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Saxena, Neha; Patiyal, Rabindar Singh; Dube, Kiran; Tiwari, Virendra K.
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Population dynamics and reproductive biology of *Barilius bendelisis* (Cyprinidae: Cypriniformes) from river Gaula, Central Indian Himalaya

Neha Saxena¹, Rabindar Singh Patiyal², Kiran Dube*¹ & Virendra K. Tiwari¹

1. Central Institute of Fisheries Education, Versova, Mumbai 400061; nehapnr@gmail.com, kirandr@cife.edu.in, vktiwari@cife.edu.in
2. Directorate of Coldwater Fisheries Research, Bhimtal 263136; rspatiyal1@gmail.com

* Correspondence

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Abstract: The Indian hill trout cyprinid, *Barilius bendelisis* is a member of family Cyprinidae that dwells in shallow, cold, and clear water. In this study, growth parameters and reproductive biology of Indian hill trout, *Barilius bendelisis* from river Gaula, Central Himalaya region, India, were studied. The length-frequency data were grouped sex wise and were analyzed to determine the growth and mortality parameters using the computer software programme, FAO-ICLARM Stock Assessment Tool (FISAT II). Altogether, 501 individuals were collected from river Gaula (November 2013-October 2014) and were preserved in formalin for further analysis. The results showed that the female outnumbered the male population. The minimum GSI of females was observed in the month of October (4.93 ± 0.26) and for males in the month of June and July (0.093 ± 0.12), whereas, the maximum value was in the month of April for both females (13.47 ± 0.52) and males (1.21 ± 0.12). Fluctuation in GSI values had a bimodal pattern showing two peaks during March-May and August-September in both the sexes, indicating the common spawning period of fish. The slope of regression showed the negative allometric growth for both males and females ($b = 2.65$ for male and $b = 2.5$ for female). A significant relationship between length and weight was observed in the present study ($p < 0.05$). The ELEFAN-I estimated L_{∞} and K of the von Bertalanffy growth factor for males (17.33 cm and 0.310 per year), females (17.33 cm and 0.3 per year) and pooled sexes (17.33 cm and 0.240 per year). The results indicated that *Barilius bendelisis* is a small sized fish having negative allometric growth that spawns twice a year. Thus, the present study on biological traits represents the baseline information for effective production, conservation and restoration planning. Rev. Biol. Trop. 64 (3): 1287-1295. Epub 2016 September 01.

Key words: *Barilius bendelisis*, sex ratio, gonadosomatic index, river Gaula, India.

The Indian hill trout cyprinid, *Barilius bendelisis* (Hamilton) is a member of family Cyprinidae, subfamily Danioninae, dwells in shallow, cold and clear water (Gurung et al., 2005). It is characterized by the pointed head, compressed body, blue/black vertical bands on the lateral side of body and origin of dorsal fin inserted behind the mid of the body (Talwar & Jhingran, 1991). This fish is an upland water fish, found in several countries of Southeast Asia such as India, Bangladesh, Nepal (Talwar & Jhingran, 1991), Myanmar, Pakistan, Thailand and Srilanka (Eschmeyer & Fricke, 2011). In India, this species is commonly distributed

in Ganga and Brahmaputra drainages along the Himalayan foothills. *Barilius bendelisis* plays a considerable role in the capture fishery of the Himalayan parts of Arunachal Pradesh, inhabiting in lentic and lotic water bodies where other carps cannot be raised successfully (Sahoo, Saikia, & Das, 2009).

Growth parameters are crucial for sustainable use and exploitation of aquatic macrofauna and their management (Yakub, 2010). Therefore, understanding the population dynamics of species in a particular condition, spawning season, growth, mortality, among others are pre-requisite for identifying the proper

management techniques for the wild population (Rahman & Hafzath, 2012).

B. bendelisis is a popular ornamental species among aquarists as well as a highly known for its food value among Himalayan population; recently it achieved a market price of Rs 160-200 per kg (US \$ 2.43-3.04) (Sharma, Akhtar, Pandey, Singh, & Singh, 2015). As per IUCN red list *B. bendelisis* has been categorized as least concern (Vishwanath, 2010); however, its population has been gradually declining in natural water bodies in the recent past (Sah, Barat, Pande, Sati, & Goel, 2011). Therefore, it is important to collect all the pre-requisite information on the growth and reproduction of this species as a tool for stock assessment, in order to meet the need of sustainable management of its fisheries, and to reduce the pressure on natural resources. Although the reproductive biology and length-weight analysis of *B. bendelisis* has been described by few authors (Dobriyal & Singh, 1987; Gairola, Singh, Malhotra, Nanda, & Ghildiyal, 1990; Grower, 1971; Mir, Patiyal, & Sharma, 2015) but unfortunately, no studies on population dynamics have been reported for this species from river Gaula, Central Himalayans region, India. Therefore, the present investigation was taken up to assess the population dynamics and the reproductive biology of *B. bendelisis* in the river Gaula, Central Himalayans region, India.

