



Epidemiology of Myxosporean Infections in Economically Important and Dietary Freshwater Fishes in the Sudano-Guinean Zone of Cameroon

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Abstract

The epidemiology of Myxosporean infections was carried out from May 2016 to May 2017. Thus, 857 Teleosts (350 *Oreochromis niloticus*, 305 *Barbus callipterus*, 118 *Hemichromis fasciatus* and 84 *Clarias gariepinus*) from the Mayo -Banyo Division in the Sudano-guinean zone of Cameroon were sampled and the prevalence of myxosporean infections was determined after examination of fishes. A total of 21 myxosporean species belonging to four genera (*Myxobolus*, *Myxidium*, *Henneguya* and *Thelohanelus*) were recorded. The genus *Myxobolus* exhibited the highest prevalence (37.11%) and *Henneguya* (0.35%) the lowest. All the four fish species were infected with the genus *Myxobolus* with the highest (P < 0.001) prevalence in *O. niloticus* (45.43%) and *B. callipterus* (45.90%). A total of 325 fishes were infected (37.92%). *B. callipterus* (48.20%) followed by *O. niloticus* (45.43%) were the most infected (P < 0.001) compared to *C. gariepinus* (9.52%) and *H. fasciatus* (9.32%). The prevalence of parasite species was not correlated (P > 0.05) with the condition factor and fish size except that of *Myxobolus tilapiae* which was positively correlated with *O. niloticus* size (r = + 0.17; P < 0.01). Males were significantly (P < 0.001) more infected than females in *H. fasciatus* only. The overall prevalence was insignificantly (P > 0.05) higher in the dry season than in the rainy season. Out of 12 parasitized organs, *O. niloticus* and *C. gariepinus* exhibited the highest (10 organs) and lowest (3 organs) number of infected organs respectively. This study provided some baseline data useful in myxosporean infections prevention and control in fishes from Adamawa-Cameroon.

Keywords: Fish; Myxosporean; Infections; Prevalence; Cameroon

Introduction

Fish represents about 51% of animal proteins intake in Africa [1]. In Cameroon particularly, the national annual

production of fishes is only 180, 000 tons versus a yearly demand of 400, 000 tons. As a result, a supplementary quantity of 250, 000 tons is imported every year corresponding to CFA F 200 billions expenditure [2]. This situation is paradoxical

since the Sudano-guinean zone of the country is particularly endowed with a great hydrographic potential. This includes the MAPE dam in the Adamawa region of Cameroon which is an important fish reservoir. Four fish species are commonly found in this dam namely *Oreochromis niloticus*, *Hemichromis fasciatus*, *Clarias gariepinus* and *Barbus callipterus*, all of economic and dietary importance. Unfortunately, from 1990 to 2015, a 15% drop of the annual fish production was recorded [2] due to a number of constraints. These constraints limiting fish productions include not only climate change [3] and overfishing, but also parasitic diseases one of is Myxosporidiosis [4].

Myxosporidiosis impedes fish growth [5] and reproduction [6] and is involved in epizootics responsible for massive fish deaths in farms and hatcheries [7,8]. Epidemiological studies are a prerequisite to myxosporidiosis prevention and control because it provides both qualitative and quantitative data about the spatio-temporal spread of the infection as well as associated risk factors. This study

aimed at assessing the prevalence and some epidemiological aspects of myxosporidian infections in fishes in the Sudano-guinean zone of Cameroon in order to provide baseline data for their effective prevention and control.

Materials and Methods

Study Area and Period

Fishes were collected from May 2016 to May 2017 in MAPE dam (Figure 1) built on MAPE River, a tributary of Mbam River, Bankim subdivision (6°00'- 6°20'NL / 11°20'- 11°40' EL), Mayo-Banyo Division and Adamawa Region of Cameroon. The average altitude is about 724m. The soil is composed of clay and sand. Climate is of the tropical Sudano-guinean type with two seasons: a long rainy season running from March to November and a short dry season from November to March. The annual average temperature is about 23°C and the rainfall varies between 1500 and 2000 mm [9].

