Journal of Insect Biodiversity and Systematics
ISSN: 2423-8112
2026 | 12 (03), 491–502
Website: https://jibs.modares.ac.ir
Contents list: https://www.biotaxa.org/jibs
https://doi.org/10.48311/jibs.12.03.491

Original Article

An integrated study on the biodiversity and ecology of mayflies (Insecta: Ephemeroptera) in Arunachal Pradesh, India

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Academic Editor
Srinivasan Pandiarajan

Received
January 28, 2026

Revised
April 21, 2026

Accepted
April 29, 2026

Published online
May 11, 2026

ABSTRACT. The Indian Eastern Himalaya (Arunachal Pradesh) remains poorly explored for the diversity and ecology of mayflies (Ephemeroptera). The present study provides a comprehensive assessment of mayfly diversity, community structure, and species-environment relationships across 15 selected streams in Arunachal Pradesh. A total of 2,014 individuals belonging to 46 species, 25 genera, and seven families were recorded from the region. Baetidae was the dominant family, followed by Heptageniidae, whereas Caenidae and Vietnamellidae were the least represented. Diversity indices revealed considerable spatial variation, with the highest Shannon diversity, richness, and evenness observed in mid-elevation, fast-flowing streams, and the lowest values recorded at the sites with fewer individuals. Canonical Correspondence Analysis (CCA) exhibited that environmental variables such as pH, stream width, elevation, water current, canopy cover, and temperature influenced species distribution.

KEYWORDS: CCA, Diversity indices, Eastern Himalaya, Ephemeroptera, FFGs

Citation: Muthukatturaja, M., Kubendran, T., Vasanth, M., Basak, S. & Subramaniam, K.A. (2026) An Integrated Study on the Biodiversity and Ecology of Mayflies (Insecta: Ephemeroptera) in Arunachal Pradesh, India. *Journal of Insect Biodiversity and Systematics*, 12 (03), 491–502.

INTRODUCTION

Aquatic macroinvertebrates (Arthropoda: Insecta) comprise a taxonomically diverse, ecologically essential, and fascinating group of organisms in freshwater systems, particularly of stream/ river ecosystems in the montane and submontane areas (Dudgeon 1999). They play a vital role in the food web/ chain by processing organic matter and cycling nutrients as they belong to several specialized feeding groups. In addition to this ecosystem function, they are found to be very good indicators of water quality, and they have the ability to detect even the slightest changes in an ecosystem. Documentation of aquatic insects and their diversity is considered essential to such studies. In recent years, numerous works were done on the taxonomic aspects of aquatic insect orders (Sivaruban et al. 2021; Sonaimuthu et al. 2024) and a few ecological works were carried out in both Western and Eastern Ghats of southern India (Anbalagan et al. 2004; Subramanian & Sivaramakrishnan 2005; Anbalagan & Dinakaran 2006; Priyanka & Prasad 2014; Srinivasan et al. 2019; Sivaruban et al. 2020a, 2020b; 2020c; Barathy et al. 2021; Vasanth et al. 2023; Sonaimuthu et al. 2024) but only two studies were reported from eastern Himalaya particularly Arunachal Pradesh by Subramanian et al. (2024a, 2024b). Mayflies (Ephemeroptera) are one of the aquatic macroinvertebrate communities that show responses to alterations in a variety of environmental variables (Zedkova et al. 2015). Their broad ranges of functional traits and differential tolerances to anthropogenic factors have been noted widely and are

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ISSN 2423-8112 – **Published by** Tarbiat Modares University | **Owner** The Entomological Society of Iran

either used, or have the potential for use, in the development of biotic indices to monitor agricultural practices (Svensson et al. 2018), organic pollution (Timm et al. 2001), eutrophication (Davy-Bowker et al. 2015), sediment and silt loading (Chadd et al. 2017), physical habitat alteration (Hilsenhoff 1971), and climate-change vulnerability, particularly in long-lived species, and those living at higher altitudes (Jacobus et al. 2019). Arunachal Pradesh, located in the Eastern Himalaya, harbours exceptionally rich Ephemeroptera diversity driven by steep altitudinal gradients, varied freshwater habitats, and long-term landscape stability. Recent surveys and taxonomic studies indicate the Indian Himalayan Ephemeroptera fauna comprises several genera and many regionally endemic species, with Arunachal Pradesh among the richest states for mayfly diversity. Therefore, the present study analyses the diversity and ecology of mayflies in this region.

MATERIAL AND METHODS

The present study investigates the diversity and ecology of mayflies in 15 streams of Arunachal Pradesh, India. The experiment was conducted from January 2025 to December 2025. Stream habitats selected are located in the forest area and are likely to have less anthropogenic disturbances and other pollutions. Study sites are coded as Stn. 1 to Stn. 15 as in Table 1. The mayfly larvae were collected from the streams by the kick net method, and some were handpicked from benthic substrates, leaf litter, and deadwood. The collected samples were preserved in 95% ethanol and sorted under a stereozoom microscope (NIKON® SMZ25). Identification of the mayfly up to species level was done using an appropriate field key (Kluge 2004). Environmental parameters of the streams were analyzed in the study by following APHA (2005) and Trivedy and Goel (1986). The categories of functional feeding groups were carried out based on Merritt and Cummins (2006), Baptista et al. (2006), and Merritt et al. (2008, 2014). CCA was used to assess the relationship between taxa and environmental variables among sites. The CCA diversity indices were performed using PAST software (Version 4.03) and MS Excel. Mapping of the study area was made by using QGIS.

Table 1. Selected study sites and their environmental variables in Arunachal Pradesh, India.

