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ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

Change in aquatic insect abundance: Evidence of climate and land-use change within the Pawmpawm River in Southern Ghana

Helen Nnoli[1], Rosina Kyerematen[2], Samuel Adu-Acheampong[3]* and Julian Hynes[4]

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*Corresponding author: Samuel Adu-Acheampong, Agronomy Department, University for Development Studies, Ghana
E-mail: nanaakyampon@gmail.com

Reviewing editor:
Michelle Bloor, School of Earth and Environmental Science, University Of Portsmouth, UK

Additional information is available at the end of the article

Abstract: Insects are key indicators of change in the landscape. They are known to be sensitive to the environment and climate in both terrestrial and aquatic ecosystems. A systemic way of monitoring river ecosystems response to land-use and climate change is critical although lacking in most West African countries. This study explored the taxonomic composition of insect assemblages within the Pawmpawm River to quantify the level of change (if any) in biodiversity of aquatic insects as evidence of a land-use and climate change in a 40-year interval. We collected insect larvae from river shores, edges, and riffles and compared diversity indices of collected samples with that of previous study conducted within the same study area 40 years earlier prior to the current study. Our results show that there were no significant differences in taxonomic diversity of aquatic insects between the two studies. This indicates that diversity of insects in the Pawmpawm River and its environment has not changed significantly in the past 40 years. However, there were significant reductions of individual insect numbers or abundances within the river and its environment giving an indication of a possible climate and land-use change

Rosina Kyerematen

ABOUT THE AUTHORS

Rosina Kyerematen is a Senior Lecturer at the Department of Animal Biology and Conservation Science, University of Ghana, Legon. She has special interest in freshwater entomology as well as impact of Climate and land use change on biodiversity.

Helen Nnoli graduated with an MPhil in Entomology from the African Regional Postgraduate Program in Insect Science (ARPPIS) at the University of Ghana-Legon.

Samuel Adu-Acheampong is a lecturer at the Agronomy Department of the University for Development Studies, Tamale, Ghana. Samuel's areas of interests are, using insects as indicators in landscape ecology studies, impact of climate change on biodiversity and predicting species distribution under change scenarios.

Julian Hynes completed BSc. Hons. in Biology at the Western University and MSc. Zoology at the University of Ghana. He spent over two decades in fish culture and fisheries management in Ontario. He returned to Ghana to focus on aqua-culture consultation and tilapia farming.

PUBLIC INTEREST STATEMENT

Change in insect abundance can be used as a measure of climate and or land-use change in aquatic bodies such as the Pawmpawm River. This study was conducted to compare findings from a similar study on invertebrate diversity and abundance 40 years ago. Our results showed that there were major reductions in insect abundances of all groups although there were no shifts in diversity or species within the river in the period under study (a 40-year interval). We attempt to explain this reduction in abundance using land-use change which is visible through logging, farming, etc., and a possible shift/or change in climatic condition through, erratic rainfall pattern and a rise in average monthly temperature. It is a study explaining a reduction in insect abundance using visible evidence of climate and land-use change using aquatic insect diversity as a monitoring tool in the river.

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in the study area. We recommend using change in aquatic insect diversity and abundance as monitoring tools for change in environment and land-use within the Pawmpawm River and other such rivers in Ghana.

Subjects: Entomology & Acarology; Freshwater Biology; Entomology

Keywords: abundance; aquatic; change; climate; environment; insects; Pawmpawm; river

1. Introduction

Aquatic ecosystems are characterised by high variability of faunal composition and complexity. In recent times, these ecosystems have increasingly been impacted by anthropogenic activities occurring within catchment areas (Liao, Sarver, & Krometis, 2018; Vörösmarty et al., 2010; Yoshimura, 2012). Such is the case of the Pawmpawm River in the Eastern region of Ghana. This river is an important tourism site and thus generates revenue for both government of Ghana and communities around it. The river and its surrounding environment have undergone some physical, biological and chemical changes since the first insect diversity study conducted there in 1971. These changes have also affected both the fauna and flora associated with it. As has been reported in other studies (Barman & Gupta, 2015; Yoshimura, 2012) an important group of organisms that is affected due to these changes are the invertebrate community within the river's environment (Jani et al., 2018; Liao et al., 2018). Insects mainly associated with water bodies are widely known to be very good biological indicators of water pollution and ecological health of rivers and other water bodies (Caspers, 1961; Heliovaara, 2018; Nasirian & Irvine, 2017; Pham, Nguyen, Nguyen, & Dao, 2016; Steward, Negus, Marshall, Clifford, & Dent, 2018). They are highly sensitive to change in their environment and can be used to monitor both the health status and impact of environmental stressors in fresh water ecosystems (Colin et al., 2016; Wernersson et al., 2015). Most importantly they are very sensitive to trace elements (Dao et al., 2017; Heliovaara, 2018; Nasirian & Irvine, 2017). Insects also play significant roles in ecosystem functioning and due to their high sensitivity, which is clearly shown by the different habitats they occupy, they have become important bioindicators of aquatic habitats and water quality (Nasirian & Irvine, 2017; Pham et al., 2016; Steward et al., 2018).

