Seasonal changes in stream habitat structure and its relationship with fish community structure in a low gradient stream in Sunyani, Ghana

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Abstract

Studies on seasonal changes in stream structure and its effect on habitat quality, distribution, abundance and biomass of stream fishes in Ghana is limited. Understanding seasonal changes in stream habitat structure and adaptive responses of fish populations is essential for stream protection and conservation of stream ecosystems and their resident fish populations. Seasonal changes in stream structure, physicochemical characteristics and fish community structure were investigated in an urban stream in Sunyani, Ghana. Data was collected monthly from November 2016 to November 2017 at upstream, midstream and downstream sites. High spatial heterogeneity and temporal variability in stream structure affected by the dry and wet seasonal cycles was observed. Twelve species of fish belonging to eight families and ten genera were recorded, with catfishes dominating community biomass. The diet pattern of fish species differentiated the community into herbivore, piscivore and omnivore trophic levels. Herbivores were most abundant and consumed a wide range of plant-based food. Fish habitats disappeared and mortality increased upstream and midstream during the dry season. However, the downstream habitat persisted as a result of the unique morphology which resulted in a relatively deep depth, large canopy cover and presence of water lettuce *Pistia stratiotes* which minimized water loss. Water quality did not differ significantly across the stream in all seasons. Higher water clarity downstream co-occurred with *Pistia* proliferation along with elevated fish biomass during the dry season. Stream structure, rather than physicochemical characteristics, controlled fish biomass. Water quality and fish biomass were strongly correlated with seasonal *Pistia* abundance. Persistence of the downstream pool habitat during the dry season sustained habitat quality and increased fish survival. Maintenance of stream pools along with opportunistic aquatic vegetation in the dry season can sustain stream ecosystems and stabilize their fish communities and biotic structure.

Keywords: Aso Kwaku, Biomass, *Clarias gariepinus*, dry season, fish community, habitat quality, Stream structure, Sunyani

Introduction

Streams are complex aquatic ecosystems that serve as habitats for fish, invertebrates, plant and amphibian species, many of which use the aquatic environment permanently or temporarily in their life history (Gebrekiros 2016; Gorman and Karr 1978). They also serve as filters of the landscape and drainage basins facilitating the movement and recycling of sediment and materials (Allan and Castillo 2007; Jones 2016). Streams are structured by differentiation in physical, chemical, biological and ecological gradients over spatial and temporal scales (Pease et al. 2012; Schlosser 1987). Habitat structure is determined by characteristics such as size, flow, substrate composition, canopy cover, rifle-pool patterns which vary spatially and dictate the distribution and abundance of stream fishes (Winemiller et al.2008). Dynamic changes in stream structure typically involve longitudinal variation from shallow, upland channels to deep downstream reaches with fish communities structured along various environmental gradients (Fischer and Paukert 2008; Rowe et al.2009).

Tropical streams contain more diversified fish communities, greater genetic variation, taxonomic structure and ecomorphologies (Winemiller et al. 2008; Boulton et al. 2008;

Dudgeon 2011). These fish populations are highly sensitive to the high degree of spatial and environmental patterns of tropical stream habitats and their distribution reflect the response to variation in abiotic and biotic conditions (Pease et al. 2012; Sternberg and Kennard 2013). Environmental filtering of species influences the taxonomic structure and functional characteristics of fishes according to the degree of tolerance to environmental conditions (Pease et al. 2012). In most stream ecosystems, there is higher fish diversity in low-gradient pools; a direct outcome of greater species aggregations in expanded habitats due to the availability of more stable niches (Winemiller et al. 2008). Conversely, species composition frequently declines in upstream areas because stream habitats tend to simplify and restrict species occurrence (Schlosser 1987). Furthermore, dams and pollution in downstream areas may compromise the suitability of such habitats for less tolerant species and increase species richness in upstream areas due to fish species escaping from the inhospitable conditions occurring downstream (Kouamélan et al. 2003). Dominant abiotic and biotic factors limiting ecosystem and fish productivity in tropical streams include nutrients, shading, disturbance, food availability, trophic structure and food web interactions (Boulton et al. 2008, Wootton 1991). Increased ecological diversity of freshwater fish species in the tropics is related to their display of profound dietary flexibility often characterized by a generalist mode of feeding and adaptations for various plant and animal food materials such as seeds and fruits (Winemiller et al. 2008). In tropical stream fishes, form and function are strongly correlated leading to specialized niches and low niche overlaps particularly during the dry and wet season cycles when food types and abundance vary significantly (Herder and Freyhof 2006; Winemiller et al. 2008). Therefore, feeding ecomorphologies are highly adaptive to habitat characteristics and resource use (Angermeier and Karr 1983). The large spectrum of feeding diversity among tropical stream fishes may be attributed to the reliability of food resources needed to support their high productivity (Flecker 1992; Winemiller et al. 2008).

Tropical stream habitats experience strong seasonality that is driven by variation in patterns of rainfall which determine their physical structure, biogeochemical properties and productivity (Winemiller 1996; Winemiller et al. 2008). Rising water levels expand habitats, increase availability of food resources and enhance fish productivity (Lowe-McConnell 1987). By contrast, dry seasons are marked by low discharge, reduced habitable space and marked reductions in water quality, fish biodiversity and ecosystem productivity (Winemiller et al. 2008). Droughts cause stream contraction and reduce habitat diversity leading to heightened stress on fish populations and a downward trend in fish production (Winemiller 1996). In certain instances, pools may be isolated and disconnected from each other by retreating water levels and drying stream beds and these pools enhance fish survival in the dry season through maintenance of the aquatic habitat and preservation of community structure and ecological relationships (Chapman and Kramer 1991).

In an era of climate change and increasing anthropogenic impacts on natural ecosystems, understanding stream structure dynamics and responses of fish communities to these stressors is essential for enhancing stream protection and freshwater biodiversity conservation interventions in this data-sparse region (Millennium Ecosystem Assessment 2005). Moreover, anthropogenic pressures resulting from dams, water withdrawal, overfishing, rapid urbanisation, agriculture, pollution and other harmful land use activities have debilitating consequences on stream ecosystems and to the already threatened fish species of the region (Millennium Ecosystem Assessment 2005; Abell et al. 2008). The aim of the present study therefore is to determine how seasonal changes in stream habitat structure affect fish populations in an urban stream of this ecologically-sensitive region. This study is the first comprehensive assessment of any stream habitat in this freshwater ecoregion of Ghana as no published records of prior research work have been documented. Inadequacies in the inventories of inland freshwater fishes also exist in Ghana (MoFAD, 2015).

