C. gibelio* along Düden Stream. While *P. antalyae* was distributed in all three sites from Kırkgöz spring to along the Düden Stream, one of the introduced fish, *C. gibelio*, was represented by only 2 individuals in the Kırkgöz spring. *C. carpio* was sampled from only two sites (sites 2 and 3) (Figure 2).

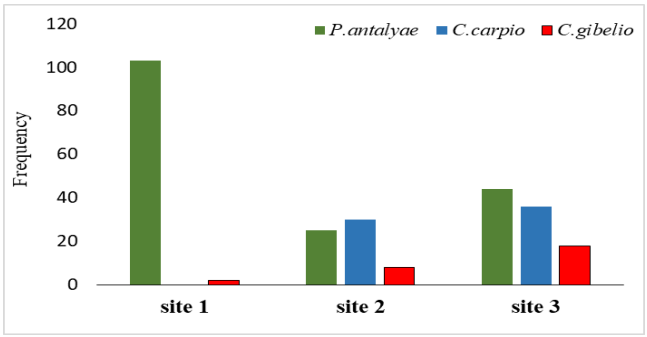

Figure 2. The frequency of species abundance from three sites along the Düden Stream.

Ranges of weight and total length of *P. antalyae* along the Düden stream were 2.85 to 66.0 gr and 6.10 to 16.3cm, respectively. Whereas the ranges of weight and total length of *C. gibelio* were 3.82 to 89.0 gr and 6.5 to 18.1cm, respectively, and ranges of weight and total length of *C. carpio* were 1.11 to 4.559 gr and 4.5 to 49.5 cm, respectively (Table 1).

Table 1. Parameters of the length–weight relationship and descriptive statistics of three species in three populations along Düden Stream (N: number of samples, TL: total lenght, max: Maximum, min: Minimum, a: intersection point, b: the slope of the equation, CI (b): 95% confidence intervals of b; r^2: regression coefficient).

			W (gr)		TL (cm)		LWR Parameters						K	
Speices	**Sites**	**N**	**mak**	**min**	**mak**	**min**	**a**	**b**	**CI (b)**	**r^2**	***t*-test**	**Growth type**	**mak**	**min**
P. antalyae	Site 1	58	66.00	3.31	16.20	6.40	0.01	3.16	3.05-3.27	0.98	58.1**	All (+)	1.74	1.05
	Site 2	25	17.20	5.05	10.30	6.80	0.03	2.90	2.51-3.29	0.91	15.3**	All (-)	0.94	0.65
	Site 3	44	55.90	2.85	16.30	6.10	0.01	3.13	2.90-3.35	0.95	27.8**	All (+)	1.24	0.62
C. gibelio	Site 1	2	4.20	3.80	5.00	4.00								
	Site 2	8	12.80	3.82	9.30	6.50	0.03	2.81	1.31-4.28	0.77	4.61*	All (-)	1.61	0.97
	Site 3	18	89.00	13.70	18.11	9.40	0.04	2.74	2.30-3.42	0.88	10.79**	All (-)	1.1	0.53
C. carpio	Site 2	29	4559.00	1.11	49.50	4.50	0.01	3.06	2.96-3.15	0.99	65.7**	All (+)	0.83	0.32
	Site 3	36	755.00	30.80	32.32	12.00	0.01	3.23	3.09-3.37	0.99	46.8**	All (+)	1.67	1.14

*** b value is significantly different from 3 (p<0.001)*
** b value is significantly different from 3 (p<0.01)*

There were significant differences between the condition factors of the endemic and introduced fish along the stream. The condition factor of *P. antalyae and C. gibelio* was lower than those of *C. carpio* at site 3 (F= 191.20, $p<0.001$), whereas the condition factor of *C. gibelio* was the greatest, those of *P. antalyae* was middle, and those of *C. carpio* was the lowest at site 2 (F= 155.41, $p<0.001$) (Figure 3, Table 1).

