Baseline information of reproduction parameters of an amphidromous croaker *Johnius coitor* (Hamilton, 1822) from Ganga river basin, India with special reference to potential influence of climatic variability

Uttam Kumar Sarkar*, Malay Naskar, Koushik Roy, Deepa Sudheesan, Sandipan Gupta, Arun Kumar Bose, Pankaj Kumar Srivastava, Saurav Kumar Nandy, Vinod Kumar Verma, Soma Das Sarkar and Gunjan Karnatak

ICAR - Central Inland Fisheries Research Institute, Barrackpore 700120, West Bengal, India

Received 6 April 2017 / Accepted 3 November 2017

Handling Editor: Henrique Cabral

**Abstract** – Reproductive biology of female amphidromous croaker *Johnius coitor* (Hamilton, 1822) was studied for the first time from various freshwater stretches of Ganga river basin, India in relation to climatic variability. The species showed high spatial variation in reproductive phenology and capable of breeding during pre-monsoon, monsoon, post-monsoon and winter. Water temperature is the most crucial environmental parameter influencing gonadal maturation and breeding. Generalized additive model (GAM) models revealed water temperature near 23–25 °C as optimum and threshold GSI above 3 units necessary for breeding. Pre-spawning fitness ($K_{spaw50}$) and size at 50% maturity ($L_{M50}$) benchmarked through Kaplan-Meier survival fit estimates were in the range 1.27–1.37 units and 19–24.5 cm respectively. First maturity of females was encountered at 11.4 cm within the size range 7.2–28.5 cm. Egg parameters in mature-ripe females ranged between 0.29–0.80 mm (diameter), 0.05–0.19 mg (weight) and 5687–121 849 eggs (absolute fecundity). Mapping of climate preferendum through LOESS smoothing technique hinted water temperatures <20 °C and >32 °C to be detrimental for attainment of pre-spawning fitness while no dependence on rainfall was observed. Based on the climato-hydrological influence on breeding and regional trends of changing climate along river Ganga, we infer minimal climate driven changes in breeding phenology of this amphidromous fish species. Results of this study may serve as baseline information for future studies assessing climate driven changes and evolutionary adaptations in croakers from river Ganga.

**Keywords**: Breeding phenology / threshold GSI / pre-spawning fitness / egg parameters / size at maturity / climatic influence

1 **Introduction**

*Johnius coitor*, commonly known as coitor croaker, is an amphidromous fish species belonging to family Sciaenidae under order Perciformes, popularly known as Jew fish, croakers or drums. Besides India, coitor croaker is widely distributed in Indo-West Pacific region with reports of occurrence from Australia, Bangladesh, Brunei, Indonesia, Malaysia, Myanmar, Nepal and Singapore (Froese and Pauly, 2017). Although it is reported to be a demersal species, fishermen in riverine stretches believe it to be pelago-demersal having preference for both pelagic and bottom habitat niche (Anon, 2016). Feeding habit is predominantly carnivorous. In terms of conservation status, *J. coitor* has been listed as a least concern species (Anon, 2016; Froese and Pauly, 2017). In India, the lesser sciaenid *J. coitor* forms a fishery throughout the year in upper stretch of river Ganga and the fish appears to be optimally exploited; being a small fish from the tropical region it also shows faster growth with high natural mortality (Rizvi et al., 2015). In terms of economic importance, coitor croakers fetch a moderate price of INR 300–400/kg (USD 4.5–6.0/kg). They are also commonly presumed as poor man’s bhetki or seabass (highly commercial, *Lates calcarifer*); justifying its vernacular (Bengali) name of “Bhola bhetki” in some fish markets of West Bengal, India (Anon, 2016).

*Corresponding author: usarkar1@rediffmail.com*
Moreover, coiters are highly fecund and air-bladders of these fishes are used to prepare isinglass which is a commercially important fish by-product (Olapade and Tarawallie, 2014).

A few studies on morphometrics of *J. coitor* have been reported from Bangladesh (Azadi et al., 1999) and India (Barman, 1992). Barman (1992) also reported the occurrence of this species for the first time from North East India. Additionally, report of a natural ecto-parasite of this species also exists (Kibria et al., 2011). Recently, studies by Rizvi et al. (2015) provided new information on length-weight relationship (LWR), age-growth model and stock dynamics, that were absent before, from upper stretch of river Ganga (Allahabad, India). However, information on reproductive biology of *J. coitor* and its relation to climatic factors is meagre or unavailable. The review of literature on breeding biology of phyllogenetically related sciaenids under genus *Johnius* from Indian waters revealed some general trends. Firstly, most studies have been reported from marine waters with exclusively marine inhabiting stocks, as reviewed by Rao et al. (1992) and Kumar et al. (2013). Secondly, the studies did not include any perspectives of climatological influence on breeding and likely impact of changing climate; the purpose of these earlier studies was to provide information on aspects of reproductive biology only (Kumar et al., 2013).

