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HACER CANAN OKGERMAN

CUMHUR HALDUN YARDIMCI

ZEYNEP DORAK

NEŞE YILMAZ

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Feeding ecology of vimba (*Vimba vimba* L., 1758) in terms of size groups and seasons in Lake Sapanca, northwestern Anatolia

Hacer Canan OKGERMAN*, Cumhur Haldun YARDIMCI,
Zeynep DORAK, Neşe YILMAZ
Freshwater Biology Department, Fisheries Faculty, İstanbul University, İstanbul, Turkey

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Abstract: The seasonal changes of diet in the guts of 298 vimbas (*Vimba vimba* L.) caught on a monthly basis in Lake Sapanca from August 2003 to July 2004 were analyzed. *V. vimba* fed on ostracods, gastropods, *Dreissena polymorpha* (mollusks), fish larvae, macrophytes, oligochaetes, chironomids, phytoplankton, and detritus. The gut fullness index (GFI) indicated that vimbas increased their feeding activity in summer and decreased it in winter. The correlation between GFI and temperature was significant (0.839, $P < 0.01$). The water temperature shift was one of the critical environmental factors affecting the feeding of vimbas in Lake Sapanca. The lowest similarity of diet composition was between the juvenile vimbas in autumn and the adult vimbas in spring (cluster analysis), while the highest similarity of diet composition was between adult individuals in autumn and winter (cluster analysis). In both size groups and in all seasons, the main food items were macrophytes, *D. polymorpha*, and phytoplankton (particularly bacillariophytes). Of animal food items, adult individuals fed mostly on *D. polymorpha*, while ostracods were consumed only by juvenile fish in spring, summer, and autumn. The benthic-omnivorous strategy of vimba is demonstrated by the high abundance of plant foods in their guts, confirming this mixed type of diet.

Key words: Vimba, *Vimba vimba* L., feeding ecology, benthic-omnivorous, Lake Sapanca

1. Introduction

Vimba (*Vimba vimba* L.) is widely distributed in inland waters of Central and East Europe, the Caucasus, Russia, Slovakia, Croatia, Kazakhstan, Slovenia, Ukraine, and Turkey (particularly northern and northwestern Anatolia) (Geldiay and Balık, 2007; Froese and Pauly, 2008). Vimba is benthopelagic as well as anadromous, inhabiting freshwater and brackish water. It inhabits the middle and lower reaches of rivers and feeds on invertebrates and plants, and is a semirheophilic species (Stakonas, 2002). Ostracods are the most important food of the younger individuals, and they constitute most of the food items of the vimbas of 8–9 cm in size (Mbahinzireki et al., 1991). Vimba is on the protected species list in Poland (Witkowski et al., 1999), Austria (Schiemer and Spindler 1989), and the Czech Republic (Lusk et al., 2004). Fewer vimba (8.71%) are caught from Lake Sapanca than rudd (*Scardinius eryhthrophthalmus* L. [24.43%]), white bream (*Blicca bjoerkna* L. [22.98%]), and roach (*Rutilus rutilus* L. [21.71%]) (Karabatak and Okgerman, 2002). Due to the decrease of other commercial fish as a result of overfishing, vimba has been fished intensively in Lake Sapanca.

Feeding characteristics of fish species and their effects on the ecosystem vary according to types of food and their abundance (Prejs and Jackowska, 1978; Lessmark, 1983; Horppila et al., 2000). The feeding preferences of fish in inland water are important in terms of ecology. Studies on the growth and reproduction of vimba in inland Turkey have been performed (Ekmekçi and Erk'akan, 1992; Becer and İkiz, 2001; Gürsoy, 2001; Tutucu, 2002; Okgerman et al., 2011), but up until now, the feeding habits of vimba in the inland waters of Turkey have not been studied. The aims of this study are to determine seasonal changes in food habits and feeding diversity for both juvenile and adult vimbas. In addition, to determine the adaptation of this species to its environment, its feeding habits in Lake Sapanca are compared to those of vimba in other European inland waters.

2. Materials and methods

Lake Sapanca is located in the northwest of Turkey (40°41′N–40°44′N, 30°09′E–30°20′E) (Figure 1; Okgerman et al., 2011). The surface area is 46.8 km^2; mean and maximum depths are 29 m and 52 m. The shores of

