Wiley
Journal of Applied Ichthyology
Volume 2024, Article ID 5556553, 10 pages
https://doi.org/10.1155/2024/5556553

WILEY

Research Article

***Bangana devdevi*, a Native Carp of the Himalayan Biodiversity Hotspot: Reproductive Biology and Hormonal Breeding Efforts for Conservation and Aquaculture Promotion**

Yumnam Bedajit,[1,2] Surajkumar Irungbam,[1,2] Soibam Ngasotter,[2,3] David Waikhom ,[2,3] Maibam Malemngamba Meitei,[2,3] Sanjenbam Bidyasagar Singh,[2,3] Wangkheimayum Malemnganbi Devi,[2] Soibam Khogen Singh ,[2,4] Pronob Das ,[5] and Soibam Basanta Singh[6]

[1]*Central Agricultural University, Lamphelpat, Imphal 795004, Manipur, India*
[2]*College of Fisheries, Central Agricultural University, Agartala 799210, Tripura, India*
[3]*ICAR-Central Institute of Fisheries Education, Mumbai 400061, Maharashtra, India*
[4]*Krishi Vigyan Kendra, ICAR-Research Complex for NEH Region, Manipur Centre, Ukhrul 95142, Manipur, India*
[5]*ICAR-Central Inland Fisheries Research Institute, Regional Centre, Guwahati 781006, Assam, India*
[6]*Directorate of Instruction, Central Agricultural University, Imphal 795004, Manipur, India*

Correspondence should be addressed to Soibam Khogen Singh; gengang@gmail.com and Pronob Das; pronob.das@icar.gov.in

Received 6 February 2024; Revised 4 July 2024; Accepted 5 July 2024

Academic Editor: Mohamed Abdelsalam

Efficient conservation efforts for valued fish species such as *Bangana devdevi*, a medium-sized minor carp prevalent in Southeast Asian countries, can be facilitated through well-established artificial breeding techniques. This study aimed to investigate the reproductive biology of *B. devdevi* and focused on optimizing hormone dosages for breeding purposes for the first time. The research findings indicated that the highest gonadosomatic index (GSI) for males (1.17) was observed in August, while for females, it peaked in July (2.24). Female fish exhibited absolute fecundity ranging from 2089 to 26287 eggs, corresponding to body weights ranging between 10.46 and 153.73 g. The relative fecundity ranged from 170 to 298 eggs g^{-1} of body weight. To induce breeding, female brooders were administered Gonopro-FH hormone through three experimental groups: G-FH_0.4, G-FH_0.5, and G-FH_0.6, with doses of 0.4 mL, 0.5 mL, and 0.6 $mL{\cdot}kg^{-1}$ of body weight, respectively. Spawning occurred within 6–10 h after hormone administration. Among these groups, G-FH_0.5 exhibited the highest fertilization rate (94.25%) and hatching rate (89.03%), significantly surpassing the rates observed in G-FH_0.4 and G-FH_0.6 ($p < 0.05$). This study provided valuable insights into the reproductive biology of *B. devdevi* and emphasized its potential application in developing management and conservation strategies for this species in rivers and tributaries. Furthermore, the knowledge gained from induced breeding holds promise for future large-scale seed production initiatives.

1. Introduction

Based on Mukherji's collection of Burmese and Siamese specimens, *Bangana devdevi*, previously known as *Labeo devdevi*, was described while disputing the identity of *Labeo dyocheilus* and *Labeo dero*. Kottelat reassigned *L. devdevi* to the genus *Bangana* [1, 2]. According to the IUCN categories specified in the Red List, it is classified as Least Concern (LC) [3]. *B. devdevi* is a medium-sized, benthopelagic minor carp of the Cyprinidae family that inhabits Southeast Asian nations such as India, Myanmar, and Thailand [4]. It is one of India's most popular valued minor carp and is broadly distributed in the Chindwin headwaters of Manipur, a northeastern state [5]. This species is known as "*Khabak*" in Manipuri for yearling and advanced stages and "*Ngaton*" for fingerling stages. The deep, transverse groove across the top of the snout is the key diagnostic feature of this species. The body of an adult is oblong and compressed. It can grow 30 cm long and is often caught in rivers using cast nets and dip nets during the postmonsoon season. *B. devdevi*'s distinct sexual dimorphism is fully established and often noticed during the breeding season. When handled with a bare hand, a mature male's pectoral fin is rough, whereas a mature female's pectoral fin is smooth. Males mature at 2+ years and are ready for breeding.

The natural populations of various medium and minor carp fish species have experienced significant declines, with some teetering on the brink of endangered or near-threatened status. Notably, species like *Labeo bata* and *Osteobrama belangeri* (Pengba) have transitioned from lower-risk classifications to near-threatened or even critically endangered statuses in their wild habitats [6]. To address this pressing conservation challenge, there is an urgent call to bolster their populations through standardized breeding and rearing practices in controlled captive environments.

In this context, Behera et al. [7] experimented on the induced breeding of *L. bata*, a minor carp species. They evaluated two commercial inducing agents, Ovatide and Ovaprim, administered at 0.5 mL·kg^{-1} body weight in both male and female fish. Their findings revealed that the highest number of eggs was released using an Ovaprim dose of 0.5 mL·kg^{-1} for females and 0.2 mL·kg^{-1} for males, along with an Ovatide dose of 0.4 mL·kg^{-1} for females and 0.2 mL·kg^{-1} for males. Similarly, controlled captive breeding of another minor carp species, *Labeo gonius*, using an Ovaprim dose of 0.5 mL·kg^{-1} of female and 0.2 mL·kg^{-1} of male body weight, resulted in a fertilization rate of 89.3% and a hatching rate of 85.2% [8]. Ovatide comprises a synthetic analogue of gonadotropin-releasing hormone (GnRH) and a dopamine antagonist, while Ovaprim consists of an analogue of salmon gonadotropin-releasing hormone (sGnRHa) and dopamine inhibitor targeting brain neurotransmitters [7].

