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Insect Assemblage as Bioindicators for Stream Quality within Two Sacred Groves in Ghana

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Abstract

Sacred groves are patches of relict forests set aside by communities for traditional, religious and conservation purposes. However, freshwater ecosystems in these sacred groves are impacted by anthropogenic activities, due to lack of enforcement of traditional edicts to check encroachment. This study measured the effect of stream dynamics (stream size and water quality) on aquatic insect diversity and by extension to assess the stream health in two sacred groves-Abiriw and Odumante-in Ghana. Insects were sampled across rainy and dry seasons using multiple standard collection methods and compared between these sacred groves via sampling different microhabitats associated with the different human impacts using Dip net and Surber Stream-bottom sampler to ensure a representative sampling at all places within the streams. We also used Eureka Sub3 multiparameter water-quality multiprobe to measure the physico-chemical parameters of the streams. Results: The study recorded 2767 aquatic insects classified into 65 families and 11 orders. The results showed that abundance did not differ significantly between groves, but family richness was higher at Odumante (60 families) compared to Abiriw (46 families). The results further revealed that seasonality influenced insect diversity with both abundance and richness significantly higher in the dry season in both sacred groves. There was low representation of Ephemeroptera, Plecoptera, and Trichoptera (EPT) and high Hemiptera dominance suggesting moderate to high environmental stress especially in these streams. Conclusions: Based on the results we can infer that streams in the two sacred groves have been impacted by anthropogenic activities with a resultant change in stream dynamics and a profound influence on aquatic insect communities, especially at Odumante with implications for integrated conservation of sacred groves freshwater ecosystems. We recommend that conservation efforts must address watershed-level waste management and farming activities along the riparian zones in sacred groves to protect aquatic ecosystems.

Keywords

Abiriw, Biodiversity, Bioindicator, Odumante, Stream

1. Introduction

Sacred groves are remnant forest patches preserved through cultural or religious practices, which may serve as refugia for biodiversity in fragmented landscapes (Aniah & Yelfaanibe, 2018; Tatay & Merino, 2023; de Souza, 2025). In Ghana, these sacred groves protect culturally significant trees, vegetation, and water bodies dedicated to deities or ancestral spirits (Anokye, 2022) and as a result, local norms are used to enforce their protection via taboos, integrating spiritual and ecological values (Diawuo & Issifu, 2017; Kosoe et al., 2020). Historically, sacred groves have been used as biodiversity conservation hubs (Patole, 2022; Sarfo-Adu et al., 2022; Kujur et al., 2025; Ziblila et al., 2025), yet contemporary anthropogenic pressures such as encroachment, farming, and mining threaten their integrity (Nganso et al., 2012; Boamah, 2020; Oppong, 2023; Asante, 2024). It is estimated that there are about 2000 - 3200 sacred groves in Ghana with close to 80% occurring in the southern half of the country (Gordon, 1992; Osei et al., 2018; Batame et al., 2023). Generally, the main objective for establishing sacred groves in communities in Ghana is to protect forests surrounding environmentally sensitive areas. The size of sacred groves in Ghana ranges from hundreds of hectares of large forest (>100 ha) to small plots (<0.5 ha) containing single trees or few stones (Gordon, 1992; Franks et al., 2017). Because of their perceived attachment to some deities or ancestral spirits, sacred groves are referred to in different communities, such as nananompow (ancestral grove or royal Mausoleum) (Adarkwa-Dadzie, 1997), abosompow or asoneyeso (shrine), mpanyinpow (ancestral forest), and nsamanpow (burial grounds) by the Akans (Ntiamoa-Baidu, 1995; Attuaquayefio & Fobil, 2005).

Sacred groves serve ecological and socio-cultural functions like preserving virgin forests, serving as a refuge for rare and endemic local biodiversity. They also serve as sources of herbs for medicinal, social and religious purposes (Asokan et al., 2015; Doffana, 2017; Ray & Ray, 2020). Because of the linkage between traditional beliefs and deities or ancestral spirits, disobedience or disregard for traditional laws (taboos) regarding the encroachments of sacred groves attract severe punishments for culprits. Such punishments include offering animals as sacrifice and the performance of traditional rites to appease the local deity to avoid ill-health, and deaths, although this is often ineffective in modern Ghana unlike centuries ago (Kwarteng, 2015; Ikenyei & Lawal, 2019). Anthropogenic activities have been reported to have been a major cause of biodiversity loss in the world although the bulk of research in this area within sacred groves is mainly focused on botanical, Ethno-botanical or socio-cultural functions (Kosoe et al., 2020; Sarfo-Adu et al., 2022; Kumar et al., 2022; Gyedu et al., 2025). Notwithstanding this general situation, there have been some studies on insect diversity assessment in sacred groves as reported by Nganso et al. (2012), Mukherjee et al. (2018), and Mondal & Mondal (2024).