Designed programmes for monitoring aquatic habitats and quality of water resources are generally expensive to maintain and sometimes only provide indirect link to the contaminant sources (Colt, 2006; Patrício et al., 2016; Rao et al., 2013). As a result, biomonitoring approaches have become more attractive for assessing the health of aquatic ecosystems because they are relatively cheaper. Biomonitoring is using sensitive species often referred to as indicator species for quantitative and or qualitative assessment of the performances of physical or biological systems (Wu et al., 2017; Zhou, Zhang, Fu, Shi, & Jiang, 2008) especially when they are affected by anthropogenic activities such as farming and mining (Adu-Acheampong, Bazelet, & Samways, 2016; Kyerematen et al., 2018a; Kyerematen, Kaiwa, Acquah-Lamptey, Adu-Acheampong, & Andersen, 2018b). Simple indices such as the presence or absence of a species, richness of a group or abundance of a species can be used as surrogates to measure pollution or change in conditions within riverine communities (D'costa, Shyama, Praveen Kumar, & Furtado, 2018; Łuczyńska, Paszczyk, & Łuczyński, 2018).

Water bodies, specifically rivers, have been shown to reflect conditions on the landscape through catchments conditions (Sandeva & Despot, 2015; Chique, Potito, Molloy, & Cornett, 2018). As a result, the aquatic insect community assemblage composition also mirrors conditions within water bodies (Kerakova, Uzunov, & Varadinova, 2017; Uhl, Wölfling, Fiala, & Fiedler, 2016). Therefore, the use of insect assemblage community composition of the Pawmpawm River can increase our understanding on changes that might have occurred within the period under investigation. This study focusses on aquatic insects because some of them have high tolerance for environmental pollutants while others are relatively less tolerant. There is a clear distinction

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between high and low pollution tolerant insect groups in river bodies compared to plankton and fish (Prabhakaran, Nagarajan, Franco, & Kumar, 2017; Sreeja, 2018). Furthermore, insects provide cheap and useful ways to bio-monitor aquatic systems than chemicals do (Abdullah, Hazwani, & Abas, 2016; Caldwell et al., 2012; Kokkali & van Delft, 2014).

The study is a follow-up to a previous one that involved sampling insect community within the Pawmpawm River and its surroundings in 1970/1971 by Hynes. Hynes focused on aquatic macro-invertebrate ecology spanning three wet and dry seasons; however, the current study was conducted within two dry and wet seasons. Although the sampling sizes were not the same rarefaction curve developed for the current study showed enough sampling for comparison and valid statistical conclusions to be made from data collected (Figure 2(a)). This paper compared insect assemblage composition between the two studies within the same sampling area at the upper reaches of the river above Boti Falls using various sampling methods. Comparing results of the two studies are considered vital and an opportunity to investigate the possible impact of land-use and evidence of climate change using the diversity and or abundance of aquatic insect community associated with the river. The study sites within the upper reaches of the Pawmpawm River are intermittent resulting in periods of no flow during dry seasons, with the river reduced to a series of disconnected pools (Amakye, 2001; Samman & Amakye, 2009; Thorne, Williams, & Gordon, 2000). This study thus become relevant and informative and has the potential of informing policy or governmental decision-making processes especially on issues affecting tourism such as environmental health within the river.

