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Seasonal Variation of Aquatic Insect Biotic Indices and Their Relationship with Water Quality in the Tropical Mong Sen Stream, Lao Cai Province, Vietnam

Hieu Van Nguyen*, Hien Thi Thu Nguyen
Faculty of Biology, Hanoi Pedagogical University 2, Phu Tho, Vietnam
***Corresponding Author: nguyenvanhieu@hpu2.edu.vn**

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ABSTRACT

Freshwater ecosystems in tropical regions are increasingly threatened by anthropogenic disturbances and climate variability, highlighting the urgent need for effective biomonitoring tools. Aquatic insects are among the most widely used bioindicators for assessing ecological quality, yet their application remains underutilized in Vietnam. In this study, we investigated the seasonal biotic indices of aquatic insects and their relationship with physico-chemical parameters in the Mong Sen Stream, a tropical stream in Lao Cai Province, Northern Vietnam, where upstream sites are subject to stronger anthropogenic impacts compared to downstream areas. A total of 86 species belonging to 72 genera, 42 families, and 9 orders of aquatic insects were identified. Both insect diversity and water quality parameters showed clear seasonal variation. Diversity was higher in the dry season, with Shannon-Weaver indices (H') ranging from 2.1 at site St4 to 2.5 at site St2, compared to the rainy season (H' = 1.5 at St4 to 2.1 at St2). Water quality was also better in the dry season, with Average Score Per Taxon (ASPT) values ranging from 6.2 to 6.8, relative to 5.0 to 6.1 in the rainy season. Furthermore, aquatic insect diversity indices (d, H') and ASPT index were positively correlated with dissolved oxygen, whereas other parameters such as BOD_5, COD, turbidity, TOC, and TN exhibited negative relationships. These findings demonstrate that aquatic insects provide reliable and sensitive indicators of seasonal water quality variation in tropical streams. This study not only contributes essential baseline data for the Mong Sen Stream but also underscores the scientific and practical significance of integrating aquatic insect-based biomonitoring into freshwater management strategies in Vietnam and other tropical regions.

INTRODUCTION

Biotic indices are among the key tools for the sustainable management of aquatic ecosystems and water resources in river and stream systems as well as in coastal areas. In several previous studies, biodiversity indices have been employed as an important instrument to assess water quality **(Cleary, 2003; Koleff *et al.*, 2003; Tuomisto *et al.*, 2003)**. Meanwhile, other studies have systematically proposed solutions to mitigate environmental impacts by developing water quality assessment scales that incorporate physical, chemical, and biological parameters **(Hou *et al.*, 2020; Feio *et al.*, 2021)**. These studies are of great significance in providing tools for predicting, monitoring, and managing water quality.

Aquatic insects play a crucial role in nutrient cycling, decomposition, and energy flow within aquatic ecosystems, particularly in river and stream ecosystems. This group of organisms is highly sensitive to changes in water conditions; therefore, they are widely used as bioindicators in biological assessments of water quality worldwide **(Thanee & Phalaraksh, 2012; Suter & Cormier, 2015)**. Several studies have highlighted the importance of benthic aquatic insects in detecting anthropogenic disturbances and assessing habitat quality **(Morse *et al.*, 1994; Stoyanova *et al.*, 2014; Sitati *et al.*, 2021)**. This is possible because these organisms exhibit limited mobility and relatively long life spans, enabling them to reflect both past and present changes in water quality during sampling. In addition, physico-chemical analyses are rapid, relatively simple to process, require only small sample volumes, and can achieve accurate results **(Leelahakriengkrai & Peerapornpisal, 2011)**. However, such methods only evaluate water quality at the time of sampling **(Shah & Pandit, 2013)**. Consequently, assessments of abundance and species composition, together with physico-chemical parameters, have been widely applied in previous studies to determine water quality. This integrated approach provides comprehensive information on the ecological condition of aquatic ecosystems, thereby supporting effective conservation strategies and the sustainable management of these valuable resources **(Jarjees *et al.*, 2019)**.

