Turkish Journal of Zoology

http://journals.tubitak.gov.tr/zoology/

Research Article

Turk J Zool
(2017) 41: 67-81
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doi:10.3906/zoo-1603-34

Seasonal and ontogenetic diet shift of two sympatric cyprinid fish species from the temperate Karamenderes River, Çanakkale, Turkey

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Received: 15.03.2016 • **Accepted/Published Online:** 28.05.2016 • **Final Version:** 25.01.2017

Abstract: Diet composition and feeding relationships of two cyprinid species, *Squalius cii* and *Barbus oligolepis*, from the Karamenderes River, northwestern Turkey, were assessed over a 1-year period. Both species were omnivorous and fed mostly on benthic plant materials (particularly algae) and insects. The diet of *B. oligolepis* primarily comprised Bacillariophyceae, Diptera larvae, and other insects, while that of *S. cii* comprised filamentous algae (Cyanobacteria and Chlorophyceae), insect larvae, and adults. Ontogenetic shifts in diet were identified in both species. The ratio of Chlorophyceae in the diet of *B. oligolepis* showed a gradual increase with increase in its body size; moreover, the number of ingested taxa decreased but diet diversity increased with increasing fish size. There were seasonal variations in feeding intensities of both fish, which decreased in the colder months. Seasonal resource availability was higher for *S. cii* than *B. oligolepis*; moreover, diet overlap was significant in the spring and summer. Findings indicate that *S. cii* may exclude *B. oligolepis* during limited resource availability conditions. The cooccurrence of these species may be explained by their generalist feeding strategies; ontogenetic and seasonal resource partitioning played an important role in the coexistence of these species.

Key words: Freshwater fish ecology, feeding ecology, river ecology, niche, competition

1. Introduction

Increases in global environmental problems make the freshwater ichthyofauna one of the major topics in terms of biodiversity loss, particularly in Mediterranean countries. In Turkey, as well as in other Mediterranean countries, a series of anthropogenic activities such as habitat degradation, pollution, new introduction of invasive species, and increase in the number of reservoirs and hydroelectric power plants along the streams together with climate change threaten the freshwater fish fauna of this region. These adverse impacts display the importance of natural resources considering the range of fish diversity with high endemism due to representing European, Asian, and even African origin (Şekercioğlu et al., 2011; Çiçek et al., 2015) in Turkey, and it requires the development of effective management plans in this regard. Data on biological and ecological characteristics of inland fish species are crucial to understand and improve effective management plans for conservation and sustainable use of freshwater ichthyofauna. However, the big gap in knowledge of the biology and ecology of native freshwater fish species limits the understanding of the natural conditions and conservation status of freshwater fish species and the fate of the biological reserve in terms of freshwater ichthyofauna is unknown in Turkey as a part of the Eurasian continent.

Feeding and diet composition data are used for evaluating biological and ecological characteristics of freshwater fish species. Gut content analysis is one of the earlier methods used in the determination of feeding patterns such as feeding intensity, trophic level, niche breadth, and intra- and interspecific competition of fish species in their habitats (Windell and Bowen, 1978). Biological characteristics such as age and size together with environmental conditions such as season play important roles in the diet composition of most fish (Nikolsky, 1963). Ontogenetic diet shifts with seasonal changes explain the intra- and interspecific competition and give valuable data for understanding the condition of native populations. The current study focused on the seasonal and ontogenetic diet shift of two sympatric fish species in a river in a temperate Mediterranean climate (i.e. northwestern Turkey), including *Squalius cii* (Richardson, 1857) and *Barbus oligolepis* Battalgil, 1941. These species are the most abundant native fish species in the Karamenderes River (Sarı et al., 2006; Yalçın Özdilek, 2008; Yalçın Özdilek and Jones, 2014). Both species are benthopelagic; however, detailed studies

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of the diets and feeding habits of these species have not been published. On a smaller scale, coexisting species may exhibit ontogenetic, spatial, or temporal differentiation in resource use in a local community. These fish species may shift their diet during ontogenesis and/or there may be seasonal changes in resource availability that affect the competitive interactions between them (Winemiller, 1989; Wood et al., 2016). Therefore, the aim of this study was to determine the feeding habits by gut content analysis and evaluate the feeding relationships between two native temperate-stream fish species across ontogenetic and temporal parameters. This study also assessed the trophic level of these species, taking into consideration the gut length. The relationship between the relative gut length and quality of diet is well known in fish (Wootton, 1990). A fish with a longer gut length has a predominantly herbivorous feeding pattern (Montgomery, 1977; Ribble and Smith, 1982; Kramer and Bryant, 1995). Plasticity in gut morphology may be observed in response to changes in diet (Sibbing and Nagelkerke, 2000), and relative gut length may help to ascertain the trophic category of fish in order to understand the ecological roles of these species and also the feeding relationships between the two species.

2. Materials and methods

Fieldwork was conducted from August 2007 to July 2008 along the Karamenderes River (39°53′28″N, 26°17′32″E and 39°54′07″N, 26°16′28″E). The Karamenderes River is ~109 km in length and located on the Biga Peninsula, northwestern Anatolia; it has five main river basins. The river originates from the Ağı and Kaz Mountains and is directed to the west and north, after passing the Kumkale plates near ancient Troy, reaching into the Çanakkale strait (Figure 1). Two reservoirs for irrigation have been established in the Bayramiç and Pınarbaşı districts along the river. The landscape around the Karamenderes River is used for agricultural purposes. The river is ~3–15 m wide; the habitat is categorized by run, small riffles, and shallow pools with an abundance of submerged vascular plants such as *Potamogeton* sp., particularly during arid summers. There is no canopy cover and the river bottom consists mainly of gravel, sand, and clay. During the study, the mean water depth was ~25 cm, and the depth of the river was as high as 80 cm during the rainy winter season in some places. Physical and chemical water characteristics are provided in Table 1.

Specimens were collected along a ~2-km section of the river below the second reservoir at Pınarbaşı by using cast nets (12- and 25-mm pore sizes) once a month. The abundances of each species were expressed as catch per unit of effort (CPUE), which is a percentage based on the number of specimens per cast net (Thompson, 1992).