We aimed at finding differences if any, in aquatic insect diversity within the Pawmpawm River between the two study periods. Due to the combined effect of possible climate and land-use change within the river's environment, we expected a reduction in insect assemblage composition in the latter study in 2013/2014 compared to the former in 1971/1972. We therefore hypothesised that the combined effect of possible climate and land-use change have had a negative impact on insect assemblage composition within the environment of the Pawmpawm River. We then draw conclusions and propose management actions to use in biomonitoring of health of water bodies in Ghana.

2. Materials and methods

2.1. Sampling site

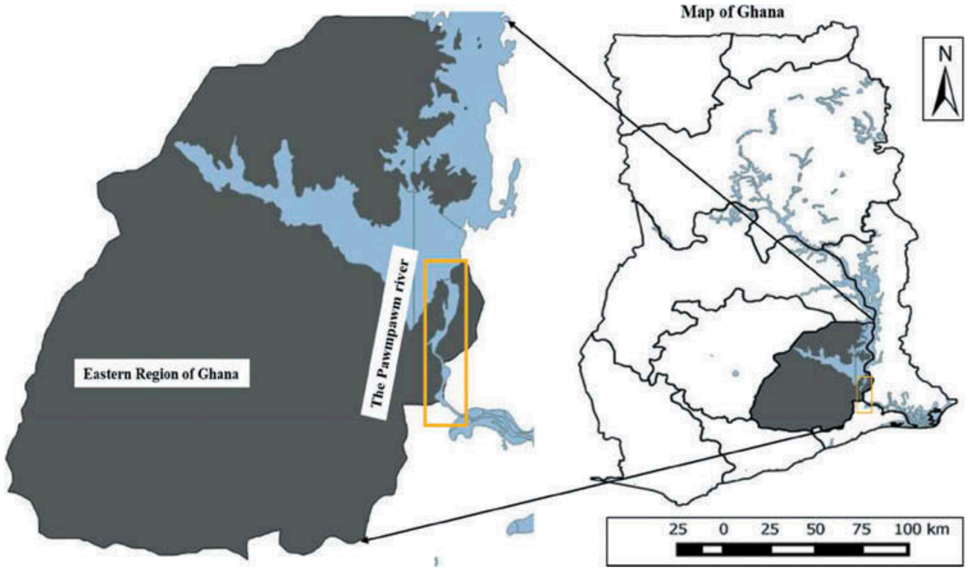
The upper reaches of the Pawmpawm River is situated within the moist semi-deciduous forest of the Eastern Region of Ghana. The river derives its sources from many spring streams which form on the steep hillsides of the Kwahu plateau, almost horizontal strata of Voltaic sandstone, at approximately 650 m high (Hynes, 1975a). The river flows towards the south-eastern part of Koforidua for about 17 km. It drains into an area approximately 160 km^2 towards the northern and north-eastern part of the Koforidua township before leaving the plateau at a height of approximately 290 m at Boti Falls and below at Akaa Falls (Figure 1).

2.2. Methods

Between 1970/1971, Hynes (1975a, 1975b) sampled aquatic invertebrate diversity within and around the Pawmpawm river using four sampling methods. Among these were the Surber stream bottom sampler (40 cm x 25 cm, nylon net aperture 0.25–0.28 mm, approx. 35 mesh per sq.cm. equivalent to Tyler and US sieve 60), drift sampling (45 cm wide x 30 cm high nylon net aperture 0.40 cm with collecting jar) and a simple light trap at dusk for emerging adult insects. Also, Occasional sampling was also carried out using a triangular long handled dip net with nylon mesh 0.30 cm sweeping 1–2 m whilst scraping and stirring the bottom upstream.

The total invertebrate collections made in 1970/1971 included 64 collections of Surber samples on 25 dates within16 months, 14 dip net samples on different days of 11 months. It also included 12 24-h drift net samples collected in 10 separate months over a 14-month period from April 1970 to May 1971 and 19 drift samples spanning 2 h at sunset (17:00–19:00h) in April–May 1971. The

Figure 1. Showing the location of the Pawmpawm River in the Eastern Region of Ghana.



volume of water sampled during each 24-h ranged from 65 to over 300 × 106 l, and in months with low river flows, the volume of water was 100 × 106 l or less.

