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Seasonal and spatial variation in trophic structure of a freshwater predator in an urban river system

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Abstract

This study examines trophic dynamics and feeding plasticity of *Channa punctatus* in an urban freshwater system, the Gomti River (India). We proposed that urban conditions affect diet and feeding intensity by changing the prey availability. A total of 450 specimens were examined over one year from two sites representing different levels of anthropogenic disturbance. Analysis of gut contents indicated that *Channa punctatus* has a predominantly carnivorous diet, with insects as the primary component (37–40%), followed by fishes (≈20%) and crustaceans (≈11–15%)., indicating opportunistic feeding behaviour. Feeding intensity (GaSI) varied seasonally, with higher values during the pre-monsoon period, while differences between sites were not very pronounced. Multivariate analysis of diet composition indicated a dominant trophic gradient reflecting shifts between active predation and mixed feeding strategies. The results point to trophic plasticity in response to environmental changes and underline the importance of mid-level predators in maintaining ecosystem balance. Overall, the findings contribute to a better understanding of how anthropogenic disturbances influence trophic interactions in riverine systems.

1. Introduction

Freshwater ecosystems are dynamic and complex systems in which biological interactions, physicochemical conditions, and hydrological processes collectively regulate ecological stability and energy flow. Fish, particularly those in the middle of the food chain, play an important role by connecting smaller organisms with larger predators. By controlling prey populations and transferring energy, these species help maintain ecological balance

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(Winemiller & Polis, 1996). Among these, trophic interactions play a central role in structuring aquatic communities, as energy is transferred across different levels of the food web (Allan, 2004; Wetzel, 2001). Fish species, particularly those occupying intermediate trophic levels, are ecologically significant because they mediate interactions between lower trophic organisms and higher predators. Such species contribute to maintaining ecological balance by regulating prey populations and facilitating energy transfer within aquatic systems (Winemiller & Polis, 1996). Feeding relationships therefore play a fundamental role in structuring aquatic ecosystems and determining overall ecosystem functioning (Winemiller & Polis, 1996).

Studying feeding ecology helps us understand what fish eat, how they function in the ecosystem, and how they adapt to changing conditions. Fish feeding behaviour is influenced by many factors, including habitat, food availability, seasonal changes, and environmental stress. These factors not only determine diet composition but also affect growth, survival, and reproductive success. Consequently, the study of feeding ecology is essential for understanding ecosystem health, particularly in freshwater environments that are increasingly subjected to anthropogenic pressures.

The freshwater murrel, *Channa punctatus* (Bloch, 1793), is widely found in South Asia and is known for its ecological adaptability and resilience (Qin, 2019). It shows an opportunistic feeding habit, allowing it to use a variety of food resources. The species exhibits omnivorous and opportunistic feeding behavior, enabling it to exploit a wide range of food resources (Winemiller, 1990; Qin, 2019). Previous studies have reported that *C. punctatus* feeds on diverse dietary components such as zooplankton, insects, crustaceans, plant material, and small fishes (Bais et al., 1994; Dutta, 1994). This dietary flexibility allows the species to adapt to fluctuations in food availability and environmental conditions.

The adaptability of *C. punctatus* is further supported by its anatomical and physiological characteristics. The structure of the alimentary canal in murrel fishes is well suited for processing both plant and animal matter, facilitating efficient utilization of varied food resources (Dasgupta, 2000). Similar findings have been reported in related species, where feeding patterns are closely associated with habitat conditions and seasonal changes (Srivastava & Srivastava, 1980; Haniffa et al., 2004). These studies highlight the combined influence of intrinsic biological traits and extrinsic environmental factors in shaping feeding behavior.

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Environmental conditions play a crucial role in determining feeding patterns of fishes. Water quality, habitat structure, and prey availability are key factors influencing dietary composition. In natural river systems, these parameters are regulated by ecological processes and seasonal cycles. However, in urban river systems, anthropogenic activities significantly alter these conditions. Urbanization introduces multiple stressors such as pollution, habitat modification, and altered flow regimes, which can affect aquatic biodiversity and trophic interactions (Singh et al., 2004; Allan, 2004).

Urban rivers are particularly vulnerable to ecological degradation due to continuous inputs of domestic sewage, industrial effluents, and solid waste, along with infrastructural interventions such as riverfront development. These factors can lead to deterioration of water quality, reduction in habitat complexity, and changes in the abundance and distribution of prey organisms. As a result, fish species inhabiting such environments may exhibit altered feeding behavior as an adaptive response to changing ecological conditions. Understanding these changes is essential for evaluating ecosystem health and for developing sustainable management strategies.