Fish were collected by recreational fisheries activities. Specimens were placed on ice blocks immediately after capture in order to prevent digestion. In the laboratory, the total length (TL) of the specimens was measured to the nearest 1.0 mm and they were weighed (W) to the nearest 1.0 mg; the entire gut tract from the esophagus to the anus was removed and measured to the nearest 1.0 mm and then preserved in 4% formaldehyde after labeling. Subsequently, the gut tract was opened and the contents were removed; the volume and W of the contents (GCW) were measured and contents were preserved in 70% ethanol. The food organisms in the contents were identified to the lowest

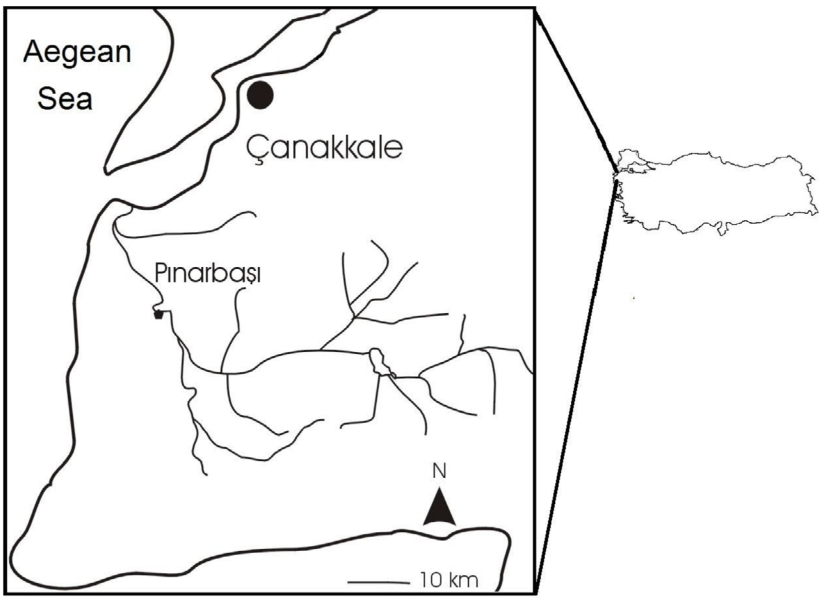


Figure 1. The Karamenderes River and sampling station.

Table 1. Physical and chemical characteristics of water measured in the study area and biological characteristics of specimens.

			Seasons		
Parameters	Summer 2007	Fall 2007	Winter 2007–2008	Spring 2008	Summer 2008
Temperature (°C)	27.7	17.17 ± 1.2	9.1 ± 3.6	19.6 ± 4.9	24.4
DO (mg/L)	12.1	10.4 ± 0.67	13.2 ± 6.29	9.5 ± 0.1	5.7
pH	8.3	7.6 ± 0.8	8.1 ± 0.72	6.9 ± 0.06	7
Nitrate (ppm)	0.2	0.2 ± 0.19	1.1	0.5 ± 0.05	-
Phosphate (ppm)	0.2	0.6 ± 0.41	0.3	0.5 ± 0.12	-
Discharge (L/s)	-	10.3 ± 0.37	19.1 ± 2.18	11.9 ± 2.21	-
Conductivity (µS/cm)	534.7	665.0 ± 145.7	764.0 ± 39.2	429.3 ± 170.8	349
S. cii					
N (♀ + ♂ + unknown)	6 (3 + 3)	15 (5 + 6 + 4)	1 (0 + 0 + 1)	32 (4 + 22 + 6)	28 (6 + 20 + 2)
Total length ± SD (mm)	16.8 ± 5.3 (12.3–24.5)	20.76 ± 8.8 (7.8–36.7)	14.3	19.44 ± 6.63 (9.0–31.0)	18.83 ± 2.42 (15.1–24.7)
Weight ± SD (g)	67.0 ± 69.2 (17.3–183)	177.98 ± 226.96 (3.5–730.0)	34.2	119.74 ± 112.88 (7.6–428.3)	80.70 ± 37.17 (39.7–216.5)
Condition factor	1.27 ± 0.10	1.37 ± 0.23	1.39	1.36 ± 0.19	1.49 ± 0.36
Gut length ± SD (mm)	18.0 ± 3.4	25.6 ± 12.1	15.6	20.9 ± 7.6	17.3 ± 5.11
Relative gut length ± SD	1.34 ± 0.38	1.14 ± 0.37		1.09 ± 0.21	0.92 ± 0.19
B. oligolepis					
N (♀ + ♂ + unknown)	8 (0 + 3 + 5)	27 (6 + 6 + 15)		25 (9 +16)	16 (1 + 12 + 3)
Total length ± SD (mm)	16.75 ± 2.95 (14.2–23.5)	16.11 ± 3.47 (11.1–26.9)		18.54 ± 4.33 (12–28.1)	17.93 ± 4.12 (13.2–26.2)
Weight ± SD (g)	44.84 ± 23.04 (25.5–98.8)	43.49 ± 30.47 (12.1–160.1)		76.71 ± 55.61 (15.1–213.4)	68.36 ± 48.74 (22.9–198.3)
Condition factor	1.22 ± 0.10	1.19 ± 0.11		1.33 ± 0.13	1.34 ± 0.12
Gut length ± SD (mm)	20.90 ± 4.26	20.19 ± 5.82		27.76 ± 7.68	22.81 ± 7.10
Relative gut length ± SD	1.28 ± 0.32	1.26 ± 0.19		1.49 ± 0.21	1.26 ± 0.21

possible taxon (Pennak, 1953; Prescott, 1964; Foged, 1981; Demirsoy, 1992) and counted using a Sedgewick rafter counting chamber under a stereomicroscope at 4× and 10×.

To examine differences in the feeding activity, the condition factor (C), which was calculated using the formula $100 \times W/FL^3$, was used for each species (Bagenal, 1978). Percent frequency of occurrence (%F) of each food item was calculated by dividing the number of all filled guts in which the food item (i) was present by the total number of filled guts and multiplying by 100. Similarly, the percentage of numerical abundance (%N) of each food item was calculated by dividing the total number of a particular food item in the filled guts by the total number of all food items in the filled guts and multiplying by 100. Both %F and %N were used for dietary analyses (Hyslop, 1980). The niche breadths of each species were estimated by measuring the uniformity of the distribution via the Shannon–Wiener diversity index (H) with evenness (E) of food items as suggested by Levins (1968). The diet overlap between the two species was assessed using the Schoener overlap index (Schoener, 1968) and the Morisita–Horn index (Krebs, 1999). The gut length was calculated per unit of body length [gut length (cm) / TL (cm)]. Costello's (1990) graphical method (Potier et al., 2004), a plot of %N with frequency of occurrence, was used to describe prey importance in the diets of both species; the graphical display indicated dominant and rare prey species, which were shown in the upper right and lower left corners of the graph, respectively. In addition, feeding strategies were primarily distributed at the bottom or upper side of the graph, indicating generalization or specialization, respectively. The relative gut lengths and feeding activities were compared statistically via analysis of variance

(ANOVA); the different seasons, sexes, and length groups were used as replicates. The length groups were determined by dividing differences between minimum and maximum total length into the square root of specimen numbers. The length group ranges for *B. oligolepis* and *S. cii* were calculated as 2 and 3, respectively.

