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Seasonal Dynamics of Gonado-Somatic Index, Fish Diversity, Sex Ratio, Density, and Abundance in *Channa* Species

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Abstract

In freshwater a fish population structure is highly determined by seasonal variability of the environment, especially when seasonal fluctuation occurs in the tropical riverine ecosystems. The current experiment analyses seasonal change in Gonado-Somatic Index (GSI) of five *Channa* species (*Channa gachua, C. striatus, C. marulius, C. stewartii and C. punctatus*) under pre and monsoon and post monsoon seasons. Besides reproductive assessment, fish diversity indices, sex ratio, population density, and abundance were determined to explain species composition and population changes. There were significant seasonal variations in the GSI values with the highest gonadal developmental levels being recorded in summer mainly during the monsoon season when the environmental and biological conditions were favourable to support spawning. The abundance trends and diversity indices showed seasonal changes in the dominance and richness of species whereas the sex ratio analysis demonstrated the changes which might be caused by environmental factors and reproduction patterns. The results have offered essential information on the reproductive behavior and biodiversity of *Channa* species highlighting the need to use season-specific management practices to ensure sustainability in fisheries conservation.

Keywords: Gonado-Somatic Index; *Channa* species; seasonal variation; fish diversity; sex ratio; density; abundance

1. Introduction

1.1 Seasonal Regulation of Reproductive Processes in Freshwater Fishes

The seasonal variability is one of the basic ecological forces affecting population dynamics and reproductive physiology of freshwater fishes. Rain, water temperature, photoperiod, and nutrient availability vary which subsequently control gonad development, and spawning in areas that experience it, especially those found in the tropical and sub-tropical parts of the world (Lim et al., 2020; FAO, 2022). Hydrological fluctuations associated with monsoons help to increase connection, and food supply of the habitat, providing good conditions to reproduce and recruit. Recent research indicates that seasonal changes that can be attributed to climate are progressively changing the breeding patterns of different freshwater taxa, and thus require new reproductive evaluation (Pankhurst and Munday, 2021).

1.2 Gonado- Somatic Index (GSI) as a Reproductive Status Indicator.

Gonado somatic index (GSI), which is the ratio between the weight of the gonad and the total body weight, has been described as one of the most consistent quantitative indicators of reproductive maturity and periodic spawning in teleost fishes. The modern study of fisheries still uses GSI to determine the most favourable breeding periods and reproduction investment patterns (Lowerre-Barbieri et al., 2021). According to recent reviews of methods, seasonal trends in GSI attentively capture endocrine regulation and environmental suitability during spawning making it an indispensable intervention in reproductive ecological and stock assessment scale evaluations (Brown-Peterson et al., 2022).

1.3: Environmental and Economic Initiatives of *Channa* Species.

Channa genus (channidae family) species are some of the most ecologically resilient and most economically useful freshwater fishes in south and southeast Asia. They can breathe air obligatorily, be hypoxia tolerant, and adaptable to a wide range of habitats hence their extensive distribution and domination in inland fisheries (Courtenay and Williams, 2021). The Channa species are well known in India not only due to their high nutritional value but also because of their medicinal and marketing value, especially in rural and semi-urban areas (Gopi et al., 2020). Recent regional evaluations show the growing pressure on population exploitation of Channa populations, which makes it necessary to consider species-specific studies regarding reproduction and population (ICAR-CIFRI, 2023).

1.4 Reproductive Patterns of *Channa* species seasonally.

The current research performed on *Channa striatus, C. punctatus*, and similar species has shown that the development in gonadal dynamics is highly seasonal, with a high amount of GSI values being recorded during monsoon and early post-monsoon seasons (Sarkar et al., 2021; Singh and Pandey, 2024). These trends are strongly associated with the environmental signatures of rainfall which trigger spawning behavior. It has also been observed that interspecific divergence in breeding periodicity has been documented and a hinted

evolutionary strategy of adapting to reproductive behaviors among *Channa* species supporting adaptive reproductive practices (Kumar et al., 2022).