* Correspondence: okgerman@istanbul.edu.tr

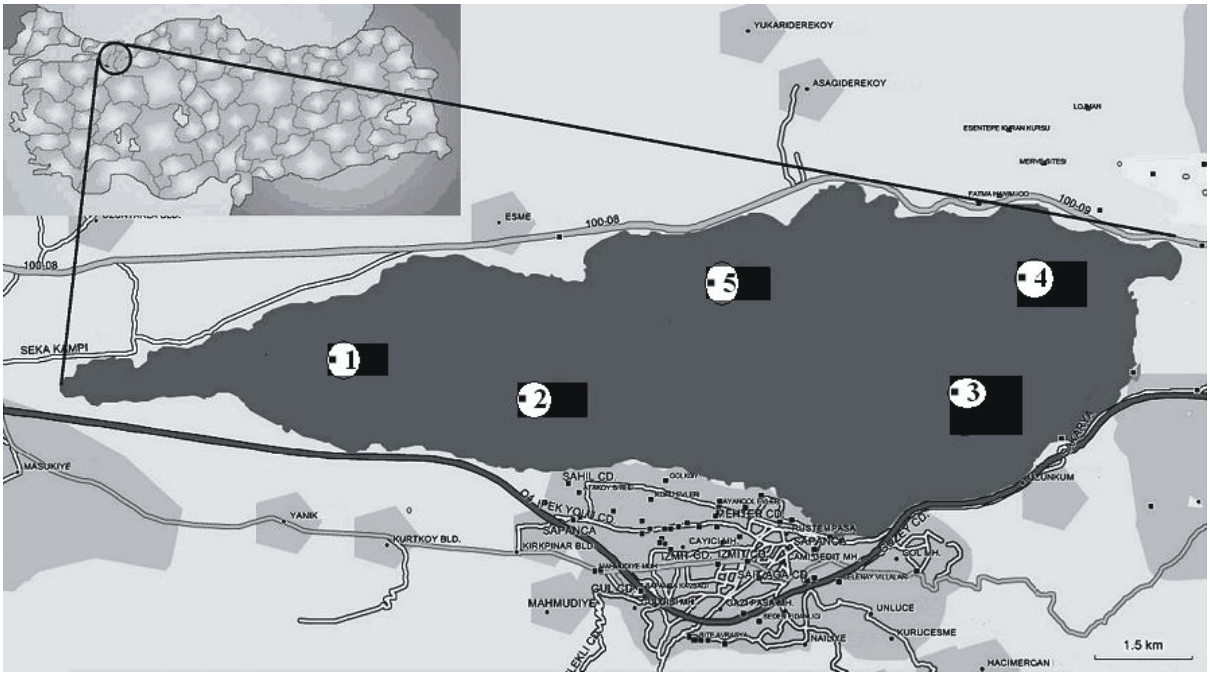

Figure 1. Lake Sapanca: location of sampling stations of *V. vimba* (from Okgerman et al., 2011).

the lake are surrounded mostly by *Phragmites* sp. There are submerged macrophytes in the lake, including *Chara* sp., *Myrophyllum* sp., *Ceratophyllum* sp., *Potamogeton* spp., *Najas* sp., and *Nuphar* sp. In Lake Sapanca, a total of 10 fish families (Cobitidae, Cyprinidae, Atherinidae, Clupeidae, Gobiidae, Balitoridae, Esocidae, Salmonidae, Siluridae, and Syngnathidae) have been identified (Rahe and Worthmann, 1986). Aykulu et al. (2006) emphasized that this lake tends to change from an oligotrophic to an oligomesotrophic state.

Some physical, chemical, and biological parameters of the lake water, such as dissolved oxygen, temperature, nutrients (PO_4^{-3}-P, NO_3^{-3}-N), and chlorophyll a, were measured monthly from August 2003 to July 2004. Water samples for the analysis of nutrients (PO_4^{-3}-P, NO_3^{-3}-N) and chlorophyll a were collected using a Nansen bottle; dissolved oxygen and temperatures were measured using a multiparameter probe (Radiometer, Pioneer 65); transparency was determined with a Secchi disk. The samples for nutrient analysis (PO_4^{-3}-P, NO_3^{-3}-N) were kept frozen (−20 °C) until spectrophotometrical analysis in the laboratory was performed according to the methods of Parsons et al. (1984). For chlorophyll a analysis, lake water (1 L) was filtered through Whatman GF/C glass fiber filters that were kept frozen until spectrophotometrical analysis, after extraction by acetone (APHA, 1985).

The fish were caught monthly from Lake Sapanca from August 2003 to July 2004, using multimesh gillnets of 10, 15, 18, 22, 26, 30, 35, 40, 45, and 50 mm mesh sizes. Vimbas were sampled from 5 lake locations (Figure 1). The nets were adhibited in the littoral of this lake during both the day (0800–1200 hours; 1400–1700 hours) and the night (2200–0500 hours). Generally, gillnets were checked every hour during the day. The diets of 298 individuals were analyzed in the laboratory. Fork lengths (FL; mm) and weights (g) of the fish were measured. Specimens caught were measured to the nearest mm (FL), and weighed to the nearest 0.1 g. They were evaluated by 2 size classes and seasons ($60 < FL < 140$ mm, $140 \leq FL \leq 213$ mm), and 119 of them in the range of $60 < FL < 140$ mm were classified as juveniles. The other fish ($n = 179$) ($140 \leq FL \leq 213$ mm) were considered as adults. The guts of the fish were preserved in 70% alcohol. Since cyprinids lack a distinct stomach, the contents of the anterior third of their gut were analyzed for volume proportions of different food items (Rask, 1989), and wet weights of the total gut content were determined to the nearest 0.0001 g. Contents of each gut were mixed with 200 mL of water and filtered through 100 µm- and 400 µm-sized meshes. The remaining food items on the meshes, and the particles retained by these meshes, were identified under a binocular and inverted microscope to the lowest possible taxon and were subsequently determined. The contribution by wet weight of each food category to the biomass of total contents was roughly estimated (Hyslop, 1980). Calculation of the mean dimensions of food items, based on measurement of a number of individuals, allows determination of mean volume. The formula employed depends upon which 3-dimensional shape the organism most closely resembles (Hyslop, 1980). Cell volume (1 mm^3/m^3), which is equivalent to biomass (1 mg wet weight/m^3), is converted into biomass.

The gut fullness index (GFI) to determine the intensity of feeding activity was calculated as wet weight (g) of gut contents / weight of fish (g) × 100 (Okach and Dadzie, 1988). A frequency of occurrence method was employed to analyze gut contents for the determination of diet composition as described by Hyslop (1980):

$$\%F_i = (N_i / N) \times 100,$$

where F_i = percent frequency of food item i, N_i = number of vimbas with food item i in the gut, and N is the total number of vimbas with gut contents. %W is the percentage of the total weight of the gut contents (wet weight) weighed for each food category (Hyslop, 1980).

Spearman's rank correlation was used to determine the relationship between GFI and temperature, chlorophyll a (Chl-a), water transparency, nitrate (NO_3^{-3}-N), phosphate (PO_4^{-3}-P), water transparency (Secchi disk), and dissolved oxygen (DO). Statistical differences ($P < 0.05$) in diet composition with respect to size groups and seasons were assessed by a chi-square test (Sokal and Rohlf, 1987) applied to the weight of a given food item.

