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Application of gonadosomatic index (GSI) and fecundity in interpreting the reproductive periodicity of an endemic snow trout, *Schiz+othorax plagiostomus* from the hill streams of

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Abstract

The objective of the present study is to describe the phases of gonadal development using Gonadosomatic index (GSI) and determine the fecundity of Schizothorax plagiostomus in Kashmir Himalaya. A total of 360 specimens of Schizothorax plagiostomus were studied for estimation of GSI and 95 female gonads for estimation of fecundity. The total length of the specimen ranged from 115 mm to 450 mm with the corresponding weight being 20 g and 502 g respectively. Maximum (gonadosomatic index) GSI values were recorded in the spawning month i.e. May with peak values of 11.4 in males and 13.0 in females. The mean absolute fecundity value of 95 specimens was 10676 ± 557. The mean relative fecundity (number of ova/g of body weight) was found to be 42.66 ± 1.83 with highest of 95.69 and minimum of 7.53. High fecundity is a crucial aspect of their reproductive strategy. It helps compensate for high natural mortality rates by increasing the number eggs produced. The species studied, exhibit an r-selected reproduction strategy (prioritize high reproductive rates over parental care). High fecundity also promotes genetic diversity and facilitates colonization of new habitats.

Keywords:
Schizothorax plagiostomus, Gonadosomatic index, Fecundity, Kashmir Himalayas

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Introduction

The present study was undertaken with the objective of precisely estimating the monthly fluctuations in the Gonadosomatic Index (GSI) to determine the spawning periodicity. The absolute and relative fecundity was studied with the aim of unraveling the breeding potential of *Schizothorax plagiostomus*. These measurements are fundamental for fisheries management, allowing the setting of sustainable fishing quotas to prevent overfishing and protect fish stocks. The Indian Himalayas encompass an extensive region with diverse coldwater resources mainly in the form of upland streams, rivers, high and low altitudinal lakes etc. located in different hill states of India (Singh *et al.,* 2015). Jammu & Kashmir falls in the great north-western complex of the Himalayan ranges with marked relief variation, snow-capped summits, antecedent drainage and complex geological structure (Nandy *et al.*, 2006).

In Kashmir Himalayas pollutants, toxic chemicals and agricultural runoff are constantly being released into the water bodies. These pollutants disrupt fish reproduction, growth, and overall health, leading to population declines. The knowledge of reproductive characteristics like GSI and fecundity will ensure sustainable fishing practices, protect the species from overexploitation, and adapt to environmental changes, ultimately contributing to the preservation of biodiversity in the region.

Coldwater resources have a wide range of altitude and water temperature and comprise of 258 fish species belonging to 21 families is and 76 genera from Indian uplands (Singh *et al.,* 2015). Order Cypriniformes has six families, 321 genera and some 3268 species is one of the most widespread and largest orders of fishes all over the world (Nelson, 2006).The cyprinids are found in Europe and Asia and comprises several species, most of which have been widely introduced as food fishes (Coad, 2006).The water bodies in Kashmir due to their peculiar natural conditions are prime centres of cold water fisheries and most fish species inhabiting the Himalayan region are small in size (Yousuf *et al.,* 2003; Bhat *et al.*, 2010). In all 44 species of fish have been reported in Kashmir valley (Yousuf, 1996; Balkhi, 2007) but presently not more than 23 species are available (Bhat *et al.*, 2010).

The river Jhelum originates from Verinag spring in the district Anantnag and meanders north-westward from the northern slope of the Pir Panjal Range through the Vale of Kashmir. It flows in loops through the valley till it enters the Wular Lake; flows out from its other side to Baramulla in south-west direction and then it enters the boundary of Pakistan (Raina, 2002). At present fish species found in river Jhelum are: *Schizothorax esocinus, S.plagiostomus, S.labiatus, S.curvifrons, S.niger, Triplophya kashmirensis, T.marmorat, Cyprinus carpio* var.*communis, C.carpio* var. *specularis, Crossochelius diplochilus* (Bhat *et al.*, 2020)