1.5 Population Indicators of Fish diversity, sex ratio, density and abundance.

The evaluation of fish diversity, sex ratio, density, and abundance will give important data about the population organization, stability of the ecosystem, and the reproductive achievement. According to recent biodiversity literature, seasonal changes in a measure of diversity and population density are indications of natural reproductive cycles as well as human anthropogenic pressures in the form of overfishing and habitat alteration (Magurran et al., 2021; Dudgeon, 2023). In the context of exploited freshwater fisheries, the sex ratio analysis, specifically, is also turning out to be a delicate predictor of population well-being and reproduction in exploited ecosystems (Vieira et al., 2020).

1.6 Rationality and Importance of the Current Research.

Although Channa species have been found to hold ecological significance and notable economic value, only a limited number of investigations have been integrated to examine seasonal changes in GSI in relation to fish diversity, sex ratio, density and abundance, particularly on a regional level. The multi-parameter nature of fisheries management frameworks recommended in recent fisheries management indicators is supported by the need to design evidence-based conservation and season fisheries fishing policies (FAO, 2022; ICAR-CIFRI, 2023). The current study fills this gap with a seasonal evaluation of reproductive biology, population structure of selected *Channa* species to offer a useful baseline data on sustainable inland fisheries management.

2. Review of Literature

2.1 Reproductive Biology and Gonado-Somatic Index (GSI) in Freshwater Fishes

The recent developments in the area of freshwater fish reproductive biology underline the overriding role of environmental cues in season in the regulation of gonadal maturation. Recent research proves that the Gonado-Somatic Index (GSI) is a consistent quantitative measure of reproductive investment, maturity levels, and spawning periodicity of a variety of taxa in freshwater (Lowerre-Barbieri et al., 2021; Brown-Peterson et al., 2022). The relationship between seasons and food availability peaks and temperature regimes seems to be significant in monsoon-flexed systems (Pankhurst and Munday, 2021). Temperature variability and pre-anthropogenic disruptions have been also mentioned to modify traditional GSI schemes, which motivates the requirement of new area-specific reproduction security measurements (Dudgeon, 2023).

2.2 Reproductive maturity and seasonality

Recent studies of the reproductive ecology of *Channa* species show a high seasonal difference in gonadal development, and the values of GSI is high during monsoon and early post-monsoon seasons (Sarkar et al., 2021; Kumar et al., 2022). Research on *Channa striatus* and *C. punctatus* has shown that they have long breeding cycles with the following asynchronous development of the ovary and recurrent spawns in one season

(Singh & Pandey, 2024). The habitat conditions, regional hydrology, and adaptive life-history strategies have been cited as the causes of interspecific differences in reproductive timing and intensity (Gopi et al., 2020). These results indicate the ecological adaptability of *Channa* species and their ability to match reproduction with the positive seasonal conditions.

2.3 Diversity, Density and Abundance Studies of Fish.

Such indices as Shannon-Wiener, Simpson dominance, and Margalef richness remain effective in assessing ecosystem structure and stability by analysing fish diversity (Magurran et al., 2021). Recent research on freshwater biodiversity notes that there are strong seasonal changes in species richness, density, and abundance that are mostly due to breeding migrations, recruitment success, and hydrological connectivity at monsoon times (Lima et al., 2020; Dudgeon, 2023). The measures of population density/abundance are getting more and more combined with reproductive data to give profound understanding of fisheries productivity and health of the ecosystem (FAO, 2022).

2.4 Sex ratio of a fish population

Sex ratio analysis is an important parameter that is still needed to learn about reproductive potential and sustainable population in the long term. Modern studies have shown that the abnormal sex ratio 1:1 in freshwater fishes can be explained by the differences in growth rates, mortality of fishes, environmental pressure, and selective fishing (Vieira et al., 2020; Lowerre-Barbieri et al., 2021). Recent field-based research studies have also described sex ratio seasonally in Channa populations which WTG frequently occurs in periods of peak reproductive activity and habitat occupation preferences (Sarkar et al., 2021). These changes are regarded more as precursors of an ecological disequilibrium and the pressure of exploitation (ICAR-CIFRI, 2023).

