Journal of Biodiversity and Conservation Research

ISSN: xxxx-xxxx Vol. 1 (1), pp. 084-092, December, 2013. © Global Science Research Journals

Full Length Research Paper

Using odonates as markers of the environmental health of water and its land related ecotone

D. Acquah - Lamptey*, R. Kyerematen and E. O. Owusu

Department of Animal Biology and Conservation Science, P. O. Box LG67, University Of Ghana, Legon, Ghana.

Accepted 12 September, 2013

The study of Odonata communities along wetlands requires the basic understanding of the abundance, distribution and number of species present. As habitat conditions change, they also exhibit changes in their diversity and distribution. Odonata assemblages were surveyed along the Densu River at Atewa Range Forest Reserve (ARFR) and Nsawam in the Eastern Region of Ghana and Weija in the Greater Accra Region of Ghana. Of the 177 species recorded for Ghana, 66 species (43 dragonfly and 23 damselfly species) were sampled along the Densu River. These belonged to eight families of which the Libellulidae dominated. The distribution of species was significantly different between the sites with the most diverse area being ARFR with 47 species. The various environmental variables along the river were recorded and their effects discussed.

Key words: Atewa range forest reserve, environmental quality, diversity indices, Densu River, dragonfly, damselfly, conservation.

INTRODUCTION

Dragonflies and Damselflies are insects belonging to the order Odonata. There are a total of 177 Odonata species that have been recorded so far in Ghana (Dijkstra, 2007a) with 72 species recorded from the streams and rivers that have their headwaters within the Atewa Range Forest Reserve (and associated standing water habitats), although only 31 (43%) were found strictly within the reserve's boundaries (Dijkstra, 2007a).

The presence of dragonflies is an important indicator for ecological balance. By way of reproduction, these insects lay their eggs in or near only freshwater (Corbet, 1999) and thus, their high abundance in an area is a good indication of the quality of freshwater. Odonata (dragonflies and damselflies) are used as bioindicators for wetland quality in Europe, Japan, the USA, Australia (Clausnitzer and Jodicke, 2004) and in South Africa (Clark and Samways, 1996; Stewart and Samways, 1998). The greatest numbers of species are found at sites that offer a wide variety of microhabitats, though dragonflies tend to be much more sensitive to pollution than damselflies (Ameilia et al., 2006). Many ecological factors affect the distribution of the nymphs. The acidity of water, the amount and type of aquatic vegetation, the temperature, and whether the water is stationary or flowing all affect the distribution of odonate nymphs. Some species can tolerate a wide range of conditions whiles others are very sensitive to their environment (Chovanec and Waringer, 2001; Schindler et al., 2003; Chovanec et al., 2004; Ameilia et al., 2006; Smith et al., 2006). Clark and Samways (1996), and Stewart and Samways (1998) who studied adult dragonfly site selection, habitat preferences, disturbance response, and bioindicator potential across a variety of wetland and aquatic systems in South Africa concluded that, adult dragonflies prefer habitats with heterogeneous vegetation and are reliable indicators of human perturbation. They based pond conservation on species-habitat associations because of predictable species turnover along gradients of vegetation structure, light regime, and hydrology (Steytler and Samways, 1995; Osborn and Samways.

*Corresponding author. E-mail: dalquino@gmail.com or dacquahlamptey@gmail.com

1996).

The use of odonates as indicators offers several advantages: they are widespread and represent one of the historically most studied insect groups, and so there is a good knowledge of the ecological requirement of a large number of species and their distribution and sea-sonality; they are relatively easy to observe and indentify, and finally they are well dependent on the ecological conditions of the environment (Corbet, 2004).

Although odonatological studies in Ghana dates back to 1871 (Dijkstra, 2007a), no studies have been con-ducted on their suitability as indicators or on their relationship with the environment. Hence this study thus sought to: 1) identify the Odonata species occurring along the Densu River; 2) estimate and compare Odonata species diversities along the river; 3) investigate the suitability of Odonata as indicators of water and environmental quality.

MATERIALS AND METHODS

Study areas

The Atewa range located in the eastern region of Ghana, lies between Latitude 4°30' N and 11°00' N and straddles the Greenwich Meridian from Latitude 1°10'E to 3°15'W and consist of a range of hills aligned approximately north-south with steep-sided slopes and flat summits (McCullough et al., 2007). The Atewa Range Forest Reserve covers an area of 232 km² and the surrounding Atewa Range Extension. Geologically, the area is underlain by Birimian formations rich in minerals such as gold, diamond, bauxite and kaolin. The Atewa Range forest is an Upland Evergreen Forest and one of the highest forest covered hills in Ghana and also serves as headwaters for the Ayensu, Sumatua, Suhen, Kuia, Birim (Brim) and the Densu river basins.

The Weija Reservoir (0° 20'' W 0° 25' W and 5° 30' N 5° 45' N) was created in 1977 as a replacement for an earlier one which was washed away in 1968 by Ghana Water Company Limited (GWCL) through damming River Densu mainly to satisfy the demand for potable water supply (Asante et al., 2008). The Weija Reservoir, located about 17 km west of Accra, is almost at the mouth of the 116 km long River Densu which takes its source from the Atewa-Atwiredu mountain range in the Eastern Region of Ghana (Asante et al., 2008). The current reservoir provides water to western parts of Accra, supports irrigation projects, as well as fisheries. The Weija Reservoir is 14 km long, 2.2 km wide and has a total surface area of 38 km^2 with mean depth of 5 m (Vanden Bossche and Bernacsek, 1990). The normal surface elevation is estimated at 14.37 km with maximum of 15.24 km (Nukunya and Boateng, 1979). The main economic activities in the catchment are fishing and crop farming with fertilizers (nitrate and phosphate based) being used on most of these farms (Ansa-Asare and Asante, 2005). Major crops include maize, cassava, sugarcane and vegetables. Untreated domestic effluents are discharged into the Reservoir (Asante et al., 2008).