Trophic diversity (H') of the diet between size classes and seasons was estimated using the Shannon index (Shannon and Weaver, 1963) based on frequency of occurrence (F). Statistical differences in diet compositions by size groups and seasons according to the weight (W) and the frequency occurrence (F), trophic diversity (H'), and gut fullness (GFI) were tested by ANOVA. Statistical analyses were performed using SPSS for Windows, v. 16.0. A principal component analysis (PCA) was carried out based on the wet weight (W) of food items per size class. A similarity matrix (cluster analysis) was conducted from $\log_e(x + 1)$ transformed wet weight (W) of food items using the Bray–Curtis similarity coefficient, and a multidimensional scaling (MDS) analysis (stress 0) based on the ordination of the wet weight (W) of the food items was performed to explain the observed similarities and dissimilarities both among seasons and between juvenile and adult fish, using PRIMER v. 6 (Clarke and Warwick, 1994).

3. Results

The minimum and maximum temperatures of lake water (depth: 10 m) were 7.5 °C and 23.58 °C, respectively. Minimum and maximum PO_4^{-3}-P, NO_3^{-3}-N, DO, Chl-a, and water transparency values year-round are given in Table 1. A total of 298 vimbas was caught in Lake Sapanca during this study period. The number of juveniles (70 mm < FL < 140 mm) and adult individuals (140 mm < FL < 213 mm) caught in each year were 36 and 55 in spring, 51 and 37 in summer, 32 and 39 in autumn, and 0 and 48 in winter, respectively. The highest GFI was found in summer, while the lowest was in winter and, secondarily, in autumn (Table 1; Figure 2). GFI values of fish were different significantly among months (ANOVA, $P < 0.05$).

Table 1. Monthly changes in some physicochemical and biological parameters, and gut fullness index [GFI ± standard error)] of *V. vimba* in Lake Sapanca from August 2003 to July 2004.

Month	NO_3^{-3}-N	PO_4^{-3}-P	DO	°C	Chl-a	Secchi disk	GFI ± SE
Aug 2003	9.42	116.65	12.69	23.35	17.27	6.32	1.81 ± 0.63
Sep	38.54	61.44	6.28	21.38	11.96	4.65	1.79 ± 0.69
Oct	27.21	64.57	4.72	18.40	12.81	4.48	1.7 5± 0.35
Nov	20.36	64.96	4.80	13.79	13.32	4.42	1.41 ± 0.27
Dec	88.10	64.12	8.72	9.65	7.10	4.18	1.01 ± 0.09
Jan 2004	57.80	67.31	7.47	7.50	7.10	3.96	0.94 ± 0.17
Feb	107.86	63.01	10.16	7.78	4.44	4.48	0.95 ± 0.16
Mar	94.27	96.29	10.55	9.56	2.22	2.53	1.46 ± 0.32
Apr	60.63	90.81	7.28	14.14	6.66	3.64	2.00 ± 0.42
May	30.15	104.90	8.50	17.34	13.32	3.03	1.29 ± 0.37
Jun	12.26	74.36	10.38	23.58	9.62	5.50	2.02 ± 0.39
Jul	36.60	93.94	10.42	23.18	12.34	6.98	2.06 ± 0.21

NO_3^{-3}-N: nitrate (μg L^{-1}); PO_4^{-3}-P: phosphate (μg L^{-1}); DO: dissolved oxygen (mg L^{-1});
°C: temperature; Chl-a: Chlorophyll a (μg L^{-1}); Secchi disk: water transparency (m).

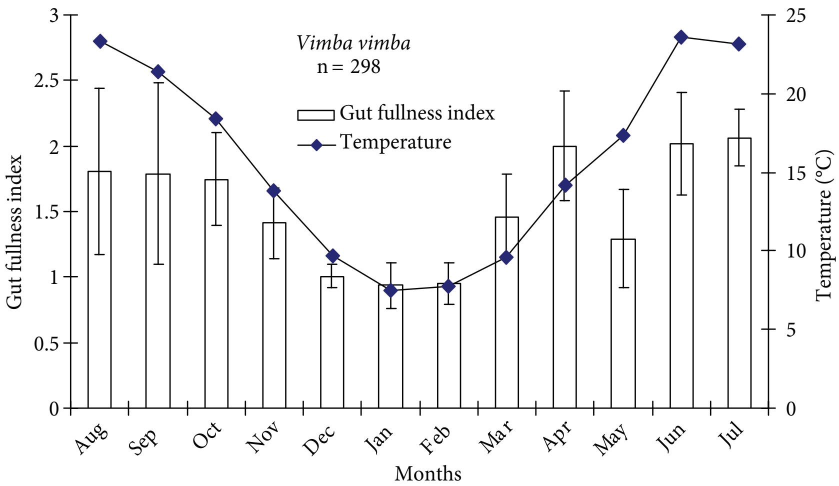

Figure 2. The relationship between temperature and GFI of *V. vimba* monthly in Lake Sapanca.

The correlation between GFI and temperature was significant (0.839, P < 0.01). The water temperature shift was one of the critical environmental factors affecting the feeding of vimbas in Lake Sapanca. There was a negative correlation between GFI and NO_3^{-3}-N (–0.469), while there was a positive correlation between GFI and PO_4^{-3}-P (0.350), Chl-a (0.242), DO (0.231), and water transparency (0.550), but the differences were not statistically significant (Table 1).

