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Diet and feeding strategy of northern pike (*Esox lucius* L., 1758) inhabiting a deep dam lake in Central Anatolia, Türkiye

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Original article

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The aim of this study was to evaluate the seasonal diet composition and feeding strategies of northern pike (*Esox lucius*) located in Sıddıklı Küçükboğaz Dam Lake (Kırşehir, Türkiye). Monthly sampling from September 2015 to August 2016 resulted in the collection of 133 northern pike individuals, with their total lengths ranging from 23.4 to 86.6 cm (mean length 53.84 ± 10.51 cm). Stomach content analyses and statistical tests, including a Kruskal-Wallis analysis, were employed to assess the seasonal variation in feeding intensity. Although numerical differences in the feeding intensity were observed, with the highest values recorded in summer (FI = 1.59) and the lowest in winter (FI = 0.51), these differences were not statistically significant (K-W test, $p < 0.05$). Among the physicochemical parameters of the surface water, temperature emerged as the primary environmental factor influencing the feeding patterns, based on the results of a Spearman's rank correlation. The northern pike exhibited an exclusively piscivorous diet, primarily consuming *Tinca tinca* (44.83% by number and 56.16% by frequency of occurrence) as well as *Atherina boyeri*. Despite the availability of multiple prey species within the habitat, the northern pike demonstrated a strong prey specialisation toward these two fish species throughout the year. The observed consistency in this dietary preference underscores the species' role as a specialised top predator and provides critical ecological insights for the management and conservation of similar freshwater reservoir ecosystems.

Keywords: prey preference, feeding features, food items, predator fish, Sıddıklı Küçükboğaz Dam Lake.

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Understanding the feeding ecology of predatory fish is essential for interpreting their functional role in aquatic food webs and for supporting ecosystem-based fisheries management (Gerking 2014; Polis & Strong 1996; Yazici *et al.* 2025). Diet studies offer insights into predator-prey dynamics, trophic niches and energy transfers, all of which are critical for biodiversity conservation and population regulation (Layman *et al.* 2007; Schmitz *et al.* 2010). A stomach content analysis, although limited to a short-term dietary snapshot, remains a widely-adopted and cost-effective method for diet reconstruction.

It is particularly useful in environments where stable isotope or molecular techniques are not feasible due to logistical, financial or ecological constraints. For instance, a stable isotope analysis often requires the collection of muscle tissue and access to mass spectrometry facilities, which may not be available in remote or resource-limited areas (Post 2002; Jardine & Cunjak 2005). Similarly, molecular techniques such as DNA barcoding or metabarcoding can be hindered by sample degradation, as well as the need for cold-chain storage or a lack of reference libraries for local species (Valentini *et al.* 2009; Deiner *et al.* 2017). In such cases, traditional morphological or ecological indicators provide a practical alternative (Baker *et al.* 2014; Nielsen *et al.* 2018). While a stomach content analysis allows for the identification of the consumed prey at relatively fine taxonomic levels (particularly in the case of short–term dietary snapshots), biomarker–based methods such as a compound–specific isotope analysis (CSIA) of fatty acids and amino acids (e.g. hydrogen and carbon CSIA of fatty acids: Pilecky *et al.* 2021; or $\delta^{15}N$ CSIA of individual amino acids: McMahon & McCarthy 2016; Martinez *et al.* 2020), and molecular techniques (e.g. DNA metabarcoding of the gut contents: Leray *et al.* 2013; Deiner *et al.* 2017) generally offer a superior taxonomic resolution and more robust seasonal or ontogenetic insights into feeding behaviours. Therefore, a stomach content analysis should be seen as complementary to these approaches, rather than as a full substitute.

The northern pike (*Esox lucius* L., 1758) is a widely distributed, top-level piscivorous predator found in freshwater habitats across the northern hemisphere. It significantly shapes fish community structures through prey selection and top-down pressure. Northern pike are known for their opportunistic feeding, yet their diet composition may reflect the availability of habitat-specific prey and predator behaviour (Jepsen *et al.* 2001; Craig 2008). The species holds economic importance for both commercial and recreational fisheries and is considered to be a key bioindicator for lentic ecosystems (Skov & Nilsson 2018).

Numerous studies have examined the diet of the northern pike across North America and Europe (Kangur & Kangur 1998; Liao *et al.* 2002; Winfield *et al.* 2012). However, there is limited information on its seasonal feeding dynamics in the artificial freshwater reservoirs of Central Anatolia. Turkish lentic systems, which are often characterised by fluctuating hydrology, variable habitat complexity and invasive prey fish populations, offer a unique context to study the pike's feeding ecology (Yılmaz & Ünver 2014; Yazıcıoğlu *et al*. 2018). These reservoirs differ ecologically from temperate natural lakes in terms of the nutrient inputs, shoreline vegetation and the prey fish assemblages.