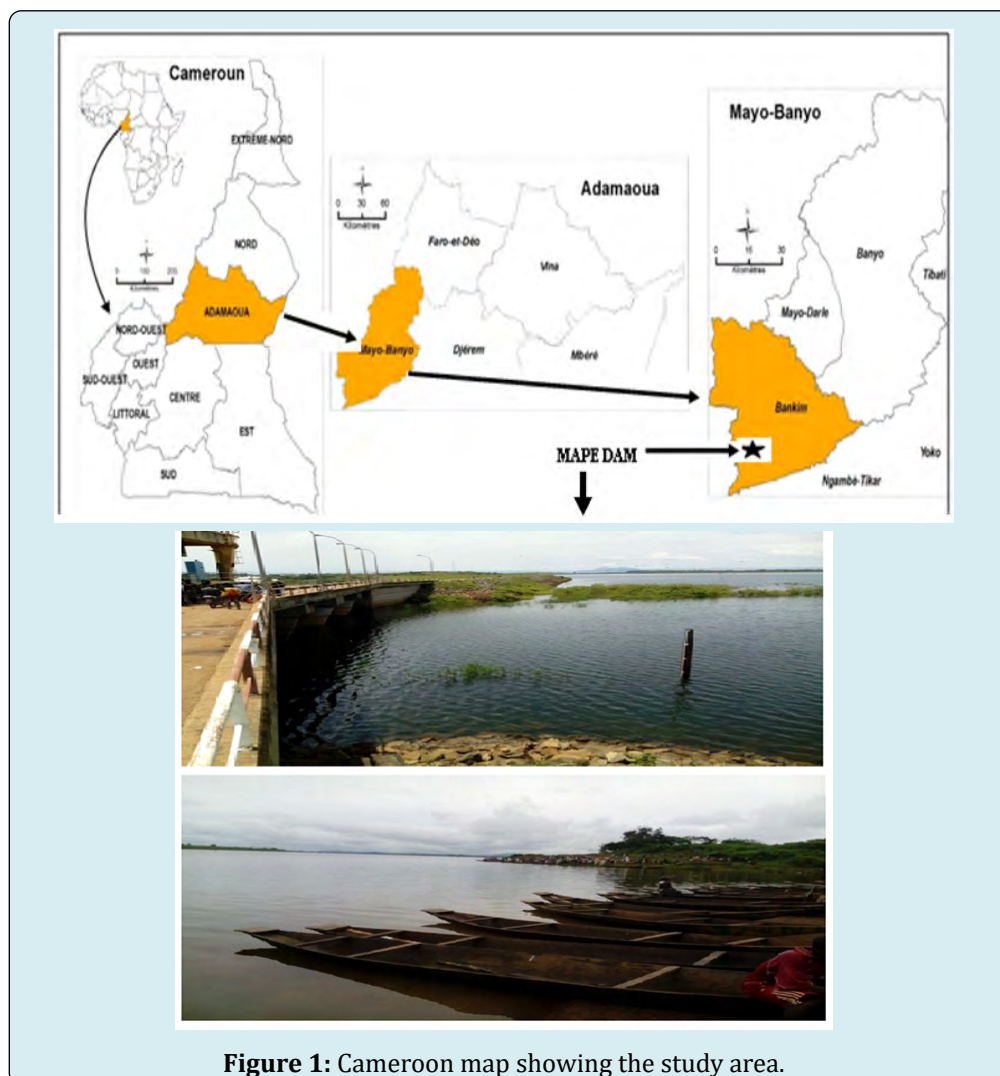
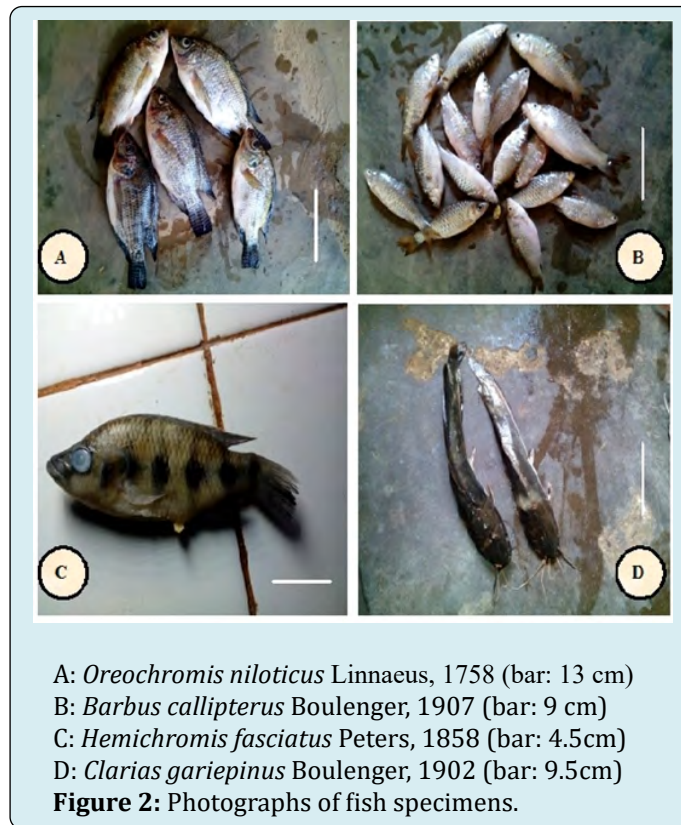


Figure 1: Cameroon map showing the study area.