Wet weight (%W) and frequency occurrence (%F) of the diet of vimba through the seasons are illustrated in Table 2. The diet of vimba consisted of 42 food items belonging mainly to 4 groups: macrophytes, phytoplankton (particularly bacillariophytes), *Dreissena polymorpha* (mollusks), and ostracods (Table 2). There was a generally clear separation of the wet weight (W) of food items eaten by vimba among the seasons (Figure 3). Diets in autumn and winter months were more similar than diet in summer. Strong specialization toward ostracods, chlorophytes, and fish larvae based on both highest wet weight and high diversity in the diet of vimba were reasons for the different position of summer in the MDS (Figure 3). In all seasons, the major foods of vimba were macrophytes (%F = 89.01, %W = 73.36 in spring; %F = 87.50, %W = 61.10 in summer; %F = 83.10, %W = 47.97 in autumn; %F = 70.83, %W = 49.18 in winter) and *D. polymorpha* (%F = 31.87, %W = 25.24 in spring; %F = 27.27, %W = 33.12 in summer; %F = 49.30, %W = 51.33 in autumn; %F = 85.42, %W = 50.76 in winter). There were significant differences among seasonal values of frequency occurrence (df = 41; F = 21.65; ANOVA, P < 0.05) and weight (df = 41; F = 24.70; ANOVA, P < 0.05) of the diet of vimba.

In spring and summer, the secondary food item of vimba following macrophytes was *D. polymorpha* (%W = 25.24 and 33.12, respectively). Detritus (%W = 0.62) was only consumed in spring. Among animal foods, ostracods (%W = 0.47 in spring; 5.08 in summer) were the most consumed food items after *D. polymorpha*. Ostracods were eaten more in summer than in the other seasons.

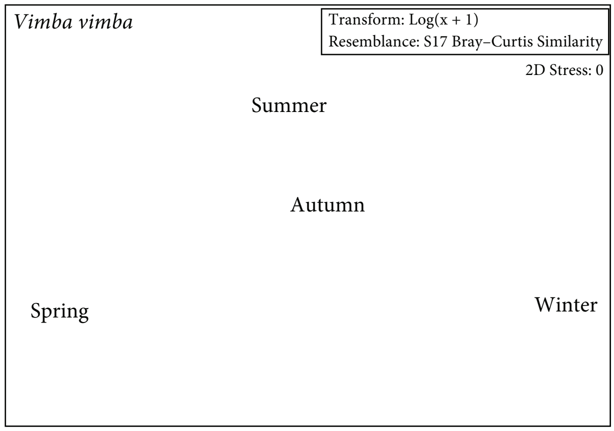

Figure 3. Ordination (MDS) of seasons based on wet weight (W) of food items in *V. vimba* guts in Lake Sapanca from June 2003 to July 2004.

In autumn, *V. vimba* fed on *D. polymorpha* more than other food items. *D. polymorpha* (%W = 51.33), in contrast with macrophytes, was also the food item most consumed by vimba during this period in comparison to the other seasons (Table 2).

In winter, vimba fed on mostly *D. polymorpha* (%W = 50.76). During the winter, macrophytes (%W = 49.18) were the secondary food items consumed by vimba. Other food items were eaten less often by vimba throughout the year.

Table 2. Diet composition of *V. vimba* by seasons based on the percentage frequency of occurrence (%F) and wet-weight (%W) in Lake Sapanca.

FOOD ITEMS	Spring		Summer		Autumn		Winter	
	%F	v	%F	%W	%F	%W	%F	%W
Tyrrehenocythere donetziensis (OSTRACODA)	8.79	0.21	36.36	1.56	25.35	0.27	0	0
Undefined Ostracoda	4.40	0.26	31.82	3.52	0	0	0	0
Bithynia tentaculata (GASTROPODA)	0	0	2.27	5.8×10^{-3}	0	0	0	0
Theodoxus fluviatilis	2.20	0.02	0	0	0	0	0	0
Planorbis planorbis	0	0	15.91	0.19	11.27	0.39	0	0
Dreissena polymorpha (BIVALVIA)	31.87	25.24	27.27	33.12	49.30	51.33	85.42	50.76
CHIRONOMIDAE	7.69	22×10^{-2}	2.27	23×10^{-2}	0	0	10.42	5×10^{-3}
OLIGOCHAETA	4.40	0.02	0	0	0	0	0	0
MACROPHYTE	89.01	73.36	87.50	61.10	83.10	47.97	70.83	49.18
Achnanthes spp. (BACILLARIOPHYTA)	0	0	2.27	1×10^{-5}	0	0	0	0
Aulocoseira italica	21.98	3.5×10^{-3}	40.91	4.4×10^{-3}	53.52	9.3×10^{-3}	54.17	6×10^{-3}
Amphora spp.	4.40	2.2×10^{-4}	4.55	3×10^{-4}	0	0	4.17	2×10^{-4}
Asterionella spp.	15.38	2.6×10^{-4}	15.91	1.5×10^{-4}	19.72	4×10^{-4}	16.67	2×10^{-4}
Cocconeis spp.	8.79	5.6×10^{-4}	43.18	1×10^{-2}	11.27	5.5×10^{-4}	33.33	2×10^{-3}
Cyclotella spp.	41.76	5.5×10^{-3}	47.73	1.3×10^{-2}	47.89	1×10^{-2}	41.67	2×10^{-2}
Cymbella spp.	48.35	1.4×10^{-3}	38.64	1.1×10^{-3}	52.11	4×10^{-4}	37.50	2×10^{-3}
Diatoma spp.	2.20	6.2×10^{-5}	0	0	2.82	9×10^{-5}	0	0
Epithemia spp.	2.20	3×10^{-5}	4.55	3.3×10^{-5}	0	0	0	0
Fragilaria spp.	59.34	8.8×10^{-3}	50	5×10^{-3}	50.70	1×10^{-2}	50	1×10^{-2}
Gomphonema spp.	37.36	8.3×10^{-3}	22.73	1×10^{-2}	25.35	5.4×10^{-3}	39.58	1×10^{-2}
Gyrosigma spp.	4.40	3.1×10^{-4}	0	0	5.63	4.6×10^{-4}	0	0
Melosira varians	2.20	2×10^{-4}	2.27	2.6×10^{-4}	2.82	5.8×10^{-4}	8.33	1×10^{-3}
Navicula spp.	46.15	9.2×10^{-3}	38.64	4×10^{-3}	45.07	4.8×10^{-3}	47.92	1×10^{-3}
Nitzschia spp.	21.98	3×10^{-4}	11.36	1.6×10^{-4}	5.63	5×10^{-5}	14.58	2×10^{-4}
Pinnularia spp.	6.59	2×10^{-4}	4.55	3×10^{-4}	8.45	4×10^{-4}	4.17	3×10^{-4}
Rhopalodia spp.	4.40	1.7×10^{-4}	4.55	1×10^{-3}	0	0	4.17	2×10^{-4}
Synedra spp.	62.64	1×10^{-2}	43.18	3.4×10^{-3}	61.97	4×10^{-3}	50	4×10^{-3}
Tabellaria spp.	2.20	8.8×10^{-5}	0	0	0	0	0	0
Spirulina spp. (CYANOPHYTA)	2.20	1.4×10^{-6}	0	0	0	0	0	0
Peridinium spp. (DINOPHYTA)	0	0	2.27	1.3×10^{-4}	0	0	0	0
Cryptomonas spp. (CRYPTOPHYTA)	0	0	2.27	2.3×10^{-3}	2.82	6.5×10^{-4}	0	0
Monoraphidium spp. (CHLOROPHYTA)	0	0	2.27	2.1×10^{-7}	0	0	0	0
Cladophora spp.	0	0	4.55	7.8×10^{-5}	0	0	0	0
Scenedesmus spp.	4.40	3×10^{-5}	2.27	1.4×10^{-5}	0	0	10.42	9×10^{-5}
Kirchneriella spp.	0	0	4.55	5×10^{-7}	0	0	0	0
Mougeotia spp.	2.20	9×10^{-4}	2.27	2.2×10^{-5}	0	0	0	0
Oedogonium spp.	2.20	5×10^{-4}	6.82	2.5×10^{-4}	2.82	1×10^{-4}	0	0
Oocystis spp.	0	0	13.64	5×10^{-3}	0	0	8.33	2×10^{-3}
Pediastrum spp.	0	0	2.27	1×10^{-2}	0	0	0	0
Trachelomonas spp. (EUGLENOPHYTA)	10.99	9×10^{-4}	13.64	1.6×10^{-3}	14.08	2×10^{-3}	14.58	3×10^{-3}
Fish larvae (OTHER FOODS)	0	0	9.09	0.40	0	0	0	0
Detritus	2.20	0.62	0	0	0	0	0	0