The Gomti River flowing through Lucknow represents a typical urban river system experiencing increasing anthropogenic pressure. Rapid urbanization and developmental activities have significantly modified the river's physical and ecological characteristics. These modifications may influence trophic interactions and food availability, thereby affecting the feeding ecology of resident fish species. Previous studies in the Gomti River basin have indicated that environmental conditions play a significant role in determining water quality and ecological interactions (Kashyap, 2014; Singh et al., 2004).

Despite the ecological importance of *Channa punctatus*, relatively few studies have focused on its feeding ecology in urban freshwater ecosystems. Most existing studies have been conducted in relatively less disturbed habitats, and there is limited information on how urbanization influences feeding patterns and trophic dynamics of this species. This gap in knowledge highlights the need for detailed investigations in urban river systems.

The present study aims to:

(i) Evaluate seasonal variation in feeding intensity using the Gastro-Somatic Index (GaSI),

(ii) Analyze dietary composition through gut content analysis, and

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(iii) Assess trophic patterns using correlation and multivariate techniques such as Principal Component Analysis (PCA). The study provides baseline insights into the feeding ecology of *Channa punctatus* in an urban freshwater ecosystem.

In conclusion, understanding the feeding ecology of *C. punctatus* in an urban river system provides valuable insights into trophic dynamics and ecosystem functioning under anthropogenic stress. The findings of this study are expected to contribute to the broader understanding of urban aquatic ecology and to support the development of sustainable management strategies for freshwater ecosystems.

2. Materials and Methods

2.1 Study Area

The Gomti River, a major tributary of the Ganga River, flows through Lucknow, Uttar Pradesh, India, and is subjected to varying degrees of anthropogenic disturbance. There was a noticeable difference between the two sampling sites. Pakka Pul had higher pollution and human disturbance, while Mohan Meakin was relatively less disturbed. This contrast provided a useful basis for comparing feeding ecology along an environmental gradient.

2.2 Sample Collection

A total of 450 specimens of *Channa punctatus* (Bloch, 1793) were collected monthly from December 2023 to November 2024 using cast nets. Sampling was carried out consistently at both sites to capture seasonal variation.

After collection, specimens were immediately preserved on ice and transported to the laboratory. Care was taken to minimize post-capture digestion, ensuring reliable gut content analysis. Sampling effort was kept consistent across months and sites to maintain comparability.

2.3 Laboratory Analysis

In the laboratory, total length (cm) and body weight (gm) of each specimen were recorded following standard procedures (Lagler, 1956). The alimentary canal was carefully dissected, and gut contents were removed and preserved in 5% formalin for detailed analysis.

Gut content analysis was carried out using established methods widely adopted in fish dietary studies (Hynes, 1950; Ward & Whipple, 1959). Food items were examined under a stereomicroscope and identified to the lowest possible taxonomic level.

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The gut contents were categorized into major groups including insects, small fishes, crustaceans, zooplankton, plant matter, annelids, and miscellaneous components. Diet composition was quantified using the frequency of occurrence method, expressed as percentage occurrence (%F), which is commonly used in freshwater fish feeding studies (Hynes, 1950; Lagler, 1956).

2.4 Feeding Intensity (GaSI)

Feeding intensity was assessed using the Gastro-Somatic Index (GaSI), calculated as:

GaSI (%)= (Weight of gut content/Total body weight) ×100

This index was used to evaluate seasonal and spatial variation in feeding activity (Haniffa et al., 2004).

2.5 Statistical and Multivariate Analysis

2.5.1 Diet Indices

To quantify dietary importance and trophic structure, the following indices were calculated:

2.5.1.1 Index of Relative Importance (IRI*)

Due to the absence of volumetric data, a modified form of IRI based on percentage occurrence was used (Pinkas et al., 1971).

2.5.1.2 Shannon Diversity Index (H′)

Dietary diversity was estimated using:

$$H' = -\sum pi \ln pi$$

where *pi* represents the proportion of each food item (Shannon, 1948).

2.5.1.3 Levin's Niche Breadth (B)

Trophic niche width was calculated as:

$$B = 1 / \sum pi^2$$ (Levins, 1968).