Material and Methods

Study Area

The Aso Kwaku stream located at 7^{o} 22'58" N and 2^{o} 21' 35" W is a low-gradient, 3.2 km clearwater first-order stream located between Fiapre and Dumasua in the Sunyani municipality of the Bono region of Ghana (Fig. 1). In terms of biogeography, the stream is confined within the Eburneo freshwater ecoregion of the world (Abell et al. 2008), which contains some of the most imperiled ecosystems and freshwater fish species in the world (Millennium Ecosystem Assessment 2005). The location of the stream can be characterized as urban, draining a mosaic of agricultural, residential, forest and industrial landscapes. The municipality covers a total land area of 506.7 km^2 and is located at latitude 07^0 20' 47" N and longitude 002^0 17'06" W (WRC 2012). The stream is located within the Black Volta basin which is one of the major watersheds in the country and experiences double rainfall maxima annually (WRC 2012). The stream takes it source from a wetland at a suburb called Berlin Top and meanders through residential and agricultural (crop and animal husbandry) landscapes, merges with another stream (Attadae) further downstream to form a second order system eventually discharging into a low elevation floodplain. The Aso Kwaku stream provides a source of water for domestic, industrial (housing construction and development) and agricultural (irrigation) purposes. Most surface water systems in the municipality are heavily polluted and are devoid of aquatic life (personal observations). Monthly temperatures vary between a low of 23 ºC in August to a high of 33 ºC between March and April. The average annual rainfall is 890 mm with a maximum occurring in May/June. Relative humidity averages between 75 % and 80 % during the wet season and below 70 % during dry periods (WRC 2012).

Measurement of stream habitat structure

Sampling was conducted monthly at the selected upstream, midstream and downstream sites from November 2016 to November 2017 covering the dry and wet seasons. Stream structure was measured along a longitudinal gradient from upstream to downstream sites. At each site, 50 m of the channel was selected and divided into 10 m replicates for sampling habitat variables (Wetzel and

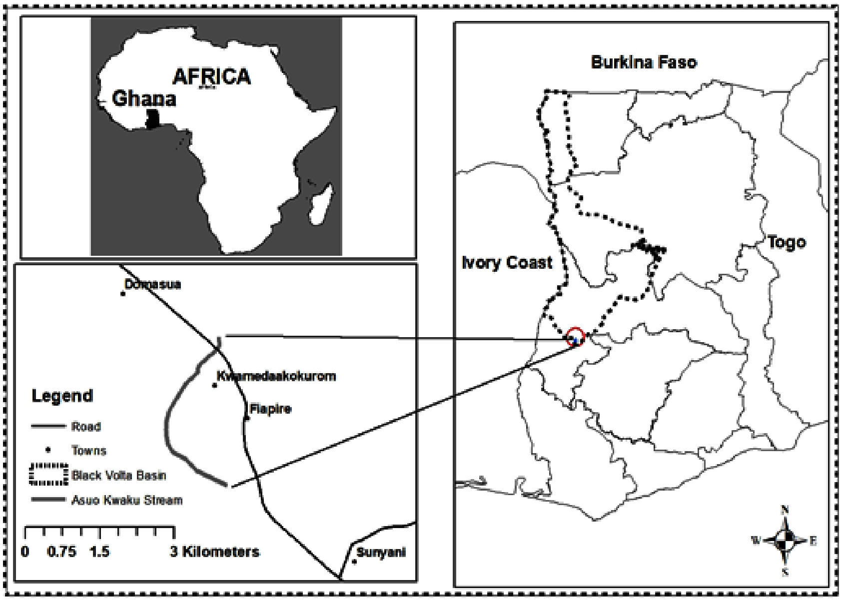

Figure 1 Map of stream and its geographical location in Sunyani

Likens 2000). Five replicates of habitat variables were therefore obtained at each site. In total, sixty site replicates for spatial data and twelve replicates of temporal variations in site conditions were obtained. Habitat variables measured included stream depth, channel width, canopy cover and substrate composition and mean values were computed. Extensive mats of *Pistia stratiotes* (water lettuce) and low densities of floating-leafed *Nymphaea* co-occurred to form the resident macrophyte vegetation. Dense mats of *Pistia stratiotes* were observed to occur mostly at the downstream site during the dry season relative to upstream and midstream sites. The percentage areal cover of the floating *P. stratiotes* was subsequently estimated from the stream surface area. The abundance of *P. stratiotes* could potentially influence habitat qualities particularly water chemistry and food availability for the resident biota, therefore an analysis of the relationship of *Pistia* with water chemistry and fish biomass were performed. Dense swarms of different types of insects including dragonflies and mayflies were observed to be associated with the *P. stratiotes* stands particularly during the dry season. The areal cover of *P. stratiotes* was monitored and measured throughout the study period and the abundance correlated with fish biomass.

Measurement of physicochemical variables

Physicochemical variables were measured concurrently with habitat and fish community variables at each site, with the number of spatial and temporal replicates corresponding to that obtained for habitat structure. Temperature, dissolved oxygen, conductivity, salinity, pH and TDS were measured with a multiparameter probe (HANNA H19829). Transparency was measured with a Secchi disk mainly at the deep downstream site as an estimate of stream turbidity.

Fish Capture

Fishing took place weekly, using a combination of gill nets and steel-mesh traps at all sites to capture both juveniles and adults. Gill nets of mesh size of one-inch and steel-mesh traps of mesh size one inch were usually deployed for twelve hours from 6pm to 6am the following day. Usually, a gill net and steel mesh trap were deployed at 10 m intervals over the 50 m section at each site resulting in a total of five gill nets and five steel-mesh traps used for fish sampling. Fry and juveniles were prevalent in midstream and upstream sites but could not be readily identified taxonomically, so no further analysis was carried out on these developmental stages. Fish species captured were mostly adults which were subsequently identified with the taxonomic reference guide of Dankwa et al. (1999). All fish samples were weighed in grams (g) and standard lengths measured in centimeters (cm).

Laboratory analysis

To determine diet and stomach content of the various fish species in the stream, individuals caught were dissected and the gut contents examined under a combination of magnifying lenses and compound light microscope to identify food items consumed. Food items were categorized into broad groups of insects, fish, plant materials and plankton and both percentage frequency of occurrence and percentage numerical occurrence were determined. Length frequency distributions and Condition index, K were also computed. Percentage frequency of occurrence was derived from the formula;

$$\%\,O_i = (N_i / N) \times 100$$

where $\%\,O_i$ is the frequency of occurrence of given food i, N_i is the number of stomachs containing prey i, and N is the total number of stomachs with some food. Similarly, percentage by number was determined from the expression $\%\,N_i = (N_i / N) \times 100$, where $\%\,N_i$ is the percentage of the food item i, N_i is the number of particular food item i, and N_t is the total number of food (gut content) items. Fulton's Condition Index, K, was calculated as

$$K = 100 \times (W/L^3)$$

where K is the Condition Index, W is the weight of the fish and L, the length.