Frequency occurrence (%F) and wet weight (%W) of the vimba's diet by seasons and size groups are given in Table 3. Macrophytes (%W = 83.50) were mostly eaten by juvenile fish in autumn, and ostracods (%W = 19.01) and gastropod *P. planorbis* (%W = 0.42) in summer. *D. polymorpha* was mostly consumed by adult fish in autumn (%W = 52.18) and winter (%W = 50.76) (Table 3). There was a significant difference between the weight in the gut contents of *Tyrrehenocythere donetziensis*, undefined ostracods, *Bithynia tentaculata*, *Theodoxus fluviatilis*, *Planorbis planorbis*, *D. polymorpha*, chironomids, oligochaetes, macrophytes, *Oocystis* spp., *Pediastrum* spp., fish larvae, and detritus among seasons and size groups (chi-square; $df = 6$, $P < 0.05$), but there were no significant differences between other organisms among seasons and size groups (Table 3). The diversity of food items ranged between 1.26 and 0.98 (Table 3). Trophic diversity differed between seasons and size groups (ANOVA, $P < 0.05$). The highest diversity was determined in juvenile fish in summer, with the highest number of identifiable food items, while the lowest diversity value was calculated in juvenile fish in autumn.

The MDS (Figure 4a), the cluster analysis (Figure 4b), and the PCA (Figure 5) of data supported the results shown in Table 3. The cluster analysis and MDS ordination of the intake of the various food items by the juvenile and adult individuals indicate intraspecific diet differences between seasons (Figures 4a and 4b). The highest similarity in the feeding preferences of vimba was observed between adults in winter and autumn (Figure 4b; cluster analysis), because the adult fish in these seasons fed more or less at the same rate on macrophytes, *D. polymorpha*, and bacillariophytes. The lowest feeding similarity was between juveniles in autumn and adults in spring (Figure 4b; cluster analysis). In autumn, the juveniles fed intensively on ostracods and macrophytes; in spring, the adult individuals fed primarily on *D. polymorpha*, chironomids, and oligochaetes (Table 3). Because of differences in quantitative and qualitative alteration in their feeding preference, the similarity between juveniles in autumn and adults in spring had the lowest value.

Considering PCA, ostracods were only consumed by juvenile individuals, but as vimbas grew, *D. polymorpha* was mostly eaten by the adult fish. Juveniles and adults consumed macrophytes and *D. polymorpha* as the primary group, gastropods and ostracods in the secondary group, and Bacillariophyta *Cymbella* spp., *Fragilaria* spp., *Navicula* spp., *Synedra* spp., *Cyclotella* spp., *A. italica*, *Gomphonema* spp., *Asterionella* spp., *Nitzschia* spp., *Cocconeis* spp., *Trachelomonas* spp., chironomids, oligochaetes, fish larvae, and detritus as the tertiary group (Figure 5).