MATERIAL AND METHODS

Study area: In total, 501 specimens of *B. bendelisis* (Total length, 6.25-17.20 cm) were collected based on external marking (vertical band) on the body from rivers Gaula (29°17'25" N - 79°37'43" E), Kumaon region of Central Indian Himalayas at 595 MSL. Sampling was carried out on the monthly basis from November 2013 to October 2014. The weight of the fish was recorded with a precision balance nearest 0.01 g. The total length of each fish was taken using digital caliper (Mitutoyo). After measuring length and weight of fish, these were dissected to determine the sex, and

collect, weight and preserve gonads in Bouin's for further analysis.

The water quality parameters of river Gaula were recorded and found in optimum range throughout the study (water temperature, 8.48-25.2 °C; pH, 7.8-9.1; dissolved oxygen, 7.9-12.2 ppm; total dissolved solids, 32-114 ppm; alkalinity, 60-75 ppm; phosphate, 0.00-0.07 ppm; nitrite, 0.00-0.03; nitrate, 0.01-2.46 ppm and ammonia, 0.00-0.03 ppm).

Length weight relationship: The length-weight relationship was analyzed following Le Cren (1951) by the formula: $\text{Log } W = \text{Log } a + b \text{ Log } L$, where, W is the total weight of fish (gram); L is the total length of fish (cm); coefficient a is the intercept at Y-axis and regression coefficient b is an exponent indicating the growth pattern of fish.

The length-weight relationship was estimated for males and females separately by transforming the values into logarithms values and fitting a straight line by least square method. The regression coefficient for males and females were compared by ANCOVA. Additionally, coefficient of determination (R^2) was estimated. The Fulton's condition factor (K) for male, female has been calculated using the formula given by Ricker (1975) as $\text{Condition Factor} = (\text{Weight of fish}) / (\text{Length of fish})^3 \times 100$

The relative condition factor (K_n) (Le Cren, 1951) was calculated separately for both the sexes using the formula $K_n = W/W^\wedge$, where, W is observed weight and W^\wedge is calculated weight.

Population dynamics: The length-frequency data were grouped sex wise and were analyzed to determine the growth and mortality parameter using the computer software programme, FAO-ICLARM Stock Assessment Tool (FISAT II) (Gayanilo, Pauly, & Sparre, 2005).

The Powell Wetherell Plot as modified by Pauly (1986) was adopted to obtain the initial asymptotic length (L_∞) and Z/K . Further, growth was investigated in terms of Asymptotic

length (L_{∞}) and growth coefficient (K) of the Von Bertalanffy Growth formula (VBGF) were estimated using ELEFAN I (Pauly & David, 1981). Length converted catch data was used to compute the mortality (Z). Estimated L_{∞} and K were used to calculate the growth performance index (ϕ') using formula (Pauly & Munro, 1984): $\phi' = 2\text{Log}_{10}L_{\infty} + \text{Log}_{10} K$.

Reproductive biology: The sex ratio was analyzed month wise during the experimental period. Chi-square formula (Snedecor & Cochran, 1967) was used to test the expected 1:1 ratio deviation between males and females by applying the formula: $X^2 = \sum [(O-E)^2/E]$, where, O is observed number of males and females in each month and E is the expected number of males and females in each month.

Gonadosomatic index (GSI) was calculated month wise for both the sexes using formula (De Vlaming, Grossman, & Chapman, 1982): $GSI = (\text{Gonads weight})/(\text{Total weight of fish}) \times 100$.

RESULTS

Length-weight relation and condition factor: The length and weight of fish, regression equation of length-weight relationship, growth type, coefficient of determination (R^2), correlation coefficient (r), growth coefficient (b) and constant is given in table 1. The slope of regression shows the negative allometric growth for both the male and female ($b = 2.65$ for male and $b = 2.5$ for female). A significant relationship between length and

weight was observed in the present study ($p < 0.05$). The results of the analysis of covariance (ANCOVA) revealed a significant difference in the regression coefficient of males and females ($p < 0.05$).