Statistical analysis

Summary statistics were computed for habitat, water chemistry and fish community variables. Analysis of Variance (ANOVA) was used to examine significant differences in the physical and water quality variations among the three sites. Prior to the ANOVA, normality tests were performed to ascertain that the data was normally distributed. For sample size of less than 50, as we have in this study, the Shapiro-Wilk test is considered the most appropriate test of normality (Shapiro & Wilk, 1965). The relationship among stream structure, water quality and fish biomass variables were analysed with Pearson statistical correlations and the correlation coefficients (r) computed to evaluate the amount of variation in habitat and water variables that could explain variation in fish community biomass at 5% probability level ($p < 0.05$). A canonical correlation model (CCA) was used to further analyse the relationship among stream structure, water quality and fish biomass. No transformation was required for the CCA, since all the fit indices (Pillais, Hotellings, Wilks, and Roys) were significant. All statistical tests and summary statistics were computed with SYSTAT statistical software version 10 (SYSTAT Inc.).

Results

Stream structure and longitudinal gradients in morphology

Stream structure and morphology were characterized by high variation in depth, channel width, substrate composition and canopy cover from upstream to downstream sites. Greater depth, width and canopy cover were recorded downstream relative to upstream and midstream points of the stream. Channel width and depth increased from upstream to downstream (Table 1). Stream depth at upstream was 36% (0.19± 0.02 m) but increased to 66% (0.74 ± 0.19 m) downstream. Channel width showed similar patterns along the longitudinal gradient of the stream increasing from 7% (1.27 ± 0.19 m) upstream to 76% (5.74 ± 0.43 m) downstream. By contrast, the pattern of variation in canopy cover was different to the longitudinal pattern in stream size. Lowest canopy cover was observed at the midstream section (12.80 ± 10.55%) whilst highest values were recorded downstream (53.61 ± 16.95%). Flow in the downstream was negligible signifying predominantly stagnant, quiet pool conditions throughout the dry and wet seasons (Table 1). Overall, the stream was generally characterized by a

TABLE 1

Mean ± standard deviation and range of habitat and water quality variables in upstream, midstream and downstream sites of the Aso Kwaku stream. n = 13

Habitat variable	**upstream**		**midstream**		**downstream**	
	Mean ± sd	Range	Mean ± sd	Range	Mean ± sd	Range
Depth (m)	0.19 ± 0.02	0.15 - 0.22	0.25 ± 0.22	0.12 - 0.64	0.74 ± 0.19	0.42 - 1.13
Width (m)	1.27 ± 0.19	1.03 - 1.40	1.37 ± 0.22	1.04 - 1.59	5.74 ± 0.43	5.32 - 6.70
Canopy Cover (%)	25.25 ± 14.11	15.00 - 30.00	12.80 ± 10.55	2.00 – 26.00	53.61 ± 16.95	30.00 -85.00
Substrate	80 % mud		60% mud		85 % mud	
	10 % stones		40 % stones		15 % stones	
	10 % leaf litter					
DO (mg L^{-1})	2.46 ± 0.78	1.17 – 3.19	2.2 ± 0.92	1.26 – 3.06	2.89 ± 0.49	2.30 – 4.16
pH	7.29 ± 0.42	6.56 - 7.61	7.29 ± 0.75	6.22 - 7.96	7.56 ± 0.54	6.91 - 8.50
Temp. (^{o} C)	25.54 ± 1.76	23.90 - 27.40	23.99 ± 2.3	21.90 - 27.10	25.16 ± 1.43	23.96 - 27.82
EC (µS/cm)	360.68 ± 46.02	298.4 - 417.80	342.19 ± 52.33	265.25 - 379.80	361.6 ± 128.82	252.8 -317.00
Salinity (psu)	0.19 ± 0.02	0.18 - 0.21	0.16 ± 0.03	0.12 - 0.18	0.17 ± 0.02	0.12 - 0.19
TDS (mg L^{-1})	191.84 ± 12.20	184.80 - 213.60	171.12 ± 30.42	126.75 - 192.2	169.83 ± 22.74	147.0 -198.33
Transparency (m)	100 %		100 %		0.59 ± 0.19	0.23 – 0.74

TABLE 2

Results of the test of normality of data prior to ANOVA analysis

Variables	Shapiro-Wilk		
	Statistic	df	Sig.
Weight	0.681	42	0.534
Length	0.706	42	0.559
Stream depth	0.965	42	0.818
Stream width	0.858	42	0.711
Canopy (%)	0.768	42	0.621
pH	0.689	42	0.542
Temperature	0.948	42	0.801
Conductivity	0.923	42	0.776
Dissolved Oxygen	0.763	42	0.616
Salinity	0.294	42	0.147
TDS	0.398	42	0.251

wider, deeper channel and elevated canopy cover at the downstream site. The substrate was made up of predominantly mud, stones and leaf litter in all sites but the proportion of each material varies spatially along the length of the stream. Muddy substrates dominated the downstream site with pool conditions whilst the fast flowing upstream was marked by relatively high amounts of stones and coarse sand (Table 1). All variables measured were approximately normally distributed, because the p-values (Sig.) are all greater than 0.05 (Table 2). Longitudinal differences in stream structure were observed. Stream depth, canopy cover and velocity did not differ significantly between upstream and midstream sites.

These morphological characteristics were sharply contrasted with significant difference between upstream/downstream on one hand and downstream on the other ($p< 0.05$, n = 13). An exception was upstream versus midstream depth, canopy cover and stream flow ($p> 0.05$, n = 13).

Seasonal variability in stream morphology was low. However, stream channel dried up in upstream and midstream sites from January to April during the dry season which usually extends from November to late March. During the dry season, upstream and downstream sites were disconnected by drying of the stream at the upstream site. The rainy season is typically bimodal. The duration of the rainy season is relatively longer beginning in April through to October with a seasonal maximum in May/June and a secondary peak in September/October. There was higher variation in stream depth than channel width at the downstream reach during the rainy season.

