Gill Monogeneans of African Tetra, *Brycinus kingsleyae* (Günther, 1896), From the Nyong River: Biotope, Distribution and Site Selection

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Abstract

Monogenea is a taxon containing flatworms that are primarily parasites of the skin and gills of fish. The African tetra, *Brycinus kingsleyae* (Günther, 1896), is a commercial fish species in artisanal fisheries in Southern Cameroon. Although the gill monogeneans of this fish species have been described, no ecological research has been carried out on this component community. The present study was conducted in the Nyong River to provide the first data about some factors that influence the structure of its infracommunities. In dry seasons, 70 fish specimens consisting of 27 males and 43 females of fork length between 9.5 and 14.1 cm were sampled. The analysis of their gill filament number indicated that the gill system of *B. kingsleyae* is heterogeneous because this factor varies with the length of the fish and depends on the gill arch. The studied guild consisted only of core species: *Annulotrema combesi* Birgi, 1988, *Annulotrema maillardi* Birgi, 1988, *Annulotrema nyongensis* Birgi, 1988, *Annulotrema bouixi* Birgi, 1988, and *Characidotrema regia* Birgi, 1988. The number of gill filaments and the parasitic load increased with the fish length, indicating that larger hosts provide a greater diversity of niches for parasites. Monogenean species exhibit various occupation patterns of gill arches, sectors, zones and gender differences in parasitological indices. This study reveals that the host length and sex, filament number, gill arch, sector and zone are largely responsible for structuring the studied component community.

Keywords: ecology, freshwater fish, gills, Monopisthocotylea, Cameroon

Introduction

Fishes are considered the most numerous and diverse major vertebrate groups (Moyle and Cech, 2004). In parasitology, fishes remain a well-known and convenient model since they are hosts for direct and complex parasitic life cycles (Carvalho et al., 2003; Ibrahim, 2012). At the same time, their gills represent one of the most common sites for establishing various ectoparasites species (Jerônimo et al., 2013). Therefore, these vertebrates are suitable hosts to study biological aspects of gill parasites.

Monogenea is a taxon containing flatworms that are mostly parasites of the skin and gills of fish (Euzet and Combes, 1998). For Poulin (2002), the specimens of the last-mentioned group are numerous in a limited area and provide enormous opportunities for ecological research. Various studies have been conducted on gill monogeneans to analyse parasite communities with emphasis on how they are structured, and some hypotheses have been thought and tested (Tavares and Luque, 2008; Violante-Gonzalez et al., 2008; Debortoli et al., 2016). Monogenean communities may be influenced by host-related factors such as body size or sex; consequently, some individuals within the host population accumulate more parasites while others are less infected (Tombi et al., 2016a). Some studies suggested that monogeneans partition the spatial resources provided by fish gills and exhibit a strict site selection (Raymond et al., 2006; Soler-Jiménez and Fajer-Ávila, 2012).

In addition, factors such as the heterogeneous water flow in the gills (Rubio-Godoy, 2008; Tombi et al., 2010; Soler-Jiménez and Fajer-Ávila, 2012); the structure of the gill system, including variation of gill surface or filament number (Hughes, 1972; Caltran and Silan, 1996; Bilong Bilong and Tombi, 2004), and interspecific relationships (Kadlec et al., 2003; Tombi et al., 2010) can affect the exploitation of gill-space by monogeneans. For Debortoli et al. (2016), the selection of microhabitats on the infestation sites of monogeneans does not show any pattern.

The African tetra, *Brycinus kingsleyae* (Günther, 1896), is a commercial fish species in artisanal fisheries in Southern Cameroon. Birgi (1988) described five monogenean species on the gills of this Alestidae and no ecological research work has been conducted on this component community. The present study is the first report on their biotope and spatial distribution structure to provide data on their ecology. Our specific objectives were to assess: (1) whether the variation of parasitic load fits the growth of gill filaments, (2) site preference, and (3) the potential effect of host length and host sex within the ecological framework (i.e., numbers and distribution of monogeneans).

Materials and Methods

Ethical approval

All authors hereby declare that "Principles of Laboratory Animal Care" (NIH publication № 85-23, revised 1985) were followed and specific national laws where applicable. All experiments have been examined and approved by the appropriate ethics committee of the University of Yaoundé I, Cameroon.