The mean condition factor (K) and relative condition factor (K_n) for females, males and pooled sexes were 1.02, 0.97, 0.99 and 1.12, 1.00, 0.97 respectively. Overall condition factor and relative condition factor of females (1.02 and 1.12 respectively) was better than males (0.97 and 1.00 respectively).

Population dynamics analysis: The estimated value of L_{∞} , Z/K for males (19.68 cm and 5.074), females (22.38 cm and 6.841) and pooled sexes (and 23.93 cm and 8.176) of *B. bendelisis* as obtained from the Powell Wetherall Plot (Fig. 1). The growth performance index (ϕ') for males, females and pooled sexes were 1.96, 1.95 and 1.85, respectively. The ELEFAN-I estimated L_{∞} and K of the von Bertalanffy growth factor for male (17.33 cm and 0.310 per year), female (17.33 cm and 0.3 per year) and pooled sexes (17.33 cm and 0.240 per year) of *Barilius bendelisis*.

The length converted catch curve procedure generated an instantaneous total mortality (Z), Natural mortality (M), Fishing mortality (F) and exploitation rate (E) from the data points as 1.16, 0.62, 0.49 and 0.42 per year, respectively.

Reproductive biology: The month wise sex distribution of male and female is given in table 2. Throughout the year there was a pre-dominance of females except in the month of

TABLE 1
Descriptive statistics and Regression parameter of *B. bendelisis* from river Gaula of Central Indian Himalaya

Sex	Descriptive statistics			Regression Parameters						
	Average weight (g)	Average total length (cm)	n	a	95 % CL a	b	95 % CL b	R^2	r	S
Female	11.22 \pm 0.45 (3.08-28.82)	10.15 \pm 0.15 (6.25-16.20)	243	-1.40	-1.55 to -1.25	2.5	2.26 to 2.54	0.817	0.904	*
Male	13.67 \pm 0.48 (5.23-25.86)	11.09 \pm 0.13 (8.20-17.20)	258	-1.65	-1.86 to -1.54	2.6	2.54 to 2.85	0.826	0.909	*
Pooled	12.30 \pm 0.34 (3.08-28.82)	10.60 \pm 0.10 (6.25-17.20)	501	-1.50	-1.61 to -1.40	2.5	2.40 to 2.61	0.831	0.911	*

Note: n = number of samples, a = coefficient of regression intercept, CL = confidence level at 95 %, b = coefficient of regression (slope), R^2 = coefficient of determination, r = correlation coefficient, S = significant.

* Indicates significant at 95 % confidence level ($p < 0.05$).