The importance of studying gonado-somatic index (GSI), breeding season and length at maturity are already well established in traditional fish reproduction themed research (Qasim and Qayyum, 1962; Rao and Karamchandani, 1986; Rao et al., 1992). The importance of investigating environmental influences on gonadal maturation and spawning, on the other hand, is also well established for both fish reproduction and conservation themed research (Pankhurst and King, 2010; Farmer et al., 2015; Lyons et al., 2015). Apart from qualitative inferences drawn from traditional studies regarding environmental influences on natural breeding of fishes, the present study envisaged to quantify environmental and biological thresholds associated with successful recruitment of the species in-situ using some new approaches. Quantification of such natural (environmental and biological) thresholds for breeding in fishes are crucial for better understanding of population-environment interactions and assessing vulnerability of a particular species to climate change (Peer and Miller, 2014; Whitney et al., 2016). The present study has also given a special emphasis on studying fitness indices as an integral part of reproductive biology studies. The study of the condition factor (*K*) have been considered to be important for understanding the life cycle of fish species as it varies with species, sex, stage of growth, reproductive maturity and feeding (Simon et al., 2009; Anibae, 2000; Mazumder et al., 2016). In an individual fish, the dynamics of *K* follow a near circular pattern alternating between reproductively active and inactive stage (Fulton, 1904; Froese, 2006). In simpler terms, a growing fish gradually attain the most robust conditions at the onset of spawning owing to higher weight of mature-ripe gonads per unit body length; and as the gonads become flaccid (emptied) after spawning, the fall in gonadal weight is reflected in a fall of *K* values as well. Therefore, condition factor in an individual may be treated as an analogue of biological time (clock) that sweeps through feeding, maturation, spawning, spent and recovery (feeding) phases. The present study used the technique of Kaplan-Meier survival analysis and imposed this idea to chalk out the cut-off *K* (range) for achieving fair chances of reproductive success at population level. The threshold *K* value beyond which more than 50% of the population may attain readiness for spawning has been coined as pre-spawning fitness (*K*_{spawn50}).

Climate change have been regarded as a potential threat to fishes and fisheries on top of many other concurrent pressures such as overfishing, habitat degradation, pollution, introduction of new species and so on (Brander, 2010; Crozier and Hutchings, 2014; Lynch et al., 2016). To the best of our knowledge, the present study provides the first baseline information on various aspects of reproductive biology of an amphidromous croaker *J. coitor* from the freshwater stretches of river Ganga, India. Information regarding the climatohydrological influences on breeding was generated to assess the likely impacts of changing climate along Ganga river basin. Another sub-component of the present study was to parameterize and benchmark *K*_{spawn50} of *J. coitor* from river Ganga with the aim to produce baseline information on the threshold condition factor required for spawning and range of egg parameters expected at this pre-spawning stage. The effort was further deepened by generating additional baseline information on species-specific preference of thermal and precipitation window (climate preferendum) within which *K*_{spawn50} is attained under Indian climatic conditions.

## 2 Materials and methods

### 2.1 Study area

The present study was conducted in three sampling stations over river Ganga: middle stretch, i.e. Patna (25.6166°N and 85.1989°E), anterior lower stretch, i.e. Farakka (24.7999°N and 87.9158°E) and posterior lower stretch, i.e. Triveni (22.9844°N and 88.4039°E) (Fig. 1).

### 2.2 Species selected for study

One commercially important species of croaker (*J. coitor*) in the river Ganga was purposively selected due to its amphidromous nature (migrating between marine and freshwater environment frequently) and thorough availability (wide geographical range) along Patna, Farakka and Triveni stretch. The species has a moderately high market price throughout the year (INR 300–400/kg or USD 4.5–6.0/kg).

### 2.3 Sample collection and analysis

Thirty specimens from each sampling station were collected on monthly basis, preferably during the last week. Altogether, 1700 specimens were collected during April 2015 to January 2017 from Patna, Farakka and Triveni stretch of river Ganga with an idealistic average of 30 nos/month/station in mind. Although every attempt was made to collect sufficient samples, field limitations were encountered in certain instances owing to the spatio-temporal variation in sample availability. Fish samples were collected during the early morning (6:00–8:00) using gill net, cast net and seines involving the local fishermen. The nets had different mesh sizes to enable collection of heterogeneous size, sex and maturity groups. Few freshly caught coitor croakers were also procured from the hauls arriving at adjacent fish
landing centers situated along the river side (Bhat, 2003). Same sample collection strategy was adopted at every sampling location since the fishing scenario, especially the range of mesh sizes in-use, were similar among the studied stretches. Thereby the aforementioned strategy eliminated inter-location variability in sample for obtaining representative of population.

Descriptive data on some parameters of female coitor croaker collected from selected stretches of river Ganga during the present study are given in Table 1. The fishes were anesthetized with MS-222 (Ethyl 3-aminobenzoate methane sulfonate), in case of live sampling, before dissection. After collection, morphological measurements of each fish specimen were recorded. Before weighing, each specimen was washed with water and left exposed to air to dry. Excess moisture was removed with blotting paper to ensure accurate measuring of weight. Specimens were dissected out ventrally; gonads were removed carefully, weighed and brought to the laboratory in preserved condition (70% Ethanol) for further analysis. GSI was calculated following the formula of Htun-Han (1978) on monthly basis for each of the fish species to get the information on breeding periodicity of these species: 

\[
GSI = \frac{\text{Gonad weight (gm)}}{\text{Body weight (gm)}} \times 100
\]

We considered five commonly identifiable gonadal maturity stages: stage I–immature, stage II–maturing, stage III–mature, stage IV–ripe and stage V–spent according to Qasim and Qayyum (1962), Rao and Karamchandani (1986). These were determined according to colour, texture, appearance, relative size of gonads and oocyte diameter in case of females.

