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Food composition and feeding strategies of an invasive species, *Carassius gibelio* (Bloch, 1782) inhabiting a eutrophic lake in Middle Black Sea region

RAMAZAN YAZICI[1], OKAN YAZICIOGLU[2], SAVAS YILMAZ[3] AND NAZMI POLAT[3]
[1]Laboratory and Veterinary Health Program, Veterinary Department, Cicekdagı Vocational School Kırsehir Ahi Evran University, Kırsehir, Turkey
[2]Department of Plant and Animal Production, Vocational School of Technical Sciences, Kırsehir Ahi Evran University Kırsehir, Turkey
[3]Department of Biology, Faculty of Arts and Science, Ondokuz Mayıs University, Samsun, Turkey
e-mail: rmznyzci@gmail.com

ABSTRACT

Diet composition and feeding features of the Prussian carp *Carassius gibelio* (Bloch, 1782) were studied by analysing the stomach content of 155 fish specimens sampled from Lake Ladik during November 2009-October 2010. Five of the specimens had empty stomachs. A total of 29 prey taxa belonging to eight major groups comprising aquatic insects, Copepoda, Cladocera, Rotifera, Bacillariopyhta, Chlorophyta, Cyanobacteria and fish eggs were identified in 150 full stomachs. Diet composition showed slight seasonal variation. Cladocera was the most important prey item in all seasons, with peak abundance in spring. Feeding intensity exhibited seasonal change and was maximum in summer. Summer and autumn diets of this species showed the highest similarity. The study indicated that the Prussian carp in Lake Ladik showed both omnivorous and opportunistic feeding habits, exhibiting specialised feeding strategy on Cladocera, while they showed generalised feeding strategy on most prey items. The wide dietary plasticity of invasive Prussian carp can help their population to expand rapidly in different aquatic ecosystems.

Keywords: Alien species, Diet composition, Feeding habits, Lake Ladik, Prussian carp

Introduction

Stomach content analysis provides important information on fish feeding patterns and diet composition. Quantitative analysis of stomach contents is an important tool to understand and elucidate predator-prey relationships (Pinkas *et al.,* 1971), feeding behaviour patterns (Preciado *et al.,* 2006), food competition (Merona and Rankin-de-Merona, 2004) and ontogenetic shifts of diet (Yazicioglu *et al.,* 2016). Data on feeding habits of fishes, especially invasive species, are important to understand the functional role of the fish within their ecosystems (Osman *et al.,* 2013).

The genus *Carassius* is represented by three species in Europe *viz.* the goldfish, *Carassius auratus*, the crucian carp, *C. carassius* and the Prussian carp, *C. gibelio* (Innal, 2011). Prussian carp is a common and invasive fish species that strongly influences ecosystem processes within the habitat. Invasive species can change aquatic ecosystems by their impacts on native biodiversity and ecosystem function (Carey and Wahl, 2010). *Carassius* spp. show negative impacts on the aquatic environment, directly through competition or predation and indirectly by altering habitat or changing disease dynamics (Innal, 2011; Lymbery *et al.,* 2014). Invasive species may predominate in new environments and reduce natural species' biodiversity in the habitat (Didham *et al.,* 2005). Many invasive species like *C. gibelio* reduce the zooplankton biomass, especially large-sized species and prevent submerged macrophyte development and indirectly causes enhanced growth of planktonic algae leading to eutrophication in the aquatic ecosystems (Razlutskij *et al.,* 2021).

The Prussian carp was recently identified in different aquatic habitats in Turkey, which was intentionally introduced in 2007 (Yilmaz *et al.,* 2012) and is now dominantly present in Lake Ladik which has been classified as a eutrophic and shallow lake (Yagci *et al.,* 2015). Knowledge on the diet and feeding habits of invasive fishes is especially important in understanding how they can affect the environment into which they are introduced. Only very little information is available on the food composition and feeding habits of *C. gibelio* (Balik *et al.,* 2003; Yilmaz *et al.,* 2007; Ozdilek and Jones, 2014; Partal and Ozdilek, 2019); and there is no information on the feeding features of this species inhabiting Lake Ladik.