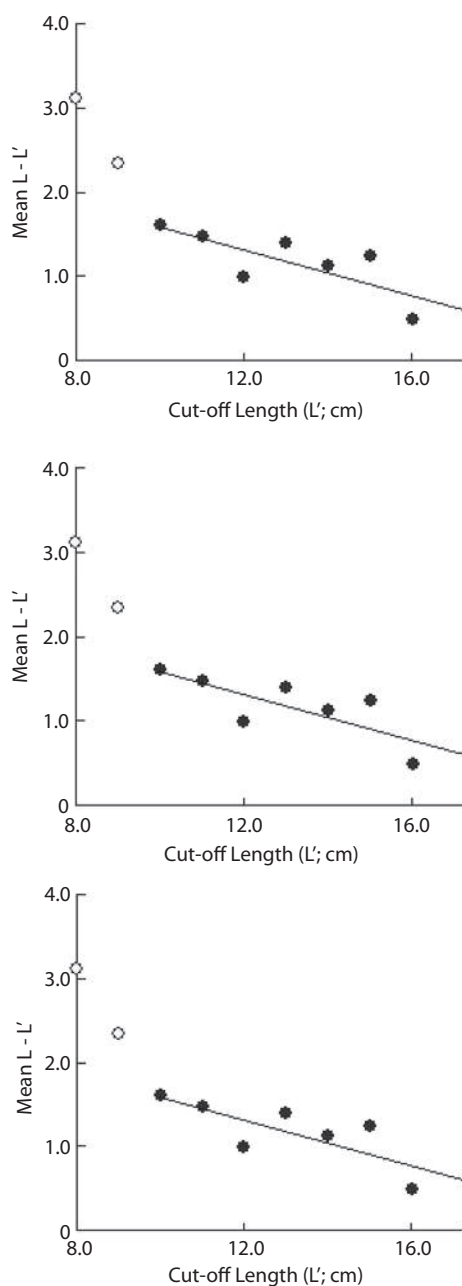


Fig. 1. Estimation of L_{∞} and Z/K using Powell Wetherall Plot for *B. bendelisis* in River Gaula of Central Indian Himalaya. **A-** Male ($L_{\infty} = 19.68$ cm and $Z/K = 5.074$, correlation coefficient for the regression was 0.804, $a = 3.24$ and $b = -0.2$); **B-**Female ($L_{\infty} = 22.38$ cm and $Z/K = 6.841$, correlation coefficient for the regression was 0.645, $a = 2.85$ and $b = -0.12$); **C-** Pooled ($L_{\infty} = 23.93$ cm and $Z/K = 8.176$, correlation coefficient for the regression was 0.704, $a = 2.61$ and $b = -0.11$).

March, April, August and October, for which males outnumbered females. Chi-square test indicated the significant difference in the sex ratio during January and February. The minimum GSI of females was observed in the month of October (4.93 ± 0.26), and for males in the months of June and July (0.093 ± 0.12); whereas the maximum GSI value was observed for females in the month of April (13.47 ± 0.52), and for males in the month of April (1.21 ± 0.12). However, GSI value during the months of March, April, May and September for females, and March, April, May, August and September for males, did not differ significantly ($p < 0.05$) (Fig. 2). Fluctuation in GSI value showed a bimodal pattern showing two peaks during March to May and August-September in both sexes.

DISCUSSION

Information on population dynamics and biological aspects of *Barilius bendelisis* from the River Gaula, Kumaon region of Uttarakhand is deficient. However, several authors (Dobriyal & Singh, 1987; Gairola, Singh, Malhotra, Nanda, & Ghildiyal, 1990; Mir, Patiyl, & Sharma, 2015) have done a brief study of the biological aspect from Garhwal region of Uttarakhand, India.

Length-weight relationship plays a significant role in fisheries sciences as it helps in estimating weight of fish from its length (Martin-Smith, 1996; Mir, Shabir, & Mir, 2012), calculating growth, biomass, gonadal maturity, seasonal variation in growth and production of population (Le Cren, 1951; Pauly, 1983; Rahman & Hafzath, 2012). The allometric coefficient (b) during the present study was found within the expected range of 2.5-3.5 (Carlander, 1969; Froese, 2006; Pauly & Gayanilo, 1997), but it can fluctuate between 2.5 to 4 (Bagenal & Tesch, 1978). In general, the regression coefficient b for fish which exhibits isometric growth ($b=3$) shall not differ significantly from 3 (Allen, 1938), and weight of fish should vary as the cube of length. As the value of b deviates from 3, then weight increase of

TABLE 2
Monthly variation in sex ratio of *B. bendelisis* collected from river Gaula of Central Indian Himalaya

Month	Percent male (M, %)	Percent female (F, %)	M:F	Significance
November 2013	53.2	46.2	1:2.3	Ns
December 2013	53.8	46.2	1:2.3	Ns
January 2014	20.8	79.2	1:3.8	S
February 2014	16.1	83.9	1:5.2	S
March 2014	51.9	48.1	1:0.9	Ns
April 2014	57.7	42.3	1:0.73	Ns
May 2014	47.6	52.4	1:1.1	Ns
June 2014	50.0	50.0	1:1	Ns
July 2014	47.9	52.0	1:1.1	Ns
August 2014	53.8	46.2	1:0.85	Ns
September 2014	50.0	50.0	1:1	Ns
October 2014	58.3	41.7	1:0.71	Ns
Total			1:1.2	

Note: Ns = non-significant ($p > 0.05$); S = significant ($p < 0.05$).