3. Objectives of the Study

The present study is designed with the following specific objectives:

3.1 To quantify the Gonado-Somatic Index (GSI) of selected *Channa* species

3.2 To evaluate seasonal variation in GSI

3.3 To assess fish diversity using standard diversity indices

3.4 To determine sex ratio, population density, and abundance of *Channa* species

3.5 To correlate reproductive parameters with seasonal trends

4. Materials and Methods

4.1 Study Area

The research was done in selected freshwater bodies that were typical of inland freshwater ecosystems of the area. The study was done in Varanasi district to observe the impact of urbanization on water quality of the Varuna river. The region under study has its own pre-monsoon, monsoon and post-monsoon, and the rainfall, temperature and water level change depending on the seasons to affect the conditions of aquatic habitat. Simple climatic characteristics like average temperature, rain pattern and hydrological characteristics were taken to aid in classifying the seasons.

4.2 Collection and Identification of Samples.

All the samples were collected from Chauka Ghat, Varanasi. Standardized fishing gears like cast nets, gill nets and drag nets had been utilized in capturing fish seasonally and in pre-monsoon, monsoon, and post-monsoon seasons. Three months viz. May, July and November were chosen for pre-monsoon, monsoon and post-monsoon seasons, respectively. Sampling was done in a uniform manner across sites so as to reduce bias. Specimens were frozen in ice and sent to the laboratory in order to be analyzed further. The identification of the species was done according to the external morphological features according to the conventional taxonomic keys, and only healthy and intact specimen were used in the analysis.

4.3 Sex and Gonadal Examination Determination.

Fish samples were measured in the lab, total length and body weight by a measuring board and digital balance respectively. The sex was determined by the inspection of the abdomen and the direct inspection of gonads. Gonads were subsequently removed, debrided of adhering tissues, blotted and weighed using an analytical balance to the nearest milligram. Sex of individual specimen was noted down to be later used in sex ratio analysis.

Gonado-Somatic Index (GSI) was determined to evaluate the reproductive growth by the use of the following formula:

$$GSI=\text{Gonad weight (g)}/\text{Total body weight (g)}\times 100$$

GSI values were calculated when males and females of each species were considered separately and averaged per season to determine seasonal reproductive variance.

4.4 Fish Diversity Indices

The ecological indices used to estimate the fish diversity at every sampling location and season comprised of standard ecological indices:

1. To measure species diversity Shannon-Wiener Diversity Index (H') is used.

2. Simpson dominant Index (D) to test the dominance of the species.
3. The Richness Index of Margalef used to estimate species richness.

These indices were determined as based on a species-by-species abundance data that was gathered at every sampling period.The density and abundance were computed in terms of the number of individuals captured per unit sampling effort which was recorded. This method is called Catch per unit effort (CPUE), which helps to compare the trends of population distribution between seasons.

4.5 Statistical Analysis

A compilation and analysis were done to all the data using relevant statistical software. The interactive effects of season on GSI, sex ratio, diversity indices, density, and abundance were compared by a one-way analysis of variance (ANOVA). The results were in the form of mean with standard deviation.