C. gibelio has been reported to exhibit an omnivorous feeding strategy (Specziar and Rezsu, 2009). This species is also known to be an opportunistic feeder with plasticity in its food items. When the population of *C. gibelio* is of low density, they prefer the most obtainable and abundant plant materials as food (Partal and Ozdilek, 2019). They are likely to compete with other cyprinid species when there isn't enough food in the aquatic ecosystem. This study aimed to determine seasonal changes in food habits and feeding features for *C. gibelio* in Lake Ladik and to compare these with the same features of this species in other inland water systems in Turkey and Europe.

Materials and methods

Study area and sampling

The present study was carried out in Lake Ladik (35°40' - 36°05'E and 40°50' - 41°00'N), located 10 km from Ladik District of Samsun Province, northern Turkey. The length, width, depth and altitude of this lake are about 5 km, 2 km, 2.5-6 m and 867 m respectively.

Sampling was conducted at monthly intervals between November 2009 and October 2010, except during the months of May and June 2010. A total of 155 Prussian carp individuals were caught from ten different points of the lake (Fig. 1) using gill nets of 20, 25, 30, 35 and 40 mm mesh sizes (knot to knot) and trammel nets of 30, 35, 45, 50, 55 and 60 mm mesh sizes (knot to knot). The nets were set at dusk and retrieved at dawn (approximately twelve h). The fish were frozen shortly after capture. Water temperature values needed for the calculation of the stomach fullness index were obtained from published sources (Yagci *et al.,* 2015).

Laboratory processes

Total length (TL) of each individual was recorded to the nearest 0.1 cm and weighed for total body weight (BW) to the nearest 0.01 g. The ranges of length and weights were 14.3-28.8 cm, 58.0-550.0 g in females (145 individuals), 15.4-26.6 cm and 73.22-372.13 g in males (10 individuals), respectively. The stomach contents of specimens were removed and weighed with a precision of 0.01 g. The contents were then analysed under an inverted microscope in a Sedgewick Rafter counting chamber at different magnifications and under a binocular microscope for aquatic insects. Prey items were sorted and identified to the lowest possible taxa with standard invertebrate identification keys (Bouchard, 2004; Benzie, 2005; van Vuuren *et al.,* 2006; Phan *et al.,* 2015).

Diet and statistical analysis

The intensity of feeding activity of fish was calculated using fullness index [FI% = (Weight of stomach content/ body weight) *100] (Hyslop, 1980). The diet was assessed from (1) Percentage frequency of occurrence (FO% = Number of stomachs containing prey i/Total number of full stomachs × 100) and (2) percentage numerical abundance (N% = Number of prey i/Total number of prey × 100) (Hyslop, 1980), for each prey item.

The absolute importance index (AII) and relative importance index (RII%), which were modified by Meye *et al.* (2008) was used to determine the importance of prey items.

AII = N% + FO%, where AII is the absolute importance index, N% is the percentage number of prey types and FO% is the percentage frequency of occurrence of prey types.