The recent study started from July 2013 and ended in March 2014. The sampling procedure consisted of Surber sampling, dip net sampling and a total of three traps (malaise trap, flight intersection trap and light trap) for sampling adult insects. In all 25 sites were sampled in both studies. Contents of sampling nets were washed into buckets with insect species collected with forceps while making sure none clung to the net. The benthic fauna of the river was also sampled using a Surber stream-bottom sampler as described by Hynes (1975a). A total of 90 dip net samples were collected for a period of 10 months, and 42 Surber samples were also collected for a period of 7 months. To collect adult insects the malaise trap was used for sampling smaller, flying, mainly nocturnal insects; a flight interception trap (FIT) was used to intercept insects in flight, and a light trap was used to collect flying insects which are attracted to light at night. Although of different lengths, approaches and few sampling modifications, both studies spanned the contrasting wet and dry seasons of this former semi-deciduous tropical environment. Sampling methods for the two studies were kept as uniform as possible in order to minimise error due to sampling procedure between the two studies.

2.3. Climate and environment

Data collected from the Ghana Meteorological Agency (GMA) show that monthly average rainfall has not changed greatly. However, rainfall appeared to be less predictable, and more erratic in the latter study compared to the former one. Lack of forest cover on steep slopes of the river surface lead to greater tendency for spates followed by rapid decrease in flow. Data from GMA also show that rainfall patterns in the two years under the current study have shifted in time and that the dry periods of February and August were more extreme in 2013 (Figure 2(c)). In addition, there has been a 1° C increase in average monthly temperature from 26.5°C to 27.5°C. The temperature change spanning all months and seasons and a shift in rainfall pattern in the study area are evidences of climate change (Figure 2(b,d)).

The study in 1970 observed two peak rainy seasons in May/June and September, but no river flow was observed in August of that same year (Hynes, 1975a). In contrast, there were three peaks of rainy seasons observed in 2013 in March, June/July and October (see Figure 2(c)). As a result, the river flowed continuously during the year 2013 with a flooding event occurring in October (see Figure 2). Water temperature varied from 21°C in December 1970 to 28°C in February–April 1970 and

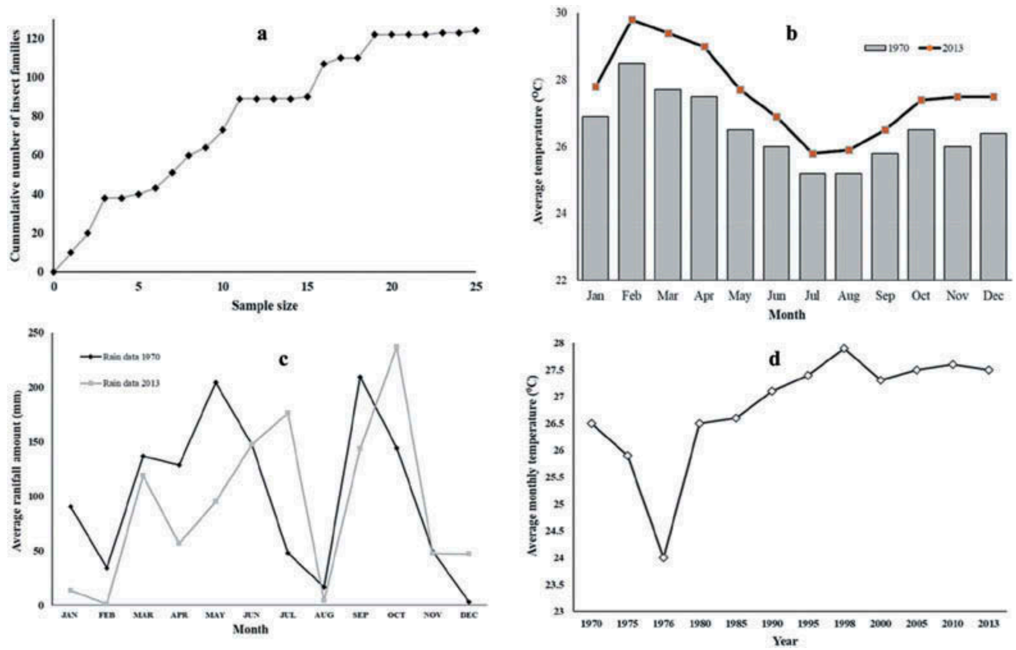


Figure 2. Species accumulation curve for 2013/2014 sample (a) and weather variables in the study area (b–d).