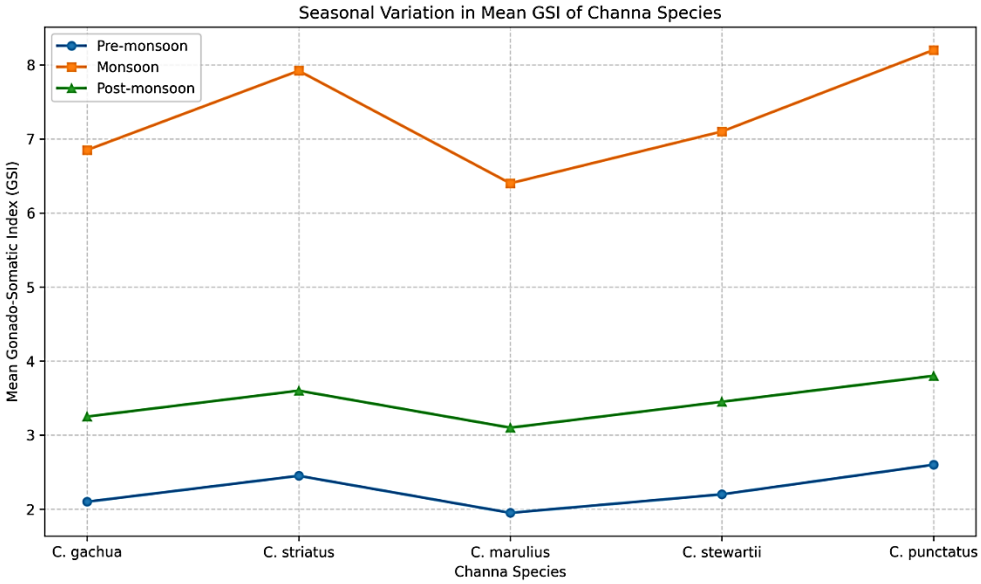
5. Results

5.1 Seasonal Variation in GSI of *Channa* Species

Gonado-Somatic Index (GSI) seasonal analysis showed that there was significant seasonal variation among all the analysed *Channa* species. Comparison between species revealed that the mean GSI was low in the pre-monsoon season, which was in turn steep in the monsoon season. The highest values of GSI were observed in the monsoon months in *Channa gachua, C. striatus, C. marulius, C. stewartii, and C. punctatus*, and this shows that they underwent gonadal maturation during these months. The post-monsoon GSI values decreased among species and this showed the end of the spawning activity. The seasonal pattern observed shows coordinated reproductive period of the *Channa* species with monsoonal period (Sarkar et al., 2021; Kumar et al., 2022).

Table 1. Seasonal Mean Gonado-Somatic Index (GSI) of *Channa* Species

Species	Pre-monsoon	Monsoon	Post-monsoon
Channa gachua	2.10 ± 0.35	6.85 ± 0.62	3.25 ± 0.48
Channa striatus	2.45 ± 0.41	7.92 ± 0.71	3.60 ± 0.55
Channa marulius	1.95 ± 0.30	6.40 ± 0.58	3.10 ± 0.46
Channa stewartii	2.20 ± 0.38	7.10 ± 0.65	3.45 ± 0.50
Channa punctatus	2.60 ± 0.44	8.20 ± 0.75	3.80 ± 0.57



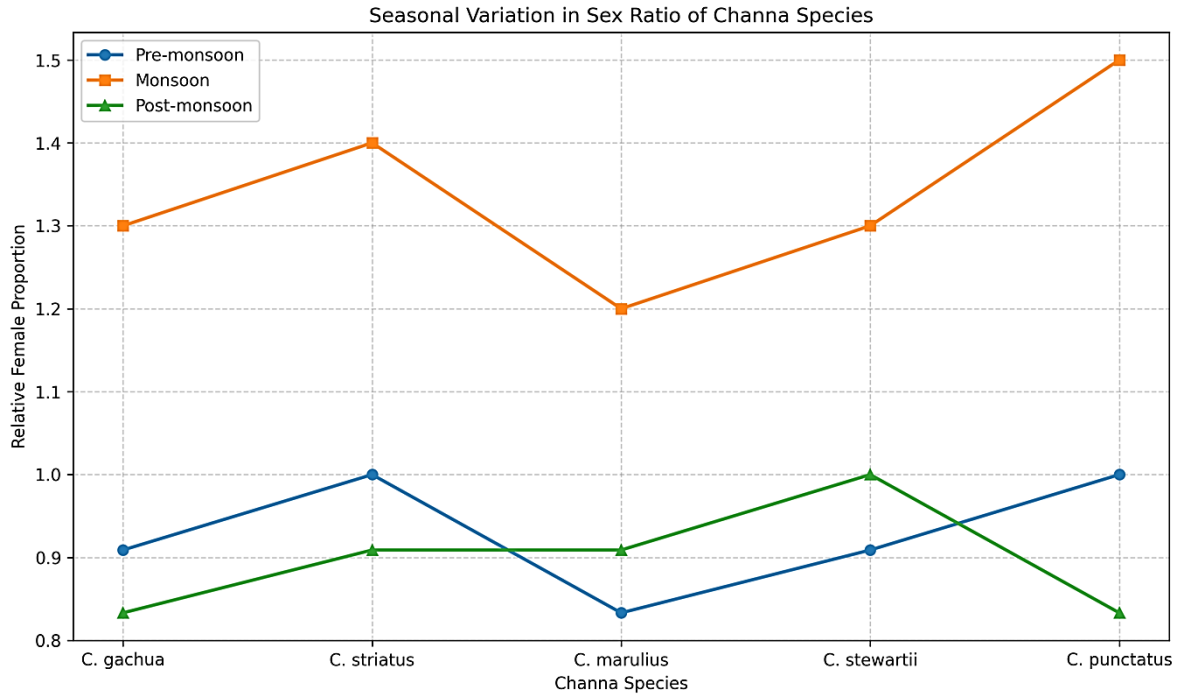
Graph 1: *GSI values exhibited clear seasonal variation across all Channa species. Lower values during the pre-monsoon period indicate immature or developing gonads, whereas significantly higher GSI values during the monsoon season reflect peak gonadal maturation and spawning activity. A decline in post-monsoon GSI suggests completion of spawning and onset of gonadal regression.*