3. Results

In total, 330 fish specimens were collected from the study area. *Carassius gibelio* (Bloch, 1782) was the most abundant (128 specimens, 37.26%) fish species. Other fish species collected in the study area were *S. cii* (82 specimens, 25.41%), *B. oligolepis* (76 specimens, 24.81%), *Alburnus chalcoides* (Güldenstädt, 1772) (24 specimens, 7.58%), and *Cyprinus carpio* L., 1758 (14 specimens, 3.25%). *Cobitis fahirae* Erk'akan, Atalay-Ekmekçi & Nalbant, 1998 (2 specimens, 0.35%), *Anguilla anguilla* L., 1758 (2 specimens, 0.67%), and *Rhodeus amarus* (2 specimens, 0.67%) were collected on rare occasions. With the exception of one and eight individual(s) of *S. cii* and *C. gibelio* respectively, specimens other than fish were primarily collected during winter season.

3.1. B. oligolepis (Steindachner, 1897)

The gut contents of 76 *B. oligolepis* specimens collected from August 2007 to July 2008 were examined. The guts of 20 specimens were empty. The mean TL and W of these specimens were 17.4 ± 3.95 cm (11.1–28.1) and 60.23 ± 45.95 g (12.1–213.4), respectively. The male-to-female ratio was 2.31, and the condition factors of females and males were 1.32 ± 0.17 and 1.30 ± 0.13, respectively. There were no statistical differences between female and male condition factors ($F = 0.35$, $F = 1.54$; $P > 0.05$). There were no statistical differences in condition factors of specimens among different size groups ($F = 1.59$, $F = 0.61$; $P > 0.05$). The condition factor values of specimens were lower in the fall than in the spring and summer ($F = 8.04$, $F = 11.7$; $P < 0.001$).

The mean gut length of examined *B. oligolepis* specimens was 23.42 ± 7.12 cm. There was no statistical difference between the relative gut length of females (1.40 ± 0.20) and males (1.34 ± 0.27) ($P > 0.05$). There was no statistical difference in the relative gut length among different size groups ($P > 0.05$). The mean gut lengths of *B. oligolepis* showed seasonal variation. The mean gut length of *B. oligolepis* was longer in spring than in other seasons ($F = 6.28$; df = 1; $P = 0.001$). There was also seasonal variation in the relative gut lengths of specimens ($F = 5.84$; df = 3; $P = 0.001$). There was a linear relationship between TL and gut lengths of examined specimens that had full guts ($r^2 = 0.61$, $n = 54$, $P < 0.001$, Figure 2). There was no statistical correlation between fish weight and gut length of *B. oligolepis* ($P > 0.05$). There was a relationship (fish weight = 4.7 × gut weight + 10.0 × fish TL – 123.5) among fish weight, GCW, and TL ($F = 314.7$; $P < 0.001$).

The main food sources of *B. oligolepis* were benthic algae; Bacillariophyceae members constituted 95.3% of all dietary organisms (Figures 3 and 4). Macrophytes (4.4%) and macroinvertebrates (0.2%) were additional important food groups. Fish eggs and zooplankters had little importance in the diet of *B. oligolepis*. In terms of the frequency of occurrence, macroinvertebrates such as Diptera larvae 1 (head length ~100–150 µm), other insect larvae, and benthic algae (particularly siliceous algae) were the most popular food sources in the gut contents (Table 2). We found that 99.8% of the gut contents contained plant materials; thus, it can be said that this species feeds mainly on plant materials. *Anabaena* sp. (98%) was the most abundant food source among the cyanobacteria.

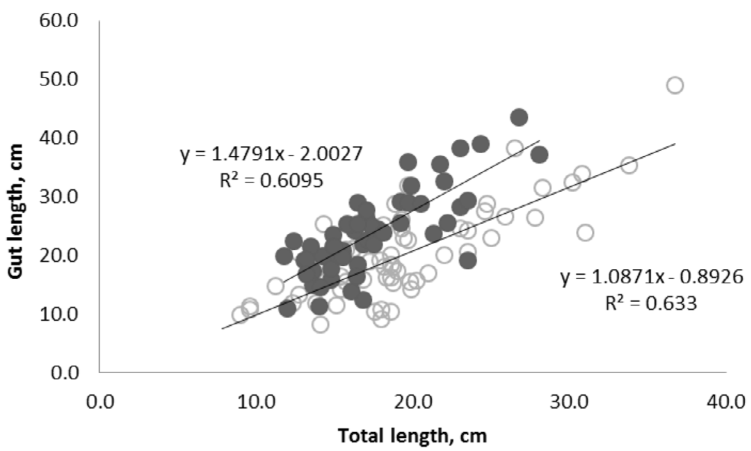
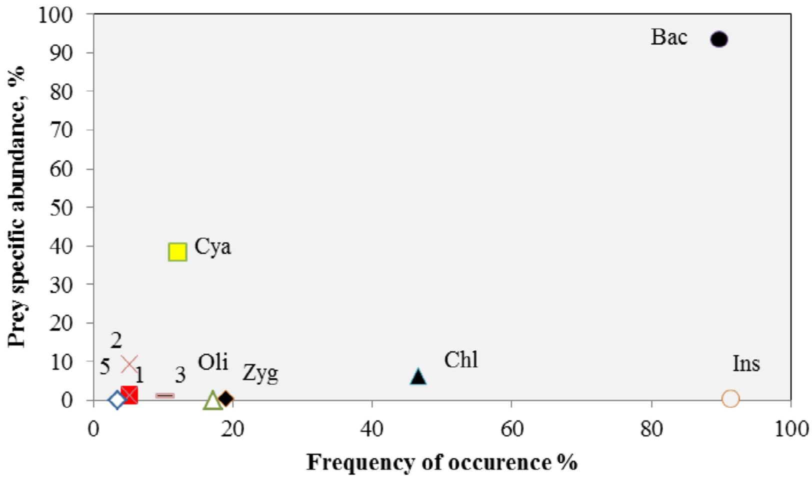


Figure 2. The relationships between the total lengths and the gut lengths of two species. Empty circles indicate *Squalius cii* and full circles indicate *Barbus oligolepis*.