Gradients in stream water quality

Water quality variables showed varied correlations among upstream, midstream and downstream sites (Table 3). . Upstream and midstream water quality conditions were generally uniform with low variability (Table 1 and 3). With the exception of dissolved oxygen, all water quality variables did not change significantly across the stream ($p > 0.05$). Levels of pH, temperature and dissolved oxygen were higher in the downstream site compared with upstream and midstream sites. However, upstream sites showed highest levels of salinity and TDS. Generally, high values of pH, conductivity, dissolved oxygen, salinity and TDS were recorded in the dry season. The rainy season was however associated with low water temperatures. Transparency was high throughout the year with the stream bed visible most times at all sites. Highest transparency in the dry season co-occurred with the *in-situ* development of *Pistia* vegetation.

Fish community composition and biomass structure

Adult fishes were identified with appropriate taxonomic keys (Dankwa et al., 1999). Twelve

TABLE 3

ANOVA results of the statistical differences in habitat and water quality variables among stream sections at 5 % significance level ($p < 0.05$). Upstream (US), midstream (MS) and downstream (DS)

Variables	**US vrs MS**	**US vrs DS**	**MS vrs DS**
Depth (m)	0.228	0.001*	0.028
Width (m)	0.030*	0.000*	0.000*
Canopy Cover (%)	0.709	0.013*	0.010*
DO (mg/L)	4.520	0.271	0.174
pH	0.979	0.361	0.769
Temp. (^{o} C)	0.295	0.276	0.789
EC (µS/cm)	0.590	0.150	0.779
Salinity (psu)	0.118	0.113	0.620
TDS (mg/L)	0.202	0.088	0.807

species of fish belonging to eight families and ten genera inhabited the stream but only those inhabiting the midstream and downstream sites could be identified with reasonable certainty based on the taxonomic key used (Table 4). This included mainly four catfish species and four cichlids. With the exception of *Clarias gariepinus* (Burchell, 1822), *Oreochromis niloticus* (Linnaeus, 1758) and *Hemichromis fasciatus* (Peters, 1857) all other species showed variable seasonal occurrence in the stream (Table 4). *Heterobranchus longifilis* (Valenciennes, 1840), *Marcusenius abadii* (Boulenger, 1901) and *Brycinus nurse* (Reppelle, 1832) were exceptionally rare, occurring in October/November during the transition to dry season and the rainy season in June respectively. Large sized fishes were absent from upstream, but midstream sites harboured mid-sized *H. fasciatus*, *Hemichromis bimaculatus* (Gill, 1862) and *Oreochromis niloticus* (Linnaeus, 1758) and downstream sites harboured large, adult fish species. These fish species disappeared with the drying up of the midstream site. Juveniles and fry were encountered in both upstream and midstream sites but these could not be easily identified to genus and species level. The fish community was dominated by the catfish in terms of abundance and biomass exemplified by *C. gariepinus* as the dominant species in the community. Species richness and abundance were high in the dry season and low in the rainy season (Table 4) similar to the biomass patterns which had a high peak in January and a seasonal low in November

TABLE 4

Taxonomic composition and monthly occurrence of fish species in the downstream site of the Aso Kwaku stream. Plus, and minus signs indicate presence (+) and absence (-) of species

Species	N	D	J	F	M	A	M	J	J	A	S	O	N	Total
Clarias gariepinus (Burchell, 1822)	+	+	+	+	+	+	+	-	+	+	+	+	+	190
Clarias senegalensis (Valenciennes, 1840)	+	+	+	+	+	+	+	+	+	+	+	-	+	26
Sarotherodon galileaus (Linnaeus, 1758)	+	-	+	+	+	+	+	-	-	+	-	-	-	7
Hemichromis fasciatus (Peters, 1857)	+	-	+	+	+	+	+	+	+	-	+	-	+	46
Oreochromis niloticus (Linnaeus, 1758)	+	+	+	+	+	+	+	+	+	+	+	+	+	90
Chrysichthys nigrodigitatus (Lacepède, 1803)	-	+	-	-	-	-	+	-	+	+	+	+	-	12
Channa obscura (Günther, 1861)	-	+	+	-	-	+	+	+	-	+	+	-	-	7
Hemichromis bimaculatus (Gill, 1862)	-	+	+	+	-	-	-	-	-	-	+	+	+	38
Brycinus nurse (Reppelle, 1832)	-	-	-	-	-	-	-	+	-	-	-	-	+	6
Marcusenius abadii (Boulenger, 1901)	-	-	-	-	-	-	-	+	-	-	-	-	-	6
Heterobranchus longifilis (Valenciennes, 1840)	-	-	-	-	-	-	-	-	-	-	-	+	+	20
Hydrocynus forskahlii (Cuvier, 1819)	-	-	-	-	-	-	-	-	-	-	+	+	+	24

(Fig. 2). *Clarias gariepinus* and *C. obscura* had highest mean lengths and biomass (Table 5). Emergence and development of floating aquatic vegetation was characteristic of the seasonality of the stream ecosystem which increased in areal cover in the dry season. Dense mats of *Pistia stratiotes* floated on the surface and occupied an average of 72 % of stream surface area (Table 6). Maximum recorded body lengths and biomass in the fish community was for *C. gariepinus* at 50 cm and 998 g respectively. Non-linear regression (power analysis) was performed on length and corresponding weight of eight fish species

