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FEEDING AND REPRODUCTION OF STRIPED SNAKEHEAD *CHANNA STRIATA* (BLOCH, 1793) INHABITING THE GANGETIC RIVER SYSTEM

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Abstract. The striped snakehead *Channa striata* is a valuable food fish and has a high market value. The feeding and natural breeding grounds of this economically important fish species have been reduced due to increasing anthropogenic activities and habitat alterations in the Gangetic River system. The present study was undertaken to assess the feeding and reproductive biology of *C. striata,* which is widely distributed in India and many other Asian countries (Pakistan, Bangladesh, Thailand, China, etc.). A total of 400 fish specimens were collected from three sites on three different rivers in Uttar Pradesh, India. Feeding habits, feeding intensity, gonadosomatic index, fecundity, maturity stages based on macroscopic studies, and sex ratio were examined. *C. striata* was found to be a carnivorous species (dominantly piscivorous). The feeding intensity varied according to season and fish size, with a higher intensity being observed during pre-spawning and post-spawning seasons. The reproductive biology of the striped snakehead from the Gangetic River system demonstrated that the gamete maturation occurred during May to July. The fecundity of *C. striata* ranged from 3652 to 48,450 eggs. Fecundity was linearly correlated with body length, body weight, and ovarian weight. The average ratio of males to females was observed to be 1:3.2.

INTRODUCTION

The food and feeding habit of a fish species provides crucial information for assessing the position of the species and its ecological role in the food web (Allan and Castillo 2007). It is not possible to understand the predicted changes that might result from any natural or anthropogenic intervention without having information on feeding behaviour, food requirements, and predator-prey relationships (Hajisamae et al. 2006). Over the years, dietary analysis has been used in biology and ecology studies of many fish species and the assessment of human impacts on fresh or marine environments (Baker et al. 2014). Stomach content analysis has become a standard practice to examine feeding habits in fish (Hyslop 1980). Currently, several other methodologies, for example, radioisotopes, direct species observations, stable isotope analysis, and fatty acid analysis are now being employed (Braga et al. 2012). These methods have the advantage of exhibiting a higher accuracy and ability to detect food items that cannot be recognized by microscopic studies. However, they are costly and more difficult to implement logistically. The stomach content analysis is nevertheless one of the most used tools, has a great potential and is good enough for biological/ecological studies (Manko 2016).

Studies on the life history characteristics, such as reproductive behaviour, sex ratio, size at first maturity, longevity, and mortality, are necessary for enhancing our understanding of the population ecology and ecological role of fishes. This knowledge is invaluable for resource management and sustainable exploitation (Campana 2001; Gray et al. 2012). Sexual maturity, reproductive period, and fecundity are the three key components of reproduction which are essential demographic characteristics required for an understanding of a species' life history (Cortes 2000). Successful reproduction is determined by the adaptation of the reproductive behaviour and physiology of the fishes to their environment. Reproductive strategies in fishes often reflect local adaptation to environmental and ecological conditions (Thorsen et al. 2010). Moreover, maturation size is of remarkable interest in fisheries management and is extensively used as an indicator of minimum-permissible capture size (Lucifora et al. 1999). Information on fish fecundity is required for assessing the reproductive potential of stocks, life histories, and effective management of the fishery resources (Lagler 1967). Such evaluations are predominantly important in fisheries management for calculating the number of offspring produced in a season and the reproductive capacity of the fish species (Qasim and Qayyum 1963).

Channa striata, locally known in India as "Dharidar-Sol" or "striped snakehead", is commercially important in food, ornamental, and sport fisheries along with other species of the family Channidae. *C. striata* is a popular food fish in Asian countries, especially India. Natural fish stocks have declined dramatically in recent years due to increased anthropogenic activity, unrestricted exploitation, and habitat changes. As a result, the feeding and natural breeding habitats of this economically important fish species have been limited, resulting in a reduction in wild populations. There is no report available on the feeding habits and reproductive biology of the *C. striata* population from the Ganga River, Yamuna River, and Gomti River at the selected sampling stations, which harbour its distinct stocks (Khan et al. 2021). In the context of a changing environment, it is important to comprehend the changes in food, feeding habits, and reproductive biology of the *C. striata* population for appropriate management. Therefore, the current study has been taken to examine the feeding and reproductive biology of the *C. striata* population from the selected rivers.

MATERIALS AND METHODS

A total of 400 fish samples were collected for the study of feeding and reproductive biology from November 2016 to August 2019. Specimens were collected from the Narora site (28.1968° N, 78.3814° E) on the Ganga River, Agra site (27.1767° N; 78.0081°E) on the Yamuna River, and Lucknow site (26.8467° N, 80.9462° E) on the Gomti River (Figure 1).