S. No	Location	Site Code	Latitude (°N)	Longitude (°E)	Elevation (m.s.a.l.)	Stream Width (m)	Water depth (m)	Water Current (m/s)	Canopy cover (%)	Atm. temp. (°C)	Water temp. (°C)	pH	Substrate index
1.	Iphi River, Roing, Lower Dibang Valley	Stn. 1	28.1603	95.8475	385	22	6	0.8	15	27	26	7.1	6.45
2.	Bomjir near Sikang River, Roing, Lower Dibang Valley	Stn. 2	28.1549	95.6687	378	20	5.5	0.10	10	27	25	6.9	6
3.	Sessari stream, Sisai bridge, Aohali (Lower Dibang Valley)	Stn. 3	28.2651	95.5527	352.8	25	6	0.65	10	19	16	6.8	5.85
4.	Sibya Korong River, Mebo, East Siang	Stn. 4	28.1799	95.4717	324	12	2	0.65	30	20	18	7.1	5.5
5.	Siku River, Roing, East Siang	Stn. 5	28.1518	95.3798	328	20	5	0.8	10	26	24	7.2	6.2
6.	23 km away from Pasighat towards Yingkiong, East Siang	Stn. 6	28.1566	95.4926	330	10	3	1.0	50	21	18	6.9	6
7.	32 km away from Yingkiong towards Tutin, Upper Siang	Stn. 7	28.6727	94.9647	390	12	2.5	0.7	65	26	23	6.8	6.15
8.	65 km away from Yingkiong towards Tutin Upper Siang	Stn. 8	28.7290	94.9189	425	10	2	0.5	65	25	23	6.7	5.9
9.	Yingkiong, 50 km away from the main town (Upper Siang)	Stn. 9	28.6224	95.0355	323.7	12	1.5	0.5	60	22	20	7.2	6
10.	25 km away from Yingkiong towards Jengging, Upper Siang	Stn. 10	28.6200	95.0483	221	10	1.5	1.2	70	21	19	7.1	5.7
11.	Nyubung River, Jengging, Upper Siang	Stn. 11	28.5261	95.0495	430.7	20	4	1.5	50	19	17	6.5	6
12.	60 km away from Jengging to Boleng, Siang	Stn. 12	28.4645	95.1081	333.5	8	2.5	1.0	75	21	19	6.9	6.3
13.	NH13, Siang river, Siang	Stn. 13	28.2022	94.8278	320.5	30	5	0.8	20	29	27	7.2	6.25
14.	Rottung, Panjin tehsil, East Siang	Stn. 14	28.1362	95.1027	360	8	1.5	0.65	75	21	19	6.9	6.35
15.	Aalo, 55 km away Pasighat-Boleng East Siang	Stn. 15	28.1286	95.1224	342	7.5	2.5	0.70	50	21	18	6.8	5.8

RESULTS

The present study reports a total of 2,014 individuals collected from 15 different sites of Arunachal Pradesh, India, representing 46 species, 25 genera, 7 families of Ephemeroptera (Figs 1 & 2; Table 2). Family Baetidae was found to be the most dominant with 1,126 individuals, 21 species, and 9 genera, followed by Heptageniidae with 586 individuals, 11 species, and 5 genera. Families Caenidae and Vietnamellidae are the least dominant families, with 40 and 2 individuals belonging to a single species. Family Leptophlebiidae represented by 138 individuals, 3 species, 3 genera, and Ephemerillidae represented by 94 individuals, 6 species, 4 genera, and Teloganodidae represented by 22 individuals, 2 species, 2 genera. Baetidae > Heptageniidae > Leptophlebiidae > Ephemerillidae > Caenidae > Teloganodaidae > Vietnamellidae is the sequence in descending order in terms of number of individuals. The highest number of individuals was recorded in the Stn. 8 with 196 individuals, followed by Stn. 3 (188 individuals), Stn. 7 (168 individuals) and Stn. 6 (167 individuals); whereas a smaller number of individuals was recorded in the Stn. 15 with 62 individuals. The highest Shannon diversity index was noticed in Stn. 7 (*H = 3.2*) followed by Stn. 8 (*H = 3.123*), Stn. 6 (*H = 3.104*) and lowest in Stn. 15 (*H = 2.367*). The highest Margalef richness index was observed in Stn. 3 (4.965), followed by Stn. 2 (4.946) and Stn. 8 (4.926), and lowest in Stn. 15 (3.15). The evenness was highest in Stn. 7 (0.9432) followed by Stn. 6 (0.9285) and lowest in Stn. 11 (0.7275) streams (Tables 3 & 4). The study showed a high diversity of Functional Feeding Groups (FFGs) in Arunachal Pradesh streams, such as collectors and scrapers (Table 2).

The Canonical Correspondence Analysis (CCA) plot illustrates the relationship between the mayfly community and the environmental parameters in the 15 study sites of Arunachal Pradesh. For CCA analysis, nine environmental variables, viz., pH, water temperature, atmospheric temperature, substrate index, canopy cover, stream width, water depth, elevation, and water current, were analyzed. Table 5 and Figure 3 show the CCA loadings and the result of ordination of the collection sites, mayfly community, with respect to environmental variables in Arunachal Pradesh, respectively.