This study aims to fill this knowledge gap by focusing on the seasonal feeding ecology of northern pike located in Sıddıklı Küçükboğaz Dam Lake, a mid-sized reservoir in Central Anatolia, Türkiye. Monthly sampling and a stomach content analysis conducted over a one-year period enabled us to assess the diet composition, prey selectivity and feeding intensity in relation to environmental variations and prey availability. We hypothesised that the diet composition of northern pike (*Esox lucius*) would vary seasonally and be influenced by the abundance and availability of prey species.

Materials and Methods

All operations in relation to the fish capture and dead fish studied in the laboratory were carried out in accordance with animal health and welfare ethical rules. This study was approved by the Animal Experiments Local Ethics Committee (Document No: 68429034/05). In addition, our study complies with the ARRIVE 2.0 guidelines.

Study Area and Sampling

Sıddıklı Küçükboğaz Dam Lake (formerly called Karababa Dam) is a zonal dam built on Körpeli Boğaz Creek, located on the border of Kırşehir Province in Central Anatolia, Türkiye. Its construction began in 1991 and was completed in 2002. The dam is composed of clay with a central core and is filled with rock. The reservoir has a surface area of 1.62 km^2 and an active water volume of 25.3 hm^3 (Akkan *et al.* 2018). The dam lake, which was 14 years old at the time of the sampling, has an oval shape and features distinct habitat zones: shallow littoral areas with submerged aquatic vegetation; moderately sloping intermediate shelves; and deeper central pelagic zones. Based on the duration of the lake since its formation, the lake currently exhibits characteristics of a mid-successional reservoir ecosystem, with established fish populations and relatively stable aquatic vegetation (Yazıcı 2018).

The dam lake's fish species are: big-scale sand smelt (*Atherina boyeri* Risso, 1810), common carp (*Cyprinus carpio* L, 1758), tench (*Tinca tinca* (L., 1758)), Wels catfish (*Silurus glanis* L., 1758), Seyhan dace (*Squalius seyhanensis* Turan, Kottelat & Doğan, 2013), northern pike (*Esox lucius* L., 1758), Caucasian bleak (*Alburnus escherichii* Steindachner,

1897) and Anatolian khramulya (*Capoeta tinca* (Heckel, 1843) (Yazıcı 2018).

Pike gill nets were simultaneously used to collect fish samples monthly from September 2015 to August 2016 at Sıddıklı Küçükboğaz Dam Lake. The nets were set at dusk, left in the water for a minimum of 12 hours and were hauled in between 08:00 and 09:00 a.m. Gill nets, with bar mesh sizes ranging from 20 to 80 mm (knot to knot), were deployed to target a wide range of fish sizes. The sampling was conducted across all major habitat types of the dam lake, including the shallow vegetated littoral zones (0-2 m), moderately sloped transitional shelves (2-5 m) and the deeper pelagic areas. In the pelagic region, nets were deployed to depths reaching approximately 30 metres, corresponding to the maximum skirt length of the gill nets. This spatially inclusive sampling approach ensured the representation of the full depth gradient and habitat heterogeneity within the lake ecosystem.

Some physical and chemical parameters of the lake water, such as the dissolved oxygen (DO), temperature, salinity, pH, conductivity and total dissolved solids (TDS), were measured monthly from September 2015 to August 2016 (Yazıcı 2018) and the environmental variables are given in Table 1.

Laboratory Methods and Stomach Content Analysis

A total of one hundred thirty-three (133) samples were examined for the stomach analysis. In the laboratory, all of the fish samples were measured in cm (total length) and weighed in grams. The stomachs were removed by dissection from each specimen and preserved in a 4% formaldehyde solution for the later analysis. The stomachs were opened during the examination, and the prey was identified, weighed in grams, sorted and classified to the lowest taxonomic level, before being preserved in 70% ethanol. Also, the full and empty stomach weights were measured with a precision of 0.01 g. When a prey item was mostly digested, identification of the prey fish was based on the scales, pharyngeal bones (cyprinids), opercular bones, vertebrae, and the location of the mouth and eyes (Pavlović *et al.* 2015).

