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Physical habitat simulation of *Rainbow trout* in mountainous streams of Iran

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Abstract

River physical habitat is defined as the variation of hydraulic parameters such as depth, velocity and bed cover in habitat condition of aquatic organisms. According to the previous studies physical habitat has considerable effect on habitat condition of different fish species. This study is carried out on a mountainous stream in Iran. In this research one dimensional hydraulic habitat model is used to simulate physical habitat of *Rainbow trout* as one of the first habitat simulation studies about the interaction between ecology and hydraulic in Iran. Based on the results as the flow increases the amount of habitat suitability decreases rapidly for fry life stage, but for adult physical habitat condition will be improved with increasing discharge. Streams with similar hydrological and geomorphic condition to the study stream can provide suitable habitat condition for different life stages of *Rainbow trout* in natural conditions and any changes in flow condition must occur based on the habitat time series curves. The upstream part of the stream (with slope of 0.03) has the poorest habitat condition and moving towards the downstream parts the habitat suitability condition will be improved. Habitat suitability will decrease for coldwater fish like *Rainbow trout* with increasing the earth temperature and the fish will be forced to move to the upstream parts in order to have suitable temperature condition and due to the unsuitable physical habitat condition of these parts ecological problems will increase in future. Thus, river restoration projects will be necessary.

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Introduction

In the simplest expression habitat for a living organism is the place where the organism does its biological activities (Odum, 1971), and uses its available physical and biological resources. Habitat characteristics in the streams effect on the distribution and frequency of the fish. The relationship between habitat and fish provides important information for its restoration and management (Fausch *et al.*, 1988). Effective factors on the frequency and diversity of riverine fish can be divided into two types of biological and non biological factors (Moyle and Cech, 1988). Effective biological factors include competition between species, predation, feeding, health and genetic factors. Effective non biological factors are like water temperature, water quality, the amount of light penetration, depth and flow velocity, the shear stress on the bed and flow turbulence and bed cover (Armstrong *et al.*, 2003).

Due to the excessive use of water and river resources in recent years and its effect on habitat condition in river ecosystems the researches related to aquatic habitats is developed. The role of the flow and river channel geomorphology in the condition of riverine fish communities was taken into little consideration before the 1980's (Newbury, 1984). Jowett (1997) recommended the physical habitat term as a general phrase for expressing the effects of physical habitat parameters on plants and animals, and according to this definition aquatic habitat can be defined as the function of physical and chemical water characteristics. There is enough evidence indicating the simultaneous effects of quality and quantity of available habitats on riverine biological communities, so the effect of physical habitat on the condition of riverine fish communities is completely apparent (Stanford and Ward, 1979). The importance of physical habitat in determining the river ecosystem condition is clear in its term definition, because without producing a suitable living environment other biological activities are also impossible. According to Stalnaker (1979) studies, reproduction potential in each stream system is dependant to four factors. These four factors are water quality, energy budget (include water temperature, organic matters, feeding…), physical channel structure and flow regime. Based on these factors combination of the last two factors is recognized as the physical habitat in the stream. In fact physical habitat is a useful element for measuring and evaluating the amount of river habitat health. Due to the different effective parameters riverine aquatic habitat is very intricate and comprehensive evaluation of these effects in a stream is a very difficult and complicate research activity, and the amount of their effect on various riverine communities must be investigated by dividing the effective parameters separately. As noted in previous parts physical habitat is one of the most important parameter in investigating the riverine habitats.

One of the most widely applied methods in the world especially in North America for evaluating the physical habitat condition is the Physical HABitat SIMulation model (PHABSIM) (Bovee, 1986). This model includes two components of hydraulic and habitat simulation. The hydraulic simulation component simulates the stream condition by two sub components, the first one simulates the water surface elevation and the second one simulates the velocity distribution within the cross sections (Waters, 1976; U.S. Bureau of Reclamation, 1968). Habitat component simulates the habitat suitability condition based on the habitat suitability curves (Waddle, 2001). This hydraulic habitat model is a major component of Instream Flow Incremental Methodology (IFIM) that introduced fish as a legitimate water user for the first time, so this model is applicable in simulating the riverine fish habitat (Bovee *et al.*, 1998). The effects of physical habitat on riverine fish life in Iran has not been taken into consideration until now and due to the construction of numerous dams on the rivers, water resources suffered serious problems and subsequently caused problems for aquatic physical habitats, too. The present research is one of the first studies about the interaction between ecology and hydraulic of water ecosystems.