Although physico-chemical analyses provide rapid insights into water conditions, biotic indices remain indispensable for capturing long-term ecological responses to environmental fluctuations. Among these, Margalef species richness (d), Shannon-Weaver biodiversity index (H’), and the Average Score per Taxon (ASPT) have been widely recognized as effective tools for assessing ecological integrity in running waters **(Rosenberg & Resh, 1993; Buss *et al.*, 2015)**. Margalef species richness (d) directly reflects habitat heterogeneity and resource availability, while H’ index incorporates both richness and evenness, thus offering a more balanced measure of community structure under varying disturbance regimes **(Karr, 1991)**. Meanwhile, ASPT, based on the sensitivity scores of benthic taxa, is particularly valuable for detecting organic pollution and habitat degradation, as it accounts for differences in tolerance among aquatic insect groups **(Morse *et al.*, 2007)**. The combined application of these indices therefore provides robust evidence for water quality assessment, complementing conventional physico-chemical monitoring.

Despite their proven effectiveness, research employing these indices to evaluate tropical stream ecosystems remains unevenly distributed across regions. Numerous studies have been conducted in temperate zones (e.g., Europe and North America) and to some extent in tropical Asia, including Thailand, Malaysia, Myanmar, China, and Indonesia **(Chiangthong & Phalaraksh, 2017; Suhaila & Che Salmah, 2017; Tor *et al.*, 2021; Guohao *et al.*, 2023; Suhri *et al.*, 2025)**. However, in Vietnam, where mountainous streams support high biodiversity and are increasingly subjected to anthropogenic pressures, studies integrating d, H', and ASPT remain limited. Most available research has focused either on taxonomic inventories or on general patterns of aquatic insect assemblages without systematically linking biotic indices to seasonal water quality dynamics **(Jung *et al.*, 2008; Nguyen & Dinh, 2019; Nguyen, 2020)**.

To address this gap, this study investigated the seasonal variation of aquatic insect biotic indices (d, H', ASPT) and their relationships with physico-chemical parameters in the Mong Sen Stream, Lao Cai Province, northern Vietnam. By integrating biological and environmental data, this study not only provides empirical evidence for the applicability of these indices in tropical montane streams but also contributes to the development of bioassessment frameworks for sustainable water resource management in Vietnam and comparable regions worldwide.

MATERIALS AND METHODS

Study area

This study was conducted in the Mong Sen stream, a tropical stream in Lao Cai province. Lao Cai province is situated in the northern mountainous region of Vietnam, bordering Yunnan Province of China. The province encompasses diverse elevations and hydrological conditions, providing a representative setting for studying stream ecosystems and aquatic biodiversity.

Table 1. Location of five study sites in the Mong Sen stream, Northern Vietnam

Stream code	Stream order	Latitude/Longitude	Altitude (m)	Category
St1	2nd	22^0 20' 54.0" N 103^0 52' 27.3" E	1323	Preserved
St2	3rd	22^0 23' 39.7" N 103^0 50' 16.3" E	1308	Preserved
St3	3rd	22^0 23' 39.0" N 103^0 50' 12.0" E	1305	Preserved
St4	4th	22^0 24' 05.0" N 103^0 54' 35.7" E	937	Altered
St5	4th	22^0 24' 49.6" N 103^0 53' 55.3" E	744	Altered

Sampling of Aquatic Insects

Aquatic insects were collected at five sampling sites in December 2023 (Dry season) and June 2024 (Rainy season). Sampling was conducted following the methods:

placing the net mouth facing upstream and disturbing the substrate in front of the net by foot for 3-5 minutes (kick sampling). In areas with dense vegetation, hand nets were used. At sites with large cobbles where kick sampling could not be performed, stones were lifted, and the attached specimens were carefully collected with soft forceps to avoid damaging them. Qualitative sampling was carried out in both riffle and pool water. In areas with aquatic shrubs, the net was swept through submerged vegetation and along the roots of riparian plants. In small streams or narrow channels, samples were taken using a hand net. For quantitative sampling, a Surber sampler (mesh size 0.2 mm, frame size 30 × 30 cm) was used; at each site, two samples were collected according to flow characteristics-one from a riffle water section and one from a pool water section. Specimens were preliminarily sorted in the field with soft forceps, and additional samples were sieved in trays **(McCafferty, 1983; Nguyen, 2003; Nguyen *et al.*, 2004)**. All specimens were preserved in 80% ethanol and identified using available taxonomic keys **(Morse *et al.*, 1994; Merritt *et al.*, 1996; Nguyen, 2003; Yule & Yong, 2004; Hoang, 2005; Jacobus & McCafferty, 2008; Cao, 2008)**.

