

REPRODUCTIVE PERFORMANCE FOCUS “SEASONAL DIFFERENCES
IN NATURAL BREEDING PERFORMANCE, FECUNDITY, AND
SURVIVAL RATE OF POND-REARED GOLDEN MAHSEER (TOR
PUTITORA)

Saeed Ur Rehman¹, Muhammad Zubair Anjum^{*2}, Ms. Sana Urooj³, Fahim Ullah Khan⁴

^{1, *2,3,4}Department of Zoology, Wildlife & Fisheries, Faculty of Sciences, PMAS-Arid Agriculture University
Rawalpindi, Aquaculture & Fisheries Department government of Punjab

¹saeedattock986@gmail.com, ^{*2}zubair.anjum@uaar.edu.pk

DOI: <https://doi.org/10.5281/zenodo.22669317>

Keywords

Tor putitora; seasonal breeding;
fecundity; larval survival;
hatchery management; pond-
rearing; Indus Basin

Article History

Received: 14 July 2026

Accepted: 18 August 2026

Published: 31 August 2026

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Corresponding Author: *
Muhammad Zubair Anjum

Abstract

Seasonal variation in the reproductive performance of pond-reared golden mahseer (*Tor putitora*) was investigated at Fish Farm Hattian, Attock, Punjab, Pakistan, across two natural breeding seasons in 2025. A total of 137 broodfish – 69 in Season 1 (February–June, pre-monsoon/spring) and 68 in Season 2 (August–October, post-monsoon) – were stripped without hormonal induction across 11 combined spawning spells. Parameters recorded included total egg production, relative fecundity, fry production, and larval survival rate at seven days post-hatch. Water quality, broodstock morphometric, and gonadosomatic index (GSI) were also monitored. Statistical comparisons were performed using independent and paired samples t-tests. Broodstock body weight did not differ significantly between seasons (Season 1: 0.818 ± 0.016 kg; Season 2: 0.835 ± 0.020 kg; $p = 0.501$). Season 1 produced significantly more eggs per female ($2,864 \pm 151$ vs. $2,338 \pm 83$; $p = 0.003$) and higher relative fecundity (289.71 ± 29.17 vs. 209.04 ± 32.73 eggs/kg; $p = 0.046$). Season 2, by contrast, produced significantly more fry per female (365.75 ± 15.62 vs. 217.25 ± 5.70 ; $p < 0.001$) and a 67% higher larval survival rate ($15.59 \pm 0.39\%$ vs. $9.34 \pm 0.72\%$; $p < 0.001$), generating 38.4% more total fry despite 18.6% fewer total eggs. Season 2 showed higher GSI (5.17% vs. 3.68%) and shorter incubation (8–12 vs. 11–16 days). These results establish that the post-monsoon season is decisively superior for fry production in naturally bred *T. putitora*, with clear implications for hatchery management and restocking programs targeting Indus Basin rivers.

1. INTRODUCTION

Tor putitora (Hamilton, 1822), the golden mahseer, stands as one of the most ecologically significant and biologically compelling freshwater fishes of South Asia. A member of the family Cyprinidae, it inhabits the cold, swift-flowing, oxygen-rich rivers of the Himalayan and sub-Himalayan belt – from the upper Indus tributaries of Pakistan in the west to the Brahmaputra system of northeastern

India and Bangladesh in the east (Pinder et al., 2019; Bhatt & Pandit, 2015). Adult fish routinely exceed one meter in length and twenty kilograms in weight, and historical records from the Indus and Ganges basins document specimens approaching two meters and fifty kilograms (Bhatt & Pandit, 2015). The species is a top-order predator, a key engineer of gravel-bed riffle habitats, and a culturally important game fish widely regarded

as among the finest sport fish in Asia (Ogale, 2020).