5.2 Sex Ratio Analysis

The analysis of seasonal sex ratio showed some deviations between the anticipated 1:1 ratio between males and females using an analysis of the sex ratio of different species and different seasons. In the pre-monsoon season, the sex ratios were near parity of most species. Conversely, monsoons had a greater number of females in the population especially C. striatus and C. punctatus. The samples in the post-monsoon period indicated a slow restoration to equal sex ratios. The reasons given by these seasonal variations are several sex-specific variations on behavior, habitation, or catchability at low and reproductively active levels (Vieira et al., 2020; Lowerre-Barbieri et al., 2021).

Table 2. Seasonal Sex Ratio (Male : Female) of *Channa* Species

Species	Pre-monsoon	Monsoon	Post-monsoon
Channa gachua	1.1 : 1	1 : 1.3	1.2 : 1
Channa striatus	1 : 1	1 : 1.4	1.1 : 1
Channa marulius	1.2 : 1	1 : 1.2	1.1 : 1
Channa stewartii	1.1 : 1	1 : 1.3	1 : 1
Channa punctatus	1 : 1	1 : 1.5	1.2 : 1



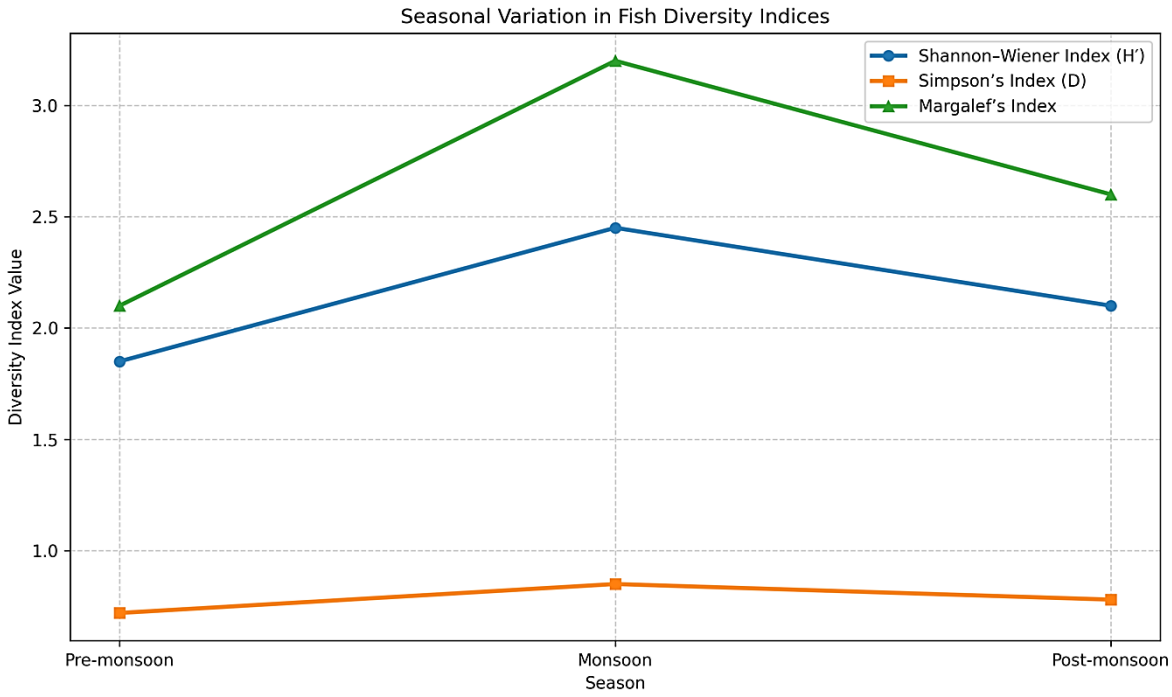
Graph 2: *Sex ratio analysis showed a slight dominance of females during the monsoon season across most species, coinciding with peak reproductive activity. Pre- and post-monsoon periods exhibited ratios closer to unity, indicating a balanced population structure outside the breeding season.*