The sampling stations were at the Aqua Vitens Rand Ltd (AVRL) dam site, Oblogo, Tetegu and water fetching site. Nsawam is located in the Akuapem South District of the Eastern Region of Ghana. The township is about 40 km from the capital Accra, on coordinates 05° 48' 15'' N 00° 21' 49'' W. It is highly populated with industries. The river Densu flows through the township with fishing and farming being the main activities along it. Some of the industries as well as homes have their drainage systems terminating into the river. Sewage discharge points from industries and homes were observed along the stream.

Data collection

Permit was sought from the Forestry Commission of Ghana and the management of the Atewa Range Forest Reserve (ARFR) and Aqua Vitens Rand Ltd (AVRL) at Weija Dam site before sampling commenced. The other sampling stations were in Nsawam and Weija. Sampling stations were chosen within 100 m of the main access points and were at least 400 m apart. GPS points were recorded using a Garmin GPS at a central location for each site, and sampling took place within a 50 m radius of this point.

Data collection was done 5 days per month starting from September, 2010 to April, 2011 with a sampling effort of 2-man per hour. Capturing of Odonates was done along transects with width of 50 m perpendicular from the water systems to maximize the area along the water systems (Bried, 2005).

All the odonates were identified visually with the aid of a pair of close-focus binoculars or caught with an aerial net when necessary and identified using the keys from Dijkstra and Clausnitzer (2013), and by Olsvik (1993) as well as by using comparative material in the Biodiversity and Entomology Museum of the Department of Animal Biology and Conservation Science, University of Ghana, Legon. When it was necessary to transport captured specimen to the laboratory for further identification, pressure was applied on the thorax to paralyze it, the wings folded to one side and put in plastic envelops which were labelled.

Subsequent captures were identified, photographed with a digital camera for further identification and confirmation and released from the aerial nets. The geographical position and altitude were taken with a Garmin GPS. The type of land use (bank side vegetation) was also recorded.

Environmental parameters were recorded for the sample points which included the colour of the stream, type of immediate vegetation use/cover and shade cover. Type specimens of the dragonflies and damselflies are being kept at the Biodiversity and Entomology Museum of the Department of Animal Biology and Conservation Science, University of Ghana, Legon, Ghana.

Data analyses

Species accumulation curve, species richness estimators (Colwell and Coddington, 1994; Colwell, 2000; Magurran, 2010) as well as actual species diversity indices (Shannon-Wiener, Margalef, Pielou and Simpson) were computed and treated as surrogates for biodiversity (Marshall et al., 2006).

The program PRIMER (Clarke and Warwick, 2001; Clarke and Gorley, 2006) was employed to conduct all multivariate analysis. Overall fourth root transformation was applied to the species abundance data and Bray -Curtis similarity resemblance matrix was then generated and then the data was analyzed through ordination by Non-metric Multidimensional Scaling (NMDS) (Clarke and Warwick, 2001). Analysis of Similarity (ANOSIM) was applied to these factors to test significance (Chao et al., 2000).

RESULTS

A total of 5143 individuals belonging to 66 species from eight families comprising of 43 Anisopterans and 23 Zygop terans species were recorded at all 22 sites (4 Weija, 4 Nsawam and 14 within the Atewa Range Forest)

Table 1. Species diversity indices for the study sites.

Site	S	N	d	J'	H'(loge)	1- λ	Rank
Weija	22	3190	2.603	0.4052	1.252	0.5310	3
Atewa	47	1215	6.477	0.8463	3.258	0.9478	1
AOR	39	791	5.694	0.8649	3.169	0.9467	-
AR	27	424	4.298	0.8757	2.886	0.9283	-
Nsawam	34	738	4.997	0.8456	2.982	0.9321	2
All sites	66	5143	7.606	0.6221	2.606	0.8067	-

S = Species Richness, N =species Abundance, d = Margalef index, J' = Pielou's evenness, H' = Shannon's index, 1-λ=Simpson's index Rank, 1- Highest diversity, 2 - Medium diversity, 3- Lowest diversity.

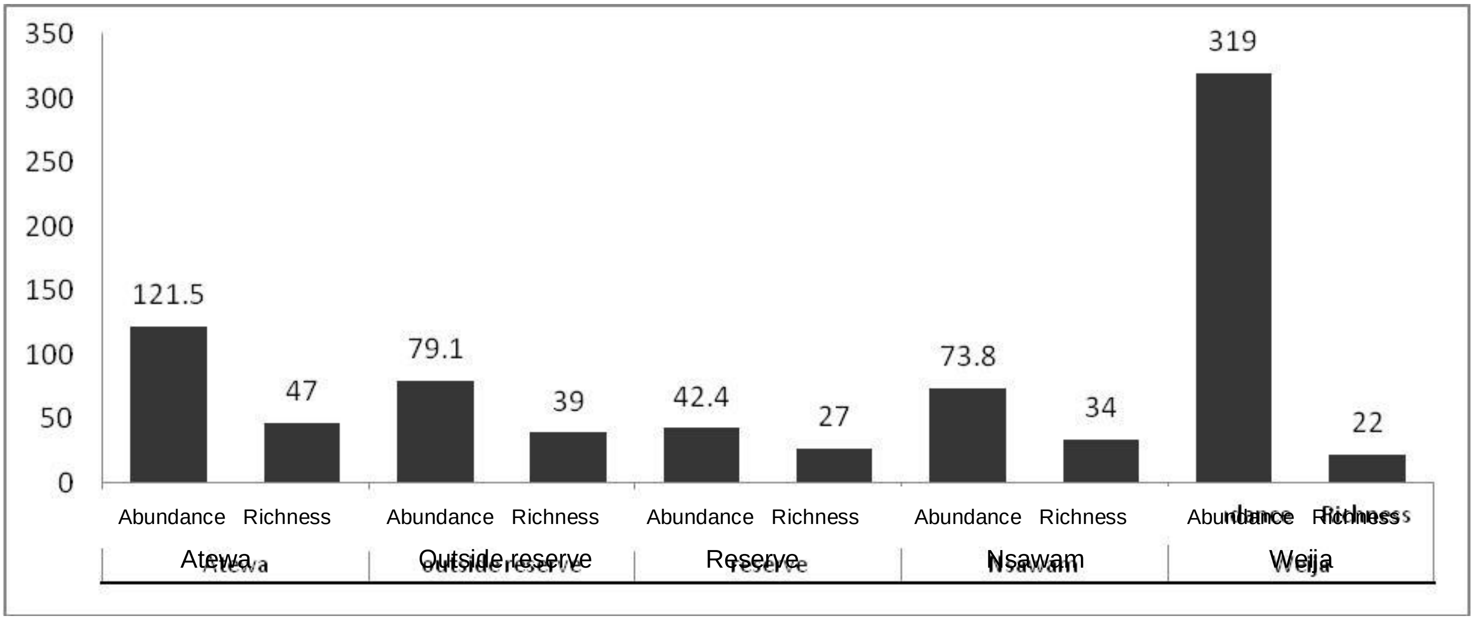

Figure 1. Distribution of Odonata over the entire study area. Abundance frequency is (values are in multiples of 10).