Medium carp species like *O. belangeri* have also been successfully bred in captivity using WOVA-FH (containing sGnRHa and domperidone) at a dose of 0.5 mL·kg^{-1} of female and 0.2 mL·kg^{-1} of male body weight, resulting in impressive fertilization and hatching rates of 91.7% and 85.0%, respectively [9]. These species can also be bred using various inducing agents other than WOVA-FH, such as carp pituitary extract (CPE) or synthetic hormones like Ovaprim and Ovatide [10]. Synthetic hormones have shown greater efficacy compared to CPE. Furthermore, Udit et al. [11] achieved remarkable results with another medium-sized carp species, *Puntius sarana*, using Ovatide at a dose of 0.2 mL male^{-1} (180 g) and 0.3 mL female^{-1} (232–240 g), resulting in fertilization and hatching rates of 90.5% and 75.39%, respectively.

Analyzing fish biology is crucial for gaining insight into various aspects of fish life cycles, including migration, distribution, fishery management, and conservation [12]. Research focusing on fish reproduction, such as evaluating size at first maturity, fecundity, daily spawning behavior, spawning fraction, and duration of the reproductive season, provides valuable information about the reproductive capacity of specific fish species [13]. Due to its significant demand in local markets, particularly in Manipur, Northeast India, *B. devdevi* is considered an economically important species, often commanding a price nearly three times higher than that of Indian Major Carps (IMC). Consequently, there is an urgent need to study and develop induced breeding strategies to produce high-quality seeds of this species to meet the growing market demand. To the best of our knowledge, no prior investigations have been conducted on the reproductive biology and optimization of hormone dosage for breeding *B. devdevi*. Therefore, the present study aims to explore reproductive biology and establish standardized induced breeding protocols to optimize the effective dosage of a commercially available synthetic hormone (Gonopro-FH, manufactured by Hemmo Pharmaceuticals Pvt. Ltd., Maharashtra, India), composed of gonadorelin A, domperidone BP, and benzyl alcohol, in *B. devdevi* to assess its efficacy in fertilization, spawning, and hatchability in captivity.

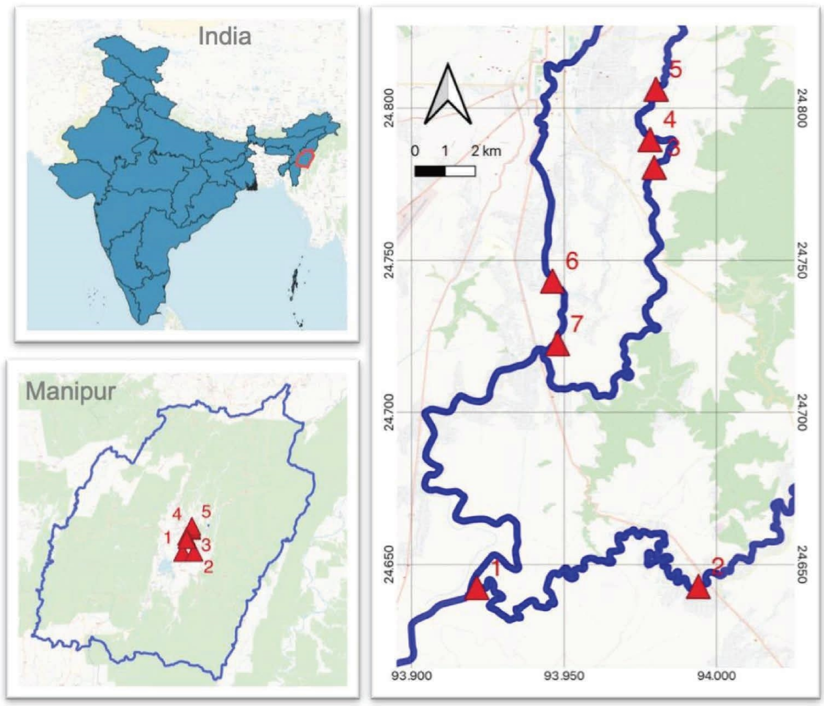
2. Materials and Methods

2.1. Collection of Fish. Specimens of *B. devdevi* were collected from the Thoubal River, Iril River, and Imphal River, all tributaries of the Manipur River in Manipur, India. Samples were collected monthly for a period of two years, from October 2015 to September 2017, using cast nets, dragnets, gill nets, and bamboo traps. The geographical details of the sampling sites along these rivers are shown in Figure 1.

2.2. Length at First Maturity. The minimum size at which a fish attains its first maturity was determined by examining the maturity stages. Following Grier [14], female specimens at maturity stages III and above were considered mature. Cumulative frequency was plotted against length groups. The length at first maturity was defined as the size at which 50% of the fish in a population reached sexual maturity.

2.3. Reproductive Biology. Samples were collected monthly for a detailed investigation of reproductive biology. However, due to the insufficient sample size caused by the scarcity of this species in the rivers of Manipur, we pooled data from the two years and analyzed the reproductive biology collectively. To study fecundity and ova size, ovaries were preserved in 5% formaldehyde, and Gilson's fluid was used to separate ova.

2.3.1. Spawning Season. Maturity stages were segregated based on the different parameters, including colour, shape, ovary size, and body cavity space, to study maturity and spawning season. Further, ova diameter and yolk deposition in the ova were considered to recognize the different maturity stages for females. Different ovary maturity stages were determined using the method of Tamhane and Somvanshi [15] as immature, maturing, mature, ripe, and spent.