The indigenous schizothoracines or snow trouts are highly preferred by the local masses because of their nutritional value and taste that fetches high price market (Singh and Paul, 2010). Schizothoracids, contribute 15-25% in total fish catches in Kashmir. The introduction of the exotic species for commercial gains has resulted in the loss of diversity. The introduction of the exotic common carp, *Cyprinus carpio* L. in 1956 caused a sharp decline in the population and almost exterminated the Schizothoracine fishes in Kashmir valley (Zutshi and Gopal, 2000). In Kashmir, the fish catch is dominated by common carp in lakes and by Schizothoracids in riverine water bodies (Yousuf, 1996; Balkhi, 2007 and Bhat *et al.*, 2010). *Schizothorax*, the indigenous cyprinid is dominant in torrential mountain streams of Himalayas and Central Asia inhabiting both lotic & lentic water bodies of Kashmir (Sehgal, 1999).

Heckel (1838) while documenting fish fauna from Kashmir valley, described a Freshwater, benthopelagic fish Schizothorax plagiostomus. It is a species of ray-finned fish in the genus *Schizothorax*. It is locally known as Khont, snow trout, snow carp, snow barble and Swati fish. *Schizothorax plagiostomus* is characterized by elongate fusiform body with projecting snout. Mouth is distinctly inferior, wide and lower jaw very deep. The fish is characterised by a lower papillose lip which is folded and expanded, and is particularly distributed in different rivers, streams and tributaries of all over the Himalayan regions extended to China, Afghanistan, Nepal, Pakistan, Ladakh, Tibet, North East India and Bhutan (Kullander *et al.*, 1999). It feeds on detritus material and breeds in streams (Heckel, 1838). It is one of the most valuable and suitable fish for the up scaling of the nutritional status. The population of *Schizothorax* have so far been satisfactory status as per conservation status lists but are declining in the water bodies of Jammu and Kashmir due to habitat destruction, over fishing, competition for food and breeding grounds with exotic carps and lack of captive breeding facilities or has not been bred artificially as yet (Akhtar et al., 2013).

Reproduction has three key components of sexual maturity, reproductive period, and fecundity, which are vital demographic characteristics essential to an understanding of a species' life history (Cortes, 2000). Without understanding of geographical variation in growth and reproduction cycles, it is difficult to effectively manage, and subsequently conserve, endemic fish populations (Al-Saleh *et al.*, 2012). Studies on reproduction behavior (fecundity) of fish are important and a basic requirement for improvement and effective fishery resources management and conservation (Marshall *et al.*, 2003; Grandcourt *et al.*, 2009). In aquatic systems, the successful timing of reproduction is based on sensing environmental cues as temperature, photoperiod, food availability and chemical cues of con-specifics. An accurate timing of breeding is requisite for the successful reproductive outcome. The most suitable method of determining the reproductive cycle in female fishes is to observe seasonal developmental changes in the gonads (Sivakumaran, 2003). The maturation cycle describes morphological changes that gonads undergo to attain full growth and ripeness. Determination of fecundity and the development of sexual maturity is fundamental to fishery science.

Methodology

Fish collection

Every month 30 specimen of *S. plagiostomus* (Figure 1) were collected collected on random basis (Taherdoost, 2016) from the hill streams of the valley (Figure 2) over a period of 12 months from September 2021 to September 2022. The fish was identified using the standard taxonomical tools (Talwar, P.K. and Jhingran, A.G., 1991). After collection the specimens were immediately preserved in 5% formalin and brought to Fisheries Resource Management (FRM) Laboratory, Faculty of Fisheries, SKUAST-K, Rangil, Ganderbal for the estimation of Gonadosomatic index (GSI) and Fecundity.

