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The Low Ontogenetic Diet Diversity and Flexibility of the Pike-Perch, *Sander lucioperca* (Linnaeus, 1758) (Osteichthyes, Percidae): A Case Study

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Abstract: This study reveals the diet of pike-perch from two habitats within the Tersko-Caspian region. The feeding habits of pike-perch in the Sulak and Terek rivers and Tersko-Caspian region were investigated based on 354 specimens sampled monthly from a commercial catch in 2019. Their diet consisted of different prey, with fish representing the most important prey group (up to 90%). *Rutilus caspicus* dominated with a frequency of occurrence of 20.5, and *Aspius aspius*, *Perca fluviatilis*, and *Chondrostoma oxyrhynchum*, had 13, 9.5, and 8.3%. In the earlier ages 1+ and 2+, zooplankton dominated, followed by mysids and chironomids, which continues into the older ages but at decreasing rates. Analysis of monthly variations in stomach fullness indicated that feeding intensity fluctuated in time, with the highest values in March–April, and lowest in September and November. It was found that the diet of pike-perch in the western Caspian changed considerably from season to season. They begin to actively feed after wintering and before, or even during, spawning period. The spectrum of the diet of *Sander lucioperca* includes more than 20 elements, mainly juveniles of commercially valuable fish. This fish is characterized by a relatively low ontogenetic diet diversity and flexibility, which makes it sensitive to environmental changes, including anthropogenically induced ones. This fish partially compensates for this disadvantage with its lifestyle, namely, its active foraging movements and migrations from fresh water to salt water and back, following its prey species.

Keywords: Caspian Sea basin; fish; feeding habits; stomach fullness; predator–prey interactions

Key Contribution: The economic and ecological major interest of *Sander lucioperca* related to original field data obtained in an exquisite biogeographical hotspot of biodiversity, which were used in a special integrated biological and ecological research analytical frame and with the results offering not only a new perspective on this fish but a better understanding of the associated risks of the studied aquatic ecosystems for management decision makers.

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1. Introduction

Globally, a high diversity of stressors presents significant risks on aquatic ecosystems and their associate parameters, habitats, and organisms [1–5]. Due to these stressors (e.g., pollution, habitat fragmentation, climate change, overexploitation, invasive species, land use, etc.), fish, as one of the most important group of organisms (as aquatic ecosystems' cornerstone structural and functional elements; as ecosystem service generators; as key components in building ecosystem resilience and increasing and speeding up productivity; as an important link in food chain dynamics and nutrient cycling as food, as diseases control vectors, a source of income and employment, etc.) [6–8] are also extremely threatened as highly needed and wanted natural resources around the world and as collateral victims due to the direct and indirect impact effects of extremely variable human activities [9–22]. This is why fish biology and ecology research results are of high interest for the global scientific community and decision makers.

The Ponto-Caspian fauna has evolved in an unusually rich and peculiar way over the millennia due to its dynamic geology in a series of lakes and seas with widely varying salinity and water levels, intermittent periods of the separation and establishment of connections between the basins of the Caspian and Black Seas, as well as between them and the Mediterranean Sea and the world's oceans and seas [23].

The salinity in the Caspian Sea is almost three times lower than in the open areas of the world's oceans. The highest variability of salinity is observed in the north of the Caspian Sea, where in the estuarine areas of the Volga and the Urals, the water is fresh (less than 1%). Differences in salinity between the north and the south of the Caspian Sea are small; the salinity increases slightly from the northwest to the southeast, reaching 13.6% in the Turkmen Gulf. Vertical salinity changes are small and rarely exceed 0.3%, which indicates good vertical mixing of waters. The water transparency varies widely from 0.2 m in the estuaries of large rivers to 15–17 m in the center areas of the sea [24].

It is with significant changes in the salinity field that the ecosystem is being broken down: the species composition of algae and living organisms, their number, the distribution of fish in the sea area, the survival rate of juvenile fish, etc., change [25].

The dynamics of the salinity of the Northern Caspian depends mainly on the magnitude of the Volga runoff [26]. With an increase in the flow of the Volga river and sea level, there is a decrease in the salinity of the Northern Caspian and, conversely, with its decrease, an increase in the salt reserve in this part of the Caspian Sea. The most important role in the salt balance of the Caspian Sea is played not only by river runoff but also by other processes, especially the discharge of groundwater. The salt content in groundwater is often tens, hundreds, and even thousands of times higher than the mineralization of river waters. Therefore, the inflow of even a small amount of groundwater into the sea has a significant impact on its hydrochemical regime [27].

Since 1989, the desalination of the Northern Caspian has been taking place, and in recent years its salinity has reached 6.7% [28]. All of this period can be considered favorable for feeding semi-migratory and riverine fish because the area of the zone with reduced salinity was greater than the average long-term value [26].

The salinity off the coast of Dagestan is influenced by both salty sea and fresh river waters. Back in the 1970s, the Tersko-Caspian coast could be attributed to brackish reservoirs. However, now it is characterized by seasonal changes in the composition of water: in summer, it is desalinated due to fresh Volga runoff.

Over the past four years, the salinity of the coastal waters of the sea has been in the range of values from 4.02 ‰ in the Northern Caspian to 12.94‰ in the Middle Caspian Sea; all of these variations were between 3.3‰ and 9.2‰ [29–35].

Accordingly, in this unique Ponto-Caspian biogeographical region, a remarkable specific and rich fauna appears and evolves, including fish [35]. Here, in the modern era, a major and variable negative human impact was observed. In this general naturally and anthropogenically induced context, specific regionally applied biological and ecological research is more than needed.