▲ Sampling locations. 1,2=Thoubal River; 3,4,5=Iril river; 6,7=Imphal river

Figure 1: Location details of the sampling area along different rivers of Manipur, India.

For two years, the percentage of incidence of different phases of maturity in various months was explored. The presence of ripe specimens in the acquired samples was used to determine the spawning season.

2.3.2. Spawning Periodicity. Both Clark [16] and Prabhu [17] illustrated the measurements of the ova diameter of intraovarian eggs recorded from preserved ovaries. For ova diameter studies, ten mature ovaries were taken for each fish. The ova were taken out of the anterior, middle, and posterior areas and were investigated to understand the differential egg distribution pattern. At least 1000 eggs from each ovary were analyzed to rule out any possible misrepresentation of various stages of development. A Leica DFC 425 camera fitted on Leica S8APO stereo zoom microscope was used to measure ova diameter. The frequency polygons were generated using the measured ova diameters divided into class intervals into 0.01 mm divisions.

2.3.3. Gonadosomatic Index (GSI). The weight of each specimen was collected to the closest gram to examine the GSI, and the weight of the gonad was also documented every month following dissection. The following equation was used to enumerate the ratio of month-wise and sex-wise [18].

$$\mathrm{GSI} = \frac{\text{Weight of the gonad}}{\text{Total body weight}} \times 100. \tag{1}$$

2.3.4. Fecundity. The gravimetric method was utilized to study fecundity following the method of Hunter and Goldberg [19]. Ten mature ovaries (preserved in 5% formaldehyde) were used for fecundity estimation. Gilson's fluid was applied for the ova separation. Moreover, it was evaluated by summing the number of mature ova from a specific weight of mature ovary, i.e., 0.1 g of subsamples was taken from three different parts (anterior, middle, and posterior) of each ovary. The number of mature ova was counted after the subsamples were dispersed uniformly on a counting slide along with two or three drops of water. The following formula was used to calculate fecundity using an average of three subsamples:

$$\text{Fecundity} = \frac{\text{Number of ova in the subsample} \times \text{Total ovary weight}}{\text{Weight of the sample}}. \tag{2}$$

Relative fecundity, i.e., the number of eggs g^{-1} of body weight (unit body weight or ovary weight), was achieved by dividing absolute fecundity with the total weight of fish. To establish the relationship of fecundity "*F*" with total length "TL" and body weight "TW," the following formula was used [20]:

$$F = aL^b,$$
$$F = aW^b, \tag{3}$$

where a and b are constants; L is the total length in mm; and W is the body weight in g.

The least-square method was employed to estimate the correlation coefficient between fecundity and total length and also between fecundity and body weight.

2.3.5. Sex Ratio. The sex ratio is believed to be 1 : 1 in nature. However, inequality in sex ratio is frequently noticed in fish due to the opposite sexes' behavior, environmental conditions, fishing methods employed, and bias in sampling [21].

To study the distribution of sexes as per season and size, the sex ratio of females and males was noted for two whole years, and later, data were combined. The ratio of females to males was calculated monthwise and lengthwise. Here, the chi-square test was employed to determine the homogeneity of the sex distribution [22] by applying the following formula:

$$X^2 = \frac{(O - E)^2}{E}, \tag{4}$$

where "O" represents observed frequencies and "E" represents expected frequencies.

2.4. Induced Breeding

2.4.1. Broodstock Collection and Maintenance. Fish collected from the sampling sites were shifted in a well-aerated Hundi (vessels used for fish transport) and underwent an acclimatization phase within the central farm pond at the premises of the Central Agricultural University (Imphal), located in Lamphelpat, Imphal West District, Manipur, India. This specific site served as the experimental location. Subsequently, the fish were reared within a specialized brooder pond. They were provided with a formulated floating feed, primarily consisting of fish meal, which was administered at a rate of 3% of their body weight per day. This feed formulation contained 32% protein and 5% lipid content. This feeding regime was consistently maintained and monitored until the onset of the breeding season. In preparation for induced breeding, the females and males were housed separately in individual tanks for approximately one month. This arrangement was made to ensure optimal conditions leading up to the impending induced breeding activities.

2.4.2. Experiment Designs. The breeding experiment was conducted in June 2018, coinciding with the early monsoon in India, which is the best suitable time for breeding of carp [23]. For this investigation, the brooders were caught by netting from the earthen (brooder) pond and transferred to fiber-reinforced plastic (FRP) tanks for acclimatization for around 5-6 h. Three distinct experimental groups, viz. G-FH_0.4, G-FH_0.5 and G-FH_0.6 were given corresponding to the three individual doses of hormone Gonopro-FH, i.e., 0.4 mL, 0.5 mL, and 0.6 $mL{\cdot}kg^{-1}$ body weight, respectively, for females. Males were given half doses of females. The positive control group (P_CTRL) was injected with crude pituitary extract (CPE) with an initial dose of 2 $mg{\cdot}kg^{-1}$ body weight of female fish. Then, 4 $mg{\cdot}kg^{-1}$ bodyweight of female fish was injected as the final dose after 6 h. A single dose of CPE was administered to males at 4 $mg{\cdot}kg^{-1}$ body weight. Finally, a negative control group (N_CTRL) was maintained that received no hormone injection.

2.4.3. Selection of Broodfish. Each experimental group consisted of twelve fish, comprising four females and eight males, maintaining a 1 : 2 (female: male) ratio. There were four replicates in each group. The experiment utilized fully matured females weighing 65 ± 2 g alongside males demonstrating milt oozing. The females were considered fully matured when they exhibited a swollen abdomen with easily oozed eggs upon being pressed.

