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Research Article

Determinants of fish distribution pattern and habitat preference in protected Karaj River, Iran

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Abstract

Lack of information about ichthyofauna makes it difficult to predict human effects on the communities. In this study, the effects of the environmental and human factors were examined on altitudinal patterns of fish habitat selection, faunal changes, species richness and fish abundance from upstream to downstream in the southern part of the central Alborz Protected Area during 2016 and 2017. 366 fish individuals of five species in three families were identified and brown trout was the dominant species. The river was divided into three zones based on habitat structure, species composition and influence of physical and chemical variables. The results indicate that, in some situations, including small changes in habitat structure indices, physical and chemical variables along the altitudinal gradient are more effective in habitat preference, describing the composition, and abundance. Chemical variables can help to have a better understanding of the conventional patterns, shaped by the habitat structure and physical variables. Habitat suitability index model for brown trout in three zones is completely different over the two years and this species could overcome these conditions. However, upstream areas were more appropriate. Dam, with decreases of outlet water temperature, also creates homogeneous and simple habitats leading to changes in expected fish distribution patterns with decreasing altitude. These conditions may have increased habitat suitability index for the brown trout in downstream, while despite favorable ecological conditions in the middle zone, habitat suitability index and alternative habitats available in this zone are likely to decline due to density and interspecific competition. The natural pattern of fish distribution and habitat selection varies along the altitudinal gradient due to various factors and human disturbances. Optimal management of protected areas can control the effects of some of these factors at least temporarily.

Keywords: Karaj River, Selectivity index, Fish abundance, Biotic, Fish composition, Altitude gradient

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Introduction

Sustainable utilization and biodiversity conservation in riverine ecosystems, especially those exposed to anthropogenic activities, must address the requirements of occupying species (Porter *et al.*, 2000). The distribution of species across spatial and temporal scales is created by biotic and abiotic factors, especially among freshwater fish (Jackson *et al.*, 2001).

Commonly, the most critical environmental factors affecting the determination of fish distribution are river size, elevation, habitat complexity, current velocity, depth, conductivity and temperature (Tejerina-Garro *et al.*, 2005). Decreasing species diversity and replacement have been observed as a function of altitude, although the determinant processes of this pattern are less well-known (Lomolino, 2001). Fish diversity is correlated with altitude, distance from the headwaters (Bistoni and Hued, 2002), and size of the flow during longitudinal changes, water temperature, and slope of the stream (Pouilly *et al.*, 2006).

As the altitude increases, mountainous area changes from warmer, darker and more moderate waters to cold oxygenated and turbulent waters, respectively; these alteration changes the structure and composition of fish communities, based on the morphology and habitat used (Rahel and Hubert 1991; Jaramillo-Villa *et al*., 2010).

Many studies of longitudinal change in fish fauna focus exclusively on the richness and composition pattern of fish species due to the presence or absence of that species. A review of species relative abundance distribution (Tokeshi, 1993; Hubbell, 2001) and survey of its preferred habitat can provide a better insight into features. Furthermore, because of the importance of habitat selection as one of the essential processes affecting fish distribution in aquatic ecosystems (Craig and Crowder, 2002), recognizing its determinants can play a key role in the proper conservation of species.

The protected Karaj River, situated within the Namak Lake basin, originates from the highlands of the Alborz Province and is exposed to anthropogenic activities including farm wastes, dam construction, and ecotourism. The average height of Karaj River is about 1600 m from the above sea level (a.s.l.). 61% of this basin is located at the heights higher than 2500 m. The minimum height of the Karaj river basin was about 1320 m and the maximum height being equal to 4000 m in the north. The Karaj River with a length of 75 km, width of 8 to 15 m and depth of 1-2 m, is considered as one of the most important rivers flowing in the South Alborz Mountains. The average flow of the river is about 17 m^3/s. The water flow is higher in the winter and early spring and lower in the summer and autumn. The river finally empties in the Salt Lake of Ghom in the Central Iran. Karaj River and Karaj dam have always been considered as one of the main sources of drinking and farming water in the Tehran province

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(Talari and Gholizadeh, 2016; Movagharnejad *et al.*, 2017).

This is the first coherent study on fish in the Karaj River, which was conducted to determine the factors affecting the formation of species diversity and distribution. In addition, this research has studied effects of combination of biotic and abiotic factors on the abundance, richness and composition of fish. This study was performed to determine the fish species composition and survey of habitat selection changes along altitudinal gradients from upstream-to-downstream. Also, the evaluation of the effect of abiotic (habitat structure, physical, and chemical variables) and biotic variables as well as anthropogenic activities (e.g., hydroelectric dams, agriculture, and pollution) on the abundance, composition and habitat selection of species has been studied. Lastly, determination of how species composition may change due to anthropogenic activities (e.g., hydroelectric dams, agriculture, and pollution). Such information is required to generate useful conservation strategies for aquatic ecosystems.

Materials and methods

Study area

The survey was carried out in the south-central Alborz Protected Area in the Alborz mountains between latitudes 35° 2´-36° 11´ N, and longitudes 51° 2´-51° 35´ E, located in Northern Iran. Karaj River is approximately 75 km in length. At 42 km, it is confluent with the Shahrestanak and Sedic rivers to join and reach the Amirkabir dam and finally empty into Salt Lake.

Fish samples

Sampling sites were selected to allow for non-overlapping, observance of distance from the main river, variation of river morphology, altitude, river margin quality (Oberdorff *et al.*, 2001). Using the method of Whitton (1975) and considering variables such as water depth, slope, and type of substrate, the river was divided into 3 districts, i.e., upstream (more than 2000 meters above sea level), middle zone (altitude between 1700 and 2000 meters), and downstream (less than 1700 m). In two years (2016 and 2017), 16 sampling sites, 60 m in length, were selected from 1522 to 2428 m a.s.l. for the upstream-downstream gradient. Before sampling, each site was outfitted upstream and downstream with nets. Each sampling site was electrofished at the end of the summer during two consecutive years, 2016 and 2017. Fish specimens were collected from each site over 30 min, anesthetized in clove powder solution, identified according to Coad (2014), counted, photographed, and finally placed in slow-moving water along the river bank to recover and be returned to the river.

The elevation (m) and geographic coordinates were recorded for each site, and the river and sampling sites were mapped using ArcGIS 9.3 (Fig. 1).