Hydrological parameters were also studied for the purpose of habitat characterization on monthly basis at each sampling station following standard methodologies (APHA, 2012). The recorded parameters were: temperature, dissolved oxygen, free carbon dioxide, pH, total dissolved solids, conductivity, alkalinity, salinity, nitrate \( \left( \text{NO}_3^- \right) \) and phosphate \( \left( \text{PO}_4^{3-} \right) \). At each sampling station, water samples were collected in duplicate viz. one at the fishing site itself and another one little away from the fishing site (Bhat, 2003). A composite water sample was made from the duplicate sub-samples and used for analysis of water quality parameters following Gomez and Gomez (1984). In order to make sure that the measure of water quality parameters is comparable through space and time, a fixed sampling hour between 7:00–8:00 am was consistently followed throughout the sampling period in all the stations. Data on monthly rainfall (mm) was obtained location-wise from Indian Meteorological Department (IMD, Alipore). Habitat parameters recorded during the study period are listed in Table 2.
2.4 Modeling climato-hydrological influence and threshold GSI for breeding

Statistical analyses were done in the software R (R Core Team, 2015). An all out attempt was made to identify the significant climato-hydrological parameters (hereinafter referred as environmental parameters), quantify their nature and magnitude of influence, find out their threshold values and predict future impacts due to climate change on the gonadal maturity and spawning of the selected fish species.

As the environmental parameters are highly interrelated among themselves, the need of eliminating multicolinearity among the variables was felt necessary as it violates the principle of multiple regressions. Principal component analysis could have been a choice to tackle this problem but the data interpretation was very difficult in terms of original environmental parameters. Instead, this was accomplished through Table 1.

<table>
<thead>
<tr>
<th>Stretch</th>
<th>Parameters#</th>
<th>Length (cm)</th>
<th>Weight (gm)</th>
<th>GSI (units)</th>
<th>Condition factor (units)</th>
<th>Growth coefficient (b-value of LWR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle stretch (Patna)</td>
<td></td>
<td>7.5–18.9</td>
<td>5.15–61.02</td>
<td>0.06–9.82</td>
<td>0.61–1.23</td>
<td>3.069</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(12.88±0.21)</td>
<td>(22.01±1.15)</td>
<td>(0.82±0.10)</td>
<td>(0.88±0.01)</td>
<td>(0.974, &lt;0.01)</td>
</tr>
<tr>
<td>Anterior lower stretch (Farakka)</td>
<td></td>
<td>10.3–18.5</td>
<td>9.25–63.42</td>
<td>0.19–4.75</td>
<td>0.64–1.06</td>
<td>3.011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.48±0.17)</td>
<td>(27.51±1)</td>
<td>(1.07±0.05)</td>
<td>(0.86±0.01)</td>
<td>(0.948, &lt;0.01)</td>
</tr>
<tr>
<td>Posterior lower stretch (Triveni)</td>
<td></td>
<td>13–28.5</td>
<td>29–261</td>
<td>0.15–10.51</td>
<td>0.64–1.71</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(19.86±0.47)</td>
<td>(93.01±6.06)</td>
<td>(3.01±0.3)</td>
<td>(1.15±0.03)</td>
<td>(0.885, &lt;0.01)</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>7.5–28.5</td>
<td>5.15–261</td>
<td>0.06–10.51</td>
<td>0.61–1.71</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.62±0.2)</td>
<td>(36.39±1.88)</td>
<td>(1.29±0.09)</td>
<td>(0.92±0.01)</td>
<td>(0.965, &lt;0.01)</td>
</tr>
</tbody>
</table>

# Data presented in range and mean ± standard error of mean (in parentheses).

Table 2. Habitat parameters recorded in river Ganga during the study period.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Stretch#</th>
<th>Middle stretch (Patna)</th>
<th>Anterior lower stretch (Farakka)</th>
<th>Posterior lower stretch (Triveni)</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water temperature (°C)</td>
<td></td>
<td>20.1–32.2 (28.71±0.32)</td>
<td>18.3–31.5 (27.44±0.42)</td>
<td>21.1–35.2 (28.53±0.6)</td>
<td>18.3–35.2 (28.29±0.24)</td>
</tr>
<tr>
<td>Dissolved oxygen (ppm)</td>
<td></td>
<td>3–10.9 (6.18±0.15)</td>
<td>5.8–9.8 (7.05±0.11)</td>
<td>2.8–6.8 (4.93±0.18)</td>
<td>2.8–10.9 (6.22±0.1)</td>
</tr>
<tr>
<td>Free carbon dioxide (ppm)</td>
<td></td>
<td>0.9–2.6 (1.39±0.04)</td>
<td>0–9.5 (5.89±0.34)</td>
<td>0.5–7.7 (4.72±0.31)</td>
<td>0–9.5 (3.36±0.16)</td>
</tr>
<tr>
<td>pH (units)</td>
<td></td>
<td>8.1–8.7 (8.4±0.01)</td>
<td>8.1–8.8 (8.46±0.02)</td>
<td>7.8–8.2 (8.04±0.02)</td>
<td>7.8–8.8 (8.35±0.01)</td>
</tr>
<tr>
<td>Conductivity (umhos)</td>
<td></td>
<td>198–476 (360.28±5.97)</td>
<td>190–366.6 (270.78±5.76)</td>
<td>206–371 (293.77±7.37)</td>
<td>190–476 (320.98±4.34)</td>
</tr>
<tr>
<td>Alkalinity (ppm)</td>
<td></td>
<td>90–171 (128.26±1.99)</td>
<td>70–142 (103.7±2.2)</td>
<td>74–109 (93.06±1.25)</td>
<td>70–171 (114.44±1.46)</td>
</tr>
<tr>
<td>Salinity (ppm)</td>
<td></td>
<td>107–231 (177.83±2.26)</td>
<td>96.5–174 (130.25±2.63)</td>
<td>96–199 (147.85±4.46)</td>
<td>96–231 (157.90±1.97)</td>
</tr>
<tr>
<td>Nitrate (ppm)</td>
<td></td>
<td>0.06–0.92 (0.3±0.02)</td>
<td>0.16–0.79 (0.4±0.02)</td>
<td>0.78–1.09 (0.97±0.01)</td>
<td>0.06–1.09 (0.45±0.02)</td>
</tr>
<tr>
<td>Phosphate (ppm)</td>
<td></td>
<td>0.02–0.06 (0.03±0.01)</td>
<td>0.01–0.12 (0.05±0.01)</td>
<td>0.08–0.12 (0.1±0.01)</td>
<td>0.01–0.12 (0.05±0.01)</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td></td>
<td>0–368.81 (42.2±7.32)</td>
<td>0–332 (221.58±28.2)</td>
<td>0–928 (256.46±39.55)</td>
<td>0–928 (135.46±12.77)</td>
</tr>
</tbody>
</table>