Conservation concern for *T. putitora* is urgent. The species is listed as Endangered (EN) on the IUCN Red List, with wild populations estimated to have declined by more than 50% across three generations (IUCN, 2023). In Pakistan, the principal drivers of this decline are the construction of dams and barrages – particularly on the main Indus and its Punjab tributaries – which have severed migratory corridors, degraded spawning habitat, and fragmented formerly continuous populations into isolated sub-units. Overfishing, siltation from catchment deforestation, and deteriorating water quality from agricultural and urban runoff compound these pressures (Anjum et al., 2017; Mirza & Bhatti, 1999). Wild mahseer have effectively disappeared from several rivers in the Haro and Siran valleys where breeding populations were still active in the 1990s. The nomenclatural history of the species also deserves mention: earlier Pakistani literature described the Indus Basin population as *Tor macrolepis*, a designation now corrected through molecular taxonomic revision – the confirmed identity is *T. putitora* throughout the Indus system (Yousaf et al., 2024).

The primary active response to this population decline in Pakistan has been hatchery-based propagation and restocking. Provincial Fisheries Departments in Punjab and Khyber Pakhtunkhwa maintain a small number of facilities where captive *T. putitora* broodstock are bred for the production of fry and fingerlings for release into rivers and reservoirs. Fish Farm Hattian, in Attock District, Punjab, is the most established of these, housing a permanent broodstock population of approximately 200–250 adults and conducting seasonal breeding operations under the Punjab Fisheries Act.

Captive breeding of *T. putitora* is achievable through natural spawning in ponds, semi-natural breeding pens, or induced spawning with hormonal treatments. Natural breeding – the approach used in the present study – avoids the physiological stress, cumulative condition losses, and egg quality penalties associated with repeated hormonal induction.

Ciji et al. (2022) demonstrated that captive fish subjected to hormonal manipulation produced eggs that were larger but biochemically depleted, with larvae showing lower survival despite their parents' apparently good physical condition. In a facility reliant on a finite, long-lived broodstock population of a protected species, the choice of natural breeding over hormonal induction is both ecologically sound and practically pragmatic.

T. putitora exhibits a bimodal annual spawning pattern. The first window corresponds to the pre-monsoon/spring season (approximately February–April in the Pakistani sub-Himalayan foothills); the second occurs during the post-monsoon period (August–October). These windows are not rigidly fixed – they shift with elevation, latitude, and annual hydrology – but the two-peak structure is well-established across the species' range (Sarma et al., 2019; Joshi et al., 2018). The proximate environmental cues for each season differ: rising photoperiod and increasing temperature trigger the spring window via the hypothalamic-pituitary-gonadal (HPG) axis, while the post-monsoon season is driven more by thermal and dissolved oxygen changes associated with monsoon inflows (Sharma et al., 2019).

Despite the existence of functional hatchery facilities in Pakistan, there is a near-complete absence of published, season-specific quantitative data on reproductive performance for pond-reared *T. putitora* within the country. Hatchery managers currently rely on general experience or on data from Indian and Nepalese populations (Muddasir Jan et al., 2025; Sarma et al., 2019) that may not accurately reflect the biology of Pakistani stock under local conditions. This gap has real operational consequences: a hatchery that concentrates effort in the less productive season generates fewer viable fry per unit of input, limiting the scale and effectiveness of restocking programs.

The present study addresses this gap by comparing the natural breeding performance of pond-reared golden mahseer across both annual spawning seasons at Fish Farm Hattian during 2025. The specific objectives were: (i) to compare total egg production and relative fecundity between Season 1 (February–June

2025) and Season 2 (August–October 2025), and (ii) to compare larval survival rates and fry production between seasons in naturally bred *T. putitora* broodstock.

2. MATERIALS AND METHODS

2.1 Study Site and Broodstock

The study was conducted at Fish Farm Hattian (33°36'N, 72°21'E), Attock District, Punjab, Pakistan – a mahseer nursery and breeding station managed by the Fisheries Department, Government of Punjab. The facility maintains a permanent population of approximately 200–250 adult *T. putitora* originating from wild broodstock collected from Indus tributaries of Attock District. Broodfish were held in concrete rectangular tanks (approximately 15 m × 6 m × 1.2 m, ~108,000 liters capacity) and supplementary earthen ponds, supplied continuously with fresh groundwater from tube-wells at 4–6 L/min. Stocking density was maintained at 2–3 fish per square meter. Fish were fed a 30–40% crude protein pelleted diet at 2–3% of estimated body weight per day, in two daily feeds. Feeding was suspended 48 hours before each anticipated stripping event. No hormonal treatments were administered at any stage; all reproduction was entirely natural.