Fish of different size class were collected using a cast net and dragnet of varying mesh size. Identification of the fish specimens was based on the descriptions given by Jayaram (1999) and Talwar and Jhingaran (1991). The total length (TL) of the fish was measured to the nearest 0.1 mm. Fish guts were dissected out, uncoiled, cleaned off the attached tissues, and measured for the length nearest to 0.1 mm using a wooden measuring board and weight using digital balance nearest to 0.1 g. Guts were then immediately preserved in 10% buffered formalin on site to avoid continued digestion of food contents (Chipps and Garvey 2007) and brought to the laboratory in an icebox for further analysis (Figure 2). Prey items were identified to the lowest possible taxonomic level. The index of preponderance (I) for each food item was computed based on the total occurrence of all food items (Natarajan and Jhingran 1961) and then ranked accordingly. From each size class (22–32 cm, 33–43 cm, and > 43 cm), fish samples were collected to study the variation in diet composition between small, medium, and large fishes (Alikunhi 1953; Li et al. 2016). Feeding

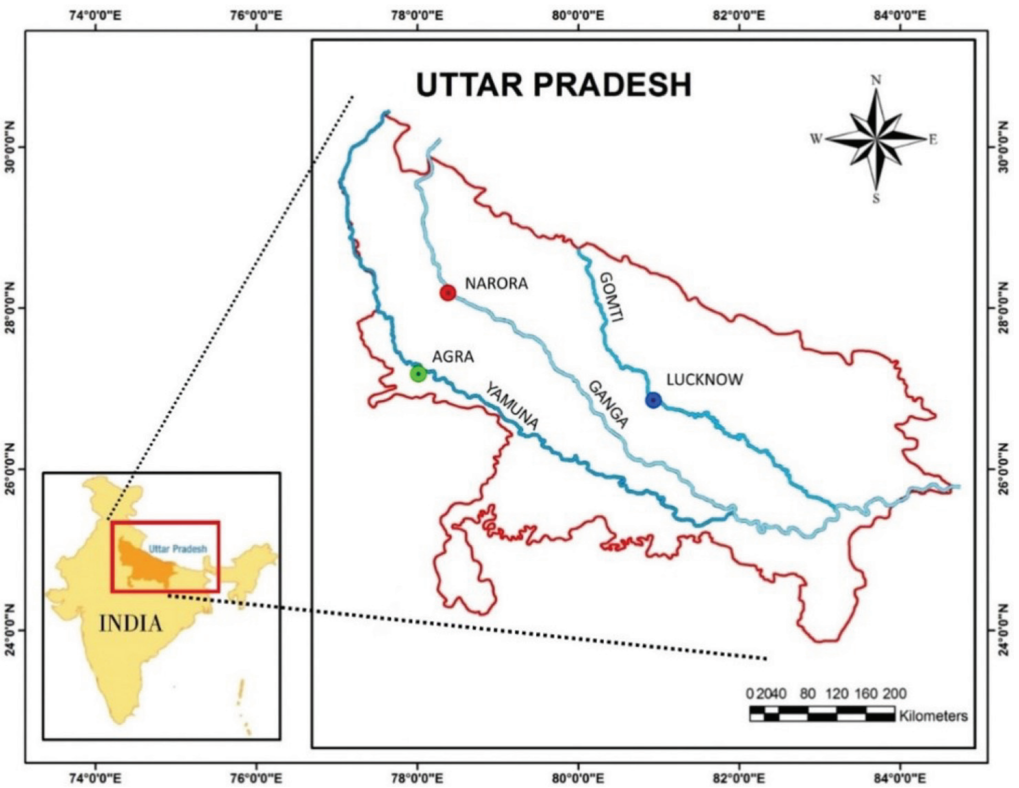

Figure 1. Map showing sampling sites.

intensity was estimated based on the gastrosomatic index (GaSI) = (weight of stomach/total weight of the fish) × 100, and vacuity index (VI) = (no. of empty stomachs / total no. of stomachs) × 100. The relative gut length (RGL) was calculated as the ratio of the gut length to the total length. This ratio was used to determine fish feeding habits, e.g., herbivores (RGL > 3), carnivores (RGL < 1), or omnivores (RGL = 1–3) (Biswas 1993; Pogoreutz and Ahnelt 2014).