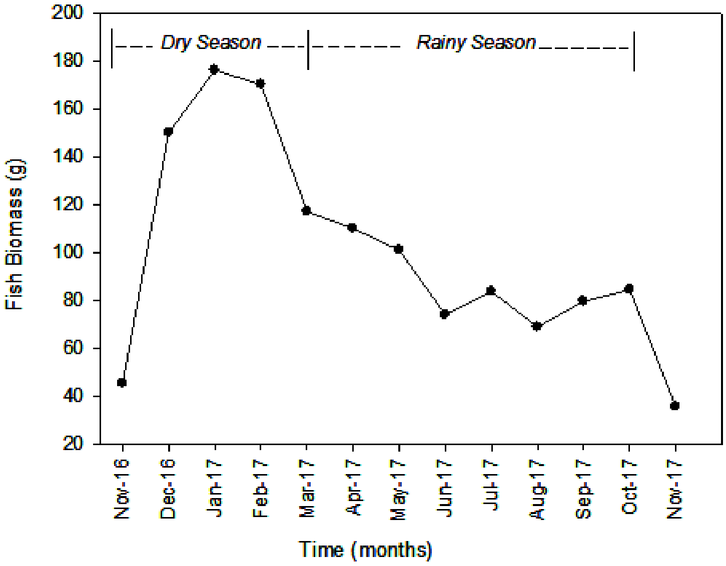

Figure 2 Seasonal variation in fish biomass in the Aso Kwaku stream

TABLE 5

Mean length (cm) and biomass of fish species

Species	**Biomass**		**Body Length**		**Sample**
	Mean ± sd	Range	Mean ± sd	Range	Size (*n*)
Clarias gariepinus (Burchell, 1822)	115.10 ± 101.10	38.00 – 998.00	21.30 ± 3.70	16.00 – 50.00	190
Clarias senegalensis (Valenciennes, 1840)	76.60 ± 49.80	32.00 – 142.00	15.50 ± 6.90	9.10 – 24.00	26
Sarotherodon galileaus (Linnaeus, 1758)	26.00 ± 0.00	26.00 – 26.00	14.00 ± 0.00	14.00 – 14.00	7
Hemichromis fasciatus (Peters, 1857)	35.90 ± 17.50	9.00 – 85.00	9.80 ± 1.80	4.00 – 13.00	46
Oreochromis niloticus (Linnaeus, 1758)	44.50 ± 33.60	8.00 – 155.00	10.20 ± 2.40	7.00 – 16.50	90
Chrysichthys nigrodigitatus (Lacepède, 1803)	60.00 ± 10.30	48.00 – 66.00	13.30 ± 1.20	12.00 – 14.00	12
Channa obscura (Günther, 1861)	172.50 ±54.40	134.00 – 211.00	23.00 ± 2.10	21.50 - 24.50	7
Hemichromis bimaculatus (Gill, 1862)	10.20 ± 3.00	4.00 – 15.00	6.80 ± 1.10	5.00 – 9.50	38
Brycinus nurse (Reppelle, 1832)	7.00 ± 0.00	7.00 – 7.00	6.50 ± 0.50	6.00 – 7.00	6
Marcusenius abadii (Boulenger, 1901)	92.60 ± 33.50	58.00 – 125.00	19.30 ± 2.10	16.90 – 20.50	6
Heterobranchus longifilis (Valenciennes, 1840)	85.50 ± 23.30	69.00 – 102.00	19.50 ± 0.70	19.00 – 20.00	20
Hydrocynus forskahlii (Cuvier, 1819)	67.50 ± 67.40	13.00 – 166.00	16.60 ± 4.70	11.00 – 22.50	24

TABLE 6

Percentage cover of Pistia stratiotes on downstream site

Month	Percentage (%)
Nov	70
Dec	80
Jan	80
Feb	70
Mar	70
Apr	60
Mean	72 %

(Table 7) . The growth equation is described by the mathematical expression

$$W = a L^b$$

where W = weight of fish, L = standard length of fish, a = intercept and b = slope. Fish biomass increased with decreasing depth as depicted by the negative but strong correlation between stream depth and fish biomass (Fig. 3).

Habitat influences on fish community biomass variations

Dissolved oxygen, channel width and *Pistia stratiotes* cover (percentage surface area) were positively correlated with total community biomass (Table 8). By contrast,

TABLE 7

Results of the length-weight non-linear regression (power analysis) of fish species. Growth equation is $W = a L^b$, where W = wet weight, L = standard length, b = slope, a = intercept. All regressions were significant at $p < 0.0001$. Species not shown in the table had insufficient number of individuals to perform analysis

Species	Intercept (*a*)	Gradient (*b*)	Equation	R^2	Normality Test	n
Clarias gariepinus	0.036	2.617	W = 0.036 L 2.6179	0.985	P = 0.994	85
Clarias senegalensis	0.050	2.505	W = 0.050 L 2.505	0.775	P = 0.882	15
Hemichromis fasciatus	0.036	2.981	W = 0.036 L 2.981	0.828	P = 0.612	26
Oreochromis niloticus	0.056	2.792	W = 0.056 L 2.792	0.467	P = 0.001	51
Chrysichthys nigrodigitatus	2.150	1.290	W = 2.150 L 1.290	0.627	P = 0.974	10
Hemichromis bimaculatus	1.042	1.183	W = 1.042 L 1.042	0.435	P = 0.641	19
Heterobranchus longifilis	0.004	3.402	W = 0.004 L 3.402	0.908	P = 0.868	15
Hydrocynus forskahlii	0.002	3.627	W = 0.002 L 3.627	0.983	P = 0.440	12

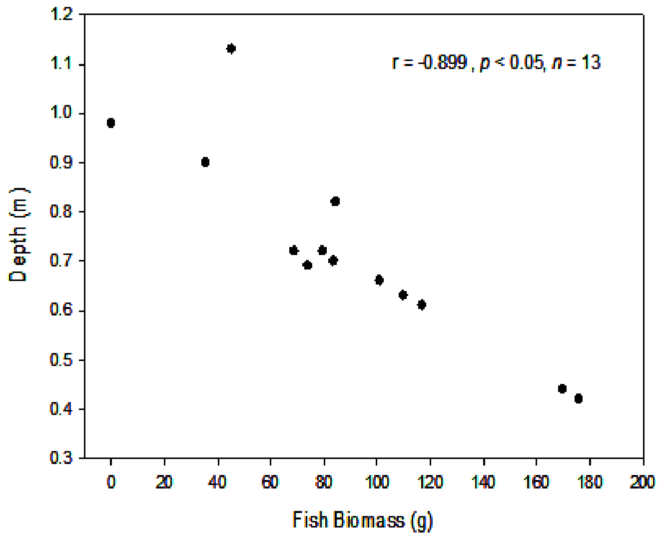

Figure 3 Covariation of stream depth and fish community biomass

TABLE 8

Correlation analysis between total community fish biomass with habitat and water quality variables. Correlation coefficient (r) all significant at 5 % significance level ($p < 0.05$)

Variables	Total Biomass
DO (mg/L)	0.638
Temp. (° C)	-0.173
EC (µS/cm)	-0.393
pH	-0.753
Salinity (psu)	0.131
TDS (mg/L)	0.131
Depth (m)	-0.899
Canopy (%)	-0.369
Width (m)	0.305
Pistia stratoites cover (% surface area)	0.639

pH, stream depth, canopy cover and electrical conductivity showed negative correlation with fish biomass (Table 7). Fish biomass responded strongly to increasing DO (r = 0.638, p < 0.05, n = 13) and *P. stratiotes* (r = 0.639, p < 0.05, n = 13) particularly in the dry season (Fig. 4 and 5). These variables explained 64 % of the seasonal variation in community biomass. Stream width however showed a weaker effect on fish biomass accounting for less than 40 % of the fish biomass variation (r = 0.305, p < 0.05, n = 13). Mean stream pH was generally neutral ranging from 7.2 – 7.5. Stream depth (r = - 0.899, p < 0.05, n = 13) and pH (r = -0.753, p < 0.05, n = 13) were inversely correlated with fish biomass indicating increased fish biomass with lower pH and shallow stream depth (Table 8 and Fig. 3). Length frequency distribution of the various fish species show the numerically dominant species (Fig.6).

