



Spatiotemporal dynamics and ecological drivers of freshwater bivalve assemblages in semi-arid tropical waters of India

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Abstract

Freshwater bivalves are filter feeders and sensitive bioindicators, yet their spatiotemporal community dynamics in semi-arid tropical inland waters remain poorly quantified. This empirical study evaluated the seasonal variation, spatial heterogeneity, and physicochemical drivers of freshwater bivalve assemblages across three distinct freshwater ecosystems in the state of Maharashtra India viz. Hipparga Reservoir, Jawalgaon Reservoir, and Bhima River at Machnur. A total of 2,018 individuals belonging to eight species across two families Unionidae: *Lamellidens corrianus*, *Lamellidens marginalis*, *Lamellidens* sp. 1, *Lamellidens* sp. 2, *Parreysia corrugata*, *Indonaia caerulea*; Cyrenidae: *Corbicula peninsularis*, *Corbicula striatella* were reported. They sampled on monthly basis covering Summer, Monsoon, and Winter seasons. Bivalve community composition was dominated by *L. marginalis* (23.24%), *L. corrianus* (19.82%), and *L. sp. 1* (18.73%), while *I. caerulea* (2.82%) represented a minor component. Total bivalve abundance exhibited a marked seasonal peak during Summer (30.08 ± 4.47 ind./sample), driven by habitat contraction and thermal metabolic stimulation, compared to Monsoon (27.46 ± 8.21 ind./sample) and Winter (26.54 ± 5.14 ind./sample). Statistically significant seasonal shifts were observed for *Parreysia corrugata* ($F_{269}=3.832$, $p=0.0264$), *Corbicula striatella* ($F_{269}=3.323$, $p=0.0419$), and Pielou's Evenness index J' ($F_{269}=4.776$, $p=0.0114$). Inter-site variation was pronounced for *Lamellidens* sp. 1 ($F_{269}=5.447$, $p=0.0064$) and *P. corrugata* ($F_{269}=4.882$, $p=0.0104$), linked to substrate differences and hydrodynamic regimes between lentic reservoirs and lotic riverine habitats. Ordinary Least Squares (OLS) regression demonstrated that water temperature ($\beta=-0.0084$, $p=0.004$) and pH ($\beta=0.0322$, $p=0.021$) significantly structured community evenness ($R^2=0.233$, $p=0.0254$). Principal Component Analysis (PCA) identified temperature, dissolved oxygen, turbidity, and nutrient concentrations (nitrates and phosphates) as primary environmental axes governing species distribution. These findings provide baseline ecological thresholds for tropical Unionid and Cyrenid conservation under escalating climate warming and hydrologic regulation.

Keywords: Biodiversity, freshwater bivalvia, hydrobiology, solapur

Introduction

Freshwater bivalves (Mollusca: Bivalvia) play indispensable functional roles in continental aquatic ecosystems. Acting as filter-feeders, benthic-pelagic couplers, and habitat modifiers, these organisms mediate bio-filtration, sediment oxygenation, nutrient cycling, and benthic community structuring (Vaughn & Hakenkamp, 2001; Strayer, 2014; Lopes-Lima *et al.*, 2018) [7, 13, 15]. Through continuous suspension feeding, bivalves remove suspended particulate organic matter (POM), microalgae, and bacteria from the water column, thereby enhancing water clarity and transferring energy to the benthos. Consequently, freshwater mussels and clams have been widely designated as "ecosystem engineers" and sensitive bioindicators for monitoring ecological integrity and environmental contamination in inland waters (Vaughn, 2018) [9].

Despite their ecological significance, freshwater bivalves are among the most imperiled faunal groups globally, with over 40% of species listed as threatened or near threatened (Lydeard *et al.*, 2004; Lopes-Lima *et al.*, 2018) [7, 8]. The primary drivers of population decline include habitat loss, hydrological alteration through dam construction, thermal stress, agricultural runoff, siltation, and biological invasions (Ferreira-Rodríguez *et al.*, 2018) [5]. In tropical and semi-arid regions such as the Deccan Plateau of Peninsular India freshwater bivalve communities face acute seasonal stressors resulting from severe monsoonal oscillations, prolonged dry-season drawdowns, elevated water

temperatures, and intensive agricultural land-use (Subba Rao, 1989; Ramakrishna & Dey, 2007) [11, 14].

The freshwater bivalve fauna of the Indian subcontinent is predominantly represented by two major families: Unionidae (native freshwater mussels, including *Lamellidens*, *Parreysia*, and *Indonaia*) and Cyrenidae/Corbiculidae (freshwater clams, including *Corbicula*) (Subba Rao, 1989; Nesemann *et al.*, 2007) [10, 14]. While the taxonomy and distribution of Indian freshwater molluscs have been documented historically, quantitative ecological studies examining seasonal fluctuations in community structure, species diversity, and their explicit coupling with physicochemical water quality parameters remain sparse.

Seasonal variations in temperature, pH, turbidity, dissolved oxygen (DO), and nutrient dynamics directly govern bivalve physiology, reproductive phenology, burrowing behavior, and filtration efficiency (Aldridge, 2000; Spooner & Vaughn, 2008) [1, 12]. Understanding these spatiotemporal patterns is paramount for establishing environmental baseline conditions and formulating effective conservation management frameworks.