2.4.4. Hormone Injection. A 1 mL graduated syringe was used to administer intramuscular injections of the required hormone doses to the males and females in each group at a 45° angle between the lateral line and dorsal fin. The brooders were randomly placed into sixteen distinct hapas installed in the farm pond immediately following the hormone injection. Following spawning, each female's fecundity was calculated by randomly selecting eggs from the total number of eggs released by the female and placing them in a 10 mL graduated measuring cylinder. The total eggs present in 1 mL were counted and multiplied by the total volume of eggs released. The rate of egg fertilization was evaluated by randomly selecting 100 eggs and placing them in a glass Petri plate. Fertilized eggs showed intact nuclei inside the clear egg cells. After spawning, the spent fishes were pulled out from each respective breeding hapa.

The water quality parameters of the breeding ponds, analyzed according to APHA (2005) [24] standards, were maintained at the following levels: water temperature at 27.36 ± 0.095°C, pH at 7.57 ± 0.032, dissolved oxygen at 6.23 ± 0.032 $mg{\cdot}L^{-1}$, total alkalinity at 110 ± 2.5 $mg{\cdot}L^{-1}$, transparency at 29.33 ± 0.398 cm, and ammonia at 0.173 ± 0.0088 mg·L^{-1}.

2.5. *Calculation*

$$
\begin{aligned}
\text{Fertilization rate }(\%) &= \frac{\text{Number of the fertilized eggs}}{\text{Total number of the eggs in a batch}} \times 100,\\
\text{Hatching rate }(\%) &= \frac{\text{Number of the eggs hatched}}{\text{Total number of the eggs in a batch}} \times 100.
\end{aligned}
\tag{5}
$$

2.6. Statistical Analysis. Statistical analysis was executed by using SPSS version 23. Analysis of variance (ANOVA) and Duncan's post hoc comparison tests were used to determine the association between the hormone dosage and several metrics, including egg production, fertilization, and hatching rate ($p < 0.05$).

2.7. Ethics Statement. The manuscript does not need an ethical approval.

3. Results

3.1. Reproductive Biology

3.1.1. Gonadosomatic Index (GSI). The monthwise distribution of the GSI is depicted in Table 1. The maximum value of GSI (1.17) was observed during August for males, whereas for females, the highest was observed during July (2.24).

3.1.2. Fecundity. The total length, body weight, and ovary weight of 10 specimens of *B. devdevi* are presented against individual fecundity in Table 2. The length of *B. devdevi* ranged from 96.3 to 237.76 mm, and body weight varied from 10.46 to 153.73 g. The ovary weight varied from 0.76 to 61.02 g. The absolute fecundity ranged from 2089 to 26287 eggs, whereas the relative fecundity ranged from 170 to 298 eggs g^{-1} of body weight.

The relationship between total length and fecundity and body weight and fecundity was established for *B. devdevi* as

$$
\begin{aligned}
\log F &= 118.9944 - 52.6391 \log \mathrm{L},\\
\log F &= 10.3661 - 4.1809 \log \mathrm{W}.
\end{aligned}
\tag{6}
$$

3.1.3. Length at First Maturity. The study on the length at first maturity is based on 22 matured females of *B. devdevi*. A maturity curve was plotted using the cumulative percentage against the length groups of mature females. Moreover, the length at which 50% of the fish attain maturity was observed to be 93 mm for *B. devdevi* (Figure 2).

Maturity stages of *B. devdevi*:

Stage I. The size ranges from 0.9 mm to 1.1 mm, with a mode at 1.02 mm.

Stage II. The average mode of mature ova falls at 1.23 mm with a maximum size of 1.3 mm.

Stage III. The size of the ova increases to a maximum size of 1.5 mm with a mode of 1.45 mm.

Stage IV. The mode shifts to 1.59 mm. There was a slight increase in ova diameter to 1.7 mm.

Stage V. Immature and maturing groups of ova have a diameter averaging from 0.96 mm to 1.72 mm. The immature eggs are widely separated from the mature ones, indicating a significant gap in their release once the mature eggs are shed.

3.1.4. Spawning Periodicity. The ova diameter study was performed to understand the spawning periodicity. The percentage of ova diameter frequency in various maturity stages of the ovary was plotted against the ova diameter. The ova diameter frequencies showed an increase in ova diameter with the advancement of maturity stages. The stagewise distribution of ova diameter is presented in Figure 3. All the mature ovaries gave bimodal distribution, showing spawning twice a year.

3.1.5. Sex Ratio. The sex ratio (female: male) recorded for *B. devdevi* was 1 : 2. The analysis of the sex ratio for the entire study period indicates the slight dominance of males over females in the studied species. The observed ratio was tested against 1 : 1 using the chi-square test for (n-2) degrees of freedom at a 1% level of significance ($p < 0.01$). The calculated chi-square value for *B. devdevi* was 0.04, indicating no significant difference in the 1% significance level ($p < 0.01$).

3.2. Induced Breeding. Table 3 displays the results of the hormone optimization for the three doses of Gonopro-FH used to induce breeding in *B. devdevi.* Among the three doses, G-FH_0.6 produced the most eggs but had the lowest fertilization and hatching rates. Compared to G-FH_0.6, G-FH_0.5 had slightly fewer eggs produced but had a noticeably greater rate of fertilization and hatching. G-FH_0.4 had the lowest egg output, fertilization rate, and hatching rate among the three treatments. Furthermore, there was no significant difference in egg production, fertilization, and hatching rates between G-FH_0.5 and P_CTRL ($p > 0.05$). The N_CTRL group did not produce any eggs because they were not administered any hormones. After injection, spawning started within 6–10 h and ended in less than 4-5 h. The unfertilized eggs were pale and opaque, whereas the

Table 1: Monthwise gonadosomatic index of *B. devdevi*.