For reproductive biology, gonads and liver were weighed to the nearest 0.1 g and then preserved in 10% formalin. Mature healthy males and females were identified by sexual dimorphism as well as macroscopic examination of gonads (Figure 3). The vent was pale and slit-like in males, whereas reddish and round in female fish. The abdomen in mature female fish was slightly bulged which was not observed in male fishes. The anal papilla-like structure appears prominently with the pointed tip in male fish; a slightly reddish dot is noticed in female fish (Chakrabarthy 2006; Paray et al. 2013). Gonadosomatic (GSI) and hepatosomatic (HSI) indices were calculated by using the formula (Simon et al. 2009) GSI = (weight of gonad/total weight of the fish) × 100 and HSI = (weight of liver/ total body weight) × 100. The formula given by Hunter et al. (1992) was used to calculate fecundity (F) = (S/100) × OW, where

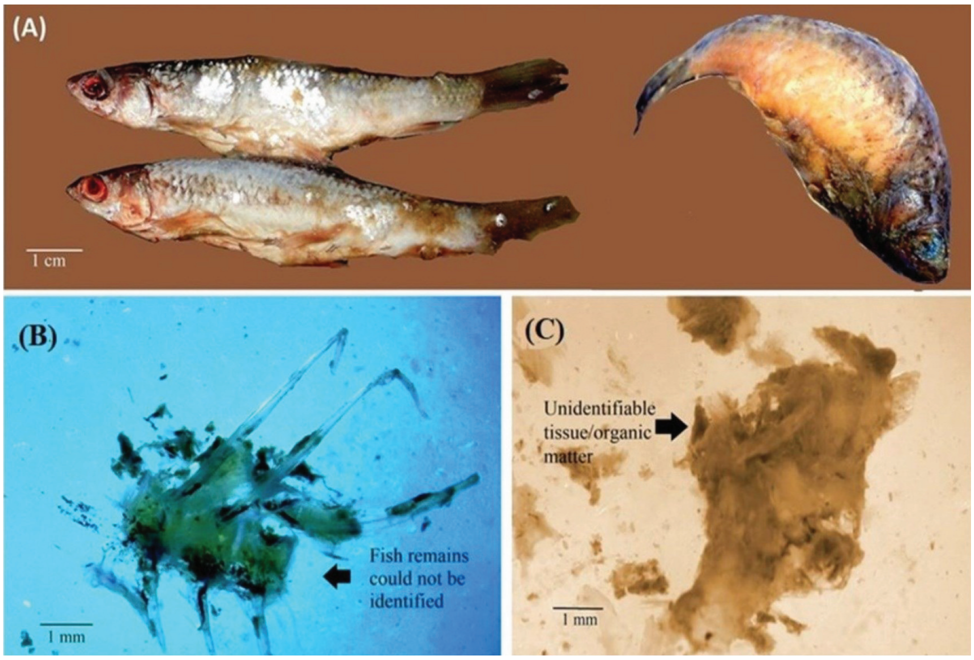

Figure 2. Commonly encountered contents in the stomach of *Channa striata*: (A) fishes; (B) fish remains that could not be identified; (C) contents dominated by unidentifiable tissue/organic matter.

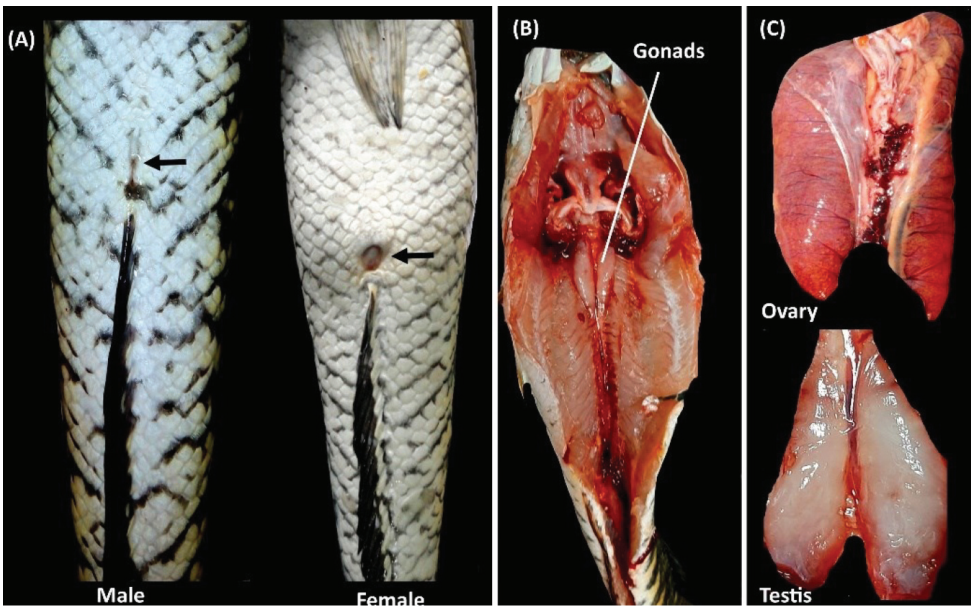

Figure 3. (A) Sexual dimorphism in *Channa striata*; (B) Ventral view after dissection showing gonads; (C) Mature gonads.