4. Discussion

The diet of the vimba includes a broad range of food items, a common general characteristic of cyprinid species. The mixed feeding strategy of this fish is shown in the diverse animal and plant food items consumed throughout the year. Generally, the population in Lake Sapanca fed on mollusks and macrophytes, tending to shift into omnivorous behavior while growing. Between juvenile and adult vimba, a quantitative and qualitative alteration of the dietary constituents was clearly visible. The macrophytes at the sampling sites are a shelter for small-sized fish species. Therefore, both size groups of vimba fed on mostly benthic organisms associated with submerged vegetation throughout the year. In spring and summer, vimba fed on animal-based foods less than plant-origin foods in respect to wet weight (%W) and food diversity. However, though the diversity of animal foods was low in autumn and winter, the fish consumed predominantly animal foods rather than vegetal foods during these periods. In Lake Sapanca, adult individuals fed mostly on *D. polymorpha* among animal food items, while ostracods were only preyed on by juvenile vimba.

Though there were no statistically significant differences among the seasons (ANOVA, $P > 0.05$), small seasonal fluctuations in the vimba diet were observed. This could be explained by the environmental parameters of Lake Sapanca in accordance with a positive relationship between temperature ($P < 0.01$; Spearman rank correlation) and gut fullness, as well as the proportion of food items and food supplies. Water temperature (0.839, $P < 0.01$) is the principal environmental factor affecting the gut fullness of fish. A variation in the feeding strategy of vimba was determined in summer (highest values of gut fullness, trophic diversity) in relation to the other seasons. The highest values of gut fullness could be attributed to the fact that during summer the vimba fed on heavier food items such as macrophytes, *D. polymorpha*, gastropods, and fish larvae. The difference could also be explained by the increase in life activities such as reproduction. The spawning period of fish began at the end of April and continued until the beginning of July in Lake Sapanca (Okgerman et al., 2011). At the beginning of summer in this lake, the spawning period is just completed, and the vimba begins to feed more than the other seasons.

Vimba's trophic spectrum changes in various biotopes. Vimbas, showing great flexibility in using the food sources in Lake Mondsee, feed on organisms in the sediment (Uiblein and Winkler, 1988). In research done at Nida and Klaipėda Aquatory in the Baltic Sea, the diet (in weight) of vimba in the 25–28 cm size groups consisted of mollusks (51%), copepods (33%), shrimp (10%), and detritus and algae (6%). There were 80% polychaetes and 20% amphipods in the diet (in weight) of vimba captured

Table 3. Diet composition of *V. vimba* diet by seasons and size groups based on the percentage frequency of occurrence (%F) and wet weight (%W) in Lake Sapanca; chi-square test and Shannon–Wiener Diversity Index (H[1]) according to frequency of occurrence.