Physico-chemical Analysis

Prior to sampling, the coordinates and elevation of each sampling site were determined using a Garmin GPS device. Several physico-chemical parameters of water were measured *in situ* at the sampling sites with a multi-parameter water quality meter (WQC-22A, TOA, Japan). The measured parameters included water temperature (°C), pH, DO (Dissolved Oxygen, mg/l), EC (Electrical Conductivity, mS/cm), and turbidity (NTU). Biochemical Oxygen Demand, Chemical Oxygen Demand, Total Organic Carbon and Total Nitrogen were analyzed in the laboratory using specialized analytical instruments: BOD Trak II (Hach) for determining BOD_5 (Biochemical Oxygen Demand, mg/l); DRB 200 (Hach) for COD (Chemical Oxygen Demand, mg/l); and Multi N/C 2100S (Analytik Jena) for TOC (Total Organic Carbon, mg C/l) and TN (Total Nitrogen, mg N/l).

Data Analysis

Shannon-Weaver index (H’) and Margalef richness index (d) were estimated using the equation **(Hammer *et al.*, 2001)**.

Shannon-Weaver index:

$$H' = -\sum_{i=1}^{s} p_i \ln(p_i)$$

Where, H’: Index of taxa diversity; p_i = number of individuals of species i/total number of samples.

Margalef richness index:

$$d = (S-1)/\ln(N)$$

Where, S is the number of species, and N is the number of individuals.

Table 2. The level of biodiversity is based on d index and H’ index

d - index	Level	H’ - index	Level
> 3.5	Very rich	> 3.0	Good
2.6 - 3.5	Rich		
1.6 - 2.5	Relatively good	2.0 - 3.0	Rather
0.6 - 1.5	Normal	1.0 - 2.0	Normal
< 0.6	Least	< 1.0	Least

Source: **Staub *et al*. (1970)**.

The Biological Monitoring Working Party Index

BMWP was determined by adding all the families' sensitivity scores in a sample.

The Average Score per Taxon index

ASPT was calculated as the ratio of the BMWP index value to the number of families found in a sample.

$$ASPT = \frac{\sum_{i=1}^{n} BMWP}{N}$$

Where, N is the number of scored families found in the site.

The list of macroinvertebrate families and their sensitivity scores for $BMWP^{VIET}$ and $ASPT^{VIET}$ is referred to **Nguyen *et al.* (2004)**.

Table 3. Evaluation of water quality using the ASPT score and H’ index

ASPT score	Pollution level	H’ index	Pollution level
0	Extremely polluted	(0, 0.5]	Very poor
[1.0, 2.9]	Polysaprobe (very polluted)		
[3.0, 4.9]	α-Mesosaprobe (quite polluted)	(0.5, 1.0]	Poor
[5.0, 5.9]	β- Mesosaprobe (quite polluted)	(1.0, 2.0]	Fair
[6.0, 7.9]	Oligosaprobe (fairly clean)	(2.0, 3.0]	Good
[8.0, 10]	Clean water	> 3.0	Excellent

Source: **Nguyen *et al.* (2004)** and **Guohao *et al.* (2023)**.

Principal Component Analysis (PCA) was applied to evaluate which variables best explained the environmental variation among the sampled sites. In addition, biotic indices and water quality indices were analyzed to clarify the correlations between them. Data processing was performed using Primer V6 **(Clarke & Gorley, 2005)** and Microsoft

Office Excel® 2017, while other statistical analyses were carried out in R program with a significance level of 0.05.

RESULTS

Aquatic insect diversity and water quality

Based on the identification results of aquatic insect specimens collected in two field surveys with 2621 individuals for quantitative sampling and 5831 individuals for qualitative sampling, a total of 86 species belonging to 72 genera, 42 families, and 9 orders of aquatic insects were found in the tropical Mong Sen stream. Ephemeroptera, Trichoptera, and Odonata were the three major aquatic insect orders accounting for 66.3% of the total species, followed by Diptera and Hemiptera with 8 species each, respectively. Coleoptera and Plecoptera, with the number of species ranging from 5-6. The other orders, Lepidoptera and Megaloptera, were the minor taxa with 1 species each, respectively. Species diversity during the dry season was higher than in the rainy season, as reflected by the number of taxa recorded, with 34 families in the dry season compared to 30 families in the rainy season. Similarly, quantitative sampling revealed a greater abundance of individuals in the dry season (1375 individuals) than in the rainy season (1246 individuals).