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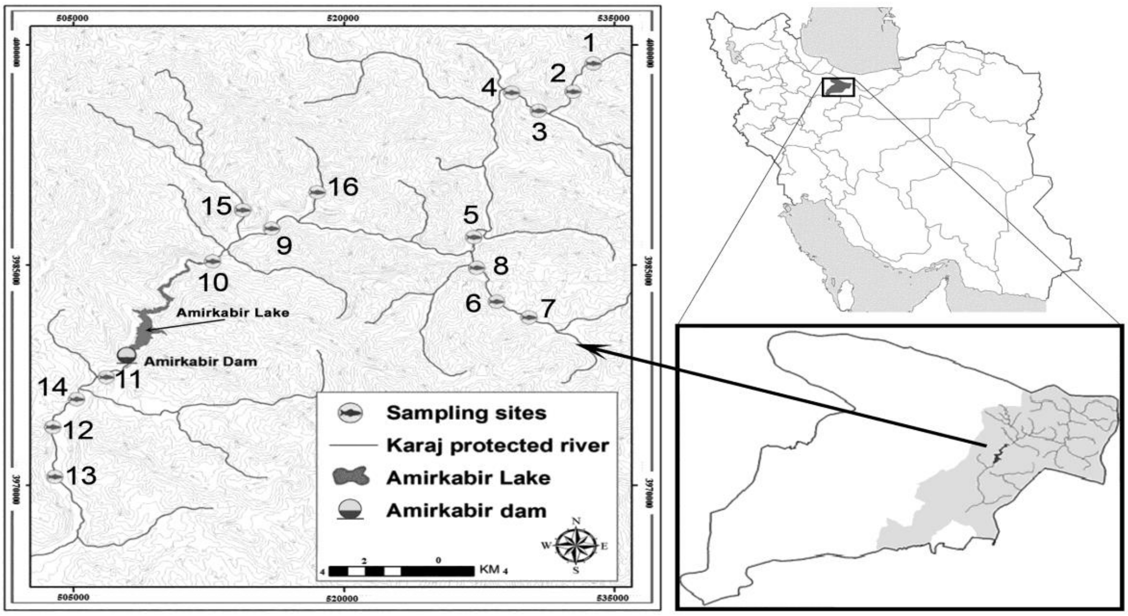

Figure 1: Location of Alborz Province, Karaj River, and sampling site.

Habitat data

Different characteristics have been introduced as affecting the distribution of species in rivers, including habitat structure (Angermeier and Karr, 1983), physical, and chemical variables (Araújo *et al.*, 2009). Physical variables (width, current velocity, Froude number, depth and elevation), chemical variables (dissolved oxygen (DO), water temperature, electrical conductivity (EC), pH, turbidity, total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), phosphate (PO_4^{3-}), ammonium (NH_4^+), and nitrate (NO_3^-) concentrations) and habitat structure indices (substrate, substrate shelter, visual cover, combined cover, and pool indices) were recorded at each site. The substrate was classified according to the system of Platts *et al.* (1983). Substrate indices and Froude number were calculated according to Jowett and Richardson (2008) and Gordon *et al.* (2004), respectively. According to the method of Jowett and Richardson (2008), the substrate index is based on the percentage of eight substrate categories that was calculated as follows:

The substrate index = 0.08 bedrock + 0.07 boulder + 0.06 cobble + 0.05 gravel + 0.04 fine gravel + 0.03 sand + 0.02 mud/silt + 0.01 vegetation/woody debris

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The Froude number for each location was calculated by the following equation:

$$Fr = V / (g.\ D)^{0.5}$$

V is the water column velocity, g, the acceleration of gravity, and D, is the depth of water.

Substrate classification was obtained according to the classification description of Platts *et al*. (1983). Substrate shelter was defined as any available space between the substrate of the river as refuge for fish. Visual and combined cover classification was done according to Ayllón *et al*. (2013). In this classification, the coverage is divided into two visual cover, including elements that provide visual protection (such as aquatic vegetation, overhanging vegetation and the undercut riverbanks), and combined cover that, in addition to visual protection, provide shelter against high current velocity (such as wood debris, combination of vegetation and woody debris, and under-cascade)

The mean depth (cm) of each site was estimated by measuring the depth at 20 random points. The mean width of the river (m) was measured at three sections, i.e., upper, middle, and lower sections at each sampling site. Surface velocity (m/s) was recorded by a current meter and elevation with GPS (Global Positioning System; Garmin). Chemical variables data of the selected sites were provided by the Alborz Provins Water and Waste Water Company.

Data analyses

ANOVA with Bonferroni post-hoc test and PERMANOVA were used for the analysis of environmental factors variation for each factor and between zones. The PERMANOVA was performed to evaluate the overall environment variables changes. The similarity of the three areas, abundance percentage variation of each year and the average of two years data were performed by CLUSTER analysis with the SIMPROF test, MDS and Cramér's V. BIO-ENV (replicated randomly 1000 times) and LINKTREE tests (Clarke and Warwick, 2001) were used to recognize and explain the relationship between environmental variables with biotic data and to understand the most effective environmental variables interpreting the abundance variation and species composition patterns.

Selectivity index was estimated according to the Guay *et al.* (2000) model. Habitat Suitability Index (HSI) was calculated as follows:

$$HSI=\sqrt[n]{SIV_1 \times SIV_2 \times \ldots \times SIV_n}$$

SIV is selectivity index of environmental variable that was estimated by Habsel software 1.0 (Jowett, 2019).

Variables were evaluated statistically significant at $p<0.05$. Analyses of ANOVA, Cramér's V and PERMANOVA were conducted with SPSS and PAST, respectively. Habitat selection data were analysed using Habsel software 1.0 (Jowett, 2019). The

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rest of analyses were performed in PRIMER-E.

Results

Fluctuations of environmental variables

The fluctuations of environmental variables over two years are presented in Table 1. In overall environmental variables analysis, substantial variations of all three groups of environmental variables (habitat structure indices, physical, and chemical variables), were found between stream sections (Table 2).