along the Densu River system. The Atewa Range Forest exhibited the highest number of species (47) with 1215 individuals, compared to 34 species (738 individuals) occurring at Nsawam, and 22 species (3190 individuals) occurring at Weija respectively (Table 1, Figure 1). Within the Atewa Range Forest there was a difference in species composition within the protected area (27 species, 424 individuals) and outside the protected area (39 species, 791 individuals) (Figure 1). These differences in species numbers correspond to diversity indices (Shannon-Wiener Index) calculated for these three areas: Atewa (3.258), Nsawam (2.982) and Weija (2.603) (Table 1).

An alternative diversity descriptor, the Simpson index, classified the sites in the same order: Atewa Range Forest as the most species rich habitat (0.9478) followed by Nsawam (0.9321) and then Weija (0.531) (Table 1). Of all the diversity indices calculated, Atewa (outside reserve and within reserve) was the most diverse fol-lowed by Nsawam and then Weija (Table 1). The overall Shannon's diversity index for the whole study region was 2.606 (Table 1).

The most abundant Anisopteran species was *Brachythemis leucosticta* (2113 individuals) present at all sites especially along the Densu River at Weija (2092 individuals), whereas the most dominant Zygopteran was *Sapho ciliata* (139) which was only encountered at the Atewa Range Forest Reserve. The Gomphidae, Aeshnidae and Corduliidae families recorded five (3), three (3) and one (1) species respectively.

A summary of estimated species per site as well as the observed species richness is given (Table 2) and species accumulation curve (Figure 2) for the entire sample area and the three major areas. The latter complement the estimates of observed species richness in the three habitats (Table 2), with the Chao 1 and 2, Jackknife 1, Jackknife 2, Bootstrap, Abundance-based Coverage Estimate (ACE) and the Incidence-based Coverage Estimate (ICE) of expected species richness. These estimates emphasize the representativeness of sampling effort in this study, based on the occurrence of rare species (especially singletons and doubletons), as

Table 2. Species richness estimators for Atewa Range Forest, Nsawam, Weija and all sites combined.

Site	N	Sobs Mau Tao	Chao 1	Chao 2	ICE	ACE	Jack knife 1	Jack knife 2	Bootstrap
All sites	22	66	66	68.15	70.72	66	74.59	69.79	71.54
Atewa	14	47	47	50.65	56.41	47	57.21	56.36	52.67
Weija	4	22	21	21.64	23.2	21.44	24	24	22.66
Nsawam	4	34	34	35.05	38.28	34.46	39.25	38.08	37.11

N - Number of sites.

