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RELATIONSHIPS BETWEEN LENGTH-WEIGHT, LENGTH-LENGTH, AND FISH LENGTH TO OTOLITH MORPHOMETRY IN *RITA RITA* (HAMILTON, 1822)

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Abstract. The present study deals with fish length-weight, length-length, length-otolith size and length-otolith weight relationships in *Rita rita*. Specimens (N = 117) were collected monthly from September 2018 to August 2019 from Narora site of the River Ganga, India. The slope (b) in length-weight relationship equation was 2.40, suggesting a negative allometric growth pattern. The Student's *t*-test showed no significant differences in the size of right and left otoliths in *Rita rita*, therefore, a single linear regression based on left otoliths was used. Fish length was plotted against otolith length, otolith height and otolith weight. The linear regression model was found to fit the data well for fish length to otolith size. Fish length was positively correlated with otolith height ($R^2 = 0.97$), otolith length ($R^2 = 0.94$) and otolith weight ($R^2 = 0.91$). The mean value of condition factor was 1.13, which suggested a good condition of the target fish species in the River Ganga. Findings of this study could be used to study the population characteristics of *Rita rita,* and to explore the food and feeding biology of piscivores based on correlating the otolith morphometry of the prey items to the fish length at age.

INTRODUCTION

Fish growth can be defined as the change in size (weight or length) of an individual. It is one of the most important factors influencing individuals, populations and assemblages of fishes. Fish length-weight relationships (LWRs) have been used to provide significant data on the condition of fish and to determine isometric or allometric pattern of fish growth (Le Cren 1951). These types of relationships are required in fishery management as they help in the production evaluation of fish populations when only length measurements exist. It also enables the computation of condition indices, and allows comparisons of species growth trajectories (between sexes, seasons, or regions) (Froese 2006). Length-length relationships (LLRs) have utility in fisheries management for comparative growth studies (Moutopoulos and Stergiou 2002). LWRs and LLRs also help in stock assessment and inter/intra-specific morphological comparison of populations (Moutopoulos and Stergiou 2002; Vaslet et al. 2008; Kashyap et al. 2015; Singh and Serajuddin 2017).

Otoliths, the paired structures found in teleosts' internal ears, are made primarily of calcium carbonate ($CaCO_3$) in the form of aragonite crystals and are used for hearing and balance (Popper et al. 2005). Due to their property of being metabolically inert and growing continuously by daily growth increments throughout the life history, otoliths may serve as markers for groups of fish that have lived in diverse environmental situations (Campana 1999). Traditionally, otoliths have been used to obtain information about the taxon, age, growth, and size of fishes which is useful for monitoring population dynamics, understanding trophic interactions as well as for carrying out stock assessments (Campana et al. 2000; Harvey et al. 2000; Viva et al. 2015; Khan et al. 2018). Otoliths are taxonomically distinct and species-specific (Morrow 1979). Due to high levels of inter and intraspecific variations in otolith size and its morphometry, it can be used as a taxonomic tool for species identification and delineation of fish stocks (Campana et al. 2000; Stransky and MacLellan 2005; Aneesh-Kumar et al. 2017; Ferri et al 2018; Nazir and Khan 2019; D'Iglio et al. 2021). Otoliths tend to grow linearly in length and width with increasing fish size and to grow linearly in thickness and weight with increasing fish age (Donkers 2004). For most species, the relationship between otolith length and fish length can be described by simple linear regression (Harvey et al. 2000).

By establishing a relationship between the fish length and otolith size, it is possible to back-calculate the fish size and biomass (Harvey et al. 2000; Zan et al. 2015; Aneesh-Kumar et al. 2017). Otoliths do not show reabsorption and their growth is acellular rather than by calcification (Secor et al. 1995). In particular, otoliths are quite resistant to digestion and they are an important tool for prey classification in several dietary studies (Pierce et al. 1991; Pierce and Boyle 1991; Granadeiro and Silva 2000). Moreover, the resistance of otoliths to deterioration, due to their particular calcareous structure (a concretion of calcium carbonate and other trace elements deposited in a protein matrix), makes it possible to use them in paleontological studies. It is reported that fossil otoliths are very helpful for studying ancient teleost fish fauna (Nolf 1995; Annabi et al. 2013).