Month	Male	Female
January	0.33	1.56
February	0.76	1.08
March	0.95	1.74
April	1.02	1.88
May	1.07	1.92
June	—	—
July	1.13	2.24
August	1.17	2.03
September	—	—
October	1.05	1.18
November	0.70	1.46
December	0.66	1.04

Table 2: Total length, body weight, ovary weight, absolute fecundity, and relative fecundity of ten specimens of *B. devdevi*.

Total length (mm)	Bodyweight (g)	Ovary weight (g)	Absolute fecundity	Relative fecundity with respect to body weight
192.07	73.66	45.11	22024	298
228	98.20	47.02	20370	207
116	15.11	0.81	2583	170
122	15.91	0.76	2830	177
96.3	10.46	0.93	2089	199
237.76	153.73	61.02	26287	170
119.53	15.93	1.14	2734	171
212.89	86.28	44.25	15738	182
159.38	44.27	1.15	7770	175
130.52	23.56	1.55	4428	188

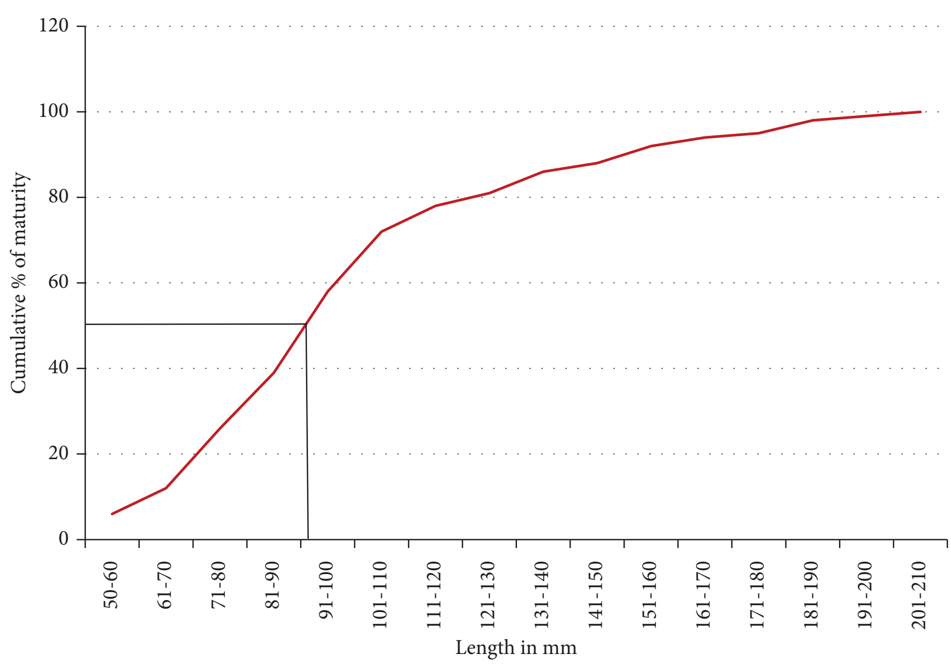


Figure 2: Length at first maturity of female *B. devdevi*.

fertilized eggs were bluish-white, translucent, and demersal. After 11–16 h of fertilization, fertilized eggs hatched out at their optimal temperature of 26.4–27.5°C. The hatchlings had a wide oval head, a prominent yolk sac, and a short tail. They were translucent in colour and ranged in length from 3.20 to 3.80 mm.

Figure 3: Percentage of ova-diameter frequency of *B. devdevi*.

Table 3: Hormone dosage optimization for Gonopro-FH to induce breeding of *B. devdevi* with carp pituitary extract (CPE) as positive control and no hormone administration as negative control.

Experimental group	Hormone dose for female ($mL{\cdot}kg^{-1}$)	Hormone dose for male ($mL{\cdot}kg^{-1}$)	Latency period (h)	No. of eggs released (,000)	Fertilization (%)	Hatching (%)
G-FH_0.4	0.4	0.2	10	10.400 ± 0.13^{b}	90.00 ± 0.40^{c}	78.93 ± 0.26^{b}
G-FH_0.5	0.5	0.25	8	12.325 ± 0.05^{c}	94.25 ± 0.63^{d}	89.03 ± 0.14^{d}
G-FH_0.6	0.6	0.3	6	12.800 ± 0.04^{d}	86.75 ± 0.63^{b}	80.35 ± 0.12^{c}
P_CTRL						
1st dose	$2\,mg{\cdot}kg^{-1}{\cdot}BW$	—	7	12.200 ± 0.09^{c}	93.75 ± 0.85^{d}	88.88 ± 0.09^{d}
2nd dose	$4\,mg{\cdot}kg^{-1}{\cdot}BW$	$4\,mg{\cdot}kg^{-1}{\cdot}BW$				
N_CTRL	0	0	0	0^{a}	0^{a}	0^{a}

G-FH_0.4, G-FH_0.5, and G-FH_0.6: experimental groups with hormone doses of 0.4 mL, 0.5 mL, and 0.6 $mL{\cdot}kg^{-1}$ of body weight (BW), respectively; P_CTRL: positive control group injected with crude pituitary extract (CPE); N_CTRL: negative control group that received no hormone injection. Different letters in the same column indicate a significant difference ($p < 0.05$).

4. Discussion

The biology of fishes begins with the development of sexual maturity and the determination of fecundity. These parameters are often evaluated for species of economic interest due to their role in population dynamics [25]. Observing seasonal developmental changes in the gonads is the most effective way to identify the reproductive cycle of female fish [26–28].