Fish host

In 2018, a total of 100 *B. kingsleyae* sampled from random catches of professional fishers were collected from Nyong River at Akonolinga (Fig.1) and preserved in 10 % formalin-freshwater solution according to Tombi and Bilong Bilong (2004). Their fork lengths (distance from the extremity of the muzzle to the last vertebra) varied from 9.5 to 14.1 cm. The study of the structure of the gill system of *B. kingsleyae* was made on the 100 sampled hosts, but, that of the distribution of monogeneans on this biotope was carried out on 70 (27 males and 43 females) of them.

Fig. 1. Picture showing a partial view of the Nyong River at Akonolinga, where *Brycinus kinsleyae* was captured by gillnet for monogeneans collection.

Akonolinga is located approximately 130 km from Yaoundé, the political capital of the Republic of Cameroon and is subjected to subequatorial climate type. This climate is characterised by two distinct rainy seasons extending from September to November (short rainy season) and from March to June (long rainy season), and by two dry seasons extending from July to August (short dry season) and from November to February (long dry season). During the sampling period, 32 host fish were collected in a short dry season (10 males and 22 females) and 38 in a long dry season (17 males and 21 females). In the laboratory, each fish's fork length (FL) was measured, and two length classes were determined, namely: FL <11.5 cm and FL ≥11.5 cm. The gonads were observed to determine their sex (female or male). The gill arches were excised on the right and left sides and placed separately in Petri dishes containing tap water. The four gill arches of each side were numbered from the outer to the inner region of the operculum as arches I, II, III, IV. Each arch has two faces or hemibranches: the anterior (A) and the posterior (P). The hemibranches were named IA, IP, IIA, IIP, IIIA, IIIP, IVA, and IVP from arch I to arch IV. Gill arches were subdivided into five sectors, namely dorsal (S1), medio-dorsal (S2), median (S3), medio-ventral (S4) and ventral (S5). All filaments were individually divided into three equidistant parts or zones (basal, median and distal zones), using an ocular micrometre of the stereomicroscope (Tombi et al., 2010). The number of gill filaments for each fish was counted under a stereomicroscope. The evolution curves of the filaments were plotted using the maximum likelihood according to Ross (1970).

Parasites

Individual gill arch was examined under a stereomicroscope (Novel, China) at 20× magnification. The parasites of each filament were collected separately; the gill arch, hemibranch, sector and zone on which each parasite specimen found was recorded before removal. After being unhooked and placed on a slide, each specimen was cleared with a drop of haematoxylin and identified under a light microscope (Olympus CH2, Japan) 40× and 100× magnifications. Species identification was made based on the number, shape, and size of the sclerotised structures of their haptor and the reproductive organs (Kritsky et al., 1995) as described by Birgi (1988).

According to Bush et al. (1997), all parasites in a given host species population constitute the component community and all the parasites in a host individual are designated as the infracommunity. Based on the prevalence, species were considered core if the prevalence was greater than 50 % (Koskivaara and

Valtonen, 1992; Valtonen et al., 1997). The mean intensity (MI) was high if its value was greater than 100, medium if MI ranged between 50 and 100, low if MI ranged between 10 and 50 and very low if MI was less than 10 (Bilong Bilong and Njiné, 1998). The parasite species distribution was considered aggregate when the variance was greater than the mean intensity (Wilson et al., 1996).

Statistical analysis

The χ^2 test was used to compare the prevalence, while the Mann-Whitney (U) and Kruskal-Wallis (K) tests permitted the comparison of two and more than two mean intensities, respectively. Except for any subsequent indications, the degree of security retained here was 95 %. All statistical tests were computed with Statistix version 2.0.

Results

Variation of gill filament number

The scatter diagram revealed a positive relationship between fork length and total filament number (Fig. 2) with a significant correlation (r = 0.333, $P < 0.01$). The equation which describes this relationship is: $Y = 30.637\ FL + 107.9$, $R^2 = 0.1025$. This implies that the number of gill filaments increased with fish fork length.

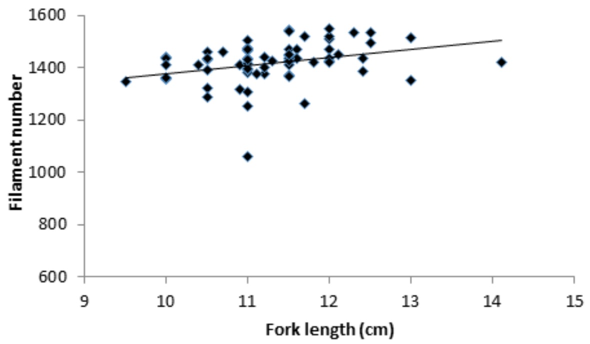

Fig. 2. Relationship between the fork length of *Brycinus kingsleyae* and the total gill filaments.