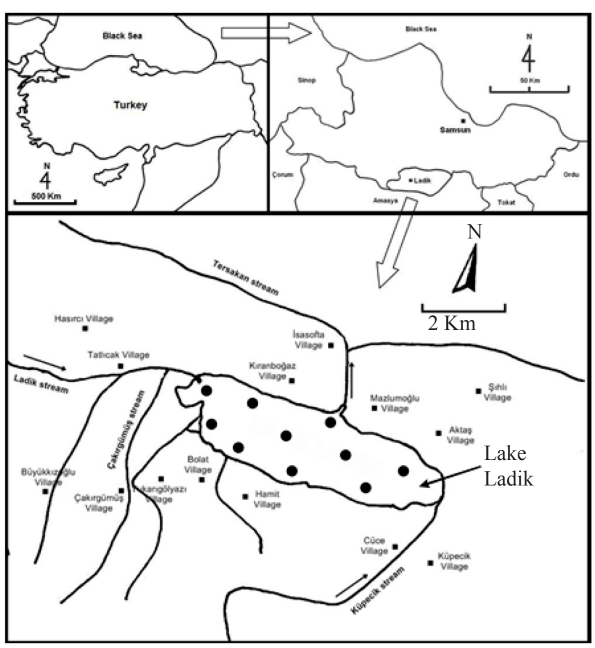

Fig. 1. The study area and sampling stations

RII% = AII × 100/nΣAII, where RII% is relative importance index and n is the number of the different prey types.

Feeding strategy

The feeding data such as FI% and RII% were evaluated as seasonal and general in this study. The similarity of the type of prey between the seasons was calculated using the Bray-Curtis similarity index (Marshall and Elliott, 1997). The modified Costello (1990) graphical method (Amundsen *et al.,* 1996) was used to evaluate seasonal variations in feeding strategy and to determine dominant prey groups of Prussian carp. In this method, prey-specific abundance (Pi%) (y - axis) was plotted against frequency of occurrence (F) (x - axis) on a two-dimensional graph, and was expressed as:

$$Pi\% = (\Sigma\ Si / \Sigma\ Sti) \times 100$$

where Si is the number of preys i and Sti is the total number of preys in the stomachs containing prey i.

The seasonal (Winter: December, January and February; Spring: March, April and May; Summer: June, July and August; Autumn: September, October and November) variation of Fullness index (FI%) was tested by the non-parametric Kruskal-Wallis test (Zar, 1999). The relationship between fullness index (FI%) and water temperature was tested using Spearman's rank correlation among seasons. Statistical analyses were performed using SPSS 24 software package.

Results

Feeding intensity

The mean fullness index (FI%) showed variation among seasons. The fullness index (FI%) was significantly different between the seasons (Kruskal-Wallis test, $p<0.001$). The relations between the seasonal values of Fullness index (FI%) and water temperature (°C) (Fig. 2) indicate that the highest feeding intensity was found in summer (1.25), followed by spring (0.69) while the lowest value was recorded in winter (0.27), followed by autumn (0.49). The mean water temperature values recorded were highest in summer season (23.8°C) and the lowest in winter season (5.6°C) (Yagci *et al.,* 2015). This situation indicated that the mean seasonal FI% value showed positive correlation with increase in water temperature. Spearman rank correlations showed that mean FI% was significantly correlated with water temperature in this habitat ($r = 0.696$, $p<0.01$).

Diet composition

Out of 155 stomachs examined, 5 (3.22%) were empty. The diet of this species showed a wide spectrum, ranging from animal origin to plant origin food. A total of 29 prey items belonging to 8 main prey groups (aquatic insects, Copepoda, Cladocera, Rotifera, Bacillariophyta, Chlorophyta, Cyanobacteria and fish eggs) were identified in the diet of the Prussian carp. The percentage frequency of occurrence (FO%), percentage numerical abundance (N%), absolute importance index (AII) and relative importance index (RII%) of prey items found in stomach are presented in Table 1 and the relative importance index (RII%) of main prey groups is shown in Fig. 3. Prey items of animal origin were dominant and constituted 77.62% of the total RII. The overall prey composition of Prussian carp consisted mainly of Cladocera (FO% = 98.67 and N% = 61.48). Rotifera and Cyanobacteria were secondary prey while aquatic insects, Copepoda, Bacillariophyta, Chlorophyta and fish eggs were less frequent. Among Cladocera, *Bosmina* and *Chydorus* were found in the highest abundance (N%: 33.96 and 22.96, respectively) and the highest frequency of occurrence (FO%: 96.0 and 87.33, respectively). Among secondary prey items, *Keratella* was the most consumed food item in terms of frequency of occurrence (FO% = 56.67), while *Microcystis* was ranked higher in abundance by number (N% = 17.19) (Table 1).