Rita (Hamilton 1822) belongs to the family Bagridae, which is found in Indian freshwaters as well as in those of many other countries in the Asian continent. This commercially important fish has good nutritional value and palatability (Gupta 2015). This fish is also used for its ornamental value, which has a high export potential (Gupta and Banerjee 2014)**.** The *Rita* population has been reported to be at risk of extinction due to its overexploitation and loss of breeding sites (Gupta 2015). This fish species is documented as lower risk near threatened in the Indian riverine system, and as critically endangered in Bangladesh (Mishra et al. 2009). There are a few reports on length-weight relationship, length-length relationship, and condition factor of this fish species (Sarkar et al. 2013; Baitha et al. 2018; Kumar et al. 2019). However, no published reports are available on the relationship between fish length and otolith size in *Rita*. Therefore, the aim of the present study was to investigate the relationship between length-weight, length-length and between fish length, otolith size and otolith weight of *Rita rita* inhabiting the River Ganga.

MATERIALS AND METHODS

A total of 179 specimens of *Rita rita* were collected during the period lasting from September 2018 to August 2019 from the River Ganga at Narora site (28.1968° N, 78.3814° E), in the state of Uttar Pradesh, India (Figure 1) for the determination of length-weight relationship, and 117 fish specimens were collected for the determination of fish length- otolith size relationship. Fish were collected by using a drag net and a cast net of varying mesh size. Fish were identified according to Talwar and Jhingran (1991). Fish samples were placed on ice, transported to the laboratory, measured for total length (nearest 0.1 cm) and total weight (nearest 0.1gm). Total length, standard length, fork length and total weight were recorded to estimate the LWRs and LLRs. Otoliths (lapilli) were removed and cleaned with water, kept at room temperature to dry and then placed into marked envelopes (Khan et al. 2016).

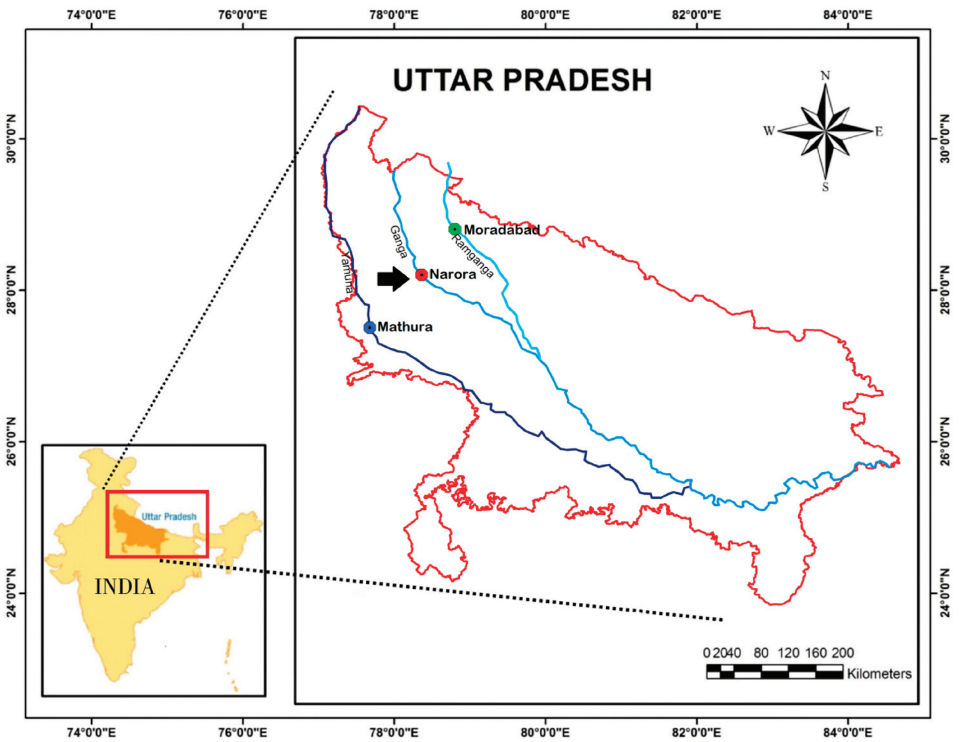

Figure 1. Map showing collection site (marked with an arrow) of *Rita rita* at Narora site of the River Ganga.

Length-weight relationship

The length-weight relationship was calculated following the equation of Le Cren (1951):

$$W= aL^b$$

Where, W = weight of fish in gm along with gut and gonads;

L = total length of fish in cm;

a = intercept, and

b = regression coefficient.

The parameters a, b and r^2 (coefficient of determination) were calculated by logarithm-transformation of the linear regression equation, Log W = log a + b log L (Garcia 2010). The coefficient of determination was calculated to assess the degree of association between the variables.