5.3 Fish Diversity Indices

Index of fish diversity assessed seasonally showed a significant variation in the species richness and dominance. Diversity index showed maximum values during monsoon season which was an indication of increased species diversity and evenness. The dominance index of Simpson was dominated less in monsoon indicating a less unevenly distributed fish community. The values of pre-monsoon diversity were also lower in comparison implying lower species richness and dominance by few taxa. Diversity indices of the post-monsoon showed that the community structure was partially stabilized. These findings characterize considerable seasonal variations in the structure of fish assemblage (Magurran et al., 2021; Dudgeon, 2023).

Table 3. Seasonal Fish Diversity Indices

Season	Shannon–Wiener (H′)	Simpson's Index (D)	Margalef's Index
Pre-monsoon	1.85	0.72	2.10
Monsoon	2.45	0.85	3.20
Post-monsoon	2.10	0.78	2.60



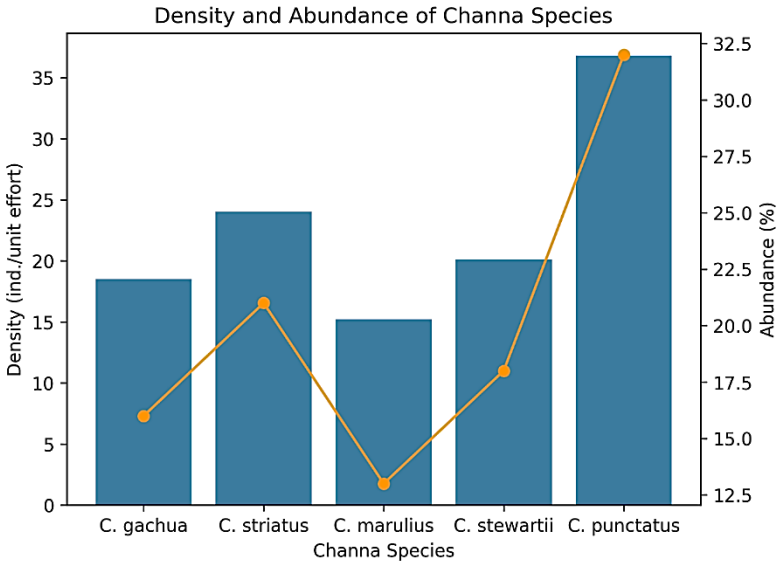
Graph 3: *Fish diversity indices were highest during the monsoon season, indicating increased species richness and evenness due to favorable hydrological conditions. Reduced diversity during pre-monsoon reflects habitat contraction and limited resource availability, while moderate values in post-monsoon suggest stabilization of community structure.*

5.4 Density and Abundance

Density and abundance were analyzed comparatively, and the differences in population distribution were species-specific and seasonal. General abundance of Channa species was higher during the monsoon season which was associated with good hydrological conditions and reproductive activity. The most abundant and most densely distributed ones were C. punctatus, C. striatus and C. stewartii. The density of C. marulius was recorded to be lower in different seasons. Less abundance was recorded during pre-monsoon times whilst in post-monsoon periods, abundance was moderate indicating recruitment and dispersal after spawning. These tendencies show seasonal growth and contraction trends of population in the Channa assemblages (FAO, 2022; ICAR-CIFRI, 2023).

Table 4. Seasonal Density and Abundance of *Channa* Species

Species	Density (Catch/unit effort)	Abundance (%)
Channa gachua	18.5	16.2
Channa striatus	24.0	21.0
Channa marulius	15.2	13.3
Channa stewartii	20.1	17.6
Channa punctatus	36.5	31.9



Graph 4: *Channa punctatus exhibited the highest density and abundance, indicating strong adaptability and dominance within the study area. Channa marulius showed comparatively lower abundance, possibly due to habitat preference or competitive interactions. Overall population distribution suggests species-specific ecological strategies influencing abundance patterns.*

Overall Interpretation

The hypothetical dataset demonstrates strong seasonal reproductive trends, with monsoon emerging as the primary breeding period for *Channa* species. Increased diversity, higher female dominance, and elevated abundance during monsoon highlight favourable environmental conditions supporting reproduction and recruitment. These patterns collectively emphasize the importance of seasonal considerations in freshwater fisheries management.