The class Insecta contains some important groups with several characteristics that make them suitable for ecosystem health monitoring (Mensah et al., 2018; Nnoli et al., 2019; Menta & Remelli, 2020; Parikh et al., 2021; Chowdhury et al., 2023). They inhabit all habitat types and play major roles in the functioning and stability of both terrestrial and aquatic ecosystems (Adler & Foottit, 2009). For instance, it has been reported in several studies that diversity and abundance of grasshoppers (Adu-Acheampong et al., 2016; Adu-Acheampong & Samways, 2019; Khan et al., 2023; Mariottini et al., 2024), butterflies (Sharma & Sharma, 2017; Kyerematen et al., 2018a, 2018b; Ismail et al., 2020; Pallottini et al., 2023) beetles (Mukwevho et al., 2017; Carvalho et al., 2020; Karpiński et al., 2021; Makwela et al., 2023), and ants (Carvalho et al., 2020; Zina et al., 2021; Lutinski et al., 2024) can be used as good indicators of ecosystem health. The most common features that make insect ideal for bioindication are their ubiquitous occurrence, high species richness, basic sedentary nature, sensitivity to environmental pollutants, easy and inexpensive sampling and well-described taxonomy for families and genera (Resh et al., 2004; Bonada et al., 2006; Anderson et al., 2025). In line with that, aquatic insects have been widely used for measuring health within freshwater ecosystems in the past few decades (Hodkinson & Jackson, 2005; Bonada et al., 2006; Nicacio & Juen, 2015; Mensah et al., 2018; Nnoli et al., 2019). Orders like Ephemeroptera, Plecoptera, and Trichoptera (EPT) are highly responsive to changes in water quality and as such have been used in bioassessment frameworks globally (Bonada et al., 2006; Miguel et al., 2017; El Yaagoubi et al., 2025; Indraswari Suhri et al., 2025).

Recent evidence however suggests that the structure of aquatic insect communities is not solely shaped by pollution or land use, but also by intrinsic ecological factors such as seasonality and stream dynamics, such as stream size and physicochemical parameters (water quality) of the stream (Kasangaki et al., 2008; Ohler et al., 2023; Pedrosa Guimarães et al., 2025). For instance, a study conducted at the University of Ghana and such similar studies elsewhere exploited the sensitivity of Odonata to changes in the freshwater ecosystem in generating baseline information about the current state of aquatic systems (Acquah-Lamptey et al., 2013; Miguel et al., 2017). Odonata diversity associated with freshwater bodies has further been exploited as a tool for predicting the potential future changes in habitat quality (Acquah-Lamptey et al., 2013; Miguel et al., 2017; Manu et al., 2023; Datto-Liberato et al., 2024). While well-documented globally, seasonal multi-taxon assessments remain under-represented in West African sacred grove literature. Seasonal variation in tropical streams, particularly the shift between rainy and dry seasons, is known to cause profound changes in aquatic insect communities. Studies from Ghana and other tropical countries (e.g. Sánchez-Argüello et al., 2010; Kyerematen & Gordon, 2012; Agodzo et al., 2023) consistently show peaks in abundance and diversity during the dry season, often due to concentration of individuals in residual pools and more stable water conditions. Similarly, stream dynamics affects habitat heterogeneity, with smaller streams often experiencing greater environmental variability and stronger community shifts (Maloney et al., 2011; Brasil et al., 2020; Sankone et al., 2023).

Despite studies done in sacred groves in Ghana, there is no study in these streams that seeks to measure the effect of stream dynamics (e.g. stream size and water quality) on aquatic insect diversity and by extension, assess the stream health in the two sacred groves, Abiriw and Odumante, in Ghana. And so, this study could serve as a baseline study to kick start other studies that will lead to comprehensive studies on stream health within these two sacred to be used to inform conservation strategies in the same. In line with that this study investigates how seasonality and stream dynamics affected by anthropogenic activities interact to shape aquatic insect diversity within two sacred groves in Ghana as a measure of stream health within these sacred groves.

We hypothesized that seasonality and stream dynamics including localized disturbances, have a profound influence on aquatic insect diversity within Abiriw and Odumante sacred groves. This study contributes to the growing body of literature advocating for integrated ecological and cultural conservation of sacred groves using aquatic insect diversity as a bioindicator in measuring the health within aquatic ecosystems. Specifically, the study determined aquatic insect diversity in the two sacred groves, assessed the seasonal variation in insect communities and used the information to evaluate stream health within these sacred groves.

2. Materials and Methods

2.1. Study Area

The Abiriw sacred grove (5˚48'N, 0˚06'W) is in Abiriw and covers an area of 400 m^2 in the Akwapim North District of the Eastern Region of Ghana. The area falls within the Moist Semi-Deciduous Forest vegetation zone which is characterized by two rainfall peaks annually. This study site has rich floral diversity with climbers being most dominant. Most of the trees within this area grow up to 37 m high (Ayivie, 2005). Some of the dominant tree species within this sacred grove are *Antaris toxicaria*, *Trichilia monadalpha*, *Bahia pubescens*, *Viten gradifolia* and *Macaranga bateri* (Ayivie, 2005). Even though there was no active human activity within this stream, there were both biodegradable and nonbiodegradable wastes found at the base of the waterfall of the stream as they are carried from surrounding villages along the upper reaches of the stream to the sacred grove as indication of human activity. The adjacent lands to the Abiriw stream were semi natural lands from which the villagers collect firewood. The stream flow in Abiriw sacred grove is a first-order or low-order (1 to 2) stream in the Strahler stream order system.