S = average number of ova obtained from three samples of 100 mg each, and OW = total weight of the ovary.

An ocular micrometer coupled to a stereo-zoom microscope (Nikon® SMZ745T, Tokyo, Japan) was used to measure the diameter of oocytes (Farrell et al. 2012). The maturity stages of the selected fish were decided based on morphological examination of gonads (ovary and testis). The gonads were categorized into 4 different maturity stages as described by Ali (1999). The total number of each sex in the collected samples was used to calculate monthly variations in the sex ratio (Qasim 1966).

Data Analysis

To study the variation in the relative gut length (RGL), the data from three fish size classes were subjected to one-way ANOVA followed by a post-hoc test (Bonferroni Test) using SPSS v.18.0 (Alcaraz et al. 2015). The relationships between fish fecundity and (i) total body length, (ii) total body weight, and (iii) gonad weight were assessed by linear regression using MS-Excel v.19.0.

RESULTS

The relative gut length (RGL) differs among fish species depending on feeding ecology types. The relative gut length (RGL) of *C. striata* was 0.588. Although the RGLs varied significantly with fish size (ANOVA, $p < 0.05$; Figure 4) but stayed within the carnivorous feeding category, i.e., RGL = < 1. The observation of feeding intensity was based on the gastrosomatic index (GaSI) and vacuity index (VI) taken monthly as summarized in Figure 5. The GaSI ranged from 2.21% to 4.62% for the fish inhabiting the Gangetic River system. The highest level of vacuity index was observed in July and the lowest level of vacuity index was found in April. The annual average vacuity index was 48.4 for the fish in the selected rivers. A sharp rise and fall in the feeding intensity were noticed in different months. In the current study, a total of 400 guts of *C. striata* were studied. The seasonal variation of food items in the fish gut are presented in Figure 6. The gut contents of *C. striata* were composed mainly of fishes, crustaceans, amphibians, insects, and reptiles along with semi-digested materials and unidentified items. In the gut content, fish were identified as the teleosts (Cyprinids) but many of the fish remains could not be identified because of being in an advanced stage of digestion. In certain months, the presence of sand and mud along with the decaying organic matter was also observed.

The variation of food composition in different size classes of fish is presented in Table 1. Small-size class (22–32 cm) fish mainly consumed insects, while crustaceans were dominant in the medium-size class

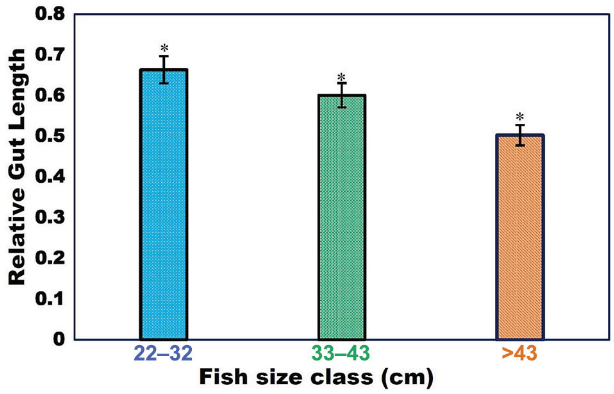

Figure 4. Relative gut length in *Channa striata*.

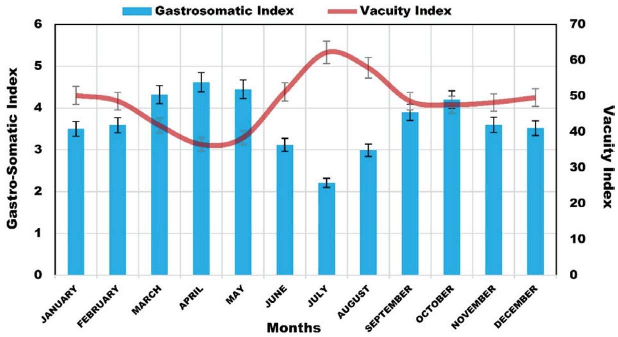

Figure 5. Monthly variation in gastrosomatic index and vacuity index of *Channa striata*.