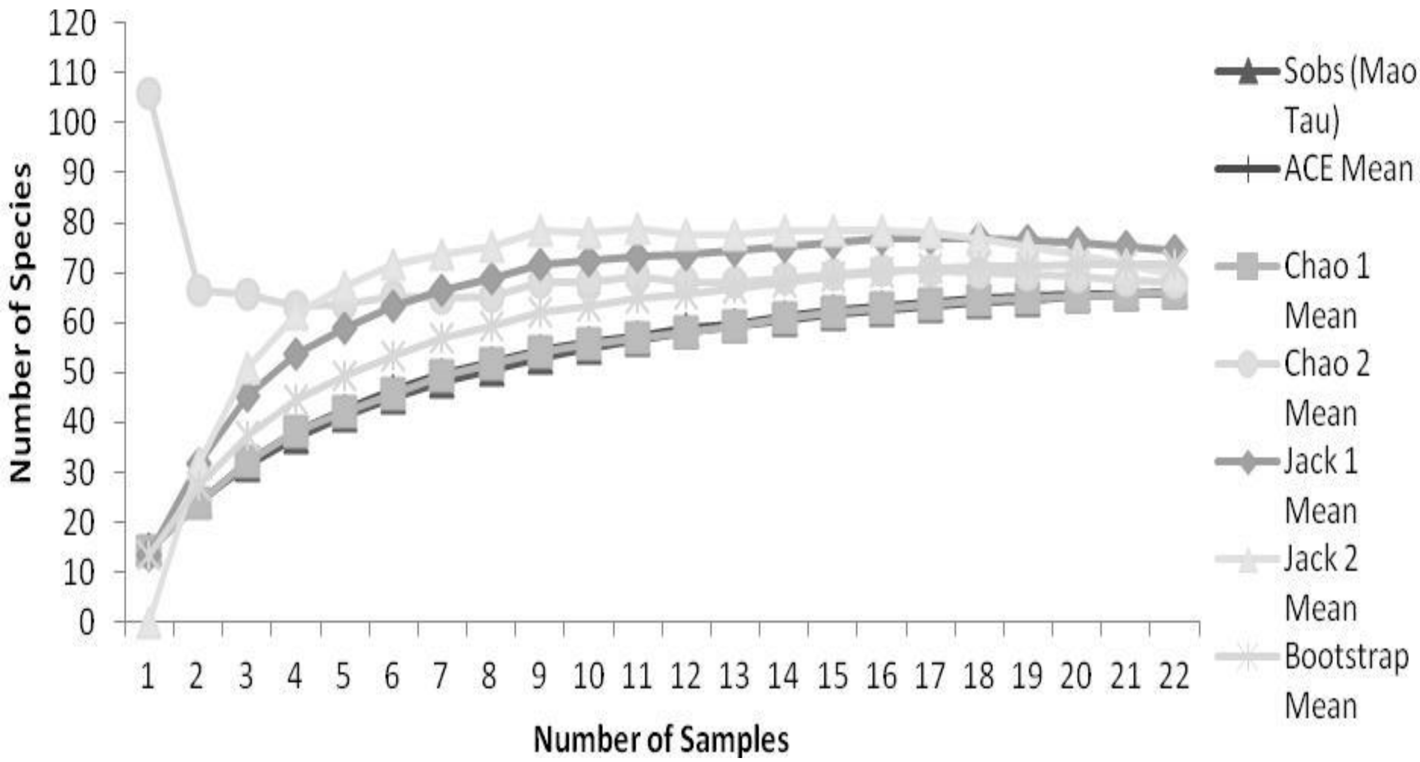

Figure 2. Species accumulation curve for Odonata assemblages along the Densu river system with its associated species richness estimators. Average species richness is based on 50 randomizations (Colwell, 2000).

explained by Colwell et al. (2004) and Colwell and Coddington (1994).

The spatial agglomerative dendrogram of pooled sites species abundance revealed that the study sites can be grouped into six significant groups distinguished at a Bray-Curtis similarity of 63.68% (Figure 3). The SIMPROF test based on the spatial variation in Odonata assemblage composition showed no significant structure at 47.03, 47.7, 51.19, 58.68 and 63.68% similarity respectively.

However, an evidence of structure was found at 42.96% (P=1.6%), 39.36% (P=0.1%), 34.77% (P=0.3%), 34.69% (P=0.1%), 17.07% (P=0.1%), and at 12.9% (P=0.1%) similarity (Figure 4). The following groupings can thus be obtained: Group A: SITES (5, 8, 9), B: SITES (7, 17, 18), C: SITES (10, 11, 12, 13, 14, 15, 16), D: SITES (19, 20, 21, 22), E: SITES (1, 2, 3, 4) and group F: SITE (6).

In comparison, Analysis of similarities (ANOSIM) (Chao et al., 2000) demonstrated a significant difference in species composition between the main geographic areas (Atewa, Nsawam and Weija) (R=0.809, p= 0.001) pair wisely: Atewa-Weija (p=0.002), Atewa-Nsawam (p=0.029) and Weija-Nsawam (p=0.001) (Table 3). In terms of the colour of the stream, the sites with their various abundance were significantly different from each other (R=0.619, p=0.001) (Table 4).

The colour of a water body is an indication of its transparency and transparency is directly affected by the level of suspended particles and dissolved materials in the water Similarly there were significant differences between species composition of the type of immediate

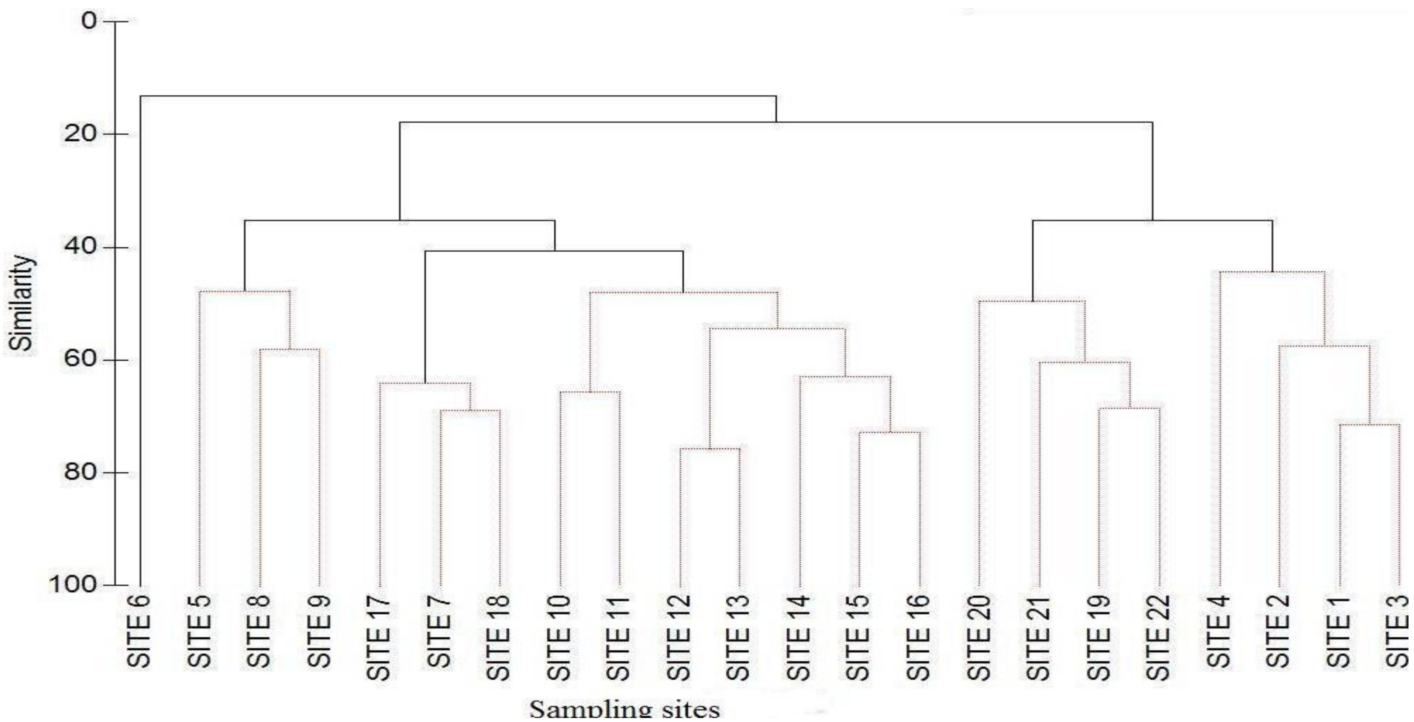

Figure 3. Group average agglomerative dendrogram of Bray-Curtis Similarity of Odonata Species abundance data for 22 different sites along the Densu River system. Thinner lines show evidence of structure (SIMPROF test, $p<0.05$) whereas the darker lines show no evidence of structure.

