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Research Article

Patterns of Odonata Assemblages in Lotic and Lentic Systems in the Ankasa Conservation Area, Ghana

Issah Seidu ,[1] Collins Ayine Nsor ,[2] Emmanuel Danquah ,[1] Paul Tehoda,[1] and Samuel K. Oppong[1]

[1]*Department of Wildlife and Range Management, Faculty of Renewable Natural Resources, Kwame University of Science and Technology, Kumasi, Ghana*
[2]*Department of Ecotourism and Forest Recreation, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

Correspondence should be addressed to Issah Seidu; antwiseidu88@gmail.com

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Our study examined Odonata assemblages distribution pattern and the predictive factors that accounted for this in the lotic and lentic water systems within the Ankasa Conservation Area (Ghana). A total of 23 sites with sampling protocol of 2 researchers per hour per sampling site were used to survey Odonata species over two seasons in the three water bodies (streams, rivers, and ponds). Broken stick model, individual-based rarefaction, and Renyi diversity ordering were employed to quantify community assemblages. Ordination technique was also used to determine the Odonata-environmental relationship. A total of 1403 individuals, belonging to 47 species (22 Zygoptera and 25 Anisoptera) in six families, were recorded. Species richness ($Hc = 3.414$, $p = 0.169$) and diversity ($Hc = 1.661$, $p = 0.44$) generally did not differ among the three water systems. However, from individual sites, ponds appeared mostly diverse (α-scale = 0.04, Renyi index (r) = 5.86 to $\alpha = 3.5$, r = 3.12), in spite of their lowest species abundance and richness. At the suborder level, ponds equally exhibited the highest Anisoptera species richness (9.90 ± SE 0.640) compared with Zygopterans (0.80± SE 0.291). Overall, Anisopterans ($K= 16.51$, $p= 0.00026$) and Zygopterans richness ($K= 16.39$, $p= 0.00023$) differed significantly among the three subsystems, while Odonata composition also differed significantly among the various water bodies (ANOSIM: global $R= 0.94$, $p<0.001$). Flow rate, water temperature, channel width, and turbidity were the key predictive factors that influence the structure of Odonata species assemblages. The results highlight the need to improve the functional status of the lentic and lotic systems, with the ultimate goal of conserving diverse Odonata fauna and other sympatric freshwater biodiversity.

1. Introduction

Freshwater habitats cover only 1% of the total earth surface and contain 10% of the earth biodiversity [1]. Their importance in sustaining biodiversity and human welfare is undeniable. Freshwater resources are the major sources of livelihood to Afrotropical rural and periurban folks [2]. They provide water supplies for human consumption, industrial utilization, and ecosystems support for fisheries and other aquatic biodiversity. However, wetlands are considered one of the most jeopardized ecosystems in the world [3]. Many wetlands worldwide are experiencing dramatic anthropic change, mostly for agricultural purpose [4]. Generally, these changes are associated with abiotic conditions which are normally not found in nature with cascading impacts on residence aquatic biota.

Freshwater habitats present two major differing water systems, lotic (running) and lentic (standing) waters, which differ in their environmental and spatiotemporal settings [5]. They are distinguished by physicochemical parameters of the water such as turbidity, organic matter, pH [6], dissolved oxygen [7], nutrients content [8], and flow regimes. These water systems together support heterogeneous environment which provide favorable conditions for both vertebrate and invertebrates communities including the amphibious Odonata taxa.

Odonata are denizen of freshwater environments such as rivers, lakes, ponds, wetlands, and, to some extent, phytotelmata and brackish water resources [9, 10]. They play significant role in freshwater ecosystem functioning, acting as both prey (fed by vertebrates and other large insects) and top predators (feeding on smaller insects in vertebrate free aquatic environment) [11]. Due to the reliability of both larval and adult Odonata to specific water conditions for survival [12], and their sensitivity to habitat disturbances, they are effectively used as indicators of water quality [13, 14]. Odonata, therefore, serve as an umbrella species in biodiversity conservation [15] and represent specific biotic wetland assemblages.

Sustainability of Afrotropical freshwater resources and their associated Odonata fauna requires knowledge of the contribution of different water bodies in particular ecosystems. These include knowledge about the species richness, diversity, and community structure in different water types, the variability of water systems across the landscape, and the net contribution of these water systems to the catchment biodiversity [16]. In general, such information is practically scanty worldwide but particularly in West Africa. This is the result of traditional Odonata research being geared towards specific water body. For example, especially in Ghana, most current research on Odonata assemblages has virtually focused on rivers (see [17–19]), and streams [19, 20] with little or no studies describing other natural and artificial lentic freshwater systems such as ponds, pools, and lakes, although these water bodies are well known to harbor diverse Odonata fauna and higher Odonata richness elsewhere [21].

In order to contribute to the initial understanding of the importance and the influence of different water types on the Ghanaian Odonata biodiversity, differences in Odonata assemblage structure of lotic and lentic systems were investigated. We hypothesized that adult Odonata composition will be significantly different among the water types due to their preference for different water bodies [12, 13]. Accordingly, we addressed two major questions: (1) are there any significant differences in Odonata abundance, richness, and community composition between the lotic (rivers and streams) and lentic systems (ponds)? and (2) are there significant differences in the abundance and richness of Anisopterans and Zygopterans among the water types? In order to address these questions, we compared adult Odonata assemblages occurring in 7 sites along two major rivers, 6 sites along three different streams, and 10 different ponds found in and outside the Ankasa Conservation Area.

2. Materials and Methods

2.1. Study Site. Ankasa Conservation Area (5° 17′ N and 2° 39′ W) is a twin Protected Area comprising Nini-Suhien National Park and the Ankasa Resource Reserve [22]. It is about 500 km^2 situated in the Western Region of Ghana, and the only area in the Wet Evergreen Forest [23]. Ankasa Conservation Area is designated as a Globally Significant Biodiversity Area (GSBA) and Important Bird Area (IBA) [23].

Ankasa Conservation Area presents an ideal ecosystem for this study, as it boasts of a significant number of complex and diverse freshwater systems including riverine, streams, and ponds. These wetlands and their associated forest environment support the most biological diversity of any kind in Ghana [22]. The climate of the area is characterized by a distinctive bimodal rainfall pattern occurring from April to July and September to November, with average annual rainfall of 1700 to 2000 mm [22].

2.2. Description of Sampled Water Types in the Study Area. Stream ($n = 7$)*:* We located all the sampling sites along the Asufia stream and a stream which is tributary to the Ankasa River (Figure 1). Three sites were laid along the Asufia stream, while four were located on the other stream. The sites were characterized by sandy substrate. The channel width ranged from 1 m to 1.9 m while the depth was from 0.1 m to 0.21 m. The water was flowing rapidly through dense canopy cover, with the trees and shrubs being the dominant bank vegetation.