Therefore, the main objectives of this study were to quantify the seasonal and spatial variations in species composition, abundance, and ecological diversity indices (H' , $1-D$, J' , d) of freshwater bivalve assemblages across three distinct aquatic ecosystems in Bhima River basin. Identify key physicochemical water quality parameters driving bivalve

abundance and community structure. Elucidate interspecific ecological strategies and niche partitioning between Unionid mussels and Cyrenid clams in response to environmental gradients.

Materials and Methods

The investigation was conducted across three ecologically contrasting freshwater bodies located in the Solapur and adjacent districts of Maharashtra, Peninsular Deccan Plateau region of India. Hipparga Lake (Site 1) a permanent, peri-urban lentic impoundment fed by the Adila River, characterized by moderate water depth, moderate agricultural runoff, and silt-clay benthic substrates. The official name of Hipparga tank is Ekrukh Dam which situated at 17°44'24" N to 75°54'53" E, established in year 1871 before independence for irrigation and water supply. It is an earth fill dam based on Adila River in north Solapur. The height of dam is 21.45 m while the length is 2360 m. Hipparga tank is rich source of flora and fauna. Hipparga lake is one of the beautiful sites where there is natural abundance of flora and fauna with beautiful migratory birds. It is major source of domestic water. The agricultural waste, pesticides etc. goes into this lake and cause diverse effect on molluscan diversity. Jawalgaon Lake (Site 2) an irrigation

reservoir situated in an agricultural catchment, exhibiting pronounced seasonal water level drawdown, mixed sand-mud substrate, and moderate macrophyte growth. Jawalgaon dam was established in year 1997 for irrigation and located at 18°00'47" N to 75°55'24" E in Jawalgaon village in Solapur district. The height of dam above foundation is 21.71 m and length 1229 m with 223 sq.km backwater area. Jawalgaon dam is an earthen type dam constructed on Nagzira River and from all sites covered with agricultural land. Machnur (Site 3) Machnur is a place in Solapur District of Maharashtra in India. It is well known by its Siddheshwar temple on the bank of Bhima river. The Bhima river flow near Machnur village in Mangalwedha taluka. It is situated between Latitude 17°34'9.3" N and Longitude 75°33'35.3"E. It is lotic riverine stretch along the Bhima River, subjected to direct hydrological flow, coarse sand-gravel substrate, and lower water residence times. The regional climate is tropical semi-arid, categorized into three distinct seasons; Summer: April to June high ambient temperature, water level recession, elevated concentration of dissolved solids. Monsoon July to October (heavy precipitation, high river discharge, elevated turbidity, and sediment loading. Winter November to March moderate temperatures, stable water levels, and clear water clarity.

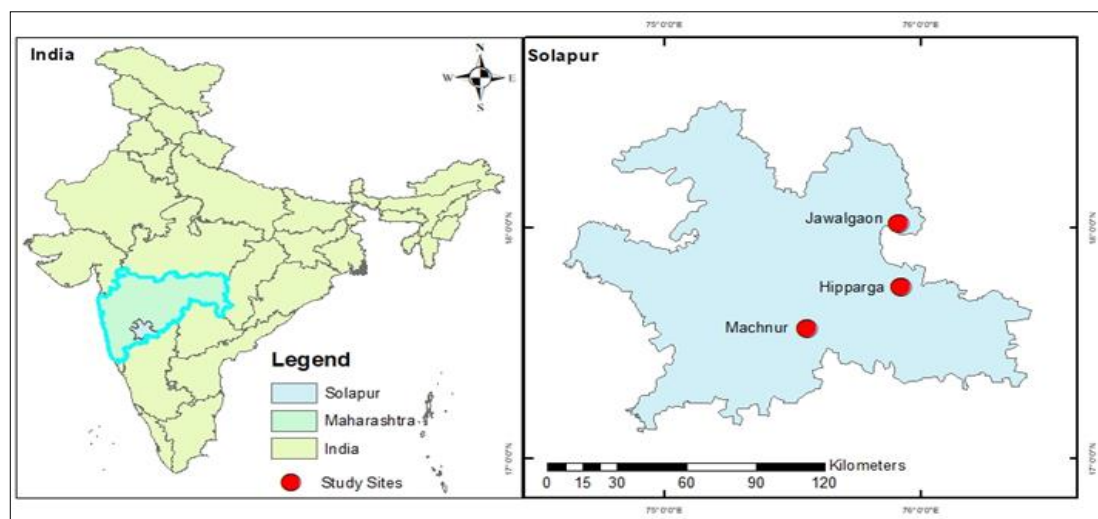


Fig 1: Map of the study sites

Sampling was carried out monthly during April 2017 to March 2019. A total of 72 sampling events; 24 events per site were conducted. At each site, bivalves were recorded using a quantitative quadrat sampling technique. Within each designated 100 m reach, three 1.0 m² rope quadrats were placed randomly along sub-littoral zones (approximately depth 0.5 m). All bivalves were identified to the species level following standard taxonomic keys (Subba Rao, 1989; Ramakrishna & Dey, 2007) [11, 14]. Specimens were subsequently returned to their natural habitat. Simultaneously with bivalve sampling, surface water samples (0.5 m depth) were collected in pre-cleaned 1 L polyethylene bottles for water quality analysis. The evaluated parameters included: Water Temperature (T , °C) and pH, measured *in situ* using calibrated portable digital probes. Turbidity (NTU), determined using a portable nephelometer. Dissolved Oxygen (DO, mg/L), determined via the standard Winkler titration method with azide modification (APHA, 2017) [2]. Sulphate (SO₄²⁻, mg/L), measured spectrophotometrically using the barium sulphate