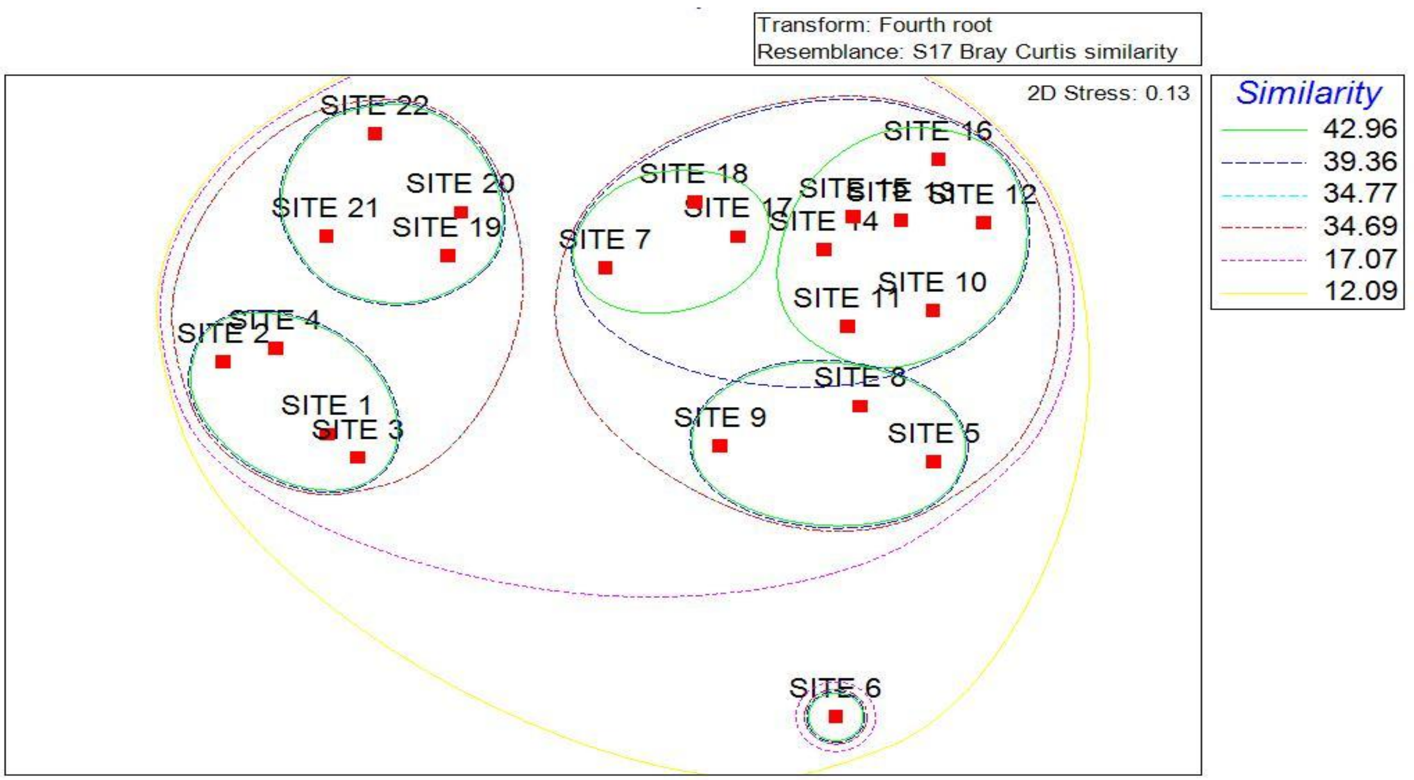

Figure 4. Multidimensional scaling (MDS) ordination plot of the Odonata community structure, based on Bray-Curtis similarity of fourth root transformed species abundances. The significantly separated sample groups by SIMPROF are indicated in blue-green circles.

Table 3. Pair wise analysis of similarity (ANOSIM) comparison of the three stations along the Densu River with Global R=0.809, significance level =0.0001 and 999 permutations.

Group	R Statistic	Significance level %	Possible permutations	Actual permutations	Number >= observed
Weija, Atewa forest	0.893	0.2	3060	999	1
Weija, Nsawam	0.823	2.9	35	35	1
Atewa forest, Nsawam	0,823	0.1	3060	999	0

Table 4. Pair wise analysis of similarity (ANOSIM) comparison of species resemblance matrix with respect to colour of stream with Global R=0.619, significance level =0.0001 and 999 permutations.

Group	R Statistic	Significance level %	Possible permutations	Actual permutations	Number >= observed
Green, brown	0.397	15.6	45	45	7
Green, clear	0.956	1.1	91	91	1
Brown, clear	0.552	0.1	125970	999	0

Table 5. Pair wise analysis of similarity (ANOSIM) comparison of species resemblance of sampled sites with respect to the type of bank side vegetation type with Global R=0.479, significance level =0.0001 and 999 permutations.

Group	R Statistic	Significance level %	Possible permutations	Actual permutations	Number>= observed
Grassland, farmland	0.453	0.3	3003	999	2
Grassland, secondary forest	0.976	0.1	792	792	1
Farmland, secondary forest	0.215	2.2	19448	999	21

vegetation cover along the stream (R=0.479, p=0.001) (Table 5).

DISCUSSION

Of the 5143 individuals of Odonata sampled, a total of 66 species belonging to 8 families were identified in this inventory from 22 sampled sites along the Densu River system, which takes up its source from the Atewa Range Forest Reserve, flowing through several towns and settlements and discharging into the sea at the Densu Delta at Weija. Dijkstra and Clausnitzer (2006) suggest that, the odonatofauna of Ghana is estimated to be about 226 species even though till date only 177 species have been discovered (Neville, 1960; Pinhey, 1962; Frempong and Nijjhar, 1973; Marshall and Gambles, 1977; Olsvik, 1993; D'Andrea and Carfi, 1994; O'Neill and Paulson, 2001; Dijkstra, 2007a).