Among the fish fauna of the Ponto-Caspian region, one of the most economically and ecologically important pelagic and potamodromous species, and a higher predator in freshwater and brackish habitats, is *Sander lucioperca* (Linnaeus, 1758) [36–38]. Adults which reach a maximum length of over 100 cm live in turbid rivers and eutrophic lakes, brackish coastal lakes, deltas, and estuaries [39,40]. Specific to this fish in the studied area, data about its trophic relations and the food composition are vital when researching fish biology and ecology, at least because the growth of fish and, consequently, the productivity of the fish herd depends on the availability of food. Knowledge of the main food sources of various species of the fish community will lead to knowledge of the trophic network and, consequently, of the interrelationships of species [41–49].

The pike-perch is an ecologically significant predator in the waters of Eurasia and is of great importance for fishing [43] and, in recent years, for fish farming [50,51]. It usually plays a crucial role in eutrophic inland waters in ecologically controlling the number of carnivorous and omnivorous fish [52,53].

The pike-perch's preferred foods items vary along its life cycle [54–64], and are an interesting topic to be studied in the context in which this species' biological and ecological relevance should be established and reveal what a complex, rich, and variable biogeographical region as the Ponto-Caspian area is. The top trophic/predatory position of this species in fish communities is a supplementary reason as to why its role is important in aquatic ecosystems and, thus, should be studied [62–64].

If we consider growth as a natural consequence of the nutrition process, then the study of the feeding behavior of fish becomes very important. Thus, there is an increased need for studies of changes in the diet during life cycle development, since the pike-perch has a rather rigid ontogenetical nutrition scheme [63] which is very sensitive to environmental changes, especially those that affect the components of the food web.

This study was carried out to probe the feeding habits and diet of *Sander lucioperca* juveniles and adults in different habitats of the western Caspian Sea. The main aim of the study was to describe the diet, frequency of occurrence of different food items in the stomach, monthly changes in diet, feeding intensity, and feeding in relation to fish size and age due to a lack of such studies in the biogeographical research area [65–71].

The main question addressed by the research is that, currently, of all the valuable species of fish, the pike-perch population is experiencing the greatest anthropogenic load due to increased oil production, poaching, and plundering from commercial catches. The pike-perch was depressed in the Kizlyar Bay, a fact confirmed by its age structure. In this regard, the relevance of this study approach in the pike-perch in the Tersko-Caspian subdistrict in the modern period is beyond doubt. Assessments of the ontogenetic variability of the common pike-perch and the state of its population in the changed conditions of the water area of the Tersko-Caspian regions and analysis of the variability in the diet of pike-perch formed in the western part of the Middle Caspian Sea were targeted. For a more complete understanding of the importance of pike-perch in the ecosystem of the Tersko-Caspian region, knowledge of its nutrition is required, as is clarification of the qualitative and quantitative characteristics of trophic relationships.

Our results should also be a background for assessing the impact of pike-perch as a predator on commercially valuable fish, since the data in the literature are extremely limited and this issue has not found proper attention from the relevant research entities.

In spite of the fact that a lot of studies of the fish of the region took place but did not deal in detail with the biology of pike-perch, this study is considered to have addressed a fundamental gap in the study of the biology of pike-perch in the region [72–82]. The majority of studies focused on the sizes and age structures, the nature of growth, and the dynamics of stocks, and we did not find anything that gives an effective picture of the biology of reproduction and food habits, in addition to the absence of a comparison between the river and the sea. Our study and our results add new information and documented facts to the previous studies that have not dealt with this topic.

2. Materials and Methods

2.1. Data Analysis

This is a quantitative descriptive study using direct observation methods. Determination of locations was done by exploratory method and sampling was conducted randomly with direct observation in the field. Data analysis was performed using the relative index method to determine the percentage composition of food in the stomach.

2.2. Study Area

Fish samples were collected in the lower reaches of the Terek and Sulak rivers in addition to The Tersko-Caspian coast (Figure 1).

Figure 1. Map indicating pike-perch sampling stations and area in the western Caspian Sea.

The Tersko-Caspian fishery region occupies a coastal shallow zone on the western coast of the Northern and Middle Caspian Sea and is of great importance for the fisheries of Dagestan. Geographically, the Tersko-Caspian region in the north borders with the Northern Caspian and northwestern fishery regions (44°47′00″ N–46°57′00″ E), located in the Republic of Dagestan. In the south it runs along the line north of the city of Makhachkala, the capital of Dagestan. In the east, at sea, it is located above a depth of 15–50 m along the coast of Dagestan. The internal water bodies of Dagestan, especially the Terek and Sulak rivers, also belong to this subdistrict.

The Terek, Sulak, and Samur rivers flow directly into the Dagestan waters of the Middle Caspian, which have a significant impact on the hydrological and hydrochemical regime of the coastal waters of the Caspian. According to its hydrological, hydrochemical, and hydrobiological indicators, the coastal zone of the Dagestan part of the Caspian Sea is characterized as an area with fluctuating environmental factors—temperature, salinity, oxygen content, currents, and biogenic composition, and, depending on the amount of the latter, an abundance of hydrobionts.

2.3. Pike-Perch Sampling and Diet Analysis

Tersko-Caspian surveying was conducted in spring to autumn (March–November 2019) on the Sulak, Terek, and Tersko-Caspian sea region to obtain comparative characteristics on the diet of the predator pike-perch.