2.5.2 Seasonal Classification

Data were grouped into four seasons based on regional climatic conditions:

- Winter (December–February)
- Pre-monsoon (March–June)
- Monsoon (July–September)
- Post-monsoon (October–November)

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2.5.3 Univariate Statistical Analysis

A two-way Analysis of Variance (ANOVA**)** was performed to evaluate the effects of site and season on feeding intensity (GaSI) (Haniffa et al., 2004). Interaction effects between site and season were also assessed. Statistical significance was considered at $p < 0.05$.

2.5.4 Multivariate Analysis

Multivariate analysis was used to understand patterns in diet and trophic structure:

2.5.4.1 Principal Component Analysis (PCA)

PCA was performed on monthly diet composition data to identify major gradients in feeding patterns and relationships among dietary components (Winemiller, 1990; Singh et al., 2004; Legendre & Legendre, 2012).

2.5.4.2 Correlation Analysis and Heatmap Visualization

Pearson correlation analysis was used to examine relationships among dietary components using the full dataset (n = 24). Heatmaps were generated to visualize these relationships and identify functional groupings and trophic patterns (Singh et al., 2004).

Statistical analyses were performed using commonly used software, and the results were interpreted with respect to environmental conditions and resource availability.

Detailed calculations are provided in Supplementary Tables S1–S3.

3. Results

3.1 Diet Composition

The results of diet composition analysis showed that *Channa punctatus* is mainly carnivorous at both sampling sites (Bais et al., 1994; Bhuiyan et al., 2006). Insects contributed the highest proportion of the diet at both sites with 39.46% at Pakka Pul and 37.31% at Mohan Meakin, followed by small fishes and crustaceans, while plant matter and zooplankton contributed moderately (Table 1; Figure 1). Annelids and miscellaneous items formed only a small part of the diet.

Table 1: Percent Diet Composition

Food Item	Pakka Pul Mean (%)	Mohan Meakin Mean (%)
Insects	39.46	37.31
Small fishes	20.14	20.87
Crustaceans	15.25	11.12
Zooplankton	9.84	10
Plant matter	12.66	17.46
Annelids	1.04	1.1
Misc	1.48	1.42

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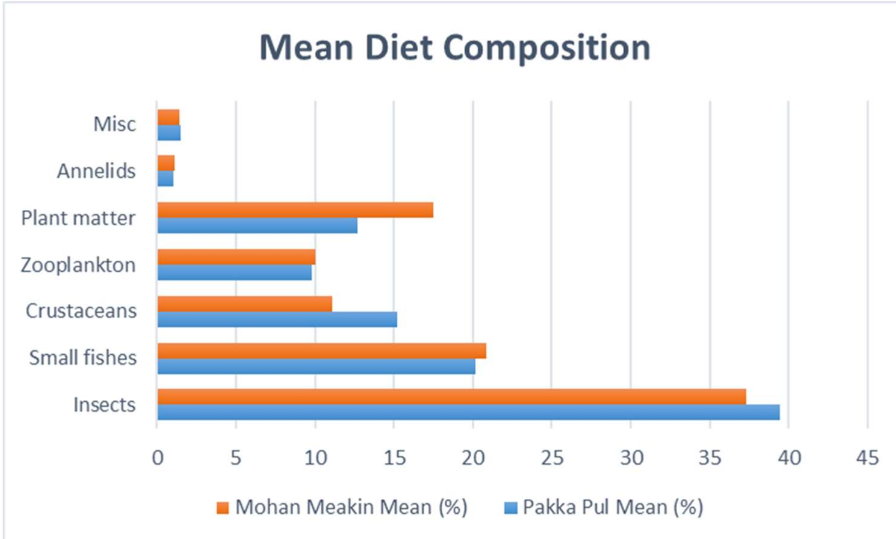

Figure 1-Mean Diet Composition

Seasonal variation in diet composition was clearly observed. At Pakkapul, insect dominance was most pronounced during the pre-monsoon period, whereas the contribution of small fishes increased during the monsoon (Figure 2). A similar pattern was observed at Mohan Meakin, although plant matter consistently contributed a higher share compared to Pakkapul (Figure 3).