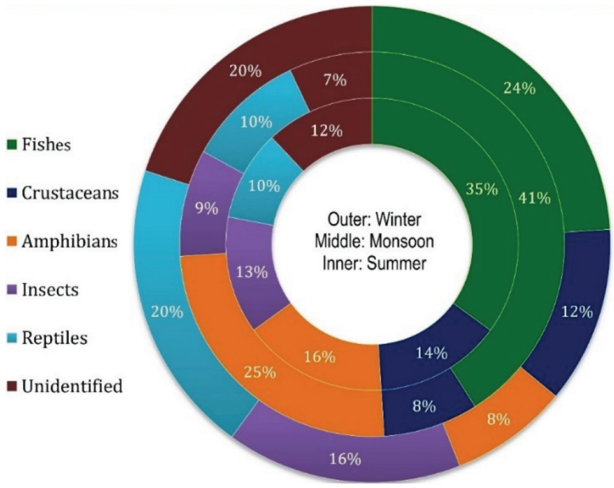

Figure 6. Seasonal variation in food items of *Channa striata.*

(33–43 cm) fish. Large fish specimens (> 43 cm) tended to consume a diverse range of prey species, comprised mostly of fishes followed by amphibians (Anura) and reptiles (Squamata). The preferred food items of *C. striata* inhabiting the Ganges as revealed from the index of preponderance are shown in Table 2. Fishes and amphibians exhibited higher index of preponderance values in the gut contents, as compared to other prey items: reptiles, crustaceans, and insects.

The gonadosomatic index (GSI) as well as the hepatosomatic index (HSI) in *C. striata* showed a significant

Table 1. Variations in diet composition (%) of three length categories of *Channa striata.*

Food items	Fish size (cm)		
	22–32	33–43	> 43
Fishes	8.02	33.05	42.04
Crustaceans	34.89	23.67	12.03
Amphibians	Absent	18.09	24.06
Insects	36.05	13.02	8.06
Reptiles	6.00	6.02	9.73
Unidentified	15.04	6.15	4.08

Table 2. Index of preponderance of various food items in *Channa striata.*

Food items	% of volume	% of occurrence	Vi × Oi	Vi Oi * 100 / Σ Vi Oi	Grading
Fishes	42.24	41.56	1755.49	68.42	I
Crustaceans	9.47	12.52	118.56	4.621	IV
Amphibians	20.24	23.32	471.99	18.39	II
Insects	8.67	2.86	24.79	0.96	VI
Reptiles	10.43	12.32	128.49	5.00	III
Unidentified	8.95	7.42	66.40	2.58	V
Total	100	100	2565.75		

Table 3. Fecundity in different size class of *Channa striata.*

Body length (cm)	Mean body length (cm)	Mean body weight (g)	Mean ovarian weight (g)	Mean fecundity
22.5–26.5	24.64	210.42	11.42	3652
26.6–30.5	28.43	304.2	12.24	4162
30.6–34.5	32.14	256.76	16.2	6123
34.6–38.5	35.74	450.32	28.32	16543
38.6–42.5	39.4	920.3	32.42	18956
42.6–46.5	44.55	876.55	42.42	24500
46.5–50.5	48.43	1242	44.56	40065
50.6–54.5	52.9	1200.5	54.82	48450

variation ($p < 0.05$) in different months of the year. Higher GSI values for both females and males were noted during May to July. Afterward, a gradual decrease in GSI was observed in August and reached its lowest value in October. The highest HSI values for both females and males occurred in April and then decreased to their minimum value in July (Figure 7).

The mean egg diameter ranged ($p < 0.05$) from 351 to 1356 µm with the highest egg diameter observed in July and the least in October. The fecundity of *C. striata* ranged from 3652 to 48450 eggs per female (Table 3). Fecundity was linearly correlated with body length, body weight, and ovarian weight, as presented in Table 4. Fecundity increased with body size. The average ratio of males to females was observed to be 1:3.2. Overall, the females showed significant ($p < 0.01$) dominance over males in the collected fish samples.

Maturity classification based on macroscopic gonadal characteristics is presented in Table 5. The ovaries of *C. striata* were sac-like, paired, and elongated structures lying dorsal to the alimentary canal and ventral to the swim bladder. The colour of the ovary varied from reddish brown in immature ovaries to light yellowish in