Preliminary studies of the biological indicators of pike-perch from two rivers, Terek and Sulak, showed no differences, which gave us the opportunity to combine them as one population.

As we can see on the site map, the deltas of Terek and Sulak rivers are considered to be a single basin of Dagestan water resources, and from the point of view of technical characteristics and ecochemistry they are identical parallels [83–89]. KaspNIRKh considers the Terek and Sulak rivers to be a single basin in all their fishery considerations (Tersko-Caspian fishery area, Tersko-Caspian fisheries subdistrict). Even from the point of view of geology, they are considered one unit (the Tersko-Sulakskaya lowland coincides with the Tersko-Caspian foredeep tectonic structure [89]).

According to the X-ray phase analysis, the mineral compositions of the suspended sediments near the Terek and Sulak estuaries are almost the same. They are characterized by approximately equal contents of anhydrous aluminosilicates, clayey and carbonate materials. Significant differences in the suspended sediment compositions are manifested in the quantitative ratio of minerals at the plume boundaries [85].

Pike-perch were caught with a fishing rod and gill nets. A total of 354 specimens were analyzed (100 specimens from the Terek river, 94 from the Sulak river and 160 from the Caspian Sea). Standard length (SL) and weight were measured in all studied pike-perch; sex, stage of maturity of sexual products, and age by pectoral ray were determined (59); the gastrointestinal tract was extracted and fixed in 6% formalin for subsequent laboratory analysis. The processing of the contents of the predator's stomach was carried out according to the method of Fortunatova and Popova [59]. The number and species composition of ingested fish and their lengths were calculated in the food content. The species and size of the digested fish prey were determined by the shape and size of the pharyngeal teeth (for cyprinids) of the axillary and bones (for the percids) according to the tables of Bogutskaya et al. [57].

Food indicators were used as the proportion of feeding individuals, the total index of filling of stomachs, as well as the frequency of occurrence of forage objects (in % of the total number of analyzed stomachs with food) and the proportion of their mass (in % of the mass of the stomach contents).

Each stomach's contents were dried with filter paper and weighed on laboratory scales with an accuracy of 0.1 mg. Then the stomach contents were separated among the components of food. The components of animal origin have been determined to the best possible level.

The masses of food components in the stomachs were calculated by weighing them separately. The ratio of food components by weight was determined as a percentage of the total mass of the stomach contents.

The frequency of occurrence of food components of stomach contents, expressed as a percentage of the total number of studied digestive tracts of this type of fish, was set as the number of food tracts containing any food component.

Due to the large difference in the length of food products, we took indicators for both weight and length.

2.4. Pike-Perch Age Determination Methodology

Several normal scales (10–15 pieces) were removed from the front of the caudal peduncle of specimens, below the lateral line opposite the beginning of the second dorsal fin (where the first scales arise during the juvenile squamation of the pike-perch fish, cleaned with a 5% KOH solution and washed with distilled water, then stored dry in paper bag with individual labeling. The scales were placed between two slides and observed with a binocular magnifier. The readings were taken by three independent observers; the scales were used in subsequent analyses only when all three readings coincided.

2.5. Statistical Analysis

Multivariate similarity analysis (ANOSIM) was carried out especially in order to check the significance of differences between habitats, months, and ages for prey species. ANOSIM was performed using the statistical software PRIMER 6 (Clarke and Warwick, 2001).

Linear regressions were used to find the relationships between predator and prey fish sizes in each habitat (all prey fish combined).

All calculations, evaluation and graphicalization were performed in MS Excel 2010.

3. Results

During the study, the standard lengths of pike-perch varied from 12.5 to 61.5 cm with an average value of 41.7 ± 0.48 and 44.2 ± 0.37 cm for riverine and marine specimens, respectively. The total weights ranged from 485 to 5000 g with an average value of 1798.14 ± 15.4 and 1958.5 ± 18.71 g for riverine and marine specimens, respectively. The average lengths for all were 38.67 ± 0.40 in spring, 39.40 ± 0.58 in summer, and 43.84 ± 0.58 in autumn. Ages ranged from 2 to 10 years.

Analysis of the total stomach contents of the pike-perch showed that the basis of its diet is fish (Tables 1 and 2). Of all the species of prey in the food of the pike-perch of the Terek and Sulak rivers and the Caspian coast, the roach (*Rutilus caspicus*) dominated, which occupied the first place in the frequency of occurrence (Table 1). In rivers, the frequency of occurrence in the food of pike-perch was dominated by roach (*Rutilus caspicus*) too, the second place was taken by asp (*Leuciscus aspius*), then perch (*Perca fluviatilis*), and nase (*Chondrostoma oxyrhynchum*), amounting to 20.5, 13, 9.5, and 8.3%, respectively. In the sea, the composition of the predominant, in terms of the number of prey, was similar: roach, ruffe (*Gymnocephalus cernua*), pike-perch, and nase, with a frequencies of 18.1, 15.4, 11.3, and 11.2%, respectively (Tables 1 and 2).

One-way analysis of similarities showed that there were no significant differences in frequency of occurrence of objects by weight (%) between sea and river prey ($F = 0.71960$; $p = 0.57401$). The result is *not* significant at $p < 0.05$.