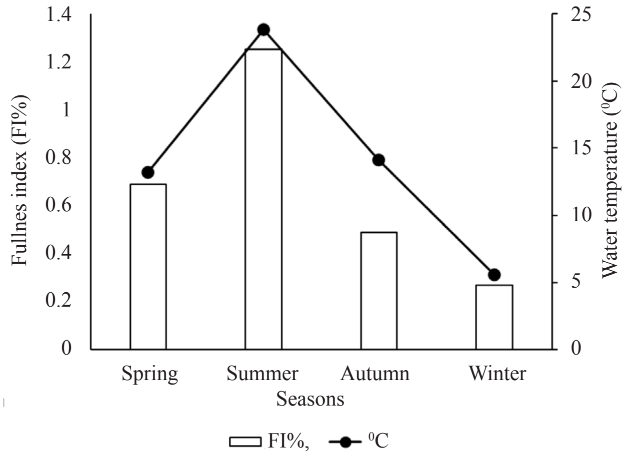

Fig. 2. Seasonal changes in Fullness index and water temperature

Cladocera as main prey group constituted the most important prey item, with 41.38% of total RII; followed by Rotifera (RII% = 18.26) and Cyanobacteria (RII%=16.27). The other main prey groups were less important and each of them constituted less than 8% of the total RII. (Fig. 3).

Seasonal changes in diet composition

The relative importance index values (RII%) for the main prey categories found in Prussian carp's stomach contents are given in Fig. 4. The fish was found to have fed on 23 different prey types in summer, followed by 21

Table 1. The diet of *Carassius gibelio* in Lake Ladik

Main prey	Prey items	N	N%	FO	FO%	AII	RII%
Aquatic insects	Chironomid larvae	630	0.82	27	18.00	18.82	3.50
	Odonata larvae	25	0.03	2	1.33	1.37	0.25
Copepoda	Calanoida	435	0.57	10	6.67	7.24	1.35
	Cyclopoida	1480	1.93	32	21.33	23.27	4.33
	Harpacticoida	170	0.22	6	4.00	4.22	0.79
Cladocera	*Bosmina*	25990	33.96	144	96.00	129.96	24.19
	Chydorus	17570	22.96	131	87.33	110.29	20.53
	Daphnia	1055	1.38	33	22.00	23.38	4.35
	Coronotella	2265	2.96	30	20.00	22.96	4.27
Rotifera	*Keratella*	10675	13.95	85	56.67	70.62	13.14
Bacillariophyta	*Cocconeis*	40	0.05	2	1.33	1.39	0.26
	Cyclotella	260	0.34	10	6.67	7.01	1.30
	Cymatopleura	70	0.09	3	2.00	2.09	0.39
	Cymbella	375	0.49	8	5.33	5.82	1.08
	Licmophora	10	0.01	1	0.67	0.68	0.13
	Melosira	805	1.05	20	13.33	14.39	2.68
	Navicula	355	0.46	10	6.67	7.13	1.33
	Nitzchia	60	0.08	3	2.00	2.08	0.39
	Pinnularia	15	0.02	1	0.67	0.69	0.13
	Surirella	10	0.01	1	0.67	0.68	0.13
	Stauroneis	10	0.01	1	0.67	0.68	0.13
Chlorophyta	*Ankistrodesmus*	365	0.48	9	6.00	6.48	1.21
	Cosmarium	25	0.03	2	1.33	1.37	0.25
	Oedogonium	95	0.12	5	3.33	3.46	0.64
	Pediastrum	10	0.01	1	0.67	0.68	0.13
	Scenedesmus	30	0.04	1	0.67	0.71	0.13
Cyanobacteria	*Anabaena*	305	0.40	9	6.00	6.40	1.19
	Microcystis	13150	17.19	62	41.33	58.52	10.89
Eggs	Fish eggs	235	0.31	7	18.00	4.97	0.93