Gonadosomatic index (GSI)

The fish specimens were dissected open and sex of individuals was identified macroscopically and the gonads were assigned a gross maturity stage based on their macroscopic appearance. Gonado Somatic Index *(GSI)* is an index that represents the relative weight of the fish gonad to the fish weight. It has been widely used to evaluate reproduction timing (Lowerre-Barbieriet al., 2011). GSI is also widely used to indicate the maturity and periodicity of spawning and also helps in predicting the spawning season of the fish species (Towers, 2014). Total length and weight of gonads was recorded and GSI was determined using the following formula (Desai, 1970; Strum, 1978):

$$\mathrm{GSI} = \frac{\text{weight of gonad (g)}}{\text{Total weight of fish (g)}} \times 100$$

Fecundity

Fecundity may be described as seasonal spawning potential and alternatively is defined as the number of ova ripening between current and next spawning period in a female fish (Bagenal and Tesch, 1978). It is also defined as number of eggs that are likely to be laid by a fish during a spawning season (Towers, 2014). During the present study fecundity was calculated using gravimetric method (Bagenal, 1978; Kwei, 1978).

Absolute Fecundity

The ovary subsamples were taken from the anterior, middle and posterior regions of the ovary (James *et al.,* 1978). The absolute fecundity was then worked out by calculating the number of ova in the whole ovary.

$$\text{Absolute Fecundity} = \frac{\text{Number of ova in subsample}}{\text{weight of subsample}} \times \text{Total ovary weight}$$

Relative Fecundity

Relative fecundity was calculated as number of ova per g of the body weight.

$$\text{Relative Fecundity} = \frac{\text{Absolute fecundity}}{\text{weight of fish}}$$