Table 1: Range (Min-Max) and Mean±SD of the environmental variables of sampling sites

Environmental variables	Range (Min-Max)		Mean±SD	
	2016	2017	2016	2107
Width (m)	4.04-20.78	4.1-21.87	10.32±5.26	10.26±5.23
Current velocity (ms^{-1})	0.23-0.53	0.24-0.55	0.41±0.09	0.40±0.09
Froude Number	0.14-0.47	0.14-0.32	0.26±0.09	0.24±0.05
Depth (cm)	12.96-44.4	18.29-46.13	27.34±8.80	29. 14±8.52
Elevation (m)	1522-2428	1522-2428	1973.06±297.91	1973.06±297.91
DO (mg/L)	8.11-9.23	7.78-9.02	8.60±0.32	8.3±0.31
Water temperature (°C)	8.5-14.3	8.6-15.3	11.24±1.93	11.36±2.32
EC (µs/cm)	294-442	277-416	328.37±51.89	330.43±52.43
pH	8.01-8.65	8.33-9.1	8.27±0.14	8.53±0.18
Turbidity (NTU)	4-14	3-4	8.62±2.30	3.21±0.36
TDS (mg/L)	189-285	180-270	212.25±28.44	219.25±33.01
TSS (mg/L)	1-5	2-4.5	2.78±1.18	3.09±0.63
BOD5 (mg/L)	0.8-1.4	2.3-2.9	1.11±0.17	2.76±0.19
COD (mg/L)	12-17	13-19	14.12±1.5	16.18±1.83
PO_4^{3-}(ppm)	3.20-4.20	0.05-0.5	3.66±0.28	0.13 ±0.14
NH_4^+(mg/L)	0.02-0.6	0.02-0.55	0.11±0.18	0.10±0.15
NO_3^- (mg/L)	0.7-4.9	0.8-3.5	2.17±1.41	2.00±1.10
Substrate index	4.47-6.64	4.9-6.61	5.66±0.63	5.80±0.55
Substrate shelter	0.05-0.12	0.10-0.16	0.08±0.01	0.12±0.01
Visual cover	0.01-0.11	0.01-0.08	0.05±0.02	0.04±0.02
Combined cover	0-0.01	0-0.01	0.004±0.005	0.003±0.005
Pool	0-0.07	0-0.05	0.02±0.02	0.01±0.01

Table 2: Zone differences in Karaj River based on environmental variable groups based on PERMANOVA.

Environmental variable group	Zones		Upstream	Middle zone
Habitat structure indices	Middle zone	F	36.19	
		p	0.0024	
	Downstream	F	4.135	7.45
		p	0.0535	0.0139
Physical variable	Middle zone	F	9.529	
		p	0.012	
	Downstream	F	54.15	41.19
		p	0.0015	0.0291
Chemical variable	Middle zone	F	11.18	
		p	0.2493	
	Downstream	F	17.4	0.8066
		p	0.0022	0.2871

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In terms of physical factors, this difference was evident among the three regions. This difference was only related to elevation ($F_{(2,29)}$=60.299, p<0.0005) and depth ($F_{(2, 29)}$=4.824, p<0.016), which with excluding the two last variables the difference in physical factors will not be significant. Regarding the chemical factors, upstream has significant difference with two other areas, and this difference was more due to water temperature ($F_{(2, 29)}$=6.796, p<0.004), COD ($F_{(2, 29)}$=7.494, p<0.002), NH_4^+ ($F_{(2, 29)}$=10.876, p<0.0005) and NO_3^- ($F_{(2, 29)}$=41.498, p<0.0005) variables. The middle part of the river differed from the upstream and downstream, in terms of habitat structure indices. This difference was due to the variable substrate index ($F_{(2, 29)}$=19.878, p<0.0005). Interestingly, despite significant differences in the air temperature between the upstream and downstream of the river ($F_{(2,29)}$=4.515, p=0.032), there was no significant difference between water temperature of the two zones ($F_{(2, 29)}$=1.722, p=0.196).

Distribution pattern of species and abundance

The 366 captured fish belonged to five species, two species of Cyprinidae (*Alburnus atropatenae* and *Barbus lacerta*), two of Nemacheilidae (*Oxynoemacheilus bergianus* and *Paracobitis malapterura*) and one species of Salmonidae (*Salmo trutta*). *S. trutta* with 208 individuals was dominant (Table 3). The number of fish species in each site differed from zero to four species, and fish abundance changed from 0 to 48 fish in 2016 and from 0 to 40 fish in 2017. The highest species richness and fish abundance were found at sites 10, 12 in 2016 and 2017 respectively (Table 4). No specimens were captured in three locations (sites 9, 11, and 14) in both years.

Table 3: Range, mean, and standard deviation of standard length of fish species in Karaj River.

Species	2016			2017		
	n	Range (mm)	Mean (mm)±SD	n	Range (mm)	Mean (mm)±SD
S. trutta	97	58-274	153.48±52.59	111	51-223	99.43±16.01
A. atropatenae	60	120-157	135.15±7.15	46	95-146	131.55±10.01
O. bergianus	34	56-135	95.5±55.86	5	55-94	73.25±16.72
P. malapterura	1	140	140	3	43-78	58.37±10.02
B. lacerta	1	122	122	8	120-135	127.87±5.41

Table 4: Abundance percentage of fish species in Karaj River zones.

	2016					2017				
	U	M	D	Cramer's V	p<	U	M	D	Cramer's V	p<
S. trutta	49.5	0.5	2.0			58.5	1.2	3.7		
A. atropatenae		29.8					27.5			
O. bergianus		17.2		0.7	0.0005		2.4		0.689	0.0005
P. malapterura		0.5					1.8			
B. lacerta		0.5					4.9			

U=Upstream: > 2000m; M=Middle zone: 1700-2000m; D=Downstream: <1700m

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Although there is a significant difference in the abundance of fish in the three river sections in each year, the CLUSTER analysis group with SIMPEROF test shows two upstream-downstream and middle zone groups in both years (Fig. 2). This clustering is also confirmed by the MDS analysis (Fig. 3).

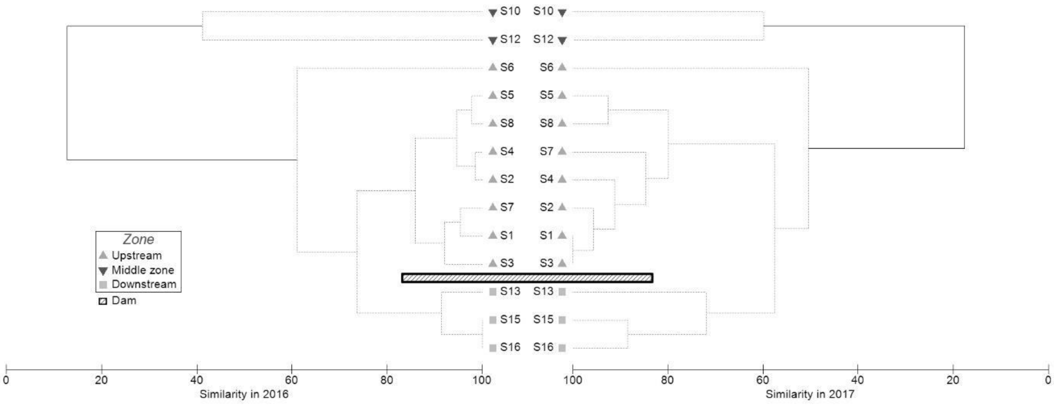

Figure 2: The similarity of sites and zones in Karaj River (The red dash and the black lines indicate that there is no significant and significant difference between sites/zones based on the SIMPROF test, respectively. In order to compare the variations of two years, the results of each year are presented separately).