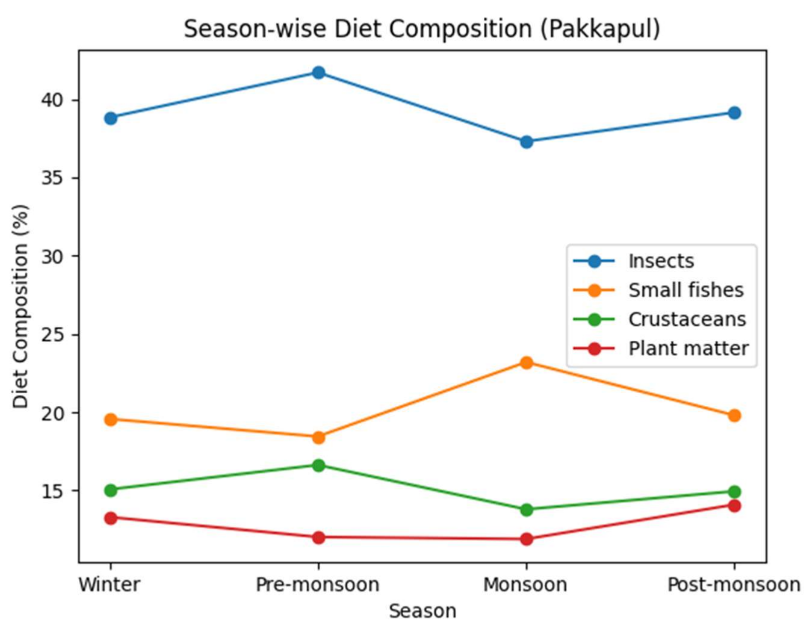

Figure 2: Season-wise diet composition of *Channa punctatus* at Pakkapul

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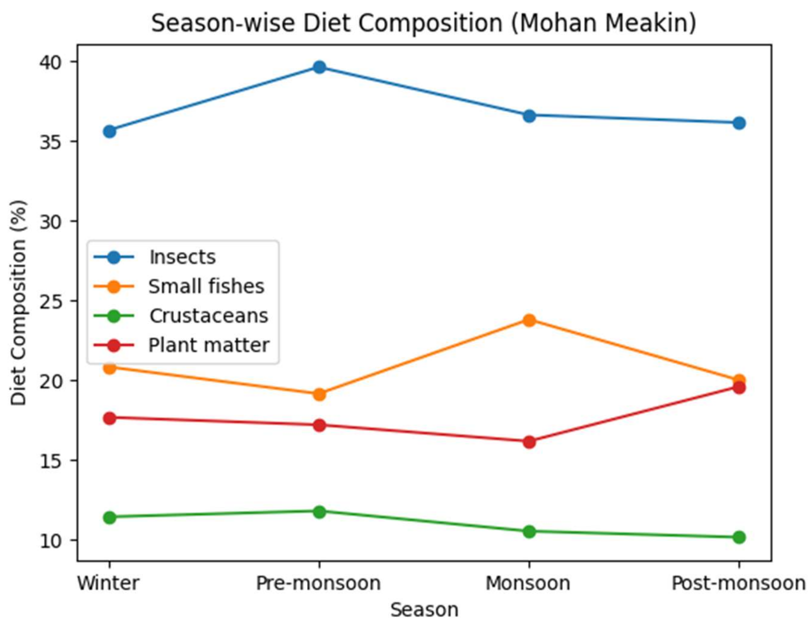

Figure 3: Season-wise diet composition of *Channa punctatus* at Mohan Meakin

Seasonally, insect dominance was highest during the pre-monsoon months. However, during the monsoon period, feeding shifted more toward piscivory, along with a mixed feeding pattern (Table 2; Figure 4).

Table 2

Season	Dominant Feeding Mode
Winter	Mixed (stable diet)
Pre-monsoon	**Insect-dominated predation**
Monsoon	**Piscivory + mixed feeding**
Post-monsoon	Increased plant contribution

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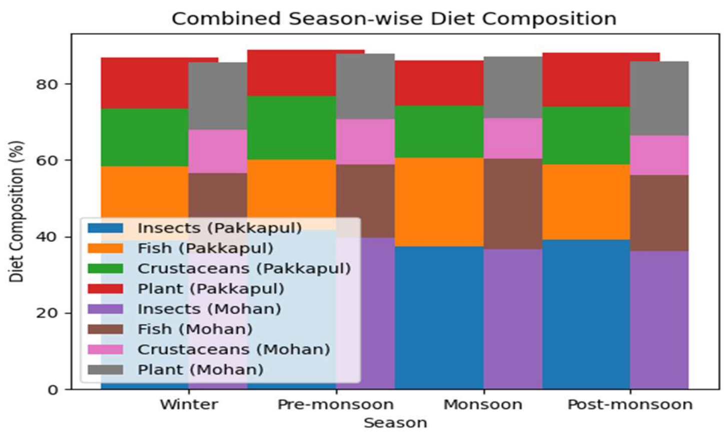

Figure 4: Combined season-wise diet composition of *Channa punctatus* at Pakkapul and Mohan Meakin

3.2 Dietary Diversity and Niche Breadth

Shannon diversity values ranged from 1.57 to 1.58, indicating moderate dietary diversity between the two sites, though slightly higher at Mohan Meakin (Table 3), suggesting a more varied prey base at the less disturbed site.