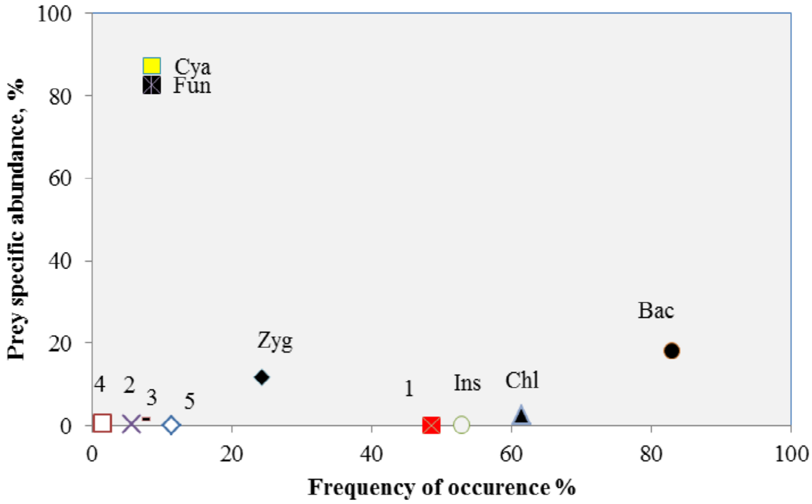


Figure 3. Relationship between prey specific abundance and the frequency of occurrence of the food categories in *B. oligolepis* (upper) and *S. cii* (lower) diets based on Costello's method. Bac: Bacillariophyceae, Cya: Cyanophyceae, Fun: fungi, Chl: Chlorophyceae, Ins: Insecta, Zyg: Zygnomophyceae, Oli: Oligochaeta, 1: Byrophyta, 2: Bryozoa, 3: Xantophyceae, 4: Amphipoda, 5: zooplankton.

The most frequently encountered organisms in this group were *Oscillatoria* sp. 1 (5.2%) and *Oscillatoria* sp. 2 (3.5%). *Fragilaria* sp. (400 µm) was the most abundant (49.2%) and frequent (41.4%) dietary resource in the gut contents among the Bacillariophyceae. *Cocconeis* sp. was the second most abundant and frequently encountered Bacillariophyceae, which was particularly identified on filamentous algae in the gut contents. Other siliceous algae (<50 µm) were found in considerable amounts in the gut contents. Filamentous algae, particularly those of 50 µm × 60 µm in size, were the most abundant food resources among the Chlorophyceae members. *Cosmarium* sp. (17.2%) and *Vaucheria* sp. (10.3%) were the most frequently encountered organisms among the Zygnemophyceae and Xanthophyceae, respectively. Therefore, the gut content analysis concluded that *B. oligolepis* is a generalist feeder in the Karamenderes River.

The percent abundance and frequency of occurrence of food organisms varied between females and males (Table 3). Both sexes fed primarily on Bacillariophyceae, Chlorophyceae, and Insecta. Zooplankters, fish eggs, Zygnemophyceae, and Bryophyta were found only in the gut contents of males. The diet of males was more diverse than that of females.

Animal (Insecta and Oligochaeta setae) and plant (Bacillariophyceae, Chlorophyceae, and Cyanobacteria) materials were found in all seasons in the gut contents of *B. oligolepis* (Table 4). Zooplankton was found only in spring and summer of 2008.

Zooplankton was consumed by fish species that were <15.2 cm in TL (Table 5). Fish eggs were found only in

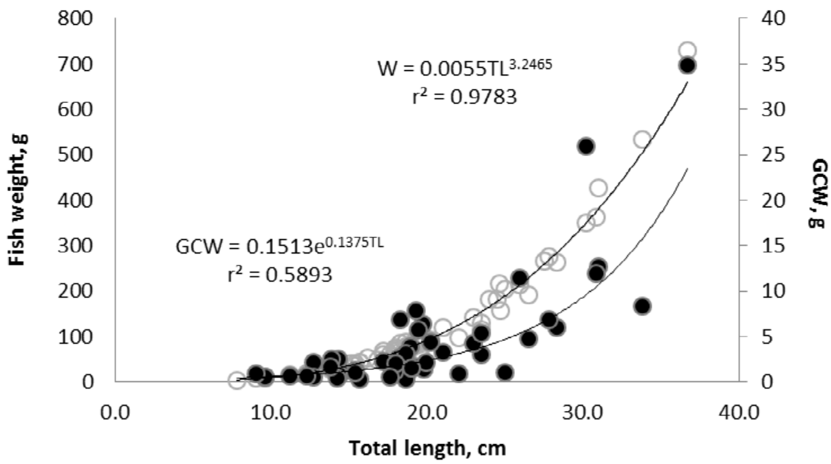


Figure 4. Percent abundance (gray columns) and frequency (white columns) of *B. oligolepis* (upper) and *S. cii* (lower) gut contents.

the size group of 17.4–19.4 cm for males in the summer of 2008. The siliceous algae and insects were consumed abundantly and frequently by almost all size groups. All size classes of fish fed on Chlorophyceae members, particularly filamentous algae (Chlorophyceae), which were found abundantly in the gut contents of fish specimens with a TL of >21.5 cm. The number of components in food was highest in the size group of 13.2–15.2 cm.

3.2. Squalius cii (Richardson, 1857)

The gut contents of 82 *S. cii* specimens were examined between August 2007 and July 2008. The guts of 13 specimens were empty**.** The mean TL and W of these specimens were 19.2 ± 5.92 cm (7.8–36.7) and 112.2 ± 126.2 g (3.5–730), respectively. The male-to-female ratio was 2.83, and the condition factor values were 1.57 ± 0.41 and 1.37 ± 0.13 for females and males, respectively. There were no significant differences between the condition factors of females and males ($F = 0.11$, $F = 0.37$; $P > 0.05$). There was a statistical difference among the condition factors of specimens among different size groups ($F = 3.20$, $F = 2.44$; $P < 0.05$). There were no seasonal differences in the condition factors ($F = 0.48$, $F = 2.23$, $P > 0.05$) (Table 1).

There were no statistical differences between the mean gut length (19.63 ± 7.62 cm) and TL (19.21 ± 5.92 cm) of *S. cii* species ($F = 0.15$; df = 1; $P > 0.05$). The relative gut lengths of female *S. cii* (1.24 ± 0.28) were longer than those of males (0.96 ± 0.28) ($F=9.2$; $P < 0.05$). There was no size-dependent variation with regard to the relative gut length of the specimens ($P > 0.05$). The mean gut lengths and relative gut lengths of *S. cii* showed seasonal variation ($F = 2.86$; $P < 0.05$; $F = 3.69$, $P < 0.05$). The mean and relative gut lengths were lowest in the summer of 2008 (Table 1). As seen in Figure 2, a linear relationship was found between TL and gut length of the fish ($r^2 = 0.633$; $n = 62$; $P < 0.001$). A correlation was found between body weight (BW) and GCW of the fish ($r = 0.845$; $n = 60$; $P < 0.001$), and there was an exponential relationship between TL and GCW, similar to that between TL and W (Figure 5). Therefore, it can be said that fish weight was affected by GCW and that GCW increases as TL increases, or vice versa. Fish weight was a function of TL and GCW according to the formula $W = 9.1\ GCW + 13.9\ TL - 192.6$ ($F = 251.7$; $P < 0.001$).