turbidimetric method. Total Hardness (CaCO₃, mg/L), estimated via EDTA titrimetric method. Phosphate (PO₄³⁻, mg/L) and Nitrates (NO₃⁻, mg/L), measured spectrophotometrically using ascorbic acid and cadmium reduction methods, respectively (APHA, 2017) [2].

To evaluate community structure and species diversity, five standard ecological indices were calculated for each sample. Species Richness (S): Total number of species present. Shannon-Wiener Diversity Index (H'). Simpson's Index of Diversity ($1-D$), Pielou's Species Evenness Index (J'), Margalef's Species Richness Index (d).

Data processing, statistical hypothesis testing, and multivariate ordination were executed using PAST 2026. Normality of data distributions was tested using Shapiro-Wilk tests. Differences in bivalve abundances, diversity metrics, and water quality parameters across Seasons (Summer, Monsoon, Winter) and Sites (Hipparga, Jawalgaon, Machnur) were assessed using One-Way Analysis of Variance (ANOVA) followed by Tukey's Honest Significant Difference (HSD) post-hoc test, along

with non-parametric Kruskal-Wallis H -tests. Relationships between environmental variables and bivalve populations were tested using Pearson (r) and Spearman (ρ) correlation matrices. Multiple Linear Regression (OLS) models were constructed to evaluate environmental predictors of community diversity. Principal Component Analysis (PCA) was performed on z-score standardized water quality and bivalve abundance datasets to elucidate main environmental gradients and community structuring.

Results

A total of 2,018 individual bivalves were recorded across the 72 sampling events. The assemblage comprised eight

distinct taxa belonging to two families: Unionidae (6 species) and Cyrenidae (2 species) (Table 1). *Lamellidens marginalis* was the most dominant species, accounting for 469 individuals (23.24% of total abundance; mean 6.51 ± 4.14 ind./sample), followed by *Lamellidens corrianus* (400 individuals, 19.82%; mean 5.56 ± 3.76 ind./sample) and *Lamellidens sp. 1* (378 individuals, 18.73%; mean 5.25 ± 1.28 ind./sample). *Parreysia corrugata* contributed 14.72% (297 individuals), while *Corbicula striatella* constituted 11.79% (238 individuals). The least abundant taxa were *Indonaia caerulea* (57 individuals, 2.82%) and *Lamellidens sp. 2* (82 individuals, 4.06%).

Table 1: Bivalve Species Composition

Species	Family	Total Count (N)	Mean per Sample	Std. Dev. (σ)	Relative Abundance (%)
<i>Lamellidens marginalis</i>	Unionidae	469	6.51	4.14	23.24%
<i>Lamellidens corrianus</i>	Unionidae	400	5.56	3.76	19.82%
<i>Lamellidens sp. 1</i>	Unionidae	378	5.25	1.28	18.73%
<i>Parreysia corrugata</i>	Unionidae	297	4.13	1.43	14.72%
<i>Corbicula striatella</i>	Cyrenidae	238	3.31	1.98	11.79%
<i>Corbicula peninsularis</i>	Cyrenidae	97	1.35	1.04	4.81%
<i>Lamellidens sp. 2</i>	Unionidae	82	1.14	1.00	4.06%
<i>Indonaia caerulea</i>	Unionidae	57	0.79	0.82	2.82%
Total Community	—	2018	28.03	6.26	100.00%