different preys in autumn and spring, respectively. The least number of prey types was recorded in winter diet (11). Animal prey items, with a peak value recorded in winter (RII%=98.02), were preferred over plant prey during all seasons. Prey items of plant origin were most abundant in summer, with 31.3% of total RII. Cladocera was the most important prey item and the dominant prey group in diet throughout the year, especially in spring (RII%=56.19) and winter (RII%=54.73). Among Cladocera, *Bosmina* and *Chydorus* were the most consumed prey items with RII% of 24.19 and 20.53, while *Daphnia* and *Coronotella* were least consumed with RII% of 4.35 and 4.27. Rotifera, Aquatic insects, Copepoda, and Chlorophyta were also present in the diet throughout the year. The peak values of Rotifera and Aquatic insects were recorded in autumn (RII% = 23.21) and winter (RII% = 19.07), respectively. Copepoda and Chlorophyta were found in smaller quantities. Cyanobacteria and Bacillariophyta were eaten in all seasons, except in winter, while fish eggs were consumed in summer and autumn (Fig. 4).

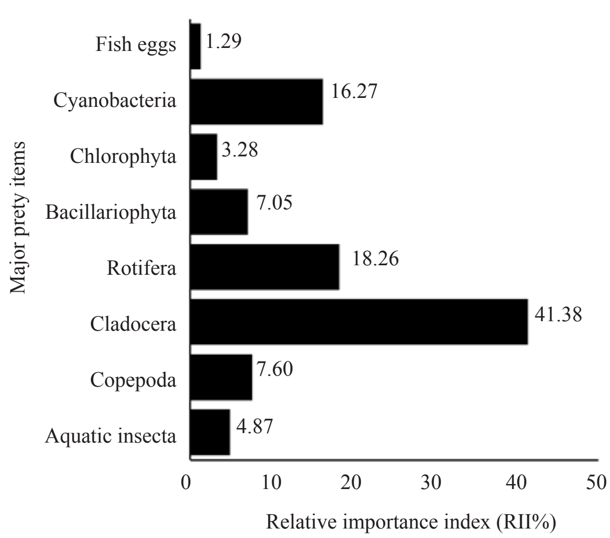

Fig. 3. RII% values of the main prey groups in diet of Prussian carp in Lake Ladik

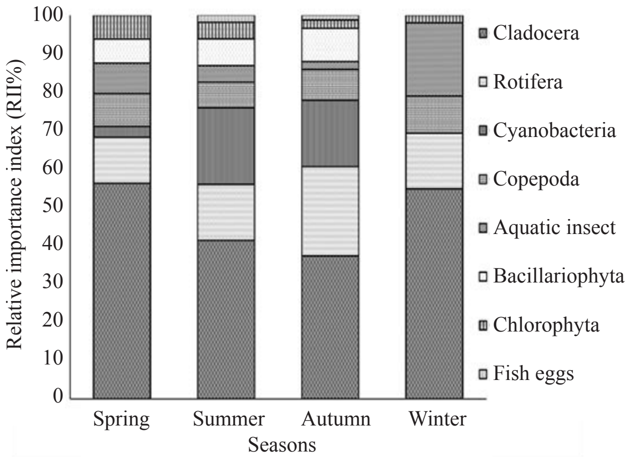

Fig. 4. Seasonal variation of diet of Prussian carp with respect to RII% values of the main prey groups

Hierarchical cluster analysis differentiated two main groups, with a similarity of 60%. The highest similarity in the diet of Prussian carp was observed in summer and autumn (0.8465). Besides, a clustering dendrogram indicated that winter diet formed a separate group (Fig. 5).