The mean total number of gill filaments did not differ between the right and the left sides of the fish (Table 1, U; $P > 0.05$).

Arch II and arch IV had, respectively, the highest and the lowest number of gill filaments ($P < 0.05$), while gills I and III were equivalent ($P > 0.05$). This filament distribution pattern (II > I = III > IV) on various gill arches did not change with the increasing fish length (Fig. 3).

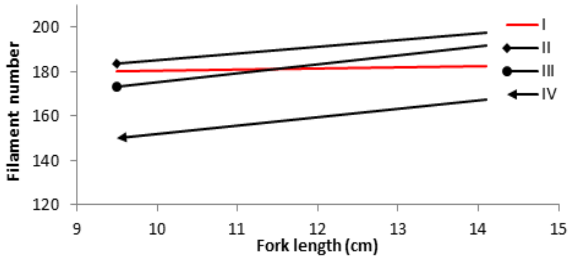

Fig. 3. Relationship between *Brycinus kingsleyae* fork length and the number of filaments per gill arch.

Holistically (Table 1), and whatever the gill arch considered (Fig. 4), each hemibranch statistically harboured the same number of filaments as its homologous ($P > 0.05$). The decreasing rank of hemibranches by comparing their filament number taken two by two is IIP = IIA > IA = IP = IIIA = IIIP > IVA = IVP.

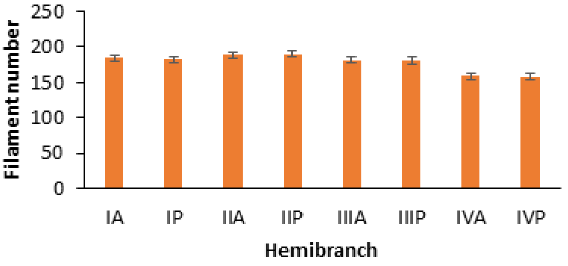

Fig. 4. Variation of gill filament number on each hemibranch of *Brycinus kingsleyae*.

Parasitological aspects

A total of 18066 monogeneans were collected from the gill filaments of 70 *B. kingsleyae* involved in the distribution of these parasites. The component community was composed of five species. *Characidotrema regia* Birgi, 1988 was the most abundant, followed by *Annulotrema bouixi* Birgi, 1988, *Annulotrema nyongensis* Birgi, 1988, *Annulotrema maillardi* Birgi, 1988 and *Annulotrema combesi* Birgi, 1988 (Table 2).

Table 1. Variation of gill filament number as a function of *Brycinus kingsleyae* side, arch and hemibranch

Side		Arch				Hemibranch	
Left	Right	AI	AII	AIII	AIV	Anterior	Posterior
712.14 ± 35.74	706.48 ± 55.86	366.16 ± 20.55	378.14 ± 19.36	361.97 ± 20.03	322.80 ± 76.66	712.61 ± 36.37	709.37 ± 34.11
U; $P > 0.05$		K = 139.5; $P < 0.05$				U; $P > 0.05$	

Table 2. Distribution of *Annulotrema* spp. and *Characidotrema regia* ectoparasites of *Brycinus kingsleyae*.

Parasitic species	*A. combesi*	*A. maillardi*	*A. nyongensis*	*A. bouixi*	*C. regia*
Number of specimens	258	425	462	6562	10359
Prevalence	51.43 %	81.43 %	91.43 %	100 %	100 %
MI (σ)	7.17 (7.90)	7.44 (4.87)	7.22 (5.69)	96.04 (90.14)	147.97 (105.07)
Gender's prevalence					
Male	53.49	83.72	95.35*	100	100
Female	51.85	77.77	85.19	100	100
Gender's MI (σ)					
Male	7.78 (9.43)	5.57 (4.64)	7 (5.45)	73.22 (82.06)	103.04 (83.17)
Female	7.08 (7.21)	8.55 (4.71)*	7.19 (5.77)	109.60 (92.11)	176.25 (108.35)*
Host side and arch prevalence					
Left	41.43	74.29	82.86	100	100
Right	38.57	71.43	81.43	95.71	100
I	30	70*	74.29*	97.14*	100
II	34.29	65.71	68.57	94.29	100
III	27.14	48.57	52.86	95.71	100
IV	38.57*	35.71	48.57	91.43	100
Host side and arch MI (σ)					
Left	6.41 (6.23)	4.27 (2.94)	4.28 (3.59)	49.43 (47.53)	76.89 (54.57)
Right	3.74 (3.32)	4.04 (2.95)	3.75 (3.132)	48.85 (44.18)	70.94 (52.43)
I	3.90 (4.90)*	3.04 (2.07)*	3.42 (2.64)*	30.87 (27.63)*	43.06 (33.06)*
II	3.63 (2.80)	2.83 (1.77)	2.23 (1.36)	30.71 (28.50)	38.96 (28.91)
III	3.05 (3.52)	2.71 (1.76)	2.65 (2.16)	23.36 (22.34)	36.93 (27.67)
IV	1.69 (1.13)	2.32 (1.52)	2.47 (2.10)	16.72 (16.10)	29.06 (21.93)