In *B. devdevi*, the GSI has been high since July-August, with the maximum fecundity observed reaching 26,287 eggs. The relative fecundity ranged from 170 to 298 ova g^{-1} of body weight. The highest value of GSI observed in the present study indicates the peak spawning season, consistent with findings by Sivakami [29]. However, contrasting observations were reported in common carp (*Cyprinus carpio*), where multiple peak spawning seasons were observed from February to April, with the highest observed in April [30].

In our study, the ova diameter frequency distribution revealed an increase in ova diameter with the advancement of maturity stages. Likewise, all mature ovaries exhibited a bimodal distribution, indicating spawning twice a year, a phenomenon observed in several fish species, such as white bass *(Roccus chrysops)*, koi carp (*Cyprinus* sp.), and common carp (*Cyprinus carpio*) [31–33]. In contrast to these findings, unimodal oocyte distribution was reported in mature giant gourami, African catfish (*Clarias gariepinus*), *Heterobranchus longifilis*, and clown loach [34]. The observed fecundity in this study falls within the recorded values in our preliminary study on breeding the same species [35].

Several studies have observed that the size of 50% maturity of fish differs based on species [17, 36]. In the case of *B. devdevi*, the length at which 50% of the fish attain maturity was found to be 93 mm. This finding underscores the importance of fish stock management [37] and maintaining the sustainability of the fish stock. It suggests that individuals shorter than this length should not be caught from the river to ensure they have a chance to mature at least once in their lifetime. However, in our study, the spawning of both batches of eggs appears not to be widely separated, as the distance between the mature and maturing stock is not very far.

In the present study, the sex ratio (female: male) of *B. devdevi* is 1 : 2. Furthermore, analysis of the sex ratio for the entire study period suggests a slight predominance of males over females in the studied species. The occurrence of more female specimens indicates the peak spawning season. Therefore, the dominance of males over females may be attributed to less sampling during the spawning season.

Induced breeding or hypophysation is a scientific technique whereby a mature animal is induced to discharge eggs by giving pituitary hormones or any one of the synthetic hormones or by providing conditions to breed in captive conditions [38, 39]. The stimulation urges the timely discharge of sperm and eggs from ripe gonads. Induced breeding in the confinement of numerous native fish species was performed effectively by utilizing the different hormones [36]. The brooders used in our investigations were 2+ years old, weighed 100–250 g, and reached full maturity in captivity between July and August at a water temperature of 18–22°C. In their natural environment, they breed during the southwest monsoon season. The current findings revealed that a dose of 0.4 mL·kg^{-1} to 0.6 mL·kg^{-1} of hormone was required for adequate spawning of *B. devdevi*. The hormone dosage significantly affects the percentage of egg production, fertilization, and hatching rate [10]. Induced spawning and hatching were successful at 0.5 mL·kg^{-1} body weight for females and 0.25 mL·kg^{-1} for males. It can be used as a standard dose for *B. devdevi* induced breeding and is an efficient way to conserve this species. Additionally, it is possible to recommend to farmers the use of our standardized optimal hormone dose to increase the output of *B. devdevi* seeds grown in confined areas. The latency period of *B. devdevi* in this investigation was observed to be approximately 6–10 h, which was nearly comparable to the latency period of *B. dero,* i.e., 7–10 h, as reported by Bashuda et al. [36]. Similarly, Purkayastha et al. [40] reported the latency period of *Ompok pabda* to be 9-10 h when Ovatide was administered at 0.6 mL·kg^{-1} body weight in females. Additionally, fertilization and hatching rates are dependent on temperature, and even small temperature changes can substantially affect developmental time. A temperature difference of >3°C resulted in a variation of 15–17 h in hatching time. Furthermore, Rath et al. [41] also described a more significant hatching rate in IMC by injecting WOVA-FH at 0.4–0.5 mL·kg^{-1} bodyweight of females.

The objective of the present study is a breakthrough in revealing that Gonopro-FH, which is administered at 0.5 mL·kg^{-1} body weight, can produce the optimum egg production, spawning, and hatching rate in *B. devdevi.* Both females and males showed a favourable response to a single dose of Gonopro-FH. This breeding protocol can be viable for both economic and commercial seed production. It is more interesting that this breeding protocol does not require a high investment, so marginal farmers can adopt it for seed production and thereby contribute to the species restoration and conservation needed to achieve sustainability in fisheries [42].

5. Conclusion

This study has uncovered the most important aspects of the *B. devdevi* reproductive biology, such as the sex ratio, size at first sexual maturity, GSI, fecundity, and spawning season, which can help with strategies for managing and conserving the species in rivers and their tributaries. The current investigation further revealed that the ideal dosage of Gonopro-FH for induced spawning was 0.5 mL·kg^{-1} bodyweight of female *B. devdevi*. The information obtained on induced breeding may be successfully applied for large-scale seed production in the future, considering the strong seed demand for *B. devdevi* due to its preferred flavour and nutritional qualities.

Data Availability

Data are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yumnam Bedajit was responsible for conceptualization, data investigation, initial draft preparation, and funding acquisition. Surajkumar Irungbam was responsible for data investigation and manuscript editing. Soibam Ngasotter, David Waikhom, Maibam Malemngamba Meitei, Sanjenbam Bidyasagar Singh, and Wangkheimayum Malemnganbi Devi were responsible for data investigation, reviewing, and editing. Soibam Khogen Singh and Pronob Das were responsible for supervision, reviewing, and editing. Soibam Basanta Singh was responsible for reviewing and editing. Yumnam Bedajit and Surajkumar Irungbam contributed equally and are co-first authors.