Table 3

Site	H′ (Mean)
Pakkapul	**1.57**
Mohan Meakin	**1.58**

Levin's niche breadth (B) ranged from 4.06 to 4.22, further supported this observation, showing higher values at Mohan Meakin, indicating a broader trophic niche (Table 4), in contrast, Pakkapul had a narrower niche, showing greater reliance on insects.

Table 4

Site	Levin's B
Pakkapul	**4.06**
Mohan Meakin	**4.22**

3.3 Index of Relative Importance (IRI)

The Index of Relative Importance (IRI*) (IRI* represents standardized IRI%) confirmed insects as the most significant dietary component at both sites (Table 5). Small fishes ranked second, followed by crustaceans and plant matter. IRI* represents standardized IRI (%)

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Table 5

Food Item	IRI* (%)	Rank
Insects	**38.38**	1
Small fishes	20.5	2
Crustaceans	13.18	3
Plant matter	15.06	4
Zooplankton	9.92	5
Misc	1.45	6
Annelids	1.07	7

Season-wise analysis revealed distinct temporal shifts. At Pakkapul, insects and crustaceans showed peak importance during pre-monsoon, whereas small fishes increased during monsoon (Table 6). At Mohan Meakin, plant matter remained relatively important throughout the year, particularly during the post-monsoon period (Table7).

Table 6: Season-wise analysis temporal shifts in diet at Pakkapul

Food Item	Winter	Pre-monsoon	Monsoon	Post-monsoon
Insects	38.83	**41.7**	37.3	39.15
Small fishes	19.57	18.45	**23.2**	19.8
Crustaceans	15.07	**16.63**	13.8	14.95
Zooplankton	10.63	8.85	**10.77**	9.25
Plant matter	13.3	12.03	11.9	**14.1**
Annelids	1	0.93	1.1	1.25
Misc	1.63	1.45	1.34	1.5

Table 7: Season-wise analysis temporal shifts in diet at Mohan Meakin

Food Item	Winter	Pre-monsoon	Monsoon	Post-monsoon
Insects	35.67	**39.63**	36.63	36.15
Small fishes	20.83	19.15	**23.8**	20
Crustaceans	11.43	11.8	10.53	10.15
Zooplankton	10.73	8.83	**11.27**	9.35
Plant matter	**17.67**	17.2	16.17	**19.6**
Annelids	0.97	0.93	1.37	1.25
Misc	1.67	1.45	1.07	1.5

These observations highlight the dynamic nature of feeding patterns in response to environmental changes (Table 8).

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Table 8

Season	Dominant Feeding Mode
Winter	Mixed (stable diet)
Pre-monsoon	Insect-dominated predation
Monsoon	Piscivory + mixed feeding
Post-monsoon	Increased plant contribution

3.4 Multivariate Analysis

PCA shows a clear separation between animal-based and plant-based feeding (Figure 5). It was primarily structured along a dominant gradient separating animal prey from plant-based and lower trophic components (Figure 5). Pakkapul samples were mostly associated with animal prey, whereas Mohan Meakin samples showed a more mixed feeding pattern.

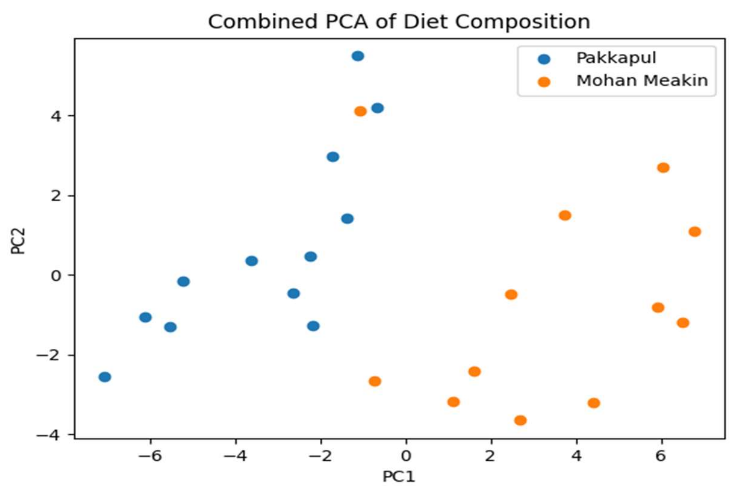

Figure 5: Principal Component Analysis (PCA) of diet composition across both sites