Feeding strategy

The feeding strategy plot showed the importance of Cladocera which was consumed by majority of the samples (high Frequency Occurrence). Cladocera, therefore, was located in the upper right corner of the graph. Prussian carp tended to exhibit a specialist feeding strategy towards Cladocera and it was the numerically dominant prey (high Pi). Although about half of the samples fed on

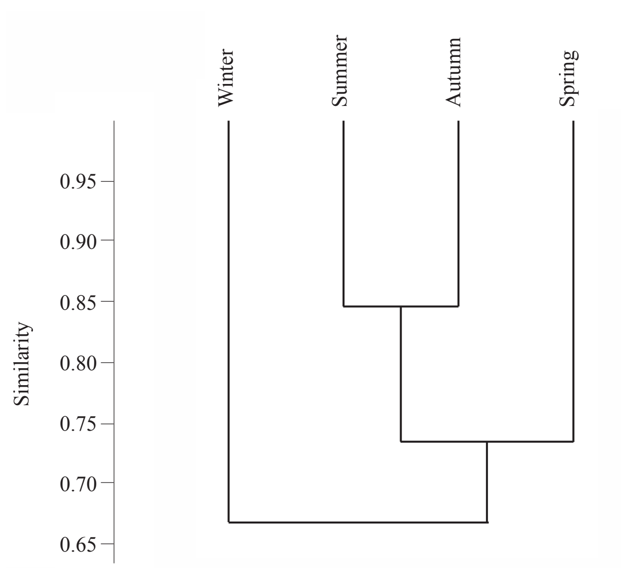

Fig. 5. Dendrogram for hierarchical clustering of the prey composition of *C. gibelio* according to seasons

Rotifera and Cyanophyta, the contributions of these were low in the diet in terms of abundance. Other prey items (Chlorophyta, aquatic insects, Bacillariophyta, fish eggs and Copepoda) were consumed occasionally by less than 30% of fish. These prey groups presented a low F and a low Pi (lower left quadrant), displaying evidence of a generalist feeding strategy (Fig. 6).

Discussion

Several studies have been carried out on the dietary habits of Prussian carp (Balik *et al.,* 2003; Yilmaz *et al.,* 2007; Rogozin *et al.,* 2011; Partal and Ozdilek, 2019). However, there is no information on feeding features of this species inhabiting Lake Ladik. This study provides the first data on the food types and feeding habits of this invasive species inhabiting Lake Ladik.

Results of this study showed that the feeding activity (FI%) was affected by seasonal changes and it was significantly different between the seasons (Kruskal-Wallis test, $p<0.001$). The Prussian carp fed more intensively during summer, while their feeding intensity exhibited a downward trend from autumn to winter in Lake Ladik. Yagci *et al.* (2015) reported that the monthly water temperature of the lake ranged from 3.8 to 25.2ºC. The lowest average temperature value was recorded in winter with 5.6ºC, while the highest average value was found in summer with 23.8ºC. Water temperature was found to be an important environmental factor positively affecting the feeding of the Prussian carp ($p<0.001$, Spearman rank correlation). This finding agrees with data regarding the feeding activity of *Vimba vimba* inhabiting Lake Sapanca (Okgerman *et al.,* 2013). Generally, seasonal changes in feeding activity of cyprinid fishes are associated with water temperature (Turker, 2006). Variations in feeding activity between seasons could be attributed to fluctuations of water temperature (Balik *et al.,* 2003) and spawning