MI = mean intensity, σ = standard deviation, * = the value is significantly higher.

The number of parasites per host ranged between 41 and 734. The prevalence of each species was >50 %, indicating that all members of the studied component community were core species. The mean intensity was very low for *A. combesi*, *A. maillardi* and *A. nyongensis*, low for *A. bouixi* and high for *C. regia*. The variance (σ^2) of each species was greater than its mean intensity showing that parasitic individuals were aggregated among their hosts at the population level (Table 2).

At the component community scale, females showed a significantly high mean parasitic load (313.97 ± 190.28) compared to males (183.04 ± 197.98; U, $P < 0.05$). At the specific scale (Table 2), *A. nyongensis* was the only species whose prevalence varied significantly with the sex of the host (χ^2, $P < 0.05$). The mean intensity values of both *A. maillardi* and *C. regia* were significantly higher in females ($P < 0.05$). For *A. bouixi*, even if the mean intensity of females seemed greater than that of males, the difference remained insignificant (U, $P > 0.05$). The total parasitic load (Fig. 5) increased as a function of fork length with a significant correlation ($r = 0.202$, $P < 0.01$).

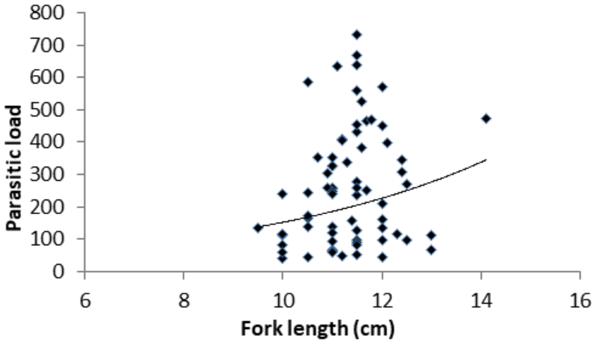

Fig. 5. Relationship between the fork length of *Brycinus kingsleyae* and the total monogenean load.

No significant difference was observed in the prevalence and mean intensity of each parasitic species according to the host side (χ^2, U, $P > 0.05$) (Table 2). Regardless of parasitic species, the prevalence values of the four gill arches were statistically equal (χ^2, $P > 0.05$). Whatever the fish examined, each gill arch harboured at least one specimen of monogenean. The mean parasitic loads of gill arches were: I = 78.60 ± 57.22; II = 71.97 ± 51.25; III = 62.78 ± 44.47, and IV = 46.96 ± 33.98 showing that this parameter decreased significantly in the anteroposterior direction ($K = 13.74 > 7.81$; $P < 0.05$). The variation of the mean parasitic load of the various gill arches increased as a function of the fork length and was also done in the anteroposterior direction (Fig. 6).

The prevalence of *C. regia* was identical on the four gill arches ($P > 0.05$). Those of *A. maillardi*, *A. nyongensis* and *A. bouixi* decreased from arch I towards arch IV, with certain differences being significant, and only *A. combesi* had a different pattern with the highest prevalence on arch IV ($P < 0.05$) (Table 2). All the species were more abundant on arch I, but the

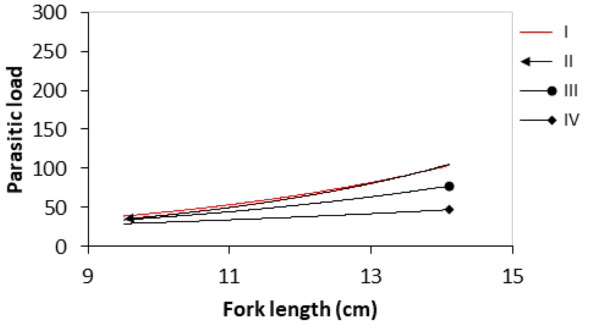

Fig. 6. Relationship between the fork length of *Brycinus kingsleyae* and the monogenean load per gill arch.

difference was significant only for *A. nyongensis* ($P < 0.05$) (Table 2). The five species did not show a preference for the anterior or posterior hemibranch of each arch. The decreasing rank by comparing the mean number of all monogenean species was IA = IIP = IP = IIIP = IIA = IIIA = IVP = IVA.