This study recorded 37% of the species discovered so far in Ghana. This can be pooled from the species richness estimators provided (Table 1) where for instance, for the entire study, jack knife, a non-biased estimator looking at rare/unique species, estimates a total richness of 72 as opposed to the 66 recorded which is the lower boundary of the true number (Smith and Pontius, 2006). Another non-biased estimator of species richness accounted for is the bootstrap which also compensates for underestimating. The other estimators of species richness include the Abundance - based Coverage Estimator (ACE), Incidence-based Coverage Estimator (ICE), Chao 1, Chao 2 and they all give a fair idea of the actual number of species (Chao, 1984; 1987; Chao and Lee, 1992) which is necessary if conservation measures are to be put in place. The species richness recorded for the study however falls within the range of species richness estimators indicating a fair sampling effort (or uniformity of sampling)

The highest species diversity (S = 47) as well as high diversity indices recorded at Atewa (Table 1) can be attributed to the high biodiversity at Atewa as well as its spatial heterogeneity. Streams within the Atewa Forest Reserve have thicker vegetation along their banks which serve as perching sites for less mobile species and the fact that more sites were sampled here due to its heterogeneity compared to the other sites may also account for the highest species diversity at Atewa. Forests are known and expected to have the greatest diversity of Odonata (Dijkstra and Clausnitzer, 2006; Kalkman et al., 2008). In terms of species occurrence, Atewa had 5 singletons where as Nsawam had 1 singleton and 2 doubletons with Weija having 1 singleton and 1 doubleton. This could be as a result of poor 'detectability' of species within the forest as it is expected to harbour rare and low abundance species (Dijkstra and Clausnitzer, 2006). The diversity of Odonata is higher in the forest with some generalist species occurring in both forest and non forested regions.

Sites similar in community composition and or environmental variables were grouped together which is an indication of the environmental variables that accounted for their grouping. This demonstrates the suitability of using the insect order Odonata to indicate the environmental conditions (variables) of the Densu River and its land related ecotones.

In addition, non metric multidimensional plots showed the similarity between sites based on a Euclidean distance matrix on encountered species and their abundance at each site. The relative distance between the sites demonstrates their level of dissimilarity, however, this enhances straightforward, quantitative and objective interpretation, whereby inductive inferences on environmental structure can be readily formulated as proposed by Tong (2002a, 2002b).

Upon analysis of sites based on species abundance matrix using Bray - Curtis dissimilarity, the geographic areas were significantly different. Species abundance also differed between the sites. These could be due to the difference in environmental structures such as shade cover (Dijkstra and Lempert, 2003; Dijkstra and Clausnitzer, 2006; Remsburg et al., 2008), land use type (Kalkman et al., 2008) and micro-climate (Oertli, 2010). Also, Dijkstra and Lempert, (2003) 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. This is also mentioned by Hofmann and Mason (2005), when they found shade to strongly affect adult dragonflies near a river in Eastern England. According to them, vegetation type is an important influence on controlling shading and temperature of streams and thus there was a relationship between shade, temperature and vegetation type with species diversity.

A similar pattern was observed in this study, which reinforces the argument that shade, as well as vegetation cover play an important role in determining Odonate assemblages in the study area as the highest species richness is observed in areas with shade cover and forest as the principal land use type. When species compositions were grouped by similar environmental conditions, it was observed that differences between them were mostly significant. This is probably an indication that, these environmental conditions (land use type and water colour) serve as boundaries distinguishing Odonate assem-blages. These factors again are considered by odonates in selecting for ovipositing sites (Corbet, 1999; Thompson et al., 2003), mating sites (Remsburg et al., 2008), roosting and resting sites (Askew, 1982; Pritchard and Kortello, 1997), feeding sites (Corbet, 1999) as well as requirement for nymphs (Samways and Steytler, 1996; Corbet, 1999; Thompson et al., 2003).

Out of the eight families (4 Anisoptera, 4 Zygoptera) of Odonata recorded, the most represented families were Libellulidae and Coenagrionidae with 33 and 12 species respectively (Figure 1), confirming Dijkstra (2007b) results. The dominance of the Anisopterans by the Libellulidae family is also mentioned in (Dijkstra, 2007b; Dijkstra and Clausnitzer, 2013; Lawler, 2001; Silsby, 2001; Kadoya et al., 2004 Suhling et al., 2004; Suhling et al., 2005).

The Gomphidae and Aeshnidae families are known to be very sensitive to ecological, habitat and environmental changes eventhough they do not occur in large numbers (Ameilia et al., 2006; Dijkstra and Clausnitzer, 2013; IUCN, 2010). They are relatively larger in size, are very fast flyers and were mostly observed flying at dusk. According to Clausnitzer (2003) they hunt above streams and along forest paths at dusk. Hence could have resulted in their low encounter rates.

The dominance of the Zygopterans by the Coenagrionidae family could be as a result of the following reasons: Coenagrionidae is the largest of the Zygoteran odonates, they have a shorter life cycle and a wide distribution (Norma-Rashid et al., 2001) and can tolerate a wide range of habitats (Samways, 1989). The low numbers of the Zygopterans is generally due to their low dispersal ability. *Pseudagrion nubicum, Ceriagrion glabrum*, *Ischnura senegalensis* and *Elattoneura nigra* were the only species found only in open areas in high abundance, whereas all the other Zygopterans such as *Pseudagrion torridum*, the Chlorocypha and Phaon species had higher numbers in shaded areas. This confirms work done by Subramanian (2005) and Arulprakash and Gunathilagaraj (2010) who proposed that shade could favour damselflies more than dragon-flies.

Conclusion

This study has shown that, Odonata diversities along the Densu River vary hence these populations can be monitored, related and used as indicators of the physical structure of the river and its surrounding water related ecotones.

The Odonata is an insect order suitable for measuring the environmental quality of the Densu River and its land related ecotones. Though sections within the Atewa Forest showed signs of high disturbance, with illegal felling of trees on daily basis, it still harboured diverse fauna, including typical forest Odonates like *Umma cincta*, *Sapho ciliata*, *Chlorocypha luminosa*, *C. radix* and *Cyanothemis simpsoni*. This suggests that the water quality of the Densu River is still good enough to support these species despite extensive damage to the surrounding landscape. The detection of migratory and open habitat species like *Crocothemis erythraea* serves as an indicator of an anthropogenic change in habitats in the Atewa Range Forest Reserve.