Fish Sampling and Characteristics of Samples

Fishes (Figure 2) were purchased monthly from fishermen. They were captured both at day and night using fish nets and fishing canes. Fish specimens were

immediately stored in a vial containing 10% formalin solution and transported to the laboratory for examination. The characteristics of fish samples are illustrated in Table 1.



| Host | Sex | Class size (mm) | | | | Total | Seasons | | MSL (mm) |
|------------------------------|-----|-----------------|-----------|-----------|-------------|-------|---------|--------|-----------------|
| | | [50-100] | [100-150] | [150-200] | [200 - 250] | | Rainy | Dry | |
| <i>Oreochromis niloticus</i> | ♂ | 134 | 76 | 8 | 1 | 219 | 129 | 90 | |
| | ♀ | 95 | 34 | 2 | 0 | 131 | 68 | 63 | |
| | ♂+♀ | 229 | 110 | 10 | 1 | 350 | 197 | 153 | 97.13 (51-240) |
| <i>Hemichromis fasciatus</i> | ♂ | 57 | 3 | 0 | 0 | 60 | 39 | 21 | |
| | ♀ | 55 | 3 | 0 | 0 | 58 | 39 | 19 | |
| | ♂+♀ | 112 | 6 | 0 | 0 | 118 | 78 | 40 | 30.10 (54-150) |
| <i>Clarias gariepinus</i> | ♂ | 0 | 17 | 16 | 11 | 44 | 19 | 25 | |
| | ♀ | 0 | 19 | 12 | 9 | 40 | 17 | 23 | |
| | ♂+♀ | 0 | 36 | 28 | 20 | 84 | 36 | 48 | 32.28 (110-250) |
| <i>Barbus callipterus</i> | ♂ | 156 | 3 | 0 | 0 | 159 | 79 | 80 | |
| | ♀ | 146 | 0 | 0 | 0 | 146 | 63 | 83 | |
| | ♂+♀ | 302 | 3 | 0 | 0 | 305 | 142 | 163 | 28.87 (52-110) |
| Total | ♂ | 347 | 99 | 24 | 12 | 482 | 266 | 216 | |
| | ♀ | 296 | 56 | 14 | 9 | 375 | 187 | 188 | |
| | ♂+♀ | 643 | 155 | 38 | 21 | 857 | 453 | 404 | 47.57 (51-250) |
| | % | 75.03% | 18.09% | 4.43% | 2.45% | 100% | 52.86% | 47.18% | |

Mean Standard Length (MSL) is followed in bracket by minimum-maximum values; ♂: male; ♀: female

Table 1: Characteristics of fish samples.

Fish Examination and Myxosporeans Identification

Fishes were identified as described by Stiasny, et al. [10] and examined according to Abakar [4]. Standard and total lengths of fishes were measured to the closest millimeter using a slide caliper of stainless brand. Fishes were weighed using Sartorius electronic scale of 0.01g accuracy and the sex- determined after dissection. The fish condition factor (K) was calculated using the following formula by Charles and Alan [11]:

$$K = \frac{\text{Fish body weight (g)}}{[\text{Total Length}]^3 \text{ (cm)}} \times 100$$

The condition factor expresses the health status or the fish well-being at a given time [12]. As fish grow their condition factor or well fare increases [13]. The fish's health is good if $k > 1$ and poor when $k < 1$ [14]. The condition factor varies according to fish age, sex, season, the stage of development of the reproductive organs, the fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development [11].

External organs (fins, skin, scales and eyes) and internal organs (gills, spleen, kidneys, intestines, gall bladder, stomach and gonads) were examined with naked eyes, then with stereoscopic microscope using the 10X lens to look for the cysts. Three smears of the kidneys, spleen and gonads were made per organ (anterior, medium and posterior regions) and examined at a total magnification of 1000X with a light microscope for presence of spores.

Cysts were crushed between a slide and a cover glass in a drop of distilled water and their contents were identified with the light microscope using the 100X lens. Spores were fixed and stained with methanol and May-Grünwald-Giemsa respectively and photographed with a digital camera (Canon Ixus brand). Myxosporean species were measured with a calibrated ocular micrometer as recommended by Lom and Arthur [15] and were morphologically identified. The identification keys provided by Fomena and Bouix [16], Lom and Dyková [17,18], Eiras, et al. [19,20] were equally used. Myxospores were also compared with recently published worldwide reports

Epidemiological Parameter and Statistical Analysis

The epidemiological parameter i.e. the prevalence (Pr) of infection expressed as a percentage was defined as the number of host species infected by a given parasite species divided by the number of fish examined [21]. The prevalence was classified as very low ($Pr < 10\%$), low ($10\% \leq Pr \leq 50\%$) and high ($Pr > 50\%$) corresponding to scarce, intermediate and principal parasite species respectively. This classification was adapted from Valtonen, et al. [22].

The comparison of prevalence was performed using the Chi-square (X^2) test and the Spearman correlation coefficient "r" was determined. The error probability was $P < 0.05$ and the Graph Pad Prism 5 software was used for analysis.