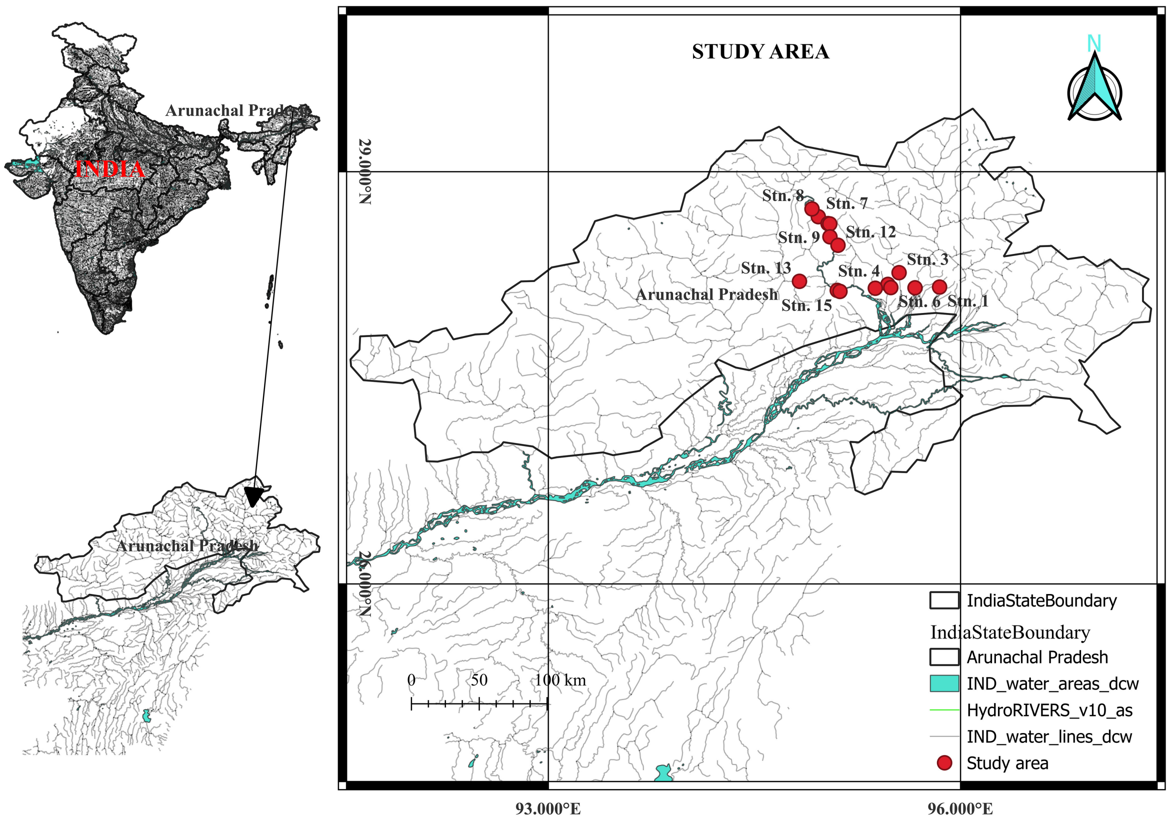

Figure 1. Map of the selected study sites in Arunachal Pradesh, India.

Table 2. Mayfly species composition of the selected study site in Arunachal Pradesh, India.

S. No.	Species name	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 6	Stn. 7	Stn. 8	Stn. 9	Stn. 10	Stn. 11	Stn. 12	Stn. 13	Stn. 14	Stn. 15	Total
Baetidae (Collector-gatherer)																	
1.	*Acentrella vera*	0	0	15	0	0	0	0	0	5	0	8	0	0	10	0	**38**
2.	*Baetis* sp.	4	0	10	0	5	0	0	8	0	7	0	6	0	0	0	**40**
3.	*Platybaetis selvai*	0	4	0	0	0	0	8	0	0	0	3	0	0	0	0	**15**
4.	*Platybaetis arunachalensis*	15	9	11	24	0	9	0	13	20	6	34	0	19	0	0	**160**
5.	*Platybaetis uenoi*	2	0	5	0	0	9	0	4	0	0	4	1	0	0	0	**25**
6.	*Acentrella (Acentrella) isacki*	0	0	0	6	2	7	0	5	0	0	0	0	0	0	0	**20**
7.	*Baetiella armata*	10	7	14	5	9	11	16	13	5	6	3	8	0	0	0	**107**
8.	*Baetiella ausobskyi*	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	**6**
9.	*Baetiella imanishii*	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	**5**
10.	*Baetiella marginata*	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	**6**
11.	*Baetiella spathae*	3	4	0	0	0	2	11	6	0	0	8	8	0	6	0	**48**
12.	*Baetis (Tenuibaetis) arduus*	14	23	30	18	20	13	10	22	25	16	15	11	9	10	5	**241**
13.	*Baetis (Tenuibaetis) inornatus*	0	0	5	0	9	13	0	11	0	0	0	4	6	6	0	**54**
14.	*Baetis (Tenuibaetis) himani*	0	2	0	4	10	0	5	0	8	0	3	0	8	0	0	**40**
15.	*Baetis (Tenuibaetis) frequentus*	10	9	11	13	8	14	7	20	6	7	15	8	5	4	7	**144**
16.	*Procloeon* sp.	0	1	3	0	0	1	5	2	2	1	0	0	0	0	0	**15**
17.	*Procloeon* **sp. (RTU 1)**	0	0	0	0	3	4	8	0	5	0	0	0	0	0	0	**20**
18.	*Labiobaetis* **sp. (RTU 1)**	0	0	0	2	2	3	6	0	0	1	0	2	2	2	0	**20**
19.	*Labiobaetis* sp.	4	6	4	6	0	7	2	0	8	8	4	3	5	5	1	**63**
20.	*Megabranchiella* **sp. (RTU 1)**	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	**3**
21.	*Centroptella* sp.	0	8	4	8	7	0	7	5	2	5	0	0	7	3	0	**56**
Ephemerellidae (Collector-gatherer)																	
22.	*Cincticostella braaschi*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	**2**
23.	*Torleya coheri*	3	8	0	2	5	3	6	0	1	2	2	3	0	0	0	**35**
24.	*Torleya lacuna*	4	1	2	0	2	5	0	0	3	0	2	0	3	0	0	**22**
25.	*Torleya nepalica*	0	2	1	0	2	4	4	0	2	2	1	3	0	2	2	**25**
26.	*Drunella submontana*	0	0	0	0	0	0	4	3	1	0	0	0	0	0	0	**8**
27.	*Teloganopsis jinghongensis*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Heptageniidae (Scraper-shredder)																	
28.	*Epeorus (Caucasiron) papillatus*	5	9	10	0	8	7	0	6	9	11	9	10	0	5	1	**90**
29.	*Epeorus (Epeorus) gilliesi*	5	3	0	4	5	0	8	7	2	6	0	0	10	5	5	**2**
30.	*Epeorus (Epeorus)* **sp. (RTU 1)**	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	**3**
31.	*Epeorus (Caucasiron) psi*	0	0	5	6	0	10	0	7	5	0	0	0	0	0	0	**33**
32.	*Epeorus (Proepeorus) aculeatus*	4	6	8	7	11	5	2	12	10	8	9	4	2	5	3	**96**
33.	*Epeorus (Proepeorus) bifurcatus*	0	0	2	1	0	3	1	3	0	0	0	0	0	0	0	**10**
34.	*Epeorus (Epeorus) unicornutus*	7	3	5	0	0	6	10	8	0	11	0	0	8	5	4	**67**
35.	*Epeorus (Proepeorus) unispinosus*	4	3	9	0	0	0	10	5	0	1	0	0	0	0	0	**32**
36.	*Notacanthurus pange*	2	6	7	4	5	8	4	3	9	7	3	0	3	4	0	**65**
37.	*Cinygmina assamensis*	0	0	5	0	4	0	6	0	0	0	0	0	0	0	0	**15**
38.	*Ecdyonurus* **sp. (RTU 1)**	8	2	7	0	3	0	4	6	0	9	5	2	9	6	4	**65**
39.	*Rhithrogena* **sp. (RTU 1)**	2	3	0	6	0	8	7	5	0	0	9	4	2	0	4	**50**
Leptophlebiidae (Scraper)																	
40.	*Choroterpes (Dilatognathus) nigella*	0	0	8	10	6	11	9	13	8	12	6	7	5	5	3	**103**
41.	*Isca (Isca) purpurea*	0	3	1	4	0	0	0	2	0	0	1	1	3	0	0	**15**
42.	*Gilliesia* sp.	2	2	0	5	3	0	0	1	2	2	0	0	1	0	2	**20**
Teloganodidae (Collector-gatherer)																	
43.	*Teloganodes* sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	**2**
44.	*Teloganodes (Dudgeodes) selvakumari*	3	2	1	2	0	4	0	1	2	0	0	2	0	2	1	**28**
Vietnamellidae (Collector-gatherer)																	
45.	*Vietnamella* sp. A	0	0	0	0	0	0	0	5	3	0	0	0	0	0	0	**8**
Caenidae (Scraper)																	
46.	*Caenis* sp.	0	0	0	0	0	0	0	0	0	5	0	0	15	0	20	**40**
	Total No. of insects	**111**	**128**	**188**	**143**	**137**	**167**	**168**	**196**	**143**	**133**	**144**	**87**	**122**	**85**	**62**	**2,014**