Acknowledgments

The authors acknowledge the Director, ICAR-National Bureau of Fish Genetics Resources (ICAR-NBFGR), Lucknow, India, for financial support to conduct this research work successfully. The authors also thank the Vice-Chancellor of Central Agricultural University, Imphal, India, for providing the necessary facilities for conducting the study.

References

[1] M. Kottelat, "Zoogeography of the fishes from Indochinese inland waters with an annotated check-list," *Bulletin Zoologisch Museum*, vol. 12, no. 1, pp. 1–55, 1989.

[2] M. Kottelat, "Fishes of the Nam Theum and Xe Bangai basins, Laos, with diagnosis of twenty-two new species (Teleostei: Cyprinidae, balitoridae, cobitidae, coiidae and odontobutidae)," *Ichthyological Exploration of Freshwaters*, vol. 9, pp. 1–128, 1998.

[3] W. Vishwanath, H. H. Ng, R. Britz, L. K. Singh, S. Chaudhry, and K. W. Conway, "The status and distribution of freshwater fishes of the Eastern Himalaya region," in *The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya*, pp. 22–41, IUCN, Gland, Switzerland, 2010.

[4] Talwar, P. Kumar, and A. G. Jhingran, *Inland Fishes of India and Adjacent Countries*, CRC Press, Boca Raton, FL, USA, 1991.

[5] W. Vishwanath, W. S. Lakra, and U. K. Sarkar, *Fishes of North East India*, National Bureau of Fish Genetic Resources, Indian Council of Agricultural Research, Lucknow, India, 2007.

[6] S. Molur and S. Walker, "Report of the workshop on conservation assessment and management plan for freshwater fishes of India," Technical Report, Zoo-Outreach Organization, Coimbatore, India, 1998.

[7] B. K. Behera, P. Das, N. S. Singh, and A. K. Sahu, "Observations on the induced breeding of *Labeo bata* (Hamilton) with ovaprim and ovatide as inducing agents with a note to its development," *Journal of Aquaculture*, vol. 15, pp. 11–16, 2007.

[8] B. K. Behera, P. Das, N. S. Singh, and A. K. Sahu, "Breeding and seed production of *Labeo gonius* (Hamilton) under captive condition in Manipur," *Journal of Aquaculture*, vol. 17, pp. 1–6, 2009.

[9] B. K. Behera, P. Das, N. S. Singh, and A. K. Sahu, "Captive breeding of an endemic medium carp Pengba, *Osteobrama belangeri* (Val.) with Wova-FH in Manipur," *Journal of Aquaculture*, vol. 18, pp. 23–29, 2010.

[10] P. Das, B. K. Behera, D. K. Meena et al., "Comparative efficacy of different inducing agents on breeding performance of a near threatened cyprinid *Osteobrama belangeri* in captivity," *Aquaculture Reports*, vol. 4, pp. 178–182, 2016.

[11] U. K. Udit, A. K. Reddy, P. Kumar, M. A. Rather, R. Das, and D. K. Singh, "Induced breeding, embryonic and larval development of critically endangered fish *Puntius sarana* (Hamilton, 1822) under captive condition," *JAPS: Journal of Animal & Plant Sciences*, vol. 24, no. 1, 2014.

[12] D. V. Bal and K. V. Rao, *Marine Fisheries of India*, Tata McGraw-Hill Publishing company Limited, New Delhi, India, 1990.

[13] H. Murua, G. Kraus, F. Saborido-Rey, P. R. Witthames, A. Thorsen, and S. Junquera, "Procedures to estimate fecundity of wild collected marine fish in relation to fish reproductive strategy," *Journal of Northwest Atlantic Fishery Science*, vol. 33, pp. 33–54, 2003.

[14] H. J. Grier, M. C. Uribe, and L. R. Parenti, "Germinal epithelium, folliculogenesis, and postovulatory follicles in ovaries of rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792) (Teleostei, Protacanthopterygii, Salmoniformes)," *Journal of Morphology*, vol. 268, no. 4, pp. 293–310, 2007.

[15] A. V. Tamhane and V. S. Somvanshi, "Observations on maturity and spawning in Indian scad, *Decapterus russelli* (Ruppell, 1830) along the north-west coast of India," *Bulletin Fishery Survey of India*, vol. 26, pp. 59–64, 1998.

[16] F. N. Clark, "Maturity of the California sardine (*Sardina caerulea*), determined by ova diameter measurements. California. Division of Fish and Game," *Fishery Bulletin*, vol. 42, pp. 1–49, 1934.

[17] M. S. Prabhu, "Maturation of intra-ovarian eggs and spawning periodicities in some fishes," *Indian Journal of Fisheries*, vol. 3, pp. 59–90, 1956.

[18] V. D. Vladykov, "Fecundity of wild speckled trout (*Salvelinus fontinalis*) in Quebec Lakes," *Journal of the Fisheries Research Board of Canada*, vol. 13, no. 6, pp. 799–841, 1956.

[19] J. R. Hunter and S. R. Goldberg, "Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax*," *Fishery Bulletin*, vol. 77, pp. 641–652, 1980.

[20] T. B. Bagenal, "Methods for assessment of fish production in freshwaters," *IBP Handbook No. 3*, p. 300, Blackwell Scientific Publication, London, UK, 3rd edition, 1978.

[21] I. S. Jega, M. I. Miah, M. M. Haque, M. Shahjahan, Z. F. Ahmed, and M. K. Fatema, "Sex ratio, length-weight relationships and seasonal variations in condition factor of menoda catfish Hemibagrus menoda (Hamilton, 1822) of the Kangsha River in Bangladesh," *International Journal of Fisheries and Aquatic Studies*, vol. 5, no. 5, pp. 49–54, 2017.