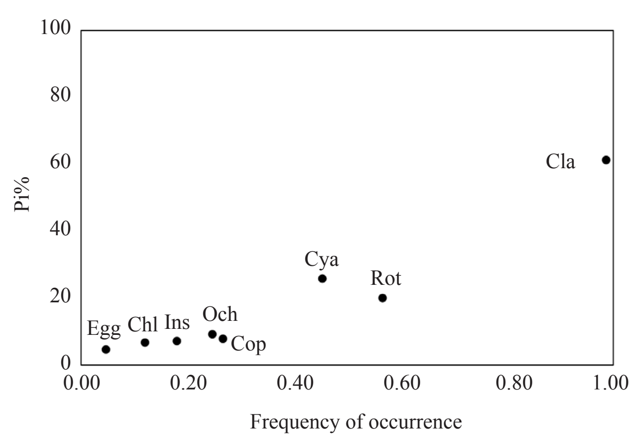

Fig. 6. Feeding strategy of *C. gibelio*

period of fish (Yilmaz *et al.,* 2007). Increase in feeding activity and food intake are seen in fish species during the spring and summer months with higher temperature (Chen *et al.,* 2019). Prejs (1973) and Balik *et al.* (2003) reported that feeding activity did not decrease during reproductive period. In the present study, feeding activity was maximum in summer, which is the breeding period in *Carassius* spp. (Yilmaz *et al.,* 2007).

The present study revealed that the Prussian carp exhibited an omnivorous feeding behaviour, with a high diversity of food items. Different species of the genus *Carassius* have been reported to show omnivorous feeding behaviour in various aquatic systems (Hirpo, 2012; Khelifi *et al.,* 2017; Mohamed and Abood, 2018) but some studies have indicated a preference of plant based foods in the case of *C. gibelio* (Yilmaz *et al.,* 2007; Yilmaz *et al.,* 2008; Partal and Ozdilek, 2017). The food composition of Prussian carp in Lake Ladik included 29 food items. High diversity of prey has been reported for this invasive species inhabiting different habitats (Yilmaz *et al.,* 2007; Yilmaz *et al.,* 2008; Rogozin *et al.,* 2011; Partal and Ozdilek, 2017). Prejs (1973) reported that the diet of *C. carassius* comprised of both animal origin and plant origin prey and animal origin food constituted a large portion of the diet, with 94% of the total food weight. Mohamed and Abood (2018) indicated that *C. auratus* consumed a wide range of food items of plant and animal origins in Shatt Al-Arab River. It has been suggested that the broad diet spectrum of the invasive Prussian carp in different habitats is due to opportunistic feeding habits (Perdikaris *et al.,* 2012). Due to flexibility in its prey spectrum, the Prussian carp can compete with native fish species for food items. Yazicioglu *et al.* (2017) indicated that *Blicca bjoerkna* (white bream) inhabiting Lake Ladik consumed a wide variety of food types and *Bosmina* (Crustacea), macrophytes, chironomid larvae, *Melosira*, *Navicula*, *Cymbella* (Bacillariophyta) and cyclopoid copepods were the most important prey items in the diet. Considering the general prey composition and main preys of white bream, invasive Prussian carp may compete with white bream for available food.

The results of the present study indicated that the major prey items of this species were Cladocera in all the seasons. However, secondary prey item changed with season. Secondary prey items were Rotifera and Cyanobacteria in both summer and autumn, aquatic insects in winter and Rotifera in spring. The diet composition showed highest similarity between summer and autumn. Seasonal variation of food composition have been reported earlier in this species from different habitats (Yilmaz *et al.,* 2007; Yilmaz *et al.,* 2008; Khelifi *et al.,* 2017; Mohamed and Abood, 2018).

It has been reported that predator species living in Lake Ladik do not prefer Prussian carp in their diets (Yazicioglu *et al.,* 2017; Yazicioglu *et al.,* 2018). This situation increases the infestation potential of *C. gibelio* in the lake and negatively affects the population status of native species. The Prussian carp has a broad diet spectrum and is an opportunistic feeder, varying the diet to suit different aquatic habitats (Perdikaris *et al.,* 2012; Partal and Ozdilek, 2019). Because of this feeding feature, Prussian carp is a potential competitor to the native fish species inhabiting Lake Ladik. In this situation, it may be necessary to formulate management actions to control the overpopulation of *C. gibelio* in Lake Ladik based on regular monitoring of its stock and biological acivity in this habitat.

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