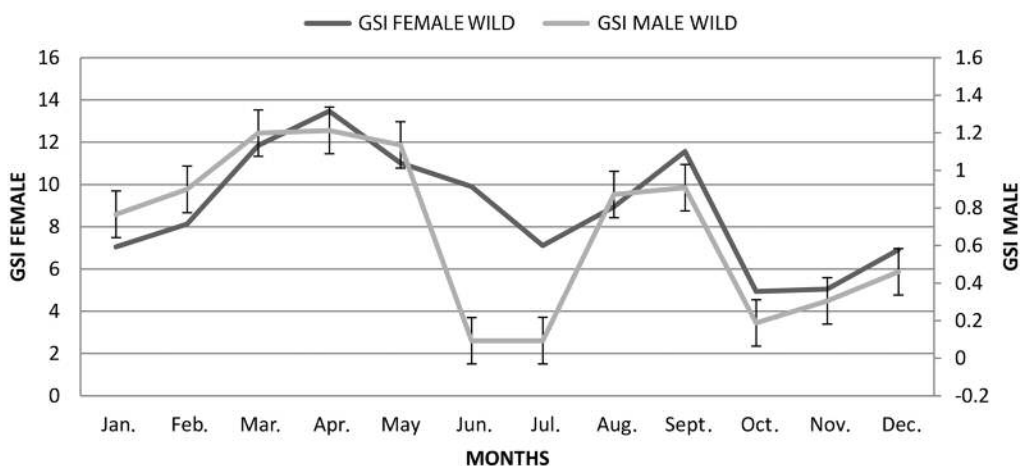


Fig. 2. Gonadosomatic Index (GSI) of male and female *B. bendelisis* collected from river Gaula of central Indian Himalaya.

fish exhibits allometric behavior. In case of *Barilius bendelisis*, negative allometric growth was observed ($b < 3$), which indicates that the weight of fish increased by the power less than 3 with unit increase in body total length showing deviation from the cube law. Such deviation from cube law is reported by several authors in variety of fishes such as *Barilius bendelisis* (Gairola, Singh, Malhotra, Nanda, & Ghildiyal, 1990), major carps (Jhingran, 1952), *Labeo calbasu* (Rao & Rao, 1972), *Labeo fimbriatus*

(Rao, 1974), Indian major carps (Mohan & Sankaran, 1988) and *Pangasius pangasius* (Deepak, Sarkar, & Negi 2002). Mir, Patiyl, & Sharma (2015) reported growth regression coefficient less than 3 in *Barilius bendelisis* ($b = 2.84$) and *Barilius vagra* ($b = 2.97$) from spring fed stream of Garhwal Himalayas. In case of *Barilius bendelisis*, the b value was more or less similar for both sexes, and was marginally higher in case of males, indicating that males were comparatively heavier than the females

of the same length group. These changes may be due to various factors involved in growth of fish like availability of food and feeding (Le Cren, 1951), gonadal maturity (Frost, 1945), sex (Hile & Jobes, 1942) between different population of species (Hile, 1936; Jhingran, 1968), season, habitat, stomach fullness and preservation techniques (Bagenal & Tesch, 1978; Soomro, Baloch, Jafri, & Suzuki, 2007). The results of this study coincided with the results of Gairola, Singh, Malhotra, Nanda, & Ghildiyal (1990) in *Barilius bendelisis* from Garhwal Himalayas.

Condition factor (K) of fish reflects the physiological condition of fish (fatness, maturity and gonadal development) and general welfare in relation to fish health (Shakir, Mirza, Khan, & Abid, 2008; Rahman & Hafzath, 2012). In the present study, the value of K of *Barilius bendelisis* deviated from the recommended range of 2.90-4.80 for mature freshwater fishes (Bagenal & Tesch, 1978). This deviation could be due to environmental factors such as water temperature, water fluctuation and conductivity (Dalu, Clegg, & Nhiwatiwa, 2013).

Asymptotic length (L_{∞}) denoted the largest hypothetical size a fish species may attain throughout its life span in its ecological habitat and environment (Etim, Sankare, Brey, & Arntz, 1998). Generally, growth parameters (growth coefficients, growth performance index) are species-specific in nature and their values are commonly similar within the taxa with narrow normal distribution (Etim, Brey, & Arntz, 1996). Due to lack of data on population structure of *Barilius bendelisis*, the results of present study could not be compared with the other studies of *Barilius bendelisis*. Branstetter (1987) classify the growth of fish based on its K value as 0.05-0.10/y for slowly growing species, 0.10-0.20/y for average growing species and 0.20-0.50/y for rapidly growing species. So, based on this criterion, *Barilius bendelisis* falls under the rapidly growing species.

The sex ratio of *Barilius bendelisis* in the present study showed a deviation from 1:1, with the predominance of females (1:2).