As can be seen from Table 2, in addition to the constant dominance of the roach in all age groups, there is an absence of some predominant species in its diet in the years preceding sexual maturity among the commercial species of pike, bream, and carp. This can be explained by the inaccessibility of these species to pike-perch and the differences in localization during spawning and feeding of predator and prey. In addition to changes in the qualitative composition of forage objects in certain seasons and periods, age variability was found in the food composition of pike-perch. This variability may be the result of physiological changes that occur with the age of the predator and may contribute to the changings in intraspecific trophic relations. The latter manifests itself in a different ranges of nutrition and prey sizes, and differences in fattening rhythms of different age groups of pike-perch.

In summer, the percentage of pike-perch containing prey was high (63.5%), and was below 50.0% in other seasons. The share of pike-perch containing prey was 73.56% in medium-sized pike-perch (40–50 cm) and 13.28% in small-sized pike-perch (25–40 cm). The maximum filling index was observed in April, while the minimum was observed in September and November (Table 3).

Table 1. Fish composition/content in the pike-perch diet (%); NS—non-significant, *—a significant superiority at $p \leq 0.01$, **—a significant difference at $p \leq 0.01$.

Composition of Diet Elements	Terek and Sulak Rivers	Western Caspian Region	Significant
Caspian roach *Rutilus caspicus*	20.5 + 1.25 A	18.1 + 0.98 A	NS
Asp *Leuciscus aspius*	13 + 0.78 B	2.2 + 0.15 D	**
European Perch *Perca fluviatilis*	9.5 + 1.14 C	2.4 + 0.56 D	**
Terek nase *Chondr.oxyrhynchum*	8.3 + 0.94 C	11.2 + 1.25 B	*
Ruffe *Gymnocephalus cernua*	7.5 + 0.87 C	10.4 1.18 B	*
Pike-perch *Sander lucioperca*	1.5 + 0.30 E	1.3 + 0.25 D	NS
Freshwater bream *Abramis brama*	7.2 + 0.8 C	3.4 + 0.68 CD	*
Pike *Esox lucius*	5.8 + 0.7 CD	2.1 +0.40 D	*
Common carp *Cyprinus carpio*	3.8 + 0.76 E	3.1 + 0.65 D	NS
Sabrefish *Pelecus cultratus*	1.7 + 0.34 E	0.3 + 0.05 E	*
Bleak *Alburnus alburnus*	3.5 + 0.75 E	-	
Caspian kutum *Rutilus frisii*	3.3 +0.80 E	2.2 + 0.44 D	NS
Mysida	2.4 +0.6 E	1.3 + 0.36 D	NS
Round goby *Neogobius melanostomus*	1.3 0.39 E	6.5 +0.81 C	**
Caspian tyulka *Clupeonella caspia*	-	3.2 +0.96 D	
Digested fish remains +	3.4 0.70 E	4.4% + 0.90	**

Table 2. Age dynamics of occurrence (% by weight) of the main forage objects in the diet of pike-perch of the western subdistrict of Caspian Sea; Values with different letters in the line or column differ significantly ($p < 0.05$).

Age		1+	2+	3+	4+	5+	6+	7+	8+	9+
Species/elements in the alimentary tract	Zooplankton	27.2 + 3.019 a	9.13 + 1.1 B	–	–	–	–	–		
	Mysida	18.31 + 2.5 A	7.10 + 0.78 A	5.6 + 0.65 B	3.5 + 0.38 C	1.7 + 0.51 C	0.75 + 0.04 D	1.1 + 0.34 D	-	-
	Chironomidae	11.42 + 1.53 A	10.42 1.4 A	2.6 + 0.52 B	0.57 + 0.04 C	0.3 + 0.02 C	0.65 + 0.03 C	1.5 + 0.65 C	0.53 + 0.06 C	-
	Fragments of crustaceans	15.5 + 2.20 A	8.7 0.92 B	4.3 0.9 + 0.9 C	4.1 + 1.5 C	2.2 + 0.68 D	2 + 0.4 D	1.4 0.56 D	0.6 0.04 C	-
	Fishes: the main ones are listed below	27.57 + 2.84 C	58.15 + 5.83 B	87.7 + 5.94 A	86.33 8.2 A	90.8 10.4 D	96.4 8.8 A	95.4 + 98 A	98.87 9.23 A	100 +0.0 A
Caspian roach *Rutilus caspicus* (Yakovlev, 1870)		10.71+ 1.72 B	14.86 + 3.0 B	20.82 + 1.44 A	18.62 2.8 A	20.13 2.46 A	18.14 + 2.36 A	20.17 2.38 A	18.5 2.40 A	18.6 + 2.39 A
European perch *Perca fluviatilis* (Linnaeus, 1758)		-	6.44 + 0.5 B	11.1 + 1.33 A	6.15 + 0.75 B	4.81 + 0.96 C	7.88 + 1.43 B	6.32 + 0.36 B	5.3 + 1.06 B	7.5 1.5 B
Round goby *Neogobius melanostomus* (Pallas 1814)		3.94 +0.97 B	2.42 + 0.55 C	6.40 + 0.74 A	4.5 + 0.54 A	3.48 + 1.43 B	5.63 + 0.95 A	5.85 + 0.95 A	3.25 + 0.28 B	4.8 + 1.5 B
Caspian tyulka *Clupeonella caspia* (Svetividov, 1941)		2.12 + 0.34 B	4.23 + 0.5 B	6.65 0.76 A	3.5 0.85 B	3.8 + 0.83 B	5.8 0.68 A	6.3 + 0.72 A	6.1 + 1.3 A	7.7 + 1.14 A
Ruffe *Gymnocephalus cernua* (Linnaeus, 1758)		0.41 + 0.04 B	7.5 + 0.87 A	7.7 + 0.84 A	6.2 + 0.92	5.44 + 0.94 A	6.53 + 0.98 A	7.21 + 0.91 A	7.75 + 1.25 A	7.25 + 1.05 A
Pike-perch *Sander lucioperca* (Linnaeus, 1758)		-	2.7 + 0.36 C	6.6 + 0.72 B	5.21 + 0.71 B	9.6 + 1.48 A	3.72 + 0.9 C	2.46 + 0.5 C	4.15 + 0.55 B	3.5 + 0.75 C
Caspian kutum *Rutilus frisii (Nordmann* 1840)		-	-	-	7.5 + 0.82 A	5.25 + 1.75 B	5.0 0.75 B	4.5 + 0.55 B	4.65 + 1.13 B	4.5 + 0.416 B
Sabrefish *Pelecus cultratus* (Linnaeus, 1758)		-	-	-	3.12 + 0.42 a	5.17 + 0.87 a	4.48 + 0.93 a	5.45 + 0.5 a	4.75 + 1.2 a	3.64 + 0.4 a