Results

The results are illustrated in Tables 2 & 3 and Figures 3 - 12.

| | Fish species | | | |
|---|---------------------|---------------------|----------------------|-----------------------|
| | <i>O. niloticus</i> | <i>H. fasciatus</i> | <i>C. gariepinus</i> | <i>B. callipterus</i> |
| r | 0.17 | 0.06 | 0.00 | 0.07 |
| P | 0.05 | 0.556 | 0.940 | 0.219 |

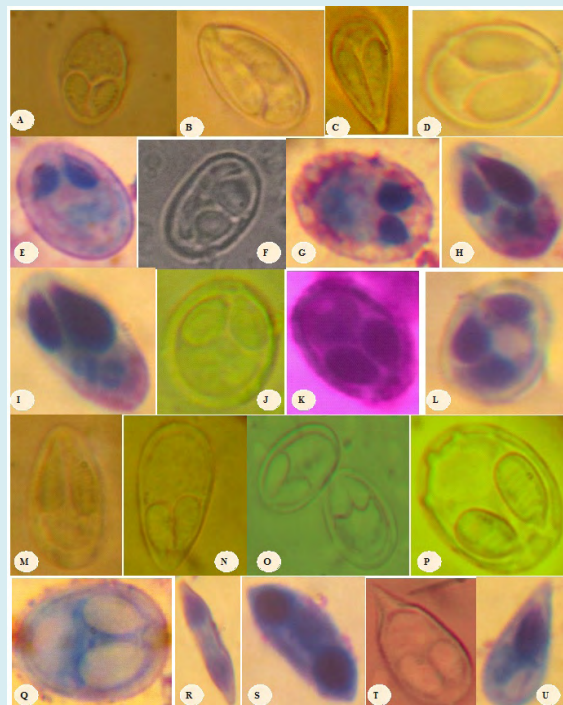
r : correlation coefficient ; P : error probability

Table 2: Correlation between the prevalence and fish condition factor (K).

| Parasite species | Infection sites | | | | | | | | | | X^2 | P |
|--------------------------------|-----------------|-----------|------|------|-------|---------|-------|--------|-----------|---------|-------|--------|
| | Eyes | Operculum | Skin | Fins | Gills | Kidneys | Liver | Spleen | Intestine | Ovaries | | |
| <i>Myxobolus camerounensis</i> | 2.28 | 1.43 | 1.43 | 2 | 0.86 | 3.14 | 0 | 0 | 0 | 0 | 36.54 | <0.001 |
| <i>Myxobolus israelensis</i> | 0 | 0.57 | 0.29 | 0 | 0 | 8.57 | 0 | 0.86 | 0 | 0 | 227.6 | <0.001 |
| <i>Myxobolus heterosporus</i> | 0.57 | 0 | 0 | 0 | 0 | 8 | 0.57 | 0.57 | 0 | 0 | 209.3 | <0.001 |
| <i>Myxobolus agolus</i> | 0 | 0 | 0 | 0 | 0 | 5.43 | 0.29 | 0 | 0 | 0 | 161.9 | <0.001 |
| <i>Myxobolus tilapiae</i> | 0 | 0 | 0.29 | 0 | 0.57 | 14 | 0.57 | 0.29 | 0 | 0 | 398.1 | <0.001 |