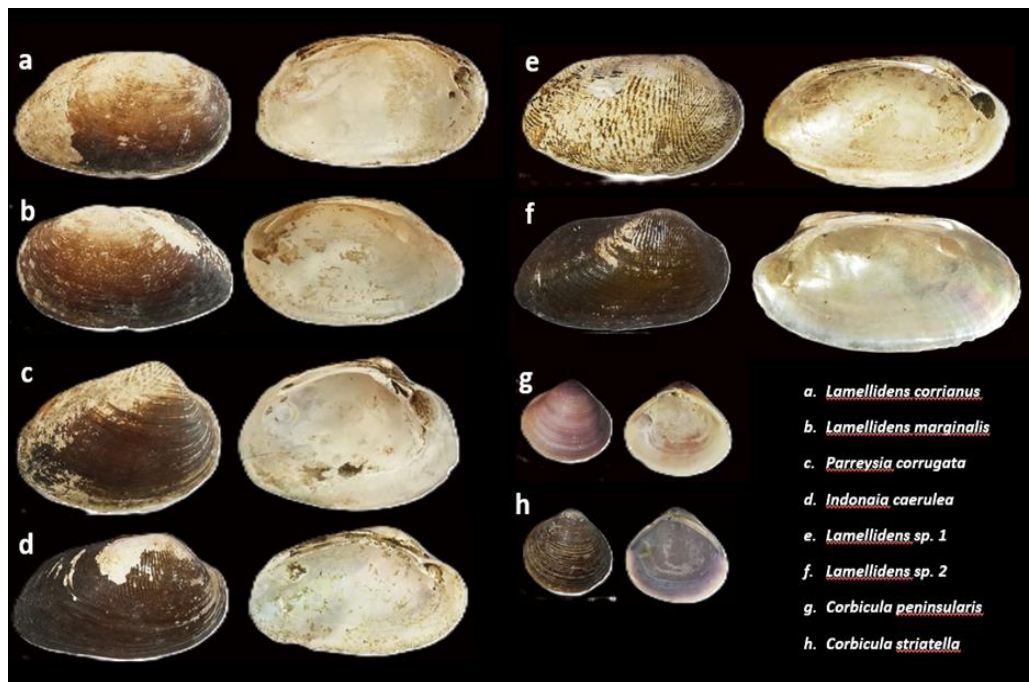


Fig 2:

Physicochemical water quality parameters demonstrated significant temporal and spatial variability across the study sites (Table 2). Surface water temperature ranged from 18.3°C to 27.0°C (mean $22.16 \pm 2.65^{\circ}\text{C}$). Temperature varied significantly across seasons ($F_{2,69}=16.567$, $p<0.0001$), peaking during Summer ($23.88 \pm 2.25^{\circ}\text{C}$) compared to Monsoon ($22.38 \pm 2.45^{\circ}\text{C}$) and Winter ($20.23 \pm 1.88^{\circ}\text{C}$). Spatial differences were also highly significant ($F_{2,69}=31.211$, $p<0.0001$), with Machnur ($24.20 \pm 2.18^{\circ}\text{C}$) recording higher temperatures than Hipparga ($19.80 \pm 1.28^{\circ}\text{C}$). pH exhibited strong seasonal fluctuations ($F_{2,69}=54.288$, $p<0.0001$), with alkaline peaks during Monsoon (7.93 ± 0.35)

and near-neutral values during Winter (7.12 ± 0.18). Turbidity displayed extreme spatial heterogeneity ($F_{2,69}=195.383$, $p<0.0001$), averaging 60.50 ± 5.70 NTU at Hipparga, 31.19 ± 11.43 NTU at Jawalgaon, and 19.58 ± 0.83 NTU at Machnur. Dissolved Oxygen (DO) averaged 7.26 ± 1.53 mg/L overall, varying significantly by site ($F_{2,69}=26.741$, $p<0.0001$). Hipparga maintained highest mean DO (8.29 ± 1.31 mg/L), while Machnur registered lower DO levels (5.92 ± 1.15 mg/L). Sulphate, Hardness, Phosphate, and Nitrates all showed significant site-specific signatures ($p<0.01$), reflecting differences in local geology, agricultural intensity, and hydrological residence times (Table 2).

Table 2: Physicochemical water quality parameters across Seasons and Sites (Mean $\pm$ SD).

Parameter	Monsoon	Summer	Winter	Hipparga	Jawalgaon	Machnur	Overall Mean
Temperature ($^{\circ}$ C)	22.38 $\pm$ 2.45	23.88 $\pm$ 2.25	20.23 $\pm$ 1.88	19.80 $\pm$ 1.28	22.48 $\pm$ 2.22	24.20 $\pm$ 2.18	22.16 $\pm$ 2.65
pH	7.93 $\pm$ 0.35	7.52 $\pm$ 0.26	7.12 $\pm$ 0.18	7.58 $\pm$ 0.50	7.41 $\pm$ 0.23	7.58 $\pm$ 0.50	7.52 $\pm$ 0.45
Turbidity (NTU)	32.46 $\pm$ 19.98	41.71 $\pm$ 18.07	37.10 $\pm$ 17.93	60.50 $\pm$ 5.70	31.19 $\pm$ 11.43	19.58 $\pm$ 0.83	37.09 $\pm$ 18.63
DO (mg/L)	7.27 $\pm$ 1.53	7.35 $\pm$ 1.61	7.17 $\pm$ 1.48	8.29 $\pm$ 1.31	7.58 $\pm$ 0.99	5.92 $\pm$ 1.15	7.26 $\pm$ 1.53
Sulphate (mg/L)	684.22 $\pm$ 258.28	668.03 $\pm$ 257.99	681.34 $\pm$ 249.37	831.75 $\pm$ 18.00	364.97 $\pm$ 203.26	836.88 $\pm$ 26.77	677.86 $\pm$ 251.60
Hardness (mg/L)	300.97 $\pm$ 120.58	315.04 $\pm$ 144.09	298.90 $\pm$ 147.15	231.62 $\pm$ 22.27	359.53 $\pm$ 206.15	323.75 $\pm$ 70.97	304.97 $\pm$ 136.27
Phosphate (mg/L)	15.23 $\pm$ 6.59	19.32 $\pm$ 8.28	17.20 $\pm$ 7.38	20.62 $\pm$ 7.78	20.28 $\pm$ 5.87	10.83 $\pm$ 3.96	17.25 $\pm$ 7.48
Nitrates (mg/L)	26.88 $\pm$ 4.71	27.92 $\pm$ 4.94	29.03 $\pm$ 4.71	24.67 $\pm$ 3.23	29.29 $\pm$ 5.84	29.88 $\pm$ 3.11	27.94 $\pm$ 4.81