From the CCA ordination, Stn. 2, Stn. 3, Stn. 5, Stn. 9, and Stn. 10 show positive correlation with *pH*. Stn. 4 and Stn. 8 show a negative correlation with *pH*. Stn. 6 and Stn. 14 show positive correlation with atmospheric temperature and water temperature. Stn. 1, Stn. 7, Stn. 13, and Stn. 15, show a positive correlation with water current, elevation, and canopy cover. Stn. 11 is positioned away from the 95% ellipses, and it has a strong correlation with all environmental parameters. *Notacanthurus pange, Tenuibaetis arduous, Labiobaetis* sp., *Epeorus* (*Caucasiron*) *papillatus,* and *Gilliesia* sp., are positioned far along the positive side of Axis 1, indicating that these species are adapted to or thrive in an environment with elevated *pH* in a large stream or river. Conversely, *Platybaetis arunachalensis, Tenuibaetis frequentus, Epeorus* (*Proepeorus*) *aculeatus, Rhithrogena* sp., and *Ecdyonurus* sp., located on the negative sides of Axis 1, appear to prefer optimum or low *pH* and a small stream. *Baetiella armata, Torleya nepalica, Tenuibaetis himani, Platibaetis selvai, Platybaetis uenoi,* and *Epeorus* (*Proepeorus*) *unispiosus* are positioned far along the upper side of Axis 2, indicating that these species are adapted to or thrive in the environment with elevated temperature. Conversely, they are sensitive to canopy cover, water current, and elevation. *Labiobaetis* sp. (RTU 1), *Drunella submontana, Tenuibaetis inornatus*, *Torleya lacuna*, *Vietnamella* sp., and *Procloeon* sp. (RTU 1) are positioned near the center of the plot, suggesting the general tolerance to all the environmental variables. The eigenvalues associated with the first four canonical axes are presented in Table 6. The first two axes capture a substantial portion of variation, explaining 29.99% and 20.94% of the constrained inertia. The third and fourth axes capture a portion of variation, explaining 18.05% and 10.88 % of the constrained inertia. Combined, these axes account for 79.86% of the variation in the species-environment relationship, suggesting that the primary gradients in the data are well represented in CCA. Axis 1 has the highest eigenvalue (0.017753), explaining 29.99% of the total inertia, indicating that it represents a significant gradient influencing species distribution among the sites. Environmental variable *pH* and the stream width seem to correlate strongly with this axis.