Fig. 1: Specimen of *S. plagiostomus*

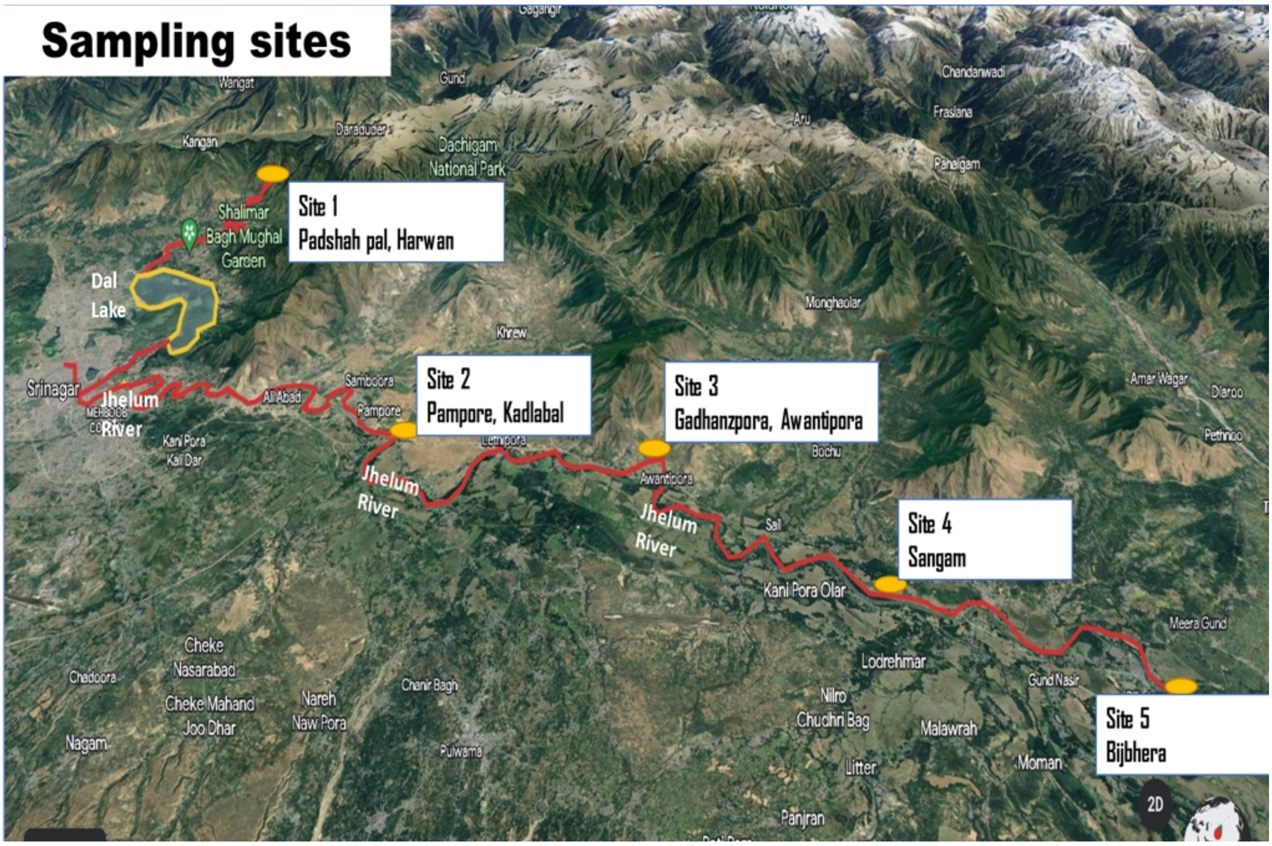

Fig. 2: Sampling sites

Results and discussion

Gonadosomatic index (GSI)

During present study the monthly variation of GSI of male and female specimens of *Schizothorax plagiostomus* is given in Table 1. The graphical representation is given in Figures 1. In females the mean GSI was found to be minimum in the month of July (2.08) with the gradual rise to 13.02 in the month of May. From May to June the value of GSI showed a sharp decline, indicating the onset of spawning season. In males the GSI was found to be minimum in the month of August (1.54) and maximum in the month of May (11.74).

Table 1: Monthly variation of gonadosomatic index of *Schizothorax plagiostomus*

Month	Male GSI Range (Mean)	Female GSI Range (Mean)
January	2.83-11.83 (5.28)	3.83-9.12 (6.28)
February	3.59.9.41 (5.54)	3.89-6.46 (5.64)
March	2.52-12.58 (7.34)	4.52-10.85 (6.7)
April	4.35-14.89 (7.61)	3.86-18.50 (8.87)
May	4.59-21.85 (11.74)	7.70-16.84 (13.02)
June	1.21-4.76 (2.78)	2.87-9.18 (5.41)
July	0.34-6.45 (2.16)	0.62-4.69 (2.08)
august	0.67-2.77 (1.54)	0.89-6.70 (2.48)
September	2.01-7.66 (3.69)	4.64-8.45 (6.16)
October	2.78-21.66 (4.04)	4.26-7.97 (5.12)
November	0.69-9.86 (4.87)	3.90-7.24 (5.91)
December	0.92-8.69 (4.97)	4.41-13.45 (7.03)