Characidotrema regia was the monogenean species that exploited the sector gradient better (Fig. 7). This species colonised simultaneously the five sectors of each gill arch. *Annulotrema bouixi* and *C. regia* showed a preference for sectoral colonisation of all four gill arches. The specimens of *A. bouixi* mostly occurred on the third sector of the arch I, while those of *C. regia* were more abundant in S2, S3, and S4 of arches I, II, III ($P < 0.05$). In all other cases, the difference remained non-significant.

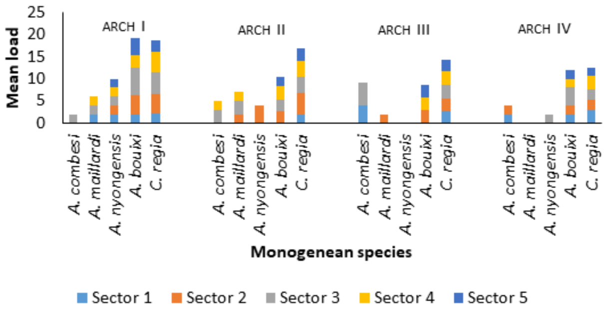

Fig. 7. Mean number of monogeneans per species, collected on each of the five sectors of each *Brycinus kingsleyae* gill arch.

Annulotrema combesi, *A. maillardi* and *A. nyongensis* did not occupy the distal filament part, but the first two monogenean species were more frequent and more abundant in the median part, while the last was more frequent and more abundant in the basal one (Figs. 8 and 9).

Annulotrema bouixi and *C. regia* exploited the entire filamentous parts. The zonal infection rate and parasitic load reduced progressively and significantly ($P < 0.05$) from the distal part towards the basal one for *A. bouixi*. *Characidotrema regia* occupied the basal zone significantly less ($P < 0.05$). The mean parasitic load was significantly lower ($P < 0.05$) on the basal zone for *A. bouixi* and average for *C. regia*.

Each parasitic species observed in the study infected hosts of both length classes (Table 3). Whatever the species considered, no significant difference in prevalence was observed according to the length class (χ^2, $P > 0.05$). In terms of mean intensity, the longer fish harboured more specimens of *A. bouixi* and *C. regia* than smaller ones (U, $P < 0.05$).

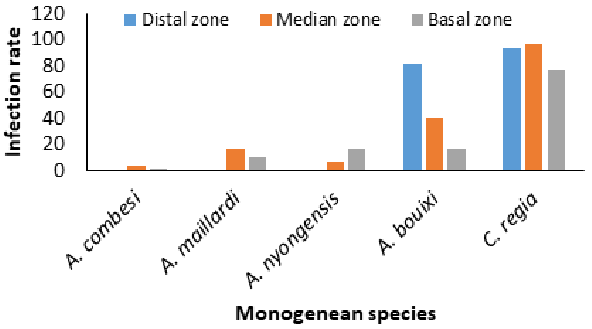

Fig. 8. Infection rate of *Annulotrema* spp. and *Characidotrema regia* on each of the three zones of *Brycinus kingsleyae* gill arches.

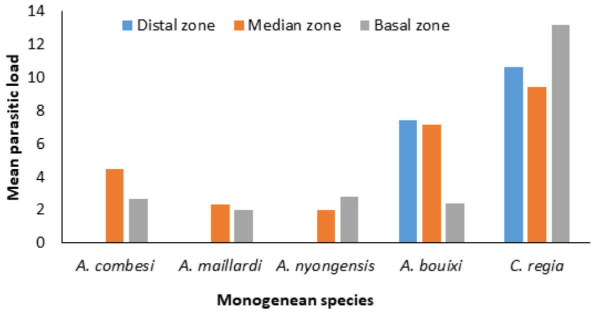

Fig. 9. Infection rate of *Annulotrema* spp. and *Characidotrema regia* on each of the three zones of *Brycinus kingsleyae* gill arches.