Table 2. *Cont.*

Age	1+	2+	3+	4+	5+	6+	7+	8+	9+
Pike *Esox lucius* (Linnaeus, 1758)	-	-	-	4.56 + 0.60 b	6.52 + 6.52 + 0.92 a	7.64 + 0.78 a	7.35 + 1.45 a	8.63 + 1.71 a	7.46 0.96 a
Terek nase *Chondr. oxyrhynchum* (Kessler, 1877)	-	-	-	3.98 + 0.33 a	3.83 + 0.36 a	4.81 + 0.48 a	3.90 + 0.52 a	3.93 + 0.63 a	2.36 + 0.129 a
Bleak *Alburnus alburnus* (Linnaeus, 1758)	9 + 0.89 a	4.54 + 1.02 b	8.82 + 1.44 a + 1.1 b	6.2 + 5.7 + 0.97 b	5.7 + 0.97 b	5.35 + 0.85 b	4.73 + 0.36 b	6.26 + 0.38 b	7.2 + 0.94 b
Freshwater bream *Abramis brama* (Linnaeus, 1758)	-	-	-	-	11.35 + 1.3 a	7.85 + 1.8 b	9.55 + 1.6 a	10.35 + 1.4 a	9.6 + 1.9
Asp *Leuciscus aspius* (Linnaeus, 1758)	-	-	5.68 + 1.73 c	4.25 + 0.65 c	4.65 + 0.69 c	8.53 + 1.38 b	8.82 + 1.41 b	12.33 + 0.99 a	11.8 + 1.6 a
Common carp *Cyprinus carpio* (Linnaeus, 1758)	-	-	-	2.84 + 0.43 a	1.07 + 0.47 a	3.39 + 0.42 a	1.71 0.81 a	2.25 + 0.68 a	2.79 + 0.81 a
Digested fish remains +	1.4 + 0.4 d	15.4 + 1.4 a	13.8 + 1.4 a	9.7 + 1.1 b	4.7 + 0.9 c	1.6 + 0.13d	1.1 + 0.2 d	0.67 + 0.2 d	1.3 + 0.3 d

Table 3. Seasonal dynamics of pike-perch feeding activity by the main species of fish prey in the rivers and the sea (in % by weight of the stomach contents) *; Values with different letters in the line or column differ significantly ($p < 0.05$).

Months	% of Full Stomachs from the Total Number of Examined		Frequency of Occurrence of Objects (%) by Weight. (Numerator—Rivers, Denominator—Sea)									Lengths of Pike-Perch with Full Stomachs (cm)	
	Rivers	**Marine**	**Roach**	**Asp**	**Perch**	**Nase**	**Ruffe**	**Pike-Perch**	**Freshwater Bream**	**Pike**	**Carp**	**Rivers**	**Marine**
March	71.4 + 3.12	-										12.5–16.5	–
April	77.3 + 3.17 A a	69.2 + 3.34 A a	9.4 + 3.6 Bb	13.5 + 3.5 Bb	4.7 + 2.8 Cc	4.7 + 2.16	6.9 + 3.1 C	1.5 + 1.05 D	1.5 + 0.2 D	1.4 + 0.1 D	1.5 + 0.1 D	13.5–61.5	15.5–21.7
May	84.3 + 4.21 A	63.3 + 3.16 B	15.4 + 3.65 C a	15.3 + 3.5 D b	1.79 + 1.3 D	4.7 + 2.2 E	6 + 2.8 E	2.25 + 0.8 F	3.9 + 0.8	2.5 + 0.3 F	1.3 + 0.2 F	21.5–53.5	21.5–31.5
June	62.1 + 2.62 A	72.7 + 3.36 A	14 + 3.6 B a	8.93 + 3.8 C b	5.4 + 3.2 D	3.9 + 2.2 D	4.9 + 2.8 D	2.4 + 0.5 E	5.6 + 1.2 D	2.8 + 0.7 E	1.7 + 0.01	41–53	38–49.8
July	56.2 + 2.82 B	83.3 + 4.16 A	11.6 + 3.5C b	6 + 3.2 C b	1.87 + 0.15 D	2.4 + 1.6 D	4.9 + 1.5 C	1.8 + 0.7 D	4 + 0.6 C	3.3 + 0.4 D	1.5 + 0.2 E	23–53	23–47.5
August	45 + 2.8 B	88.9 + 4.42 A	6.0 + 1.7 D	4.16 + 3.6 D b	2.15 + 1.03 D	7.4 + 3.2 C	3 + 1 D	2.7 + 0.7 D	3.3 + 1.2 D	1.35 + 0.2 D	2 + 0.35 D	29–42	31.5–53
September	57 + 2.83 B	73 + 3.81 A	11.4 + 4.6 C	5.85 + 2.6 B	3.7 + 0.8 D	4.9 + 1.9 D	6 + 1.4 D	1.5 + 0.6 E	5 + 0.7 D	3.8 + 0.3 D	3.6 + 0.7 D	43.5–53	28.5–51.8
October	65.2 + 3.26 A	63.6 + 3.18 A	9.6 + 3.5 B	10.5 + 3.6 B	5.1 + 2.4 B	5 + 2.2 B	6.9 + 1.7 B	1.3 + 0.2 c	4.7 + 0.7 B	3 + 0.3 C	0.9 + 0.01	28.5–51.5	29.5–58.5
November	59.1	63.6	6.8/9.8	10.6/9.5	3.8/6.5	5.4/4.8	5.5/4.1	1.2/2.5	3.8/3.1	3.5/1.7	1.3/0.0	43.5–49.6	42.5–54.6
	66.8 + 6.3 A	72.7 + 6.5										12.8–61	15.5–58.5