Benthic algae were found in nearly all gut contents of fish specimens, accounting for 97.4% of all dietary organisms. While macroinvertebrates were present in low abundances, they were the most frequently encountered and basic food resource (Figure 3). Benthic algae were also among the most frequently encountered organisms, and Cyanobacteria were among the most abundant dietary organisms (Figure 4). Diptera larvae were the most frequently consumed insects (Table 2). The Cyanobacteria primarily included *Oscillatoria* sp. (2.5 µm × 5 µm), *Fragilaria* sp. (400 µm), *Cymbella* sp. (20 µm × 80 µm), and *Gomphonema* sp. However, the branched and unbranched algae could not be adequately identified because of digestion; the unbranched algae (50 µm × 60 µm cell size) were the most abundant (24.7%) and frequently (30%) encountered Chlorophyceae in the gut contents. In terms of Zygnemophyceae members, *Desmidium* sp. was the most abundant (80.3%) and *Cosmarium* sp. was the most frequently identified (17.1%) in the gut contents. The gut content analyses indicate that *S. cii* is a generalist feeder in the Karamenderes River.

Plant material was abundant in the gut contents of both sexes of *S. cii*. Animal food components (i.e. different species consumed) were more abundant in the gut contents of males than females (Table 3). While members of Cyanobacteria were abundant in the gut

Table 2. Percent abundance and frequency of foods for *B. oligolepis* and *S. cii*.

		B. oligolepis		*S. cii*	
Food organisms		%N	%F	%N	%F
Bryozoa statoblasts		0.005	5.17	0.020	5.71
Nematoda		<0.001	1.72	<0.001	2.86
Amphipoda (*Gammarus* sp.)				<0.001	1.43
Diptera larvae 1 (100–150 µm head length)		0.171	81.03	<0.001	15.7
Diptera larvae 2 (800–900 µm head length)		0.006	13.79		
Chironomid larvae		0.003	6.90	<0.001	8.57
Coleoptera				<0.001	1.43
Trichoptera larvae		0.008	13.79		
Insecta larvae		0.027	25.86	<0.001	20.00
Diptera Pupae		0.002	8.62		
Insecta pupae		0.001	6.90		
Adult Diptera		<0.001	3.45		
Insecta adult		0.003	13.79	0.018	21.43
Insecta eggs				0.001	7.14
Hemiptera pupae				<0.001	1.43
Oligochaeta setae		0.012	17.24		
Rotifera (*Keratella* sp.)		<0.001	3.45	<0.001	2.86
Copepoda		<0.001	1.72	<0.001	1.43
Cladocera				<0.001	7.14
Fish				<0.001	4.29
Fish eggs		0.007	1.72	<0.001	1.43
Anabaena sp.		1.475	1.72		
Merismopedia sp.		<0.001	1.72	0.449	2.86
Oscillatoria sp. 1 (2.5 µm × 5 µm)		0.018	5.17	78.391	1.43
Oscillatoria sp. 2 (3.2 µm × 10 µm)		0.010	3.45	<0.001	1.43
Oscillatoria sp. 3				0.003	2.86
Amphora sp. 1		0.184	5.17	0.017	8.57
Amphora sp. 2		0.084	12.07		
Amphora sp. 3		0.039	10.34	0.112	1.43
Cyclotella sp.		0.019	3.45		
Cymbella sp. 1		1.003	15.52	0.011	11.43
Cymbella sp. 2		1.480	39.66	3.145	17.14
Cymbella sp. 3		0.123	25.86	0.007	17.14
Cocconeis sp.		10.985	37.93	0.342	22.86
Cymatopleura sp.		0.046	13.79	0.113	8.57
Diatoma sp.		3.505	13.79	0.561	12.86
Gomphonema sp.		0.477	15.52	2.297	12.86
Gyrosigma sp.		0.034	15.52	<0.001	7.14
Gyrosigma sp.		0.035	18.97	0.001	7.14
Navicula sp. 1		0.801	3.45	0.122	7.14
Navicula sp. 2		1.807	15.52		
Navicula sp. 3		0.221	10.34		
Nitzschia sigmoida		0.043	3.45		
Nitzshia sp.		0.912	22.41	0.490	28.57

Table 2. (Continued).

Fragilaria sp. 1 (150 µm)				0.019	1.43
Fragilaria sp. 2 (8 µm × 215 µm)		1.710	13.79	1.934	18.57
Fragilaria sp. 3 (8–320 µm)		1.118	3.45		
Fragilaria sp. 4 (10 µm × 200–250 µm)		2.323	25.86	1.830	10.00
Fragilaria sp. 5 (400 µm)		49.223	41.38	6.131	58.57
Fragilaria sp. 6 (370–500 µm)		7.166	15.52	0.134	8.57
Frustulia sp.		0.151	3.45		
Melosira sp.		1.538	36.21	0.310	24.29
Pinnularia sp. 1		0.063	3.45	0.001	1.43
Pinnularia sp. 2				<0.001	1.43
Stauroneis sp. 1		0.044	8.62		
Stauroneis sp. 2		0.183	3.45	0.112	1.43
Surirella sp. 1		0.020	10.34	<0.001	2.86
Surirella sp. 2		0.066	10.34	<0.001	2.86
Bacillariophyceae (<50 µm)		8.152	13.79	0.455	12.86
Ankistrodesmus sp.		0.017	1.72		
Closterium sp.		0.009	1.72	<0.001	4.29
Scenedesmus sp. 1		0.010	5.17		
Scenedesmus sp. 2		0.012	6.90		
Pediastrum sp.		0.010	10.34	<0.001	1.43
Branched filamentous algae (40 µm × 250 µm)		1.015	8.62	0.031	4.29
Branched filamentous algae (50 µm × 400 µm)		0.035	1.72	0.885	12.86
Branched filamentous algae (150 µm × 200 µm)				0.009	1.43
Unbranched filamentous algae (10 µm × 50 µm)				<0.001	1.43
Unbranched filamentous algae (20 µm × 20 µm)				0.007	5.71
Unbranched filamentous algae (30 µm × 100 µm)		0.463	3.45	0.450	20.00
Unbranched filamentous algae (50 µm × 60 µm)		2.288	13.79	0.647	30.00
Unbranched filamentous algae (25 µm × 5–10 µm)				0.125	5.71
Unbranched filamentous algae (50–60 µm × 75 µm)				0.215	8.57
Unbranched filamentous algae (70 µm × 80 µm)				0.011	1.43
Unbranched filamentous algae (20 µm × 30 µm)		0.033	3.45	<0.001	1.43
Unbranched filamentous algae (120 µm × 100 µm)				0.002	4.29
Unbranched filamentous algae (40–50 µm × 200 µm)				0.053	10.00
Unbranched filamentous algae (100 µm × 200–300 µm)				0.010	4.29
Oedogonium sp.		0.149	3.45	0.180	7.14
Table 2. Continued.					
Desmidium sp.				0.173	11.43
Cosmarium sp.		0.068	17.24	0.042	17.14
Particles of higher vascular plants		0.185	5.17	0.020	47.14
Vaucheria sp.		0.399	10.34	0.022	7.14
Fungus				0.090	8.57
Number of components in food		64		66	
Condition value		1.27 ± 0.13		1.35 ± 0.3	
Vacuity index		23.7		15.9	
Repletion index		2.42 ± 1.29		3.76 ± 2.33	
Relative gut length		1.3 ± 0.2		1.0 ± 0.3	
Shannon–Wiener diversity index		2.05		1.07	
Evenness		0.49		0.25	
Morisita–Horn index		0.07			
Schoener overlap index		0.16			