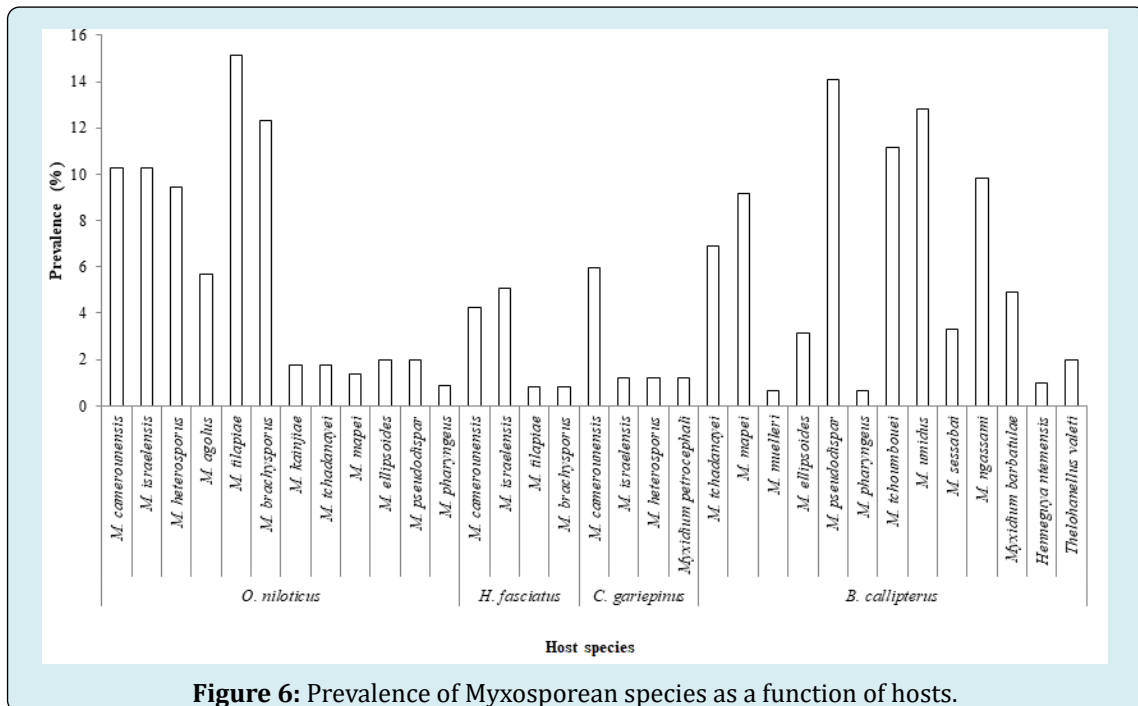
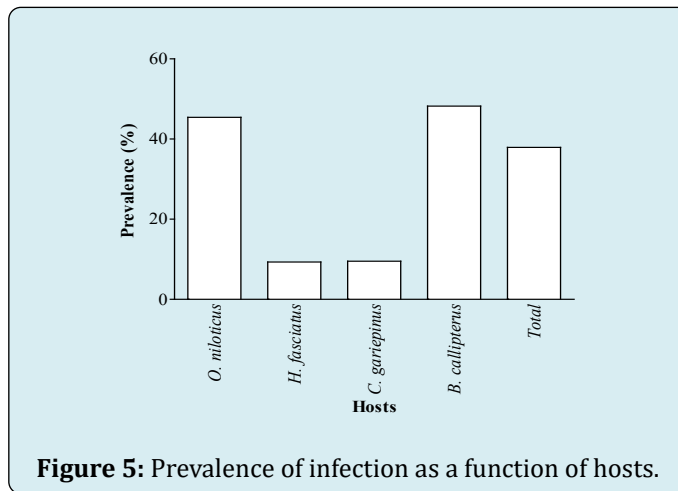
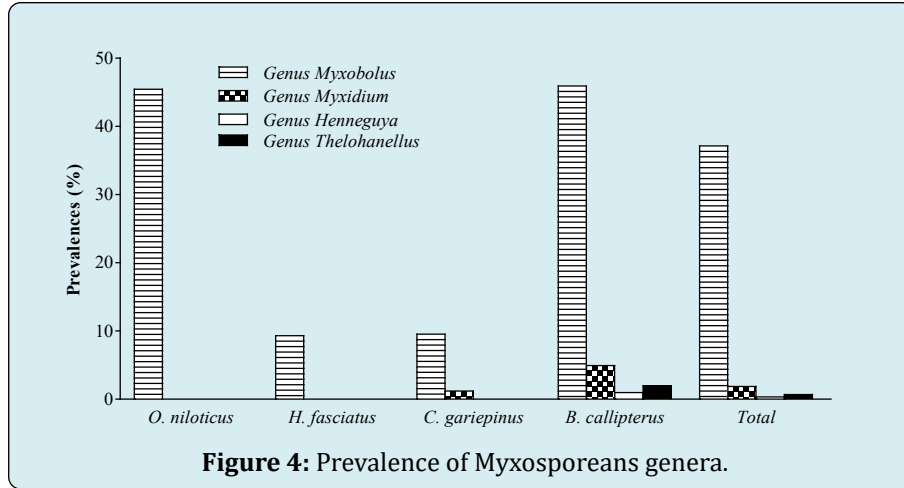
| | | | | | | | | | | | | |
|-------------------------------|--------|--------|--------|--------|-------|--------|-------|-------|------|--------|-------|--------|
| <i>Myxobolus brachysporus</i> | 0 | 0 | 0 | 0 | 0 | 11.14 | 0.57 | 0.29 | 0.57 | 0 | 316 | <0.001 |
| <i>Myxobolus kainjiae</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.29 | 135.6 | <0.001 |
| <i>Myxobolus tchadanayei</i> | 0 | 0 | 0.29 | 0 | 0 | 3.14 | 0.29 | 0 | 0.29 | 0 | 69.97 | <0.001 |
| <i>Myxobolus mapei</i> | 0 | 0 | 0 | 0 | 0 | 2.86 | 0.57 | 0 | 0 | 0 | 74.92 | <0.001 |
| <i>Myxobolus ellipsoides</i> | 0 | 0 | 0 | 0 | 0 | 4.57 | 0.29 | 0 | 0 | 0 | 134.8 | <0.001 |
| <i>Myxobolus pseudodispar</i> | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 63.13 | <0.001 |
| <i>Myxobolus pharyngeus</i> | 0 | 0 | 0 | 0 | 0 | 0.85 | 0 | 0 | 0 | 0 | 27.02 | <0.01 |
| Total | 2.85 | 2 | 2.29 | 2 | 1.43 | 36.57 | 2 | 1.43 | 0.86 | 4.29 | 719.6 | <0.001 |
| X ² | 54.62 | 37.4 | 32.4 | 88.17 | 26.02 | 140.9 | 9.75 | 18.75 | 10 | 165.6 | | |
| P | <0.001 | <0.001 | <0.001 | <0.001 | <0.01 | <0.001 | 0.553 | 0.066 | 0.53 | <0.001 | | |