Figure 3: MDS ordination plots of fish species communities in Karaj River.

Impact of environmental factors on species composition and abundance pattern

According to the results of BIO-ENV test, all three groups of environmental variables (habitat structure indices, physical, and chemical) were important in determining the pattern of species composition and abundance of fish in the Karaj protected River (ρ=0.856, p=0.01) (Table 5). Of course, this does not mean that all variables in the above groups played a primary role in the formation of the species composition and abundance pattern. The elevation (mean±SD= 1973.06±297.91) and depth (mean±SD= 27.34±8.66) of the physical variables, temperature (mean±SD= 11.3±2.125), EC (mean±SD= 329.4±52.16), turbidity (mean ± SD = 5.915 ± 1.33), BOD_5 (mean±SD = 1.935±0.18), COD (mean±SD= 15.15±1.665), PO_4^{3-} (mean±SD= 1.895±0.21), NH_4^+ (mean±SD= 0.105±0.165), NO_3^- (mean±SD= 2.085±1.255) of chemical variables and substrate index of habitat structure indices more affected in the obtained pattern than the others. Among the expressed variables, according to LINKTREE analysis, the chemical variables PO_4^{3-}, NH_4^+, COD, and NO_3^- and substrate index (π=6.18, p=0.018) had a more significant effect on the upstream and downstream separation from the middle zone (Table 6).

Table 5: Harmonic rank correlations (p_w) between fish species abundance and environmental similarity matrices.

Number of variables	Best variable combinations	Correlation (p_w)
8	Depth, Elevation, Temperature, Turbidity, BOD_5, COD, PO_4^{3-}, NH_4^+	0.856
9	Depth, Elevation, Temperature, Turbidity, BOD_5, COD, PO_4^{3-}, NH_4^+, Substrate index	0.854
9	Depth, Elevation Temperature, Turbidity, BOD_5, COD, PO_4^{3-}, NH_4^+, Substrate index	0.853
11	Elevation, Temperature, EC, Turbidity, TDS, BOD_5, COD, PO_4^{3-}, NH_4^+, NO_3^-, Substrate Index	0.852
8	Elevation, Temperature, Turbidity, BOD_5, COD, PO_4^{3-}, NH_4^+, Substrate index	0.851
9	Depth, Elevation, EC, Turbidity, BOD_5, COD, PO_4^{3-}, NH_4^+, Substrate index	0.850

Table 6: LINKTREE analysis of fish species abundance in Karaj River.

Node/station split	Variable	LHS (RHS) split	π	p	R	B (%)
A	PO_4^{3-} or NH_4^+ or COD or Substrate index or NO_3^-	>2.25(≤0.288) or >1.75(≤0.226) or ≤1.61(≥0.613) or ≤1.12(≥0.838) or >1.54(<1.27)	6.18	0.018	96	98.4

Habitat preference

Due to the presence of brown trout in all three areas, only the habitat preference of this species was evaluated. As can be seen in Figure 4, the pattern of habitat selection in the three zones is completely different over the two years. In most models, the changes of determinant ranges in the middle zone are more limited than two others in the two years. Comparison of the HSI between 2016 and 2017 (HSI=0.61 in both years) also revealed slight changes in the range of determinants in the middle zone (Table 7).

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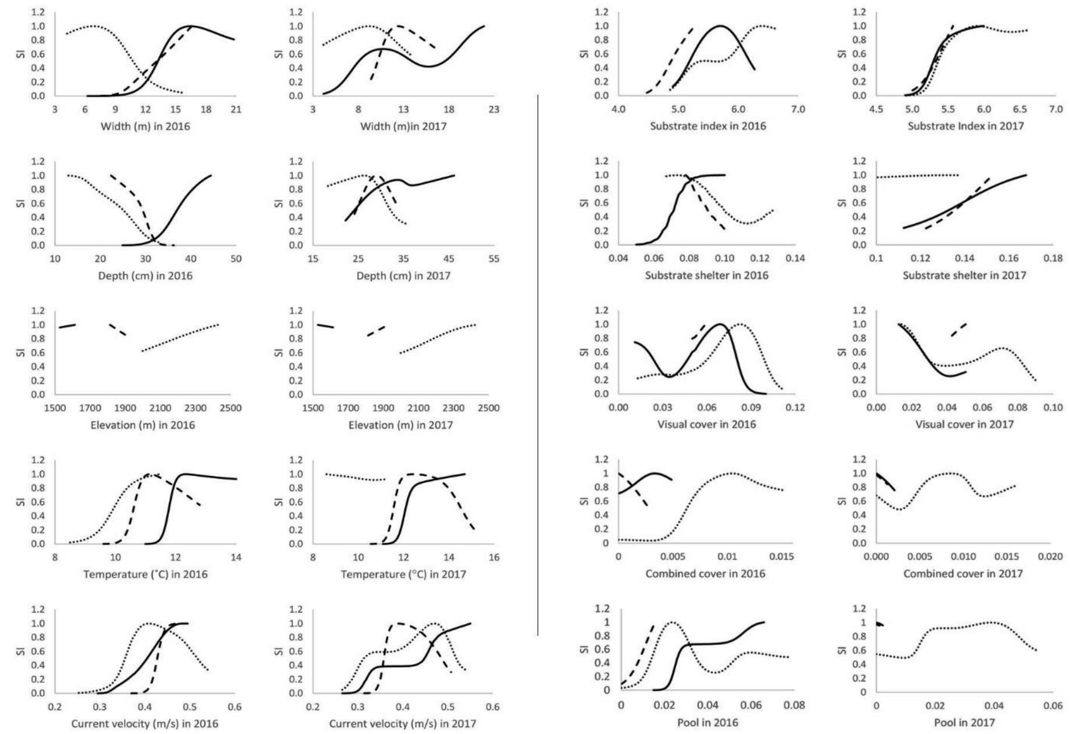

Figure 4: The changes of determinant ranges in three zones of Karaj River in 2016 and 2017, SI=selectivity index, dotted line=upstream, dashed line=midstream, solid line= downstream.