To compare the changes of feeding intensity between seasons the fullness index (FI = weight of stomach content/weight of fish * 100) and the vacuity index (VI% = the number of empty stomachs/total number of the examined stomachs * 100) were calculated (De Santis & Volta 2021). Low feeding activity is considered to have occurred when a high vacuity index is observed (Martinho *et al.* 2012). The Kruskal-Wallis test was applied to evaluate seasonal differences in the fullness index (FI), since the data did not meet the normality assumptions required for a parametric ANOVA. Normality was assessed using Shapiro-Wilk tests. The Spearman's rank correlation was used to assess the relationship between the fullness index (FI) and surface water physicochemical parameters, including the temperature, dissolved oxygen, pH, conductivity, salinity and the total dissolved solids. Also, a Chi-square test (χ^2) was applied to determine changes in the vacuity index (VI%) between the seasons.

Traditional methods such as the percentage frequency of occurrence (FO% = number of stomachs containing prey i/number of stomachs with any food item * 100), numerical percentage (N% = number of prey i/total number of all prey items * 100) and percentage by weight (W% = weight of prey i/total weight of all prey items * 100) of the dietary analysis were used to determine the feeding features (Hyslop 1980). The main food items were identified using the index of relative importance (IRI) of Pinkas *et al.* (1971), as modified by Hacunda (1981).

$$IRI = (N\% + W\%) \times FO\%$$

This index has been expressed as the percentage of

$$\%IRI = \left(\frac{IRI}{\sum IRI}\right) \times 100$$

each prey item;

For the computation of the relative amounts of intraspecific competition between seasons, a simplified Morisita-Horn index (C_h) based on %N data was used (Horn 1966):

$$C_h = \frac{2\left(\sum p_{ij}\, p_{ik}\right)}{\sum p^2_{ij} + \sum p^2_{ik}}$$

where C_h is the Morisita-Horn index of diet overlap between different seasons, p_{ij} is the proportion of food type 'i' of the total food quantity by seasons 'j', p_{ik} is the proportion of food type 'i' of the total food used by seasons 'k', and n is the total number of food types. The degree of overlap was classified as low (0.0-0.29), moderate (0.30-0.59) and high (0.60-1.00) (Langton 1982).

Table 1

Monthly changes in some physicochemical parameters of the surface water in Sıddıklı Dam Lake from September 2015 to August 2016 (Yazici 2018)

Months	Water Parameters					
	Temperature (°C)	pH	DO (mg/l)	Salinity (‰)	TDS (mg/l)	Conductivity (µS/cm)
September 2015	22.91	8.22	9.38	0.48	6.63	940.00
October	15.77	7.51	14.90	0.52	6.73	850.00
November	10.40	8.41	7.16	0.78	9.95	1100.00
December	3.68	8.41	11.03	0.63	8.29	750.00
January 2016	3.10	8.21	11.79	0.40	5.35	820.00
February	7.40	8.15	11.76	0.44	5.77	890.00
March	8.78	8.25	9.24	0.35	4.55	700.00
April	14.93	8.16	8.79	0.34	4.48	690.00
May	18.10	8.31	7.18	0.34	4.52	700.00
June	20.85	8.40	6.86	0.32	4.28	650.00
July	24.48	8.31	6.02	0.33	4.42	680.00
August	23.05	8.37	5.97	0.33	4.72	700.00

The selectivity of prey categories in the diet was statistically tested with the χ^2-test, utilising Pearre's C index of prey selection. The index value (*Va*) varies from -1 (prey avoidance) to +1 (prey selection), with 0 indicating a random prey selection (Pearre 1982).

$$Va = \frac{(a_d \times b_e) - (a_e \times b_d)}{\sqrt{a \times b \times d \times e}}$$

where *Va* is Pearre's index for the pike's selection of prey a, a_d is the abundance of prey a in the diet, b_e is the abundance of all other prey in the environment, b_d is the abundance of all other prey in the diet, and a_e is the abundance of prey a in the environment.

Values without subscripts are expressed as follows:

$$a = a_d + a_e$$

$$b = b_d + b_e$$

$$d = a_d + b_d$$

$$e = a_e + b_e$$

The statistical significance of the selection index value (*Va*) was tested using the Chi-squared test.

$$\chi^2 = n \times C^2$$

The value of relative abundance (a_e) used in the prey selection index for each fish species inhabiting Sıddıklı Dam Lake was obtained from Yazıcı (2018).