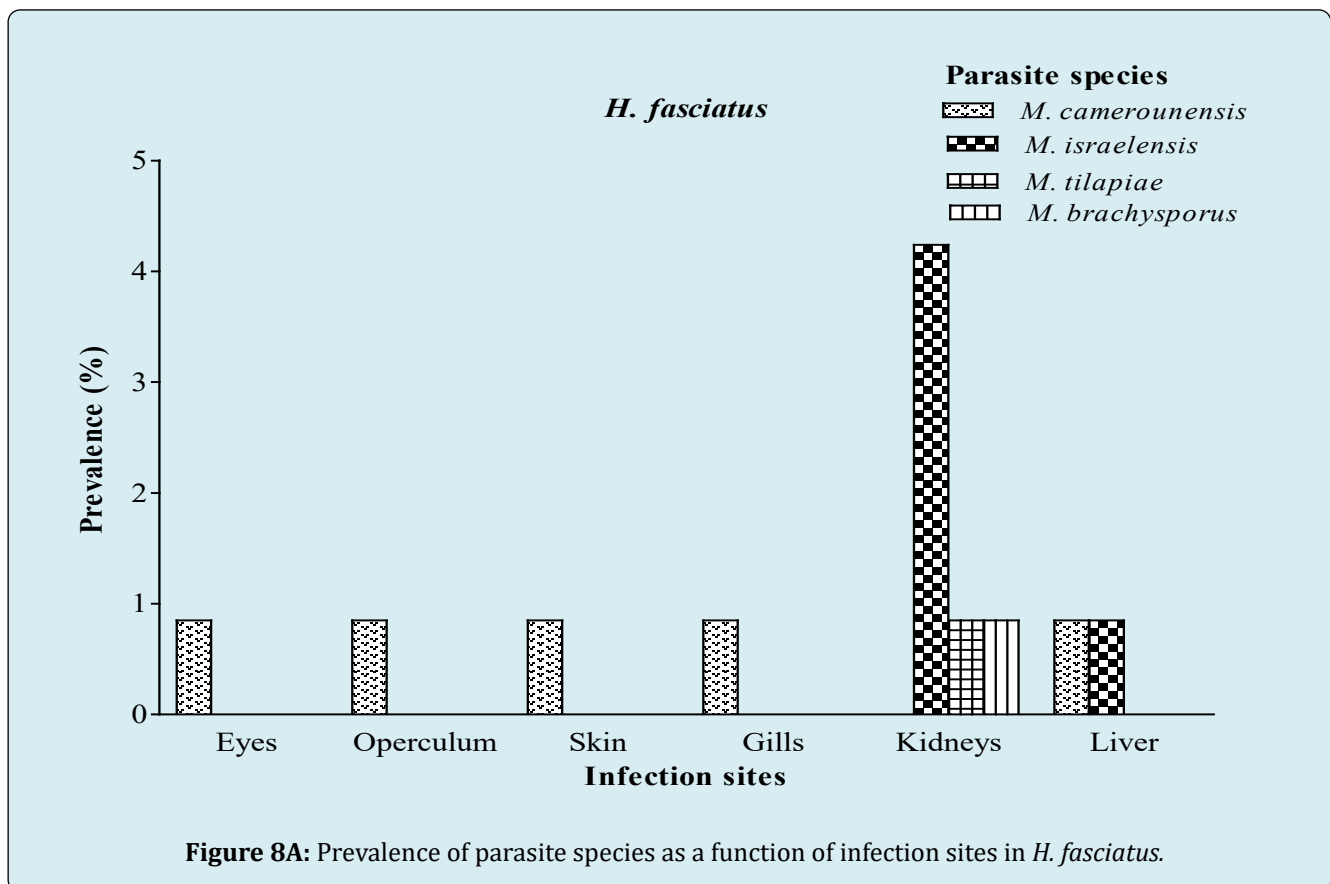
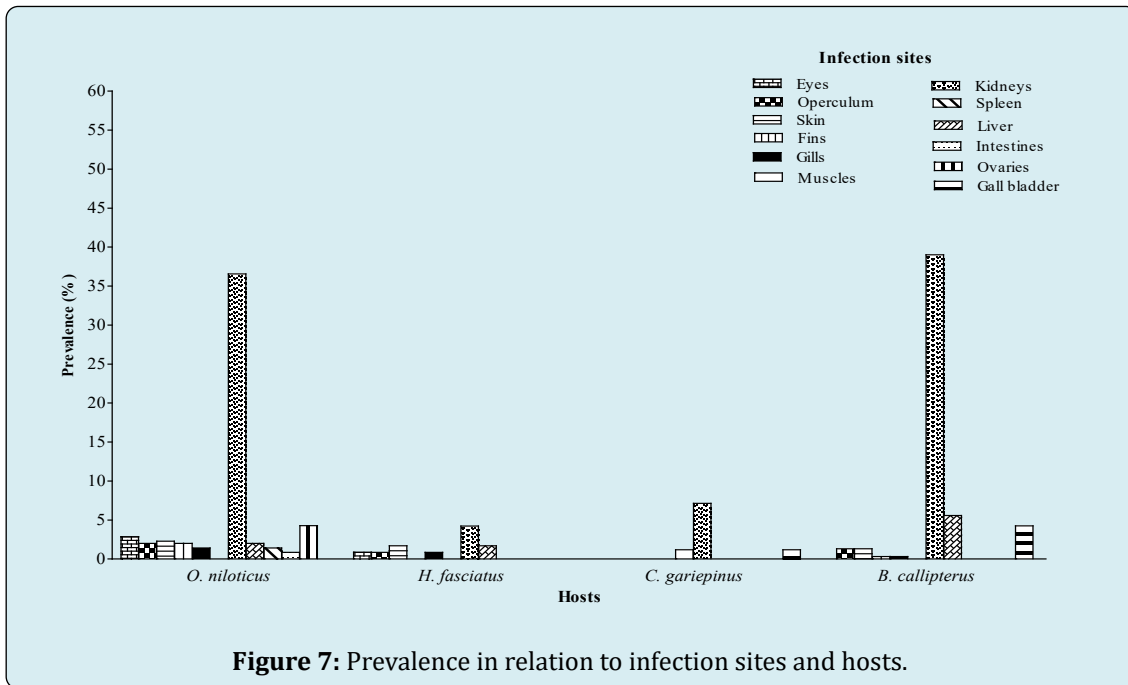
Table 3: Prevalence of parasite species as a function of infection sites in *O. niloticus*.