Table 7: Habitat suitability index for *Salmo trutta* in three zones of Karaj River in 2016 and 2017.

	Upstream		Midstream		Downstream	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
HSI	0.65	0.75	0.61	0.61	0.62	0.73

Discussion

Although sufficient information on species distribution by the effect of environmental factors along river gradients is available, a consequence of these factors on habitat selection pattern and the impact of protected areas and dam construction on a regular pattern require further studies. This study represents a new pattern of change in species richness and fish composition with elevation gradient, affected by human activities (like dam as a fragmentation of fish habitats and water pollution) on fish habitat selection.

Rivers are fluctuating environments and are periodically exposed to extreme and unpredictable changes in physical and chemical attributes. Such instability has been shown to impact the richness and structure of river fish (Carrel and Rivier, 1996). Decreasing elevation, increasing flow gradient (Brown, 2000; Quist *et al.*, 2004; Brunger-Lipsey *et al*., 2005), temperature, turbidity, and pollution will be associated with reduce velocity, turbulent, and oxygen (Jacobsen 2008). In the mountains, changes in the variables due to the altitudinal gradient occur very rapidly (Jacobsen, 2008). High fluctuating and rapid alteration of environmental variables along altitudinal gradients in

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Karaj River have been resulted in the accurate characterization of the study area into three distinct zones (upstream, midstream, and downstream).

Diverse characteristics of the above three zones cause different distributions of fish species along the river (Angermeier and Winston, 1999; Brunger-Lipsey *et al*., 2005; Quist *et al*., 2004). This distribution is achieved by replacing species, which indicate changes in biological conditions, or adding them downstream (Rahel and Hubert, 1991; Brunger-Lipsey *et al*., 2005). Physical variables and habitat structure (Ferreira and Casatti, 2006; Súarez and Petrere-Júnior, 2007; Valério *et al*., 2007) or their interaction of environmental factors (Jackson *et al*., 2001) play an essential role in fish distribution along the gradient.

In most studies of fish distribution, chemical variables are ignored; however, chemical variables (especially BOD_5, COD, PO_4^{3-}, and $NH4^+$) can alter our understanding of conventional patterns shaped by habitat structure and physical variables. For example, A study conducted by Negi and Mamgain (2013) showed that fish distribution has positive correlations with dissolved oxygen (DO), and pH.

Some studies showed that the determinants of habitat selection by fish were usually physical factors and habitat structure (Tabatabai *et al*., 2014; Verdipour *et al*., 2016; Zamani *et al*., 2014); while the analyses in this study demonstrated that chemical factors prevail over physical factors and habitat structure in explaining the presence of the mentioned species. This has been clarified in a few internal studies. For example, Moradi *et al*. (2015), by studying the factors affecting the presence of *Alburnus mossulensis* in Gamasiab River (Hamadan Province) revealed that the chemical variables including electrical conductivity, total phosphorus, nitrite, bicarbonate, and water temperature affect the distribution of this species. Typically, in rivers where the rate of encroachment and pollution is high and chemical factors are considered in the analysis, these variables can be a good explanation for the presence of species.

In the present study, except *S. trutta*, which is seen in all three zones, other species are only present in the middle zone. Many factors can play roles in creating this pattern. The middle zone is distinct from downstream and upstream due to habitat structure index. Considering the similarity of the characteristics of habitat structure at least in the end-regions of upstream and beginning-regions of downstream Rivers, and the correlation between the presence of species and chemical variables, the presence of all species in the middle zone, in addition to physical variables such as elevation and depth, is likely to be influenced more by chemical factors. Of course, it should be considered that the interaction of habitat structure and physical-chemical variables determine the presence of species, because the relationship of these variables is highly interdependent and the smallest change in environmental conditions or even

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anthropogenic inputs can alter physical and chemical attributes and ultimately directly change fish fauna along the river (Araújo and Tejerina-Garro, 2009).

Also, the entry of tributaries in the middle zone of the river changes volume, width, depth, current velocity, substrate composition, and ecological niche, which determines fish species diversity (Tejerina-Garro *et al.*, 2005) and this is well illustrated on site six. Increasing the volume and depth of water in this area, on the one hand, has led to occupation of various layers by fish that can feed on diverse layers; on the other hand, the enlarged ecological niche without significant changes in habitat conditions, justifies the presence of all species in the middle zone (Rahel and Hubert, 1991). In spite of the presence of trout in middle zone, that affect the simplification of fish species, species composition, as well as community structure and have a negative impact on the length and biomass distribution of other fish populations (Han *et al.*, 2016), it seems that the greater availability of ecological niche in the middle zone, lead to the fish fauna in the river is evident in this zone. Despite the favourable ecological conditions in the middle zone, the limited ecological selection range for brown trout in two years was probably due to the effect of species composition and density (Beier, 2013), as two important factors in intensifying interspecific competition on habitat selection. Interactions between species reduce the available habitat and thus the range of choices.

Due to the proximity of HSI in the three regions for Brown trout (at least in 2016) and the low abundance of this species in the midstream, it seems that competition has acted as an important factor. It is worth noting that the favourable ecological conditions (increased HSI in 2017, at least at the up and downstream due to more rainfall and increased habitat structure index) have led to an increase in the fecundity or survival rate of this species. The increase in the relative abundance of this species, despite the decrease in the total catch and the average length of Brown trout in 2017 compared to 2016, is a testament to this claim.

Brown trout lives in areas with high dissolved oxygen and cold water, which is similar to the conventional patterns of fish distribution along with increasing altitude resulting in presence of trout and absence of other species. The lack of other fish species in the upstream zone can be ascribed to decrease availability to areas of environmental complexity, higher intensity of climate situation, reduced in access to varied resources, and decline in primary production with increasing altitude (Huston, 1994). Also, the upstream zone is extremely variable while the downstream environmental position, if not anthropogenically influenced, is commonly more stable (Ostrand and Wilde, 2002). The presence of trout in the upstream zone can be due to its ability to overcome these conditions (Agostinho *et al.*, 2004). The high mean HSI during the two years in the

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upstream region indicates that conditions for this species are favourable.