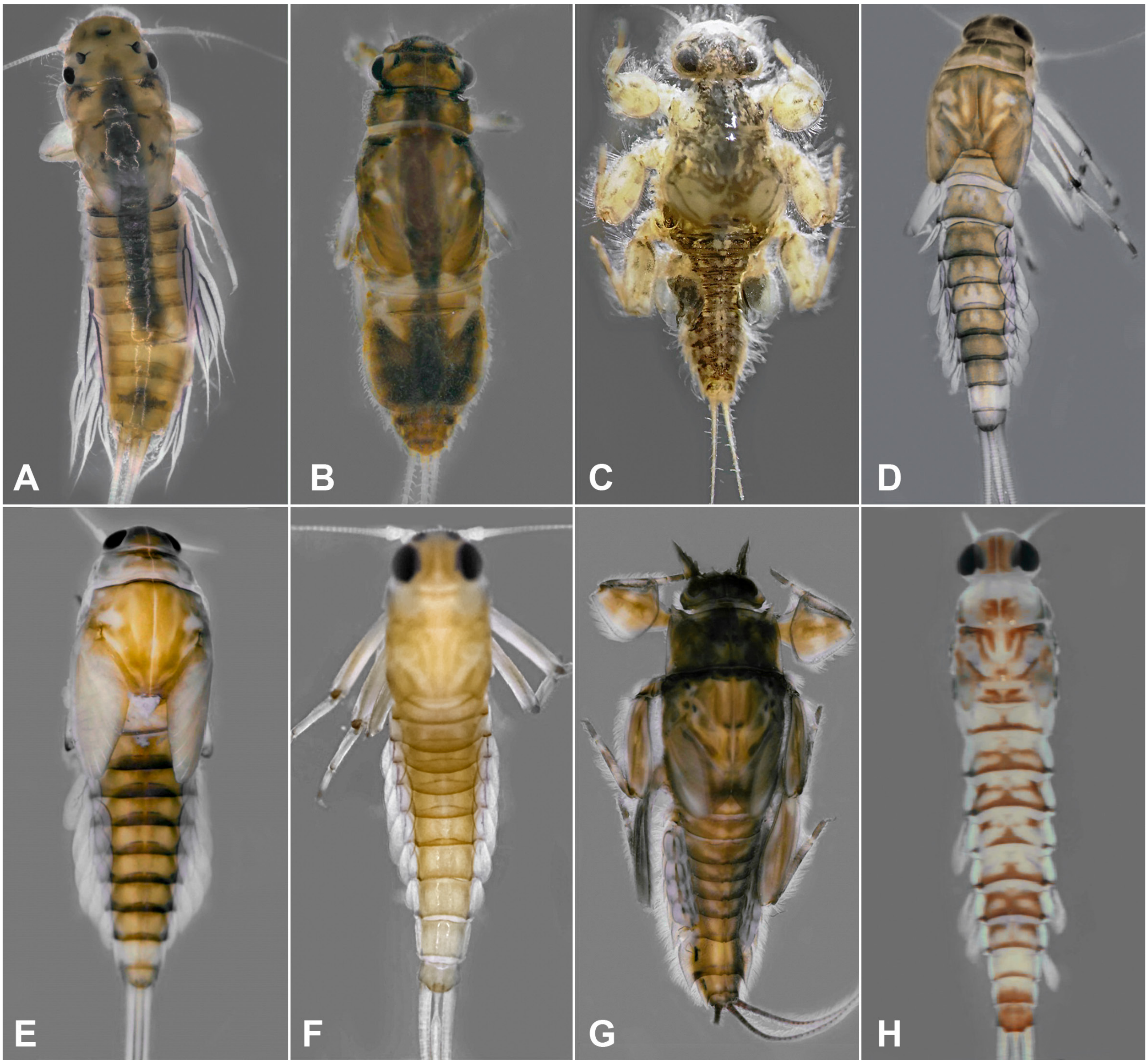

Figure 2. The mayfly larvae from the selected study sites in Arunachal Pradesh, India. **A.** *Gilliesia* sp.; **B.** *Caenis* sp.; **C.** *Teloganodes* sp.; **D.** *Centroptella* sp.; **E.** *Labiobaetis* sp.; **F.** *Baetis* sp.; **G.** *Vietnamella* sp.; **H.** *Procloeon* sp.

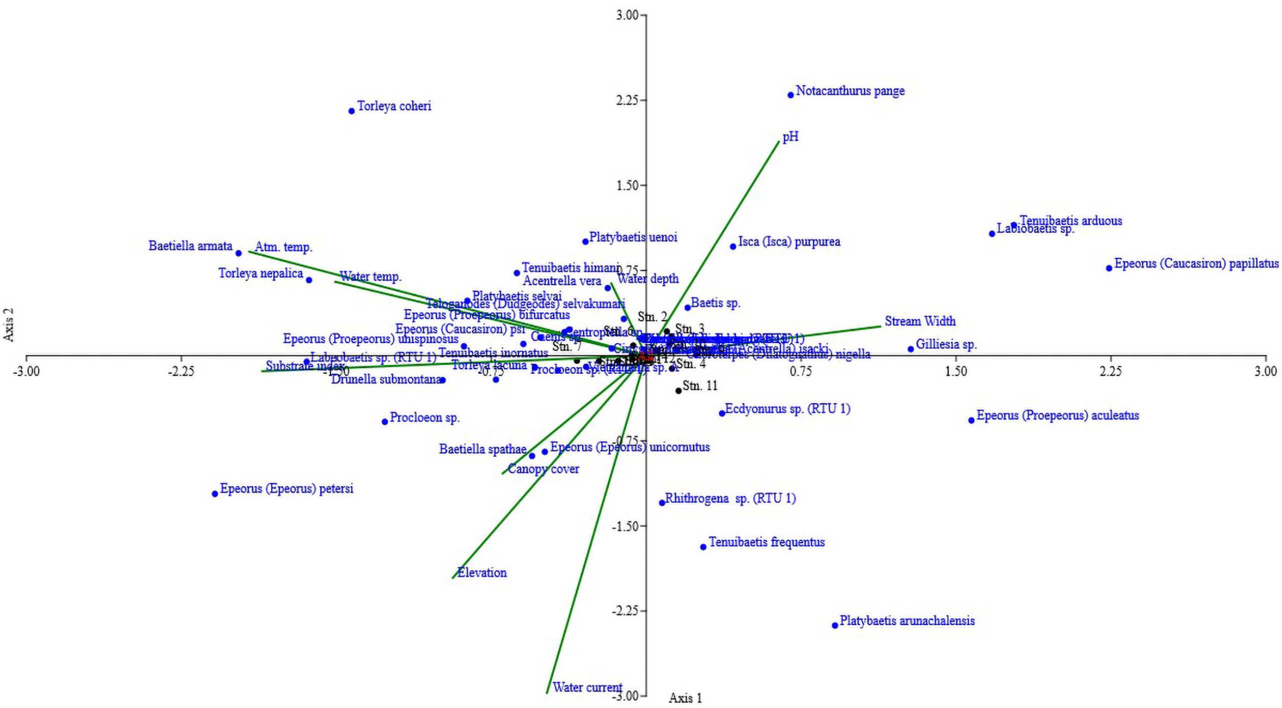

Figure 3. Biplot showing the relationship between environmental variables and mayfly communities in the selected streams of Arunachal Pradesh by Canonical Correspondence Analysis (CCA).

Table 3. Diversity indices of collected mayfly species in Stn. 1 to Stn. 8 of Arunachal Pradesh, India.

Indices/ station	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	Stn. 6	Stn. 7	Stn. 8
Taxa_S	20	25	27	22	24	24	26	27
Individuals	111	128	188	143	137	167	168	196
Dominance_D	0.06519	0.06348	0.05894	0.07032	0.05582	0.04733	0.04277	0.0516
Shannon_H	2.875	3.02	3.067	2.89	3.05	3.104	3.2	3.123
Evenness_e^H/S	0.8863	0.8198	0.7958	0.8177	0.88	0.9285	0.9432	0.8415
Margalef	4.034	4.946	4.965	4.231	4.675	4.494	4.879	4.926

Table 4. Diversity indices of collected mayfly species in Stn. 9 to Stn. 15 of Arunachal Pradesh, India.

Indices/ station	Stn. 9	Stn. 10	Stn. 11	Stn. 12	Stn. 13	Stn, 14	Stn. 15
Taxa_S	23	21	20	18	19	17	14
Individuals	143	133	144	87	122	85	62
Dominance_D	0.07466	0.05913	0.09577	0.06683	0.0714	0.05966	0.1359
Shannon_H	2.867	2.91	2.678	2.789	2.788	2.829	2.367
Evenness_e^H/S	0.7645	0.8744	0.7275	0.9039	0.8551	0.9961	0.7618
Margalef	4.433	4.09	3.823	3.807	3.747	3.601	3.15

Axis 2 contributes an additional 20.94% of the total inertia, further elucidating the species-environment relationship along the gradients of elevation, water current, and canopy cover. The third and fourth axes explain relative portions of the variation, 18.05% and 10.88% of the constrained inertia, respectively. These axes represent more suitable environmental gradients or noise in the data that are less important for explaining species distribution. Overall, the first four axes of the CCA plot describe the species-environment relationship.