The feeding strategy was determined from a plot of the percentages of prey-specific abundance (Pi%) against the frequency of occurrence (FO%). The prey specific abundance, which is the percent numerical abundance of a prey item averaged over the stomach samples in which it occurs, was calculated using the methodology detailed in Amundsen *et al.* (1996).

$$Pi = \left(\frac{\sum Si}{\sum Sti}\right) \times 100$$

where Pi = prey specific abundance of the prey i; Si = abundance of prey in the stomachs; and Sti = total abundance of prey in the predators that contain prey i. For specialist feeding, the prey items appear in the upper part of the plot, while generalists have all prey points in the lower part.

Results

During this study, 133 specimens of *Esox lucius* were collected. The total length values of the examined sample (133 specimens) were distributed between 23.4-86.6 cm, and the average total length value was determined as 53.84 (Sd = 10.51) cm. Of these, 73 specimens (54.9%) had food items, while

60 specimens (45.1%) had empty stomachs. The feeding intensity of *E. lucius* according to the season is shown in Fig. 1. The length distribution and number of samples examined according to the season are given in Table 2.

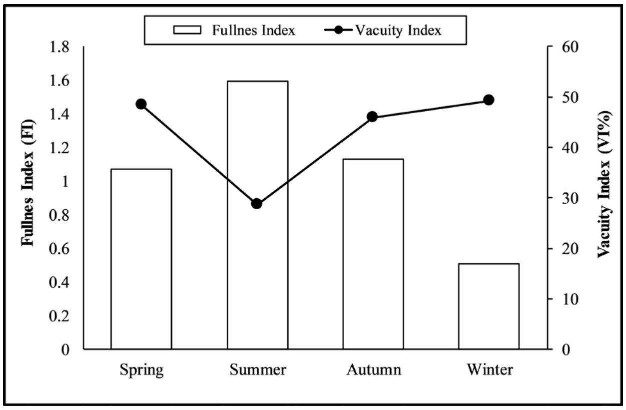

Fig. 1. The mean fullness index (FI) and vacuity index (VI %) for seasons in the northern pike inhabiting Sıddıklı Küçükboğaz Dam Lake.

Table 2

Sample numbers and total length values in different seasons

Seasons	Sample No.	Total Length (cm)		
		Mean	Min	Max
Spring	29	55.9	40.8	86.8
Summer	21	50.1	23.4	75.1
Autumn	24	52.7	33.6	64.4
Winter	59	54.5	42.7	85.3

The vacuity index (VI%) was highest during the winter (49.2%) and lowest during summer (28.6%) (Fig. 1). The VI% values did not reveal significant differences between the seasons (χ^2 = 2.832, p > 0.05). The fullness index, which is a real indicator for feeding intensity, exhibited the highest values during the summer (FI = 1.59) and autumn (F = 1.13), while the lowest values were recorded during the winter (FI = 0.51) and spring (FI = 1.07) (Fig. 1). The changes between the seasons in the vacuity index were not found to be statistically significant (K-W test, p > 0.05).

The Spearman's rank correlation analysis indicated that there was a positive correlation between the fullness index (FI) and temperature (rs = 0.117), pH (rs = 0.05), total dissolved solid (TDS) (rs = 0.061) and conductivity (rs = 0.064), but it was not statistically significant (p > 0.05). A negative correlation between the fullness index (FI) and dissolved oxygen (rs = -0.058) and salinity (rs = -0.173) was detected. The differences were statistically significant in the case of the salinity parameter (p < 0.05), while the differences were not statistically significant in the dissolved oxygen parameter (p > 0.05).

General Diet Composition

The diet of northern pike was comprised of six (6) food items, containing only prey fish species. The diets of 73 individuals included 116 prey items, including *Tinca tinca* (52), *Atherina boyeri* (40), *Cyprinus carpio* (8), *Squalius seyhanensis* (8), *Alburnus escherichii* (5) and unidentified fish (3). (Table 3).

T. tinca was the dominant preysin terms of the number with 44.83%, followed by *A. boyeri* (N = 34.48%). The frequency of the occurrence of *T. tinca* was the highest (56.16%), followed by *A. boyeri* (27.4%). The total wet weight of the 116 prey items was 675.88 g. *T. tinca* was the most

Table 3

General diet composition of the pike (*Esox lucius*) in Sıddıklı Küçükboğaz Dam Lake. n – prey number; N% – numerical percentage; W – prey weight; W% – percentage by weight; O – frequency of occurrence; FO% – percentage frequency of occurrence; IRI – index of relative importance