February 1971 (see Figure 2(b,d)). Water current measured during the sampling period ranged from zero in February 1970/71 and August 1970 to 20 m/sec. in October–November 1970. Discharge was zero in August and estimated to be 4m^3/sec. at peak flow in October 1970. The annual temperature in 1970 was 26.5°C while that of 2013 was 27.5°C (see Figure 2(d)).

3. Data analysis

A rarefaction curve was used to verify if there was enough sampling to cover almost all invertebrate species within and around the Pawmpawm River (see Figure 2(a)). Diversity indices were calculated from the 2013/2014 and compared with that of 1970/1971 to find differences in diversity of insect assemblages between the two sampling periods. A one-way ANOVA was used to test for differences in species diversity and abundances between the two study periods using Statistica 13.2 (StatSoft Incorporated, 2013).

4. Results

A total of 5,442 insects were recorded in the upper reaches of the Pawmpawm River in the recent study in 2013/14 while 28,180 aquatic insects were recorded by Hynes in 1970/71. The fauna (Hynes, 1975a, 1975b) included 38 families of eight orders identified to generic or specific level. In the recent study, the aquatic insects identified belonged to the same eight orders and 41 families that also included the previous 38 families. Comparison of the previous and current studies show that the most dominant insect orders, Diptera, Ephemeroptera and Trichoptera have maintained their ecological positions in the river's ecosystem (Table 1).

It can be observed that despite the extensive deforestation in the watershed during the 2013/2014 sampling period, we found a relatively high diversity of insects in this same period. It is apparent that the vegetation surrounding the study area has served to mitigate effects of environmental and or climate change. The diversity of aquatic insects in this area have not changed over the 40-year period and this attests to the resilience of the system in the face of both habitat or land-use change and an increase in monthly average temperatures.

In contrast, the first study in 1970/1971 recorded a higher abundance of insect assemblages compared with that of 2013/2014, with the highest numbers (N = 2487 and 2214 for November

Table 1. Comparison of aquatic insect families recorded between 1970/71 and 2013/14 from the upper reaches of the Pawmpawm River

Order/sub order	Family	1970/71			2013/14	
		Surber	Other	Drift	Surber	Other
Ephemeroptera	Baetidae	7037	1218	2110	324	778
	Caenidae	559	19	578	9	15
	Heptageniidae	0	0	0	31	110
	Oligoneuridae	0	0	0	0	9
	Other Ephemeroptera	406	22	55	0	0
Odonata						
Anisoptera:	Corduliidae	0	0	0	7	21
	Libellulidae	22	0	0	35	145
	Gomphidae	0	0	0	5	16
	Other Anisoptera	17	15	43	0	0
Zygoptera:	Chlorocyphidae	0	0	0	0	16
	Calopterygidae	0	0	0	12	51
	Coenagrionidae	0	0	0	5	27
	Lestidae	0	0	0	0	3
	Other Zygoptera	2	2	21	0	0
Plecoptera	Perlidae	30	1	10	10	19
Hemiptera	Gerridae	3	**0**	2	3	0
	Veliidae	0	0	149	0	40
	Notonectidae	0	0	0	0	3
	Pleidae	0	0	926	0	0
	Naucoridae	0	0	00	2	27
	Saldidae	0	0	0	0	3
	Other Hemiptera	3	4	32	0	0
Coleoptera	Elmidae	341	45	645	50	146

(Continued)

Table 1. (*Continued*)

Order/sub order	Family	1970/71			2013/14	
		Surber	Other	Drift	Surber	Other
	Gyrinidae	0	0	0	0	4
	Dytiscidae	28	9	31	16	50
	Hydrophilidae	0	0	0	20	84
	OtherColeoptera	0	0	34	0	0
Trichoptera	Hydroptilidae	79	12		29	53
	Polycentropodidae	0	0	0	13	48
	Philopotamidae	11	0	404	8	3
	Hydropsychidae	2249	78	5	154	648
	Leptoceridae	0	0	3	68	91
	Hydophilidae	0	0	0	0	84
	Barbarochthonidae	0	0	0	1	9
	Helicopsychidae	0	0	0	0	4
	Limnephilidae	0	0	0	11	44
	Other Trichoptera	101	6	42	0	219
Lepidoptera	Pyralidae	424	13	10	130	140
Diptera	Simuliidae	1457	495	289	0	5
	Chironomidae	6046	1026	714	566	717
	Ceratopogonidae	0	0	44	4	12
	Culicidae	50	8	63	76	52
	Tipulidae	0	0	0	9	20
	Tabanidae	0	0	0	10	3
	Psychodidae	0	0	0	0	9
	Ephydridae	0	0	0	2	14
	Athericidae	0	0	0	0	5