* The total number of full stomachs in rivers is 133 out of 199 and 101 out of 149 in the marine ecosystem.

As can be seen from Table 3, the feeding activity and food consumption of pike-perch in rivers in spring was above 70%, 55% in summer, and about 60% in autumn. In the sea, the pike-perch differed in activity in summer, although in spring and autumn it was no less active and voracious than in rivers (Table 3). Despite such differences, the frequency of occurrence of objects by weight (%) the result of a one-sided analysis of similarities showed that there are not significant differences in habitats at $p < 0.05$ (the value of the coefficient f is 2.42579. The value of p is 0.061687).

It should be noted that in the studied stomachs (3) of the Terek river pike-perch on 24 July, six specimens of 5–7 cm, standard-length juveniles of Caspian salmon bull trout (*Salmo trutta ciscaucasicus*) [59] were found. This was not repeated anywhere and never during the entire period of the study, which confirms that this event was accidental. What supports this conclusion is that the Caspian salmon is a sharply declining species of fish in the area, and it has been almost not mentioned in commercially valuable fishing reports in recent years nor included in the Red Book of the Russian Federation [60,61].

According to our data, the nutrition spectrum of mature pike-perch with a size of 41–63 cm revealed the dominance of ruffe (42.4%) and perch (30.4%) in weight and, in number, roach (35.7%), perch and ruffe (21.4%, respectively). An identical pattern in the food spectrum of pike-perch was observed in 1968–1969 with the dominance of ruffe and roach and, to a lesser extent, bream, both in weight and in number [79]. Hence, the greatest similarity in the diet of this fish was observed by the mass of the ruffe (42.4%), and by the number of roach (35.7%)

The frequency of the occurrence of nutrition components in the stomach contents of pike-perch was different for different fish species and for age classes and groups of the same species (Table 2).

In summer, the percentage of pike-perch containing prey was about 80%, and lower in other seasons (Table 3). The proportion of pike-perch containing prey was 73.56% in medium-sized pike-perch (40–60 cm) and 13.28% in small-sized pike-perch (up to 25). The maximum stomach-filling index of river animals was observed in April and July and in marine animals in June and August, while the minimum was observed in September and November and in May and November.

As part of the fish food of pike-perch in our sample, there were 13 species of fish: roach, perch, gobies, ruffe, pike-perch, silver bream, sabrefish, pike, nase, bleak, bream, asp, and carp. The roach, ruffe, and sabrefish dominate (Tables 1 and 2). The low occurrence of other forage objects is associated either with their low numbers (bleak, vendace, common roach (*Rutilus rutilus*), and ide) or low availability for pike-perch (bream, blue bream, perch, and pike).

Age-related stability in the diet of pike-perch of the studied region, associated with the stability of the spectrum of consumed species and the regularity of the nutritional significance of individual components in the diet of pike-perch (Table 2), was revealed:

The transition of fingerlings to predatory feeding is carried out through the consumption of roach—the main feeding object of pike-perch up to 9 years of age. With age, the share of roach in the diet of pike-perch decreases slightly and it is replaced by gobies and sabrefish (Table 2). The increase in the proportion of large prey with age reflects the predatory fish increasing in size [64,65]. Therefore, the biomeliorative role of pike-perch depends on the size and age structure of the population and its effectiveness decreases with the observed rejuvenation of the herd.

The diet of the western Caspian pike-perch consisted of food that included predatory fish species, insects, and other organisms (Tables 1 and 2). Predatory fish was found in the stomachs of 86 pike-perch (O = 59.88%, N = 97.29%), represented by perch, ruffe, and pike. The frequency of occurrence of perch was the highest (9.5–2.4%), followed by ruffe (7.5–13.4%), pike (5.8–2.1%), and pike-perch itself (1.5–1.3%).

The size limits of the main fish feeding objects of the pike-perch of the northwestern Caspian region have been relatively widely varied (Table 3). As can be seen from the table, the widest size range of the prey in a young asp is 1.7–23.2 cm. On the rivers zones and at sea, the pike-perch chose a roach 3–17.3 cm long; the narrowest size range turned out to be for ruffe and perch, not exceeding 10 cm, and of course for goby, which is a small fish species. The remaining fish objects ranged from 2.5 to 18.5 cm (Table 4).