FOOD ITEMS	Spring				Summer				Autumn				Winter		
	<14 cm		>14 cm		<14 cm		>14 cm		<14 cm		>14 cm		>14 cm		
	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W	Chi-sq
Tyrrehenocythere donetziensis (OSTRACODA)	22.22	2.24	0	0	62.75	5.83	0	0	56.25	16.43	0	0	0	0	2498.10*
Undefined Ostracoda	11.11	2.85	0	0	54.90	13.18	0	0	0	0	0	0	0	0	7134.56*
Bithynia tentaculata (GASTROPODA)	0	0	0	0	0	0	5.41	8×10^{-3}	0	0	0	0	0	0	13.13*
Theodoxus fluviatilis	5.56	0.24	0	0	0	0	0	0	0	0	0	0	0	0	67.67*
Planorbis planorbis	0	0	0	0	15.69	0.42	16.22	11×10^{-2}	0	0	20.51	0.39	0	0	478.84*
Dreissena polymorpha (BIVALVIA)	8.33	34.96	47.27	24.25	0	0	64.86	45.20	0	0	89.74	52.18	85.42	50.76	40,762.88*
CHIRONOMIDAE	5.56	0.53	9.09	18×10^{-2}	0	0	5.41	23×10^{-2}	0	0	0	0	10.42	5×10^{-3}	357.92*
OLIGOCHAETA	0	0	7.27	22×10^{-2}	0	0	0	0	0	0	0	0	0	0	60*
MACROPHYTE	83.33	59.11	92.73	74.81	84.31	80.38	91.89	54.07	81.25	83.50	84.62	47.39	70.83	49.18	58,585.79*
Achnanthes spp. (BACILLARIOPHYTA)	0	0	0	0	0	0	5.41	1×10^{-5}	0	0	0	0	0	0	0.02
Aulocoseira italica	11.11	1×10^{-2}	29.09	3×10^{-3}	39.22	6×10^{-3}	43.24	4×10^{-3}	43.75	1×10^{-2}	61.54	1×10^{-2}	54.17	6×10^{-3}	5.23
Amphora spp.	5.56	1×10^{-3}	3.64	1×10^{-4}	3.92	6×10^{-4}	5.41	2×10^{-4}	0	0	0	0	4.17	2×10^{-4}	0.11
Asterionella spp.	11.11	3×10^{-4}	18.18	3×10^{-4}	7.84	5×10^{-4}	27.03	7×10^{-7}	0	0	35.90	4×10^{-4}	16.67	2×10^{-4}	0.34
Cocconeis spp.	16.67	5×10^{-3}	3.64	1×10^{-4}	47.06	4×10^{-2}	37.84	6×10^{-3}	0	0	20.51	6×10^{-4}	33.33	2×10^{-3}	13.53*
Cyclotella spp.	50	8×10^{-3}	36.36	5×10^{-3}	43.14	2×10^{-2}	54.05	9×10^{-3}	46.88	4×10^{-2}	48.72	1×10^{-2}	41.67	2×10^{-2}	6.09
Cymbella spp.	27.78	3×10^{-3}	61.82	1×10^{-3}	35.29	2×10^{-3}	43.24	8×10^{-4}	50	2.2×10^{-3}	53.85	4×10^{-4}	37.50	2×10^{-3}	1.10
Diatoma spp.	0	0	3.64	7×10^{-5}	0	0	0	0	0	0	5.13	9×10^{-5}	0	0	0.16
Epithemia spp.	5.56	3×10^{-4}	0	0	3.92	1×10^{-4}	5.41	9×10^{-6}	0	0	0	0	0	0	0.06
Fragilaria spp.	44.44	5×10^{-3}	69.09	9×10^{-3}	54.90	1×10^{-2}	43.24	3×10^{-3}	40.63	1×10^{-2}	58.97	1×10^{-2}	50	1×10^{-2}	9.42
Gomphonema spp.	16.67	6×10^{-3}	50.91	1×10^{-2}	19.61	6×10^{-3}	27.03	2×10^{-2}	0	0	46.15	1×10^{-2}	39.58	1×10^{-2}	10.75
Gyrosigma spp.	0	0	7.27	3×10^{-4}	0	0	0	0	0	0	10.26	5×10^{-4}	0	0	0.78
Melosira varians	0	0	3.64	2×10^{-4}	0	0	5.41	4×10^{-4}	0	0	5.13	6×10^{-4}	8.33	1×10^{-3}	0.94
Navicula spp.	27.78	1×10^{-2}	58.18	1×10^{-2}	31.37	8×10^{-3}	48.65	2×10^{-3}	37.5	1×10^{-2}	51.28	5×10^{-3}	47.92	1×10^{-3}	9.70
Nitzschia spp.	11.11	2×10^{-4}	29.09	3×10^{-4}	11.76	4×10^{-4}	10.81	7×10^{-4}	0	0	10.26	5×10^{-5}	14.58	2×10^{-4}	0.32
Pinnularia spp.	0	0	10.91	2×10^{-4}	0	0	10.81	3×10^{-4}	0	0	15.38	4×10^{-4}	4.17	3×10^{-4}	0.36
Rhopalodia spp.	5.56	6×10^{-4}	3.64	1×10^{-4}	7.84	1×10^{-3}	0	0	0	0	0	0	4.17	2×10^{-4}	0.28
Synedra spp.	41.67	2×10^{-2}	76.36	1×10^{-2}	39.22	5×10^{-3}	48.65	3×10^{-3}	59.38	4.2×10^{-3}	64.10	4×10^{-3}	50	4×10^{-3}	10.51
Tabellaria spp.	0	0	3.64	1×10^{-4}	0	0	0	0	0	0	0	0	0	0	0.27
Spirulina spp. (CYANOPHYTA)	5.56	2×10^{-5}	0	0	0	0	0	0	0	0	0	0	0	0	0.0044
Peridinium spp. (DINOPHYTA)	0	0	0	0	3.92	5×10^{-4}	0	0	0	0	0	0	0	0	0.29
Cryptomonas spp. (CRYPTOPHYTA)	0	0	0	0	3.92	9×10^{-3}	0	0	6.25	6.5×10^{-4}	0	0	0	0	4.10
Monoraphidium spp. (CHLOROPHYTA)	0	0	0	0	3.92	8×10^{-7}	0	0	0	0	0	0	0	0	0.0005
Cladophora spp.	0	0	0	0	3.92	1×10^{-4}	5.41	6×10^{-5}	0	0	0	0	0	0	0.08
Scenedesmus spp.	0	0	7.27	3×10^{-5}	3.92	5×10^{-5}	0	0	0	0	0	0	10.42	9×10^{-5}	0.09
Kirchneriella spp.	0	0	0	0	7.84	2×10^{-6}	0	0	0	0	0	0	0	0	0.0011
Mougeotia spp.	5.56	9×10^{-4}	0	0	3.92	8×10^{-5}	0	0	0	0	0	0	0	0	0.21
Oedogonium spp.	5.56	5×10^{-4}	0	0	7.84	7×10^{-4}	5.41	8×10^{-5}	6.25	1×10^{-4}	0	0	0	0	0.18
Oocystis spp.	0	0	0	0	23.53	4×10^{-2}	0	0	0	0	0	0	8.33	2×10^{-3}	22.16*
Pediastrum spp.	0	0	0	0	3.92	4×10^{-2}	0	0	0	0	0	0	0	0	25.24*
Trachelomonas spp. (EUGLENOPHYTA)	0	0	18.18	9×10^{-4}	15.69	1×10^{-2}	10.81	2×10^{-3}	31.25	2×10^{-3}	0	0	14.58	3×10^{-3}	1.82
Fish larvae (OTHER FOODS)	0	0	0	0	0	0	21.62	0.55	0	0	0	0	0	0	919.2*
Detritus	0	0	3.64	0.68	0	0	0	0	0	0	0	0	0	0	1887*
Shannon–Wiener Diversity Index (H[1])	1.17		1.18		1.26		1.23		0.98		1.13		1.17		

*: Significant; $P < 0.05$

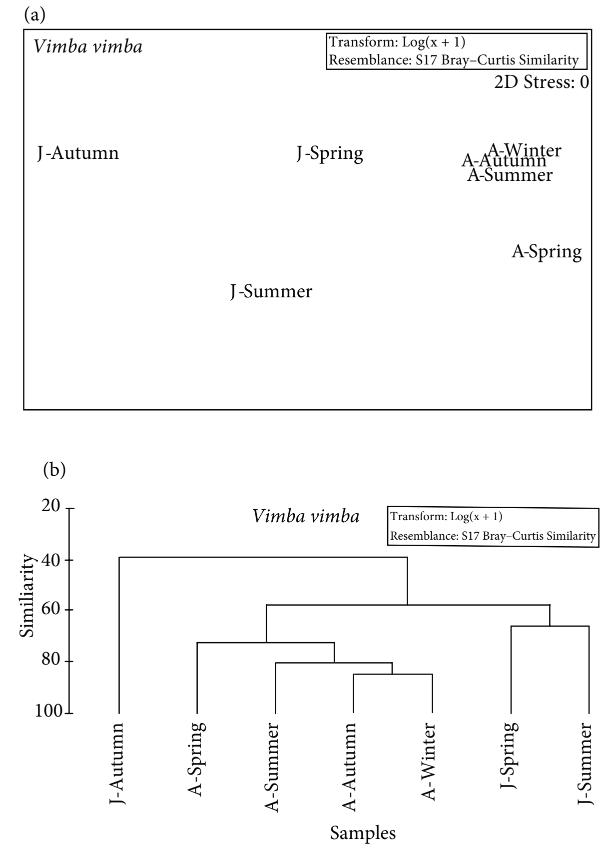

Figure 4. a) MDS based on a similarity matrix constructed on the average food consumption of *V. vimba* of juvenile and adult, and b) cluster analysis.