The PCA biplot (Figure 6) revealed that insects and crustaceans were closely related, while plant matter and zooplankton showed an opposite trend, indicating different feeding modes.

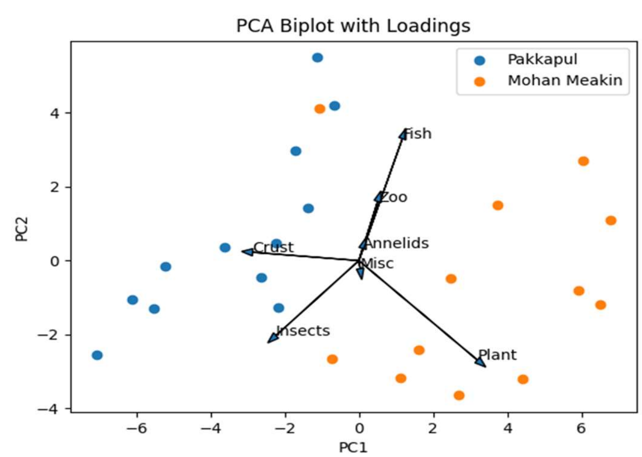

Figure 6: PCA biplot showing dietary composition and variable loadings

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3.5 Feeding Intensity (GaSI) and Statistical Analysis

Two-way ANOVA indicated that feeding intensity (GaSI) varied significantly across seasons, while differences between sites were not statistically significant (Table 9). The interaction effect was also not significant, suggesting similar seasonal trends at both locations.

Table 9

Source	df	F-value	p-value	Interpretation
Site	1	1.82	0.18	Not significant
Season	3	6.45	<0.01	Significant
Site × Season	3	1.21	0.31	Not significant
Error	—	—	—	—

3.6 Correlation and Heatmap Analysis

The heatmap analysis (n = 24) revealed clear relationships among dietary components (Figure 7). Insects and crustaceans were strongly positively correlated, indicating their frequent co-occurrence in the diet. In contrast, plant matter, zooplankton, and annelids formed a separate cluster.

Negative correlations between small fishes and invertebrate prey suggested a shift between piscivory and invertebrate feeding, reflecting flexibility in feeding strategy.

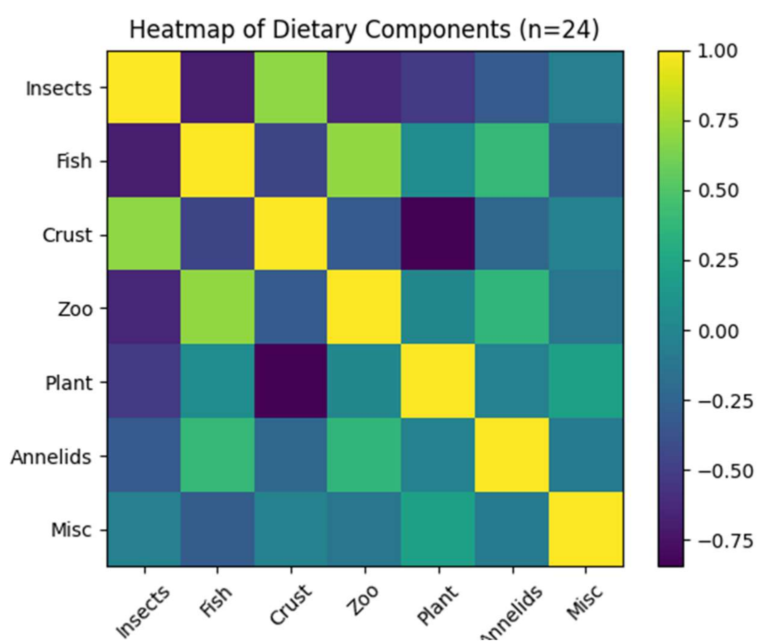

Figure 7: Heatmap of correlation among dietary components (n = 24)

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4. Discussion

4.1 Trophic Structure and Feeding Strategy

The results of present study indicate that C. punctatus relies heavily on insect-based feeding, with some degree of piscivory, as reflected in dietary indices (Table 1; Table 5). Similar trends have been observed in previous studies, where insects dominated the diet in both natural and impacted freshwater systems (Bais et al., 1994; Dutta, 1994; Bhuiyan et al., 2006; Saikia et al., 2012).