Food items	n	N%	W	W%	O	FO%	IRI	IRI%
T. tinca	52	44.83	450.66	66.68	41	56.16	6262.402	79.51
A. boyeri	40	34.48	54.41	8.05	20	27.4	1165.322	14.80
C. carpio	8	6.9	36.2	5.35	8	10.96	134.26	1.70
S. seyhanensis	8	6.9	106.08	15.7	8	10.96	247.696	3.14
A. escherichii	5	4.3	13.38	1.98	5	6.85	43.018	0.55
Unidentified fish	3	2.59	6.12	0.91	3	4.11	14.385	0.18
Fish remains	–	–	9.03	1.33	5	6.85	9.1105	0.12
Total	116	100	675.88	100			7876.193	100

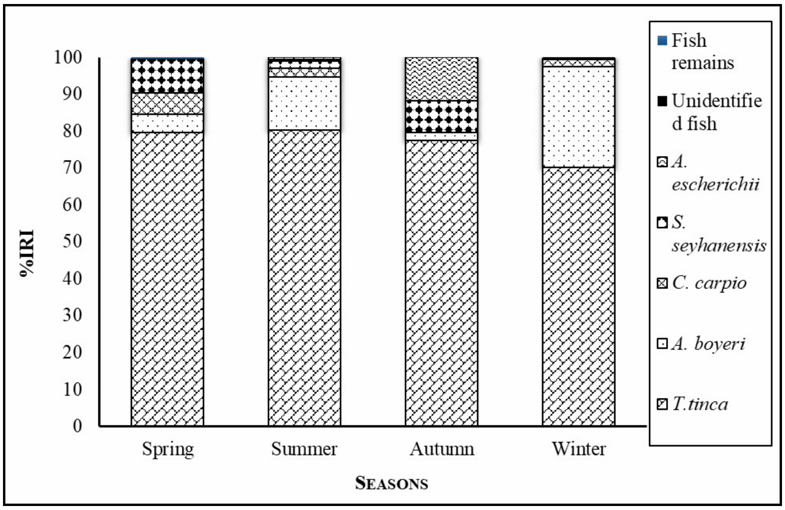

Fig. 2. Seasonal diet composition of the northern pike inhabiting Sıddıklı Dam Lake.

frequently consumed prey item with 66.68% by weight, followed by *S. seyhanensis* with 15.7%. According to the relative importance index (IRI), the most important food item was *T. tinca* (79.51%), followed by *A. boyeri* (14.8%) (Table 3).

There was a little seasonal variation in the food habits of *Esox lucius* in the studied area (Fig. 2). *T. tinca* was the dominant prey group during all seasons, particularly during spring (IRI % = 79.71) and summer (IRI% = 80.28). *A. boyeri* and *S. seyhanensis* were also present in the diet throughout the year, with a peak value recorded in the winter (IRI % = 27.38) and spring (IRI% = 9.39), respectively. *C. carpio* was present in the stomach contents during all seasons except autumn, while *A. escherichii* were only found in the autumn.

These prey items were observed in smaller quantities in the diet. The Morisita-Horn index showed a high degree of dietary overlap between seasons, ranging from 0.775 to 0.967 (Table 4). These overlap values indicate that the fish fed on similar food items when living in this habitat throughout the year. It showed that the least amount of dietary similarity (0.775) occurred in autumn-winter. In contrast, the food of the northern pike showed an extremely high degree of dietary overlap (0.967%) in spring-summer.

The dietary pattern of *Esox lucius* is graphically shown in Fig. 3, where the prey-specific abundance (Pi%) is plotted against the frequency of occurrence (FO%). The feeding strategy of the northern pike showed a variety of prey items. The diet of the northern pike was mostly based on rare species that were eaten occasionally and in relatively small amounts, such as *Cyprinus carpio*, *Squalius seyhanensis*, *Alburnus escherichii* and unidentified fish, except for *Tinca tinca* and *Atherina boyeri*, which tended to be the dominant prey. The population of the northern pike can be considered as a generalist predator with a relatively broad niche width; however, the population consists of some specialised individuals that

Table 4

Results of Morisita-Horn indices for the diet overlaps between seasons in the northern pike

C_h	Spring	Summer	Autumn	Winter
Spring	–			
Summer	0.967*	–		
Autumn	0.882*	0.870*	–	
Winter	0.884*	0.965*	0.775*	–