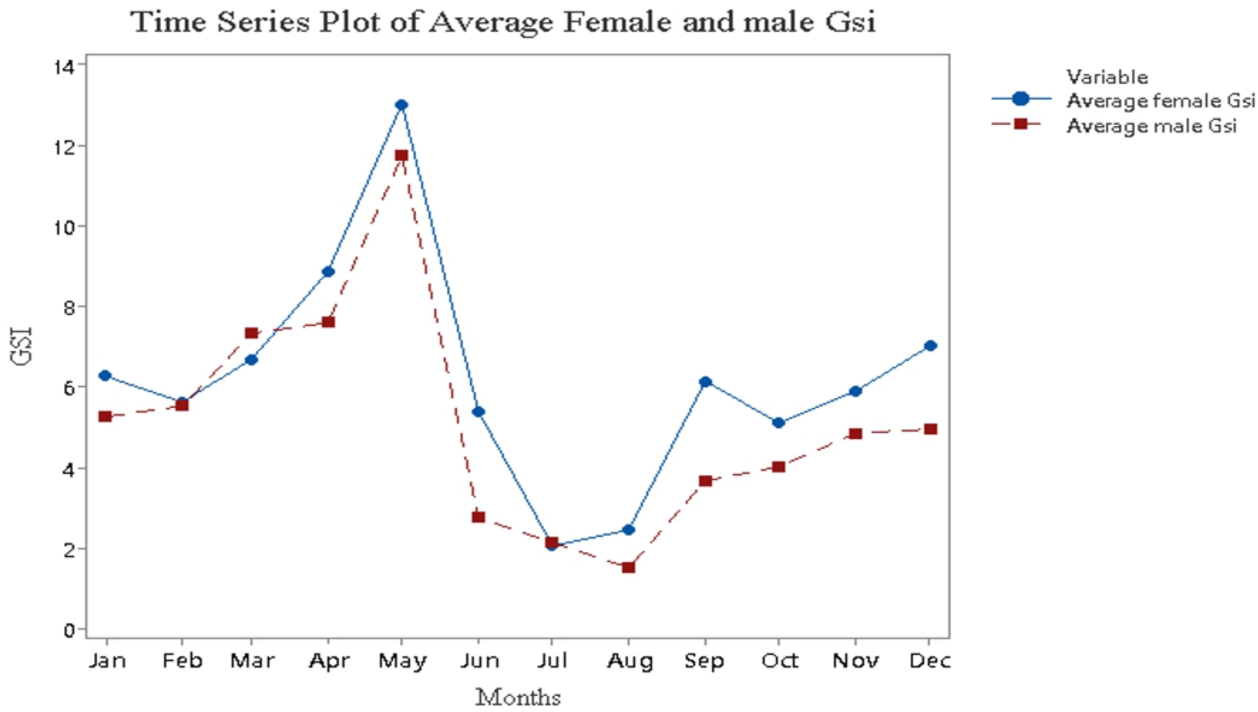

Fig. 3: Graphical representation of monthly variation in GSI of *Schizothorax plagiostomus*

Fecundity

Fecundity was studied by examining mature preserved ovaries in 5% formalin. A small portion was cut from the anterior, middle and posterior regions of the ovary and considered as one sample. After recording the weight, the sub samples were teased out and dispersed in a small amount of water. The mature ova were counted and the total number of ova was computed. The results showed the total number of mature eggs varied from 836 to 24630 in individuals of 74.6-502.2 g. The mean absolute fecundity value of 95 specimens was 10676 ± 557. The mean relative fecundity (number of ova/g of body weight) was found to be 42.66 ± 1.83 with highest of 95.69 and minimum of 7.53 (Table 2). The mean absolute fecundity was recorded maximum in the month of November (14524 ± 2368) while as it was recorded lowest in July (6004±505). Similarly the mean relative fecundity was recorded maximum in the month of November (56.71±6.85) while as it was recorded minimum in the month of July (23±13.5).

Table 2: Monthly variation in the Absolute and Relative Fecundity of *Schizothorax plagiostomus*

Month	No of Samples	Absolute Fecundity	Relative Fecundity
		Mean ± SEM	**Mean ± SEM**
January	8	8693±1900	39.84±8.69
February	8	12111±1705	42.8±3.04
March	9	12150±1969	36.85±4.35
April	9	11631±2060	38.55±6.9
May	6	7790±2407	53.6±12.3
June	6	9971±1416	46±7.83
July	2	6004±5058	23±13.5
August	2	6617±5313	25.6±16
September	9	10557±953	48.29±2.18
October	11	9608±1334	36.6±2.91
November	8	14524±2368	56.71±6.85
December	8	12728±2462	51.37±6
Average		**10676 ± 557**	**42.66 ± 1.83**

Relationship between fecundity and total length (Fig. 2) has been established as:

$$y = 106.75x - 17093 \ (R^2 = 0.7058)$$

Relationship between fecundity and total weight (Fig. 3) has been established as:

$$y = 41.968x + 171.65 \ (R^2 = 0.6423)$$

Relationship between fecundity and ovary weight (Fig. 4) has been established as:

$$y = 470.88x + 3172.4 \ (R^2 = 0.4137)$$

The relationship between total length and fecundity is strong, indicating that as the fish's length increases, its ability to produce offspring also increases. The relationship between total weight and fecundity is moderately positive, suggesting that as the fish's weight increases, its fecundity generally increases. The relationship between ovary weight and fecundity is weaker compared to the other two factors, indicating that the weight of the fish's ovaries has a less pronounced influence on its fecundity. These relationships provide valuable insights for fisheries management, conservation, and ecological studies by helping predict fecundity based on easily measurable fish characteristics.