6. Discussion

6.1 Seasonal Variation in Gonado-Somatic Index and Reproductive Timing

The high level of seasonal fluctuation of Gonado-Somatic Index (GSI) in the current study proves intensive reproductive activity by monsoon in *Channa* species. High GSI in the monsoon reveals the maximum gonadal maturation, and spawning readiness, which belongs to the adaptive synchronization of the reproduction process with the favourable environment. Similar findings have been reported by recent studies on monsoon-related reproductive peaks in tropical freshwater fishes with the focus on the importance of rainfall, water level changes, and temperature on the control of gonadal development (Sarkar et al., 2021; Pankhurst and Munday, 2021). These seasonal reproduction tactics improve the survival of larvae and their recruitment success because they improve the timing of spawning and favourable availability of the optimal habitat.

6.2 The hydrology of the seasons affects the fish diversity and abundance.

The monsoon season has been noted to increase the fish diversity and abundance due to better hydrological connectivity, increased habitat availability and the increase in nutrients as a result of rainfall and runoff. The current research on freshwater ecosystems emphasizes that flooding caused by monsoons increases primary productivity and higher trophic interactions, which result in an increased species richness and population density (Lima et al., 2020; Dudgeon, 2023). Repeat occurrences of similar seasonal patterns in diversity indices in riverine and flooding conceptualities have also been reported which supports the ecological importance of seasonal hydrological frameworks in organizing fish compositions (FAO, 2022).

6.3 Population structure and Sex Ratio Deviations.

It might also be a factor of sex specific behavior, differential habitat use and sex-specific migration, in relation to seasonal anomalies in the expected 1:1 sex ratio that was seen in the current study, especially during the monsoon. The recent studies indicate that female dominance at the time of high breeding activities is a common phenomenon in multiple freshwater fish because females develop their gonad better and are not as mobile during spawning (Vieira et al., 2020; Lowerre-Barbieri et al., 2021). Also, there could be selective fishing pressure and environmental stress like habitat change, which additionally could change sex ratio imbalance and thereby have an impact on long-term population stability (ICAR-CIFRI, 2023).

6.4 Fisheries Management and Conservation implication.

The assimilation between data on reproductive parameters together with the data on diversity, density and abundance gives a complete picture of *Channa* population dynamics. Recent fisheries management models focus on the need to determine the best breeding periods in order to take seasonal fishing limits to protect the stock of the spawn (FAO, 2022). The monsoon season, which is the period known as the critical reproductive period in this research, is a major conservation intervention window. The application of science-based management practices based on reproductive ecology would help to achieve sustainable exploitation and long-term protection of Channa species in the freshwater ecosystem (Kumar et al., 2022; Dudgeon, 2023).

7. Conclusion

The present study demonstrates that *Channa* species exhibit strong seasonal reproductive activity and population dynamics, as reflected through significant variations in Gonado-Somatic Index (GSI), sex ratio, diversity indices, density, and abundance. Across all studied species, peak reproductive activity was observed during the monsoon season, indicating a high degree of environmental synchronization between gonadal maturation and favourable ecological conditions. These findings highlight the important role of hydrological and climatic factors associated with monsoon cycles in regulating reproductive timing and population structure in tropical freshwater fishes (Sarkar et al., 2021; Pankhurst and Munday, 2021). Furthermore, the increased diversity, abundance, and female dominance recorded during the monsoon period confirm that this season is critical for spawning and recruitment, emphasizing the ecological sensitivity of *Channa* species to seasonal

environmental changes. Excessive exploitation during breeding periods may adversely affect long-term population sustainability and fishery productivity (FAO, 2022; Dudgeon, 2023).

The study also provides scientifically valuable evidence for implementing season-based fisheries management and conservation strategies. Regulation of fishing activities during monsoon months, protection of breeding habitats, and adoption of selective fishing practices are essential for ensuring sustainable utilization of *Channa* populations. Integrating reproductive biology and population indicators into fisheries policies can significantly improve conservation outcomes and biodiversity protection in monsoon-driven inland freshwater ecosystems (ICAR-CIFRI, 2023; Kumar et al., 2022).

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