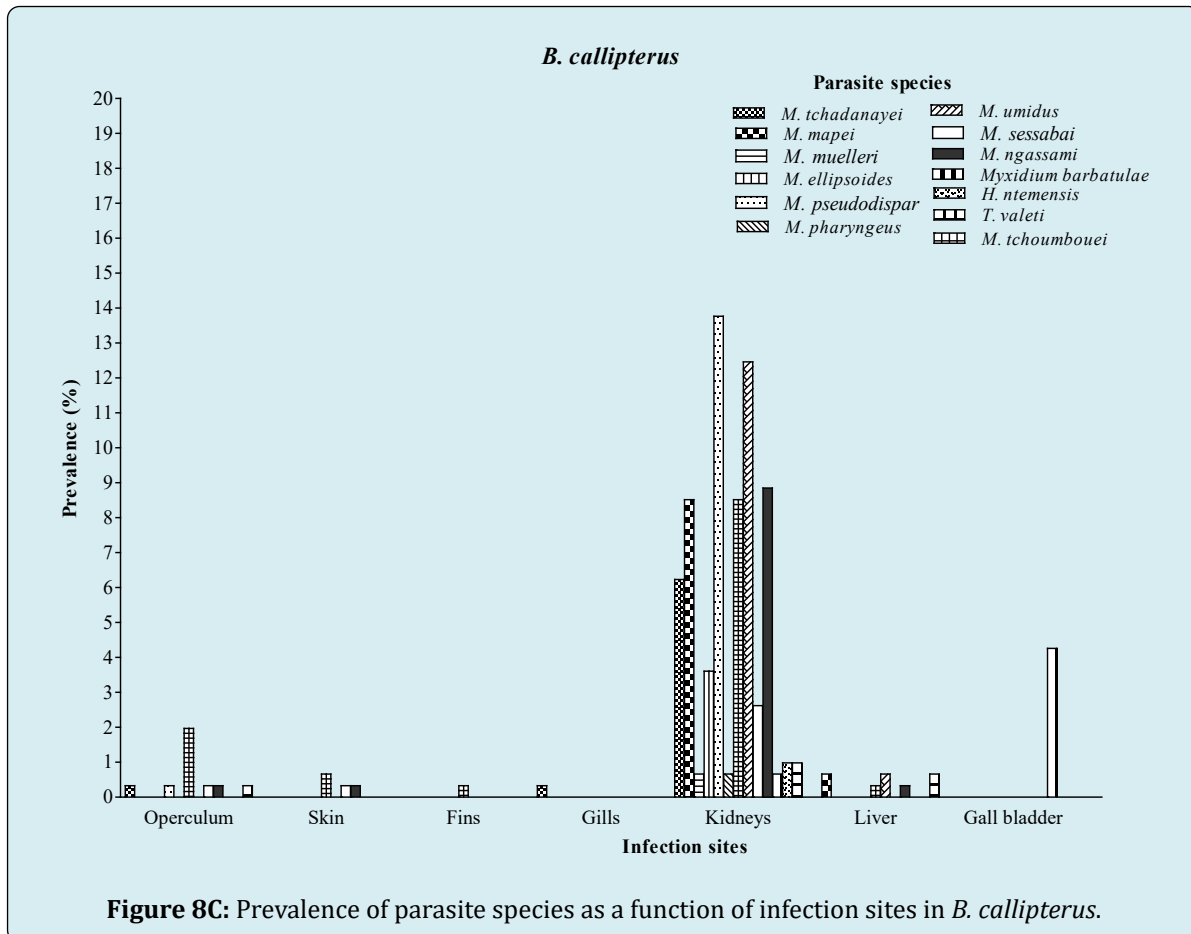
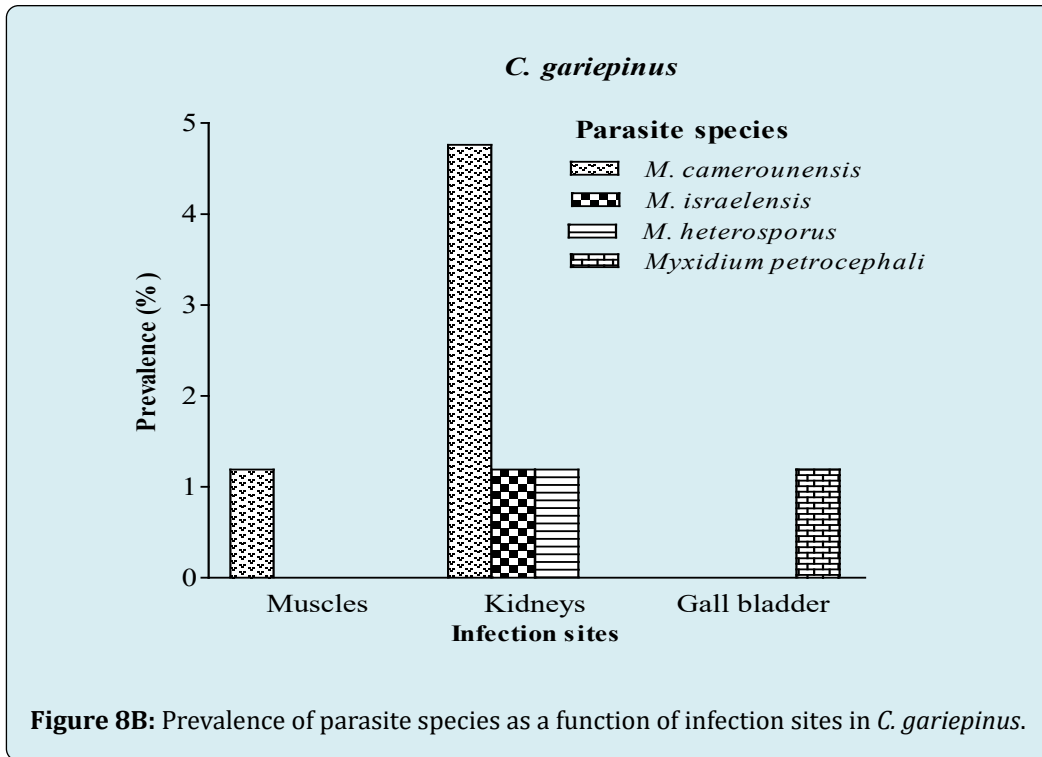