In the Mong Sen stream, biodiversity indices showed clear seasonal variation (Table 4). The Margalef richness index (d) ranged from 2.6 to 4.7, with higher values in the dry season (mean ± SD = 4.0 ± 0.8) compared to the rainy season (3.1 ± 0.4). According to the classification in Table 2, aquatic insect diversity was categorized as "very rich" during the dry season but decreased to "rich" in the rainy season. Similarly, the Shannon-Weaver index (H') declined significantly from 2.3 ± 0.2 in the dry season to 1.8 ± 0.2 in the rainy season ($p < 0.05$). This seasonal decline indicates that community composition became less even under high organic loading and increased turbidity during rainfall, when organic matter input from surrounding catchments was intensified. These patterns are consistent with studies in tropical streams in Thailand and Malaysia, where rainy-season disturbances reduced H' values due to habitat instability and organic enrichment **(Thanee & Phalaraksh, 2012; Suhaila & Che Salmah, 2017)**.

Table 4. Value of aquatic insect biotic indices of Mong Sen stream, Northern Vietnam

Sampling sites	d index		H' index		ASPT score	
	Dry	Rain	Dry	Rain	Dry	Rain
St 1	4.7	3.7	2.3	2.0	6.5	6.1
St 2	4.5	3.4	2.5	2.1	6.8	6.1
St 3	3.2	2.9	2.4	1.8	6.5	5.8
St 4	3.2	2.9	2.1	1.5	6.2	5.0
St 5	4.6	2.6	2.4	1.7	6.4	5.0

Sampling sites	d index		H' index		ASPT score	
	Dry	Rain	Dry	Rain	Dry	Rain
Mean ± SD	**4.0 ± 0.8**	**3.1 ± 0.4**	**2.3 ± 0.2**	**1.8 ± 0.2**	**6.5 ± 0.2**	**5.6 ± 0.6**
p	< 0.05		< 0.05		< 0.05	

Water quality assessment based on the ASPT index also reflected seasonal differences (Table 4). ASPT values were relatively high during the dry season (6.5 ± 0.2), classifying Mong Sen stream as "fairly clean" (oligosaprobic conditions). In contrast, rainy-season ASPT values decreased significantly (5.6 ± 0.6), indicating a shift to "quite polluted" conditions (β-mesosaprobic). These results were in accordance with the H' index, which dropped below 2.0 in most sites during the rainy season, corresponding to a "fair" water quality level. Similar seasonal trends have been reported in northern Vietnam **(Nguyen & Nguyen, 2017; Nguyen *et al.*, 2024)** where increased runoff and sediment load during the rainy season lowered diversity indices and degraded water quality scores.

Environmental Factors and Correlation Analysis

The physico-chemical parameters at Mong Sen stream are shown in Table (5).

Table 5. Environmental Factors of Mong Sen stream, Northern Vietnam

Environmental Factors	Dry season			Rainy season			*p*
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	
Water temperature (°C)	18.4	19.8	**19.2 ± 0.6**	20.2	22.4	**21.4 ± 0.9**	< 0.05
pH	7.2	8.5	**7.8 ± 0.5**	7.8	8.5	**8.0 ± 0.3**	> 0.05
DO (mg/l)	6.7	8.5	**7.7 ± 0.7**	5.0	7.5	**6.0 ± 1.0**	< 0.05
BOD_5 (mg/l)	1.8	3.5	**2.8 ± 0.7**	3.8	8.2	**5.1 ± 1.8**	< 0.05
COD (mg/l)	4.3	5.8	**5.1 ± 0.6**	7.1	10.5	**9.1 ± 1.3**	< 0.05
TOC (mg C/l)	1.7	4.3	**3.4 ± 0.1**	6.1	8.1	**6.9 ± 0.8**	< 0.05
TN (mg N/l)	0.4	0.9	**0.7 ± 0.2**	0.7	1.2	**1.0 ± 0.2**	< 0.05
Turbidity (NTU)	0.1	0.5	**0.2 ± 0.2**	0.7	2.0	**1.3 ± 0.6**	< 0.05
EC (mS/cm)	0.21	0.43	**0.32 ± 0.01**	0.58	0.76	**0.68 ± 0.07**	< 0.05

The water parameters at the five sampling sites in the Mong Sen stream are presented in Table (5). Water temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Nitrogen (TN), turbidity, and Electrical Conductivity (EC) all showed statistically significant differences between the dry and rainy seasons ($p < 0.05$), except for pH. The results indicated that mean values of water temperature, BOD_5, COD, TOC, TN, turbidity, and EC were lower in the dry season than in the rainy season. In contrast, DO values were markedly lower during the rainy season compared with the dry season.