Length-length relationship

The length-length relationship was calculated by linear regression between the total length (TL) vs standard length (SL), total length (TL) vs fork length (FL) and standard length (SL) vs fork length (FL) for the selected fish species (Hossain et al. 2006; Khan et al. 2012).

Condition Factor

Condition factor was calculated according to the formula:

$$K = 100 \times (W/ L^3)$$

Where K is Fulton's condition factor, W is the total weight in grams, L is the total length in centimetres, and factor 100 is used to bring K close to unity (Froese 2006).

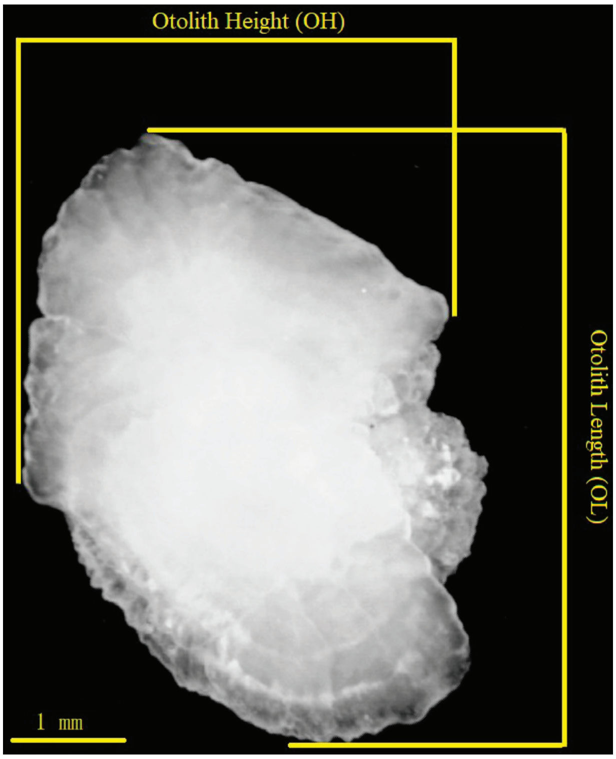

Figure 2. Otolith measurements (Otolith length, OL and Otolith height, OH) in *Rita rita* collected from the River Ganga.

Relationship between fish size and otolith size

To obtain otoliths, an incision was made on the dorsal side of the head, so as to expose the brain, on both sides of which the otic capsules are located. The largest otolith (Lapillus) was removed from otic capsules by opening the otic bulla and then cleaned with water, kept at room temperature to dry and then placed into marked envelopes (Khan et al. 2016). The otolith was photographed with a Nikon® SMZ745T. Stereozoom microscope and the morphometric measurements of the otoliths (length and height) were taken using ImageJ software (ImageJ 1.51j8, National Institute of Health, USA) (Figure 2). The otolith weight of each individual (in milligrams) was recorded using an electronic balance (SI-234 Denver Instruments, Germany) with an accuracy of 0.1 mg.

The relationships between otolith size (length, height) and fish size (TL) were determined using least square linear regression for the following parameters: otolith length (OL)-fish length (TL) and otolith height (OH)-fish length (TL).

The data were generated for both left and right otoliths, which did not show significant differences ($p < 0.05$) in their regression coefficients when subjected to Students *t*-test, thus the null hypothesis (b right = b left) was accepted. Here, left otoliths were used for further analysis. A single linear regression was described for each variable.

All statistical analyses were done using MS-Excel and SPSS (version 22).

RESULTS

The estimated parameters of length-weight relationship from the earlier published reports and those determined in the present study, i.e., sample size (N), minimum and maximum length, minimum and maximum weight, mean of length and weight, standard deviation (SD), coefficient of determination (R^2) and slope regression value (b) of *Rita rita* are presented in Table 1. Linear regression on log transformed data was highly significant ($p < 0.001$) showing $R^2 > 0.9$. The relationships between total length (TL), fork length (FL) and standard length (SL) of the target fish species, along with the estimated parameters of length-length relationships and the coefficient of determination (R^2) are presented

Table 1. Descriptive statistic and estimated parameters of length-weight and length-length relationships for *Rita rita* collected from the River Ganga.