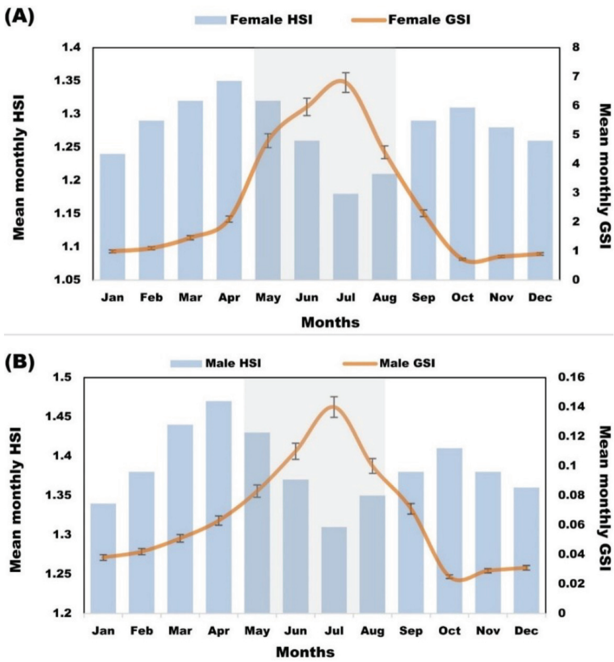

Figure 7. Monthly variation in gonadosomatic index and hepatosomatic index in females (A) and males (B) of *Channa striata.*

Table 4. Regression equations of relationships between fecundity versus body length, body weight and ovarian weight in *Channa striata.*

Relationships	Correlation coefficient	Regression equation
Fecundity (Y) and body length (x)	0.958	Y= (-0.495) + 0.959x
Fecundity (Y) and body weight (x)	0.915	Y= (0.109) + 0.688x
Fecundity (Y) and ovarian weight (x)	0.986	Y= (0.108) + 0.604x

Table 5. Macroscopic description of gonadal maturation in *Channa striata.*

Ovarian classification	Maturity stages	Ovarian description
Immature	I	Whitish and semi-transparent; oocytes not seen with the naked eye; very thin and ribbon-like ovary
Maturing	II	Reddish to yellowish in colour; oocytes granular and visible to the naked eye; vascularization of the ovary prominent
Mature	III	Deep orange in colour; blood vessels clearly seen with the naked eye; ovary distended; oocytes extruded on slight pressure
Spent	IV	Ovary flaccid, very few residual oocytes observed
Testis Classification	Maturity stages	Description
Immature	I	Testis elongated, ribbon-like and translucent
Maturing	II	Whitish to light pinkish in colour with relatively larger size than stage one
Mature	III	Testis size maximum with a creamy coloration; turgid and voluminous
Spent	IV	Testis reddish, very hemorrhagic and flaccid