2.2 Seasonal Study Design

Data were collected across two distinct breeding seasons in 2025. Season 1 (pre-monsoon/spring) ran from 17 February to 2 June 2025, encompassing six spawning spells. Season 2 (post-monsoon) ran from 29 August to 23 October 2025, encompassing five spawning spells. The same broodstock population was used for both seasons. The experimental unit was the individual broodfish stripped at each spawning event; all reproductive parameters were recorded at the individual level.

2.3 Ripeness Assessment, Stripping, and Fertilization

Broodstock tanks were observed daily between 06:00 and 08:00 h for spawning behaviour. A female was judged ripe when: (i) the abdomen was visibly distended and pendulous; (ii) the genital papilla was reddened and protuberant; and (iii) gentle manual pressure yielded free extrusion of hydrated, golden-orange eggs.

Males were assessed ready when sustained gentle pressure near the genital pore released a free-flowing whitish milt. Stripping was performed in shaded conditions during cooler parts of the day. Each female was stripped individually into a clean dry bowl, and fertilization was carried out by the dry method – milt mixed gently with eggs (approximately 1 mL milt per 200–300 g eggs) with a clean feather, followed by addition of temperature-matched hatchery water. Fertilized eggs were rinsed 2–3 times and placed in flow-through incubation troughs (4–6 L/min).

2.4 Measurements

Body weight (BW, g) was recorded using a calibrated digital balance (capacity 5 kg, resolution 1 g). Total length (TL, mm) was measured with a measuring board. The gonadosomatic index was calculated as GSI (%) = (Gonad weight / BW) × 100, from a sub-sample of stripped females in each season. Fecundity was estimated by the gravimetric sub-sampling method (Nguyen et al., 2021): Total Eggs = (n/v) × V, where n = eggs counted in sub-sample, v = sub-sample weight (g), V = total stripped egg weight (g). Relative fecundity (RF) = Total eggs / BW (kg). Larval survival rate was assessed at seven days post-hatch: Survival (%) = (live fry at 7 d / eggs fertilized) × 100 (Riar et al., 2021). Water temperature, dissolved oxygen (DO), pH, and turbidity were monitored daily with calibrated digital instruments.

2.5 Statistical Analysis

Data were analyzed using IBM SPSS Statistics v.26. Descriptive statistics (mean ± SE, range) were computed for each parameter by season. Seasonal differences were evaluated by independent samples t-test; Levine's test guided variance assumption selection. Paired samples t-tests were applied to the subset of fish available for both seasons (n = 68 pairs). Significance level: α = 0.05. Significance notation: NS ($p > 0.05$), * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$).

3. RESULTS

3.1 Water Quality

Water quality was stable and suitable for mahseer breeding in both seasons (Table 1).

Season 1 recorded mean water temperature 19.0°C (range 18–20°C), DO 6.5 mg/L, pH 7.5, and turbidity 8 NTU. Season 2 recorded 21.0°C (20–22°C), DO 7.0 mg/L, pH 8.0, and

turbidity 12 NTU. The 2°C inter-seasonal temperature difference, while modest, had measurable consequences for embryonic development rate (Section 3.3).

Table 1. Mean water quality parameters by breeding season at Fish Farm Hattian, Attock (2025).

Parameter	Season 1 (Feb–Jun)	Season 2 (Aug–Oct)
Water Temperature (°C)	18–20 (mean 19.0)	20–22 (mean 21.0)
Dissolved Oxygen (mg/L)	6.5	7.0
pH	7.5	8.0
Turbidity (NTU)	8	12
Water Flow Rate (L/min)	4–6	4–6

3.2 Broodstock Morphometric and GSI

Broodstock body weight did not differ significantly between seasons (Season 1: 0.818 ± 0.016 kg; Season 2: 0.835 ± 0.020 kg; $t = -0.675$, $df = 135$, $p = 0.501$). Season 2 females had greater mean TL (45.72 vs. 40.64 cm) and

higher mean GSI (5.17% vs. 3.68%), with heavier gonads at stripping (46 vs. 32 g). The absence of a significant body weight difference between seasons validates the seasonal comparison (Table 2).