River ($n = 6$)*:* All the sites were located along two major rivers (Ankasa and Bonwere River) in the Ankasa Conservation Area (Figure 1). Three sites were laid along each river, representing the total sampling sites. The Ankasa and Bonwere Rivers are characterized by rocky and sandy substrates. All sites were associated with rapids and highly oxygenated, cold water. The channel width was between 2 m and 15 m while the depth ranged from 0.3 m to 0.75 m. The sites were laid adjacent to intact secondary forest vegetation with the margins mainly composed of trees and shrubs, and small patches of various grasses (Poaceae). The water bodies also pass through dense canopy with low sun exposure except in sun flecks caused by tree falls.

Pond ($n = 10$)*:* All the 10 ponds were naturally permanent water bodies located in and outside the Ankasa Conservation Area. Four ponds were located in the forest reserve, while six were outside the forest adjacent to cultivated rubber, vegetables, and cocoa plantation which were mostly used for irrigation by the local communities (Figure 1). The bottoms were mainly composed of mud/clay and organic matter. Most of the ponds were surrounded by partial vegetation structure with high amount of sun penetration. The dominant plant families in the marginal zones were Cyperaceae and Poaceae. Ponds surfaces were associated with stands of emergent or floating vegetation which were utilized by the adult Odonata for perching.

2.3. Odonata Sampling Procedures. We sampled adult individuals of all Odonata species at 23 sites with a sampling protocol of 2 researchers per hour per sampling site, along the three different water types, Rivers, Streams, and Ponds in the Ankasa Conservation Area. We sampled simultaneously, collecting and noting the species occurring, and their abundances in each sampling site until no new species were encountered for approximately one hour for each visit. Sampling was done from January, 2017, to March, 2017, for the dry season while the wet season sampling took place from May, 2017, to July, 2017. We sampled all adult Odonata during the day between the hours of 9 am and 5 pm. We captured all adult Odonata individuals where possible, using a hand net. We identified each specimen to species level *in situ*, using Dijkstra, and Clausnitzer, [25] identifiction keys. Where identification of some species was not possible on the field, we photographed them and then used the African Dragonflies and Damselflies Online database (ADDO) [26], for subsequent idenitificantion.

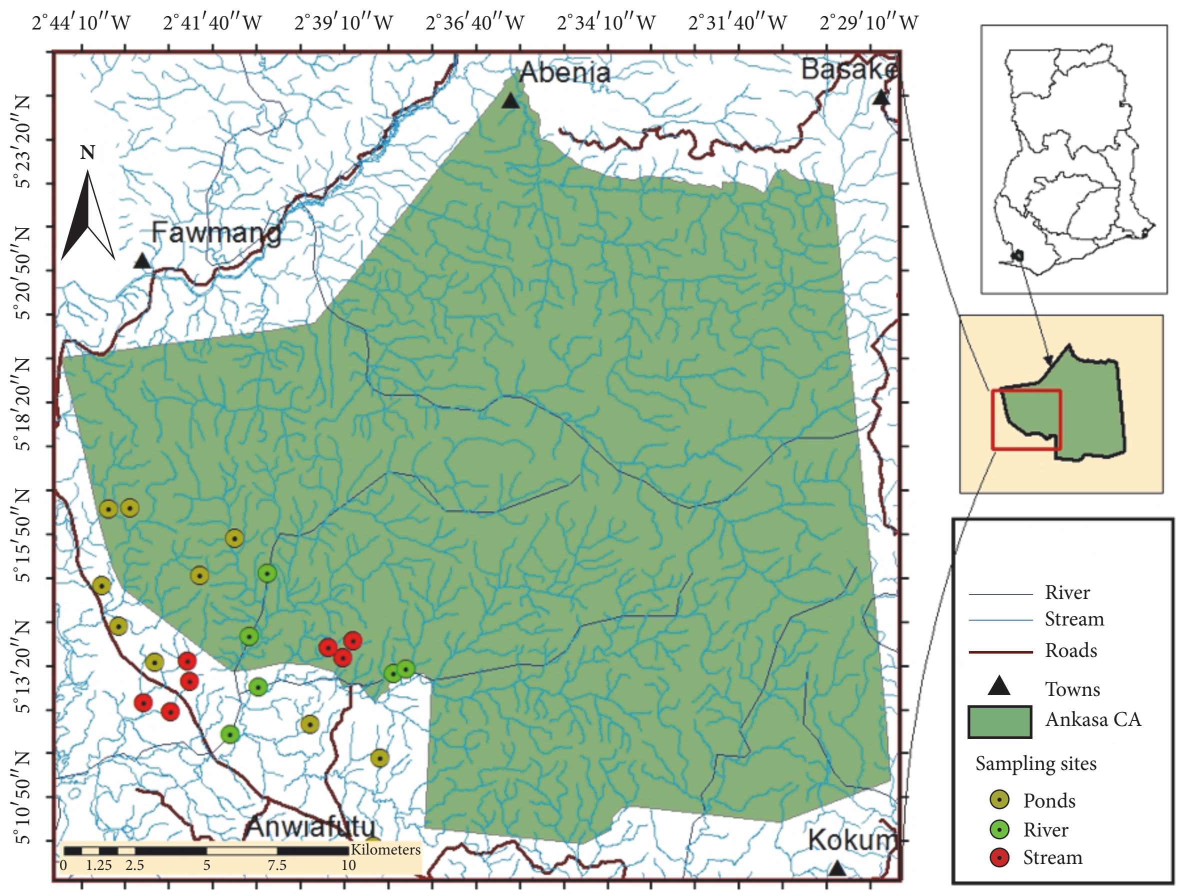

Figure 1: Map of the study area in and near the Ankasa Conservation Area, Western Region, with the situation of the 23 sampling sites of the three water types.

2.4. Measurement of Biophysical Variables. We recorded abiotic variables concurrently during the Odonate sampling, to assess their influence on Odonate community structure. Surface water temperature (°C), pH, dissolved oxygen (mg/L), turbidity, conductivity, altitudes, flow rate, channel width and depth, aquatic vegetation, substrate type, and bankside vegetation were all measured in all sampling sites following Seidu et al. [17] procedure.

2.5. Data Analysis. We first tested the normality of the abundance data set using Shapiro-Wilk test [27]. The abundance data was $\log(X+1)$ transformed prior to analysis. Bray-Curtis similarity indices and nonparametric multidimensional scaling (NMDS) were used to determine relationships of species composition among the sampling sites of the various water bodies. To test for the significant difference in species composition among the various water types, we employed one-way analysis of similarities with 999 permutations (ANOSIM; [28, 29]), with Bray-Curtis similarities as dependent and the three different water types (streams, rivers, and ponds) as independent factor. Similarity percentage analysis (SIMPER) routine in primer [30] was used to determine average dissimilarity between the water bodies and the various species contributing to the most similarity within each water body. All multivariate analyses were done using PRIMER 6.1.5 package [30].