# Data presented in range and mean ± standard error of mean (in parentheses).
variance inflation factor (VIF) analysis and as a rule of thumb those environmental parameters having VIF values >10 were excluded for building of the model. Place effect was coded place wise (Patna, Farakka and Triveni) to keep the spatial differences into consideration.

To identify the significant environmental parameters that are crucial for gonadal maturity and spawning, multiple linear regression was applied by designating filtered environmental parameters as independent variables and GSI as the dependent variable. The relative importance of the identified parameters in influencing gonadal maturity was obtained by calculating $r^2$ value and the parameters were ranked accordingly in descending order of importance. The place effect diagnostics in the multiple linear regression model also sketched out whether any significant spatial differences exist in the response of GSI while discounting the effect of environmental parameters among the study sites. An ANCOVA was carried out in R software incorporating place effect as factor and environmental parameters as continuous explanatory variables, and GSI as response variable in multiple regression framework. It helped to determine whether any spatial differences exist among stocks of three locations (Patna, Farakka, Triveni), while quantifying the effect of environmental variables.

In order to find out the threshold values of the crucial environmental parameters for facilitating breeding in a particular fish species and predicting response of that species towards that particular environmental parameter in terms of gonadal maturity, individual generalized additive model (GAM) models (Hastie and Tibshirani, 1986) were developed to unravel their non-linear relationship with GSI while keeping spatial differences exist in the response of GSI. Place effect was coded as factor and environmental parameters as continuous explanatory variables, and GSI as response variable in multiple regression framework. It helped to determine whether any spatial differences exist among stocks of three locations (Patna, Farakka, Triveni), while quantifying the effect of environmental variables.

In order to find out the threshold values of the crucial environmental parameters for facilitating breeding in a particular fish species and predicting response of that species towards that particular environmental parameter in terms of gonadal maturity, individual generalized additive model (GAM) models (Hastie and Tibshirani, 1986) were developed to unravel their non-linear relationship with GSI. Place effect was coded as factor and environmental parameters as continuous explanatory variables, and GSI as response variable in multiple regression framework. It helped to determine whether any spatial differences exist among stocks of three locations (Patna, Farakka, Triveni), while quantifying the effect of environmental variables.

2.5 Condition factor

Fulton’s condition factor ($K_F$), hereinafter referred as condition factor, was calculated using the equations given by Fulton (1904) as $K_F = 100 \times (W/L^3)$, where $W$ is the body weight in g; and $L$ is the total length in cm. Following Froese (2006), the factor 100 is used to bring $K_F$ close to unity.

2.6 Parameterization of pre-spawning fitness and identification of climate preferendum through models

Statistical analyses were carried out in the R-software (R Core Team, 2015). A two-step analysis was strategized (Sarkar et al., 2017). First, a parameter coined as pre-spawning fitness ($K_{\text{spawn50}}$) was conceptualized, and it is defined as the threshold condition factor (fitness) beyond which more than 50% of the population may attain readiness for spawning. The parameter is aimed to serve similarly like that of length at 50% maturity ($L_{50}$) and threshold GSI for breeding in the subject of reproductive biology of fishes. For this purpose, a binary coding strategy was employed. Fishes (females) in mature and ripe gonadal maturity stage were coded as ‘1’ as they were assumed to be ready to spawn while fishes in immature, maturing and spent stage were coded as ‘0’. The rationale behind spent stage not coded as ‘1’ was to avoid dampening of pre-spawning fitness estimates (condition factor) by the model, as spent individuals tend to have condition factor similar to immature individuals (Gupta and Banerjee, 2013; Hossain et al., 2006). $K_{\text{spawn50}}$ was quantitatively estimated by applying non-parametric Kaplan-Meier method for survival analysis (Kaplan and Meier, 1958). The rationale of using this technique has been clarified above.

Secondly, an attempt was made to identify the thermal and precipitation window (climate preferendum) in which the $K_{\text{spawn50}}$ is attained by the fish. Widely used LOESS smoothing technique, also known as locally weighted scatterplot smoothing (Cleveland et al., 1992), was applied to map the climate preferendum for attainment of estimated $K_{\text{spawn50}}$. Here, the climatic factors (temperature, rainfall) were taken as independent variable while condition factor as dependent variable. Generated LOESS fit curves presented in a graph were visually inspected to identify optima and/or trend of response in condition factor against selected climatic variables (Sarkar et al., 2017).