* Statistically significant

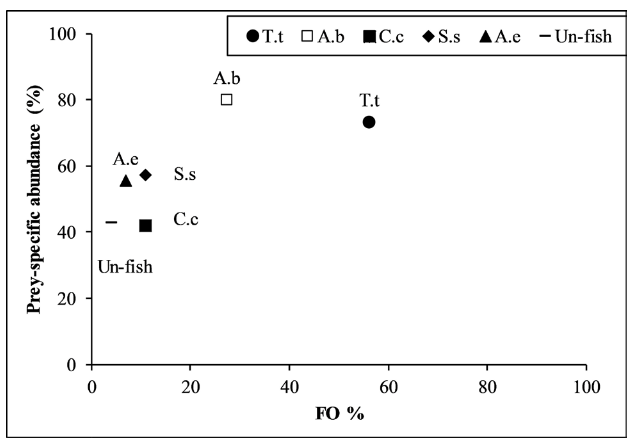

Fig. 3. Costello graph. Prey-specific abundance vs. frequency of occurrence in the diet of the northern pike, *Esox lucius*.

feed widely on *T. tinca* (i.e. prey with a high prey-specific abundance and more than a 50% frequency of occurrence) and *A. boyeri* (i.e. prey with a high prey-specific abundance and a less than 40% frequency of occurrence). *T. tinca* and *A. boyeri* were located in the upper middle part of the diagram, and this situation demonstrates the importance of these prey items in the diet of northern pike, as well as a trend toward population specialisation regarding this prey. These specialised fish shift the feeding strategy of the northern pike towards a higher between-phenotype contribution to the utilisation of the resource gradient or niche width (Fig. 3). In other words, for a generalist predator like *E. lucius*, the sharing of food resources is ensured by certain individuals who specialise in consuming a limited but plentiful prey.

According to the Yazıcı (2018) study, among the fish species identified in Sıddıklı Küçükboğaz Dam Lake, *Atherina boyeri* exhibited the highest relative abundance (43.6%), whereas *Capoeta tinca* and *Alburnus escherichii* had the lowest values, accounting for 0.29% and 0.85% of the fish, respectively. For the remaining fish species, the relative abundances were as follows: *Cyprinus carpio* (14.48%), *Tinca tinca* (13.64%), *Silurus glanis* (11.95%), *Squalius seyhanensis* (8.43%) and *Esox lucius* (6.76%). According to the prey selection index (*Va*), there was a positive selection for *Tinca tinca* (*Va*= 0.523) and *Alburnus escherichii* (*Va* = 0.111), along with a negative selection for *Cyprinus carpio* (*Va* = -0.119) and *Squalius seyhanensis* (*Va* = -0.025), and a close to neutral selection for *Atherina boyeri* (*Va* = 0.009) by northern pike individuals. The estimated prey selection indices of the prey fish were statistically insignificant (p > 0.05), except for *T. tinca* (Fig. 4).

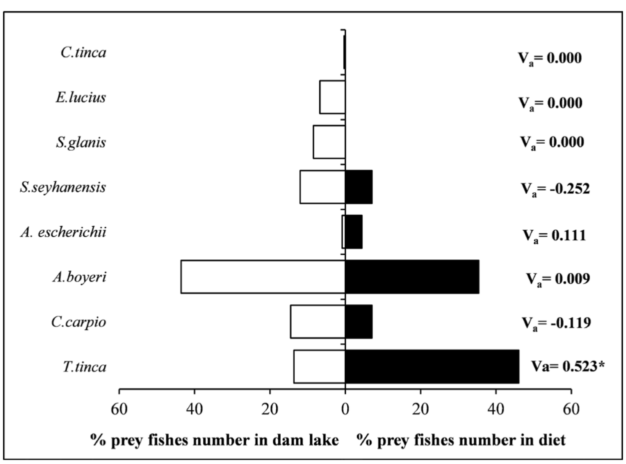

Fig. 4. Pearre's selectivity index of the prey fishes in Sıddıklı Dam Lake. *Significant at $p < 0.05$ in the x^2-test.

Discussion

This study provides information on the food items and feeding habits of *Esox lucius*, a predatory fish species caught from Sıddıklı Dam Lake in Türkiye's inland water. It was observed that the percentage of empty stomachs (VI%) was generally high during the study. The highest vacuity index was detected in the winter season. Arrington *et al.* (2002) stated that the presence of a high percentage of empty stomachs is a common situation in piscivorous fish. Similarly, the value of VI expressed as the percentage of empty stomachs was high in the study area and it was generally consistent with the results of previous studies (Kangur & Kangur 1998; Didenko & Gurbyk 2016). It has been found that the empty stomach rate (VI%) of the northern pike varies between 10.24% and 77% in studies conducted in different habitats (Soupir *et al.* 2000; Yılmaz & Polat 2005; Alp *et al.* 2008; Yilmaz *et al.* 2010; Yazicioglu *et al.* 2018). Chapman *et al.* (1989) reported that the proportion of empty stomachs in northern pike is positively related to the frequency of the occurrence of prey fish in the stomach. Most empty stomachs are probably related to the stay time of fish in the nets and the digestive process after the fish are caught. The high rate of empty stomachs may also be due to the sampling method (gill nets) that causes predator fish to vomit their stomach contents (Didenko & Gurbyk 2016).