2.5.1. Species Abundance Distribution (SAD) for Odonata Species. The application of species abundance distribution models in the study of species patterns has been widely used in community ecology by most scientists [31], as well as measuring the impact of disturbance on community structure [32]. In this study, Odonate abundance as a measure of diversity was quantified using rank abundance model [33]. In each site, we listed the number of Odonata species for all of the wet and dry seasons, say S_1, represented by one individual, and the number of species, say S_K, represented by K individuals, where K denotes the abundance of the most abundant species and $S_1 + \dots + S_K = S$ [34]. Accordingly, the sequence of relative frequencies $f_r = S_r/S$ ($r = 1 \dots K$) constitutes a frequency distribution for the number of individuals per species which is usually referred to as the *species-abundance curve* [34]. We then fitted the MacArthur broken stick model (BS) [35, 36] in the species abundance data, using the regression model approach [35] to determine the pattern of species communities in each of the freshwater systems. MacArthur [36] suggested that the niche space could be compared to a stick of length 1, where n − 1 points would randomly generate n segments of lengths proportional to the number of individuals of each species in the community, given as

$$n_i = \frac{N}{S} * \sum_{i=1}^{s} \frac{1}{n_i} \quad (1)$$

(see [36]) Where n_i represents the number of individuals of the species i; N represents the total number of individuals; and S represents the total number of species in the community.

This model approach was used in order to test against the null hypothesis (H_o) that species abundance distribution and richness did not differ in each of the three water systems. All the species in each of the sampling sites per water type were ranked from the most to the least abundant on the rank abundant curve [37]. Each species rank is plotted on the x-axis, and the abundance is plotted on the y-axis.

With the broken stick model, if a log scale is used for abundance, the species exactly fall along a straight line, according to the model equation $\log A = b_o + b_1 R$, where A is the species abundance, R is the respective rank, and b_0 and b_1 are optimized fitting parameters [32]. Analysis of covariance (ANCOVA) was applied to test for the significant difference of the slope of the SADs for the three water types, while Pearson's Chi-square test (χ^2) was applied to determine whether an observed distribution along the goodness of fit statistically differed in the BS model. Among the four notable SAD models (i.e., geometric, log series, log normal, and BS), the BS model is the only one that fundamentally describes the process of niche partitioning in a community where species exhibit continuous nonoverlapping niches [33].

Individual-based rarefaction techniques [38] were used to compare Odonate richness across the three water systems (*rarefaction curves*). Rarefaction curves are created by randomly resampling the pool of N samples multiple times and then plotting the average number of species found in each sample $(1, 2 \ldots N)$ [24]. Thus, rarefaction generates the expected number of species in a small collection of n individuals (or n samples) drawn at random from the large pool of N samples. The rarefaction curve f_n is defined as

$$f_n = E\left[X_n\right] = K - \binom{N}{n}^{-1} \sum_{i=1}^{k} \binom{N - Ni}{n} \quad (2)$$

(See [38]). Where X_n = the number of groups still present in the subsample of "n" less than K whenever at least one group is missing from this subsample, N = total number of items, K = total number of groups, Ni = total number of items in group i $(i = 1, \ldots k)$ [24, 39]. Thus, the linear model for the BS was fitted for each rarefied rank in order to build the 95% confidence limits for the slopes of all sampling sites.

Rarefaction methods, both sample based and individual based, allow for meaningful standardization and comparison of datasets [24]. We compared the estimated Odonata abundance and species richness, as well as the estimated abundance and number of species belonging to the respective suborders (Anisoptera and Zygoptera) for streams, rivers, and ponds.

Renyi [40] extended the concept of Shannon's entropy [41], by defining the entropy of order α ($\alpha \geq 0$, $\alpha \neq 1$) of a probability distribution $(p_1, p_2 \ldots p_s)$. Diversity profile values (H-alpha) were calculated from the frequencies of each component species (proportional abundances pi = abundance of species i/ total abundance) and a scale parameter (α) ranging from zero to infinity as

$$(H_\alpha) = \frac{\left(\log \sum_{i-1}^{s} pi^{\alpha}\right)}{(1 - \alpha)} \quad (3)$$

(See [42]). Odonate abundance, richness, and diversity ordering were performed using PAST version 3.06 software package [43], which provides robust algorithm as shown in Krebs et al. [44].

Due to the nonnormal nature of the data set, a Kruskal-Wallis test was applied to test for the differences in Odonata and suborders (Anisoptera and Zygoptera) abundance and richness among the 23 sites, using PAST version 3.12 [43]. Homogeneity of species variance among sample plots was evaluated, using Levene test [45], defined as $W = ((N-k)/(k-1))(\sum_{i=1}^{k} Ni(\acute{Z}i - \acute{Z}i)^2 / \sum_{i=1}^{k} \sum_{J=1}^{NI} (Zij - \acute{Z}i)^2)$ where Zij can have one of the following three definitions.

$Zij = \lceil Y_{IJ} - \acute{Y}_i \rceil$ *where* $\acute{Y}_i$ is mean of the ith subgroup; $\acute{Y}_i$ is the median of the ith subgroup, and, finally, $Zij = \lceil Y_{IJ} - \acute{Y}'i \rceil$, where $\acute{Y}'i$ is the 10% trimmed mean of the ith subgroup. $\acute{Z}i$ are the group means of the Zij and $\acute{Z}$ is the overall mean of the Zij.

2.6. Environmental Predictors of Odonata Distribution. We determined the relationships between the abiotic variables recorded and the species occurrence in the various water bodies using a canonical correspondence analysis (CCA, [45]). We used the Environmental Community Analysis (ECOM.exe) version 1.4 packages [46] to perform the CCA analysis. The significance of the first two axes generated in the analysis was validated through the Monte Carlo test (using 5000 iterations) [47]. Environmental variables utilized in the CCA were water temperature, dissolved oxygen, pH, turbidity, conductivity, flow rate, and channel width and depth. CCA is a direct method of ordination with the resulting outcome being the variability of the environmental data, as well as the variability of species data [48].

3. Results

3.1. General Pattern of Odonata Composition and Abundance Distribution across the Streams, Rivers, and Ponds. A total of 1403 adult Odonata specimens belonging to 47 species, and six families, were registered in streams, rivers, and ponds in the study area (Tables 1(a) and 1(b)). Of the 47 species recorded, 22 Zygoptera species belonging to four families (Calopterygidae, Chlorocyphidae, Coenagrionidae, and Platycnemididae) and 25 Anisopterans from two families (Aeshnidae and Libellulidae) were recorded (Tables 1(a) and 1(b)). Libellulidae was the dominant family with 13 species,

Table 1

(a) Checklist and abundance of Zygoptera (damselflies) species recorded in streams, rivers, and ponds in the Ankasa Conservation Area. Species that occurred exclusively in streams are represented by (∗), exclusively in rivers (#), and exclusively in ponds (!). Species shared between streams and rivers are represented by (∗#), between streams and ponds (∗!), and between rivers and ponds (#!)