2.7 Egg parameters

Range of egg parameters viz. total fecundity, egg weight and egg diameter at the pre-spawning stage were estimated from the preserved ovaries of mature and ripe females (i.e. the fishes coded as 1 for modeling purpose, see above). For the estimation of fecundity, the ovaries of mature females were weighed; three sub samples were taken from the front, mid and rear sections of each ovary and weighed. Then the total number of oocytes in each ovary sub sample (F1, F2, F3) was estimated and converted to absolute fecundity values using the equation, $AF = [(\text{Gonad weight} \times \text{number of oocytes in the sub-sample})/\text{sub-sample weight}]$. Later, by taking the values of three sub-sample derived absolute fecundities (AF1, AF2, AF3), the final absolute fecundity ($AF_T$) for each female fish was estimated from the average $AF_T = (AF1 + AF2 + AF3)/3$. All eggs in the subsamples were counted manually (Rahman et al., 2016). A
total of 100 eggs from the anterior, middle, and posterior portions of the ovary were randomly selected and the diameters of the intra-ovarian eggs were microscopically measured using an optical image analysis system. Mean egg diameter was derived from the individual measurements of 100 eggs and expressed in mm. The mean egg weight was determined by weighing the randomly selected 100 eggs using a mini scale with hundredth gram resolution and expressed in mg (Gueye et al., 2012).

2.8 Size at maturity

First maturity was considered to be the size of the smallest mature fish encountered, which may be regarded as a gross estimation of size at first maturity (Ainsley et al., 2011). Size at 50% maturity ($L_{50}$) was also calculated through Kaplan-Meier estimate like that of pre-spawning fitness using binary response variable (mature = 1, immature = 0) with total body length of individuals (Ainsley et al., 2011).

3 Results

3.1 Breeding phenology

In the present study, a prolonged breeding period of J. coitor was observed at Triveni from June to January covering two distinct season, i.e. southwest monsoon (June–September) and autumn–winter (October–January). At Patna and Farakka, the fish was found to breed only once a year for a shorter span during February–April (spring) and March–May (spring–summer), respectively (Fig. 2).

3.2 Climato-hydrological influence and threshold GSI

Following VIF value screening and eliminating multicollinearity among the climato-hydrological variables, only eight parameters namely water temperature, free carbon dioxide, pH, rainfall, dissolved oxygen, alkalinity, nitrate and conductivity have been identified to be the independent variables that sufficiently described the environmental influence on gonadal maturity and spawning of J. coitor. Data analysis using multiple linear regressions with place effect taken into consideration had revealed that only water temperature has crucial influence on gonadal maturity and breeding of J. coitor (Multiple R-squared: 0.302; p-value: <0.01). Water temperature had significant ($p < 0.05$) negative relationship with gonadal maturity and was observed to have maximum impact ($r^2$ value: 5.76) on breeding. ANCOVA revealed that the environmental influence on breeding (i.e. mainly temperature influence on GSI) was significantly different ($p < 0.01$) in Triveni stock from others (Patna and Farakka). In between Patna and Farakka stock, no such significant statistical difference was observed. In nutshell, this difference may be visualized as – Patna-Farakka stock as one group and Triveni stock as a different group. This also partly explains the interpretation of spatial differences in breeding season of the species between Patna-Farakka and Triveni stock, presented in previous section; a potential future research area (discussed below).

GAM model (between water temperature and GSI; with Place effect diagnostics) revealed water temperature near 23–25°C (Adj. R-sq.: 0.46; Deviance explained: 48%; GCV: 1.5917) as optimum for breeding, irrespective of spatial differences (Fig. 3). Further, the LOESS smoothing revealed the effect of spatial location on the GSI-temperature and $K$-temperature relationship (Fig. 4). Both the relationships were similar at Patna and Farrakka. Triveni showed relatively higher GSI and $K$ values as compared to Patna-Farakka, within the temperature range between 23°C and 30°C. At other places, the optimum ranges of GSI and $K$ seem to be attained between the temperatures 22–28°C, from the cross inspection of data points in addition to the trendline since the variation is not as prominent as in the case of Triveni (Fig. 4).

Irrespective of spatial differences, it was also observed that females of J. coitor having GSI values above 3 units could be considered as ready for spawning (Breeding event=1), as shown by the GAM (Adj. R-sq.: 0.721; Deviance explained: 72.9%; GCV: 0.045373) (Fig. 5). In this model, the binary coded Breeding Event was considered as response variable, while GSI was considered as explanatory variables. GAM was used to predict probability of breeding as a function of GSI. Being non-parametric, GAM does not assume any form of the function. It can be

Fig. 2. Annual trend of female GSI of J. coitor along various stretches of river Ganga.

Fig. 3. GAM models showing optimum water temperature for breeding of J. coitor.
contemplated that chance of Breeding Event will increase with the increase of GSI and thereafter attenuate to a plateau. The threshold value of GSI at which the function attained plateau was identified as the threshold GSI value of breeding. The GSI values of Triveni stock were found to be significantly different ($p < 0.01$) from that of Patna and Farakka stock, as it remained high for most part of the year at Triveni.

### 3.3 Pre-spawning fitness and climate preferendum

The $K_{\text{spawn50}}$ in female *J. coitor* was estimated at 1.31 (median) and the corresponding 95% confidence interval (C.I.) was found to be in the range between 1.27 and 1.37 units (Fig. 6). The red horizontal line in the figure denotes the threshold condition factor (fitness) beyond which more than 50% of the population may attain readiness for spawning. Furthermore, the average egg diameter, egg weight and absolute fecundity at this stage ranged between 0.29 and 0.80 mm (mean $0.39 \pm 0.01$ mm), 0.05–0.19 mg (mean $0.11 \pm 0.01$ mg) and 5687–121 849 eggs (mean $25 369 \pm 2414$ eggs) respectively. Overall, the recorded $K$ values of female ranged from 0.61 to 1.71 units.