Welcomme (1985) showed species richness and abundance increased from upstream to downstream. Current study reveals that species richness and abundance increased in the middle zone, but in the downstream (sites 14, 15 and 16) was negatively correlated with them. Suarez *et al*. (2011) found that the pattern is not linear and dependent with alteration in size, depth and width of the stream. The influence of recent variables on the distribution pattern of Karaj river fishes is evident. The increase in the depth and width of the river (due to increased rainfall in 2017) has led to the upgrading of HSI for trout in this year, which has ultimately led to an increase in Brown trout abundance. Increasing the HSI along the river can change the range and pattern of distribution. Nautiyal (2001) showed that altitudinal and longitudinal zonation of any particular river system may affect this pattern. A noteworthy point in this distribution pattern, is the presence of upstream fish in downstream (after the dam), which can be due to either low water temperature at the outlet of the dam, that has created an environment relatively similar to upstream, or the hypothesis that species occupying the mountainous habitats has highly skilled which enables them to prevent the occupation of these areas by other species, in particular species that have the same habitat preferences. The proximity of the HSI for the Brown trout in the up and downstream in both years, could indicate the effect of the dam on optimizing the determinants for this species in downstream. Also, the lower region of the dam possesses homogeneous and simple habitats (Agostinho *et al.*, 2004). This could lead to a rapid decrease in the abundance of the carp family (Maolin *et al.*, 2015) and other families because it is difficult for other species to accompany trout (Han *et al.*, 2016). In this part of the river, the lack of interspecies competition seems to have made these alternative habitats more accessible (Beier, 2013).

The effect of altitude reduction on trout abundance, as well as species composition in the middle and upstream zones, adheres to conventional patterns. The abundance of trout in the upstream zone is apparently due to high-dominance species to modify the population for access to limited resources (Matthews, 1998). Moreover, the dominance of trout is a function of changing habitat structure and physical variables, especially chemical ones (Araújo and Tejerina-Garro, 2009) that have provided a better habitat than the other two zones.

In the downstream zone, contrary to the expectation, an increase in trout and other species was not observed (at least during this study). Isolated zones lead to low species richness and dominance of a few species (Hoagstrom *et al.*, 2007). The impact of these changes on increasing HSI for brown trout is well visible in downstream.

It should be noted that, despite

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having a similar status to other branches with appropriate ecological conditions in some of the tributaries, no fish were captured. This could be due to flooding in recent years (site 14) and illegal fishing (sites 9 and 11). Abdoli (2016) findings on non-fishing in some branches in Karaj River confirm the same result.

Many protected areas are minimally effective in protecting fish species due to their small geographic size, being fragmented from the sub-branch, or due to their location in mountainous regions (Rodríguez-Olarte *et al.*, 2011). However, effective management of protected areas can be useful in maintaining the richness, composition, and abundance of freshwater fishes at least for the short-term. The results of this study in the protected area are expected to have a significant impact on the conservation of fish. Sites 9 and 11, despite being in the protected area, are less to be taken care of by rangers due to difficult access to the area. Local research has shown the presence of brown trout in those sites in recent years.

In summary, ecological factor change and human impact are two external factors that influence fish diversity (Buisson and Grenouillet, 2009; Hariri *et al.*, 2018) and habitat selection patterns along altitudinal gradients. Ecological changes directly alter species composition, diversity indices, and habitat selection. Also, human disturbance, including dam construction, can lead to extinction or at least by changing one of the determinants, modify routine distribution and habitat selection of fish patterns along altitudinal gradients. Conservation of natural patterns of distribution and habitat selection of fish requires conservation of the main and secondary branches of the rivers (Hubbell, 2001), especially in the middle zone of Karaj River (Hariri *et al.*, 2018), and several water quality factors must be monitored regularly to preserve the aquatic habitat desirable for fish life (Shrestha *et al*., 2009). Although river protection may have a limited effect on the conservation of fish species (Rodríguez-Olarte *et al.* 2011) and its alternative habitats available, it appears to be at least effective in the short term. Conservation activities in Iran have focused on mammals and birds but rarely carried out on fish. Studying the patterns of river zonation may help the river conservation (Abdoli *et al*., 2014).

In conclusion, results indicate species have different responses to habitat structure, physical and chemical variables; however, elevation gradients in particular can change the fish distribution pattern. Species inhabiting upstream river are more sensitive to basin unit, while species inhabiting middle zone and downstream regions are relative to local variables. Chemical variables are mostly underestimated in studies while they can help to have a better understanding of the conventional patterns shaped by the habitat structure and physical variables. Amirkabir Dam as a geographical barrier can affect the conventional

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patterns in downstream. The dam with impact on the determinants for Brown trout in downstream, has provided a favourable habitat for this species (increased HSI) compared to the midstream. Therefore, unlike the conventional pattern, more trout are seen in downstream than in the midstream. There was no reliable data on spatial and temporal distribution of the fish and their relationship with variables in the Karaj River, this study initiates providing information in this regard that might be useful for management and conservation.

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References

Abdoli, A., 2016. Fish Stock Assessment of Karaj Dam reservoir and Karaj river tributaries. Shahid Beheshti University and Department of Environmental, 113-114. (In Persian)

Abdoli, A., Naderi, M., Foroughifard, H. and Kiabi, B.H., 2014. Fish diversity and distribution in two protected rivers, Sardabrud and Chalus, southern Caspian Sea basin, Iran. *Iranian Society of Ichthyology*, 1(2), 91–95. DOI: 10.22034/iji.v1i2.17.

Agostinho, A.A., Gomes, J.C. and Latini, J.D., 2004. Fisheries management in Brazilian reservoirs: lessons from/for South America. *Interciencia*, 29, 334-338.

Angermeier, P.L. and Karr, J.R., 1983. Fish communities along environmental gradients in a system of tropical streams. *Environmental Biology of Fishes*, 9, 117-135. DOI: 10.1007/BF00690857.

Angermeier, P.L. and Winston, M.R., 1999. Characterizing fish community diversity across Virginia landscapes: a prerequisite for conservation. *Ecological Applications*, 9, 335-349. DOI: 10.1890/1051-0761(1999)009[0335:CFCDAV]2.0.CO;2.

Araújo, F.G., Pinto, B.C.T. and Teixeira, T.P., 2009. Longitudinal patterns of fish assemblages in a large tropical river in southeastern Brazil: evaluating environmental influences and some concepts in river ecology. *Hydrobiologia*, 618, 89-107. DOI: 10.1007/s10750-008-9551-5.