(*Continued*)

Table 1. (Continued)

Order/sub order	Family	1970/71			2013/14	
		Surber	**Other**	**Drift**	**Surber**	**Other**
	Muscidae	0	0	0	12	18
	Dixidae	0	0	0	0	1
	Other Diptera	113	4	15	0	54
Surber totals		18,978	2,977	6,225	1,622	3820
No. sampling days		25			10	
No. of surber samples		64			10	
Organisms per 1000 cm^2		297			162	
Average density/m^2		**2,965**			**1,622**	

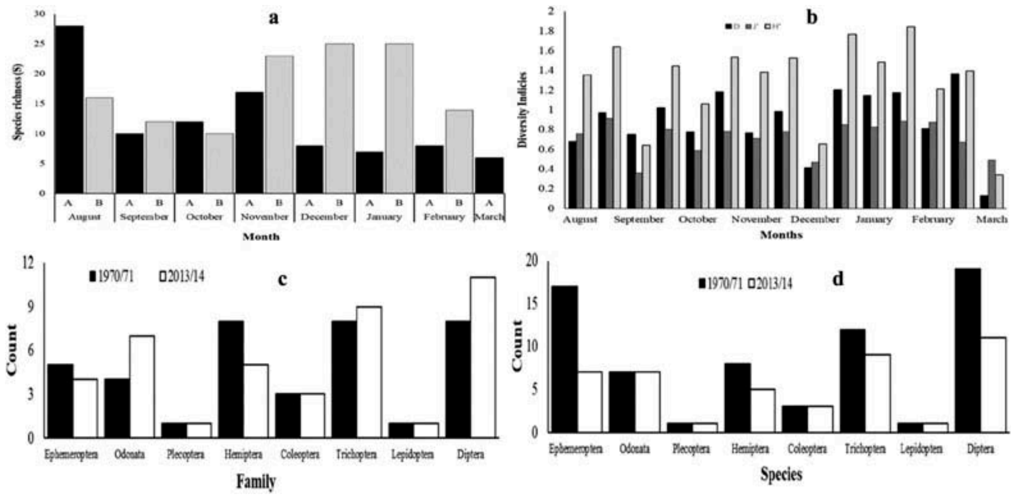


Figure 3. Summary of diversity indices for 2013/2014 sample (a and b) and comparison of count of insect families (c) and species (d) between studies in 1970/71 and 2013/2014 within the Pawmpawm River. Figure 3 (b), *D* = Simpson's Index, *J* = Pielou's evenness, *H* = Shannon-Wiener Index.

and March, respectively, Table 1) and the highest species richness (*S* = 28, 17, and 12 for August, November, and October, respectively, Figure 3(a)), with the lowest insect species abundance but relatively high species richness. September and October 2013, recorded the lowest abundance of (*N* = 133 and 158, respectively) and the lowest species richness (*S* = 12 and 10, respectively). March 2014 had the highest abundance (*N* = 535) as well as a relatively low species richness (*S* = 17) corroborated by the lowest Margalef index (*d* = 0.96). The recent study recorded a relatively lower evenness, (*J*′ = 0.67) in February. The three species, *Baetis* spp., *Cloeon* spp., and the Diptera Chironominae made up about 45% of the total numbers recorded in February 2014. Both studies had high evenness (*J*′ = 0.827) in the dry season (January) (Table 1) with individuals evenly distributed among the different species (Figure 2).

4.1. Aquatic insect abundance

The community of riffle in 1970/71 was dominated by the *Centroptilum* spp. 37% (20,039), Chironomidae 29% (15,495), *Cheumatopsyche* spp. 9% (4591), and *Simulium* spp. 8% (4295).