The second stream for this study lies at the edge of the Odumante Sacred grove. The Odumante Sacred grove (5˚28'N, 0˚18'W) is located at Kitase-Aburi in the Akwapim South District of the Eastern Region of Ghana. This Sacred grove covers an area of 250 m^2. This study site also has the same environmental factors such as rainfall, temperature, rainy seasons and vegetation type as Abiriw. Both study sites experience bimodal rainfall (major rainy season occurs between April and June, while the minor one falls within September and October). The annual rainfall ranges from 1300 mm to 1800 mm. The stream flows through the village and passes close to the Sacred grove. There were some localized disturbances in this sacred grove like active firewood gathering and pollution of the stream by both biodegradable and non-biodegradable items coming from farming and other activities emanating from the inhabitants within the village who also depend on the stream as a source of water. There were cultivated oil palm and plantain trees adjacent to the streams at Odumante and these farms were highly intensive farms. The most dominant grass at the banks of the stream was Panicum maximus. The adjacent land-use at Abiriw was a riparian forest compared to that of Odumante which was predominantly farming. The stream flow in Odumante Sacred grove is a first-order or low-order (1 to 2) stream in the Strahler stream order system. These streams are classified as headwaters under the river continuum concept (Vannote et al., 1980; Doretto et al., 2020).

2.2. Study Area Characterization

2.2.1. Stream Size

The stream at Abiriw was deeper (30 - 50 cm in the rainy season and 15 - 45 cm in the dry season) compared to that of Odumante (10 - 30 cm in the rainy season and 2 - 10 cm in the dry season) (see **Table 2**).

2.2.2. Land Use within the Sacred Groves

The human impact within these sacred groves was assigned qualitative values as highly impacted, moderately impacted and less impacted. Areas of high intensive agriculture (use of pesticides and other chemicals) within these sacred groves, especially at Odumante were labelled as highly impacted, places of less intensive agriculture (no usage of agro-chemicals) were labelled as moderately impacted and semi natural forests where the inhabitants actively collected firewood were indicated as less impacted places. We randomly selected four sites, each within the two sacred groves based on the levels of impact as stated earlier. In our site selection we assigned two of the sites at Odumante as highly impacted and two other sites as moderately impacted areas and assigned all sites at Abririw as less impacted areas.

2.3. Data Collection

Data collection was conducted via sampling different microhabitats associated with the different impacts (especially at Odumante) associated with these streams.

The sampled microhabitats were under cobbles, rocks, decaying leaves, sand and dislodgable boulders. There were four sampling sites per sacred grove (making eight sampling sites in total for the study) with each sampling site being sampled four times per season, making a total of eight sampling times per each sampling site for the entire study. The sampling period covered a one calendar year covering both dry and rainy seasons on four sampling events per each season per study site. We used Dip net and Surber sampler to sample for benthic insects. The Dip net was used to sample in the riffle areas, pool and edges of the stream. A handful of slightly decomposed and brownish leaf packs were collected with the dip nets. The benthic insects within these streams were also sampled with a Surber Stream-bottom sampler as described by Hynes (1975). Each of the streams was sampled on four occasions (replications) at four different sampling sites making a total of sixteen sampling events per stream per season (thirty-two in total per stream per year), for each of the different sampling methods described above. In total, there were sixty-four sampling events conducted across the two sacred groves for the study. We pooled the samples from the Dip net and Surber sampler before data analysis. We used the insect community analysis under NMDS to deduce the possible pollution level of the two streams.

2.4. Water Quality Analysis

The Eureka Sub3 multiparameter water-quality multiprobe was used to measure the physico-chemical parameters of the streams such as dissolved oxygen (DO), temperature, optically dissolved oxygen, conductivity, pH, and turbidity. The Eureka Sub3 multiparameter multiprobe is a portable water quality measuring device that is inserted directly into the water body. The device was calibrated prior to use for each sampling event for the four sampling occasions to ensure uniformity in measurement. The Eureka Sub3 multiparameter multiprobe was placed directly into the streams at the randomly selected points where each of the four sampling events occurred to record the DO, temperature, optical DO, conductivity, pH, and turbidity. The Eureka Sub3 multiparameter multiprobe is a multiple sensor holding single probe which can be used to measure several water quality parameters like: Oxidation-Reduction Potential (ORP), Temperature, Salinity/Conductivity, pH, Turbidity, Depth and Dissolved Oxygen (DO) at a goal and at the same location.

The advantage of using Eureka Sub3 multiparameter multiprobe water-quality multiprobe in sampling is that it gives a higher accurate and a more realistic information about the environmental factors being studied compared to measuring each factor separately. Samples from each of the streams were also taken to the laboratory for confirmatory analysis on the water quality parameters. There were two readings per each sampling event at each sampling site (one on the multiprobe and the other from confirmatory lab analysis). The average of the two readings were recorded as one reading per site per sampling event. In total, there were sixty-four readings comprising of four readings per sampling event on four occasions per season within the two seasons and used for the analysis. The average of these readings are summarized on **Table 1**.

Table 1. Diversity indices of aquatic insects of sacred groves during study period.