Species	Total Length (cm)					Weight (g)				Regression Parameter for LWR		
	N	Min	Max	Mean	SD	Min	Max	Mean	SD	b	95% CL of b	R^2
Rita rita (Present study)	179	9.3	46.7	26.36	9.54	30	1110	257.54	227.24	2.40	2.12–2.92	0.98
Sarkar et al. 2013	41	9.4	42	19.85	–	–	–	–	–	1.78	1.18–2.24	0.91
Baitha et al. 2018	104	5.5	64.9	–	–	2.49	3480.20	–	–	2.94	2.85–3.03	0.98
Kumar et al. 2019	165	5.7	65.8	–	–	2.52	3490	–	–	2.96	2.86–3.05	0.97

N, number; Min and Max, minimum and maximum; SD, standard deviation; b, regression coefficients; R^2, correlation of determination; CL, confidence limits (95%) of b.

Table 2. Estimated LLRs between TL-SL and TL-FL and SL-FL of *Rita rita* collected from the River Ganga.

Equation	N	A	b	R^2
SL = a + bTL	179	–2.29	0.99	0.99
FL = a + bTL	179	–1.37	1.001	0.99
FL = a + bSL	179	0.97	1.003	0.99

TL = Total Length, SL = Standard Length and FL: Fork Length.

Table 3. Minimum, maximum, mean and standard deviation (SD) of total fish length and otolith length, height and weight of *Rita rita*.

Parameters	Number	Minimum	Maximum	Mean	SD
Total fish length (cm)	117	9.4	44	20.88	10.17
Otolith length (mm)	117	1	5.8	2.88	1.35
Otolith height (mm)	117	0.7	5	2.19	1.29
Otolith weight (g)	117	1.2	33.4	8.15	8.04

in Table 2. All length-length relationships were highly significant ($p < 0.001$) with values of the determination (R^2) coefficient being greater than 0.99. The Fulton's condition factor ranged from 0.91–1.49. The mean calculated condition factor (K) for the target fish species was (1.13 ± 0.31).

The information about sample size, minimum and maximum values of fish length, otolith length, height and weight of *Rita rita* is presented in Table 3. The relationship between fish length and otolith length is shown in Figure 3. This relationship is depicted by the equation (OL = 0.130 TL + 0.157; R^2 = 0.947). The relationship between fish length and otolith height is shown in Figure 4. Otolith height was found to be best correlated with fish length (R^2 = 0.97), which is depicted by the equation (OH = 0.125 TL – 0.433; R^2 = 0.972). The relationship between fish length and otolith weight is shown in Figure 5. This relationship is depicted by the equation (OWT = 0.754 TL – 7.608; R^2 = 0.911).

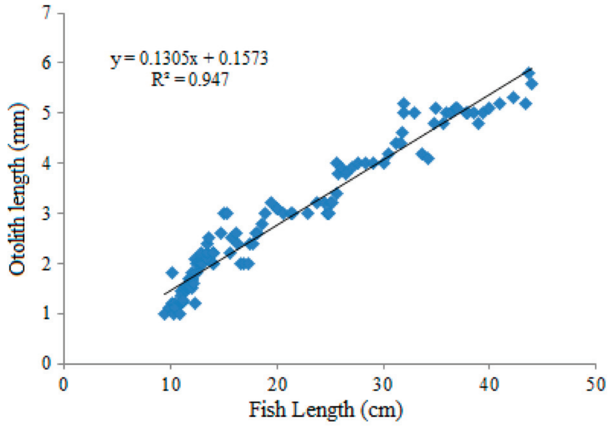

Figure 3. Relationship between total fish length and otolith length of *Rita rita*.

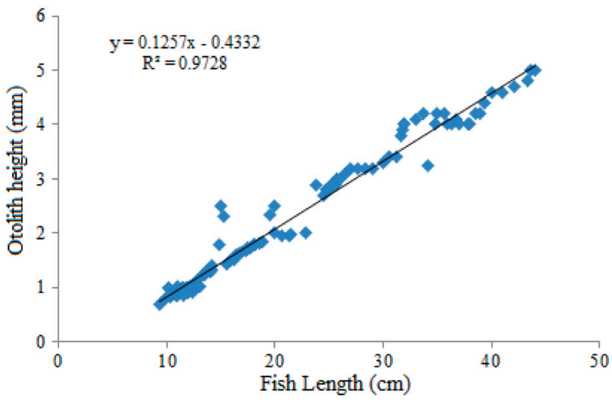

Figure 4. Relationship between total fish length and otolith height of *Rita rita*.