Table 5. CCA loadings of environmental variables and mayflies in Arunachal Pradesh, India.

Variables	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8	Axis 9
Acentrella vera	-0.18624	0.595484	0.504816	-0.29432	-0.12117	1.36093	-0.69103	1.33691	-1.38727
Baetis sp.	0.200491	0.422215	0.435933	-0.66843	-1.06851	-0.71347	0.652838	0.550325	-0.66604
Platybaetis selvai	-0.86583	0.48384	-0.46166	-0.45928	0.144848	-0.55767	-0.52869	-0.85693	0.218781
Platybaetis arunachalensis	0.913672	-2.3778	0.273227	-0.4782	0.389678	0.910823	0.632405	-0.37411	1.44975
Platybaetis uenoi	-0.29392	1.00485	0.392652	-0.72331	-1.80511	-1.32511	0.129403	2.90116	1.64736
Acentrella (Acentrella) isacki	0.14177	0.061696	-0.12317	0.592272	-1.63787	-0.06308	0.356303	-0.52912	0.596403
Baetiella armata	-1.97336	0.902822	1.04138	-1.14133	0.793717	0.070695	-0.16948	0.004121	-0.94105
Baetiella ausobskyi	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Baetiella imanishii	-0.01444	0.051993	-0.17174	-0.45029	-0.16637	0.716555	-0.58567	0.019638	-0.4364
Baetiella marginata	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Baetiella spathae	-0.55255	-0.8841	-0.37719	-1.10398	-0.69538	-0.74616	1.29053	-0.93976	-1.14871
Tenuibaetis arduous	1.77998	1.15076	1.09899	-0.39124	1.36981	-0.64215	0.655053	0.104068	0.196407
Tenuibaetis inornatus	-0.53941	-0.10583	0.056085	1.02678	-0.10588	-1.02294	-0.89586	0.04395	0.458565
Tenuibaetis himani	-0.62606	0.728146	-1.48559	-1.76465	1.8664	0.898147	-2.37096	-0.29201	0.419904
Tenuibaetis frequentus	0.27611	-1.68614	1.82193	1.69364	-0.3077	-0.65462	-0.85252	0.937914	-1.02627
Procloeon sp.	-1.26508	-0.58295	0.813514	-2.26466	0.941844	-0.45736	0.659186	-0.02933	0.454173
Procloeon sp. (RTU 1)	-0.42784	-0.12948	-0.17945	0.016958	-0.46388	-0.59291	1.44836	-0.96612	-0.01494
Labiobaetis sp. (RTU 1)	-1.64358	-0.05364	1.17043	-0.45907	-0.16667	-0.98298	2.2996	-0.41381	1.73201
Labiobaetis sp.	1.67421	1.07399	-1.92496	0.253251	0.066975	-1.18284	0.759337	-1.18965	1.06581
Megabranchiella sp. (RTU 1)	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Centroptella sp.	-0.39585	0.207001	0.029153	2.57381	0.932818	0.309946	-0.17682	2.82405	1.13658
Cincticostella braaschi	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Torleya coheri	-1.42606	2.15496	1.4663	2.307	1.61243	0.759103	3.12287	-0.73152	-0.43143
Torleya lacuna	-0.72739	-0.21096	-1.13455	-0.17478	-0.70371	1.09548	-2.03724	-0.76606	0.959418
Torleya nepalica	-1.63232	0.666097	-0.8629	0.957385	-1.03875	-0.19334	-0.43896	-2.00006	1.339
Drunella submontana	-0.98527	-0.21584	0.134666	0.537903	-0.03649	0.4501	0.151096	0.527704	-1.3061
Teloganopsis jinghongensis	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Epeorus (Caucasiron) papillatus	2.24064	0.770414	-1.28286	0.470336	-0.63028	2.48314	1.20638	0.690963	-1.22369
Epeorus (Epeorus) gilliesi	-2.0879	-1.21771	-2.25142	1.00472	1.3807	-0.74898	1.52645	0.345543	-0.25986
Epeorus (Epeorus) sp. (RTU 1)	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Epeorus (Caucasiron) psi	-0.59469	0.103161	-0.34509	0.841525	-0.7754	0.972856	-0.24193	-0.36874	-0.32521
Epeorus (Proepeorus) aculeatus	1.57429	-0.57042	0.388745	-0.50727	1.09483	-1.36782	-1.39137	-1.69383	-2.17538
Epeorus (Proepeorus) bifurcatus	-0.37048	0.229586	-0.06045	0.493628	-0.5099	1.33521	0.149761	-1.39202	-1.47809
Epeorus (Epeorus) unicornutus	-0.49078	-0.847	-2.14842	-0.39965	0.409054	-0.97431	0.159082	0.886957	-0.72877
Epeorus (Proepeorus) unispinosus	-0.88253	0.082994	1.68094	-2.4699	-0.02958	0.149544	0.394056	0.614408	1.23255
Notacanthurus pange	0.699308	2.2961	-0.65103	-0.66059	-2.88781	-0.52758	-0.25374	0.031538	1.03493
Cinygmina assamensis	-0.16757	0.063215	-0.21891	0.193445	-0.42156	0.165258	0.498805	-0.70631	-0.10068
Ecdyonurus sp. (RTU 1)	0.366924	-0.50887	-1.96031	-1.4283	1.26324	-0.2437	0.128757	2.8113	-0.26316
Rhithrogena sp. (RTU 1)	0.076696	-1.29758	0.486123	-1.10782	-2.94027	-0.62605	0.148423	0.561535	-0.57536
Choroterpes (Dilatognathus) nigella	0.241094	0.007717	-0.58954	0.969949	-0.39368	-1.98022	-0.30225	-0.48871	-0.67633
Isca (Isca) purpurea	0.4203	0.960981	-0.76417	1.87154	1.68779	-2.66044	-1.18189	-0.13237	3.05616
Gilliesia sp.	1.28073	0.057196	0.216051	0.446299	-0.47725	-0.02787	-4.50261	0.142143	1.26744
Teloganodes sp.	-0.02213	0.152376	-0.25765	0.235826	-0.08989	0.585059	-0.11879	-0.60145	-0.27084
Teloganodes (Dudgeodes) selvakumari	-0.10855	0.323976	-1.29559	0.998136	-0.35011	2.7952	0.124524	-0.62189	1.68516
Vietnamella sp. A	-0.29101	-0.09783	-0.0014	0.541052	0.078584	0.427295	-0.28524	-0.54397	-1.06431
Caenis sp.	-0.51309	0.160818	0.927379	0.3395	0.060255	0.850434	-0.70146	-0.75719	0.935564
Elevation	-0.18724	-0.39153	0.734741	0.032935	0.184196	0.140763	0.23392	-0.23101	0.168729
Stream Width	0.226389	0.051375	0.124015	-0.01317	0.594107	0.166889	0.309212	0.416452	0.016505
Water depth	-0.03384	0.127305	0.365471	0.180792	0.427346	0.388357	0.173187	0.380494	0.013322
Water current	-0.0961	-0.59398	-0.39035	-0.44018	-0.09067	0.117776	-0.2506	0.239875	-0.01251
Canopy cover	-0.13895	-0.20751	-0.23203	0.107369	-0.60241	-0.22271	0.193629	-0.40222	0.009668
Atm. temp.	-0.3844	0.183198	-0.15384	0.294055	0.681675	-0.02074	0.228624	-0.03103	0.086074
Water temp.	-0.30097	0.130148	-0.21021	0.323357	0.718621	-0.00205	0.219718	-0.07195	0.068235
Substrate index	-0.37173	-0.02747	-0.13277	-0.14142	0.321858	0.515659	0.236474	-0.31289	0.14242
pH	0.12838	0.376892	-0.58765	-0.02803	0.383689	0.008635	-0.27788	-0.03797	0.197908