One of the most important riverine fish is the *trout* fish which lives in different sub species in the rivers. Among the different species of *trout* two species of *Rainbow* and *Brown trout* are mostly found in Iran's streams, and due to the importance of the life of a species like *Rainbow trout* this species is considered in international researches too (Raleigh *et al*., 1984). *Rainbow trout* is a kind of *Salmonid* fish. Overall color is very variable but stream fish are darker and more colorful than lighter, silvery lake or sea. This species is found in rivers or streams where there are pools and riffles. Growth varies with habitat and Maturity is also variable with habitat. In Iran generally this fish mature in one-year old (Abdoli and Naderi, 2009). Spawning takes place from March to May but is usually in spring. It takes place in redds, which are gravel nests built by the female. The female covers the eggs with gravel by dislodging it from the upstream end of the redd. The eggs hatch in about 8 weeks and fry generally emerge in June to August from spring spawning (Coad, 2013). Due to the several international studies carried out on Rinbow trout, this species can be a representative of the environmental conditions of the streams.

One of the important parts in riverine habitat simulation is the existence of accurate habitat suitability criteria (HSC) curves for the target species. An example of these curves is shown in Fig 1. As can be seen in these curves one of the effective parameters like depth lies in the x- axis and y-axis shows the suitability amount of that parameter.

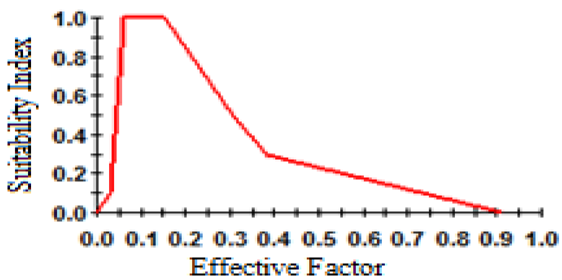


Fig. 1. An example of a habitat suitability curve.

In general, suitability curves have been classified into three categories (Bovee, 1986). Category **I** curves are expert opinion or literature curves. Category **II** curves are derived directly from observation of habitat use of the target life stage and species and they are known as habitat utilization curves. And category **III** curves known as habitat preference curves are derived from observation data on habitat use corrected for habitat availability. Due to the lack of the development of ecohydraulic researches (relationship between river hydraulic and ecology) in Iran, prior to this study no Iranian site specific or regional HSCs were available and the application of the hydraulic habitat model was limited to the use of literature HSCs. In the present research habitat simulation of *Rainbow trout* is carried out in Delichai-Simindasht stream. Considering that this stream is a mountainous stream and confined use of its water resources, so this stream is one of the suitable habitats for this species. This habitat simulation can be very useful for ecohydraulics researches related to this species in other destroyed or under destruction habitats. This study is demonstrated requirements of physical habitat simulation in river habitat management in arid and semi-arid regions.

Materials and methods

Study Stream

This study was carried out on Delichai stream in Iran. Delichai stream is one of the important tributaries of Hablerood, source of this stream is the drain of Tar and Havir lakes and joins to Hablerood in Simindasht plane. Hablerood continues its way to south direction and finally enters to Garmsar region. The stream has a watershed area of approximately 340 km². Mean altitude of region of this stream is 2182.23 m. The average slope of the stream is 2% and is a mountainous stream. The researches have been carried out on this stream showed that currently qualitative parameters of the stream are not in a critical condition. Due to the morphological and hydraulic conditions self purification of the river is possible. Because of the special topographic condition of the region, the stream is morphologically undisturbed and maintains its natural condition (Sedighkia *et al.*, 2014). Considering that the scope of this research was investigating the environmental condition of a stream under natural condition so this stream was an appropriate option. The hydraulic simulation of the stream was carried out by one dimensional hydraulic modeling component. Habitat suitability curves from Raleigh *et al.*, (1984) were used for three effective factors on physical habitat including depth, velocity and substrate for fry, juvenile and adult life stages of *Rainbow trout*.