The study has also shown that at least 66 species of Odonate can be found along the Densu River with the Atewa Range Forest Reserve recording the highest diversity, a finding that is significant in terms of ecotourism potential for Dragonfly enthusiasts.

Recommendations

This inventory has served as the baseline for Odonata communities along the Densu River hence can be a measure of monitoring in the near future.

This inventory can also serve as a point of contact to tourists interested in odonatofauna in Ghana, therefore it is recommended that Managers of such reserves and protected areas must strengthen and increase measures for deterring illegal human activities within these areas.

District authorities should embark on a massive re-education campaign to address the low levels of environmental awareness that pertains in the basin.

Finally, there must be an increase in education on the importance of using local insect species as first level indicators of environmental health which when improved upon can save the nation a lot of money otherwise used in the chemical evaluation and monitoring of water quality.

ACKNOWLEDGEMENTS

We are grateful to IdeaWild (www.ideawild.org) for supporting this study with equipment and to the Tropical Biology Association (www.tropical-biology.org) for their advice and mentoring. We are also grateful to Klaas-Douwe-Dijkstra for his mentoring, advice and guidance with species identifications.

REFERENCES

Ameilia ZS, Che Salmah MR, Abu Hassan A (2006). Distribution of Dragonfly (Odonata: Insecta) in the Kerian River Basin, Kedah-Perek, Malaysia. USU Repository. 14 p.

Ansa-Asare OD, Asante KA (2005). Changes in the Chemistry of the Weija Dam Reservoir in Ghana, Twenty Years after impoundment. West Afr. J. Appl. Eco. 8, 35-47.

Arulprakash R, Gunathilagaraj K (2010). Abundance and diversity of Odonata in temporary water bodies of Coimbatore and Salem districts in Tamil Nadu. *J. Threatened Taxa* 2(8): 1099-1102.

Asante KA, Quarcoopome T, Amevenku FYK (2008). Water quality of the Weija Reservoir after 28 years of impoundment. West Afr. J. Applied Ecol. 13:1-8.

Askew RR (1982). Roosting and resting site selection by coenagrionid damselflies. Adv. Odonatol. 1:1-8.

Bried JT (2005). Community and Conservation Ecology of Dragonfly and Damselfly Adults in Mississippi Wetlands. An MSc. Thesis Submitted to the Faculty of Mississippi State University.

Chao A (1984). Non-parametric estimation of the number of classes in a population. Scand. J. Stat. 11:265-270.

Chao A (1987). Estimating the population size for capture - recapture data with unequal catchability. *Biometrics.* 43:783-791.

Chao A, Hwang WH, Chen YC, Kuo CY (2000). Estimating the number of shared species in two communities. *Statistica Sinica* 10, 227 - 246.

Chao A, Lee SM (1992). Estimating the number of classes via sample coverage. J. Am. Stat Assoc. 87:210-217.

Chovanec A, Waringer J (2001). Ecological integrity of river-floodplain systems- assessment by dragonfly surveys (Insecta: Odonata). Regul. River 17 (4-5):493-507.

Chovanec A, Waringer J, Rajj R, Laister G (2004). Lateral connectivity of a fragmented large river system: assessment on a macroscale by dragonfly surveys (Insecta: Odonata). Aquat. Conser. - Marine and Freshw. Ecosyst. 14:163-178.

Clark TE, Samways MJ (1996). Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park. South Afr. J. Appl. Ecol. 33:1001-1012.

Clarke KR, Gorley RN (2006). PRIMER v6: User manual/tutorial, PRIMER-E, Plymouth UK, 192pp.

Clarke KR, Warwick RM (2001). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. (2nd ed): PRIMER-E, Plymouth UK. 172 p.

Clausnitzer V (2003). Odonata of African humid forests - a review. *Cimbebasia*, 18:173-190.

Clausnitzer V, Jödicke R (2004). Guardians of the watershed. Int. J. Odonatol. 7 (2):111-112.

Colwell RK (2000) EstimateS- Statistical estimation of species richness and shared species from samples. Version 6. User's guide and application published at http://viceroy.eeb.uconn.edu/EstimateS.

Colwell RK, Chang X, Chang J (2004). Interpolation, extrapolating and comparing incidence-based species accumulation curves. Ecology 98:2717-2727.

Colwell RK, Coddington JA (1994). Estimating terrestrial biodiversity through extrapolation. *Philos. T. R. Soc. Lond.* B 345, 101-118.

Corbet PS (1999) *Dragonflies:* Behav. Ecol. Odonata. Cornell University Press, New York.

Corbet PS (2004) *Dragonflies: Behav. Ecol. Odonata.* Comstock Publishing Associates, Cornell University Press, Ithaca, NY. 303pp.

D'Andrea M, Carfì F (1994). Annotations on a small dragonfly collection from Ghana, West Africa, with six new species for the national fauna (Odonata). Opuscula Zool. Fluminensia 125:1-7.

Dijkstra KDB (2007a). Dragonflies and Damselflies (Odonata) of the Atewa Range, Ghana. *In* McCullough, Alonso J, Naskrecki LE, Wright P, Osei-Owusu HE, (eds.) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bull. Biol Assess. 47. Conservation International, Arlington, VA. 50-54.

Dijkstra KDB (2007b). Demise and rise: the biogeography and taxonomy of Odonata of tropical Africa. PhD Thesis, 2007, Leiden University. pp. 143-187.

Dijkstra KDB, Clausnitzer V (2006). Thoughts from Africa: how can forest influence species composition, diversity and speciation in tropical Africa? In Cordero-Rivera, A. (ed.), Forests *and Dragonflies*, 127-151. Pensoft Publishers, Sofia.

Dijkstra KDB, Lempert J (2003). Odonate assemblages of running waters in the Upper Guinean forest. *Archiv für Hydrobiologie* 157:397-412.

Dijkstra KDB**,** Clausnitzer V (2013). The dragonflies and damselflies of eastern Africa: handbook for all Odonata from Sudan to Zimbabwe. *Studies in Afrotropical Zool.* Belgian Royal Museum for Central Africa (in press).