Canonical Correlations Analysis (CCA)

The canonical correlations model describes the fit of the model to the derived data on stream structure, physicochemical variables and fish biomass. Generally, the reported multivariate criteria showed that all values were significant with *p* < 0.05 (Pillai 1955; Hotelling 1935; Wilks 1946; Roy 1957). The significant probability value indicates that the model fits the data adequately. Table 9 shows the canonical correlation coefficients and the eigenvalues of the canonical roots. It was found that the first canonical correlations coefficient is 0.917 with an explained correlation variance of 79 % and an eigenvalue of 5.314 generally indicating that stream structure and water quality variables positively influenced fish biomass. The stream structure parameters had greater influences on the first canonical variate than the water quality parameters.

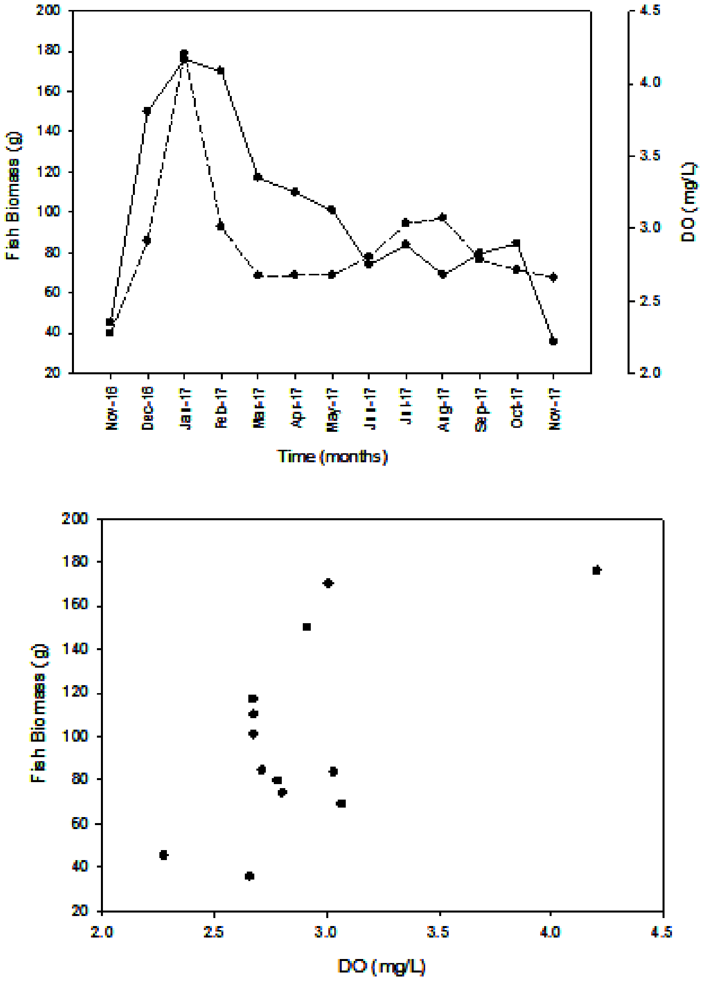

Figure 4 Patterns of variation between dissolved oxygen concentration and fish community biomass

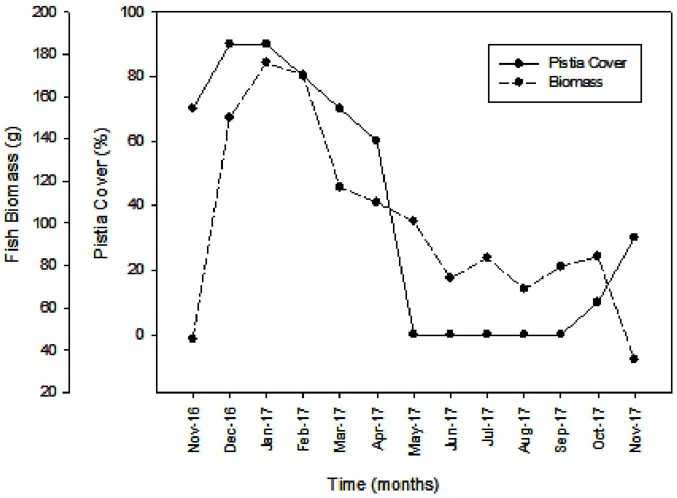

Figure 5 Patterns of variation between *Pistia stratiotes* cover and fish community biomass

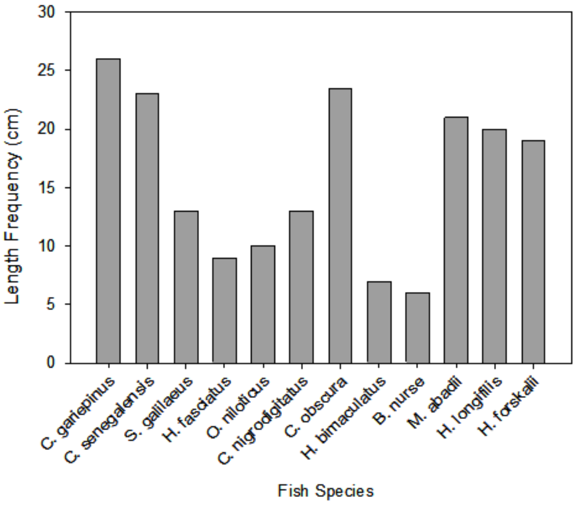

Figure 6 Length frequency distribution of fish species

Stream depth exerted a strong effect on the first canonical variate among the covariates while temperature, dissolved oxygen, salinity and TDS had the least influence (Table 10).

Diet and stomach content of fish species

From the stomach content analysis performed, three potential trophic levels were identified within the fish community namely herbivores, piscivores and omnivores (Table 11). Herbivores comprised the cichlids and *B. nurse* both of which fed predominantly on plant and detritus-based materials. The number of species occupying the herbivore niches was more abundant than any other trophic level. Catfishes had extensive dietary overlaps and wider diet breadth exhibiting mainly omnivorous feeding habits by consuming a wide range of food items such as fish, decapods, plant materials, seeds, fruits, insects and detritus. Complete insectivorous fishes were absent but insects formed a significant component of the diets of catfishes only. *H. forskahlii* consumed small fishes and was exclusively piscivorous.