Diversity Indices	Odumante	Abiriw
Shannon-Wiener Index (H')	3.41	3.04
Pielou's Index (E_H)	0.83	0.79
Jaccard's Index (C_J)	0.58	0.58

2.5. Sorting and Identification

The number of insects occurring in each family was counted and recorded. We identified all insects with the aid of identification keys developed by Scholtz & Holm (1985), Klotz et al., (2008), Samways (2008); Ball & Morris (2015), Gibb & Oseto (2019) to the lowest possible taxon.

2.6. Data Analysis

For each study area, Shannon-Wiener diversity index, $H' = -\sum_{i=1}^{S} pi \ln(pi)$ was estimated. Pielou index, $E_H = H/H_{\max}$ was estimated. Jaccard index of Similarity, $CJ = j/(a + b - j)$, was used to calculate the similarity between the two sacred groves. We also conducted a Non-Metric Multidimensional Scaling (NMDS) analysis on the total insect assemblage structure for the different levels of human impact within Abiriw (all less impacted) and Odumante (highly to less impacted) Sacred groves using the SPSS statistical package.

We further measured the Bray Curtis similarities of the various insect assemblages from the different sampling sites from Analysis of Similarity (ANOSIM) in SPSS. We used ANOSIM because it is a robust non-parametric statistic for testing for resemblances among sampled groups. We then used sample paired t-test to determine if diversity and abundance of insects were significantly different between the two sampled streams and seasons. Because the data was count data, with positive values, right skewed and heteroscedastic, it was subjected to log transformation to stabilize the variances and render it close to normal as possible. Test for normality was then conducted through Shapiro-Wilk test for normality.

The analysis was conducted at 5% significance level. Sampled paired t-test was more appropriate to analyze the transformed values of the investigated paired samples (two seasons and two streams) which meant testing whether the geometric mean ratio between the values for the different seasons or the different streams was equal to 1. The demerits associated with using paired t-test are that the number of rare taxa in data can drive non-normal differences and increase skewness and changes in community composition may not be expressed. This was corrected as much as possible through data transformation although there were just a few rare species in the dataset. The values assigned to these study sites for impact or human activities were used to construct insects assemblage community structures. Data analysis was conducted using SPSS software. There were two readings for the water quality analysis conducted.

3. Results

3.1. Comparison of Insect Abundance in the Two Sacred Groves

The study recorded 2767 individual aquatic insects belonging to 65 families from 11 orders for both sacred groves. A total of 1307 individuals, representing 47.2% of the total collection was realized at Odumante and the rest (1460 individuals) representing 52.8% of the total was collected at Abiriw. There were 19 unique insect families collected at Odumante, 5 unique families collected at Abiriw only with the two sacred groves sharing 41 common families. The most diverse insect family recorded was the Diptera while the most abundant was Hemiptera (about 40% of the entire collection).

There was no significant difference in the number of specimens sampled from the two sacred groves (t = 0.9, $p > 0.05$). The results also revealed that Odumante recorded a significantly higher insect families (60) compared to that of Abiriw (46) (t = 3.2, $p < 0.05$) (**Figure 1**). Furthermore, there were 30 families and 356 specimens collected in the rainy season which was significantly lower than that of dry season with 57 families and 964 individuals at Odumante (t = 3.6, $p < 0.05$). At Abiriw, the total number of families and individuals collected were 29 and 306 respectively, during the rainy season which was significantly lower than that of dry season with 40 families and 1154 specimens (t = 3.8, $p < 0.05$) (see **Figure 1**).