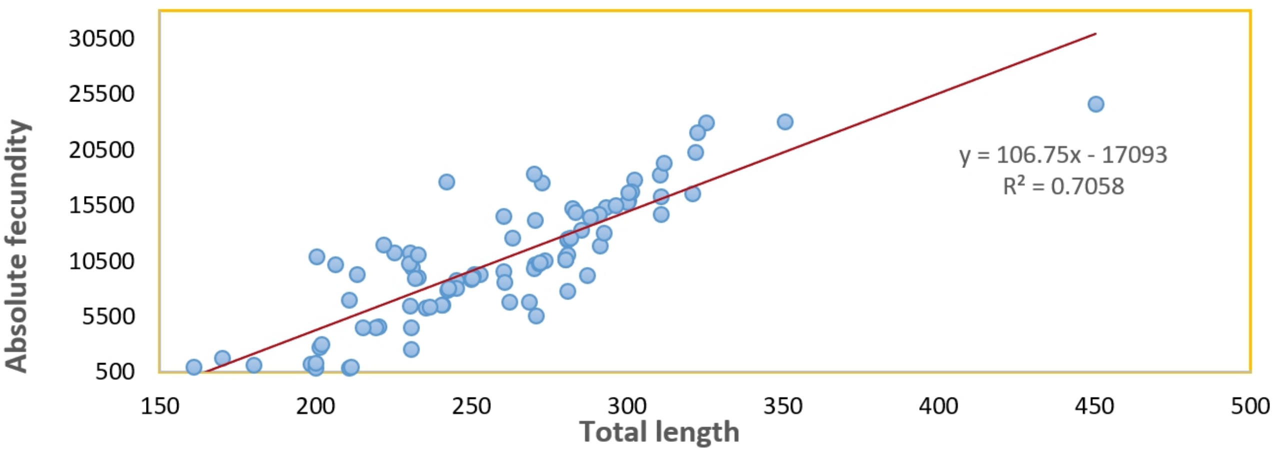

Fig. 4: Relationship between total length and absolute fecundity in *Schizothorax plagiostomus*

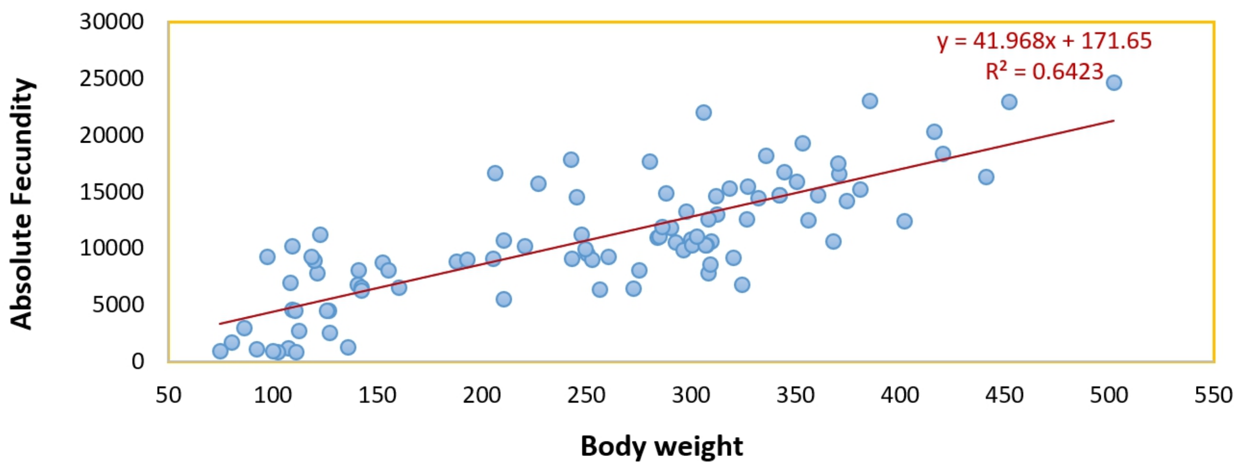

Fig. 5: Relationship between total weight and absolute fecundity in *Schizothorax plagiostomus*

DISCUSSION

Gonadosomatic Index (GSI)

In the females of *S. plagiostomus*, the mean GSI was lowest in July (2.08) and reached its peak in May (13.02). This trend indicates that the females are in their post-spawning phase in July when the GSI is lowest. As the months progress, the GSI increases, suggesting that the females are investing more energy in their gonads, preparing for the upcoming spawning season in May. In males, the minimum GSI in males was observed in August (1.54), while the maximum was in May (11.74). The sharp decline in GSI for both males and females from May to June indicates that spawning likely occurs during this period.