Family	Zygopterans	Stream	River	Ponds	Total
Calopterygidae	*Phaon camerunensis* Sjöstedt, 1900∗	19	0	0	19
	Phaon iridipennis (Burmeister, 1839)∗#	6	16	0	22
	Sapho bicolor Selys, 1853∗	2	0	0	2
	Sapho ciliata (Fabricius, 1781)∗#	39	10	0	49
	Umma cincta (Hagen in Selys, 1853)∗	20	0	0	20
Chlorocyphidae	*Chlorocypha luminosa* (Karsch, 1893)∗#	33	19	0	52
	Chlorocypha radix Longfild, 1959∗#	16	8	0	24
	Chlorocypha selysi Karsch, 1899∗#	10	29	0	39
Coenagrionidae	*Agriocnemis exilis* Selys, 1872!	0	0	4	4
	Agriocnemis zerafica Le Roi, 1915!	0	0	13	13
	Ceriagrion corallinum Campion, 1914∗!	8	0	13	21
	Ceriagrion glabrum (Burmeister, 1839)!	0	0	26	26
	Ceriagrion rubellocerinum Fraser, 1947∗#	7	6	0	13
	Pseudagrion hamoni Fraser, 1955∗#	3	9	0	12
	Pseudagrion isidromorai Sart, 1967∗#	1	5	0	6
	Pseudagrion kersteni (Gerstäcker, 1869)∗	5	0	0	5
	Pseudagrion melanicterum Selys, 1876∗#	23	24	0	47
	Pseudagrion hamoni Fraser, 1955∗#	2	6	0	8
	Pseudagrion sjoestedti Förster, 1906#	0	2	0	2
Platycnemididae	*Mesocnemis singularis* Karsch, 1891#	0	26	0	26
	Elattoneura balli Kimmins, 1938∗#	38	16	0	54
	Elattoneura villiersi (Fraser,1948)∗#	34	3	0	37
	Total number of individuals	*266*	*179*	*56*	*501*
	Total number of species	*17*	*14*	*4*	

(b) Checklist and abundance of Anisoptera (dragonflies) species recorded in streams, rivers, and ponds in the Ankasa Conservation Area. Species that occurred exclusively in streams are represented by (∗), exclusively in river (#), and exclusively in pond (!). Species shared between streams and rivers are represented by (∗#), between streams and ponds (∗!), and between rivers and ponds (#!)

Family	Anisopterans	Stream	River	Ponds	Total
Aeshnidae	*Gynacantha bullata* Karsch, 1891∗	5	0	0	5
	Gynacantha cylindrata Karsch, 1891∗	1	0	0	1
Libellulidae	*Acisoma inflatum* Selys, 1882!	0	0	147	147
	Aethriamanta rezia Kirby, 1889!	0	0	33	33
	Chalcostephia flavifrons Kirby, 1889!	0	0	90	90
	Cyanothemis simpsoni Ris, 1915#	0	9	0	9
	Eleuthemis buettikoferi Ris, 1910#	0	9	0	9
	Neodythemis klingi (Karsch, 1890)∗	14	0	0	14
	Micromacromia zygoptera (Ris, 1909)∗	10	0	0	10
	Olpogastra lugubris (Karsch, 1895)#!	0	3	22	25
	Orthetrum austeni (Kirby, 1900)!	0	0	19	19
	Orthetrum julia Kirby, 1900∗!	7	0	13	20
	Orthetrum microstigma Ris, 1911!	0	0	6	6
	Orthetrum stemmale (Burmeister, 1839)∗!	6	0	7	13
	Orthetrum trinacria (Selys, 1841)!	0	0	6	6
	Palpopleura lucia (Drury, 1773)!	0	0	81	81
	Palpopleura portia (Drury,1773)!	0	0	71	71
	Pantala flavescens (Fabricius, 1798)!	0	0	5	5

(b) Continued.

Family	Anisopterans	Stream	River	Ponds	Total
	Rhyothemis notata (Fabricius, 1781)#!	0	3	100	103
	Rhyothemis semihyalina (Desjardins, 1832)!	0	0	38	38
	Trithemis aconita Lieftinck, 1969∗!	3	0	17	20
	Trithemis arteriosa (Burmeister, 1839)#!	0	9	86	95
	Trithemis bifida Pinhey, 1970#!	0	3	2	5
	Trithemis dichroa Karsch, 1893#!	0	3	43	46
	Urothemis edwardsii (Selys, 1849)#!	0	3	28	31
	Total number of individuals	*46*	*42*	*814*	*902*
	Total number of species	*7*	*8*	*19*	

Table 2: Results of the broken stick model for the abundance rank distribution of Odonata species, calculated for each of the three water types.

Sample	Intercept ±S.E.	Slope ±S.E.	*R*	Prob.
Streams	4.05 ± 1.75	0.55 ± 0.19	0.37	0.009[a]
Rivers	2.96 ± 1.19	0.26 ± 0.09	0.38	0.008[a]
Ponds	25.27 ± 5.41	-1.02 ± 0.43	-0.33	0.02[a]
Slope of *SAD*: $F_{2,\,138} = 6.22$, *p* (regr): 0.002				
(*ANCOVA interactions x species rank*)				
Monte-Carlo Permutation (*n* = 99999): p<0.0014				
Levene test for homogeneity of variance: p<0.0015				

followed by Coenagrionidae (*n* = 12) and Calopterygidae (*n* = 4), in rivers and ponds. Community assemblages across the three sites were ranked from the most abundant to the least abundant (Figure 2). Their abundance distribution fitted well in the broken stick distribution (BS) model and generally showed significant difference in the slopes of the three water systems ($F_{2,138} = 6.22$, *p*(regr) = 0.002, *ANCOVA interactions x species rank*) (Table 2, Figure 2). Further Monte Carlo test (*n* = 99999) revealed significant difference in SAD slopes (*p* = 0.001).

At the suborder level, streams had the greatest mean Zygopterans abundance (38.0± SE 4.29) (e.g., *E. balli* = 54, *C. luminosa* = 52, and *S. ciliata* = 49), compared with Anisopterans (6.57± SE 2.05). Conversely, the ponds exhibited the greatest Anisoptera abundance (81.40± SE 8.264) (e.g., *A. inflatum* = 147, *R. notata* = 103, and *T. arteriosa* = 95) while zygopterans were the least abundant (5.60± SE 1.96) (Table 3 and Figure 4). *Sapho bicolor* and *P. sjoestedti* represented by double individuals (doubleton) and *Gynacantha cylindrata*, single individual (singleton), *T. bifida* (*n* = 5) and *G. bullata* (*n* = 5), were the least dominant Zygopterans and Anisopterans, respectively, in the study area (Tables 1(a) and 1(b), Figure 2). There was a significant difference in the abundance of Zygopterans (*K* = 16.5, *p* = 0.00025) and Anisopterans (*K* = 16.28, p= 0.0003) among the three sites. Zygopteran abundance in ponds differed significantly in pairwise comparison with streams (p= 0.0007) and rivers (p= 0.0018) but showed no difference between rivers and streams (p= 0.174). Similarly, the Anisoptera abundance in ponds varied significantly in the pairwise comparison with streams (p= 0.0007) and rivers (p= 0.001) but no significant difference occurred between the rivers and streams (p = 0.825).