Our findings show that the values of the fullness index (FI) followed an inverse trend to the vacuity index values (VI%). This finding is consistent with the results from previous studies in different species or habitats (Giarrizzo & Saint-Paul 2008; Yazicioglu *et al.* 2018). The fullness index is used to assess the feeding intensity of the fish. The positive relationship between the water temperature and fullness index indicates that the highest increase in the feeding activity of this species occurs in summer. In addition, the feeding intensity may vary depending on the spawning time (Yazıcıoğlu *et al.* 2016), seasonal changes in the water temperature (Okgerman *et al.* 2013) and the type of food items available (Yazıcıoğlu *et al.* 2018). Seasonal variations in the feeding intensity revealed an increase in the fullness index during the summer, whereas a decrease in this index was detected in winter throughout the study. Bregazzi and Kennedy (1980) determined that feeding increased in the summer and autumn, with less intensive feeding taking place during the spawning season and in winter. Alp *et al.* (2008) reported that the percentage of empty stomachs among this species in Çivril Lake was highest in winter, and that it fed more intensively during the spring and summer seasons. The reason for the lower feeding intensity in winter is most likely due to lower water temperatures, which slow down the metabolism. In this study, it was determined that the main environmental factor affecting the feeding intensity of fish is the water temperature (Okgerman *et al*. 2013; Yazici *et al*. 2022).

The northern pike consumed a narrow range of prey items in this study and their diet consisted of only prey fish. The northern pike exhibited piscivorous feeding features in this area, and the present results are similar to the findings of Liao *et al.* (2002) in Spirit Lake (Iowa, USA), as well as Yilmaz *et al.* (2010) in Lake Uluabat (Bursa, Türkiye), Yılmaz and Ünver (2014) in Sıdıklı Dam Lake (Kırşehir, Türkiye) and Pavlović *et al* (2015) in the Šumarice Reservoir (Serbia). It is thought that the consumption of only fish species in the study is due to the size distribution of the studied samples and the larger body size of the food fish compared to benthic invertebrates. Additionally, feeding exclusively on fish may be due to the small surface area of the aquatic habitat studied and the high fish density. However, previous studies have reported that this species displayed a highly diversified diet and consumed a broad range of prey items, ranging from invertebrates to vertebrates (Soupir *et al.* 2000; Alp *et al.* 2008; Yazicioglu *et al.* 2018; Cathcart *et al.* 2019). In this study, a total of five different food fish were detected in the stomachs of the pike, where the most important prey fishes were *T. tinca* and *A. boyeri*, respectively. Mêrő (2015) reported that a total of 51 prey-fish species were observed in the stomachs of pike in different studies. The differences among the prey fish in the diet composition are mainly due to the availability of prey items in different habitats. Cannibalism has been generally detected in northern pike populations (Alp *et al.* 2008; Cathcart *et al.* 2019); however, intraspecific predation (cannibalism) did not occur in the northern pike population observed in this study. Other researchers have also not observed cannibalism among northern pike found in different freshwater ecosystems (Yilmaz *et al.* 2010; Pavlović *et al.* 2015; Jacobson *et al.* 2019). The reason for the absence of cannibalism is due to the abundance of prey fish in the lake and the low density of predator species. Furthermore, Craig (1996) found that the occurrence of cannibalism varied according to the availability of prey fish and the pike density.

The feeding habits of northern pike and their predation on fish showed little change depending on the seasons. The most consumed food in all seasons was *T. tinca*, followed by *A. boyeri* and *S. seyhanensis*, respectively. Many studies have stated that there are seasonal changes in the diet of the pike (Liao *et al.* 2002; Alp *et al.* 2008). These seasonal variations in the diet can be associated with the density, abundance and availability of prey items.