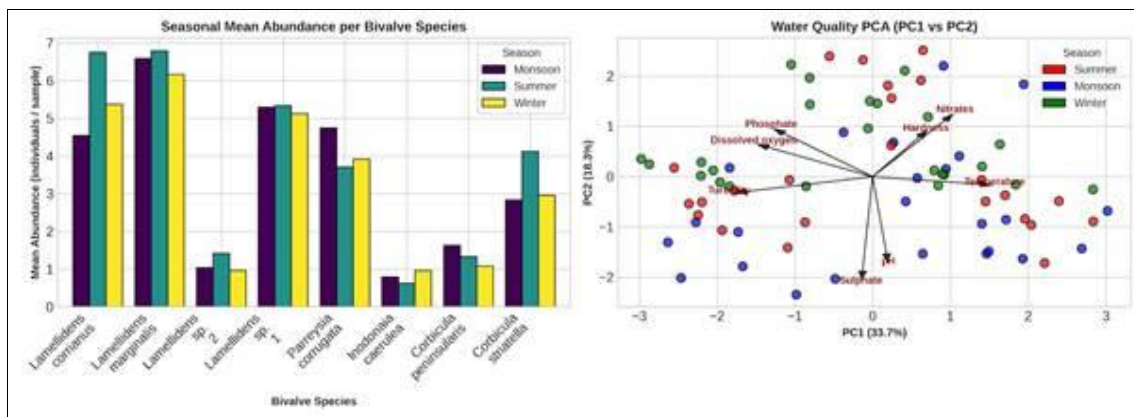
Total bivalve abundance peaked during the Summer season (30.08 $\pm$ 4.47 ind./sample), followed by Monsoon (27.46 $\pm$ 8.21 ind./sample) and Winter (26.54 $\pm$ 5.14 ind./sample) (Table 3; Fig 1). One-way ANOVA revealed statistically significant seasonal variations for specific taxa and ecological metrics. *Parreysia corrugata* showed significant seasonal abundance differences ($F_{2,69}=3.832$, $p=0.0264$; Kruskal-Wallis $H=6.394$, $p=0.0409$), with highest densities recorded during Monsoon (4.75 $\pm$ 1.51 ind./sample), declining during Winter (3.92 $\pm$ 1.38) and Summer (3.71 $\pm$ 1.23). *Corbicula striatella*: Displayed significant seasonal variation ($F_{2,69}=3.323$, $p=0.0419$),

with maximum mean abundance in Summer (4.12 $\pm$ 2.27 ind./sample), compared to Winter (2.96 $\pm$ 1.73) and Monsoon (2.83 $\pm$ 1.69). *Lamellidens corrianus* exhibited higher summer counts (6.75 $\pm$ 4.01 ind./sample) than monsoon (4.54 $\pm$ 3.32), approaching statistical significance ($F_{2,69}=2.181$, $p=0.1206$). Pielou's Evenness (J') varied significantly across seasons ($F_{2,69}=4.776$, $p=0.0114$; Kruskal-Wallis $H=9.992$, $p=0.0068$). Species evenness peaked during Monsoon (0.91 $\pm$ 0.04) and reached its minimum during Summer (0.87 $\pm$ 0.04), reflecting the disproportionate dominance of *L. corrianus* and *L. marginalis* during dry summer months.

Table 3: Seasonal bivalve species density and ecological diversity indices (Mean $\pm$ SD).

Parameter / Species	Monsoon	Summer	Winter	ANOVA ($F_{2,69}$)	p-value
<i>Lamellidens corrianus</i>	4.54 $\pm$ 3.32	6.75 $\pm$ 4.01	5.38 $\pm$ 3.73	2.181	0.1206
<i>Lamellidens marginalis</i>	6.58 $\pm$ 3.98	6.79 $\pm$ 4.81	6.17 $\pm$ 3.71	0.138	0.8711
<i>Lamellidens sp. 2</i>	1.04 $\pm$ 0.91	1.42 $\pm$ 1.10	0.96 $\pm$ 0.95	1.457	0.2400
<i>Lamellidens sp. 1</i>	5.29 $\pm$ 1.43	5.33 $\pm$ 1.20	5.12 $\pm$ 1.23	0.175	0.8397
<i>Parreysia corrugata</i>	4.75 $\pm$ 1.51	3.71 $\pm$ 1.23	3.92 $\pm$ 1.38	3.832	0.0264*
<i>Indonaiia caerulea</i>	0.79 $\pm$ 0.88	0.62 $\pm$ 0.71	0.96 $\pm$ 0.86	0.988	0.3774
<i>Corbicula peninsularis</i>	1.62 $\pm$ 1.38	1.33 $\pm$ 0.82	1.08 $\pm$ 0.78	1.672	0.1954
<i>Corbicula striatella</i>	2.83 $\pm$ 1.69	4.12 $\pm$ 2.27	2.96 $\pm$ 1.73	3.323	0.0419*
Total Abundance (N)	27.46 $\pm$ 8.21	30.08 $\pm$ 4.47	26.54 $\pm$ 5.14	2.136	0.1259
Species Richness (S)	6.62 $\pm$ 0.97	6.96 $\pm$ 0.81	6.83 $\pm$ 1.13	0.712	0.4940
Shannon Index (H')	1.72 $\pm$ 0.14	1.69 $\pm$ 0.12	1.70 $\pm$ 0.18	0.218	0.8044
Simpson Diversity ($1-D$)	0.80 $\pm$ 0.03	0.78 $\pm$ 0.04	0.79 $\pm$ 0.05	1.573	0.2149
Pielou Evenness (J')	0.91 $\pm$ 0.04	0.87 $\pm$ 0.04	0.89 $\pm$ 0.05	4.776	0.0114*