However, from three water types, we observed Odonate abundance in ponds to be the highest (*n* = 870), but their spatial distribution did not differ significantly along the slopes of the curve ($\chi^2 P = 25.07$, *P* = 0.24). Similar abundance and distribution trends were observed in streams (*n* = 312, $\chi^2 P = 7.12$, *P* = 0.99) and rivers (*n* = 221, $\chi^2 P = 4.11$, *P* = 0.99) (Table 2, Figure 2). Individuals per sample site, in ponds (87.00 ± SE 8.83), streams (44.6± SE 4.4), and rivers (36.8 ± SE 4.23), equally followed similar trend (*Hc* = 16.72, *P* = 0.0002, *Kruskal-Wallis test*) (Figure 3). Pairwise comparison test showed a significant difference between ponds and streams (*P* = 0.003) and ponds and rivers (*P* = 0.004). However, there was no significant difference in Odonata abundance between rivers and streams (*P* > 0.05). Comparison of the SADs for the three water systems helps to distinguish a specific habitat quality, in relation to its influence on Odonate abundance, while the shape of the rank abundance curve generally revealed differences in Odonate dominance and evenness from individual habitats, and which reflects in their relative tolerance to disturbances.

3.2. Comparison between Zygopterans and Anisopterans Species Richness among the Water Types. Ponds exhibited the highest Anisoptera species richness (9.90± SE 0.640) but the lowest number of Zygopterans (0.80± SE 0.291) (Figure 5). The streams had the highest Zygopteran richness (7.57± SE 0.481) but exhibited almost similar Anisoptera species richness (2.0± SE 0.577) with rivers (1.8± SE 1.014) (Figure 5). Kruskal-Wallis test showed a significant difference in Zygoptera species richness (*K*= 16.39, *p*= 0.0002) and Anisoptera richness (*K*= 16.51, *p*= 0.0003) among the water types. Pairwise comparison test showed a significant

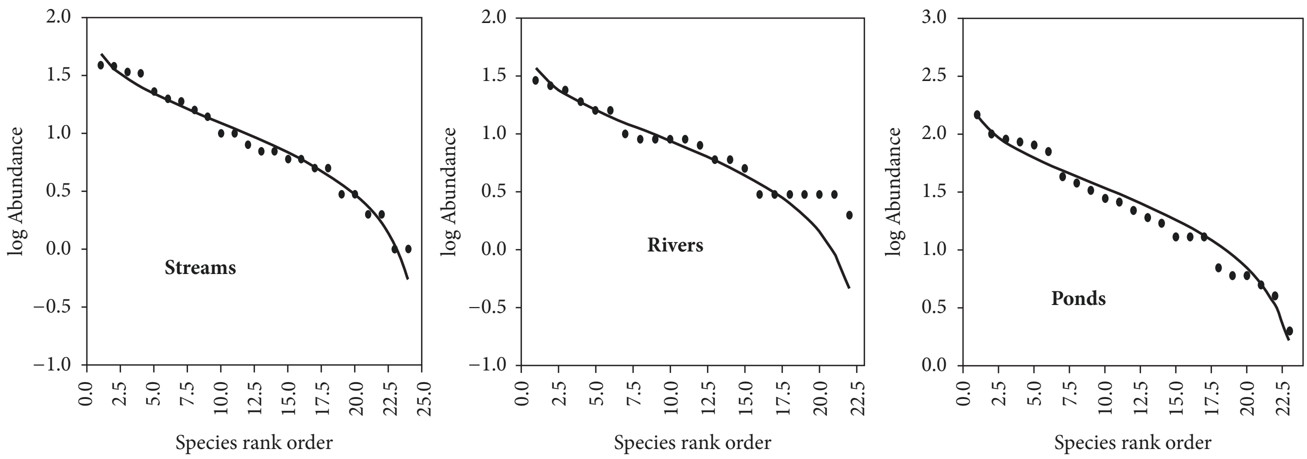

Figure 2: Broken stick model for Odonata rank abundance distribution across the three water types in Ankasa Conservation Area. Abundance is based on cumulative values per species test sites. Notice that SADs are ordered in decreasing magnitude and plotted against the corresponding rank order.

Table 3: Canonical coefficients and the correlations with the first three axes of the environmental variables of the canonical correspondence analysis (CCA) for the three water types. Interset correlations were significant (p <0.05∗) for the three axes.

Correlation	Axis I	Axis II	Axis III
Turbidity	0.573∗	0.098	-0.156
Flow rate	0.549∗	0.081	0.114
Width	-0.706∗	-0.076	0.164
Depth	-0.260	-0.009	0.114
Conductivity	-0.421	0.054	-0.092
Do	0.203	0.079	0.145
Temperature	-0.748∗	-0.060	0.070
pH	0.154	-0.137	0.091
Canonical Eigen value	0.651	0.445	0.185
% variance explained	22.3	15.29	6.338
Cumulative % variance	22.3	37.6	43.96
Pearson correlation species/environment scores	0.979	0.708	0.781
Kendal rank correlation of species/environment scores	0.684	0.463	0.597

difference in Zygopteran richness between ponds and streams (p= 0.0006), and between rivers and ponds (p= 0.001), but no difference existed between streams and rivers (p= 0.56). Similarly, Anisoptera species richness in ponds differed significantly with streams (p= 0.00071) and rivers (p= 0.001), but there was no significant difference between streams and rivers (p= 0.82).

3.3. Trends in Odonata Richness and Diversity in the Three Water Systems. Interpolating the SADs across the streams, rivers, and ponds, with sample-based rarefaction, revealed that Odonate richness among the three systems was not significantly different (Hc = 3.414, p = 0.169, *Kruskal-Wallis test*) (Figure 6) and did not follow similar pattern observed in individual abundance. Chao-1 estimated species richness for the three sites showed streams to be the highest (n = 24.33), followed by ponds (n = 23) and rivers (n = 22). However, mean species richness per sample site was rather the highest in ponds (10.7 ± SE 0.56), while rivers had the least number (8.7 ± SE 0.92) (Figure 7). Homogeneity of species variance among the three water systems differed significantly (p<0.0002, *Levene test*) (Table 2).

Observed trends in Odonate structural assemblages (i.e., abundance, evenness, and richness) reflected in the Renyi diversity ordering (from higher to lower indices; along an increasing alpha scale values) (Figure 8). Overall, Odonate diversity did not differ significantly (Hc = 1.661, p = 0.44) across the three water types. However, from individual sites, we observed that Odonates from ponds appeared mostly diverse (α-scale = 0.04, Renyi index (r) = 5.86 to α = 3.5, r = 3.12), in spite of their lowest species abundance and richness (Figure 5). This was linked to the shallower SAD curve observed in Figure 2. Thus, species abundance distributions, with shallower curve, tended to be highest in diversity, while

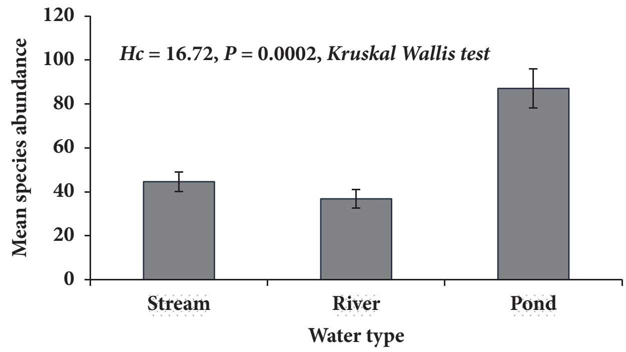

Figure 3: Mean Odonata species abundance among the various water types.