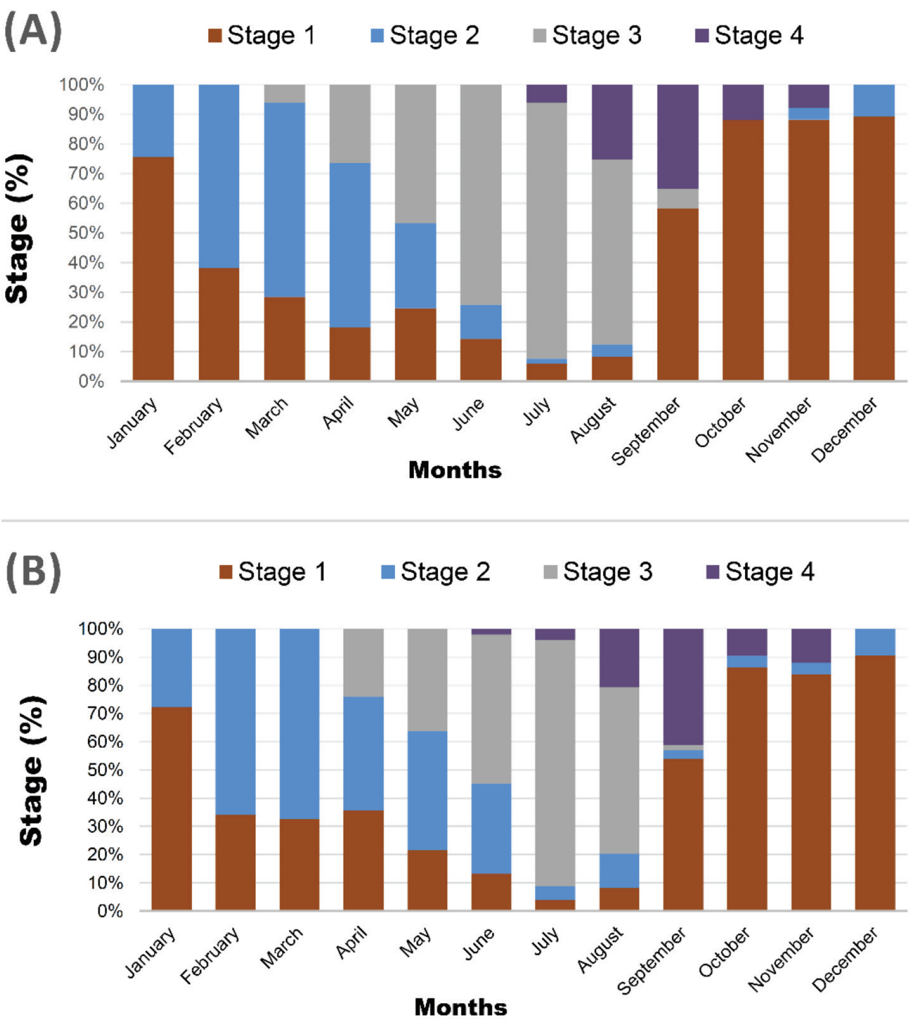

Figure 8. Percentage of gonad developmental stages in females (A) and males (B) of *Channa striata* collected from the Gangetic River system (Stage 1: Immature; Stage 2: Maturing; Stage 3: Mature; Stage 4: Spent).

mature ovaries. The testes of the fish were white, elongated, and paired. The colour of the testis ranged from light pinkish to whitish depending on the maturity. The highest percentage of immature stages in both females and males was observed in the months from October to January (Figure 8).

DISCUSSION

The relative gut length value being less than one suggests that *C. striata* is a carnivorous fish. In addition to the low RGL value, the presence of food items (fish, amphibians, reptiles, insects, and crustaceans) in the gut of *C. striata* further confirmed its carnivorous nature. The RGL values have a close relationship with the nature of the food of the fish (Das and Moitra 1956). The length of the fish intestine greatly depends upon its feeding habits. Herbivores consume food that is morphologically and chemically protected, enclosed in essentially indigestible (at least by endogenous enzymes) fibrous cell walls, which are nutrient deficient (Horn 1989). Longer digestive tracts in herbivorous animals are hypothesized to increase the amount of food that can be absorbed per feeding bout and lead to longer retention durations of refractory substances in the alimentary canal, increasing ingesta exposure to the battery of digestive processes in the gut (Horn 1989; Starck 2005). Carnivorous fish have typically small, more or less straight intestines as observed in the case of the target fish species because meat gets digested more easily as compared to plant food items that contain cellulose which is not easy to digest (Pandey and Shukla 2005; Serajuddin and Ali 2005).

The feeding intensity exhibited variable monthly patterns in *C. striata*. The feeding intensity of fish increased before and after the reproductive period (Ozyurt et al. 2012; Vahabnezhad et al. 2016). The annual reproductive cycle of *C. striata* indicated that the spawning season occurs in May–August. The poor feeding intensity during the breeding season may be attributed to the development of gonads, which occupy the major space of the abdominal cavity, thus compressing the gut and making feeding more difficult (Dadzie et al. 2000; Sourinejad et al. 2015).

C. striata showed changes in dietary composition with increasing body size. The smaller-size class fish consumed primarily small insects and crustaceans, whereas fishes and amphibians were the principal prey items in larger individuals (> 43 cm TL). A small mouth size and poor swimming ability of the smaller-sized fish could have limited their prey choice to small, slow-moving organisms in their immediate vicinity. On the other hand, larger individuals having large and terminal mouths with a protruding lower jaw can move quickly and capture relatively larger prey (Courtenay and Williams 2004). The size-related dietary shift is likely to reflect the mouth-gape limitation of smaller individuals rather than intestine length and morphology. The variable diet composition in *C. striata* with increasing body size could be attributed to the size of their jaws and ontogenetic changes in their dental characteristics (Li et al. 2016). An increase in mouth size in the large-sized individuals could have helped them to feed upon larger and active prey items such as fishes, as also suggested by Scharf et al. (2000) in *Urophycis regia*. Such ontogenetic dietary changes may be related to maximizing energy acquisition (Gerking 1994), i.e., larger fish prefer bigger prey because they contain more energy and exploit their increased mobility to catch such prey (Stoner and Livingston 1984).

Seasonal changes in fish feeding habits are associated with changes in food availability caused by environmental factors and physiological variations (Wootton 1990). In the current study, the percentage composition of fishes as food in the gut of *C. striata* was highest in the rainy season. According to Solis (1988), physico-chemical parameters including temperature, pH, conductivity, and salinity are appropriate to sustain aquatic life in the rainy season. Dissolved oxygen also is an important environmental parameter for the survival of aquatic life; it affects the growth, survival, distribution, and behaviour of aquatic organisms. The seasonal percentage of insects in the gut contents of the fish was highest in the winter and summer seasons and low in the rainy season, which could be due to the increased load of sediments, in rainy season reducing transparency, leading to the reduction in primary production of the water bodies and hence adversely affecting the population of aquatic insects (Payakka and Prommi 2014).