Discussion

A positive relationship was observed between filament number and fish size, meaning that the increased length of fish led to an increment in the number of gill filaments. Similarly, Bilong Bilong and Tombi (2004) noted the increase in filament number with *Enteromius martorelli* (Roman, 1971) length. The same finding was made in *Hemichromis fasciatus* Peters, 1858, from the Municipal Lake in Yaoundé (Bilong Bilong et al., 1999). In contrast, Caltran and Silan (1996) remarked in the case of *Chelon ramada* (Risso, 1827), that the filament number increased twofold roughly between the ages of 1 and 6 years and then declined for fishes reaching adulthood. Normally, the rapid increase of the gill epithelium in young fishes and the phenomenon of senescence which characterises old specimens may explain this result.

No significant difference was observed in the number

Table 3. Prevalence (percentage of infected hosts by each monogenean species) and mean intensity of *Annulotrema* spp. and *Characidotrema regia* according to length class of *Brycinus kingsleyae*.

Parasitic species	Prevalence (%)			Mean intensity ± standard deviation		
	FL <11.50	FL ≥11.50	χ^2	FL <11.50	FL ≥11.50	U
A. combesi	57.14	45.71	$\chi^2 = 0.91$ $P = 0.33$	6.90 ± 7.75	7.50 ± 8.56	$P = 0.99$
A. maillardi	80	82.86	$\chi^2 = 0.09$ $P = 0.76$	8.46 ± 5.85	6.75 ± 3.83	$P = 0.32$
A. nyongensis	94.28	88.57	$\chi^2 = 0.73$ $P = 0.40$	7.33 ± 5.27	7.09 ± 6.26	$P = 0.34$
A. bouixi	100	100		71.65 ± 67.74	120.14 ± 102.88	$P = 0.02$
C. regia	100	100		126.08 ± 94.46	168.71 ± 112.99	$P = 0.01$

of filaments for the left and right sides of the gills. For *E. martorelli* and *Enteromius camptacanthus* (Bleeker, 1863), Bilong Bilong and Tombi (2004) and Tombi et al. (2016b), respectively concluded also that both gill system sides of each of these teleost fishes are equivalent for filament number. Such results can be explained by a bilateral symmetry of teleost gill system.

In *B. kingsleyae* gill system, arches II and IV had a higher and a lower number of gill filaments, respectively, according to this sequence: $A_{II} > A_{I} = A_{III} > A_{IV}$. A similar model was observed by Bilong Bilong and Tombi (2004) in the gill system of *E. martorelli*. The results of the present study differed from those of Tombi et al. (2016b), who observed the following decreasing sequence: $A_{I} > A_{II} > A_{III} > A_{IV}$ from the gill filaments of *E. camptacanthus*. Nack and Bilong Bilong (2007) noted that the gill filaments of *Clarias camerunensis* Lönnberg, 1895, were globally more numerous on arches III and II but less on arch IV. In the case of *H. fasciatus*, the decreasing number of filaments was A_{II}, A_{III}, A_{I}, A_{IV} (Bilong Bilong et al., 1999).

Irrespective of the gill arch, the filament number did not vary statistically between the two hemibranches. The rank of hemibranches by decreasing filament number was IIP = IIA > IA = IP = IIIA = IIIP > IVA = IVP. These results are different from those of Tombi et al. (2016b), who counted more filaments in the anterior hemibranch of each gill arch of *E. camptacanthus* according to the following scheme: IA > IIA = IP > IIP = IIIA > IIIP > IVA < IVP. For *E. martorelli* (Bilong Bilong and Tombi, 2004) and *H. fasciatus* (Bilong Bilong et al., 1999), the anterior and posterior hemibranches of gill arch I were equivalent for this variable, but in the other three cases, the anterior hemibranches had the greater number of filaments.

It appeared that the monogenean component community of the *B. kingsleyae* gill system comprises five parasitic species. Cases in which monogenean gill parasites form multispecific communities were previously reported. Tombi et al. (2016a) collected *Dactylogyrus amieti* Birgi and Lambert, 1987, *Dactylogyrus valeti* Birgi and Lambert, 1987 and *Dogielius njinei* Birgi and Lambert, 1987 from *E. camptacanthus* in Cameroon. Daghigh et al. (2014) found, *Dactylogyrus formosus* Kulwiec, 1927, *Dactylogyrus dulkeiti* Bychowsky, 1936, *Dactylogyrus baueri* Gusev, 1955, *Dactylogyrus arcuatus* Yamaguti, 1942, *Dactylogyrus inexpectatus* Izjumova in Gusev, 1955 and *Gyrodactylus kobayashii* Hukuda, 1940 in the gill system of *Carassius gibelio* (Bloch, 1782). The omnipresence of empty niche spaces in *B. kingsleyae* gill system could explain the coexistence of several parasitic species on this biotope. The idea frequently suggested is that several species in a biotope is due to the presence of more ecological niches than in biotope with few species (Šimková et al., 2006; Tombi et al., 2011; 2014). According to Ibrahim (2012), each fish individual can be considered an independent sampler of the available parasites. Evidence for interactions was very low; thus, parasitic communities appeared to be isolationist in nature. In addition, the coexistence of four congeneric species on the gills of *B. kingsleyae* observed during the present study corroborates Rohde (1994), who noticed that positive interactions are more frequent than negative ones between gill fish ectoparasites of the same host.