An attempt was also made to identify the thermal and precipitation window in which $K_{\text{spawn50}}$ is attained by the fish irrespective of spatial differences. Identification of thermal preferendum revealed no particular temperature range that may be considered optimum for attainment of $K_{\text{spawn50}}$ due to the under-fitted nature of the model (significant but weak correlation; $r = 0.185$, $p < 0.01$). However, extrapolated interpretation of the model hints water temperatures $<20 ^\circ C$ and $>32 ^\circ C$ to be detrimental for attainment of pre-spawning fitness. This under-fitting nature of the thermal preferendum model may be due to two reasons. Firstly, the single variable (i.e. water temperature) could not explain the variability in $K$ values, as multiple drivers may influence the pre-spawning fitness. Lastly, it may be due to the ability of coitor croakers to breed during all seasons of the year across a wide thermal regime, along the river gradient. Similarly for precipitation (rainfall), no particular range could be identified due to under-fitted nature of the model (significant but weak correlation; $r = 0.140$; $p < 0.01$). Extrapolated interpretation hints no dependence of the species on rainfall, as it seems to attain $K_{\text{spawn50}}$ both during no rainfall (0 mm/month) and extreme rainfall (900 mm/month) conditions (Fig. 7).

### 3.4 Size at maturity

In the present study, first maturity of females was encountered at 11.4 cm within the size range 7.2–28.5 cm. The $L_{50}$ with 95% C.I. was found to be 19–24.5 cm (median 19.7 cm), beyond which there is more than 50% chance of encountering a mature female (Fig. 8). The minimum and maximum total body length of females encountered during this study was 7.2 cm (at Patna) and 28.5 cm (at Triveni), respectively.
Discussions

4.1 Breeding phenology

J. coitor has been described to be amphidromous in nature which also implies that the species being eurythermal and euryhaline tends to survive in both marine and freshwater environment (Fishbase, 2016). The high spatial variation observed in breeding periodicity along different stretches of river Ganga may be indicative of high adaptative potential existing within the species. The prolonged breeding season of Triveni stock may be attributed to the nearness of the sampling station from the river mouth or Bay of Bengal (Fig. 1), as sexually mature individuals from brackishwater/marine zone might have been encountered in addition to the individuals that gained sexual maturity exclusively in freshwater. This remains to be a researchable issue whether the adults of J. coitor from brackishwater/marine zone are capable of retaining gonadal morphology for most part of the year while adults in freshwater condition attain maturity only during a particular season (late winter/pre-monsoon). Review of literature revealed no historical record of breeding period for this fish species except one observation recently by Rizvi et al. (2015) from upper stretch of river Ganga (Allahabad) where it was stated that J. coitor breeds in three pulses (maximum July-September > January-May > October-December minimum) throughout the year; different from our observations in Patna-Farakka stretch but similar to Triveni stretch. Such high spatial variations in breeding season have been documented by Kumar et al. (2013) in a phylogenetically close relative J. carutta from Indian waters.

4.2 Climato-hydrological influence and threshold GSI

The reproductive consistency of the species seems to be interrupted as water warms up beyond 26°C which is evident from the prediction belt of the developed GAM model dipping downwards and touching or penetrating '0'. The sub-zero projections of GSI in the model can be ignored which was due to lack of data support in some particular temperature ranges. Lyons et al. (2015) reported water temperature around 11.2°C as the breeding threshold for Yellow perch Perca flavescens. In Lake Erie, spawning in Yellow Perch was stressed in the spring due to shorter, warmer winters (Farmer et al., 2015). Similarly in Atlantic salmon, elevated temperature during gametogenesis hindered gonadal steroid synthesis, vitellogenin production, and estrogen receptor dynamics, thus reducing female gonadal investment and gamete viability (Pankhurst and King, 2010). Schneider et al. (2010) stated that warmer water has reduced Walleye recruitment in Oregon. Previously published information on climato-hydrological influences on gonadal maturity and breeding of J. coitor is absent. There is ample evidence that water temperature has the potential impact on fish reproduction as it has a strong correlation with gonadal maturity (Lam, 1983; Mylonas and Zohar, 2007; Houde, 2008). Importance of temperature in the modulation of post-fertilization processes in fishes is also well documented (Takasuka et al., 2007; Shoji et al., 2011). Thermal preferendum vary among fish species and life stages, with larval and maturing or spawning fish typically being the most sensitive (Pörtner and Peck, 2010). Photothermal cues stimulate the onset of gamete development in fish as the spawning seasons occur within a photoperiod window but commencement of spawning is controlled by species-specific water temperature thresholds (Whitney et al., 2016). Peer and Miller (2014) reported that phenological changes in spawning behavior of fish are occurring in response to rising global temperatures. In the present study, temperature alone seems to regulate gonadal maturation and breeding of J. coitor since any significant effect of rainfall could not be identified. In this
purview, rising temperatures along Ganga river basin (0.2–0.5 °C rise in mean air temperature during 1980–2015 (Sharma et al., 2015)) and regional trends of warming climate (rate of increase higher in the upper, middle stretches compared to lower Gangetic stretch (CIFRI, 2016)) may initially appear to be a potential driver behind inflicting changes in breeding phenology of coitor croakers. However, this might not be the case in reality since (a) such meager rise in mean air temperature might not be enough for causing any changes; (b) due to high latent heat capacity of water, corresponding rise in water temperature may be far less and will not match with rise in air temperature; (c) being a bentho-pelagic species, ambient temperature of its surroundings may always remain colder than the relatively warmer surface waters. Another advantage is the amphidromous (migratory) nature of coitor croakers itself. For example — in order to avail pelago-benthic waters with optimum near surface temperatures (near 23–25 °C) for attainment of breeding GSI (>3 units), there is a probability that the fishes may cover large distances to access such suitable habitat conditions for breeding. Now it remains to be researchable issue whether the same stock migrates from place to place along the river gradient in pursuit of such suitable habitat conditions that result in such spatial differences of breeding season. A detailed telemetry based study of life history stages of J. coitor is required to examine this particular probability. Furthermore, as the species have the ability to breed during all seasons of the year, i.e. pre-monsoon, monsoon, post-monsoon and winter as observed in the present study (Fig. 2); J. coitor seem to have high adaptive potential in terms of spawning behavior over a wide spatial scale. In this light, we suspect minimal or no climate driven changes in breeding phenology of this amphidromous fish species. Our study hints towards the climate resilient nature of J. coitor in terms of reproduction. In the absence of any historical data on breeding season of this species except Rizvi et al. (2015), further research is required to validate the present hypotheses.