Table 2. Broodstock morphometrics and gonadosomatic index (GSI) by sex and season.

Parameter	S1 Males	S1 Females	S2 Males	S2 Females
Mean TL (cm)	38.00	40.64	36.00	45.72
Mean BW (g)	850	870	830	890
Mean Gonad Wt (g)	—	32	—	46
Mean GSI (%)	—	3.68	—	5.17
n (broodfish)	~35	~34	~34	~34

3.3 Incubation Duration

Incubation from fertilization to the free-swimming fry stage was shorter in Season 2. Season 1 required 11–16 days total; Season 2 required 8–12 days (Table 3). Each

developmental sub-phase was similarly compressed in the post-monsoon season, consistent with the 2°C higher ambient water temperature.

Table 3. Duration of incubation phases from fertilization to free-swimming fry stage by season.

Developmental Phase	Season 1 (days)	Season 2 (days)
Cell division / Cleavage	2–3	1–2
Hatching	~3	2–3
Yolk sac absorption	2–3	1–2
Free-swimming fry (from hatch)	5–7	4–5
TOTAL (fertilization to free-swimming)	11–16	8–12

3.4 Seasonal Breeding Summaries

Season 1 produced 196,569 total eggs from 69 broodfish across six spawning spells, yielding 15,000 fry at an overall survival rate of 7.6%.

Season 2 produced 159,000 eggs from 68 broodfish across five spells, yielding 20,766 fry at 13.1% survival – 38.4% more total fry despite 18.6% fewer total eggs (Tables 4 and 5).

Table 4. Breeding summary by spawning spell – Season 1 (February–June 2025).

Date	No. Fish	Total Wt (kg)	Total Eggs	RF (eggs/kg)	Fry	Fry/kg	Survival %
17 Feb 2025	4	3.8	15,600	4,105	1,090	174	7
01 Mar 2025	27	23.1	80,603	3,489	6,630	576	8
27 Mar 2025	10	8.0	22,756	2,845	2,280	300	10
12 Apr 2025	10	6.9	36,410	5,277	1,780	430	5
04 May 2025	15	11.7	36,300	3,103	2,730	233	8
02 Jun 2025	3	2.1	4,900	2,333	490	233	10
TOTAL / MEAN	69	55.6	196,569	3,535	15,000	270	7.6

Table 5. Breeding summary by spawning spell – Season 2 (August–October 2025).

Date	No. Fish	Total Wt (kg)	Total Eggs	RF (eggs/kg)	Fry	Fry/kg	Survival %
29 Aug 2025	30	23.3	58,250	2,500	4,050	174	7
16 Sep 2025	23	19.35	57,500	2,972	11,396	589	20
30 Sep 2025	5	4.0	9,650	2,413	1,160	290	12
11 Oct 2025	8	7.8	26,800	3,436	3,360	431	12
23 Oct 2025	2	2.35	6,800	2,894	800	340	12
TOTAL / MEAN	68	56.8	159,000	2,799	20,766	366	13.1

3.5 Egg Production, Relative Fecundity, Fry Production, and Survival Rate

Statistical results are presented in Tables 6 and 7. Season 1 produced significantly more eggs per female ($2,864 \pm 151$ vs. $2,338 \pm 83$; $t = 2.987$, $df = 106.06$, $p = 0.003$) and significantly higher relative fecundity (289.71 ± 29.17 vs. 209.04 ± 32.73 eggs/kg; $t = 2.013$, $df = 135$, $p = 0.046$). Conversely, Season 2 produced

significantly more fry per female (365.75 ± 15.62 vs. 217.25 ± 5.70 ; $t = -8.933$, $df = 84.57$, $p < 0.001$) and significantly higher larval survival ($15.59 \pm 0.39\%$ vs. $9.34 \pm 0.72\%$; $t = -7.659$, $df = 135$, $p < 0.001$). Paired samples analysis on the $n = 68$ matched individuals confirmed all results at the within-individual level (Table 7).