Table 3. Food resources for male and female *B. oligolepis* and *S. cii*.

Food organisms	*B. oligolepis*				*S. cii*			
	Female		Male		Female		Male	
	%N	%F	%N	%F	%N	%F	%N	%F
Nematoda			<0.01	3.33	<0.01	12.50		
Oligochaeta setae	0.01	16.67	0.01	16.67				
Rotifera			<0.01	3.33			<0.01	4.65
Copepoda			<0.01	3.33			<0.01	2.33
Cladocera							<0.01	4.65
Insecta	0.49	100.00	0.21	83.33	<0.01	37.50	0.02	60.47
Insecta eggs							<0.01	11.63
Fish					<0.01	6.25	<0.01	2.33
Fish eggs			0.01	3.33			<0.01	2.33
Bryozoa statoblasts	<0.01	8.33			<0.01	6.25	0.02	6.98
Cyanobacteria	16.66	8.33	0.04	16.67	0.12	12.50	81.04	4.65
Bacillariophyceae	68.92	75.00	95.85	96.67	52.46	87.50	16.67	83.72
Chlorophyceae	1.26	41.67	3.24	53.33	31.88	62.50	2.14	62.79
Zygnemophyceae			0.02	20.00	13.17	37.50	0.01	20.93
Bryophyta (250 µm × 1000 µm)			0.20	3.33	1.14	56.25	<0.01	48.84
Xanthophyceae (*Vaucheria* sp., 200 µm × 1000 µm)	0.67	8.33	0.42	13.33	1.22	12.50	<0.01	4.65
Fungus (100 µm × 5 µm fragment)							0.09	13.95

contents of *S. cii* males, members of Bacillariophyceae and Chlorophyceae were abundant in the gut contents of females.

Bacillariophyta and Chlorophyceae were abundant in a variety of size classes (Table 6). Zooplankter species such as Rotifera, Amphipoda, Copepoda, and Cladocera were consumed by specimens that were <20 cm in size. Insects were identified in the gut contents of fish across all size groups. Fish eggs were found only in the gut contents of the size group of 17.1–20.1 cm in the summer of 2008; the number of food components was highest in this size group.

Cyanobacteria were found frequently and abundantly only in the summer of 2007 (Table 4). Insects were the most frequently consumed food item in the summer and spring. The greatest diversity of food resources in the gut contents was encountered during the summer of 2008. Bryozoa statoblasts were found in the gut contents in the fall of 2007 and spring and summer of 2008; fish were found primarily in the gut contents in the fall and spring, and fish eggs were found in the gut contents in the summer of 2008.

3.3. Diet diversity and overlap of sympatric species

The calculated Shannon–Wiener diversity indexes of the diets in the gut contents for *B. oligolepis* and *S. cii* were 2.05 and 1.07, respectively, and the E values were 0.49 and 0.25, respectively (Table 2). The species richness (S), i.e. the number of identified taxa in the gut contents, was 64 and 66 for *B. oligolepis* and *S. cii*, respectively. Ontogenetic fluctuations in diet diversity were observed in *B. oligolepis* and *S. cii* (Tables 5 and 6). In *B. oligolepis*, smaller body size groups consumed more taxa (higher richness) with lower diversity; however, the gut contents of the larger body size group exhibited higher diversity with a lower even distribution of foods. Specimens of *S. cii* with body length of 14.0–20.0 cm consumed more types of food (higher richness); however, the diversity in diet decreased with increase in length, with the dominance of some diet groups such as Bacillariophyceae. Resource availability for *S. cii* was higher in comparison to *B. oligolepis* across all seasons.

The two species shared 46 of the 84 different dietary resources identified (Table 2). All plant organisms, Rotifera, Copepoda, and Insecta were found in the gut contents of both species. However, the Morisita–Horn index and Schoener overlap index were calculated as 0.07 and 15.7, respectively. The diet overlap between these species exhibited seasonal variability, and a high degree of overlap was observed in the spring and summer of 2008 (Table

Table 4. Seasonal changes in the abundance and frequency of food items consumed by *S. cii* (*S.c.*) and *B. oligolepis* (*B.o.*), and diet overlap.

Diet organisms	Summer 2007				Fall 2007				Spring 2008				Summer 2008			
	%N		%F		%N		%F		%N		%F		%N		%F	
	B.o.	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*	*B.o.*	*S.c.*
Nematoda						<0.01		9	<0.01	<0.01	5	3				
Oligochaeta setae	0.17		50		0.01		7		0.01		14		<0.01		14	
Amphipoda						<0.01		9								
Rotifera									<0.01	<0.01	5	3	<0.01	<0.01	7	4
Copepoda									<0.01		5			<0.01		4
Cladocera										<0.01		17				
Insecta	0.47	<0.01	100	40	0.25	0.01	100	45	0.66	<0.01	95	57	0.08	0.66	71	57
Insecta egg										<0.01		10		0.02		9
Fish						<0.01		18		<0.01		3				
Fish egg													0.01	<0.01	7	4
Bryozoa statoblasts					0.03	<0.01	7	9	<0.01	0.29	5	7	<0.01	<0.01	7	4
Cyanobacteria	0.23	89.42	38	60	9.73	0.25	7	18	0.10		9		<0.01	0.02	7	4
Bacillariophyceae	98.98	10.56	100	100	83.73	33.93	64	73	90.95	76.20	95	87	96.16	82.70	100	78
Chlorophyceae	0.10	0.02	50	100	5.41	64.43	43	55	8.09	20.20	50	67	2.95	13.17	43	52
Zygnemophyceae	0.06	<0.01	63	40		<0.01		9	0.05	3.01	5	27	0.10	0.05	36	26
Xanthophyceae (*Vaucheria* sp., 200 µm × 1000 µm)					<0.01	1.35	14	9	0.14	0.04	5	10	0.42	0.08	21	4
Bryophyta (250 µm × 1000 µm)	0.00	<0.01		40	<0.01	0.03	7	73		0.26			0.27	0.05	14	57
Fungus (100 µm × 5 µm) fragment														3.26		26
Number of components in food	6	6			8	11		11	12			11	13			
Shannon–Wiener diversity index	0.07	0.34			0.55	0.73		0.35	0.68			0.20	0.59			
Evenness	0.04	0.19			0.26	0.30		0.14	0.27			0.08	0.23			
Morisita–Horn index	0.12				0.51				0.97				0.98			
Schoener overlap index	0.11				0.40				0.84				0.86			

4). Bacillariophyceae members were a dominant food item in the diets of both species; however, *S. cii* also consumed Cyanobacteria (summer 2007) and Chlorophyceae, which were additional important food components in all other seasons except summer 2007.