Araújo, N.B. and Tejerina-Garro, F.L., 2009. Influence of environmental variables and anthropogenic perturbations on stream fish assemblages, Upper Paraná River, Central Brasil. *Neotropical Ichthyology*, 7, 31-38.

DOI: 10.1590/S1679-62252009000100005.

Ayllón, D., Nicola, G.G., Para, I., Elvira, B. and Almodóvar, A., 2013. Intercohort density dependence drives brown trout habitat selection. *Acta Oecologica*, 46, 1-9. DOI: 10.1016/j.actao.2012.10.007.

Beier, U., 2013. Habitat selection and indirect interactions in fish communities. M. Sc. thesis, Swedish university of agricultural sciences, Uppsala, Sweden.

Bistoni, M.A. and Hued, A.C., 2002. Patterns of fish species richness in rivers of the central region of Argentina. *Brazilian Journal of Biology*, 62, 753-764. DOI: 10.1590/s1519-69842002000500004.

Brown, L.R., 2000. Fish communities and their associations with environmental variables, lower San Joaquin River Drainage, California. *Environmental Biology of Fishes*, 57, 251-269. DOI: 10.1023/A:1007660914155.

Brunger-Lipsey, T.S., Hubert, W.A. and Rahel, F.J., 2005. Relationships of elevation, channel slope, and stream width to occurrences of native fishes at the Great Plains-Rocky Mountains interface. *Journal of Freshwater Ecology*, 20, 695-705. DOI:10.1080/02705060.2005.9664793.

Buisson, L. and Grenouillet, G., 2009. Contrasted impacts of climate change on stream fish assemblages along an environmental gradient. *Diversity and Distributions*, 15, 613-626. DOI: 10.1111/j.1472-4642.2009.00565.x.

Carrel, G. and Rivier, B., 1996. Distribution of three euryoecious cyprinids in the main channel of the Lower River Rhône. *Archiv für Hydrobiologie*, 113, 363-374. DOI: 10.1127/lr/10/1996/363.

Clarke, K.R. and Warwick, R.M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth, UK: Primer-E Ltd.

Coad, B., 2014. Freshwater fishes of Iran. www.Briancoad.com

Craig, J.K. and Crowder, L.B., 2002. Concepts and Controversies in Tidal Marsh Ecology. Dordrecht: Springer.

Ferreira, C.P. and Casatti, L., 2006. Influência da estrutura do habitat sobre a ictiofauna de um riacho em uma micro-bacia de pastagem, São Paulo, Brasil. *Revista Brasileira de Zoologia*, 23, 642-651. DOI: 10.1590/S0101-81752006000300006.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J., 2004. Stream hydrology: an introduction for ecologists. 2nd ed. West Sussex, UK: Wiley.

Guay, J., Boisclair, D., Rioux, D., Leclerc, M., Lapointe, M. and Legendre, P., 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic*

Sciences, 57, 2065-2075. DOI: 10.1139/f00-162.

Han, J.H., Paek, W.K. and An, K.G., 2016. Exotic species, *Micropterus salmoides*, as a key bioindicator influencing the reservoir health and fish community structure. *Journal of Asia-Pacific Biodiversity*, 9, 403-411. DOI: 10.1016/j.japb.2016.10.002.

Hariri, M., Mirvaghefi, A., Farahmand, H., Taghavi, L. and Shahabinia, A., 2018. In situ assessment of Karaj River genotoxic impact with the alkaline comet assay and micronucleus test, on feral brown trout (*Salmo trutta fario*). *Environmental Toxicology and Pharmacology*, 58, 59-69. DOI: 10.1016/j.etap.2017.12.024.

Hoagstrom, C.W., Gosch, N.J.C., Dewitte, A.C. and Dueher, J.P., 2007. Biodiversity, biogeography, and longitudinal fish faunal structure among perennial, warm water streams of the Cheyenne River Drainage. *The Prairie Naturalist*, 67, 117-144. DOI: 10.1007/s10750-007-9110-5.

Hubbell, S.P., 2001. The unified neutral theory of biodiversity and biogeography. Princeton, NJ, USA: Princeton University Press.

Huston, M.A., 1994. Biological Diversity: The coexistence of species on changing landscapes. Cambridge, UK: Cambridge University Press.

Jackson, D.A., Peres-Nieto, P.R. and Olden, J.D., 2001. What controls who is where in freshwater fish communities - the roles of biotic, abiotic, and spatial factors. *Canadian Journal of Fisheries and Aquatic Sciences*, 58, 157-170. DOI: 10.1139/cjfas-58-1-157.

Jacobsen, D., 2008. Tropical high-altitude streams. In Dudgeon D. (Ed.), Tropical Stream Ecology. London, UK: Academic Press, pp. 219-256.

Jaramillo-Villa, U., Maldonado-Ocampo, J.A. and Escobar, F., 2010. Altitudinal variation in fish assemblage diversity in streams of the central Andes of Colombia. *Journal of Fish Biology*, 76, 2401-2417. DOI: 10.1111/j.1095-8649.2010.02629.x.

Jowett, I.G. and Richardson, J., 2008. Habitat use by New Zealand fish and habitat suitability models. Wellington, New Zealand: NIWA Science and Technology Series. 55, 148.

Jowett, I., 2019. Jowett Consulting. www.jowettconsulting.co.nz.

Lomolino, M.V., 2001. Elevation gradients of species-density: historical and perspective views. *Global Ecology and Biogeography*, 10, 3-13. DOI: 10.1046/j.1466-822x.2001.00229.x.

Maolin, H., Qi, H., Huiming, Z., Zhiqiang, W. and Xiaoping, W., 2015. The effect of dams on the larval abundance and composition of four carp species in key river systems in China. *Environmental Biology of Fishes*, 98, 1201-1205. DOI: 10.1007/s10641-014-0342-8.

Matthews, W.J., 1998. Patterns in freshwater fish ecology. New York, USA: Chapman and Hall.

Moradi, M., Zarkami, R., Bani, A. and Abasi, K., 2015. Study of Factors Affecting the Occurrence of Mossul bleak Heckel, 1843 *Alburnus mossulensis* in Gamasiab River (Hamadan Province) Using principal component analysis. 2nd National conference on climate change and engineering sustainable agriculture and natural resources. IRAN. Tehran. August 2015. (In Persian)

Movagharnejad, K., Tahavvori, A. and Moghaddam Ali, F., 2017. Artificial neural network modeling for predicting of some ion concentrations in the Karaj River. *Advances in Environmental Technology,* 3, 109-117. DOI: 10.22104/AET.2017.1802.1084.