Based on the percentage index of preponderance values, the main prey in the diet of the fish consists of fishes followed by crustaceans, amphibians, and reptiles. The prey items found in this study were very similar to those reported for *C. striata* from the wetlands of Nadia district, West Bengal (Chakraborty et al. 2017). Generally, fishes target the most abundant locally available prey, and such behaviour may be influenced by the catch success rate and/or the probability of encountering prey (Persson and Diehl 1990).

The breeding season of *C. striata* appears to coincide with the rainy season and extends from May to August as evidenced by higher GSI values during this period. Some researchers have established relationships between HSI and GSI in fishes (Cantanhede et al. 2007; Ghafouri et al. 2019). According to Zardo and Behr (2015), gonad maturity and reproductive activity imply the use of materials obtained from ingested food and mostly from energy reserves deposited in different parts of the body. Therefore, the development and maturity of gonads could be related to the changes in liver weight.

This fact holds in the present study wherein an increase was observed in liver weight in March/April for both males and females. Typically, in many fish species, at the peak of spawning, the GSI is at the maximum and HSI is at the minimum level. Based on the obtained results in different months, the lowest value of HSI in *C. striata* females was in July and the highest in April. Variation in the HSI might be attributed to the process of vitellogenesis in the liver. The oocyte development in fish is intimately associated with the hepatic synthesis of egg-yolk precursor protein, vitellogenin, which is secreted into the blood and ultimately transported to the developing oocyte and deposited as a yolk (Singh and Srivastava 2015). The low HSI values found during the spawning period may be due to the utilization of accumulated reserve in the liver for supplying energetic requirements during the time of scarce food items, sexual product elaboration, and spawning activity.

There is a gradual increase in egg diameter from the immature stage to the ripe stage. Even though most of the eggs attained the maximum size during the spawning period, many immature eggs were noticed in all the stages as also suggested by Ali (1999). The oocyte diameter observed during the present study is in close agreement with the value reported by other researchers for the same fish species (Li et al. 2016). The highest oocyte diameter was observed in July, implying that the oocytes are mature and fish may spawn under suitable conditions. Al Mahmud et al. (2016) also noticed the highest oocyte diameter in July which is similar to the findings of the present study. The current investigation suggested that the number of eggs was directly proportional to the weight of the fish and the fecundity increased progressively with ovary weight. The number of eggs produced by a female is dependent on different factors such as the size and age of the samples (Lagler et al. 1967). Researchers have reported variations in the number of eggs present in different individuals of the same species which could be due to environmental differences experienced by conspecific populations or a different method of fecundity interpretation. Fish that get enough nutrients or feed would be able to produce more oocytes (Mohanty et al. 2017). In this study, fecundity was found to be highly correlated with ovary weight, total length, and total weight of the fish. Similar observations were reported by Boonkusol et al. (2020) in *C. striata* and Rheman et al. (2002) in *Liza parsia*.

The sex ratio in the sampled specimens of *C. striata* exhibited deviation from the expected ratio of 1:1, with the dominance of females over males. Similar observations on the deviation of sex ratio from the expected value and female dominance over males in the population of other fish species have been reported earlier by Parvin et al. (2011) and Ghofouri et al. (2019). Many factors could influence the predominance of one sex over the other, e.g., mortality, maturity, different behaviours of males and females, higher predation rates in a particular sex, or even factors related to the selectivity of collections (Raposo and Gurgel 2001).

Seasonal reproductive cycles can be highly affected by biotic factors such as competition and food availability and by abiotic factors such as photoperiod, temperature variations, and rainfall (Dala-Corte and Azevedo 2010). Also, the water level in the rivers determines the availability of the habitat and food, hence rainfall seems to be the factor that strongly influences the reproductive cycle of fish (Karnatak et al. 2018). Rainfall could be the main environmental factor, which modulates the gonadal cycle and spawning in most tropical and subtropical fish species (Bhattacharyya and Maitra 2006). The effect of environmental cues on gonadal activity may be facilitated through the neuroendocrine axis as reported in other fishes (Alvarado et al. 2015; Basak et al. 2016). Precipitation patterns influenced by climate change can be important for the spawning periodicity of fishes (Whitney et al. 2016). Rainfall is found to have a positive correlation with spawning in many tropical and subtropical fishes (Basak et al. 2016). Rainfall and other climatic conditions prevailing during the monsoon season may be considered to be important environmental cues inducing the fish to mature and breed in monsoon months. This is further supported by the mature stages of gonads being observed in *C. striata* during the monsoon months.

This research will help us understand the changes in food, feeding patterns, and reproductive biology of the *Channa striata* population, which will subsequently be used for sustainable fishery management and conservation.

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Disclosure statement

No potential conflict of interest exists among the authors.

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