Hydraulic and habitat simulation

The twenty-year review of statistical data from Simindasht gauging station located at the end part of the stream (Fig. 2) shows that the long-term mean annual flow is approximately 1.11 cms and the long-term maximum mean monthly flow (MMF) is 2.813 cms. And also the stream has experienced severe low flow periods in warm month of the year and long-term mean monthly flow in August is about 182 lit/sec.

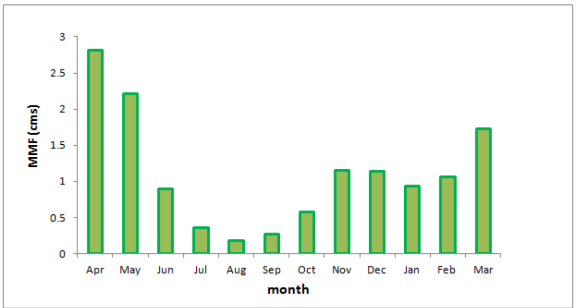


Fig. 2. Monthly flow data of the stream.

In a hydraulic habitat analysis, at first the needed hydraulic model is applied to determine characteristics of the stream in terms of depth, velocity and channel index (cover or substrate) as a function of discharge for the full range of discharges to be considered for the study. In the habitat modeling process, this information is integrated with habitat suitability criteria (HSC) to produce a measure of available physical habitat as a function of discharge. Cell values of each of the physical parameters are combined with species preference curve information through a selected functional relationship, termed the Combined Suitability Index (CSI, which has a range of 0-1), to develop the combined habitat index, termed Weighted Usable Area (WUA). WUA is expressed in units of microhabitat area per unitized distance along a stream (e.g., square feet per 1000 feet of stream or m^2 per 1000 m) and is the most commonly used output from these types of models. WUA is computed within the reach at a specific discharge from:

$$WUA = \sum_{i=1}^{n} A_i \times CSI_i$$

Where A_i is the surface area of cell i and CSI_i is the combined suitability of cell i (i.e., composite of depth, velocity and channel index individual suitabilities.)

In this research multiplicative method which is the typical CSI functional relationship is used and is represented in Eq. 2, but any alternative can be devised.

$$CSI_i = V_i \times D_i \times S_i \qquad (2)$$

Where V_i, D_i, S_i are suitability index for velocity, depth and channel index. WUA indexed by total surface area of the cell weighted by its relative suitability for a given species simulates the amount of physical habitat within that cell at different discharges.

The length of the stream that is simulated and evaluated in the present research is approximately 32 km. In this research the amount of suitability at different discharges and also suitability distribution along the stream were investigated. In order to investigate the habitat suitability distribution of the stream, having the distribution of CSI in each cross section along the stream the average of CSI for each of the three life stages of *Rainbow trout* was calculated and this amount was plotted against the distance of each cross section from upstream part of the study stream. Using the habitat- discharge curve of the stream (i.e., WUA vs. discharge) integrated with flow time series data of the stream (Fig. 2) the habitat time series curve was derived for three life stages of the target species, too.

Results and discussion

The three-dimensional depth suitability distribution graph in one part of the stream for fry life stage is presented in Fig. 3. As can be seen due to the changes in flow depth, different cells have different amount of depth suitability.

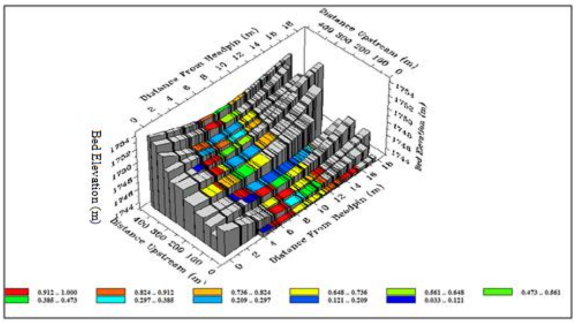


Fig. 3. Depth suitability distribution for fry life stage.