The results of this study showed that some of the analysed specimens specialised in certain types of prey fish, whereas the entire sample seems to have a generalised feeding strategy. This feeding strategy can be deduced from the fact that a few prey items had a high prey-specific abundance (Pi%) and a low frequency of occurrence. The generalist feeding strategy of the northern pike is likely associated with the fact that the pike is an opportunistic feeder (Sandlund *et al.* 2016) and can shift its prey consumed depending on the prey's availability (including its behaviour) and abundance (Craig 2008). Among the northern pike, some individuals tended to exhibit a specialist feeding strategy towards *T. tinca* and *A. boyeri* in all seasons, while other prey fishes had a low prey-specific abundance and were generally rare prey for the northern pike with generalist feeding strategies. Pike exhibited a similar feeding strategy in The Natural Park of the Ruidera Lakes. Specifically, this species showed a specialised feeding strategy towards crayfish, but a generalised strategy towards other food items (Elvira *et al.* 1996). Cathcart *et al* (2019) indicated that the feeding strategies of northern pike inhabiting 31 different waterbodies in Alaska differed among size classes, while the feeding strategy showed a specialisation toward vertebrate prey, with a generalisation toward macroinvertebrate prey, except dragonflies. Yazicioglu *et al.* (2018) reported that changes in the feeding features of northern pike living in Ladik Lake depended on the size groups (with generalist feeding features in small individuals and specialists in the large samples).

In the present study, *Tinca tinca* (C = 0.523) and *Alburnus escherichii* (C = 0.111) were the most-preferred prey fish. *Cyprinus carpio* (C = -0.119) and *Squalius seyhanensis* were negatively selected by the northern pike. *A. boyeri*, the most abundant species in the lake, exhibited a close to neutral selection by the northern pike. The environmental prey abundance did not shape the prey selection of this fish species in Sıddıklı Dam Lake. Similar results regarding the prey preferences of northern pike were also reported in Çivril Lake (Alp *et al.* 2008). Alp *et al.* (2008) reported that *Chondrostoma meandrense, Gobio gobio* and *Tinca tinca* were the most preferred food species in Çivril (Denizli) Lake, where *Hemigrammocapoeta kemali* and *Aphanius anatolicus* were not preferred. The littoral zone of lakes and dam lakes is important for fish species, especially herbivorous and omnivorous species, due to the protection it provides from predatory fish, breeding, and nesting or shelter. For marine and freshwater ecosystems, aquatic vegetation that supports a varied and abundant fish population is an important biogenic habitat (Akın & Turgut 2003). Since the northern pike is an ambush predator that needs aquatic vegetation to hide from their prey items, their density is highest in the littoral zones of shallow lotic and lentic ecosystems (Haught & Von Hippel 2011). Thus, they can exhibit predation on *Tinca tinca* and *Alburnus escherichii* that are abundant in littoral zones where aquatic plants occur. The fact that carp is not preferred by pike may be due to the high body height of *C. carpio*. Factors such as the soft rays (Eklöv & Hamrin 1989; Tyus & Beard 1990) and body height (Alp *et al.* 2008) of the prey fish plays a role in the pike's preferences for its prey. Size, shape and swimming speed of the prey, as well as the quantity and quality of prey available and the level of predator satiation and competition can play a role in the prey's selective by a predator. Mouth form and the size of the predator can also be effective in choosing the type and size of the food (Juanes *et al.* 2002). Magnhagen and Heibo (2001) determined that the gape size of the predator and the body depth of the prey are the main factors deciding whether a northern pike can ingest a potential prey fish. Pavlović *et al.* (2015) reported that the northern pike can shift its prey preference due to changes in the abundance and vulnerability of prey items in an aquatic environment. Aquatic vegetation provides a significant biogenic habitat for marine and freshwater ecosystems (Akın & Turgut 2003) and reduces the foraging success of predatory fish by obstructing the vision and attack movements of predators. Therefore, the capture time increases (Gotceitas 1990). Similarly, it is thought that the negative selection of *S. seyhanensis* and the natural selection of *A. boyeri* may have been due to the abundance of aquatic vegetation in the coastal area of the lake.

In conclusion, this study has presented the food items, feeding intensity and feeding habits of the northern pike during various seasons and the feeding strategy of the species in Sıddıklı Dam Lake, Türkiye. Furthermore, it has also revealed the relationships between environmental parameters and the feeding intensity. *Esox lucius* showed variations in the feeding intensity according to a seasonal basis. It was observed that the environmental food abundance had no effect on the prey preference of this fish species in the research area. Finally, it is thought that the morphological structure of the prey fish mostly affects the pike's food preferences.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Research concept and design: O.Y.; Collection and/or assembly of data: O.Y., R.Y., A.Y., M.Y.; Data analysis and interpretation: O.Y., R.Y., A.Y., M.Y.; Writing the article: O.Y.; Critical revision of the article: O.Y.; Final approval of the article: O.Y., R.Y.

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