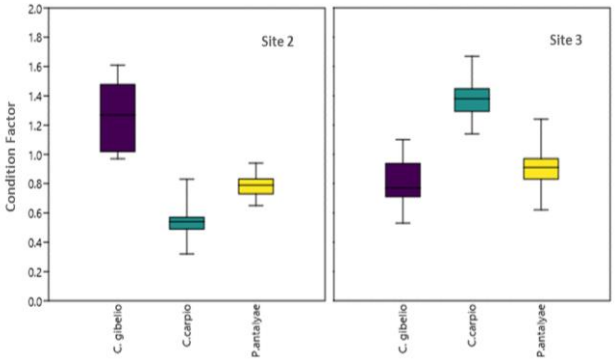

Figure 3. The mean condition factors of the population of three fish species from sites 2 and 3 (the horizontal lines in the colored box and the long vertical bars represent the mean values and the standard deviations, respectively).

There was significant spatial variation in the condition factors of *P. antalyae* population from three sites (F= 231.50; P < 0.001). While the mean condition factors of *C. gibelio* were higher at site 2 than site 3 (F = 35.49; p < 0.01), those of *C. carpio* was higher at site 3 than at site 2 (F= 112.70, p < 0.001) (Figure 4, Table 1).

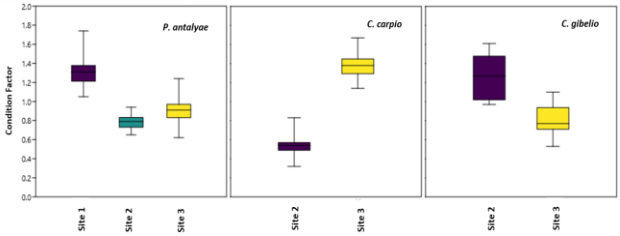

Figure 4. Spatial variation of condition factors of endemic and introduced fish species (the horizontal lines in the colored box and the long vertical bars represent the mean values and the standard deviations, respectively).

Among the constants of the relationship between the length and weight of the fish, “b” indicates whether the fish show isometric (b=3) or allometric (b<3, negative allometric; b>3, positive allometric) growth. According to the Student's t-test results, *P. antalyae* population from sites 1 and 3 showed positive allometric growth (b > 3, p < 0.001) and had an "a" value of 0.01, whereas the population from site 2 showed negative allometric growth (b < 3, p < 0.001) and had an "a" value of 0.03 (Figure 5, Table 1).

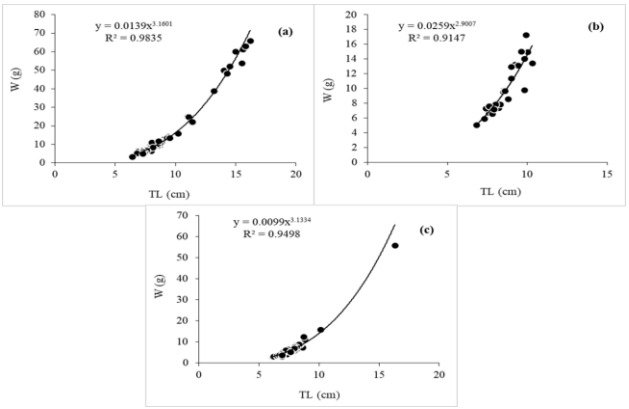

Figure 5. Relationship between Length-Weight of the population of *P. antalyae* from sites 1 (a), 2 (b), and 3 (c).

The growth was positive allometric in the population of *C. carpio* from sites 2 and 3 (b > 3, p < 0.001), and had an "a" value of 0.01, while negative allometric in *C. gibelo* from sites 2 and 3 (b < 3, p < 0.001) with “a” value of 0.03, and 0.04, respectively (Figure 6, Table 1).

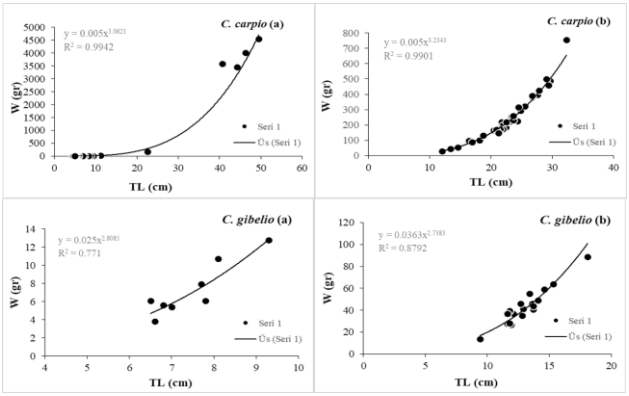

Figure 6. Relationship between Length-Weight of the population of *C. carpio* and *C. gibelio* from sites 2 (a), and 3 (b).