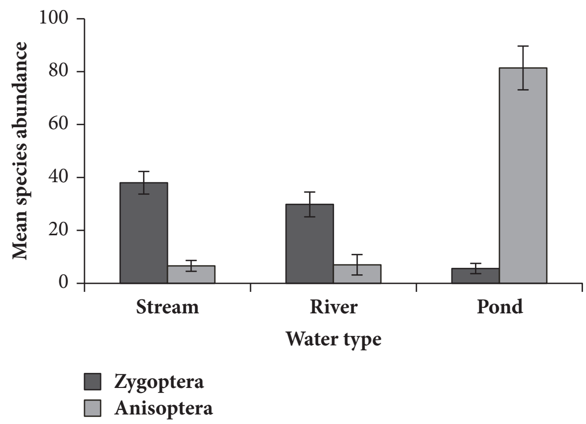

Figure 4: Comparison of mean species abundance of Zygopterans and Anisopterans among the water types.

those with steeper curves were less diverse (Figure 6). Species from the riverine systems were the least diverse and ranged from $\alpha = 0.04$, $r = 5.83$ to $\alpha = 3.5$, $r = 3.08$ and were found at the bottom of the Renyi index curve (Figure 6). Odonate diversity in streams ($\alpha = 0.04$, $r = 5.84$ to $\alpha = 3.5$, $r = 3.07$) could barely be distinguished from those in the riverine systems, as their curves were spatially similar.

3.4. Similarity in Odonata Composition among Streams, Rivers, and Ponds. The Nonparametric Hierarchical Cluster analysis of species occurrence showed five different clusters (P8, P5, P1, P2, P3, P7, P9, P6, P4, and P10), (R5 and R6), (S4, R2, R1, and S6), (S1 and S2), and (S3, S5, R4, R3, and R7) at 40% similarity index (Figure 9). The species occurrence in ponds showed a strong significant separation from streams and rivers communities. However, the sampling sites of stream and river were ecologically less distinct and showed a higher species overlap with each other (Figure 9).

The Similarity Percentage (SIMPER) analysis revealed a similar trend, suggesting that streams and ponds (98.72%) and rivers and ponds (93.87%) exhibited greatest average dissimilarity in species composition to one another. Streams and rivers (67.31%) were relatively similar to each other in Odonata species composition. SIMPER also revealed an average similarity within the streams (49%), rivers (43%), and ponds (63%). Species contributing most to similarity in the stream community were *E. balli* (23%), *S. ciliata* (17%), and *C. luminosa* (16%). *Cholorocypha selysi* (26%), *P. melanicterum* (19%), and *M. singularis* (13%) contributed most to similarity in river community, whereas *T. arteriosa* (16%), *A. inflatum* (15%), and *P. lucia* (14%) were greatest contributing species in pond communities.

The species composition of Odonata differed significantly between the various water bodies (ANOSIM: global R= 0.94, $p<0.001$). Pairwise comparison test showed a significant difference in species composition between rivers and ponds (R= 0.98, p= 0.002). Also, streams revealed weak significant difference with rivers (R= 0.52, p= 0.02) but higher significant difference with ponds (R= 0.99, p= 0.001).

3.5. Environmental Predictors of Odonata Structural Distribution and Diversity. Canonical correspondence analysis (CCA) showed the overall relationships between species distribution and the biophysical variables recorded (Table 3, Figure 10). Among the eight biophysical variables initially included in the analysis, only four biophysical variables, namely, flow rate, water temperature, channel width, and turbidity, were shown to strongly influence the structure of species assemblages. Species assemblages along the first axis correlated significantly with water temperature (r = -0.74, p<0.05), channel width (r = -0.70), flow rate (r = 0.54, p<0.05), and turbidity (r = 0.57, p<0.05) (Table 3, Figure 10). CCA axes 1 and 2 jointly explained 37.6% of the total variation in species structural distribution and diversity among sites.

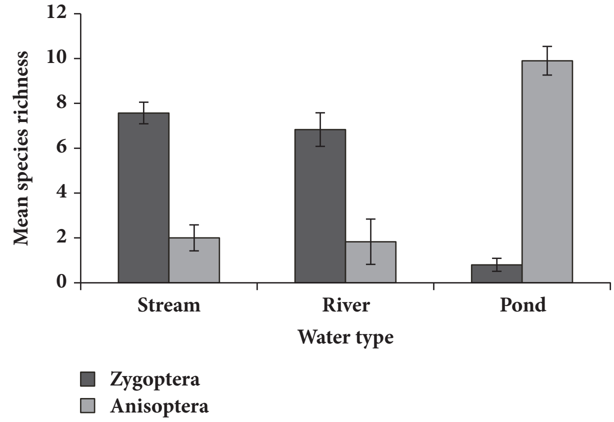

Figure 5: Comparison of mean species richness of the Zygopterans and Anisopterans among the water types.

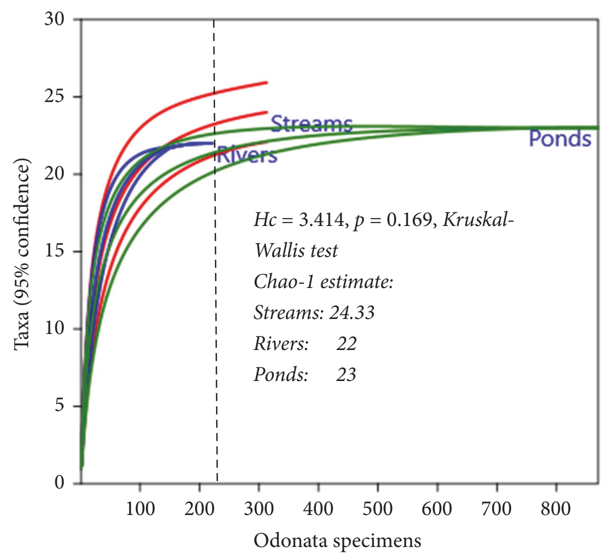

Figure 6: Standardized comparison of Odonata richness for individual-based rarefaction curves. The data represent summary counts of Odonates that were recorded from the three water types in Ankasa Conservation Area. The red, blue, and green lines are the rarefaction curves, calculated from (2) [24], with a 95% confidence interval. The dotted vertical lines illustrate a species richness comparison standardized to 24 species and 221 individuals, which was the observed Odonate abundance in the smallest (rivers) of the three water types data set.