During the rainy season, higher values of BOD_5 (5.1 ± 1.8), COD (9.1 ± 1.3), TOC (6.9 ± 0.8), TN (1.0 ± 0.2), turbidity (1.3 ± 0.6), and EC (0.68 ± 0.07) are typically accompanied by reduced DO (6.0 ± 1.0) concentrations, leading to lower species richness and diversity among aquatic insects. By contrast, the dry season is characterized by higher DO (7.7 ± 0.7) and clearer water, resulting in significantly higher values of d (4.0 ± 0.8), H' (2.3 ± 0.2), and ASPT (6.5 ± 0.2), which indicate better ecological conditions.

In this study, turbidity in the Mong Sen stream remained consistently low (0.1-2.0 NTU), indicating stable hydrological conditions and minimal sediment input during both seasons. Despite this, electrical conductivity (EC) was relatively high, ranging from 0.21 to 0.76 mS/cm. This contrasting pattern suggests that while suspended solids were scarce, ionic and mineral concentrations in the water column were substantial. Such conditions are characteristic of streams draining mountainous catchments, where groundwater inflow and weathering of bedrock contribute dissolved ions without necessarily increasing turbidity. Elevated EC values may reflect inputs of bicarbonates, sulfates, or chlorides from geological substrates and surrounding land use, which can shape the availability of ecological niches for aquatic insects.

Principal Component Analysis (PCA) revealed that the first two axes explained 81.8% of the environmental variation, with axis 1 accounting for 70.3% and axis 2 for 11.5% (Fig. 1). PCA of both aquatic insect data and environmental parameters demonstrated a clear separation into two groups: the first group corresponding to the dry season and the second to the rainy season. This suggests that seasonality influenced both biotic indices of aquatic insects (d, H', ASPT) and water parameters. Variables that strongly influenced axis 1 included water temperature, TOC, turbidity, EC, BOD_5, COD, and TN, all of which showed positive correlations with this axis. Therefore, axis 1 can be interpreted as representing the level of organic pollution during the rainy season. In contrast, DO and the biotic indices d, H', and ASPT were negatively associated with axis 1. Thus, the dry season was characterized by higher DO, d, H', and ASPT values, indicating better water quality.

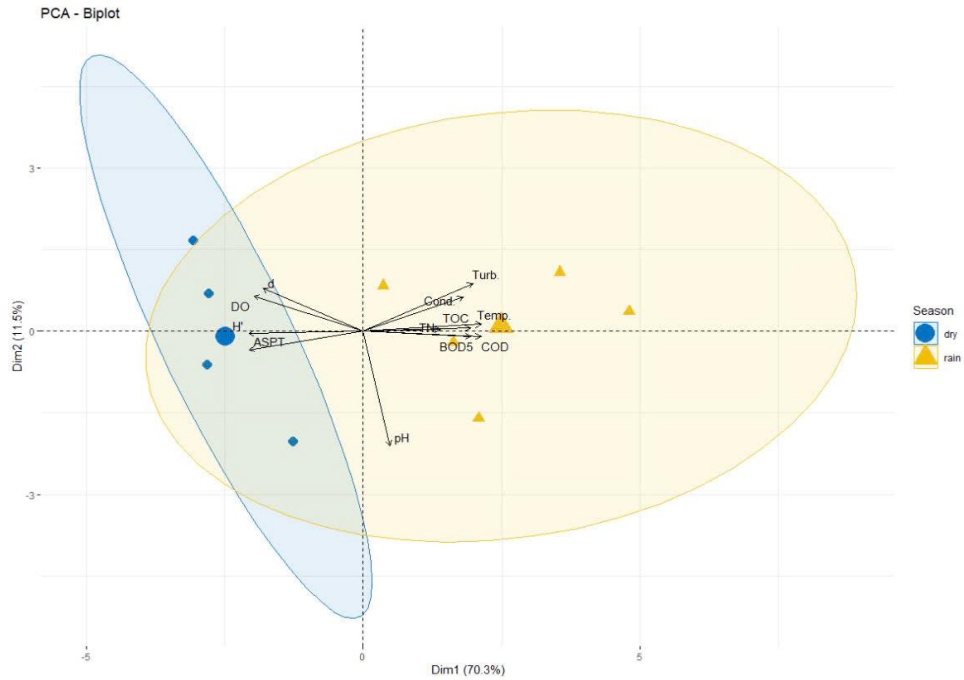

Fig. 1. The PCA ordination diagram for the data set between environmental variables and aquatic insects’ biotic index in the dry and rainy seasons