DISCUSSION AND CONCLUSION

Pseudophoxinus antalyae is the endemic fish to Kırkgöz – Düden Stream basin, has most recently been assessed as “Vulnerable” status for The IUCN Red List of Threatened Species (Freyhof, 2014). We observed that the number of *P. antalyae* was higher in Kırkgöz spring/pond relative to sites located in the Düden stream. This is probably due to the more favorable environmental conditions for *P. antalyae* in this pond, which are generally outside of urbanization. In addition, this species prefers still waters, channels, and shallow small ponds as habitats (Atalay, 2005). This endemic fish coexists with introduced fish species (*C. gibelio*, and *C. carpio*) in the Düden Stream. *C. gibelio* was sampled at selected three sites, while *C. carpio* was caught only at sites 2 and 3. According to local fishermen, *C. carpio* has never been caught or observed before in Kırkgöz Spring (site 1). It is not known by whom and when these introduced fish were transported to this system.

Environmental parameters of the habitats were not sampled in this study, but each station offers different habitat possibilities. For example, site 1 is a natural lake-swamp-type habitat, site 2 is a man-made artificial pond and channel, and site 3 is a stream channel habitat. Therefore, these habitats may show different biotic and abiotic characteristics and this may affect the growth parameters of fish. We detected body size variation among populations of three fish species. The body size of individuals in the *P. antalaye* population decreased gradually from site 1 to site 3. This variation may occur due to variability among habitat characteristics. In addition, the data from previous studies for *P. antalyae* supports habitat-specific body size variation (Erk’akan et

al., 2012, Innal, 2014, İlhan and Gücer, 2018). On the contrary, the population of *C. gibelio* from site 3 was relatively larger than those of site 2. *C. carpio* was breaking this trend, with heavier but shorter individuals at site 2. There may be many reasons for the difference in body size observed between these three species. It may be primarily the species-specific characteristics, then the environmental status of habitats, the resource availability in the habitats, and inter and intraspecific completion. Species with similar ecological preferences such as *C. gibelio* and *C. carpio*, which are opportunistic generalist species (Balık et al., 2003; Gül et al., 2010), compete for habitat and food and may show different body growth patterns in line with the resources they obtain. In addition, we caught both very small (~7.74 cm) and very large (~45.18 cm) fish individuals at site 2 which offered a lake habitat. However, medium and large-sized (12.0-32.3 cm) individuals are more common in site 3, which is a stream channel. Lake habitats offer plenty of food sources and thus can support individuals of all size classes. However, stream habitats may have different microhabitats and accordingly offer different food sources for the survival of adult individuals.

The slope b of the length-weight regressions provides information on the life history and morphological comparisons between different fish species or between different fish populations from various habitats (Uzunova et al. 2017), as well as the environmental status of streams (Vila-Gispert and Moreno-Amich, 2001). If the fish grows allometrically, the fish weight will increase either more slowly (b<3.0) or faster (>3.0) in proportion to the increase in length (Saha et al. 2009). If the fish shows negative allometry, becomes "thin and slender", in the case of positive allometry, becomes "plump" (De Leon et al. 2017). The result of this study showed positive allometric growth (b > 3) for *P. antalyae* population from sites 1 and 3, while negative allometric growth (b < 3) for the site 2 population. In Kırkgöz pond, and channels in the Düden Stream, positive allometric growth (3.34, 3.25, and 3.41) was reported for this endemic species (Erk'akan et al., 2012, Innal, 2014, İlhan and Gücer, 2018). As explained above, since different regions of a basin offer different habitats and feeding areas, the body development of the fish may change accordingly. Sites 1 (small lake/pond) and 3 (natural and wider stream channel) offer larger habitat areas, while site 2 is a small unnatural (man-made) channel and therefore may not provide adequate resources for fish growth.