* Statistically significant at $p<0.05$.

**Fig 3:** Left: Mean seasonal abundance per bivalve species across Monsoon, Summer, and Winter. Right: Environmental Principal Component Analysis (PCA) biplot showing sample clustering and environmental vectors across seasons.

Spatial comparative analysis identified significant differences in community structure between sites (Table 4). *Lamellidens sp. 1* exhibited highest density at Hipparga (5.75 $\pm$ 1.54 ind./sample) and Jawalgaon (5.38 $\pm$ 1.06), but decreased significantly at Machnur (4.62 $\pm$ 0.92 ind./sample; $F_{2,69}=5.447$, $p=0.0064$). *Parreysia corrugata* showed significant

spatial segregation ($F_{2,69}=4.882$, $p=0.0104$), favoring reservoir habitats (Hipparga: 4.50 $\pm$ 1.41; Jawalgaon: 4.46 $\pm$ 1.61) over the riverine Machnur site (3.42 $\pm$ 0.97). Pielou's Evenness (J') higher evenness was maintained at Hipparga (0.91 $\pm$ 0.04) than Machnur (0.88 $\pm$ 0.05; $F_{2,69}=3.166$, $p=0.0484$). Total species richness (S) was highest at Jawalgaon (7.00 $\pm$ 1.10).

Table 4: Spatial breakdown of bivalve abundance and diversity indices across sampling sites (Mean $\pm$ SD).

Metric / Species	Hipparga (Site 1)	Jawalgaon (Site 2)	Machnur (Site 3)	ANOVA (F2,69)	p-value
<i>Lamellidens corrianus</i>	4.83 $\pm$ 3.75	6.00 $\pm$ 4.02	5.83 $\pm$ 3.55	0.670	0.5152
<i>Lamellidens marginalis</i>	5.17 $\pm$ 3.51	6.96 $\pm$ 4.36	7.42 $\pm$ 4.32	2.036	0.1384
<i>Lamellidens sp. 2</i>	1.00 $\pm$ 0.98	1.25 $\pm$ 1.11	1.17 $\pm$ 0.92	0.384	0.6824
<i>Lamellidens sp. 1</i>	5.75 $\pm$ 1.54	5.38 $\pm$ 1.06	4.62 $\pm$ 0.92	5.447	0.0064**
<i>Parreysia corrugata</i>	4.50 $\pm$ 1.41	4.46 $\pm$ 1.61	3.42 $\pm$ 0.97	4.882	0.0104*
<i>Indonaia caerulea</i>	0.83 $\pm$ 0.82	0.92 $\pm$ 0.78	0.62 $\pm$ 0.88	0.799	0.4540
<i>Corbicula peninsularis</i>	1.54 $\pm$ 1.18	1.50 $\pm$ 1.06	1.00 $\pm$ 0.78	2.091	0.1313
<i>Corbicula striatella</i>	3.88 $\pm$ 2.40	3.38 $\pm$ 1.93	2.67 $\pm$ 1.34	2.352	0.1028
Total Abundance (N)	27.50 $\pm$ 6.90	29.83 $\pm$ 6.00	26.75 $\pm$ 5.65	1.611	0.2071
Species Richness (S)	6.62 $\pm$ 1.01	7.00 $\pm$ 1.10	6.79 $\pm$ 0.78	0.891	0.4148
Shannon Index (H')	1.71 $\pm$ 0.14	1.72 $\pm$ 0.15	1.68 $\pm$ 0.16	0.604	0.5496
Simpson Diversity (1-D)	0.80 $\pm$ 0.03	0.79 $\pm$ 0.04	0.77 $\pm$ 0.05	1.907	0.1562
Pielou Evenness (J')	0.91 $\pm$ 0.04	0.89 $\pm$ 0.05	0.88 $\pm$ 0.05	3.166	0.0484*

* indicates statistical significance at $p < 0.05$; ** indicates statistical significance at $p < 0.01$.