In contrast, the results of the current study in 2013/14 shows that the upper reaches of the river were dominated by four groups of insects, the Chironomidae 22% (857), *Hydropsyche* spp. 10% (330), *Cloeon* spp. 9% (306), and *Cheumatopsyche* spp. 8% (295). From the results presented in Table 1, the abundance of aquatic insects has substantially reduced from an average of under 3,000 individuals per square metre in 1970/71 to a little over 1,600/m^2 in 2013/14, a reduction of 45%. Results of a one-way ANOVA of insect records between the two studies show no significant differences between diversity ($P < 0.05$) but abundance was significantly lower in the latter study ($P < 0.001$). The reduced abundance was evident across all 10 months spanning wet and dry seasons and most marked in the case of the dominant families, Ephemeroptera, Diptera and Trichoptera. It is suggested that reduced forest cover in the catchment area of the river and reduced nutrient inputs, combined with greater variations in flow swinging from spates to quickly reduced flows, are responsible for the reduced numbers of species, even as the diverse community of aquatic insects has been maintained. The altered conditions allow for shorter periods for insect populations to build up in stable conditions between extremes of flow.

5. Discussion

Hynes (1975a, 1975b) recorded 38 families in the first study with Ephemeroptera, Diptera and Trichoptera constituting the dominant fauna while the 2013/14 study identified a total of 41 families. While diversity of aquatic insect species has been maintained in the latter study compared to the former, there has been a decrease in abundance of aquatic insect species. Amakye (2001) reported reductions in aquatic fauna densities within the Volta Lake 30 years after impoundment, with Chironomids constituting almost 90% of the total benthos. Samman and Amakye (2009) also recorded 19 families in the Ajenjua and Mamang Rivers with Chironomidae, Baetidae and Dytiscidae as the dominant families. Furthermore, Thorne et al. (2000) also recorded a total of 27 families in the Odaw stream with the Chironomids as the dominant fauna. The relatively higher number of families in the present study is an indication of a less degraded habitat than those other studies. This result agrees with a study by Durance and Ormerod (2007) that predicts 25% reduction in stream macroinvertebrates for every 1°C rise in atmospheric temperature. Our result and the prediction from Durance and Ormerod (2007) agrees with findings from Burgmer, Hillebrand, and Pfenninger (2007), Knouft and Ficklin (2017) and Garcia, Gibbins, Pardo, and Batalla (2017) who reported that freshwater macroinvertebrate diversity and abundance were affected by evidence of climate change. Although diversity was not affected in our study, a reduction in abundance is a clear evidence of the presence of climate and land-use change and their negative impacts on aquatic biodiversity in the study area (Pecl et al., 2017).

The current study recorded lower abundance of both *Simulium* and *Centroptilum* spp compared to the previous one. These groups were among the dominant groups of the 1970/71 study. Their abundances were 0.1% (5) and 5% (193), respectively, in the current study compared to 8% (2241) and 37% (10,130) in the 1970/71 study (Hynes, 1975a). The reduced abundance of *Simulium* species is partly due to the long-term control programme of river blindness in West Africa (Resh, Lévêque, & Statzner, 2004). On the other hand, abundance of the *Centroptilum* spp. can be attributed to the rise in current flow-evidence of climate change-of the river during the study period, making feeding difficult for these insect groups (Garcia et al., 2017; Yoshimura, 2012). All these reductions were also partly due the massive deforestation in the area. In general, the sample had a very low evenness because of dominance of a few species such as *Baetis* spp., *Cloeon* spp., Diptera and Chironominae in both studies. These groups constituted about 45% of the total recorded abundance in the recent study and are known to dominate invertebrate communities in fast flowing rivers (Liao et al., 2018; Steward et al., 2018).

The meteorological data from the GMA shows that atmospheric temperature in Ghana has increased by approximately 1°C between 1971 and 2013 (See Figure 2). Climate change over the past 30 years has produced a substantial number of shifts in the distribution and abundance of several animal and plant species and has been implicated in species-level extinction (Thomas et al., 2004; Wiens, 2016). Climate change projections are also predicted to affect aquatic systems negatively through rise in water temperatures and stream flow alteration (Poff, Brinson, & Day, 2002) with expected negative impacts on species phenology, distribution and productivity of aquatic ecosystems (Beaugrand & Kirby, 2018; Pecl et al., 2017; Poesch, Chavarie, Chu, Pandit, & Tonn, 2016). Based on evidences from findings from the above mentioned instead of stated research works and other similar works, we can partially explain trends in reductions in invertebrate abundance in the Pawmpawm River.