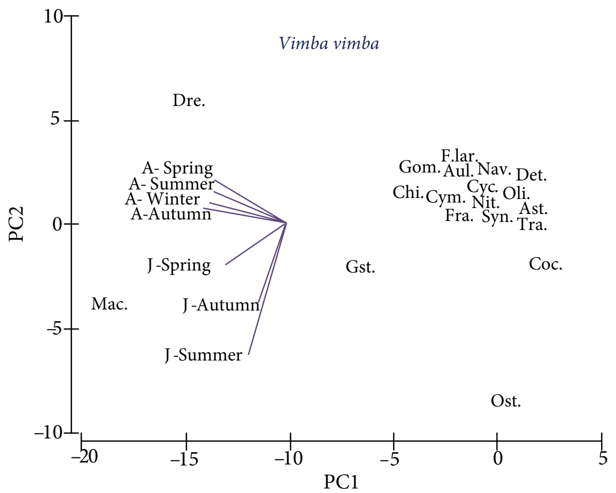

Figure 5. PCA of the diet of *V. vimba* by seasons and size groups (Macrophyte, Mac.; *Cymbella* spp., Cym.; *Fragilaria* spp., Fra.; *Navicula* spp., Nav.; *Synedra* spp., Syn.; *Cyclotella* spp., Cyc.; *Aulocoseira italica*, Aul.; *Gomphonema* spp., Gom.; *Asterionella* spp., Ast.; *Nitzschia* spp., Nit.; *Cocconeis* spp., Coc.; *Trachelomonas* spp., Tra.; Gastropods, Gst.; Chironomidae, Chi.; Oligochaeta, Oli.; *Dreissena polymorpha*, Dre.; Ostracoda, Ost.).

near the Klaipėda Strait. However, the diet (in weight) of the vimbas in the Klaipėda-Gruliai area consisted of 60% mollusks, 28% polychaetes, and 12% detritus. *Macoma baltica* prevailed over other mollusks in the vimba diet (Bubinas and Vaitonis, 2003). Unusually, the vimba of the Tkibul Reservoir fed mostly on vegetation (vegetation components 59%–60% and detritus 16%–40% in weight) (Ermolin and Shashulovskii, 2006), but the primary food component of the vimba diet in the Kaunas and Sengileevo Reservoirs was animal organisms (mostly mollusks, crustaceans, and chironomids, overall up to 97% in weight) (Ermolin and Shashulovskii, 2006). In the Volgograd Reservoir, adult vimba food consisted of 86.7% mollusks, 5.7% crustaceans, and 3.5% chironomids in weight (Ermolin and Shashulovskii, 2006). In the Sea of Azov, vimba fed mostly on mollusks (72.6%), ostracods (21.6%), benthic crustaceans (4%), polychaetes (4%), and insects (0.1%) by weight; in the Kuban River, the fish consumed mostly mollusks (61.4%), mysids (28.2%), ostracods (6.7%), amphipods (3%), insects (0.5%), plants (0.1%), and phytoplankton (0.1%) (by weight) (Podgornov, 1973). The angle of the pharyngeal teeth of the vimba in the closed position (44°) is almost identical to that of the valves of *D. polymorpha* (45°), indicating that this species is particularly well adapted for crushing the shells of *D. polymorpha* (Molloy et al., 1997). Crivelli (1996) stated that in the Mediterranean region, vimba fed mainly on animal foods. In the Tkibul Reservoir, this species fed on mostly plant food, but in other regions, the species consumed mostly zoobenthic organisms. In this study, juvenile and adult vimba consumed mainly macrophytes, epiphytic phytoplankton, and zoobenthic organisms, as observed over a broad range in Lake Sapanca. Annual average density of benthic organisms (oligochaetes, ostracods, dipterans, gastropods, bivalves, and other organisms) in Lake Sapanca was found to be 2433 ind/m^2, which indicated that the lake was very poor in terms of benthic organisms (Koşal, 2002). Therefore, it is thought that vimba fed on macrophytes more than zoobenthic foods in Lake Sapanca.

In conclusion, the present study determined that seasonal changes in the diet of vimba were influenced by seasonal variations in the food supply. The food items of juvenile and adult vimba were associated more with the lake bottom. Although both adults and juveniles fed mostly on the same type of food items, ostracods were found only in the gut contents of the juvenile vimbas. The benthic-omnivorous strategy of vimba is demonstrated by the high abundance of plant foods in their guts, confirming this mixed type of diet, and this species is well adapted to the trophic condition of the lake. Changes in the diet composition of fish might reflect changes in the environmental abundance of fish populations (Wielgosz and Tadajewska, 1988). Studies in other regions as well as Lake Sapanca indicate that the vimba mainly feeds on the most abundant food material in the biotope it inhabits and is able to adapt to environmental conditions. In summary, the broad diet spectrum of the *V. vimba* in different regions results from its nonselective, opportunistic feeding habits and includes several taxonomic groups of native hydrofauna, as well as macrophytes. In addition, when we consider the effect of vimba on macrophyte and *D. polymorpha* biomass, it is clear that vimba might play a significant ecological role in the control of both in the lake.

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