TABLE 9

Eigenvalues and canonical correlations

Root No.	Eigenvalue	Pct.	Cum. Pct.	Canon. Cor.	Sq. Cor
1	5.31368	78.98262	78.98262	0.91740	0.84161
2	0.02494	21.01738	100.00000	0.15600	0.02434

TABLE 10

Canonical coefficients for covariates

Variable	Canonical Function I Standardized Coefficients	Canonical Function I Unstandardized Coefficients	Canonical Function II Standardized Coefficients	Canonical Function II Unstandardized Coefficients
Stream depth	4.958	6.977	0.175	0.246
Stream width	-7.071	-255.801	0.558	20.188
Canopy	4.394	0.367	0.103	0.008
pH	-0.926	-3.945	-1.052	-4.481
Temperature	0.001	0.001	0.001	0.001
Conductivity	3.104	0.151	-0.338	-0.016
Dissolved Oxygen	0.001	0.001	0.001	0.001
Salinity	0.001	0.001	0.001	0.001
TDS	0.001	0.001	0.001	0.001

Frequency and percentage occurrence of food items and Condition Index

Plant-based food was the dominant constituent of the diet of fishes, followed by insects in terms of frequency of occurrence and numerical percentages of the total food items consumed by fish species. Food items made up of fish and other animal parts formed a minor fraction of the food ingested (Table 12). Higher length frequencies were recorded for catfishes (Fig.6). Condition Index was highest for cichlid fishes comprising *H. fasciatus*, *S. galileaus*, *O. niloticus* and *H. bimaculatus* (Table 13). Catfishes had the lowest condition index.

Discussion

The Aso Kwaku stream exhibited a general morphology typical of many tropical stream ecosystems. Morphometric parameters such as channel width, depth and other abiotic factors including amount of canopy cover and substrate composition varied significantly along an upstream-downstream gradient creating distinct habitats for fish populations. High water retention persisting through both the wet and dry seasons was found at the downstream site which also had predominantly standing water conditions. Key abiotic variables such as channel width, depth, canopy cover,

TABLE 11

Diet and food preference of various fish species

Species	Gut content	Sample size (n)
Clarias gariepinus (Burchell, 1822)	Fish, plant material, seeds, insects, decapods	190
Clarias senegalensis (Valenciennes, 1840)	Fish, insects, plant material, detritus	26
Sarotherodon galileaus (Linnaeus, 1758)	Plant material	7
Hemichromis fasciatus (Peters, 1857)	Plant material	46
Oreochromis niloticus (Linnaeus, 1758)	Plant material	90
Chrysichthys nigrodigitatus (Lacepède, 1803)	Plant material, insects, detritus	12
Channa obscura (Günther, 1861)	Fish, insects	7
Hemichromis bimaculatus (Gill, 1862)	Plant material	38
Brycinus nurse (Reppelle, 1832)	Plant material	6
Marcusenius abadii (Boulenger, 1901)	Empty	6
Heterobranchus longifilis (Valenciennes, 1840)	Fish, plant material, seeds, insects	20
Hydrocynus forskahlii (Cuvier, 1819)	Fingerling of *Brycinus nurse*	24

TABLE 12

Percentage frequency of occurrence and numerical percentage of food items in the stomach content of fish species identified

Food items	% Frequency of occurrence	% Numerical
Plant material	60	50.90
Fish fingerling	5	5.45
Insects	15	20.00
Pawpaw seed	10	12.72
Seeds	5	7.27
Crab parts	5	3.40
Total	100	100

TABLE 13

Fulton's Condition Index K of various fish species

Species	Condition index
Clarias gariepinus (Burchell, 1822)	0.662
Clarias senegalensis (Valenciennes, 1840)	1.079
Sarotherodon galileaus (Linnaeus, 1758)	3.356
Hemichromis fasciatus (Peters, 1857)	3.608
Oreochromis niloticus (Linnaeus, 1758)	3.818
Chrysichthys nigrodigitatus (Lacepède, 1803)	2.455
Channa obscura (Günther, 1861)	1.417
Hemichromis bimaculatus (Gill, 1862)	3.079
Brycinus nurse (Reppelle, 1832)	2.867
Marcusenius abadii (Boulenger, 1901)	1.286
Heterobranchus longifilis (Valenciennes, 1840)	1.320
Hydrocynus forskahlii (Cuvier, 1819)	1.504

dissolved oxygen and amount *Pistia* cover was positively correlated with fish diversity, abundance and biomass in the stream. On the basis of adult fishes caught, species richness was high in the downstream site but similar patterns may be present in upstream and midstream site, except that only juveniles were found that could not be identified to species level. The observed increase in species richness of adults along the upstream to downstream gradient of streams follows the general pattern of increased species richness with increasing stream size (Hugueny 1990). The pattern of species distribution, reflected by the structural and environmental variability in the stream further highlighted the importance of environmental factors in shaping species assemblages (Gebrekiros 2016).

Low to no-flow episodes observed in the upstream and midstream sites during the dry season resulted from the lack of rainfall and subsequent disruption in stream connectivity from the headwaters. Seasonally, the upstream and midstream sites dried up whereas downstream areas remained at almost bankfull levels throughout the dry season. Spates or drying of streams have been shown to affect stream structure and distribution of stream fishes but elevated *insitu* production and population increases have been linked with pools that persist into the dry season (Chapman and Kramer 1991, Chapman et al. 1991). This rainfall regulation of stream structure is consistent with the prominence of hydrology in shaping habitat structure of streams in the tropics (Winemiller et al. 2008). Habitat structure of the downstream site was also influenced by the permanence of water throughout the dry and rainy seasons as well as the high canopy cover which reduced direct evaporation on the water surface leading to reduced water loss. The combination of these factors contributed to stable habitat conditions for the fish community and the possible maintenance of critical ecological relationships.