Table 4. Mean ± SE and range of the main feeding objects of the pike-perch of the western Caspian region. (Numerator Mean ± SE, denominator—range).

Main Feeding Prey Species	The Ranges of the Length of Prey, cm	
	Rivers	Sea
Caspian roach	10.7 ± 1.34/3–16.5	11.3 ± 1.24/6.5–17.3
Asp	14.8 ± 1.2/1.7–21.5	18.4± 0.36/8.5–23.2
Perch	3.92 ± 0.21/1.8–7.5	8.5 ± 0.96/5–12
Nase	6.55 ± 0.42/3.5–11.7	9.8 ± 0.81/6–18.5
Ruffe	4.3 ± 0.43/2.2–6.1	7.8 ± 1.16/5–9
Goby	6.2 ± 1.1/7–10	7.5 ± 0.78/6–14.5
Pike-perch	4.1 ± 0.62/1–4.5	9.6 ± 1.06/8–21
Bream	7.2 ± 0.25/3.5–12.5	9.2 ± 0.94/5–12

The pike-perch's own juveniles, which accounted for only 1.3–1.5% of its prey, ranged in size from 1 to 16 cm. It is important to note that cannibalism in the case of pike-perch, according to our results, began at a length of 10 cm.

In the marine sample, among the prey, asp, kutum, roach, and pike-perch were distinguished in length, averaging 14.5–15.8 cm (Figure 2); in the rivers, asp and roach excelled, and the rest of the prey were smaller and varied between 3.9 and 9.8 cm, which corresponds to their natural parameters in the area [63].

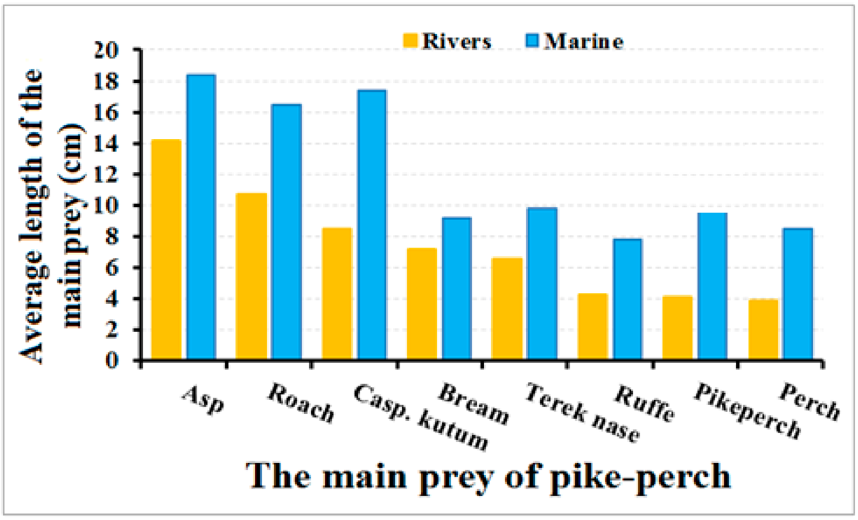

Figure 2. Average length of the main prey of pike-perch, (cm).

The average size of a pike-perch's prey in rivers is 24.2% (from 9.3 to 38.5%) of its body length. At sea, the size of the prey is 25.7% (from 7.5 to 48.8%). As can be seen from Figure 3, the size of the prey increases slightly with the size of the predator (R^2 = 0.50 in the river and 0.68 in the sea). Still, the large-sized pike-perch continues to feed on young fish with a body length of 3–16 cm (Table 3 and Figure 3).

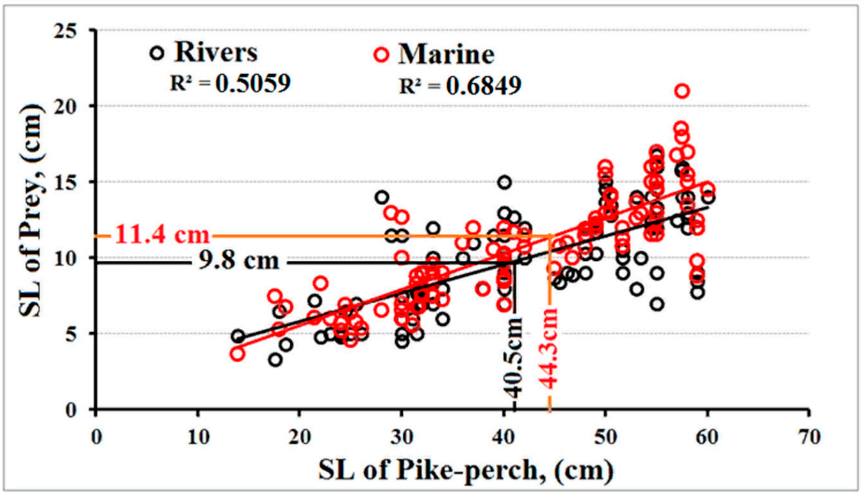

Figure 3. The ratio between the length of the pike-perch and the length of its prey.

An analysis of similarities showed that significant differences between the lengths of sea prey and river prey vs. predator length are not significant at $p < 0.05$ (the value of the coefficient f-ratio is 0.00059. The p-value is 0.980721).