Of the total individuals recorded from the latter study in 2013/2014, three insect orders, Trichoptera, Ephemeroptera and Diptera were the most dominant orders as reported by Hynes (1975a) in the former study. The dominance of these orders is partly due to the following reasons; among the Ephemeroptera and Trichoptera, diversity of form and way of life vary widely as reported in previous studies (*Ab* Hamid & Rawi, 2014; Dijkstra, Monaghan, & Pauls, 2014). Hostile aquatic habitats have been colonised by these ancient aquatic group representatives. For instance, the Chironomidae dominate deep sediments of lakes; while torrential streams are populated almost entirely by Ephemeroptera (Glime, 2017; Herrmann et al., 2016). Moreso, many species of Plecoptera, Trichoptera and Diptera are adapted to this peculiar environment (Glime, 2017; Harding, 2005; Hynes, 1970). Our study also confirms an earlier observation made in a study that assessed ecosystems health of streams in Burkina Faso which recorded dominance by few insect groups especially Plecoptera, Ephemeroptera and Trichoptera (Kaboré et al., 2016). Kaboré et al. (2016) also observed a pattern of reduced abundances of these dominant groups along streams located in highly impacted environments. The flooding event which occurred in

October 2013 ensured a continuous flow of the river throughout the sampling period. These orders were continuously sampled reestablishing their place as early colonisers in ecological succession after disturbances (Glime, 2017; Herrmann et al., 2016; Hynes, 1975a). These insects also constitute important pathways for energy flow and vital for productivity of aquatic environments (Scholl, Rantala, Whiles, & Wilkerson, 2016).

Generally, the low abundance of the other orders can be attributed to highly diverse aquatic niches, and restricted habitat ranges (Dijkstra et al., 2014). Also, the structure of aquatic insect communities is closely tied to the physical habitat attributes and is further influenced by biological factors such as dispersal, competition, and predation (Brown et al., 2011; Jones, Jackson, & Grey, 2016).

6. Conclusion and recommendation

Insect abundance was higher in the former study compared to the latter study in 2013/14. This observation is partially due to loss of habitats resulting from massive deforestation that has taken place within this period (Fugère, Kasangaki, & Chapman, 2016). The impacts can sometimes extend over long distances leading to catastrophic flooding downstream (Allan & Flecker, 2013; Lima et al., 2014). The landscape matrix surrounding the forest had changed considerably in the latter study compared to the one encountered in the previous study in 1971, now characterised by farming activities and settlements. The local inhabitants also use the river as a source of water for cancel their domestic use and activities such as washing of clothes and household utensils and swimming directly inside the river 5 km from the sampled site. All these activities have contributed to the degradation or disruption of key ecological processes within the river's ecosystem. The river is also increasingly impacted by anthropogenic disturbances within the catchment area. The high alteration of habitats associated with human activities may have a broader geographic impact on community formation and ecosystem functions (Bloch & Klingbeil, 2016). Nevertheless, the catchment area still retains much of its closed canopy most probably due to the conservation efforts of keeping the area as a tourist site. This might have helped to preserve the forest integrity and resident biodiversity. From these two studies one cannot conclude that any species have disappeared or been extirpated from the upper reaches of the Pawmpawm River, nor that there are newly established, invasive species although there has been evidence of climate and land-use change over the years.

We recommend that the abundance and diversity of aquatic insect be regularly monitored within the Pawmpawm River. This is because the reduction in insect abundance in the latter study in 2013 seems to be directly correlated with change in climate and land-use. This makes aquatic insect diversity a good environmental monitoring tool for change in environment and land-use within the Pawmpawn river and other such rivers in Ghana and elsewhere.

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Competing Interests
The authors declares no competing interests.

Author details
Helen Nnoli[1]
E-mail: helennnoli@yahoo.com
Rosina Kyerematen[2]
E-mail: rkyerematen@ug.edu.gh
Samuel Adu-Acheampong[3]
E-mail: nanaakyampon@gmail.com
Julian Hynes[4]
E-mail: hynes.intl@yahoo.ca
[1] African Regional Postgraduate Program in Insect Science (ARPPIS), University of Ghana, Legon, Ghana.
[2] Department of Animal Biology and Conservation Science, University of Ghana, Legon, Accra, Ghana.
[3] Department of Agronomy, University for Development Studies, Nyankpala, Tamale, Ghana.
[4] Hynes and Associates, P.O. Box 57, Adeiso, Eastern Region, Ghana.

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