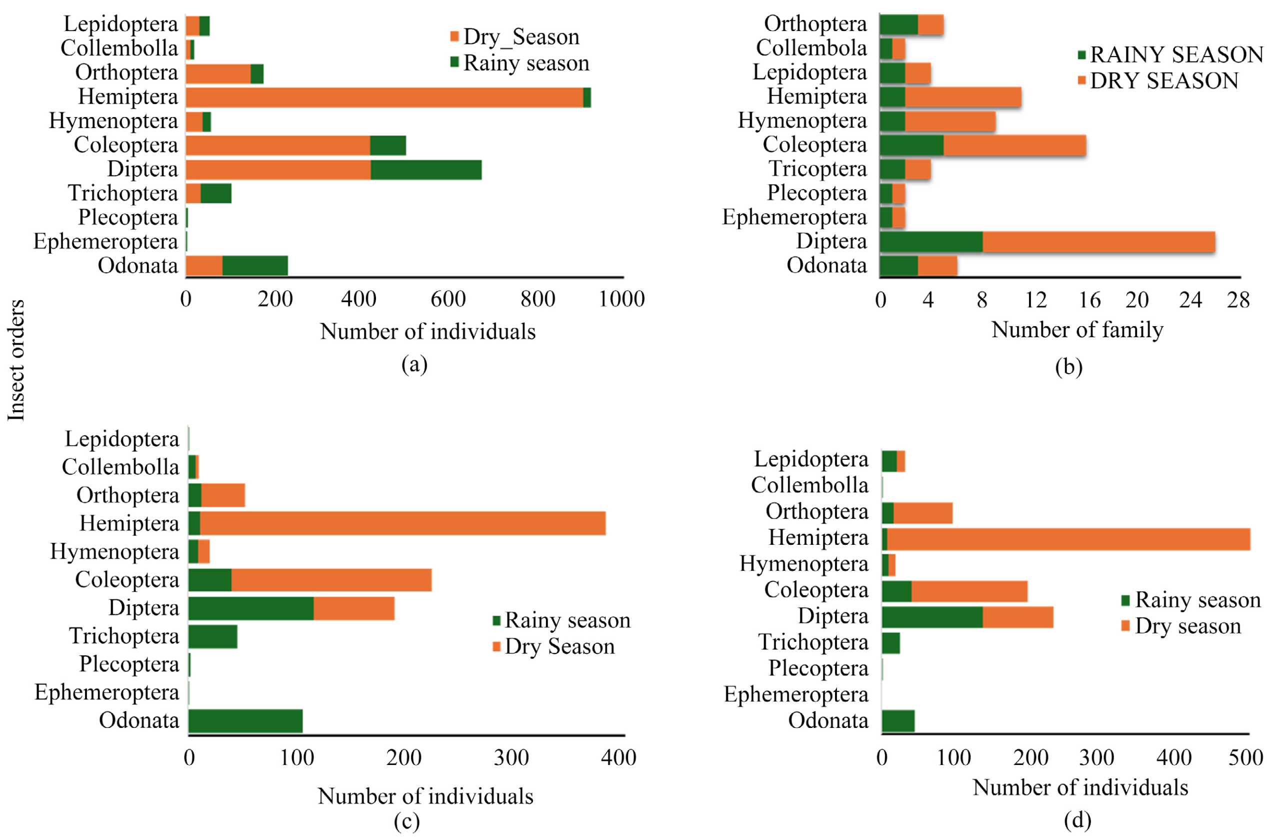

Figure 1. Graphs showing the total Insect abundance (a) and family richness (b) for the study and a comparison between the number of insects per season at the two study areas Odumante (c) and Abiriw (d) Sacred groves.

3.2. Abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT)

The orders Ephemeroptera, Plecoptera and Trichoptera (EPT) recorded the least number of insects during the study. The percentage EPT in family diversity and abundance were 12.3% and 4.1%, respectively. The *Baetis* genus was the only Ephemeroteran genus sampled from the two sacred groves. Also, *Neoperla* was the only genus of Plecoptera sampled for the study while *Hydropsychidae* Sub-families *Diplectroninae* and *Hydropsychinae* were the sampled genus for the study. The most common Odonata genera sampled in these sacred groves were *Brachythemis*, *Crocothemis*, *Orthetrum*, *Trithemis*, and *Aethriamanta*.

3.3. Comparison of Insect Diversity between the Two Streams

3.3.1. Diversity Indices

The value of the diversity indices recorded per study site shows that diversity at Odumante was slightly higher with a value of 3.41 compared to that of Abiriw, which is 3.04, and with a Jaccard similarity index of 0.58 for both sacred groves. (**Table 1**).

Both sacred groves recorded an even distribution of insect species and in both seasons (**Table 2**).

Table 2. Diversity indices of both sacred groves in the wet and dry seasons.

Diversity Index	Wet Season		Dry Season	
	Odumante	Abiriw	Odumante	Abiriw
Shannon-Wiener Index (H')	2.71	2.69	2.87	2.48
Pielou's Index (E_H)	0.80	0.80	0.71	0.67

3.3.2. T-Test Results for Insect Diversity

The results of a student t-test between insect diversity of aquatic insects between the two streams were not significantly different ($t = 0.87$, $p > 0.05$) despite marginal differences observed during the study, however, diversity was significantly higher in the dry season compared to the rainy season within the two sacred groves ($t = 3.3$, $p < 0.05$).

3.3.3. Water Quality Analysis within the Two Streams

The water quality analysis results show that stream temperature remained same within the two study streams. However, there was a general increase in temperature during the dry season compared to the rainy season in both streams. Although turbidity in these streams was slightly higher during the dry season compared to rainy season, the levels were relatively low in both streams, indicating relatively clear water conditions. The most observable difference between the two streams in the two study areas was the amount of dissolved oxygen (DO) levels recorded. The DO level remained relatively same in both seasons in Abiriw indicating a stable and healthy oxygen ecosystem in contrast to that of Odumante which showed a more pronounced reduction from the rainy season to the dry season with the average dissolved oxygen (DO) significantly reducing at Odumante during the dry season (t = 3.10, $p < 0.05$). The pH values and the amount of rock and sand substrates recorded were similar across both study areas and seasons. This shows stable chemical and habitat conditions for aquatic life in both streams. However, the riparian lands adjacent to the stream at Abiriw were surrounded by riparian forest while the stream at Odumante was surrounded by cultivated lands (See Table 3).

Table 3. Stream characteristics of the sacred groves within the study area.