Nautiyal, P., 2001. Ichthyofauna. In: Garhwal Himalaya, Nature, Culture and Society, Kandari, O.P and O.P. Gusain (Eds.). Transmedia Publication, Srinagar, pp: 191-197.

Negi, R.K. and Mamgain, S., 2013. Species Diversity, Abundance and Distribution of Fish Community and Conservation Status of Tons River of Uttarakhand State, India. *Journal of Fisheries and Aquatic Science*, 8(**5**), 617-626. DOI: 10.3923/jfas.2013.617.626.

Oberdorff, T., Pont, D., Hugueny, B. and Chessel, D., 2001. A probabilistic model characterizing fish assemblages of French rivers: a framework for environmental assessment. *Freshwater Biology*, 46, 399-415. DOI: 10.1046/j.1365-2427.2001.00669.x.

Ostrand, K.G. and Wilde, G.R., 2002. Seasonal and spatial variation in a prairie stream-fish assemblage. *Ecology of Freshwater Fish*, 11, 137-149. DOI: 10.1034/j.1600-0633.2002.00005.x.

Platts, W.S., Megahan, W.F. and Minshall, G.W., 1983. Methods for evaluating stream, riparian, and biotic conditions. General technical report 138. US Department of agriculture, forest service, intermountain forest and range experiment station, Ogden. www.treesearch.fs.fed.us/pubs/29138.

Porter, M.S., Rosenfeld, J. and Parkinson, E.A., 2000. Predictive models of fish species distribution in the Blackwater drainage, British Columbia. *North American Journal of Fisheries Management*, 20(**2**), 349-359. DOI: 10.1577/1548-8675(2000)020<0349:PMOFSD>2.3.CO;2.

Pouilly, M., Barrera, S. and Rosales, C., 2006. Changes of taxonomic and trophic structure of fish assemblages along an environmental gradient in the Upper Beni watershed (Bolivia). *Journal of Fish Biology*, 68, 137-156. DOI: 10.1111/j.0022-1112.2006.00883.x.

Quist, M.C., Hubert, W.A. and Rahel, F.J., 2004. Elevation and stream-size thresholds affect distributions of native and exotic warm water fishes in Wyoming. *Journal of Freshwater Ecology*, 19, 227-236. DOI: 10.1080/02705060.2004.9664536.

Rahel, F.J. and Hubert, W.A., 1991. Fish assemblage and habitat gradients in a Rocky Mountain-Great Plains stream: biotic zonation and addictive patterns of community change. *Transactions of the American Fisheries Society*, 120, 319-332. DOI: 10.1577/1548-8659(1991)120<0319:FAAHGI>2. 3.CO;2.

Rodríguez–Olarte, D., Taphorn, D.C. and Lobón Cerviá, J., 2011. Do protected areas conserve Neotropical freshwater fishes? A case study of a biogeographic province in Venezuela. *Animal Biodiversity and Conservation*, 34(**2**), 273-285.

Shrestha, J., Singh D.M. and Saund, T.B., 2009. Fish diversity of Tamor River and its major tributaries of eastern Himalayan region of Nepal. *Nepal Journal of Science and Technology*, 10, 219-223. DOI: 10.3126/njst.v10i0.2964.

Súarez, Y.R. and Petrere-Júnior, M., 2007. Environmental factors predicting fish communities structure of two Neotropical rivers in Brazil. *Neotropical Ichthyology*, 5, 61-68. DOI: 10.1590/S1679-62252007000100008.

Suarez, Y.R., Souza, M.M., Ferreira, F.S., Pereira, M.J., Silva, E.A., Ximenes, L.Q.L., Azevedo, L.G., Martins, O.C. and Junior, S.D.L., 2011. Patterns of species richness and composition of fish assemblages in streams of the Ivinhema river basin, upper Parana River. *Acta Limnologica Brasiliensis*, 23, 177-188. DOI: 10.1590/S2179-975X2011000200008.

Tabatabaie, S.N., Hashemzade, A., Eagderi, S. and Zamani Faradonbe, M., 2014. Determining factor in habitat selection of *Paracobitis iranica* (Nalbant & Bianco 1998) population in Kordan River, Namak Lake Basin, Iran. *Journal of Aquatic Ecology*, 3(**4**), 1-9. (In Persian)

Talari, A. and Gholizadeh, R., 2016. Hydrological Analysis and Ability Assessing of Flood Gating of Karaj Watershed According to the Form of the Watershed. *Open Journal of Geology* 6, 341-348.

Tejerina-Garro, F.L., Maldonado, M., Ibañez, C., Pont, D., Roset, N. and Oberdorff, T., 2005. Effects of natural and anthropogenic environmental changes on riverine fish assemblages: A framework for ecological assessment of rivers. *Brazilian Archives of Biology and Technology*, 48, 91-108. DOI: 10.1590/S1516-89132005000100013.

Tokeshi, M., 1993. Species abundance patterns and community structure. *Advances in Ecological Research*, 24, 111-186. DOI: 10.1016/S0065-2504(08)60042-2.

Valério, S.B., Súarez, Y.R., Felipe, T.R.A., Tondato, K.K. and Ximenes, L.Q.L., 2007. Organization patterns of headwater-stream fish communities in the Upper Paraguay-Paraná basins.

Hydrobiologia, 583, 241-250. DOI: 10.1007/s10750-006-0533-1.

Verdipour, M., Eigderi, S. and Shams Esfand Abad, B., 2016. Fish habitat use characteristics of *Barbus lacerta* (Heckel 1843) in Taleghan River (Sefid River basin). *Journal of Animal Environment*, 8, 183-190. (In Persian)

Welcomme, R.L., 1985. River fisheries. FAO Fish Technical Paper, 262, 318.

Whitton, B.A., 1975. River ecology. Oxford, UK: Blackwell Scientific Publications.

Zamani Faradonbe, M., Eagderi, S. and Poorbagher, H., 2014. Study of Habitat suitability index of Kura Barbel (*Barbus Cyri* Filippi, 1865) in Taleghan River (Sefidrud River basin: Alborz Province). *Journal of Applied Ichthyological Research*, 2(**4**), 41-54. (In Persian)