[22] G. W. Snedecor and W. G. Cochran, *Statistical Methods*, The Iowa State University, Ames, IA, USA, 6th edition, 1967.

[23] P. R. Sahoo, P. N. Ananth, S. Nandi, J. K. Sundaray, N. K. Barik, and P. Jayasankar, "Early breeding and seed production of Indian major carps: Attributes of the innovation from an adaptive trial," *Current Agriculture Research Journal*, vol. 5, no. 1, pp. 59–65, 2017.

[24] A. W. P. C. F. Apha, *Standard Methods for the Examination of Water and Wastewater*, Public Health Association, Washington, DC, USA, 2005.

[25] J. R. Hunter, B. J. Macewicz, N. C. H. Lo, and C. A. Kimbrell, "Fecundity, spawning and maturity of female Dover sole *Microstomus pacificu*, with an evaluation of assumption and precision," *Fishery Bulletin*, vol. 90, pp. 101–128, 1992.

[26] K. P. Sivakumaran, *Studies on the biology and population identification of Rastrelliger kanagurta (Curvier, 1817) (Pisces: Scombridae) from the coastal waters of India*, Ph.D. thesis, Annamalai University, Porto-Novo, India, 1991.

[27] C. Karlou-Riga and P. S. Economidis, "Ovarian atreticrates and sexual maturity of horse mackerel, *Trachurus trachurus* (L.), in the Saronikos Gulf (Greece)," *Fishery Bulletin*, vol. 94, pp. 66–76, 1996.

[28] C. Karlou-Riga and P. S. Economidis, "Spawning frequency and batch fecundity of horse mackerel, *Trachurus trachurus* (L.), in the Saronikos Gulf (Greece)," *Journal of Applied Ichthyology*, vol. 13, no. 3, pp. 97–104, 1997.

[29] S. Sivakami, "Fishery and biology of the carangid fish *Megalaspis cordyla* (Linnaeus) off Cochin," *Journal of the Marine Biological Association of India*, vol. 37, no. 1&2, pp. 237–248, 1995.

[30] A. Tessema, A. Getahun, S. Mengistou, T. Fetahi, and E. Dejen, "Reproductive biology of common carp (*Cyprinus carpio* Linnaeus, 1758) in lake Hayq, Ethiopia," *Fisheries and Aquatic Sciences*, vol. 23, no. 1, pp. 16–10, 2020.

[31] S. H. Newton and R. V. Kilambi, "Determination of sexual maturity of white bass from ovum diameters," *Southwestern Naturalist*, vol. 14, no. 2, pp. 213–220, 1969.

[32] A. J. Crivelli, "The biology of the common carp, *Cyprinus carpio* L. in the Camargue, southern France," *Journal of Fish Biology*, vol. 18, no. 3, pp. 271–290, 1981.

[33] P. Brown, *Carp Population Biology in Victoria*, Queenscliff: Marine and Freshwater Resources Institute, Department of Primary Industry, Queenscliff, Australia, 2003.

[34] O. Z. Arifin, J. Slembrouck, J. Subagja et al., "New insights into giant gourami (*Osphronemus goramy*) reproductive biology and egg production control," *Aquaculture*, vol. 519, Article ID 734743, 2020.

[35] Y. Bedajit, S. Irungbam, R. Yumnam et al., "Optimisation of hormone dosage for breeding of *Bangana devdevi*," *Journal of Krishi Vigyan*, vol. 9, no. 1, pp. 260–263, 2020.

[36] C. H. Basudha, N. G. Singh, N. S. Devi, and C. H. Sinthoileima, "Induced breeding and embryonic

development of an indigenous fish *Bangana dero* (Hamilton) in captivity using wova FH," *International Journal of Fisheries and Aquatic Studies*, vol. 5, no. 1, pp. 428–432, 2017.
[37] S. K. Karna and S. Panda, "Growth estimation and Length at maturity of a commercially important fish species i.e., *Dayscieaena albida* (Boroga) in Chilika Lagoon, India," *European Journal of Experimental Biology*, vol. 1, no. 2, pp. 84–91, 2011.
[38] B. S. Jha and S. Neupane, "Induced breeding of grass carp, *Ctenopharyngodon Idella* (valenciennes) in Rupandehi, Nepal," *ZOO-Journal*, vol. 5, pp. 82–84, 2019.
[39] P. Das, N. Saharan, A. K. Pal, N. P. Sahu, C. Prakash, and V. K. Tiwari, "*Labeo gonius* (Hamilton, 1822): A potential candidate species for diversification of Indian aquaculture," *Aquaculture Europe*, vol. 35, no. 3, pp. 13–16, 2010.
[40] S. Purkayastha, S. Sarma, U. K. Sarkar, W. S. Lakra, S. Gupta, and S. P. Biswas, "Captive breeding of endangered *Ompok-pabda* with ovatide," *Journal of Applied Aquaculture*, vol. 24, no. 1, pp. 42–48, 2012.
[41] S. C. Rath, S. K. Sarkar, S. D. Gupta, and N. Sarangi, "Comparative account of induced breeding of Indian major carps with ovaprim, ovatide, wova-FH and carp pituitary extract," *Indian Journal of Animal Sciences*, vol. 77, no. 10, 2007.
[42] S. Ngasotter, S. P. Panda, U. Mohanty et al., "Current scenario of fisheries and aquaculture in India with special reference to Odisha: a review on its status, issues and prospects for sustainable development," *International Journal of Bio-resource and Stress Management*, vol. 11, no. 4, pp. 370–380, 2020.