Study Area	Abiriw		Odumante	
Season	Rainy	Dry	Rainy	Dry
Stream order	2	2	1	1
Stream depth (cm)	30 - 50	15 - 45	10 - 30	2 - 10
Stream width (cm)	135 - 567	125 - 367	108 - 189	108
Average Temperature (˚C)	23	24.5	24	25.2
Average Turbidity (NTU)	3	4	3.3	3.5
Average Dissolved oxygen (mg/l)	7.5	7	6.5	4.5
Dominant substrates	Rock/Sand	Rock/Sand	Rock/Sand	Rock/Sand
Adjacent land use	Riparian forest	Riparian forest	Cultivated	Cultivated
Average pH	6.7	6.8	6.8	6.9

3.4. Insect Community Analysis

Overall, the total insect abundance and diversity were significantly higher in the dry season compared to the rainy season (t = 4.1, $p < 0.05$). See Figure 1.

The results of the Non-Metric Multidimensional Scaling (NMDS) analysis showed that the dispersion of insect assemblages between study sites was not very wide apart between sites. This is because there were no significant variations in insect assemblage communities between the different sites within all sacred groves (R = 0.2, $p < 0.001$). This could be seen by the nature of spread of the community structure where all the different impacted sites converged or clustered along the same plains on the NMDS graphs for Abiriw (R = 0.02, $p < 0.01$), indicating similarities in community structures although that of Odumante showed a bigger spread and differences (R = 0.36, $p < 0.01$) in sites (NMDS, stress = 0.07) (Figure 2).

4. Discussion

Our findings show the importance of environmental gradients, especially seasonality and stream dynamics in shaping aquatic insect communities within sacred groves. Although both streams examined in this study were subjected to varying

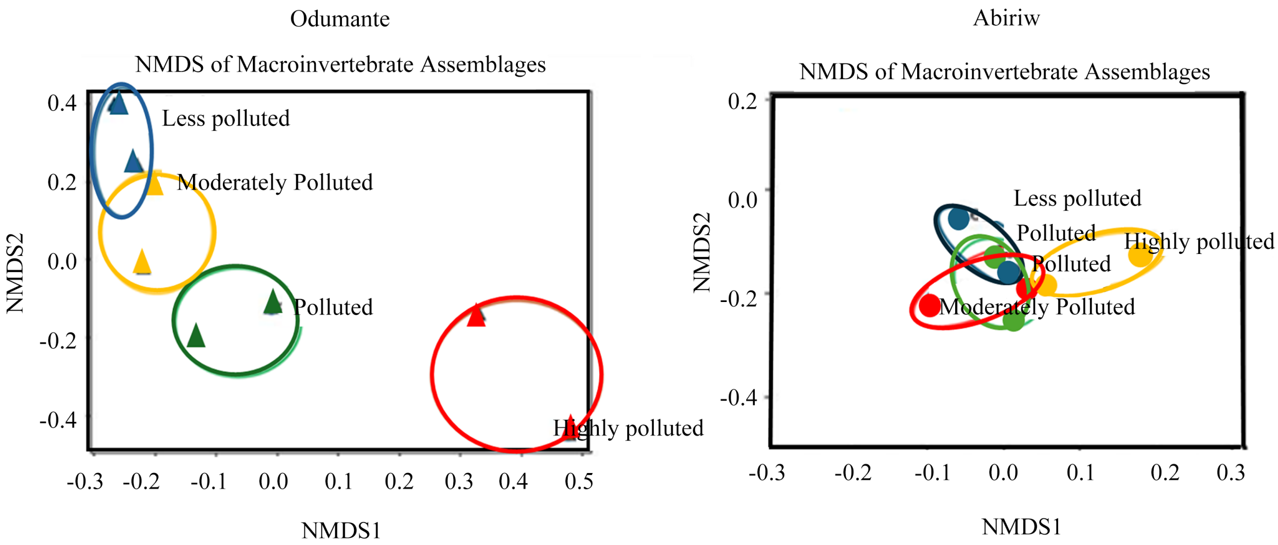

Figure 2. A Non-Metric Multidimensional Scaling (NMDS) ordination of the sampling sites (triangular and circular points) sampled within the study area, depicting insect assemblage structure within these sites. Sites categorized into same impacts fall within circles (NMDS, stress = 0.07).

degrees of impacts with Odumante more impacted compared to Abiriw, we inferred from the results that seasonal differences and stream dynamics were the main determining factors of aquatic invertebrate diversity within the sacred groves. Specifically, the high diversity recorded at Odumante shows that small streams with high to moderate anthropogenic impacts create an enabling environment for high insect diversity. This finding is consistent with published research (Stanford & Ward, 1983; Agra et al., 2021; Bouchon et al., 2025).

Seasonal shifts, especially the transition between rainy season and dry season, and periods of high temperature cause distinct alterations in aquatic insect assemblages, as reported elsewhere (Twining et al., 2019; Ergović et al., 2025; Ferreira et al., 2025; Kumari & Meena, 2026). These hydrological cycles drive predictable ecological rhythms, influencing oxygen levels, substrate composition, current velocity, and nutrient flux, which in turn affect the recruitment, emergence, and mortality of different insect taxa. Our observation of higher abundance and richness in the dry season aligns with studies showing that low-flow periods offer stable microhabitats conducive to insect aggregation, predator proliferation, and resource retention (Kasangaki et al., 2008; Basumatary, 2023).