Waheed and gull (2023) conducted a study on GSI fluctuations of *Cyprinus carpio communis* in Kashmir. They observed that the GSI index was higher in May, which is consistent with the results obtained in the present study. Sunder (1984) reported similar observations in *S. curvifrons* spawning in the month of May. Qadri *et al*., 2018 based on GSI values and gonadal conditions found that April to June is the spawning season for *S. curvifrons*. The results are in line with the results of present the present study. Jan and jan (2017) observed that the mean GSI in female *Salmo trutta fario* varied from minimum 8.4 in March to maximum 17.5 in November, suggesting that in the month of November *Salmo trutta fario* reached its peak breeding period. GSI indicates gonadal development and maturity of fish which increases with the maturation of the fish and declines abruptly thereafter (Parameswarn *et al.,* 1974). Yeldan and Avsar (2000) also reported that GSI is widely used especially for the bony fishes in order to examine the spawning period because its value is directly related to the development of the gonad. Flura *et al.,* 2015 conducted a study on GSI of *T. ilisha* from the Meghna River, Chandpur, Bangladesh where they found the peak GSI value for females in June, October, and February. The highest mean GSI value was found in October; hence it determined October as the main spawning season of *T. ilisha*.

Teleosts exhibit different spawning periodicity and are seasonal breeders. In Indian subcontinent most of the freshwater fishes are monsoon breeders (Jhingran, 1982). According to Badola and Singh (1984), most of the Garhwal Himalayan hillstream fishes spawn during summer and monsoon months as *Tor tor* and *Tor putitora* (April to July), *Labeo dyocheilus* and *L. dero* (March to June), *Barilius* spp. (April-June), *Glyptothorax pectinopterus* and *Pseudocheilus sulcatus* (April to August) and *Nemacheilus* spp (July to August). In schizothoracids, diversity in spawning season and periodicity exists because of varied ecological environments. According to Jhingran (1982), *S. richardsonii* in Himachal Pradesh spawns from March to June, in Kumaon waters, it spawns from July to December (Bisht, 1974) and in Garhwal Himalaya from July to September (Misra, 1982). However, Kashmir snowtrout, *S. niger* exhibits spawning from mid April to May end (Malhotra, 1966). Bhatnagar (1964) reported that *S. plagiostomus* of Bhakra reservoir breeds twice in a year i.e. from July to August and from December to January. Similarly, two breeding seasons (from September to October and February to March) in *S. plagiostomus* of Nepal waters have also been reported by Shrestha and Khanna (1976). Shafi (2013 a) while studying breeding biology of *Schizothorax niger* from Dal lake revealed that the GSI recorded its highest value during February (14.35) which is the peak breeding season of the fish, then it decreased gradually upto June attaining its lowest value in June (3.88), females exhibiting higher GSI value than males. The values of gonadosomatic index increase with the maturation of the fish and become maximum during the peak of maturity and decrease abruptly and sharply when the fish becomes spent and females generally exhibited comparatively higher GSI values than males (Khan, 1945; Ganpatti and Chako, 1954; Pathak and Jhingran, 1977; Piska and Devi, 1993). Similar observations were recorded during the current study on *S. curvifrons* which showed the maximum recorded GSI in the month of April (6.5 in males and 12.0 in females) and minimum GSI in the month of July (1.6 for males and 1.5 for females). Sunder (1986) reported similar observations and values in *Schizothorax longipinnis* as the GSI was lowest in July (1.0) and started increasing till September (5.2).

Fecundity

Many fishery biologists have worked on the fecundity of different fish (Naeem *et al*., 2005; Jacobson *et al.,* 2009; Mekkawy and Hassan, 2011 and 2012; Shinkafi *et al.,* 2011). The knowledge of fecundity is one of the most important part of the reproductive biology (Nikolsky, 1969). According to Khallaf and Authman (1991) fecundity is not a constant feature but it fluctuates with variations in environmental conditions and species specific factors. Horwood *et al.* (1986) reported that even within a stock, fecundity may vary annually.