4. Discussion

B. oligolepis was recently renamed by Kottelat and Freyhof (2007) and there is no current literature comparing the feeding characteristics of this species with other populations. *S. cii* was also renamed by Kottelat and Freyhof (2007) in Turkey. The condition factor of this species was comparable to that of *Leuciscus cephalus*, which is the prior name for this species in the Karamenderes (Sarı et al., 2006). The condition value of *S. cii* was consistent with the results of additional works conducted in central and western Anatolia (Koç et al., 2007; Bektaş et al., 2009). Nevertheless, the condition value of this species was higher in the Karamenderes River than in various European freshwaters (0.99–1.29) (Treer et al., 1997, 1999) and Eastern Anatolia (1.35) (Erdoğan et al., 2002). Studies on the feeding habits of *S. cii* for comparison are lacking. The findings on *S. cephalus* indicate that it feeds primarily on plant material, zoobenthos, detritus, and fish in various European and Turkish rivers (Hellawell, 1971; Ünver and Erk'akan, 2011); these findings are in accordance with the results of the current study, in which 95% of all foods were benthic algae. *S. cii* also exhibits similarities in feeding habits to those of *L. cephalus* (Altındağ, 1997; Nastova-Gjorgjioska et al., 1997; Balestrieri et al., 2006; Marković, 2007).

Fish with smaller gut lengths have been shown to exhibit more carnivorous feeding habits (Montgomery,

Table 5. Percent abundance and frequency of food items of *B. oligolepis* across varying size groups.

Food organisms	Fish size group (cm)													
	11.1–13.1		13.2–15.2		15.3–17.3		17.4–19.4		19.5–21.5		21.6–23.6		23.7–29.9	
	N = 4		N = 14		N = 16		N = 7		N = 5		N = 7		N = 3	
	%N	%F	%N	%F	%N	%F	%N	%F	%N	%F	%N	%F	%N	%F
Nematoda							<0.01	14.3						
Oligochaeta setae			<0.01	7.1	0.02	31.3			<0.01	20	0.02	28.57	0.05	33.3
Rotifera (*Keratella* sp.)	0.01	25	<0.01	7.1										
Copepoda	<0.01	25												
Insecta	1.01	100	0.24	100	0.10	87.5	0.33	85.7	0.11	100	0.4	71.43	0.63	100
Fish eggs							0.04	14.3						
Bryozoa statoblasts			<0.01	7.1									0.01	33.3
Cyanobacteria	0.03	25	0.10	14.3	0.02	12.5	8.11	14.3	0.02	20				
Bacillariophyceae	98.9	100	90.8	78.57	97.5	100	88.59	100	91.58	100	63.0	85.7	77.4	100
Chlorophyceae	0.01	25	7.7	42.9	2.01	50	1.66	71.4	8.00	80	36.6	14.3	21.9	66.7
Zygnemophyceae			0.3	21.4	0.02	43.8			0.01	20				
Bryophyta (250 µm × 1000 µm)			0.2	7.1			0.82	28.6						
Xanthophyceae (*Vaucheria* sp., 200 µm × 1000 µm)			0.7	14.3	0.34	6.25	0.45	28.57	0.28	20				
Number of components in food	6		10		7		8		7		4		5	
Relative gut length	1.46 ± 0.4		1.29 ± 0.2		1.34 ± 0.3		1.38 ± 0.1		1.48 ± 0.2		1.32 ± 0.2		1.52 ± 0.2	
Repletion index	2.20 ± 1.6		1.95 ± 1.6		2.42 ± 0.8		3.06 ± 0.4		2.51 ± 1.4		2.59 ± 1.4		2.89 ± 2.5	
Shannon–Wiener diversity index	0.06		0.38		0.13		0.47		0.31		0.68		0.57	
Evenness	0.03		0.16		0.07		0.22		0.16		0.49		0.35	

1977; Ribble and Smith, 1982; Kramer and Bryant, 1995). The relative gut lengths to body lengths of *B. oligolepis* [1.3 ± 0.2 (0.7–1.8)] and *S. cii* [1.0 ± 0.3 (0.5–1.8)] were in accordance with the values typical for carnivores (0.5–2.4) (Al-Hussaini, 1947). However plant materials with detritus were recorded in the gut contents of both species. Nonetheless, it is hard to determine the contribution of plant materials to diets and the trophic positions of these species, and further studies should be implemented for clarification. At the same time, as stated by Olsson et al. (2007), plasticity in gut morphology might be observed in response to diet quality, which varies across seasons. The smaller relative gut lengths of *B. oligolepis* and *S. cii* in the summer of 2008 might be explained by the consumption of a higher quality diet (e.g., fish) during that season. Hence, there was a seasonal shift in the diet and gut morphology of both species in the Karamenderes River. In addition, through the positively significant correlation between gut length and TL, the TL of these specimens can be used for estimating changes in feeding habits without sacrificing specimens. However, this relationship should be supported further in studies from different localities.

During ontogenesis, both species shifted their diets, feeding on zooplankton as juveniles and then shifting mainly to benthic algae, macroinvertebrates, and fish (*S. cii* only). Fish were a limited food resource for *S. cii of* >26.4 cm in TL; fish were not found in the gut contents of *B. oligolepis*. In other *Squalius* and *Barbus* spp., an ontogenetic flexible diet, switching from zooplankton to benthic algae, macroinvertebrates, and eventually fish, has been shown in several studies (Magalhãtes, 1992; Admasu and Dadebo, 1997; Desta et al., 2008; Ünver and Erk'akan, 2011; Sanchez-Hernandez and Cobo, 2011). In the Karamenderes River, in terms of the ingestion of fish as a diet by larger specimens, the ontogenetic feeding patterns of *B. oligolepis* found in this study were not similar to those reported for several other *Barbus* species in the aforementioned studies. Likewise, limited amounts of fish as a dietary item were found in the gut contents of *S. cii* specimens in the Karamenderes River. This might be explained by the absence of suitable prey species because of the low abundance of other fish species during the study in the Karamenderes River.