The permutation test evaluates the statistical significance of the relationship between species distribution and the measured environmental variables. A trace value of 0.05919 with the *p-value* of 0.322 suggests that the observed association could reasonably occur by chance, and the environmental variables do not explain a meaningful portion of the variation in species distribution in this analysis (Table 7). The permutation test for the individual axes revealed that Axis 1 has an eigenvalue of 0.01775 with a *p-value* of 0.568, indicating the variation explained by the axis is statistically not significant. Axis 2 shows a *p-value* of 0.276, indicating that it is not statistically significant. Axis 3 shows a *p-value* of 0.016, indicating that this axis is statistically significant and explains variation beyond what would be expected by chance. Axis 4 shows a *p-value* of 0.41, indicating that it is not statistically significant.

Table 6. The eigenvalues associated with the first four canonical axes.

S. No.	Axis	Eigenvalue	% of constrained inertia	% of total inertia
1.	1	0.017753	29.99	17.93
2.	2	0.012392	20.94	12.52
3.	3	0.010685	18.05	10.79
4.	4	0.006437	10.88	6.501

Table 7. Permutation test for the first four canonical axes of CCA.

S. No.	Axis	Eigenvalue	P value
1.	1	0.01775	0.568
2.	2	0.01239	0.276
3.	3	0.01068	0.016
4.	4	0.006437	0.41

Permutation Test Results, Trace value: 0.05919; Trace *p-value*: 0.322

DISCUSSION

Since there is no study regarding the diversity and ecology of the mayflies in Arunachal Pradesh, India. Subramanian et al. (2024a) reported nine species of mayflies belonging to four families in 8 genera from Dihang-Dibang Biosphere Reserve (DDBR), and Subramanian et al. (2024b) reported 18 species of mayflies belonging to five families in 13 genera from Tale Wildlife Sanctuary (TWS), Arunachal Pradesh, India. Similar works were done for the Western Ghats, Eastern Ghats (Tamil Nadu region), and Indian Himalayas (Anbalagan et al. 2004; Subramanian & Sivaramakrishnan 2005; Anbalagan & Dinakaran 2006; Priyanka & Prasad 2014; Srinivasan et al. 2019; Sivaruban et al. 2020a, 2020b, 2020c; Barathy et al. 2021; Vasanth et al. 2023; Sonaimuthu et al. 2024). However, only two works were reported from the present study region (Subramanian et al. 2024a, 2024b), and they are reporting the species occurrence. On the community structure of mayflies in tropical streams of Western Ghats, the family Baetidae was found to be most dominant (Barathy et al. 2021). It is generally expected that the aquatic insects are diverse and abundant in streams and rivers with acceptable water quality, such as community structures influenced by the changes in the water quality and habitat structure (Priyanka & Prasad 2014; Sonaimuthu et al. 2024). Species diversity pattern in selected streams of the Eastern Himalayas (Arunachal Pradesh) has been documented (Vasanth et al. 2023; Subramanian et al. 2024a, 2024b). The richness of genera in microhabitats varies within the cascades, riffles, and pools. In the riffles, high richness was observed among cobbles and trapped litter. However, in the pools, high richness was among the bedrock and trapped litter. The pool surface, unlike the run and riffle surfaces, was rich in taxa (Sonaimuthu et al. 2024). In this study, all the materials were predominantly collected in runs and riffles, and a few were collected from cascades and pools. The family and genus turnover across the habitats clearly demonstrates that riffles were similar in community composition to pools. This similarity was due to the presence of the representative genera of the Ephemeroptera, Plecoptera, and Tichoptera (EPT) complex, such as *Hydropsyche* (Trichoptera), *Choroterpes*, *Notophlebia*, *Epeorus* (Ephemeroptera), and *Neoperla* (Plecoptera), which were adapted to fast-flowing waters (Sonaimuthu et al. 2024). Stream insect communities respond to habitat morphology (Sivaramakrishnan 1992; Subramanian & Sivaramakrishnan 2005). The difference in FFGs between sites could be due to the availability of food/ organic matter, presence/ absence of riparian vegetation, and substratum in each site (Koneri et al. 2017; Birara 2020).