There was no evident of significant relationship along axes two and three. Following the CCA components, two main groups of species were distinguished. The first one (e.g., *Urothemis edwardsii, Palpopluera lucia, Palpopluera portia*, *Rhyothemis notate,* and *Acisoma inflatum*) was representative of the pond community. This group was mainly composed of the generalist heliophilic species, which mostly avoid flowing water (Figure 10). The second group was represented by the combined effect of streams and rivers (e.g., *Chlorocypha selysi, C. luminosa*, *Sapho ciliata*, and *Phaon camerunensis*). The group was mainly composed of Zygopterans which were favoured by fast flowing water. The only Anisopteran species found in group two was the *Micromacromia zygoptera*, which was also influenced by fast flowing water body.

4. Discussion

Several studies have shown that majority of Odonata families and species from anisopterans and zygopterans are either associated with lentic (Coenagrionidae and Libellulidae) or lotic systems (e.g., Calopterygidae, Coenagrionidae, and Libellulidae) [19, 49]. In this study, we observed similar pattern of association, where Calopterygidae, Chlorocyphidae, Platycnemididae, and Aeshnidae were found in lotic systems, while Libellulidae and Coenagrionidae were found in both lentic and lotic environments but showed strong affinity to lentic systems (ponds). The presence of Calopterygidae and Chlorocyphidae exclusively in the lotic systems may be explained by their strong affinity to canopied cover and fast flowing water bodies, which were characteristics of streams and rivers in the Ankasa Conservation Area. These features are well known to represent the preferred habitat type of most species within the Calopterygidae and Chlorocyphidae families [19, 49].

Species from the Aeshnidae family are crepuscular in nature and are well noted to shun the sun during the day but to come to light at night [26]. This is confirmed in our study where most species from the family Aeshnidae showed

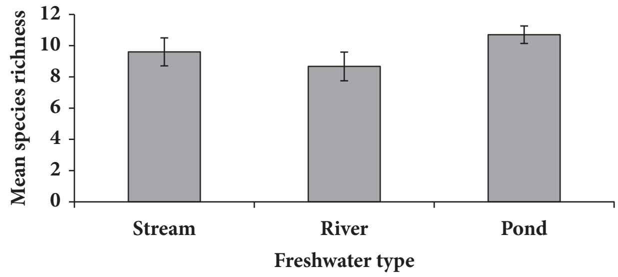

Figure 7: Mean Odonata species richness among the various water types.

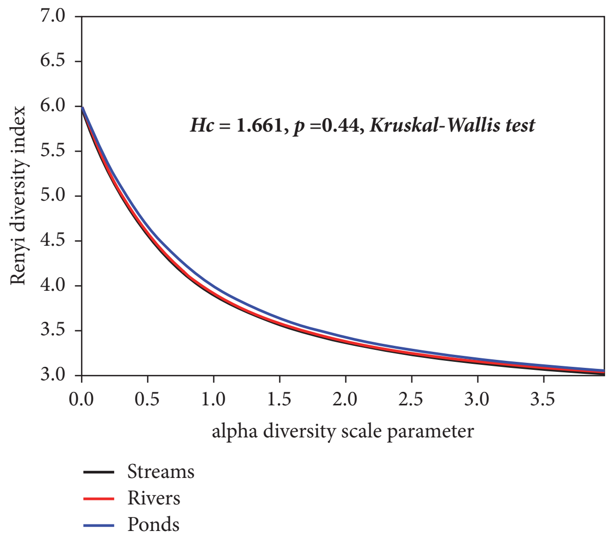

Figure 8: Renyi diversity ordering that compares Odonata evenness and richness of 1403 individuals, across the three water types. Note that the shape of a habitat profile is an indication of its evenness.

a strong association with dense vegetation cover along the stream banks and utilized the vegetation for perching and roosting during the day. Also, a large section of Ankasa and Bonwere rivers that were characterized by rocky substrates appeared to support the perching, roosting, and copulating of some zygopterans like *Mesocnemis singularis* and this probably explains their high abundance. Dijkstra and Clausnitzer [25] and Dijkstra [26] reported that *Mesocnemis singularis* typically prefersunny rocky substrate, as ecological niches for perching, roosting, and copulating.

Several pond-associated species, such as the Ceriagrions, *Agriocnemis species, A. inflatum*, *C. flavifrons, O. lugubris, T. arteriosa,* and *P. lucia,* have been classified as Heliophilics or stagnant water tolerance species [17, 25, 26], which concur with this current study. Though small in catchment area, ponds supported several distinct species that were never recorded in other water types and contributed to the greatest Odonata assemblages (abundance and richness) compared to the lotic environments. Globally, these pond-associated species from the families Libellulidae and Coenagrionidae are composed of several ubiquitous species that dominate in unshaded habitats with stagnant water bodies [50].

Higher Odonata species richness and diversity in lentic systems relative to lotic environments have been reported in several studies (e.g., [51, 52]) and have been linked to higher colonization rate characterized by lentic systems [51, 52]. Such is the case observed among lakes in the Brazilian Atlantic Forest, where higher Anisoptera species richness was recorded [53]. But our findings rather revealed ponds to support the least abundance and species richness of damselflies relative to dragonflies which are composed of only species from the Libellulidae family. This was probably due to the scale of environmental disturbance and the geographical location of the ponds. For instance, in the tropics where this study was conducted, extreme temperatures and erratic rainfall in recent times could have wider ramifications on surface water temperatures of the ponds, which were beyond the thermal threshold tolerance of the species.

Lentic environments tend to be geologically less predictable through time [54], and this phenomenon tended to exert pressure on species to adapt faster in order to be able to disperse and then persist [5]. Ponds are important refuge for Odonata conservation because they are relatively isolated and show greater heterogeneity in species assemblages [55, 56], owing to stochastic effects acting on the colonization process [57]. Variability in pond isolation has the tendency to attract good disperser Odonata such as species within