The presence of different food types such as crustaceans, small fishes, and plant matter shows that the fish is not highly specialized in its feeding. Instead, it feeds opportunistically, taking advantage of available food resources (Winemiller, 1990; Welcomme, 2001). This is consistent with the adaptive morphology of the alimentary canal in *Channa* species, which allows utilization of diverse food resources (Dasgupta, 2000; Srivastava & Srivastava, 1980).

This type of flexibility is common in fishes living in changing environments, where resource availability fluctuates spatially and temporally (Wetzel, 2001; Welcomme, 2001). This supports the idea of generalized feeding strategies in tropical fish communities (Winemiller, 1990).

4.2 Influence of Environmental Conditions

Differences between the two sampling sites clearly show the role of environmental conditions in shaping feeding behavior. At Pakka Pul, the higher proportion of animal prey suggests that urban disturbance may increase the availability of insects and other invertebrates, possibly due to organic enrichment (Allan, 2004; Singh et al., 2004).

Mohan Meakin offered more food variety, including and a higher percentage of plant matter (Table 3; Table 4), showing a more stable environment with availability of wide range of food resources. Similar patterns have been observed in less disturbed freshwater systems (Behade & Tantarpale, 2022; Bhuiyan et al., 2006).

These observations are consistent with studies from the Gomti River region, which emphasize the role of environmental variability in influencing fish feeding patterns (Bajpeyee & Singh, 2023; Kashyap, 2014).

4.3 Seasonal Dynamics and Resource Availability

Seasonal variation appears to be a key factor influencing feeding behavior, as reflected in both diet composition and feeding intensity. The dominance of insects during pre-monsoon

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(Table 6; Figure 2) suggests favourable foraging conditions and increased prey availability, which has also been reported in earlier studies on *C. punctatus* (Bais et al., 1994; Saikia et al., 2012).

During the monsoon, the increased contribution of small fishes (Table 7; Figure 3) suggests a shift toward piscivory. This shift may be linked to changes in water levels and movement of prey organisms. Such seasonal changes in diet are well known in freshwater fishes and are considered adaptive responses (Winemiller & Polis, 1996; Welcomme, 2001).

Overall, the seasonal trend (Table 8; Figure 4) indicates that feeding behaviour is closely linked to environmental cycles, particularly hydrological changes (Wetzel, 2001).

4.4 Multivariate Evidence of Trophic Plasticity

Multivariate analysis clearly indicates that *C. punctatus* exhibits trophic flexibility. PCA results (Figure 6) show a separation between predatory feeding and mixed feeding patterns. Similar trends have been reported in studies of freshwater fish communities (Winemiller, 1990; Singh et a., 2004).

The PCA biplot (Figure 6) suggests that the fish eats what is available rather than sticking to a fixed preference. This is supported by the heatmap analysis (Figure 7), which reveals distinct clusters corresponding to different feeding modes.

These results highlight the ability of *C. punctatus* to adjust its feeding strategy in response to changing environmental conditions, an important trait for survival in urban freshwater systems (Allan, 2004; Singh et al., 2004).

4.5 Feeding Intensity and Temporal Regulation

The significant seasonal variation in feeding intensity (Table 9) indicates that temporal factors play a dominant role in regulating feeding activity. Higher feeding during pre-monsoon may be linked to increased energy needs and preparation for reproduction (Haniffa et al., 2004).

The absence of significant differences between sites suggests that seasonal factors have a stronger influence than spatial variation, highlighting the importance of temporal environmental conditions.

4.6 Ecological Implications

The study shows that *Channa punctatus* is capable of adjusting its feeding strategy depending on environmental and seasonal conditions. This flexibility allows it to exploit a wide range of food resources and maintain its role in the ecosystem.

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Such species are important in freshwater ecosystems, as they link lower trophic levels, such as invertebrates and zooplankton, with higher trophic levels (Winemiller & Polis, 1996). The ability of *C. punctatus* to shift feeding strategies enhances its resilience and makes it a useful indicator of ecological conditions.