No previous information on the threshold GSI for breeding of the species is available. Interestingly, in a phylogenetically close relative J. carutta from Indian waters the peak breeding season was observed to be coinciding with GSI values reaching above 3 units (Kumar et al., 2013).

4.3 Pre-spawning fitness and climate preferendum

A gradual increase of the condition factor indicates the increased deposition of fat as a result of the adaptability and high feeding activity of the individuals for the development of the gonads (Venkateshwarlu et al., 2007). Fulton’s (K) condition factor show apparent variation in different seasons. Based on experiments with Esomus danricus, Amblypharyngodon mola, Pethia ticto and Glossogobius giuris, Alam et al. (2013) opined that the fishes in pre-spawning phase show maximum robustness due to availability of food and suitable environmental condition. The K tends to increase with increasing gonad weight which reaches maximum just before the spawning period and then dropped during the spawning month due to loss of gonadal products (Hernandez et al., 2003; Kiran and Puttaiah, 2003; Gupta and Banerjee, 2013). According to Jørgensen et al. (2006), sexually mature fish skip reproduction, especially in response to poor condition or fitness which signifies the importance of attaining a minimum pre-spawning fitness. A threshold condition factor is essential for the population to spawn under natural conditions as more stored energy allows for more eggs being spawned (Jørgensen and Fiksen, 2006). Moreover, the recruitment potential of natural fish stocks was found to be positively correlated with K (Rätz et al., 2000). On a comparative account, female coitor croakers seem to spawn at a higher fitness level than the females of some catfishes from river Ganga whose pre-spawning fitness estimates are lower than that of J. coitor — viz. Mystus tengara (1.13–1.21 units), M. cavsius (0.846–0.954 units), Eutropiichthys vacha (0.716–0.779 units) as reported by Sarkar et al. (2017).

In the present study, water temperatures <20 °C and >32 °C was projected to be detrimental while rainfall seemed to have no effect. In the presence of such a wide thermal preferendum (20–32 °C) for maintenance of requisite pre-spawning fitness, the natural breeding of J. coitor do not seem to be at high risk on the face of warming climate along river Ganga (reported in CIFRI, 2016; Sharma et al., 2015). Temperature has been related to inter-annual fluctuations in condition of cod off Greenland (Lloret and Rätz, 1999), and has been demonstrated to influence growth and recruitment of different cod stocks (Jørgensen, 1992; Brander, 1995; Rätz et al., 1999). Hossain et al. (2006) attributed the variation observed in condition of M. vittatus to the seasonality of the flooding cycle related to the monsoons that rule the reproductive cycle and growth of fish species in Bangladesh. This climatic preference (both temperature and rainfall) for attainment of required fitness before spawning has also been opined by Craig et al. (2004). Interestingly, the thermal window for attainment of requisite pre-spawning fitness in females of some catfishes from river Ganga viz. M. tengara (31–36 °C), M. cavsius (30–32 °C), E. vacha (29.5–31 °C) seem far narrower than that of female coitor croakers (Sarkar et al., 2017).

From a physical perspective, fishes in general tend to closely follow cube law in terms of body growth pattern in three-dimensional space but deviate from it during extraordinary events of their life like spawning, adverse conditions and food scarcity (Froese, 2006). In the presence of a subtle, long term and irreversible stressor like climate change (changes in thermal, precipitation, flow, hydro-period, etc. regimes) such ideal scenario of complying to cube law might silently disappear and become virtually non-existent; more specifically during the phases when fish species are adapting themselves to new patterns of climate in a region. As a result, the deviations from cube law might covertly manifest in the population and may have implications on future natural selection (evolution) of the species in-situ. The present parameters, pre-spawning fitness (K spawn50), along with its reference data of climate preferendum for attainment of K spawn50 can aid in tracking such deviations in future (Sarkar et al., 2017). From a nutritional perspective, climate change can also influence pre-spawning fitness of fishes indirectly through food chain. Pankhurst and Munday (2011) opined changing climate can modulate changes in availability of natural fish food organisms in the aquatic environment; reduction in most cases. If the temporal availability of food items did not shift in the same manner (asynchronous) as fish reproduction, mismatches between predator-prey might lead to reduced growth, starvation (Krabbenhoft et al., 2014); might also lead to skipped
spawning (Jorgensen et al., 2006), increased or reduced pre-spawning fitness in adults.