Insect diversity may differ from one stream to another, probably in relation to differences in flow, oxygen concentration and other factors such as the accumulation of organic debris (Vannote et al., 1980; Birrell et al., 2020; Doretto et al., 2020; Findlay, 2021). Rainfall affects water levels and current strengths of aquatic insect habitats. For instance, net-spinning caddisflies and stoneflies suffer population reduction during heavy rains that could cause floods (Jennings et al., 2023; Phillips et al., 2023). The significantly higher insect abundance and diversity observed in the dry season support patterns observed in other tropical freshwater systems. Reduced flow during the dry season creates stable microhabitats that promote aggregation of aquatic insects, particularly collectors and predators. Also, the significantly lower DO levels in these streams may be an indication of oxygen stress affecting breeding sites in these streams during dry seasons although there is physical stability during same period (Simaika & Macadam, 2024; Enns et al., 2025; Jaulin, 2025). In contrast, the rainy season often brings heavy flow variability and turbidity, leading to displacement and reduced capture efficiency. These seasonal shifts influence beta diversity and community composition, a trend observed in similar studies elsewhere (Kasangaki et al., 2008; Sánchez-Argüello et al., 2010; Dong et al., 2021; Tan et al., 2021; Wang et al., 2023; Yang et al., 2025).

We could draw direct inferences from our results that the increase in temperature of the streams during dry season could be because of the loss of shade cover coupled with the high solar radiation in the study areas, as reported elsewhere (Johnson, 2004; Windoloski, 2024). Also, the little differences in the turbidity of the two sacred groves and in the different seasons may be an indication of minor anthropogenic disturbance or a reduction in water volumes especially in the dry season (Windoloski, 2024; Morilla et al., 2026). Furthermore, the decline in DO in the streams, especially in the dry season, is an indication of environmental stress which can adversely affect aquatic insects (Omokunle, 2024; Nguyen & Nguyen, 2025). Further, the pH values recorded for this study show stable chemical and habitat conditions for aquatic life in both streams (Omokunle, 2024; Nguyen & Nguyen, 2025). Also, the largely secondary forests at the riparian areas of the Abiriw stream could have ensured relatively better water quality in that stream by offering protection from erosion through better shading, and a better natural filtration system (Vero & Snell, 2025; Morilla et al., 2026). In contrast to Abiriw sacred grove, the Oduamante stream with highly intensive riparian agricultural activities can potentially contribute to increased water and nutrient runoff into the stream and thereby affecting the water quality as was observed in the reduced dissolved oxygen levels (Vero & Snell, 2025; Morilla et al., 2026).

The dominance of Hemiptera is an indicator of low levels of dissolved oxygen, moderate pollution, high nutrients and some amount of habitat disturbance in these streams especially within the Odumate sacred grove. This is because Hemiptera is known to tolerate oxygen stressed aquatic environment better than most EPT taxa. This is due to their characteristic carriage of air bubbles under water and constant respiration at the water surface. Also, several studies have shown that Hemiptera are usually tolerant in moderately polluted environment (Bakonyi et al., 2022; El Yaagoubi et al., 2024; Omokunle, 2024; Wani et al., 2024).

The results of insect diversity during the rainy season contrast with other studies that showed that aquatic insect abundance in the rainy season is relatively higher compared to dry season in streams and rivers (Santana et al., 2015; Yuen & Dudgeon, 2016; Pedrosa Guimarães et al., 2025) but in support with results of other studies (Ferreira et al., 2025; Zhang et al., 2025). This may be because most aquatic insects in the study area might have been displaced from their habitats due to increased flow rate and strong current that normally accompany rainfall in the study area as has been reported in earlier studies (Godoy et al., 2022; Cooke et al., 2022; Marques et al., 2025). Stream dynamics critically moderates insect community structure by mediating trade-offs between taxonomic richness and abundance (Vannote et al., 1980; Kasangaki et al., 2008; Lehti, 2025). The NMDS for the two study areas were clearly distinct, especially in Odumante, supporting this analysis as was the result in other studies elsewhere (Susanto et al., 2023; Zhao et al., 2023).

Furthermore, the smaller Odumante stream exhibited higher family richness despite lower abundance, contrasting sharply with the larger Abiriw stream where greater water volume supported higher abundance but reduced diversity. This result probably emanates from environmental filtering processes at Abiriw, with an extensive catchment area, amplified diffuse pollution and sedimentation, reducing microhabitat heterogeneity which favours pollution-tolerant generalists (Brasil et al., 2020; Cararo et al., 2026); whereas at Odumante, constrained dimensions maintained heterogeneous microhabitats that buffered localized disturbances, enabling specialized guild persistence (Sankone et al., 2023). Consequently, stream dynamics driven environmental heterogeneity increased directly might have shaped community outcomes explaining Odumante's relatively higher richness and Shannon diversity versus Abiriw's abundance-dominated assemblages. The river continuum concept which states that small streams such as the current study streams (1 - 3 Strahler stream order) are classified as headwaters which are heavily influenced by riparian vegetations by leaving allochthonous detritus and its shading effect (Vannote et al., 1980; Doretto et al., 2020) could also be used to explain this dynamic of high diversity at Odumante.