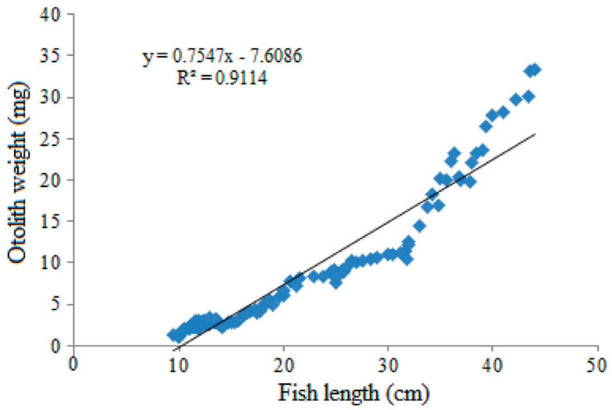

Figure 5. Relationship between total fish length and otolith weight of *Rita rita*.

DISCUSSION

The slope parameter (b) value in the LWR equation exhibited a negative allometric growth pattern in *Rita rita*. According to Wootton (1990), the b-value lower than 3.0 is indicative of the negative allometric growth, where gain in length growth is faster than in weight, while the b-value greater than 3 implies the positive allometric growth, where the weight gain is faster than the length increment. A positive linear relationship was observed between total length and each of the body lengths (TL, SL, FL) in *Rita rita*. Length and weight data are not representative of a particular season or time of the year; therefore, the estimated parameters a and b should be considered to be mean annual values. In this study, the value of b for *Rita rita* was slightly lower than the b-value of the fish from the lower stretch of the river (Baitha et al. 2018) and also from the middle stretch of the river (Kumar et al. 2019). However, the b value for *Rita rita* in the present study was higher than that reported by Sarkar et al. (2013) in the River Ganga. Variation in b values may be due to several factors such as sample size, area/season of sampling and differences in the length range of the observed samples (Moutopoulos and Stergiou 2002). Moreover, it could be also due to temperature variation, different habitat types, and/or potential inherent differences in fish behaviour and physiology across the sampling locations of different studies (Al Nahdi et al. 2016).

Although LWRs of the target fish species inhabiting the River Ganga have been investigated in a number of studies, there are no published reports on LWRs of the fish at the Narora site, which is a significant location because of the presence of a barrage in the river, and also an Atomic Power Station near to its bank. Therefore, the habitat characteristics (not documented in the present study) at the Narora site may exhibit unique variations compared to other parts of the river. All LLRs were highly significant ($p < 0.001$), with all values of the determination coefficient close to 0.99. LLRs perform a significant role in interconversions of different body lengths such as standard length to total length (Klassen et al. 2014). The variation in LWR, LLR and its parameters, may be due to the fact that the present study focused on fresh and healthy specimens, which included mature as well as immature fish collected in different seasons of the year. Also, fish of a larger size range were relatively less represented in the total samples of the study.

Fulton's condition factor (K) represents the health condition or the well-being of fish. The fish whose condition factor value is greater than 1 are said to be in good health condition (Nash et al. 2006). The mean value of the condition factor of *Rita rita* in the River Ganga was found to be higher than 1, which means that condition of the fish population of the target fish species therein is good. As reported by Deka et al. (2015), the value of *Rita rita* condition factor was greater than 1, which indicates its good condition. Since the weight of a fish species is a function of the cube of its length assuming that the fish shape and specific gravity remains constant, any variations in the fish shape (usually happens because of maturation of gonads) or in fish fatness may result in variations in the condition factor values. The condition factor value can also be affected by both endogenous and environmental variables (Sarkar et al. 2017). The basic information on LWR, LLR and condition factor of *Rita rita* generated in the present study may be used by fishery biologists and managers to efficiently manage the fish population in the s Ganga. It may prove useful in comparing fish growth responses to varying habitat conditions.

Otolith dimensions and weight were linearly correlated to the total fish length. Several researchers have reported that the relationships between fish length and otolith size can be used to back-calculate fish length from otolith size (Harvey et al. 2000; Zan et al. 2015; Aneesh-Kumar et al. 2017). In the present study, linear regressions between fish length and otolith height showed a stronger positive correlation than fish length versus otolith length and fish length versus otolith weight. A strong relationship between fish length and otolith size suggests that the somatic growth of fish has a major impact on otolith growth (Munk 2012); there are a number of studies that have reported similar relationships (Aneesh-Kumar et al. 2017; Nazir and Khan 2019; Yilmaz et al. 2019). Fish length and otolith size relationships are affected by several factors such as variations in fish species, food availability, condition of the habitat and various environmental factors (Aydin et al. 2004); therefore, to understand the impact of these variables, further studies are needed.

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DISCLOSURE STATEMENT

No potential conflict of interests exists among the authors.

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