Bivariate correlation analysis revealed critical physicochemical influences on individual species abundances and community metrics (Table 5). Temperature is positively correlated with *Lamellidens sp. 2* ($r=0.270$, $p=0.0218$), but negatively correlated with *Lamellidens sp. 1* ($r=-0.335$, $p=0.0040$), *Parreysia corrugata* ($r=-0.265$, $p=0.0247$), and Pielou's Evenness J' ($r=-0.328$, $p=0.0048$). Turbidity strong positive correlation with *Corbicula striatella* ($r=0.339$, $p=0.0035$) and *Lamellidens sp. 1* ($r=0.261$, $p=0.0271$). Dissolved Oxygen is Positively associated

with *Corbicula peninsularis* ($r=0.248$, $p=0.0357$), but negatively correlated with *L. marginalis* ($r=-0.279$, $p=0.0175$). Hardness is Strongly correlated with *L. marginalis* abundance ($r=0.333$, $p=0.0042$), while negatively correlated with *C. striatella* ($r=-0.266$, $p=0.0241$). Phosphate correlated positively with *P. corrugata* ($r=0.321$, $p=0.0059$) and *C. striatella* ($r=0.289$, $p=0.0138$). Nitrates exhibited significant negative correlations with *P. corrugata* ($r=-0.283$, $p=0.0160$), *L. sp. 1* ($r=-0.247$, $p=0.0367$), and Evenness J' ($r=-0.293$, $p=0.0126$).

Table 5: Statistically significant Pearson correlation coefficients (r) between water quality parameters and bivalve species / diversity indices ($n=72$).

Biological Metric	Environmental Variable	Pearson r	p-value	Spearman ρ	p-value
<i>Corbicula striatella</i>	Turbidity	+0.339	0.0035	+0.321	0.0059
<i>Lamellidens sp. 1</i>	Temperature	-0.335	0.0040	-0.326	0.0052
<i>Lamellidens marginalis</i>	Hardness	+0.333	0.0042	+0.332	0.0044
Pielou's Evenness (J')	Temperature	-0.328	0.0048	-0.329	0.0048
<i>Parreysia corrugata</i>	Phosphate	+0.321	0.0059	+0.352	0.0024
Pielou's Evenness (J')	Nitrates	-0.293	0.0126	-0.341	0.0034
<i>Corbicula striatella</i>	Phosphate	+0.289	0.0138	+0.310	0.0079
<i>Parreysia corrugata</i>	Nitrates	-0.283	0.0160	-0.302	0.0100
<i>Lamellidens marginalis</i>	Dissolved Oxygen	-0.279	0.0175	-0.314	0.0073
<i>Lamellidens sp. 2</i>	Temperature	+0.270	0.0218	+0.247	0.0366
<i>Corbicula striatella</i>	Hardness	-0.266	0.0241	-0.224	0.0587
<i>Parreysia corrugata</i>	Temperature	-0.265	0.0247	-0.256	0.0303
<i>Lamellidens sp. 1</i>	Turbidity	+0.261	0.0271	+0.277	0.0185
<i>Corbicula peninsularis</i>	Dissolved Oxygen	+0.248	0.0357	+0.240	0.0424

An Ordinary Least Squares (OLS) multiple regression model built to predict species evenness (J') from the eight water quality parameters yielded a significant overall fit ($F_{8,63}=2.394$, $p=0.0254$, $R^2=0.233$); $J'=0.9211-0.0084 \cdot \text{Temperature}+0.0322 \cdot \text{pH}-0.0017 \cdot \text{Nitrates}$. Water temperature ($\beta=-0.0084$, $t=-3.000$, $p=0.004$) and pH ($\beta=0.0322$, $t=2.358$, $p=0.021$) emerged as the key individual drivers of community evenness. Principal Component Analysis (PCA) performed on environmental parameters extracted four principal components accounting for 77.05% of total variance; PC1 (33.65% variance): Defined by strong positive loadings for Temperature (+0.462) and Nitrates (+0.312), and strong negative loadings for Turbidity (-0.543), Dissolved Oxygen (-0.448), and Phosphate (-0.383). PC2 (18.35% variance): Loaded heavily by Sulphate (-0.627), pH (-0.512), and Nitrates (+0.375). PCA on bivalve species abundances extracted two main components (PC1 = 21.12%, PC2 = 20.11%,

cumulative 41.24%). PC1 was dominated by *Corbicula peninsularis* (+0.556) and *Indonaia caerulea* (+0.527), representing habitat-specific Cyrenid-Unionid associations, whereas PC2 was governed by *Lamellidens corrianus* (+0.581) versus *Lamellidens marginalis* (-0.483), indicating ecological niche differentiation between these two co-occurring congeners.

Discussion

1. Thermal and Hydrological Drivers of Seasonal Bivalve Phenology

Our findings demonstrate that freshwater bivalve abundance and community structure in Western India undergo marked seasonal dynamics. The overall bivalve density peaked during Summer (30.08 $\pm$ 4.47 ind./sample). This pattern aligns with observations from other tropical and semi-arid water bodies (e.g., Baby *et al.*, 2010; Jadhav & Gulave, 2012)^[3, 6] and can be attributed to two main drivers. First is