The riparian vegetation at Odumante sacred grove was found to have been highly impacted by human activities which have eventually affected the physico-chemical characteristics of the water specifically the reduction of DO but might have led to increased allochthonous detritus and thereby providing more opportunities and support for higher diversity. This nonetheless was at the expense of high abundance which may be due to low oxygen levels that will eventually impact breeding sites and increased inter and intra-specific competition, leading to a reduction in individual populations and other such impacts especially during the dry season and may be a sign of relatively some level of pollution which ends up affecting the most sensitive groups like the EPT groups. This demonstrates how intrinsic stream dynamics and seasonal influence community structure in freshwater ecosystems.

The major aquatic insect orders of Ephemeroptera, Plecoptera and Trichoptera which are very sensitive to pollutants were poorly represented at both sacred groves in both seasons. This may be an indication of the poor water quality of the streams, including oxygen stress as reported by (Akamagwuna et al., 2022; Tubić et al., 2024; Barasa et al., 2025). Also, the dominance of Diptera, Hemiptera and Coleoptera in both sacred groves, was a confirmation that these insect orders were the most described and largest in relations to other insect orders and they can inhabit almost every habitat in the aquatic environment in this case in the two sacred groves in agreement with other studies (Amusan & Akin-Aina, 2024; Liebhold et al., 2024; Akinmuleya & Adu, 2025).

Furthermore, this study showed that the persistence of Odonata especially Libellulidae on the aquatic landscape was heavily influenced by structures within the environment, mostly biosphere such as shade cover (Santos & Rodrigues, 2022; Worthen & Guevara-Mora, 2024; Kaltsas et al., 2025) and land use type (Rodriguez-Tapia et al., 2022; Calvão et al., 2023) and micro-climate (Marta et al., 2021; Guim Ursul et al., 2024). Acquah-Lamptey et al., (2013), Dijkstra & Clausnitzer (2014), and De Knijf & Van Grunsven (2015), point out that the degree of shadiness seems to be a principal cue for Odonates to select a forest habitat, but the forest type (species composition) as well as the age of the forest bordering running water sites is of little influence for the Odonata assemblages as long as the required cover is present. These conditions were normally depicted in Abiriw.

Studies have shown that EPT are very sensitive to pollution within aquatic ecosystems. For instance, studies have reported that they are very sensitive to sediment, heavy metals, eutrophication pesticides, etc. pollution (Adubor et al., 2025; Barasa et al., 2025) within the aquatic ecosystem. In general, these studies have shown that low diversity and abundance of EPT is an indication of pollution by high nutrient levels or reduced dissolved oxygen in the water body. The result of our study aligns with these findings and further confirmation that these streams might be polluted or have low dissolved oxygen levels. The low levels of EPT may also be due to chemical runoff from nearby agricultural fields, and the loss of forest cover and land-use change in the riparian environment especially at Odumante as reported in Adubor et al. (2025), Barasa et al., 2025 and El Yaagoubi et al., (2025). The low levels of EPT coupled with the dominance of Diptera in our studies are an indicator of declining macroinvertebrate diversity within these streams (Tubić et al., 2024; Barasa et al., 2025; Indraswari Suhri et al., 2025).

5. Conclusion

Overall, the study demonstrates that seasonal variation, spatial location, and stream dynamics specifically environmental stress like low oxygen in the stream especially during dry season and pollution from agricultural fields significantly influence aquatic insect diversity and abundance in the study areas especially at Odumante sacred grove. These findings underscore the ecological importance of preserving both sites, especially during the dry season when aquatic insect communities are more diverse and abundant. The study further showed that both Odumante and Abiriw sacred groves harbour a high number of aquatic insects. The traditional norms and taboos which were previously used to deter people from encroaching in the sacred groves appeared to have been relaxed, resulting in encroachment and pollution of the streams.

Odumante sacred grove had a higher insect diversity compared to Abiriw sacred grove even though Odumante was more fragmented. One major contributory factor to the low insect diversity at Odumante was human impact stemming from the surrounding villages along the upper reaches of the stream to the sacred grove. It is also concluded from this study that aquatic insects prefer impacted environment especially for streams in sacred groves classified under first-order or low-order (1 to 2) in the Strahler stream order system because according to the river continuum concept such streams are classified as headwaters and are heavily influenced by riparian vegetations by increasing shading and allochthonous detritus which further gives rise to more resources and increased heterogenous environment. The low abundance of EPT shows that the stream dynamics such as dissolve oxygen is low and pollution from runoff from agricultural fields is increasing. The EPT diversity in this study can therefore be used as surrogate organisms to conclude on the stream dynamics that the stream is moderately to severely impacted. We recommend that there should be reduced human activities to slow human impact in these streams in these sacred groves to improve aquatic insect biodiversity conservation.

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Availability of Data

Data will be made available on request.

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Authors' Contributions

Victor Parry: Conceptualization, Writing of manuscript, Data collection and analysis; Roger, Sigismund Andersen: Conceptualization, Data collection and analysis and identification of insect groups, Samuel Adu-Acheampong: Data processing, Writing of manuscript, Review & editing of manuscript, Mukundi Mukundamago: Writing of manuscript, Review & editing of manuscript, Emmanuel Robert Blankson: Writing of manuscript, Review & editing of manuscript, Rosina Kyerematen; Conceptualization, Writing review & editing of manuscript and Supervision.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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