PCA also revealed a strong correlation between aquatic insect biodiversity (d and H’ indices) and the ASPT index with certain water quality parameters. Among these, DO showed a positive correlation with diversity indices: d index ($r = 0.7$, $p < 0.05$), H’ ($r = 0.9$, $p < 0.05$) index and ASPT score ($r = 0.8$, $p < 0.05$), whereas the other parameters (TOC, turbidity, EC, BOD_5, COD, and TN) were negatively correlated with these indices ($- 0.9 \leq r \leq - 0.4$), especially with BOD_5 and COD ($- 0.8 \leq r \leq - 0.7$) (Fig. 2).

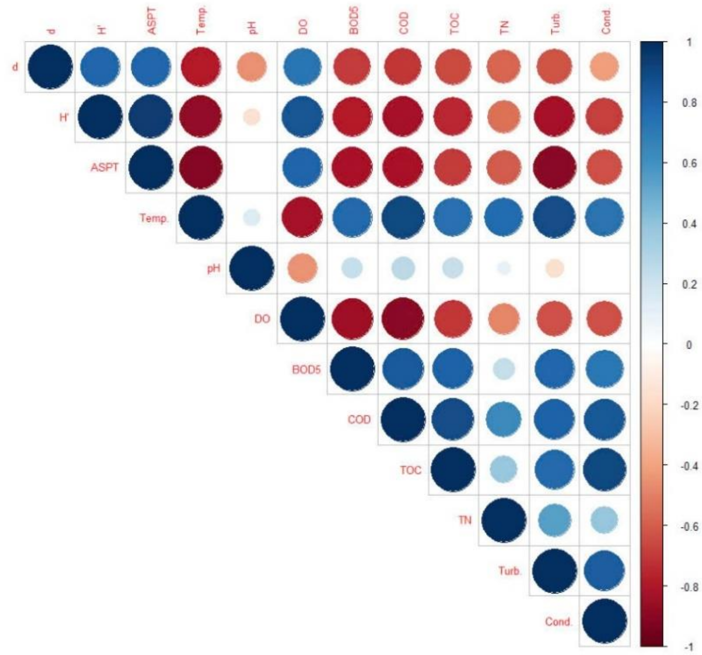

Fig. 2. Correlation coefficient between physico-chemical parameters and biotic aquatic insects' biotic index in the Mong Sen stream

DISCUSSION

Notably, the aquatic insect biodiversity observed in the present study revealed lower numbers of species, genera, and families compared to the findings of **Nguyen *et al.* (2001)**, who previously reported 145 species, 127 genera, 63 families, and 9 orders. Although both studies were conducted during the same season, applied the same field collection methods, and investigated sites that were either collapsed or located in close proximity, the current results still indicate a reduced taxonomic richness. Similarly, the species richness recorded in the Mong Sen stream was considerably lower than that of other tropical montane streams, such as the Dak Pri stream in the Central Highlands of Vietnam (268 species, 230 genera, 91 families, and 9 orders), or even in temperate regions such as the Gapyeong stream in Korea (133 species, 98 genera, 51 families, and 9 orders) **(Hoang & Bae, 2006)** or other streams in northern Vietnam, such as the Muong Hoa stream (Lao Cai province) with 216 species, 139 genera, 61 families, and 9 orders **(Jung *et al.*, 2008)**, the Quan Boong stream (Phu Tho province) with 110 species, 98 genera, 49 families, and 9 orders **(Nguyen & Nguyen, 2017)**, the Nam Cang and Seo My Ty streams (Lao Cai province) with 141 species, 108 genera, 50 families, and 9 orders **(Nguyen & Dinh, 2019)**, the Dai Dinh stream (Phu Tho province) with 91 species, 76 genera, 44 families, and 9 orders **(Nguyen, 2020)**, and the Thac Bac stream (Phu Tho province) with 122 species belonging to 111 genera, 56 families and 9 orders of aquatic insects was found **(Nguyen *et al.*, 2024)**.