High dissolved oxygen concentrations in the stream may suggest reduced biological oxygen demand and limited organic pollution from anthropogenic activities originating from the urban landscape. This suggests high stream water quality conditions which was found to be spatially uniform and seasonally less variable. Low dissolved oxygen concentration in water is evidence of organic matter pollution and increased biological oxygen demand (Wen et al. 2017) but the consistently high DO in the water column suggest limited organic matter pollution from the catchment run-off of point and non-point sources of pollutants and rapid water renewal rates, which increases rates of flushing. Dissolved oxygen level was highly correlated with community biomass as it is one of the critical factors regulating fish physiology and growth and therefore regulates community composition of freshwater fishes (Jackson et al. 2001; Ostrand and Wilde 2001). High water quality and transparency was observed during the dry season at the downstream site which was linked with a break in stream connectivity and flow from upstream. Lack of flow and sediment transport from upstream to downstream sites occurred as a result of drying of the former. The lack of flow and subsequent break in the transport of suspended particulate and dissolved organic and inorganic substances to the downstream site may have resulted in increased water stagnation. This condition may have caused rapid sedimentation of suspended materials over the shallow depth of the channel, thus clarifying the water column in the process. The stagnant conditions may have stimulated the emergence and progressive proliferation of *P. stratiotes* which covered an average of 72 % of the surface area of the stream during the dry season. The *P. stratoites* proliferation was associated with seasonally high fish community biomass which could have been enhanced by the high-water clarity mediated by the presence of *P. stratoites* as noted by Wang et. al (2018).

The proliferation of floating *P. stratiotes* on the water surface of the stagnant downstream site is further evidence of the extent of water column stability but other floating vegetation such as the broad-leafed *Nymphaea* were also present. *Pistia stratiotes* only emerged in the dry season when discharge was curtailed and stagnant conditions had developed. *Nymphaea* was less abundant, restricted to small patches and occupied the shallow outflow point of the downstream pool exclusively. This zone was devoid of *Pistia* and had particularly high-water column transparency. *Channa obscura* occurred only at this *Nymphaea* dominated zone. The physical characteristics of the stream imposed by the channel morphology and the development of associated biological structures combine to make the downstream site a stable habitat favouring high fish biomass. This community production is facilitated by the moderating effects of floating aquatic vegetation on habitat conditions through enhanced water quality of the water column. Water lettuce purifies the stream water by removing TP and NH_4 –N thereby reducing turbidity (Wang et al. 2018). However, negative impacts of *Pistia* infestations on aquatic ecosystems include reductions in DO and indigenous plant diversity through shading out of light available to algae and submerged aquatic macrophytes (Sajna et al. 2007; Wang et al. 2018). In this study, fish diversity and biomass both increased during the dry season but other studies have reported significant declines in fish production in the dry season because dwindling water levels shrunk habitat volume and increased risk of capture by predators (Valbo-Jørgensen et al. 2000). Furthermore, senescing aquatic macrophytes removed refuge cover and also increased risk of capture (Valbo-Jørgensen et al. 2000). It seems that the increase in fish diversity in the stream during the dry season may be a function of stream contraction and subsequent aggregation of fish assemblages. High dispersal in the rainy season may be due to flooding and expansion of the habitable volume.

There was strong correlation between fish biomass and *Pistia* abundance. The seasonal development of *Pistia* imposed structural changes to the stream habitat that enhanced the growth and survival of fish during the dry season. Aquatic macrophytes typically colonize shallow areas and play an important role in habitat structuring, biological community composition and biodiversity (Thomaz and da Cunha 2010). The presence of *Pistia* provided large swarms of different varieties of flying insects with a suitable habitat that supplied the fish populations with abundant food. This explains the high dry season biomass. *Pistia* serves as habitat and breeding substrates for invertebrates which have frequently proven to be important food sources for fish (Borawa et al. 1979; Killgore et al. 1989; Petr 1968). In one study, densities of aquatic invertebrates contained in *Pistia* roots ranged between 5000 – 16000 individuals m^{-2} with a wet weight biomass of 5 – 35 gm^{-2} (Petr 1968; 2000). Furthermore, fish are also known to prey heavily on many larval stages of disease-causing insect vectors associated with aquatic macrophytes (Obeng 1969). However, capture of larval prey may be hampered by excessive macrophyte growth and certain secretions from aquatic plants toxic to fish (Lindèn and Lehtiniemi 2005). This will likely restrict feeding opportunities for fishes and increase deoxygenation of the water column (Petr 2000). Oxygen concentrations remained high and comparable to pre-emergence period of *Pistia*. The cause of this highly oxygenated condition despite copious amounts of aquatic vegetation is unknown especially due the relatively low phytoplankton densities in the water column caused by shading of floating vegetation. Root-dwelling invertebrates could further reduce oxygen concentrations in the water surface due to metabolic consumption of dissolved oxygen.

The fish community in the stream was moderately diverse in relation to stream size and degree of heterogeneity of the stream habitat. The resident species are native to West Africa and reflect the general biogeography of tropical African fishes (Dudgeon 2011). Fish diversity increased with increasing stream size, with large fishes occupying wider and deeper downstream areas whereas larvae and juveniles inhabited narrow and shallower upstream and midstream areas. This type of fragmented distribution is generally typical of stream fishes and is a strategy for young fish to avoid predation from large predators when they coexist in the same habitat zone. Habitat segregation was found in *C. obscura* but most species populations were evenly distributed in the stream utilizing the entire range of habitat available. The localization of *C. obscura* may be evidence of habitat partitioning to avoid direct competition with fishes in order to promote coexistence within the stream habitat. Catfish dominated the fish community in terms of abundance and biomass. These fishes are omnivores but are also effective carnivores that can suppress prey populations (McGinty 2002). The dominance of catfish in the fish community seems to be favoured by stable water column, benthic conditions and diversified food sources and omnivory both of which are factors that may be supportive of growth and reproductive success. The constancy in the downstream pool habitat may give prominence to density-dependent regulation of community structure through competition and predation. Competition and predation pressure potentially exerted by the abundant catfish may reduce assemblage diversity leading to low representation of other species. These factors can be characteristic of fish assemblage dynamics during dry season spells which curtail density-independent effects (Winemiller et al. 2008). Evidence suggest that high predatory success of catfish and their omnivorous habit may support their high biomass in the fish community (Schmitt et al. 2017).

In conclusion, the proximal factor shaping stream habitat structure was stream size and increased water retention in the downstream site habitat. These factors were strongly correlated with fish abundance and biomass. Seasonal drought constituted key density-independent factors that restricted fish distribution in upstream and midstream areas while density-dependent factors may regulate community dynamics in the downstream pool habitat. Fish biomass declined in the rainy season and increased in the dry season. Aquatic vegetation enhanced water quality and supplied abundant invertebrate food to fish ultimately increasing fish biomass. High biomass was clearly aided by omnivorous feeding habit of the dominant catfish populations and favourable habitat. Climatic factors may induce significant selective pressures in tropical stream ecosystems by altering stream hydrology, habitat structure and fish community dynamics and shifting community patterns towards dominance of species able to cope with extremes of environmental change such as drought.

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