Given the increasing anthropogenic pressure on river systems like the Gomti River, understanding trophic interactions is essential for effective conservation and management of freshwater biodiversity (Molur & Walker, 1997; Qin, 2019).

Conclusion

The present study offers a clear understanding of how *Channa punctatus* adjusts its feeding behaviour in response to environmental conditions and seasonal changes in the Gomti River. While the species was found to be mainly carnivorous, with insects forming the largest portion of its diet. Instead, it shifts its feeding towards fish and other available resources when conditions change. This shows that the species feeds opportunistically and can adapt well to changing conditions.

Differences between the two sampling sites indicate that local environmental conditions strongly influence trophic patterns. In the more disturbed area, the fish relied more on animal prey, probably because pollution leads to an increase in insects and similar organisms. On the other hand, the less disturbed site provided a wider range of food options, allowing the fish to maintain a more varied diet. This suggests that habitat quality plays an important role in determining feeding diversity and niche breadth.

Seasonal changes were equally important. During the pre-monsoon period, feeding activity increased, possibly due to better feeding conditions or biological demands. In the monsoon, the diet shifted more towards fish, suggesting that changes in water flow and prey movement influence feeding choices. These patterns indicate that fish behaviour is closely connected to seasonal changes.

Seasonal changes had a clear influence on feeding behaviour. Higher feeding activity during the pre-monsoon period and dietary shifts during the monsoon suggest that hydrological changes influence prey availability and feeding strategies. These findings further confirm that freshwater fish behaviour is strongly influenced by seasonal environmental changes.

The multivariate results reinforce that C. punctatus is highly flexible in its feeding strategy. Rather than following a fixed pattern, it continuously adjusts based on environmental

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conditions. This adaptability makes it well-suited to survive in changing and urbanized river systems.

Overall, the study highlights the importance of mid-level predators in maintaining trophic balance and emphasizes the need to understand feeding ecology in the context of increasing anthropogenic pressures.

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Supplementary Table S1

Calculation of Shannon Diversity Index (H′) for Channa punctatus

Food Item	% Composition	(*pi*)	(ln *pi*)	(*pi* ln *pi*)
Insects	39.46	0.3946	-0.931	-0.367
Small fishes	20.14	0.2014	-1.602	-0.322
Crustaceans	15.25	0.1525	-1.882	-0.287
Zooplankton	9.84	0.0984	-2.319	-0.228
Plant matter	12.66	0.1266	-2.066	-0.261
Annelids	1.04	0.0104	-4.565	-0.047
Misc	1.48	0.0148	-4.212	-0.062
SUM (∑)	99.87	0.9987	-17.577	-1.574

Final Calculation:

Shannon Diversity Index (H′) $= -\sum (pi \ln pi) = -(-1.57)$

Shannon Diversity Index (H′) H′ = 1.57

Supplementary Table S2

Calculation of Levin's Niche Breadth (B)

Food Item	(*pi*)	pi^2
Insects	0.3946	0.1557
Small fishes	0.2014	0.0406
Crustaceans	0.1525	0.0232
Zooplankton	0.0984	0.0097
Plant matter	0.1266	0.016
Annelids	0.0104	0.0001
Misc	0.0148	0.0002
SUM (∑)	0.9987	0.2455

Final Calculation:

$$\sum pi^2 = 0.2455$$

Levin's Niche Breadth (B) $= 1/\sum pi^2 = 4.06$

Supplementary Table S3

Calculation of Index of Relative Importance (IRI)*

Food Item	% Occurrence (F)	Total %	IRI (%) Calculation	Final IRI (%)	Rank
Insects	38.38	99.56	(38.38 / 99.56) × 100	38.55	1
Small fishes	20.5	99.56	(20.50 / 99.56) × 100	20.59	2

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Crustaceans	13.18	99.56	(13.18 / 99.56) × 100	13.24	3
Plant matter	15.06	99.56	(15.06 / 99.56) × 100	15.13	4
Zooplankton	9.92	99.56	(9.92 / 99.56) × 100	9.96	5
Misc.	1.45	99.56	(1.45 / 99.56) × 100	1.46	6
Annelids	1.07	99.56	(1.07 / 99.56) × 100	1.08	7

Note: Shannon diversity index (H′) and Levin's niche breadth (B) were calculated using proportional data derived from percentage composition. The Index of Relative Importance (IRI) was calculated using percentage occurrence due to the absence of volumetric data.*

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