The prevalence of each species was more than 50 % showing that the studied component community was composed only of core species. The values of mean intensities were very low or low except for *C. regia* whose mean intensity was high. Similarly, Tombi et al. (2016a) reported very low or low mean intensities of monogenean gill parasites of *E. camptacanthus*. These observations could be partly associated with the natural environment where the parasitic load is generally limited due to the low host's density (Ergens, 1983; Buchmann and Lindenstrom, 2002) and the low water current velocity (Chaudhary et al., 2013). In the present study, parasitic species were aggregated at population level. According to Morand et al. (1999), aggregation can be caused by numerous factors; among them are the heterogeneous contacts between sources of infection and hosts and the differential susceptibility of hosts to parasite attacks.

The smaller and longer fish were similarly infected by *A. combesi*, *A. maillardi* and *A. nyongensis*. Such observations were made by Boungou et al. (2008) and Rubio-Godoy (2008), who noticed that host length did not significantly affect the prevalence and mean intensity of monogenean gill parasites of *Oreochromis niloticus* (Linnaeus, 1758) and *Oncorhynchus mykiss* (Walbaum, 1792), respectively. Globally, in the case of *B. kingsleyae*, the number of filaments and the parasitic load increased with fish length and the mean intensity values of *A. bouixi* and *C. regia* were significantly higher in the longer length class. Several studies have identified positive correlations between host body length and the intensity of parasitic infection (Lizama et al., 2005; Tombi et al., 2014). Larger hosts provide more filaments or a greater diversity of niches for parasites. The relationship between length and infection level is also related to host fish and parasite life histories. Assuming that fishes do not recover from the infection and parasite-induced mortality is low, the parasitic infection often increases with fish length because older individuals have been exposed for a long time to pathogens.

The present work detected no significant relationship between the host sex and the prevalence except in the case of *A. nyongensis*, which was more prevalent in males. Based on parasitic loads, globally and for all species except *A. combesi*, females had more parasites than males. Various works have reported that helminth infections sometimes correlate with the sex of the host (Tombi and Bilong Bilong, 2004; Boungou et al., 2008) and sometimes it does not (Le Roux et al., 2011; Blahoua et al., 2016). The sex-biased parasitic load observed in the cases of some studied monogenean species is in accordance with previous reports (Lizama et al., 2005; Tombi et al., 2016a). The sex difference in infection may be attributed to the difference in endocrine glands activities between the genders (Ibrahim, 2012; Allalgua et al., 2015). Sex-specific behaviour may also affect exposure and susceptibility to parasite infection, with one sex being more vulnerable. Colonial and sedentary habits of females during the breeding period favour vertical and horizontal parasite transmission (Christe et al., 2007).

Moreover, the high temperature of nursery sites, including the heat generated by tight association among individuals in a colony, may favour parasites' reproduction output. Also, during this reproduction period, females experience increased stress levels which may be linked to immunosuppression and an increased degree of parasitism (Tombi and Bilong Bilong, 2004; Šimková et al., 2005). For the present study, 70 specimens of fish, including 27 males and 43 females, were sampled to study the distribution of monogeneans. It appears that the sex ratio is in favour of females, and considering that females were larger than males, their large sizes could accommodate a greater number of parasites (Özer and Öztürk, 2005). In contrast, for Aloo et al. (2004), males tend to harbour more parasites than females in many freshwater fish species. Khara and Sattari (2014) concluded that few ichthyoparasite species show a preference for host gender.

None of the parasitic species showed a preference for the left or right side of the gill system of *B. kingsleyae*. Several authors have previously obtained such results (Tombi et al., 2010; Soylu et al., 2013; Crafford et al., 2014; Allalgua et al., 2015; Lim et al., 2016). The bilateral symmetry of *B. kingsleyae* gill system observed through the study of the variation of its filament number could explain this result. Otherwise, since the body of all the studied monogenean species exhibits a bilateral symmetry (Birgi, 1988), it is likely that their distribution is equitable through the gill system, which also presents a bilateral symmetry. It also emerges from this study that arch 4, which had the smallest number of gill filaments, harboured the fewest parasites.