4. Discussion

The biology and ecology of the pike-perch diet in the studied region are almost the same as in other regions. The first food of juveniles is zooplankton and mysids (Tables 1 and 2). In our study, the pike-perch becomes a fish eater a little later in the first year of life, if not in the first summer, but fish constitute a significant proportion of the diet already at its length of about 9–12 cm. From this size, the mysids begin to decrease noticeably. From the second year of life, fish prevail in its diet. The species composition of prey varies depending on the area; however, the most important are roach, asp, and perch.

The pike-perch of the western Caspian demonstrates significant conapolism, in contrast to what is observed in the Volga and Akhtuba, where a significant conapolism was not observed [90]. The feeding migration of pike-perch from the river to the open sea is due to the fact that it follows the growing young and adult fish, with these being its exclusive diet and one of the main requirements for its rapid growth.

In the sea, the food of the pike-perch consists almost exclusively of fish (Tables 1 and 2): roach, ruffe, and nase. In addition to fish, its food includes crustaceans, mainly mysids and shrimps, some of which were well digested and included in the category of digested fish remains +.

The share of commercially important fish species in the food of pike-perch was more than 47%, of which the main fish species were roach, asp, perch, bream, and carp (Tables 1 and 2). In the sea, the share of commercially valuable fish was over 67%. Moreover, medium-sized fish with a length of 20–30 cm prevailed in the food spectrum. Unlike the river, in the diet of pike-perch in the sea, there are ruffe and nase. The large number of small fish in the diet of pike-perch indicates that it feeds mainly on juvenile fish, and possibly juveniles of freshwater species. The number of these young fish in the mouth of the Terek and Sulak rivers is high, as are the main commercial freshwater fish species, such as roach and asp [63].

In general, the range of pike-perch diet in the western Caspian region covers more than 20 objects, the basis of which are juveniles and adults of commercially important fish. Consequently, it would be unreasonable to assume that the pike-perch in natural water bodies will feed only on small “weed” fish, and in this case it will become a trophic competitor to some predators of the water bodies feeding on weed fish [43,66,67].

Apparently, one of the reasons for such a limited size range of pike-perch prey is that it has a limited gape, usually consuming prey no longer than 50% of its own length in central Europe [69–72], which was similar to our data.

Evidently, the species managed to adapt to new conditions and create for itself. Strains that succeeded spread further, even migrating from the rivers to the brackish waters of the shores and bays surrounding northern and southern Europe—the Baltic Sea, the Mediterranean, and even across the Mediterranean Sea to Morocco and Tunisia in the north of Africa [91,92]. This predator found the conditions of its diet and reproduction, which led to it even being considered as endemic in some water bodies of Norway, Finland, and Poland [93,94].

With such a weak rate of feeding and a narrow size of prey, it is impossible to think about the excessive influence of pike-perch on representatives of the ichthyofauna of the Caspian Sea and its tributaries, as is observed in the case of Kuibyshev reservoir on the Volga River [72] where the pike-perch acts as a biomeliorator and controls the number of fish species in the reservoir, including its own juveniles. This is similar to that noted in Europe, where its effects led to the reduction and extinction of several important species, like pike (*Esox lucius* L.) in England and the Netherlands [73,74]. The latter has led to the fact that pike-perch is considered an invasive species in some countries. Thus, in England, it was recognized as responsible for the reduction of populations of carp and perch (*Perca fluviatilis* L.) [73]. Its introduction into Lake Egridir in Turkey led to the extinction of three species (genus *Phoxinellus*), two of which were endemic [75].

It is known that along the western coast of the Caspian Sea and in the rivers of the region there are migration routes of valuable fishes like sturgeon and herring, and there are also many species of fish that feed and spend the winter there, such as kutum, vimba bream, Caspian shemaya, and carp. There are also marine fish such as atherina and gobies [62,63]. With such a relatively small fish species composition of pike-perch prey, here we can talk about a considerable selectivity to the fish prey of pike-perch. Also, about 70 species and subspecies of fish live or migrate near the western coast of the Caspian Sea [57,63].

Based on the pike-perch's identified relatively rigid ontogenetical nutrition scheme and its sensitivity to environmental changes, especially those that affect its specific food organisms, this fish species can be considered from this perspective as having a relatively low ontogenetical diet diversity and flexibility [56,57], a fact which makes it sensitive to environmental changes, especially induced by human activities. This species is considered as being endangered in this area.

This novel biological and ecological study approach brings a new integrated perspective about the studied fish species' adaptative resilience in a special hotspot of biodiversity which faces a significant human impact.

Specific improvements are needed in future monitoring programs in order to improve the results of field research to study the diet of pike-perch as a predatory fish, a voracious and quickly assimilating fish. It is necessary to plan sampling methods for research directly in the places of the presence of populations in the feeding area using active and fast fishing methods such as direct netting, in addition to spinning, trolling, and on-board fishing rods in rivers, to separate river inhabitants and migrants in the sea which will determine the importance of both environments in ensuring productive feeding.

Finally, the authors consider that the conclusions of the discussion are in the majority consistent and address the main scientific questions of this study, following monitoring data which needs to improve over a long-term period.

5. Conclusions

The pike-perch is characterized, in the studied hotspot area of biodiversity with significant human impact presence, by a relatively rigid ontogenetical nutrition scheme, with a relatively low ontogenetical diet diversity and flexibility. In this framework, it is very sensitive to environmental variations, specifically those that impact its particular food organisms. This species is considered as being endangered in the studied area.

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