In order to evaluate the habitat condition of *Rainbow trout*, three-dimensional graphs of habitat suitability distribution were derived in all parts of the stream for fry, juvenile and adult life stages and then the WUA-discharge curve was plotted for the target species (Fig. 4). This habitat-discharge relationship exhibits different forms and absolute values amongst different life stages. The amount of habitat suitability decreases with increasing discharge for fry life stage, but in adult life stage physical habitat condition will be improved with increasing discharge, and there is not considerable variation in habitat condition for juvenile life stage. Dividing the WUA values at each discharge to the maximum value of WUA that is for adult life stage at flow of 2.813 cms, dimensionless WUA for all life stages were computed and represented in the right axis of Fig. 4.

The habitat time series of the stream for three life stages of the target species is shown in Fig. 5. This habitat time series shows that during Jun to October that is the period of decreasing flows for the stream the habitat suitability of the stream is developed in fry life stage while there will be very poor condition for adult life stage during this period.

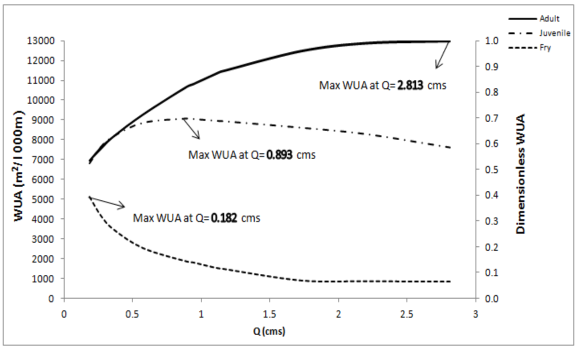


Fig. 4. Flow-habitat curve for three life stages of *Rainbow trout*.

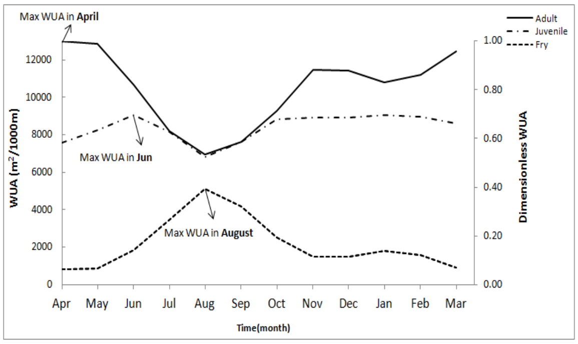
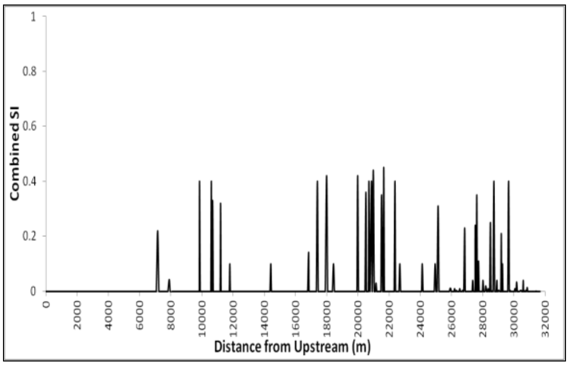


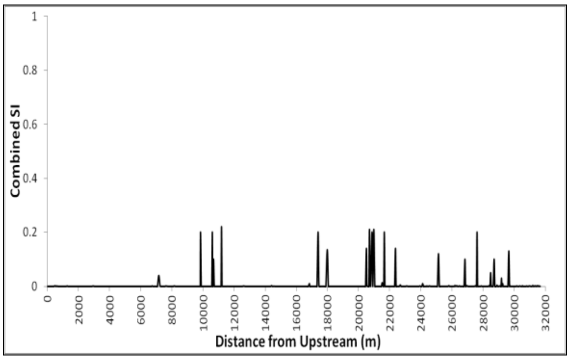
Fig. 5. Habitat time series for three life stages of *Rainbow trout*.