Dobriyal & Singh (1987) obtained similar results in *Barilius bendelisis* from Garhwal Himalaya, India. The unequal sex ratio in *Barilius bendelisis* population of river Gaula may be attributed to higher total mortality of male as reported in the present study. Del-Zarka & El-Sedfy (1970) reported that physical activity and differences in natural and fishing mortality between the sexes are important factors that influence sex ratio (Del-Zarka & El-Sedfy, 1970). Qasim (1966) also concluded that dominance of one sex in a population is linked to differences in growth rate of sexes as individuals with faster growth are exposed to low predation and subsequent loss from population, hence, this influences sex ratio. However, this can result from several physiological factors such as inter specific sex physiology, sex linked tolerance of species, and differential migration of species (Sarkar, Kumar, Dubey, Pandey, & Lakra, 2012).

Gonado Somatic Index is a reliable indicator of gonadal maturity, as in general, the weight of the gonad increases with maturity. When fish spawns, there is a decrease in the weight of the gonad because of the release of gametes (De Vlaming, Grossman, & Chapman, 1982). The changes in the magnitude of GSI in the present study revealed that the *Barilius bendelisis* spawns twice in a year during March to May, and in the month of September, which is similar as reported by Dobriyal & Singh (1987). However, Grower (1971) has reported that *Barilius bendelisis* spawns during the month of November to December.

The present study revealed growth pattern, dynamics and reproductive biology of *Barilius bendelisis* in river Gaula of Central Himalaya region, India. The present investigation concluded that *Barilius bendelisis* is a small sized fish with comparatively good growth rate that spawns twice a year. However, mortality and exploitation rate of target species is quite high in River Gaula. Therefore, there is a need to reduce the fishing pressure by imposing several restrictions in fishing for getting the sustainable yield of fish from River Gaula. Hence, the present study will provide the baseline

information on biological and population structure aspects of this species, and will be useful for its effective production, conservation and restoration plans.

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and K of the von Bertalanffy growth factor for males (17.33 cm and 0.310 per year), females (17.33 cm and 0.3 per year) and pooled sexes (17.33 cm and 0.240 per year). The results indicated that *Barilius bendelisis* is a small sized fish having negative allometric growth that spawns twice a year. Thus, the present study on biological traits represents the baseline information for effective production, conservation and restoration planning.

RESUMEN

Dinámica poblacional y biología reproductiva de *Barilius bendelisis* (Cyprinidae: Cypriniformes) en el río Gaula del Himalaya Central, India. *Barilius bendelisis* es un miembro de la familia Cyprinidae que habita en agua superficial, fría y clara. En esta investigación se estudiaron los parámetros de crecimiento y la biología reproductiva de *Barilius bendelisis* en el río Gaula, Himalaya Central, India. Los datos talla-frecuencia fueron agrupados por sexo, y analizados para determinar parámetros de crecimiento y mortalidad usando el programa de computador, FAO-ICLARM Stock Assessment Tool (FISAT II). En total, 501 individuos fueron recolectados en el río Gaula (Noviembre 2013-October 2014) y fueron preservados en formalina para futuros análisis. Los resultados mostraron que la población de hembras supera en número la población de machos. El GSI mínimo en hembras fue observado en octubre (4.93 ± 0.26) y en machos en Junio y Julio (0.093 ± 0.12), mientras, el valor máximo en abril para ambos, hembras (13.47 ± 0.52) y machos (1.21 ± 0.12). La fluctuación en los valores del GSI tenía un patrón bimodal mostrando dos picos durante Marzo-Mayo y Agosto-Septiembre en ambos sexos, indicando el periodo de desove común del pez. La pendiente de regresión muestra crecimiento alométrico negativo tanto para machos como para hembras ($b = 2.65$ para machos y $b = 2.5$ para hembras). Se observó una significativa relación entre talla y peso en el presente estudio ($p < 0.05$). El ELEFAN-I estimó L_{∞} y K del factor de crecimiento von Bertalanffy para machos (17.33 cm y 0.310 por año), hembras (17.33 cm y 0.3 por año) y sexos combinados (17.33 cm y 0.240 por año). Los resultados indicaron que *Barilius bendelisis* es un pez de talla pequeña con un crecimiento alométrico negativo que desova dos veces al año. Además, el presente estudio de rasgos biológicos representa la información de base para la efectiva producción, conservación y planeamiento de la restauración.

Palabras clave: *Barilius bendelisis*, sex ratio, índice gonadosomático, río Gaula, India.

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