Physical Habitat Contraction. During the dry summer season, ambient water temperatures ($23.88 \pm 2.25^\circ\text{C}$) elevate evaporation rates, causing reservoir water levels to recede. Bivalves, possessing constrained burrowing mobility, migrate shoreward and aggregate in remaining shallow littoral sediments, leading to higher localized spatial densities per unit area. This concentration-driven risk is consistent with a growing body of evidence that habitat contraction and elevated temperatures during drought and dewatering events are among the most significant emerging threats to freshwater mussel populations globally (Cushway & Schwalb, 2025). Second is Thermal Metabolic Stimulation & Spawning Phenology. Warmer temperatures increase metabolic and filtration rates in tropical Unionids, triggering gametogenesis and mass spawning (Subba Rao, 1989; Dillon, 2004; Lopes-Lima *et al.*, 2018) [4, 7, 14]. *Lamellidens corrianus* and *Corbicula striatella* reached peak abundances during Summer (6.75 and 4.12 ind./sample, respectively). In *L. corrianus*, elevated summer temperature correlates with intense metabolic utilization of glycogen and protein reserves for reproductive output. Conversely, during the Monsoon season, intense discharge and high flow velocities flush fine benthic sediments and dislodge juvenile bivalves, leading to temporary dispersion. However, *Parreysia corrugata* achieved its highest density during Monsoon (4.75 ± 1.51 ind./sample). Unlike *Lamellidens*, *Parreysia corrugata* possesses a heavier, deeply sculptured shell with robust pseudocardinal teeth adapted for anchoring in high-energy, turbid flow regimes (Subba Rao, 1989; Ramakrishna & Dey, 2007) [11, 14].

2. Niche Partitioning Between Unionidae and Cyrenidae

Co-existing freshwater bivalves exhibit distinct ecological strategies to minimize interspecific competition. Unionid Filter-Feeders (*Lamellidens* spp. & *Parreysia* spp.): Unionids dominate overall community biomass (80.57% combined relative abundance). *Lamellidens marginalis* (23.24%) and *L. corrianus* (19.82%) represent generalist filter-feeders capable of exploiting both fine mud-silt in reservoirs and riverine deposits. The strong positive correlation between *L. marginalis* and Hardness ($r=0.333$, $p=0.0042$) underscores its physiological requirement for calcium ions (Ca^{2+}) for shell growth and thick periostracum maintenance in alkaline waters (Aldridge, 2000; Strayer, 2014) [1, 13]. Cyrenid Opportunists (*Corbicula* spp.): *Corbicula striatella* (11.79%) and *C. peninsularis* (4.81%) employ an *r*-selected life-history strategy characterized by rapid growth, early sexual maturity, high fecundity, and pedal-feeding ability (Vaughn & Hakenkamp, 2001; Ferreira-Rodríguez *et al.*, 2018) [5, 15]. The strong positive correlation between *C. striatella* and Turbidity ($r=0.339$, $p=0.0035$) and Phosphate ($r=0.289$, $p=0.0138$) reflects its capacity to thrive in turbid, nutrient-enriched waters where organic particulate detritus provides ample food for both suspension and deposit feeding.

3. Bioindicator Value and Anthropogenic Stressors

The inverse relationship between water temperature and species evenness (J' , $r=-0.328$, $p=0.0048$; OLS $\beta=-0.0084$, $p=0.004$) highlights the vulnerability of tropical bivalve communities to thermal stress. As water temperatures exceed physiological optima, tolerant generalists (*L. marginalis*, *L. corrianus*) maintain high abundances,

whereas sensitive taxa (*Indonaia caerulea*, 2.82%) experience population suppression, leading to reduced overall community evenness. Furthermore, negative correlations between nitrate concentrations and bivalve abundances (*P. corrugata*: $r=-0.283$, $p=0.0160$; *L. sp. 1*: $r=-0.247$, $p=0.0367$) point to agricultural runoff as an emerging threat. Excess nitrogenous compounds (NO_3^-) and elevated unionized ammonia can impair ciliary movement, reduce oxygen consumption, and induce larval mortality in glochidia during fish-host attachment stages (Lydeard *et al.*, 2004; Spooner & Vaughn, 2008) [8, 12].

4. Conservation and Water Management Implications

Freshwater bivalves in Peninsular India face compound threats from hydrological impoundment, habitat degradation, agricultural pollution, and dry-season desiccation. Based on our empirical findings, we propose the following conservation and management priorities. Maintain minimum environmental baseflows during summer months to prevent complete desiccation of littoral bivalve beds in irrigation reservoirs like Jawalgaon and Hipparga. Establish vegetated riparian buffer zones around reservoir catchments to intercept agricultural nitrate and phosphate runoff, mitigating eutrophication. Identify and designate core benthic sanctuaries in river stretches (such as Machnur) to protect vulnerable, less abundant Unionid species (*Indonaia caerulea* and *Lamellidens* sp. 2).

Conclusion

This study provides a quantitative analysis of the spatiotemporal structure and environmental drivers of freshwater bivalve assemblages across tropical reservoir and riverine ecosystems in Western India. Bivalve communities exhibited pronounced seasonal fluctuations, with peak abundances in Summer driven by habitat contraction and thermal metabolic activity. Community structuring was controlled primarily by water temperature, pH, turbidity, hardness, and nutrient levels (nitrates and phosphates). *Lamellidens marginalis*, *Lamellidens corrianus*, and *Corbicula striatella* displayed broad environmental tolerances, whereas *Indonaia caerulea* exhibited habitat sensitivity. Integrating bivalve population monitoring into regional freshwater basin management frameworks is crucial for conserving these bioindicators and safeguarding the ecological services they provide.

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