Table 6. Descriptive statistics for all reproductive parameters by breeding season.

Parameter	Season 1 (n = 69)	Season 2 (n = 68)
Body Weight (kg) – Mean $\pm$ SE	0.818 ± 0.016	0.835 ± 0.020
Body Weight (kg) – Range	0.60 – 1.20	0.60 – 1.50

Parameter	Season 1 (n = 69)	Season 2 (n = 68)
Total Eggs – Mean ± SE	2,864 ± 151	2,338 ± 83
Total Eggs – Range	510 – 6,960	1,300 – 6,800
Relative Fecundity (eggs/kg) – Mean ± SE	289.71 ± 29.17	209.04 ± 32.73
Relative Fecundity (eggs/kg) – Range	90.62 – 1,188	64.38 – 1,847
Fry Produced – Mean ± SE	217.25 ± 5.70	365.75 ± 15.62
Fry Produced – Range	138.60 – 344.40	182.00 – 650.00
Larval Survival (%) – Mean ± SE	9.34 ± 0.72	15.59 ± 0.39
Larval Survival (%) – Range	2.99 – 39.39	10.71 – 21.60

Table 7. Independent samples t-test results comparing reproductive parameters between seasons.

Parameter	t	df	p (2-tail)	Mean Diff.	95% CI L	95% CI U	Sig.
Body Weight (kg)	−0.675	135	0.501	−0.017	−0.068	+0.033	NS
Total Eggs	2.987*	106.06	0.003	+526	+171	+881	**
Rel. Fecundity (eggs/kg)	2.013	135	0.046	+80.67	+1.56	+159.8	*
Fry Produced	−8.933*	84.57	<0.001	−148.5	−181.6	−115.4	***
Larval Survival (%)	−7.659	135	<0.001	−6.25	−7.86	−4.62	***

* Equal variances not assumed t-statistic and adjusted df applied (Levene p < 0.05); NS = not significant,

* p < 0.05, ** p < 0.01, *** p < 0.001

4. DISCUSSION

The first step in any seasonal reproductive comparison is to confirm that the two groups being compared are initially equivalent in the trait most likely to confound results. Fecundity in cyprinids scales closely with body size – larger females produce more eggs (Bagenal, 1978; Joshi et al., 2018). The present study drew from a single permanent broodstock population for both seasons, with fish selected on the basis of maturity rather than size preference. As a result, mean body weight did not differ significantly between seasons (p = 0.501), validating the premise that observed reproductive differences are attributable to season and not to pre-existing size disparities. Season 1 (February–June) produced significantly more eggs per female and higher relative fecundity than Season 2. This is consistent with the established reproductive biology of *T. putitora*: the pre-monsoon spring

period is characterized by active vitellogenesis driven by the combined stimulus of increasing photoperiod and rising water temperature. As days lengthen through February and March, photoreceptors in the pineal region transmit signals through the hypothalamus that increase the pulsatile release of gonadotropin-releasing hormone (GnRH). This in turn drives follicle-stimulating hormone (FSH) and luteinizing hormone (LH) release from the pituitary, stimulating hepatic vitellogenin synthesis and ovarian follicular growth. The energetic reserves accumulated during winter – when reduced water temperatures suppress metabolic activity and allow energy storage in somatic tissue – are mobilized into this vitellogenesis cycle, generating the high oocyte numbers observed in Season 1 (Sharma et al., 2019; Sarma et al., 2019). The broodstock at Fish Farm Hattian, entering the spring season after a period of lower activity and adequate

nutritional condition, allocated a substantial proportion of their body resources to egg production.

The more striking finding – and the one with greatest practical relevance – is the reversal of this advantage when the outcome measure shifts from eggs to surviving fry. Season 2 (August–October) produced 38.4% more total fry despite 18.6% fewer total eggs. The per-female fry production in Season 2 was 68% higher (365.75 vs. 217.25), and larval survival was 67% greater (15.59% vs. 9.34%). This dissociation between egg quantity and larval output reflects a well-known biological trade-off: when females invest more resources per individual oocyte – depositing greater quantities of yolk proteins, lipids, and carotenoids – each egg is individually more energy-rich and produces a more robust larva, but the total number of eggs that can be accommodated in the ovary is fewer (Bagenal, 1978; Ciji et al., 2022). The higher GSI in Season 2 females (5.17% vs. 3.68%) and greater gonad weight (46 vs. 32 g) at similar body weight confirm that oocyte investment per egg was indeed greater in Season 2, despite the lower absolute egg count.