Fecundity is known to vary within species with latitude and location (Crushing, 1968; Mann *et al*., 1984) and also with spawning time (Ware, 1975). According to the Murua and Saboride-Rey (2003) different fish species reflect marked differences in their reproductive patterns and exhibit different reproductive potentials in terms of fecundity.

In the current study, the average absolute fecundity of *Schizothorax plagiostomus* was estimated at **10676 ± 557** eggs and average relative fecundity at **42.66 ± 1.83** per g of body weight. The high average absolute fecundity of *Schizothorax plagiostomus*, suggests that the species invests significantly in reproduction. Such high fecundity might be an adaptive strategy to compensate for the challenges and risks faced by their offspring during early life stages. The results showed the fecundity in *Schizothorax plagiostomus* varied from

836 to 24630 in individuals of 74.6-502.2 g in contrary to the results obtained by (Agarwal, 1988) for the same species, *Schizothorax plagiostomus* in Garhwal Himalaya. It indicates, fecundity can vary significantly between different regions or populations of the same species. This variation in fecundity is often influenced by a combination of ecological, environmental, and genetic factors. Understanding the reasons behind these regional differences in fecundity is essential for comprehending the species' reproductive ecology and can have important implications for conservation and management efforts.

The estimated high value of fecundity in the current holds the ecological significance. This can be indicative of a strategy to maximize reproductive success and increase the chances of survival for its offspring, especially in environments with high predation or environmental variability. *Schizothorax plagiostomus* serve as a vital food source for brown trout (*Salmo trutta fario*) in the torrential streams of Kashmir Himalayas (Bhat *et al*., 2020), thus play a role in nutrient cycling, affecting the overall health of the ecosystem. A large number of eggs contribute to genetic diversity within the species, which is essential for adaptation to changing environmental conditions. It provides the raw material for evolution and potential responses to selective pressures. Qadri *et al.* (1983) recorded fecundity of *Schizothorax richardsonii* from Kashmir waters from 2598 to 27846 eggs for the fish ranging between 220 and 475 mm with average fecundity of 12744 eggs, while Das and Kaul (1965) reported fecundity between 2600 and 16,605 for 216-331 mm length group for the same fish. Sunder (1986) studied the fecundity of *S. longipinnis* in River Jhelum and fecundity per kg of body-weight was estimated at 41,355, relative fecundity was found to vary from 25 to 71. Shafi *et al*. (2013a) studied the fecundity of *Schizothorax niger* from Dal Lake Kashmir and reported that absolute fecundity varied from 1550-3444, while relative fecundity ranged from 24-124 per g body weight with a mean value of 53. Hussain *et al*. (2018) recorded the mean absolute and relative fecundity of *Schizothorax niger* from Dal Lake Kashmir 11590 ± 718.33 and 48.90 ± 1.83 respectively. Farooq *et al.* (2019) reported the mean absolute and relative fecundity of *Schizothorax labiatus* from River Jhelum as 10323 and 42 respectively. Mohan (2005) studied the spawning biology of *Schizothorax richardsoni* (Gray) from River Gaula Kumoan, Himalaya and reported that the fecundity ranged from 2248 to 8726 in fishes of 160-245 mm TL and 40- 110 g in weight. Therefore both absolute and relative fecundity of *Schizothorax plagiostomus* during the present study does not showed much variation with respect to other Schizothoracines.

Conclusion

There is a seasonal pattern in the reproductive activity of *Schizothorax plagiostomus*, with both male and female fish showing distinct peaks in GSI during the month of May. The variation in GSI between males and females could be indicative of differences in investment of reproductive efforts in these two sexes. The fecundity of *Schizothorax plagiostomus* is influenced by multiple factors, including body weight, total length, and ovary weight. The study indicates that as these factors increase, fecundity tends to increase as well. The research also highlights significant monthly variations in fecundity, with maximum average value occurring in the month of November. These findings contribute to our understanding of the reproductive biology of *Schizothorax plagiostomus* and may have implications for its management and conservation.

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