The reduction in species richness and individual abundance of aquatic insects during the rainy season compared to the dry season may be explained by hydrological stability during the dry season, which provides more favorable conditions for colonization and persistence of aquatic insects. Lower discharge and reduced sediment loads enhance habitat heterogeneity, promote resource availability, and limit physical disturbance, thereby supporting higher species richness. In contrast, the rainy season is characterized by increased runoff, elevated turbidity, and fluctuations in water chemistry, which can dislodge benthic organisms and reduce community stability. Similar seasonal trends have been documented in tropical streams of Southeast Asia and South America **(Boyero & Bailey, 2001; Buss *et al.*, 2004)**.

Species richness of aquatic insects is often underestimated because many taxa remain undescribed, and genera may contain multiple cryptic species **(Ochieng *et al.*, 2019)**. However, since this limitation applies across all studies, the low diversity observed here cannot be solely attributed to taxonomic uncertainty. Our findings suggest that the relatively low species richness observed in Mong Sen Stream cannot be solely attributed to taxonomic limitations, but may instead reflect the influence of other contributing factors. In particular, human-induced disturbances, climate change, and seasonal variability are likely to play important roles **(Edegbene *et al.*, 2015; Wohl, 2006; Heino *et al.*, 2009; Shah *et al.*, 2020)**. The present study highlights the role of seasonal variation by integrating water quality parameters with aquatic insect bioindicators. Seasonal changes have been shown to alter stream ecosystems by modifying physico-chemical conditions and reshaping biological communities, often leading to shifts toward more tolerant assemblages or declines in water quality **(Leelahakriengkrai & Peerapornpisal, 2011; Violin *et al.*, 2011)**. These results emphasize that seasonal dynamics are a critical driver of aquatic insect diversity and should be carefully considered when assessing stream health and managing freshwater ecosystems in northern Vietnam.

The three biotic indices: Margalef's richness index (d), Shannon-Weaver diversity index (H'), and Average Score Per Taxon (ASPT) collectively provide a comprehensive assessment of stream health from both structural and functional perspectives. The index d reflects species richness and community composition, while H' incorporates both richness and evenness to evaluate diversity balance within the assemblage. In contrast, ASPT focuses on the tolerance levels of taxa to organic pollution, thus capturing ecological sensitivity. Together, these indices complement each other by integrating taxonomic, diversity, and biotic tolerance dimensions, providing a holistic interpretation of ecosystem integrity and water quality conditions.

Interestingly, despite this decline, the Mong Sen stream maintained relatively high biodiversity compared to many lowland tropical streams in Southeast Asia, where the d index rarely exceeded 3.0 and ASPT values often indicated meso - to polysaprobic conditions year-round **(Yule & Yong, 2004; Dudgeon, 2008)**. The persistence of high d values even during the rainy season suggests that the stream supports diverse habitats and relatively intact riparian vegetation, buffering against complete community collapse. This ecological resilience is a characteristic feature of montane streams in northern Vietnam, where steep gradients and fast-flowing waters promote oxygenation and habitat heterogeneity.

Mong Sen stream exhibited a distinct seasonal pattern: biodiversity (d and H') and water quality (ASPT) were significantly higher in the dry season, while the rainy season was associated with reduced diversity and moderate pollution levels. Compared with other regional studies, Mong Sen demonstrates both sensitivity to seasonal hydrological changes and resilience in maintaining relatively rich assemblages of aquatic insects. These findings underline the importance of using integrated indices (d, H', and ASPT) in biomonitoring tropical montane streams and provide baseline data for future conservation and management strategies.