Frempong E, Nijjhar B (1973). Some preliminary observations on the fauna and flora of Barekese Lake, Ghana. Buleltin de l'Institut Fondamental de l'Afrique Noire 35 (1):67-78.

Hofmann TA, Mason CF (2005). Habitat characteristics and the distribution of Odonata in a lowland river catchment in eastern England. Hydrobiologia 539:137-147.

IUCN (2010). IUCN Red List of Threatened Species. Version 2010. 3. Retrieved from http://www.iucnredlist.org. Accessed on 05 October 2010.

Kadoya T, Suda S, Washitani I (2004). Dragonfly species richness on man-made ponds: effects of pond size and pond age on newly established assemblages. *Ecol. Res.* 19:461-467.

Kalkman VJ, Clausnitzer V, Dijkstra KDB, Orr AG, Paulson DR, van Tol J (2008). Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia* 595, 351-363.

Lawler SP (2001). Rice fields as temporary wetlands: a review. Israel J. Zool. 47:513-528.

Magurran AE (2010). Measuring Biological Diversity. Blackwell Publishing, Malden, MA. 256pp

Marshall AG, Gambles RM (1977). Odonata from the Guinea Savanna Zone in Ghana. J. Zool. Lond. 183, 177-187.

Marshall JC, Steward AL, Harch BD (2006). Taxonomic resolution and quantification of freshwater macroinvertebrate samples from an Australian dryland river: the benefits and costs of using species abundance data. Hydrobiologia, 572:171-194.

McCullough J, Alonso LE Naskrecki P, Wright HE, Osei-Owusu Y (eds.) (2007). A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bull. Biolog. Assess. 47. Conservation International, Arlington, VA.

Neville AC (1960). A list of Odonata from Ghana, with notes on their mating, flight and resting sites. *Proc. Roy. Entomolog. Soc. Lond.* 35: 124-128

Norma-Rashid Y, Mohd-Sofian A, Zakaria-Ismail M (2001). Diversity and distribution of odonata (dragonflies and damselflies) in the fresh water swamp Lake Tasek Bera, Malaysia. Hydrobiologia, 459 p.

Nukunya GK, Boateng EO (1979). Weija Dam Project: An Evaluation/Study of Water Utilisation Behaviour and its Related Socio-economic Impact. Report submitted to Canadian International Development Agency (CIDA).

O'Neill G, Paulson DR (2001). An annotated list of Odonata collected in Ghana in 1997, a checklist of Ghana Odonata, and comments on West African Odonate biodiversity and biogeography. Odonatologica 30:67- 86.

Oertli B (2010). The local species richness of Dragonflies in mountain water bodies: an indicator of climate warming? In: Ott, J. (Ed) (2010) Monitoring Climatic Change With dragonflies. *BioRisk* 5:243-251.

Olsvik H (1993). Adult Odonata. A preliminary Key to Afrotropical Families and Genera with a checklist and Bibliography of West Africa Species. Unpublished. 29-38.

Osborn R, Samways MJ (1996). Determinants of adult dragonfly assemblage patterns at new ponds in South Africa. Odonatologica 25:49-58.

Pinhey E (1962). Some records of Odonata collected in Tropical Africa. J. Entomol. Soc. South Afr. 25:20-50.

Pritchard GD, Kortello A (1997). Roosting, perching and habitat selection in *Argia vivida* and *Amphiagrion abbreviatum* (Odonata: Coenagrionidae), two damselflies inhabiting geothermal springs. Canadian Entomol. 129:733-743

Remsburg AJ, Olson AC, Samways MJ (2008). Shade Alone Reduces Adult Dragonfly (Odonata: Libellulidae) Abundance. *J. Insect Behav.* 21(6):460-468.

Samways MJ (1989). Taxon turnover in Odonata across a 3000m altitudinal gradient in Southern Africa. *Odonatologica* 18:263-274.

Samways MJ, Steytler NS (1996). Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management. Biol. Conserv. 78:279-288.

Schindler M, Fesl C, Chovanec A (2003). Dragonfly associations (Insecta: Odonata) in relation to habitat variables: a multivariate approach. Hydrobiologia 497(1):169-180.

Silsby J (2001). Dragonflies of the World. Smithsonian Institution Press, Washington, DC.

Smith CD, Pontius JS (2006). Jackknife estimator of species richness with S-PLUS. J. Stat. Software, 15 (3):12pp.

Smith J, Samways MJ, Taylor S (2006). Assessing Riparian Quality Using Two Complementary Sets of Bioindicators. *Biodiversity and. Conservation,* 16 (9):2695-2713.

Stewart DAB, Samways MJ (1998). Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savannah game reserve. Conserv. Biol. 12, 683-692.

Steytler NS, Samways MJ (1995) Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. Biol. Conserv. 72: 381-386.

Subramanian KA (2005). Dragonflies and Damselflies of Peninsular India: A Field Guide. Project Lifescape. Indian Academy of Science, Bangalore, India. 118 p.

Suhling FF, Sahlen G, Kasperski J, Gaedecke D (2005). Behavioural and life history traits in temporary and perennial waters: comparisons among three pairs of sibling dragonfly species. Oikos 108:609-617.

Suhling, FF, Schenk K, Padeffke T, Martens A (2004). A field study of larval development in a dragonfly assemblage in African desert ponds (Odonata). Hydrobiologia 528:75-85

Thompson DJ, Rouquette JR, Purse BV (2003). Ecol. Southern Damselfly. Conserving Natura 2000 Rivers Ecology Series. English Nature. Peterboroug. 24 p.

Tong STY (2002a). The use of non-metric multidimensional scaling as an ordination technique in resource survey and evaluation: a case study from southeast Spain. Appl. Geogr. 12(3):243-260.

Tong STY (2002b). On non-metric multidimensional scaling ordination and interpretation of the matorral vegetation in lowland Murcía. Plant Ecol. 79 (1-2) 65-74.

Vanden Bossche JP, Bernacsek GM (1990). Source Book for the Inland Fishery Resources of Africa, 1. CIFA Technical Paper No 18/1. 240 p.