The occupation of gill arches by studied monogenean species presented some differences according to species. These results favour the view that monogeneans exhibit various gill occupation patterns. In some instances, parasites more frequently occurred on the first and second gill arches (Rubio-Godoy, 2008; Jerônimo et al., 2013; Tombi et al., 2014). Arches II and III, in other cases, were most parasitised (Allalgua et al., 2015). The strongest water current passing through those gill arches creates convenient conditions for parasite settlement. Bashirullah and Rodriguez (1992) indicated that a greater occurrence of monogeneans on arches I, II and III of *Caranx hippox* (Linnaeus, 1766) is related to the respiratory current over the gills which is greater over the arches I, II and III as opposed to the fourth. Rubio-Godoy and Tinsley (2002) and Rubio-Godoy (2008), have observed a high number of adult *Discocotyle sagittata* (Leukart, 1842) on the first and second gill arches, and a high number of larval stages on the third and fourth arches of the rainbow trout, *O. mykiss*, suggesting that the larval stages invade the gill passively using the respiratory current of these posterior most arches (III and IV) and then developing worms migrate anteriorly to preferred arches.

All the parasitic species were evenly distributed on the two hemibranches of each arch. These results corroborate the findings of Crafford et al. (2014) on the gill monogeneans of *Clarias gariepinus* (Burchell, 1922), *Cyprinus carpio* Linnaeus, 1758 and *Labeobarbus* spp. This agrees with the observation in the present study that; the gill filament number is similar on the two faces of each gill arch of *B. kingsleyae*.

Characidotrema regia and *A. bouixi* were accumulated more on the median sectors (medio-ventral, median and medio-dorsal), concurring Yang et al. (2006), who had reported that *Poylabris mamaevi* Ogawa and Egusa, 1980, mostly colonised the median sectors of *Siganus fuscecens* (Houttugn, 1782). These results can be justified by the high-water flow that passes through the median zones (Tombi et al., 2017). Also, Tombi et al.

(2010) signalled the presence of a greater number of *D. amieti* on both the median and medio-ventral sectors of *E. camptacanthus*. In addition, all the representatives of *Tilapia rendalli* (Boulenger, 1897) component community were preferentially found in the median sector. Other models of monogenean sectoral colonisation have been mentioned. For examples, Tombi et al. (2010) observed an equipartition of gill monogeneans of *E. martorelli* through the five sectors. In *Rutilus rutilus* (Linnaeus, 1758), *Dactylogyrus crucifer* Wagener, 1857 showed more affinity for the second and fifth sectors (Soylu et al., 2010) while according to Madhi and Belghyti (2006), in *Trachinotus ovatus* (Linnaeus, 1758), sector 5 of the first arch was more parasitised by *Gotocotyla acanthura* (Parona and Perugia, 1896).

The exploitation of the three zones by *C. regia* and *A. bouixi,* which are the most present species, recalls the observations made by Ramasamy et al. (1985) on the teleost fish of the genus *Scomberoïdes* Lacépède, 1801 and indicates that the choice of infestation site by these two monogenean species are density dependant. No individual belonging to *A. combesi*, *A. maillardi* and *A. nyongensis* was found in the distal zone. Some authors explained this behaviour by the small size of the haptoral parts of some species, which tend to abandon the distal zone more exposed to ventilatory currents (Nack et al., 2010). In the present work, this hypothesis could not be retained because our observations revealed that, *A. combesi* and *A. maillardi* have the most robust haptoral parts, while *C. regia* presents the smallest ones.

Conclusion

The present study provides the first data about the occurrences of *Annulotrema combesi*, *A. maillardi*, *A. nyongensis*, *A. bouixi*, and *Characidotrema regia*, gill monogeneans of *Brycinus kingsleyae* and contributes towards the knowledge of the colonisation of their biotope. There was a correlation between filament number, parasitic load and fish length. Each monogenean species exhibited specific gill arches occupation patterns. All these species were core, but *C. regia* was the most abundant. *Annulotrema bouixi* and *C. regia* parasitised all five sectors and the three filamentous zones. The sex of the host influenced the distribution of the studied component community. Future ecological analysis should include seasonal effects that would allow studying population dynamic differences between the parasitic species examined.

Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Ivan Ndongo: Fieldwork, laboratory, data analysis and redaction. Michel Thierry Onana Ngono: Data analysis. Jeannette Tombi: Supervision.

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