In tropical stream ecosystems, key physico-chemical parameters such as DO, BOD_5, COD, EC, turbidity, TOC, and TN play pivotal roles in determining water quality and consequently shaping aquatic insect diversity. High DO levels typically indicate well-oxygenated, ecologically healthy habitats that support diverse aquatic insect assemblages, while elevated BOD_5 and COD suggest increased organic load consuming oxygen and potentially inducing hypoxic stress detrimental to sensitive species. EC, reflective of ionic and mineral content, and turbidity, indicative of suspended particles, can both alter microhabitats and resource availability for aquatic insects. Nutrient enrichment the form of higher TOC and TN can fuel algal blooms, followed by oxygen depletion, thereby impacting biodiversity **(Nguyen *et al.*, 2022)**. In this study, turbidity values in the Mong Sen stream were consistently low, ranging only from 0.1 to 2.0 NTU, whereas electrical conductivity (EC) exhibited comparatively high values of 0.21-0.76 mS/cm. Previous studies have highlighted the ecological implications of conductivity for stream biota. EC was one of the strong influences on the structure of aquatic insect communities in Indonesia and China **(Guohao *et al.*, 2023; Nasaruddin *et al.*, 2023)**. Similarly, EC was one of the major environmental parameters shaping aquatic insect biodiversity in tropical streams of Thailand **(Thanee & Phalaraksh, 2012)**. These findings support our interpretation that ionic enrichment in clear-water systems, such as the Mong Sen stream, may exert a significant influence on aquatic insect assemblages even when turbidity is minimal.

Seasonal variation, especially the dichotomy between dry and rainy seasons in tropical Vietnam, further modulates these relationships. A study in Vinh Long Province, Southern Vietnam found that turbidity, EC, and DO were among the most important parameters distinguishing seasonal variations, with turbidity and EC increasing markedly due to rainfall-driven runoff in the rainy season, while DO showed significant fluctuations across seasons **(Nguyen *et al.*, 2022)**. These seasonal patterns are consistent with broader observations in tropical regions, where rainy seasons elevate BOD_5, COD, TOC, EC, and turbidity, and concurrently reduce DO, leading to declines in aquatic insect richness and diversity. Conversely, the dry season often brings clearer, more oxygen-rich conditions that favor higher biodiversity **(Valente-Neto *et al.*, 2019)**.

The assessment of water quality in tropical streams requires an integrated approach that combines physicochemical parameters with biotic indices. Variables such as dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), electrical conductivity (EC), turbidity, total organic carbon (TOC), and total nitrogen (TN) are widely recognized as key determinants of aquatic ecosystem health. However, these variables fluctuate strongly with hydrological regimes in tropical regions, where the alternation between dry and rainy seasons significantly alters water chemistry and habitat conditions **(Thanee & Phalaraksh, 2012)**. To complement these short-term measurements, biotic indices such as the Margalef richness index (d), the Shannon-Weaver diversity index (H'), and the Average Score Per Taxon (ASPT) provide integrative assessments of long-term ecological quality based on aquatic insect communities **(Merritt *et al.*, 2008)**.

In the Mong Sen stream, northern Vietnam, the combined use of environmental and biological indicators has proven valuable in detecting seasonal water quality changes. These findings are consistent with previous studies in Vietnam and Southeast Asian streams, where aquatic insect assemblages have been shown to respond sensitively to seasonal variation in water quality **(Thanee & Phalaraksh, 2012; Suhaila & Che Salmah, 2017; Suhri *et al.*, 2025)**. Integrating both physicochemical and biotic indices, therefore provides a robust framework for evaluating ecological health and guiding sustainable water resource management in tropical streams. This season-linked interplay of water quality parameters and aquatic insect diversity highlights the utility of biotic indices in biomonitoring and underscores the necessity of incorporating seasonal variability in water resource management and conservation planning.

CONCLUSION

This study highlights the pivotal role of aquatic insects as bioindicators for assessing water quality in the Mong Sen stream, Lao Cai province, Northern Vietnam. Seasonal variation was evident, with higher diversity indices (d and H') and ASPT scores recorded during the dry season, corresponding to better physicochemical conditions characterized by higher dissolved oxygen and lower organic pollution. In contrast, the rainy season was associated with elevated BOD_5, COD, TOC, TN, turbidity, and EC, resulting in reduced DO and consequently lower biodiversity. The strong correlations between biotic indices (d, H', ASPT) and key water quality parameters, particularly dissolved oxygen, underscore the sensitivity of aquatic insect assemblages to seasonal fluctuations in stream environments.

Our findings align with regional and global studies, but they also reveal distinctive features of the Mong Sen stream, where the combined impacts of altitude and anthropogenic disturbance influence community structure and ecological quality. By integrating physicochemical parameters with biological indicators, this research provides a robust framework for water quality monitoring and management in tropical montane ecosystems. Importantly, the results emphasize the necessity of incorporating seasonal dynamics into biomonitoring programs and contribute valuable baseline data for future conservation and sustainable water resource management in northern Vietnam.

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Conflict of Interest

The authors declare no conflict of interest.

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