Populations of *C. carpio* exhibited positive allometric growth, on the contrary, those of *C. gibelio* were negative at sites 2 and 3. This result agrees with the findings of Alagöz Ergüden (2015), Birecikligil et al. (2016), Çiçek et al. (2022) which reported negative allometric growth for *C. gibelio* from Seyhan River, Kızılırmak River, Çoruh River, respectively. In contrast, Innal (2012) and Şimşek and Kale (2022) reported positive allometric growth from Aksu and Asi River, respectively. Apart from this, there are also records for the growth parameters of C. carpio: Şen and Elp (2009) determined negative allometric growth for Karasu Stream, Birecikligil et al., (2016) positive for Kızılırmak River. The length-weight relationship in fishes is affected by numerous abiotic and biotic factors such as season, habitat, nutrition, environmental conditions, growth phase, degree of stomach fullness, gonad maturity, sex, size range, health, and preservation techniques (Froese 2006, Tsoumani et al., 2006).

The condition factors, K >1 may indicate better fitness than the average fitness of other individuals of the same length, while K < 1 may indicate a worse condition (Sabaridasan et al. 2015, Uzunova et al. 2017). Only the population of *P. antalyae* from site 1, that of *C. gibelio* from site 2, and *C. carpio* from site 3 showed K values > 1. The condition value of endemic fish was low at sites where endemic and introduced fish species coexisted (sites 2 and 3), indicating that the fish may be negatively affected by the presence of introduced fish species. In addition, low condition values indicate less favorable environmental conditions (Radkhah and Eagderi, 2015). According to Leventeli et al. (2019) and Ayaz et al. (2013), the downstream of the Düden Stream which was located in Antalya city center, suffered from heavy metal pollution (defined as poor and very poor habitat conditions) and anthropogenic disturbance, respectively. It has also been reported that fish deaths are frequently experienced in this region due to industrial waste (Anonymous, 2021; 2022). Therefore, unnatural stream channel (site 2) and intense anthropogenic pressures (site 3), as well as the introduction of non-native fish, may indicate that endemic fish are exposed to unfavorable environmental conditions and biotic relationships in these two sites.

The condition values of the introduced fish species differed between sites, for example, the K of. *C gibelio* was higher at site 2, while the K of *C. carpio* was higher at site 3. In particular, the population abundance of *C. carpio* was much higher than those of *C. gibelio* at site 2 (personal observation of N. Kaymak). Therefore, intraspecific competition may have negatively affected the feeding and health status of the population of *C. carpio* at site 2. Interestingly, the *C. gibelio* population with smaller individuals in site 2 had higher conditions than the larger individuals from site 3. This is most likely attributed to the change in food preferences due to the ontogenic development of *C. gibelio*. Juvenil fish feed on plankton and detritus, while adults prefer benthos and relatively large plankton (Tsoumani et al. 2006). The presence of zooplankton and benthic invertebrates in the stream

channel generally is very low due to stream flow, and thus this may affect fish growth. Especially stomach contents of some large individuals of *C. gibelio* from site 3 were mostly composed of mostly filamentous algae, detritus, and less small invertebrates, while some individuals from site 2 were mostly composed of larger crustacea and insect larvae (Unpublished data). Similar results were also reported by Akın et al. (2016); individuals of *Capoeta banarescui* (Cyprinidae), which mostly consume animal diet (such as chironomid larvae), have the highest condition values; those fed mostly with diatoms had the lowest values.

In conclusion, this study provided valuable information on how the growth parameters and condition factors of sympatric endemic and introduced fish species changed along the Düden Stream. Both abiotic (environmental condition, such as pollution) and biotic (presence of introduced fishes) factors may have affected the body condition and growth type of the endemic fish species, *P. antalyae*. The natural Kırkgöz spring provides a favorable environmental condition for the growth, development, and fitness of *P. antalyae* because its environmental parameters provide a healthy habitat ("good" habitat condition based on Leventeli et al. (2019)) and there were no non-native fish species. On the other hand, the conditions of the introduced fish species were higher than those of the endemic fish at sites 2 and 3 along the Düden Stream. The predation rate, completion, presence of disease in the environment, food availability, feeding, and temperature, dissolved oxygen, and pollution status of the environment influence the growth and condition of organisms. In order to more clearly determine the effects of these introduced species and water quality on endemic species in the Düden Stream, future studies should determine the environmental parameters of the stream and trophic relationships of all fish species.

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