The results imply that the selected streams of Arunachal Pradesh support most of the pollution-sensitive taxa, such as Leptophlebiidae and Heptageniidae, in an unpolluted and cool environment for their survival. A similar observation was reported by Srinivasan et al. (2019) in the Western Ghats. The high abundance of *Caenis* sp. and *Baetis* sp. in the selected study area represents slight organic pollution and an alkaline *pH* nature of the streams. This was substantiated by the results obtained by Barathy et al. (2021). Their study revealed the presence of *Caenis* sp. and *Baetis* sp. in the stream with high *pH*. Sivaruban et al. (2020a) recorded *Caenis* sp. in the Gadana River, Tamil Nadu, which has high *pH* and Temperature. The study region is vulnerable to natural calamities because of both high monsoon rainfall and occasional earthquakes (Vaidya et al. 2019), which have recently been increased by anthropogenic influences, including land use changes, construction of dams, hunting, and deforestation (Paudel et al. 2018). Vasanth et al. (2023) have studied mayflies in the Eastern and Western Himalaya of India, suggesting that the habitat of mayflies, particularly the hill streams of the subcontinent, is endangered because of anthropogenic actions such as habitat destruction, hydrological modifications, and pesticides. Long-term mayfly conservation is dependent on preserving natural riparian vegetation and preventing human-induced changes to lentic and lotic environments. However, anthropogenic influences such as pollution, invasion of alien species, habitat loss and degradation, and climate change could deplete mayfly populations and increase extinction risk. More efforts are needed to examine the conservation status of mayfly species across the Indian Himalayan biogeographic zones based on their diversity and ecology (Vasanth et al. 2023).

The present study provides the first comprehensive assessment of mayfly diversity and ecology in selected streams of Arunachal Pradesh, India. A total of 2,014 individuals across 15 sites comprising 46 species, 25 genera, and 7 families of Ephemeroptera were recorded. Baetidae was the most dominant family, followed by Heptageniidae, whereas Caenidae and Vietnamellidae were the least represented. Species richness, diversity, and evenness varied among sites, with higher diversity associated with riffles and runs, emphasizing the influence of habitat structure and water quality. The Functional Feeding Group was diverse, dominated by collectors and scrapers, indicating well-structured stream ecosystems. Canonical Correspondence Analysis revealed a relationship between mayfly assemblages and environmental variables such as *pH*, temperature, elevation, canopy cover, substrate index, and water current, with pollution-sensitive taxa indicating generally unpolluted, cool streams, though the overall species–environment relationship was not statistically significant based on permutation tests.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution to the paper as follows: M. Muthukatturaja, T. Kubendran, M. Vasanth, and Saheli Basak: Field studies and specimen samplings; M. Muthukatturaja, T. Kubendran, and M. Vasanth: Identification of the specimens; M. Muthukatturaja, T. Kubendran, M. Vasanth, and K.A. Subramanian: drafting, editing, and proofreading the manuscript. All authors read and approved the final version of the manuscript.

FUNDING

This research was financially supported under the Annual Programme of Research (2025–2028), Zoological Survey of India, MoEF & CC, Government of India, and National Post-Doctoral Fellow (NPDF) scheme (F.N. PDF/2025/003770) under Anusandhan National Research Foundation (ANRF), Government of India.

AVAILABILITY OF DATA AND MATERIAL

The specimens listed in this study are deposited in the Miscellaneous Insect Order Section, Zoological Survey of India, Prani Vigyan Bhawan, 535, M- Block, New Alipore, Kolkata–700053, West Bengal, India, and are available from the first author upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study only included arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

GENERATIVE AI STATEMENT

We declare that no generative AI tools were used for content generation, data analysis, or interpretation while preparing this manuscript. All work presented, including the writing, analysis, and conclusions, was conducted solely by the authors.

ACKNOWLEDGMENTS

The authors are grateful to the Director, Zoological Survey of India, Kolkata, for encouraging the Indian mayfly studies and providing facilities to carry out the research work. The corresponding author, M. Muthukatturaja, thanks Anusandhan National Research Foundation (ANRF), Government of India, New Delhi, for the financial support under the National Post-Doctoral Fellowship (NPDF) Scheme (F.N. PDF/2025/003770). The authors also thank the Forest Department of Arunachal Pradesh for extending all cooperation in carrying out the field work. The authors thank the anonymous reviewers for their valuable comments and suggestions.

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مطالعه تلفیقی تنوع زیستی و بوم‌شناسی یک‌روزه‌ها (Insecta: Ephemeroptera) در آروناچال پرادش، هند

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دریافت: ۰۸ بهمن ۱٤٠٤
ویرایش: ۰۲ اردیبهشت ۱٤٠٥
پذیرش: ۰۹ اردیبهشت ۱٤٠٥
انتشار: ۲۱ اردیبهشت ۱٤٠٥

چکیـده: هیمالیای شرقی هند (آروناچال پرادش) هنوز به‌طور کامل در زمینه تنوع و بوم‌شناسی یک‌روزه‌ها (Ephemeroptera) مورد بررسی قرار نگرفته است. مطالعه حاضر ارزیابی کاملی از تنوع یک‌روزه‌ها، ساختار جامعه و روابط گونه–محیط را در ۱۵ جویبار انتخابی در آروناچال پرادش ارایه می‌دهد. در این منطقه مجموعاً ۲۰۱۴ فرد متعلق به ۴۶ گونه، ۲۵ جنس و هفت خانواده ثبت شد. خانواده Baetidae غالب‌ترین خانواده بود و پس از آن Heptageniidae قرار داشت، در حالی که کمترین تعداد گونه‌ها متعلق به Caenidae و Vietnamellidae بودند. شاخص‌های تنوع نشان‌دهنده تغییرات فضایی قابل توجهی بودند، به‌طوری که بالاترین تنوع شانون، غنای گونه‌ها و یکنواختی در جویبارهای با ارتفاع متوسط و جریان سریع مشاهده شد و کمترین مقادیر در سایت‌هایی با تعداد کمتری از افراد ثبت گردید. تحلیل همبستگی کانونی (CCA) نشان داد که متغیرهای محیطی مانند pH، عرض جویبار، ارتفاع، جریان آب، پوشش درختان و دما بر توزیع گونه‌ها تأثیرگذار بوده‌اند.

واژگـان کلیدی: تحلیل همبستگی کانونی، شاخص‌های تنوع، هیمالایای شرقی، یک روزه‌ها، گروه‌های غذایی عملکردی