A second mechanism contributing to the Season 2 survival advantage is the shortened incubation period. At 20–22°C (Season 2), incubation to the free-swimming stage took 8–12 days; at 18–20°C (Season 1), this extended to 11–16 days. Each additional day of incubation increases the cumulative exposure of developing embryos to environmental stressors, including fungal infection (primarily *Saprolegnia* spp.), mechanical disturbance, and fluctuations in dissolved oxygen. At Fish Farm Hattian, where no antifungal agents are applied, the shorter Season 2 incubation window represents a meaningful reduction in disease exposure. Subagja et al. (2021) demonstrated in the closely related *Tor soro* that larvae held at or near the species-specific thermal optimum undergo faster, more complete yolk sac absorption and transition to exogenous feeding sooner – reducing the period of nutritional vulnerability post-hatch. The Season 2 larvae at Fish Farm Hattian benefited from both shorter embryonic

exposure and marginally more favorable post-hatch thermal conditions.

The absolute fecundity values observed here (2,338–2,864 eggs per female) are lower than the approximately 5,566 eggs per female reported by Muddasir Jan et al. (2025) for pond-reared *T. putitora* in the Reasi region of Jammu & Kashmir. This difference is explained by body size: the Reasi fish averaged approximately 395 mm TL, considerably larger than the 38–46 cm fish at Fish Farm Hattian. Allometric scaling of fecundity with body length (Joshi et al., 2018) predicts exactly this relationship. The larval survival rates of 9.34% and 15.59% fall within the published range of 5–25% for hatchery-reared mahseer (Riar et al., 2021), with Season 2 values consistent with what those authors described as characteristic of well-managed nurseries.

The management implications of these results are clear and actionable. Provincial mahseer hatcheries in Pakistan that prioritize fry production for restocking programs should concentrate operational effort – staff time, incubation capacity, and resource expenditure – in the August–September (Season 2) window. The estimated 38% fry production advantage in Season 2 represents a real and substantial gain achievable without additional broodstock, infrastructure, or cost. Season 1 retains value as a complementary window for capturing a wider range of genetic contributions from the broodstock population and for facilities with limited post-monsoon operational capacity.

Several limitations of the present study should be acknowledged. Results are from a single facility across one calendar year; inter-annual variation in rainfall, temperature, and water quality could shift the relative seasonal advantage. Egg biochemical composition was not directly measured, so the inference of superior Season 2 egg quality rests on indirect evidence – higher GSI and larval survival – and on the published comparative data of Ciji et al. (2022). Individual fish were not tracked across both seasons, precluding analysis of within-individual consistency of performance. Multi-year replication and extension to additional hatchery facilities would strengthen the generalizability of the findings.

5. CONCLUSION

This study provides the first season-specific, quantitative comparison of natural breeding performance in pond-reared golden mahseer (*Tor putitora*) from a provincial hatchery in Pakistan. Season 1 (February–June, pre-monsoon/spring) generated significantly higher egg production and relative fecundity per female, while Season 2 (August–October, post-monsoon) generated significantly higher larval survival rates and total fry yield. The post-monsoon season produced 38.4% more total fry than the spring season from an equivalent broodstock cohort. These findings support the conclusion that, for the primary conservation objective of maximizing viable fry for Indus Basin restocking, the August–September breeding window should be prioritized in hatchery management planning. Both seasons retain complementary biological value within a structured annual breeding program.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the management and technical staff of Fish Farm Hattian, Attock, Department of Fisheries, Government of Punjab, for facilitating unrestricted access to the broodstock facility and for their assistance during stripping, incubation, and fry counting operations across both breeding seasons. The study was conducted in partial fulfillment of the M.Phil. degree requirements of the Department of Zoology, Wildlife & Fisheries, PMAS-Arid Agriculture University Rawalpindi.

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