Habitat suitability condition of Rainbow trout in this mountainous stream can be analyzed with a general evaluation. Considering that the fry generally emerge from the gravel during the summer, therefore summer will be a sensitive habitat time period for fry life stage. As can be seen in Fig. 5 during this period Weighted Usable Area (WUA) is optimum for this life stage and represents the suitable habitat condition. Spawning takes place from March to May and according to the Fig. 5 during this period the most suitable habitat condition is provided for adult life stage. Generally, there is an average habitat condition for juvenile life stage during the year. According to the results, streams with similar hydrological and geomorphic condition to the study stream can provide suitable habitat condition for different life stages of *Rainbow trout* in natural conditions and any changes in flow must occur based on the habitat time series to avoid serious problems for habitat condition in sensitive life stages.

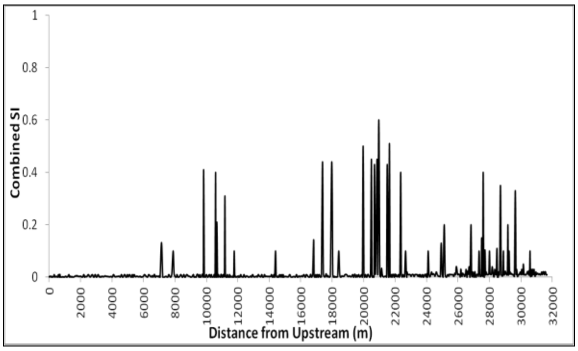
In the next step, habitat suitability distribution along the stream was investigated and this investigation is performed for the full range of discharges to be considered for the study. As an example, the habitat suitability distribution (CSI) at 0.893 cms discharge along the stream is shown in Fig. 6. Based on the geomorphologic condition of the stream, the total stream reach is divided into three parts of upstream with the average slope of 0.03 (distance from 0 to 11000 m), middle part with the average slope of 0.02 (from 11000 to 21000 m) and downstream part with the average slope of 0.01 (from 21000 to 32000 m).



a



b



c

Fig. 6. Habitat suitability distribution for three life stages (a- fry, b- juvenile, c- adult).

Habitat suitability distribution along the stream at different discharges showed that the upstream part of the stream (with slope of 0.03) has the poorest habitat condition and moving towards the downstream parts the habitat suitability condition will be improved. In other words, if the fish moves towards the upstream parts physical tensions on fish will be increased and consequently damages to *Rainbow trout* fish communities will increase, too. Available field data about the frequency and distribution of *Rainbow trout* at different stations of this stream also verify this fact (Fig. 7). As can be seen in Fig. 7 from station 1 to 8 (from upstream to downstream part) the number of target species is increasing.

Habitat suitability will be decreased for coldwater fish like *Rainbow trout* with increasing the earth temperature in recent years and the fish will be forced to move to the upstream parts in order to have suitable temperature condition, and due to the unsuitable physical habitat condition of these parts ecological problems will increase in future. Thus, river restoration projects will be necessary. Available field data about the stream water temperature at different stations also verify this fact and shows the increasing of temperature from upstream station (station No. 1) to downstream (station No. 8) (Fig. 8).

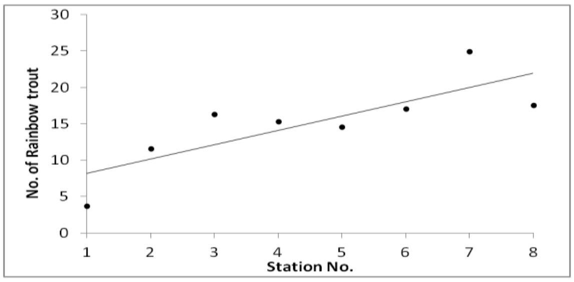


Fig. 7. *Rainbow trout* distribution along the stream.

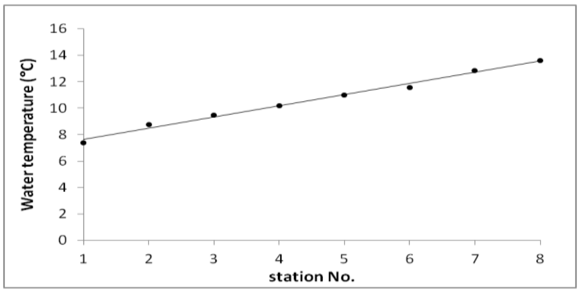


Fig. 8. Water temperature distribution along the stream.

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