Based on some recent reviews (Crozier and Hutchings, 2014; Lynch et al., 2016; Whitney et al., 2016) it is apparent that climate change and its impact on reproductive biology of fishes have multiple dimensions. It includes changes in breeding phenomenology, length at first maturity, fecundity, skipped spawning and evolutionary adaptations through natural selection of adults or larvae in response to changing environmental cue, primarily water temperature and flow pulse or precipitation. In the Indian scenario, region-specific adaptation in reproductive phenomenology based on local trends of changing climate along river Ganga has already been suspected and documented for some fishes (Sharma et al., 2015; CIFRI, 2016). Additionally, an advancement of breeding season in Indian major carps (Catla catla, Labeo rohita, Cirrhinus mrigala) by 2–3 months, decrease in age at first maturity in female Rainbow trout Oncorhynhus mykiss (from 3+ years to 2+ years) and reduction in length at first maturity of female Tenuolosa ilisha (30.9–34.1 cm) have been documented from Indian waters (Sharma et al., 2015). We hypothesize that in the presence of changing length at first maturity, reproductive phenology and evolutionary adaptations of fishes under changing climate, the minimum fitness (condition factor) required for spawning successfully at individual or stock level may also be changing. This changing pattern may have evolutionary implications and should be an area of interest for future research. The present body of knowledge on climate research although takes various aspects of fish reproductive biology into consideration but information on the climate driven changes on pre-spawning fitness indices are scanty. It implies the parameter of parameterization and benchmarking of pre-spawning fitness ($K_{spaw50}$) in addition to other conventional reproductive biology parameters in this study. Accordingly, the present study generated baseline information on $K_{spaw50}$ of female coito r croakers and is aimed to inoculate thought process on this aspect. Similar information may be generated for other species replicating the innovative methodology used in this study. The data generated may serve as future references while assessing climate driven changes on reproduction and evolutionary adaptations (changes through natural selection) of croakers in river Ganga.

4.4 Size at maturity

Only one previous record of $L_{50}$ (range 11–12 cm, median 11.5 cm) of J. coitor have been reported from upper stretch of river Ganga (Rizvi et al., 2015) as a part of stock assessment study; interestingly matching with our first maturity estimate (11.4 cm) that we assessed in addition to $L_{50}$. However it is not clear whether male or female or pooled data of J. coitor was used by Rizvi et al. (2015) for estimation of $L_{50}$. Moreover Rizvi et al. (2015) seemed to use an in-situ gill netting experiment during peak breeding season of the species and used probability of capture as a parameter for indirect estimation of $L_{50}$, in contrast to the present study where a maturity coding strategy was followed for year round samples and first maturity was given separate emphasis from $L_{50}$ (length at >50% chance of encountering a mature female) following Ainsley et al. (2011). The present estimate of female $L_{50}$ exceeds the estimate (sex not-specified) given by Rizvi et al. (2015). However, the present estimates of female coitors are comparable to the ones given for small sciaenids (15–17 cm) by Rao et al. (1992) and a close relative J. carutta (14–17.5 cm) given by several authors over the years from Indian marine waters (reviewed in Kumar et al., 2013). Kumar et al. (2013) attributed the differences observed in size at maturity estimates due to the sampling process, influence of environmental factors and availability of food supply.

5 Conclusion

Information on various aspects of reproductive traits of J. coitor from freshwater stretches of river Ganga was generated for the first time that too in relation to climatic variability. High spatial variation in breeding season was observed. Temperature alone seem to regulate gonadal maturation and breeding in J. coitor. Pelago-benthic waters with optimum near surface temperatures (near 23–25°C) may be regarded as ideal habitat conditions for attainment of breeding $GSI$ (>3 units) in female coitor croakers. The species seem to maintain requisite pre-spawning fitness ($K_{spaw50}$) within a wide thermal range (20–32°C) during which mere availability of suitable habitat conditions (discussed above) may straightway induce successful spawning decisions. In general, J. coitor seem to have high adaptive potential in terms of spawning behavior over a wide spatial scale. We hypothesize minimal or no climate driven changes in breeding phenomenology of this amphidromous fish species. Results of the present study, especially the biological thresholds ($K_{spaw50}$, sizes at maturity, threshold $GSI$ for breeding), may serve as baseline information for future references while assessing climate driven changes on reproduction and evolutionary adaptations in croakers from river Ganga basin.

Acknowledgement. Authors are thankful to the Director, ICAR-Central Inland Fisheries Research Institute, Barrackpore. The financial help of Indian Council of Agricultural Research (ICAR) for funding in the project National Innovations in Climate Resilient Agriculture (NICRA) is also gratefully acknowledged. Authors also gratefully acknowledge the help of anonymous reviewers for reviewing this article.

References

Anon. 2016. Information gathered from fisher folk and market during the study period through personal communication.


Qasim SZ, Qayyum A. 1962. Spawning frequencies and breeding seasons of some freshwater fishes with special reference to those occurring in the plains of northern India. Indian J Fish 8: 24–43.


Cite this article as: Sarkar UK, Naskar M, Roy K, Sudheesana D, Gupta S, Bose AK, Srivastava PK, Nandy SK, Verma VK, Sarkar SD, Karnatak G. 2018. Baseline information of reproduction parameters of an amphidromous croaker Johnius coitor (Hamilton, 1822) from Ganga river basin, India with special reference to potential influence of climatic variability. Aquat. Living Resour. 31: 4