Some macrophytes are thought to be aquatic nuisances. Aquatic plant eradication in streams is not

Figure 5. The relationships between fish total body length (TL), gut content weight (GCW), and fish body weight (W) in *S. cii*. The full circles indicate GCW and the empty circles indicate W.

recommended (Barko and Smart, 1986); one of the suggested management plans for controlling submerged plant development in warm temperate lakes is the top-down effects of fish (Beklioglu et al., 2003). A high rate of consumption of plant materials by the two most abundant native species, *B. oligolepis* and *S. cii*, may be important in controlling macrophyte populations, particularly in the summer when macrophytes cover nearly all the lowland areas of the Karamenderes River.

Only a single specimen of *S. cii* was caught in the cold winter months in the study area. The study area was located in the lower part of a reservoir, which probably affects important ecological processes by changing the water flow, sediment, nutrient levels, energy, and biota (Ligon et al., 1995). Thus, both species may migrate to other habitats, perhaps into a deeper section of the lowland river.

Predation, competition, and symbiotic relationships among fish species allow the formation of fish communities in river ecosystems (Crowder, 1990). The potential for competitive exclusion by any particular prey species may decrease due to different prey preferences of coexisting generalist species (Shurin and Allen, 2001). Therefore, generalist feeding patterns may explain the coexistence of different species (Sánchez-Hernández et al., 2011). The cohabitation of *S. cii* and *B. oligolepis* may be explained by their potential generalist feeding patterns in the Karamenderes River. The seasonal resource use of these species also indicates that *S. cii* had a greater advantage than *B. oligolepis* in terms of the diversity of food ingested and the number of food taxa consumed in each season. When comparing the overall feeding patterns of the two species, *S. cii* consumed more types of food items with lower diversity because of lower evenness value, which

Table 6. Percent abundance and frequency of occurrence of *S. cii* diets across different size groups.

				Fish size group (cm)				
Food resources	7.8–10.8	10.9–13.9	14.0–17.0	17.1–20.1	20.2–23.2	23.3–26.3	26.4–29.4	29.5–36.7
	%N %F N = 4	%N %F N = 7	%N %F N = 13	%N %F N = 24	%N %F N = 4	%N %F N = 8	%N %F N = 4	%N %F N = 5
Nematoda			<0.01 7.7					<0.01 20.0
Amphipoda			<0.01 7.7					
Rotifera		<0.01 14.3	<0.01 7.7					
Copepoda				<0.01 4.2				
Cladocera	0.02 25.0	0.01 24.3	<0.01 7.7	<0.01 8.3				
Insecta	<0.01 25.0	0.01 42.9	0.01 30.8	0.01 66.7	10.8 100	<0.01 50	<0.01 75	<0.01 20
Insecta eggs				0.02 12.5	0.01 25			0.06 20.0
Fish	<0.01 25.0						<0.01 25.0	<0.01 20.0
Fish eggs				<0.01 4.2				
Bryozoa statoblasts				<0.01 8.3			0.46 50.0	
Cyanobacteria	0.02 25.0	0.28 14.3	0.40 15.4	0.01 4.2		88.10 12.5		
Bacillariophyceae	65.6 75.0	56.2 85.7	82.8 84.7	84.8 83.3	82.9 50	10.9 100	78.1 75	32.9 80
Chlorophyceae	34.3 50.0	41.3 85.7	16.7 69.2	12.2 54.2	5.5 25.0	0.7 62.5	21.5 75.0	66.1 60.0
Zygnemophyceae		2.19 57.1	0.08 38.5	0.05 20.8	0.11 25.0	0.23 12.5		0.43 20.0
Xanthophyceae (*Vaucheria* sp., 0.2 µm × 1 µm)	0.09 25.0			0.56 16.7				
Bryophyta (1 mm × 1 mm)	<0.01 50.0	0.04 14.3	0.04 46.2	0.02 50.0	0.01 50.0	0.02 87.5	0.02 25.0	0.44 60.0
Fungus (100 µm × 5 µm)				2.34 20.8	0.69 25.0			
Number of food component	8	8	10	13	7	6	6	8
Relative gut length	1.1 ± 0.1	1.1 ± 0.3	1.1 ± 0.3	1.0 ± 0.3	0.9 ± 0.1	1.0 ± 0.1	1.2 ± 0.3	1.1 ± 0.2
Repletion index	7.6 ± 2.2	5.5 ± 2.5	3.7 ± 2.2	3.3 ± 2.3	2.9 ± 1.6	3.0 ± 1.7	2.4 ± 0.1	3.4 ± 2.2
Shannon–Wiener diversity index	0.66	0.79	0.49	0.53	0.36	0.40	0.55	0.67
Evenness	0.32	0.38	0.21	0.20	0.18	0.23	0.31	0.32

signifies the higher dominancy of food components. *B. oligolepis* exhibited lower feeding intensity, smaller TL, and larger relative gut length (i.e. the quality of food items consumed was lower) than those of *S. cii*, indicating that *S. cii* has a greater advantage than *B. oligolepis* and *S. cii* may exclude *B. oligolepis* during times of limited resource availability. The feeding characteristics of both species are shaped by abiotic and biotic conditions, including the disruption of anthropogenic activities over long periods of time, from an evolutionary perspective. However, the introduction of invasive *C. gibelio*, the most abundant fish in the study area, might affect the trophic position and feeding patterns of native species; the potential impacts should be further investigated in the future.

Rivers are important components of terrestrial ecosystems and are more affected by their environs than marine and ocean ecosystems. Therefore, the ecosystem of a river may be adversely affected by changes in adjacent ecosystems. The Karamenderes basin is heavily used for agricultural activities, and pesticides, fertilizers, irrigation, and dams may affect river biota, including the feeding ecology of *S. cii* and *B. oligolepis*, directly or indirectly. Therefore, the effects of pollution and other human impacts on the population dynamics and feeding relationships of river fish should be further studied in this river system.

Acknowledgments
This study was supported by the Çanakkale Onsekiz Mart University Bilimsel Araştırma Projeleri 2007/51 project. I would like to thank fisherman Selahattin Erol for specimen collection, Assoc Prof Dr Hasan Göksel Özdilek and Dr Emel Okur Berberoğlu for assistance with the field studies, Yusuf Güder and Burçin Sezer for assistance with the laboratory studies, and Prof Dr F Güler Ekmekçi for previewing this paper. I would also like to thank the two anonymous referees for valuable contributions to the manuscript.

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