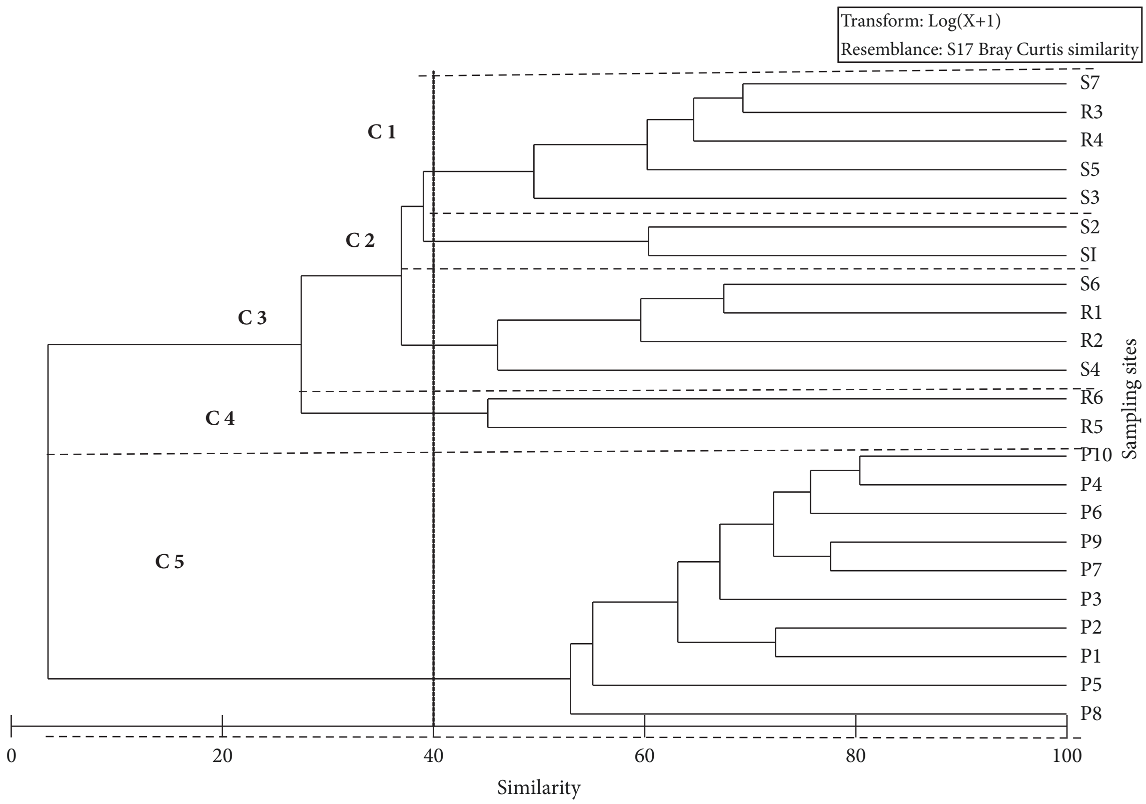

FIGURE 9: Group average dendrogram of similarity of species composition for Odonata among the water types in the Ankasa conservation area.

the Libellulidae family which are flyers and heliothermic in nature [58].

Streams and rivers (i.e., typical lotic systems) in contrast, which were characterized with dense vegetation cover, supported the greatest abundance and species richness of zygopterans relative to anisopterans, as a result of their association with dense vegetation cover along the fringes of the systems, which provide conducive environment for resting, mating, and breeding. The suit of different microhabitat complexity along these lotic systems continuum may have contributed in species heterogeneity, largely dominated by the Zygopteran functional group. Streams and rivers worldwide have been reported to provide heterogeneous and favourable environmental conditions for diverse Zygoptera species, [55, 58, 59] for their numerous life activities including nocturnal roosting, oviposition, emergence, reproduction, and perching substrate to thermoregulate [55, 58]. Streams and rivers also share similar characteristics linked to their geomorphology and flow regimes [16]. These systems have extensive catchments as compared to other lentic systems and this dovetailed with similar geomorphological features, flow rate, and uniform vegetation cover of the waters will ensure less variability in their physicochemical variables [16]. This may result in similar colonization and dispersion rate, which may lead to higher overlap in their Odonata fauna as evident in this study.

It was not uncommon that none of the species occurred in all the three water types which reinforced our hypothesis. This, however, indicates that Odonata fauna in the Ankasa Conservation Area are restricted to specific water types, with each water body supporting some specific species or assemblages not found in other water types. This finding supports the importance of maintaining a diversified body of water, both lentic and lotic, natural or artificial, in ecosystem management to achieve the ultimate goal of conserving diverse Odonata fauna and other sympatric freshwater biodiversity.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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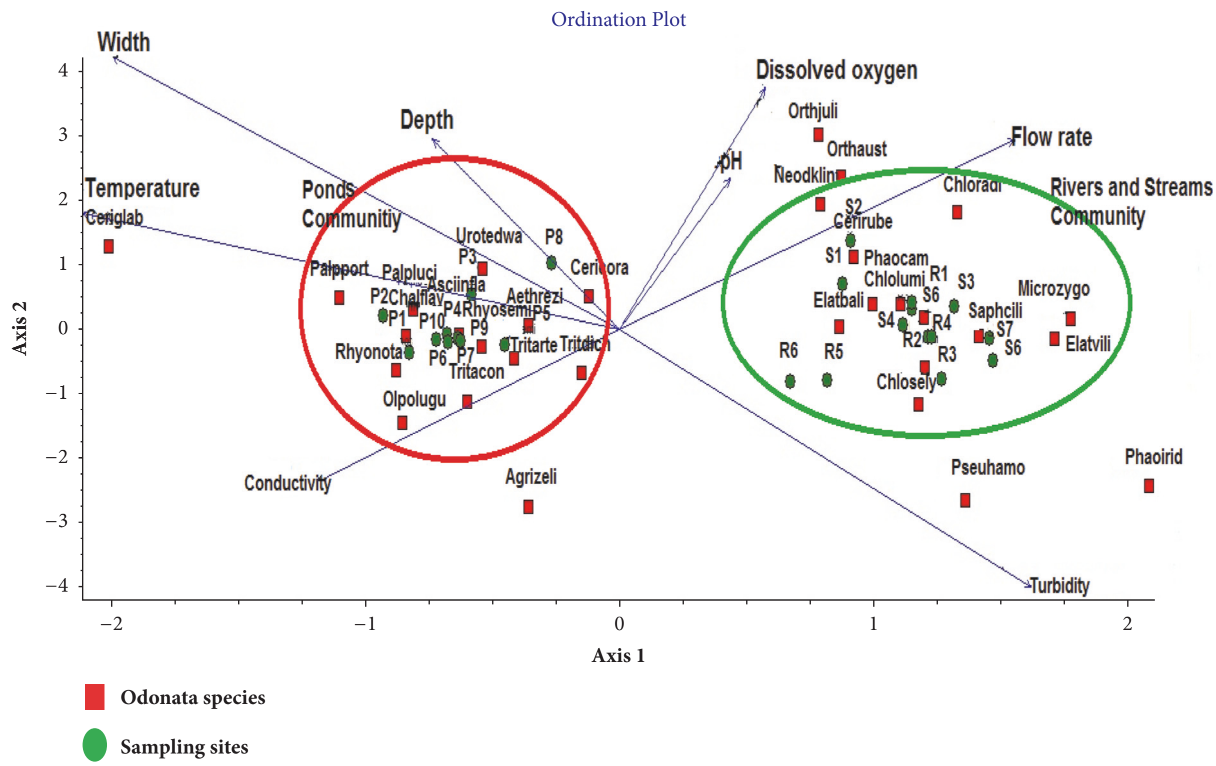

Figure 10: Canonical correspondence analysis (CCA) ordination diagram, showing the relationship between environmental variables and Odonata species across the three water types in the Ankasa Conservation Area in Ghana. Species names are abbreviated with the first four letters of the genus and the first four letters of the species following Seidu et al., [17]. The blue arrows represent each of the environmental variables plotted pointing in the direction of maximum change of explanatory variables across the water types. Red and green ovals represent specialists' species in lentic (ponds) and lotic (rivers and streams), respectively.

the successful completion of the study. Finally, the authors are grateful to David Amaning Kwarteng, Daniel Acquah-Lamptey, Sulemana Bawa, and Emmanuel Amoah, for their special role in field data gathering.

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