- A:** *Myxobolus camerounensis* Fomena et al., 1993 (x1500)
B: *Myxobolus israelensis* Landsberg, 1985(x1800)
C: *Myxobolus heterosporus* Baker, 1963 (x1500)
D: *Myxobolus agolus* Landsberg, 1985(x1500)
E: *Myxobolus tilapiae* Abolarin, 1974 (x1400)
F: *Myxobolus brachysporus* Baker, 1963(x1500)
G: *Myxobolus kainjiae* Obiekezie and Okaeme, 1990 (x1800)
H: *Myxobolus tchadanayei* Abakar et al., 2006 (x1300)
I: *Myxobolus mapei* Fonkwa et al., 2017 (x1500)
J: *Myxobolus muelleri* Bütschli, 1882 (x 1600)
K: *Myxobolus ellipsoides* Thelohan, 1982 (x 1500)
L: *Myxobolus pseudodispar* Gorbunova, 1936 (x 1600)
M: *Myxobolus pharyngeus* Parker et al., 1971 (x 1600)
N: *Myxobolus tchoumbouei* Fonkwa et al., 2017 (x1200)
O: *Myxobolus umidus* Carriero et al., 2013 (x1500)
P: *Myxobolus sessabai* Lekeufack et al., 2017(x1200)
Q: *Myxobolus ngassami* Lekeufack et al., 2017 (x1300)
R: *Myxidium petrocephali* Fomena et Bouix, 1986 (x1200)
S: *Myxidium barbatulae* Cépède, 1906 (x 1800)
T: *Henneguya ntemensis* Fomena et Bouix, 1996 (x 1800)
U: *Thelohanellus valeti* Fomena et Bouix, 1987 (x1700)

Figure 3: Spore micrographs of Myxosporeans found in fishes in MAPE dam, Adamawa-Cameroon.







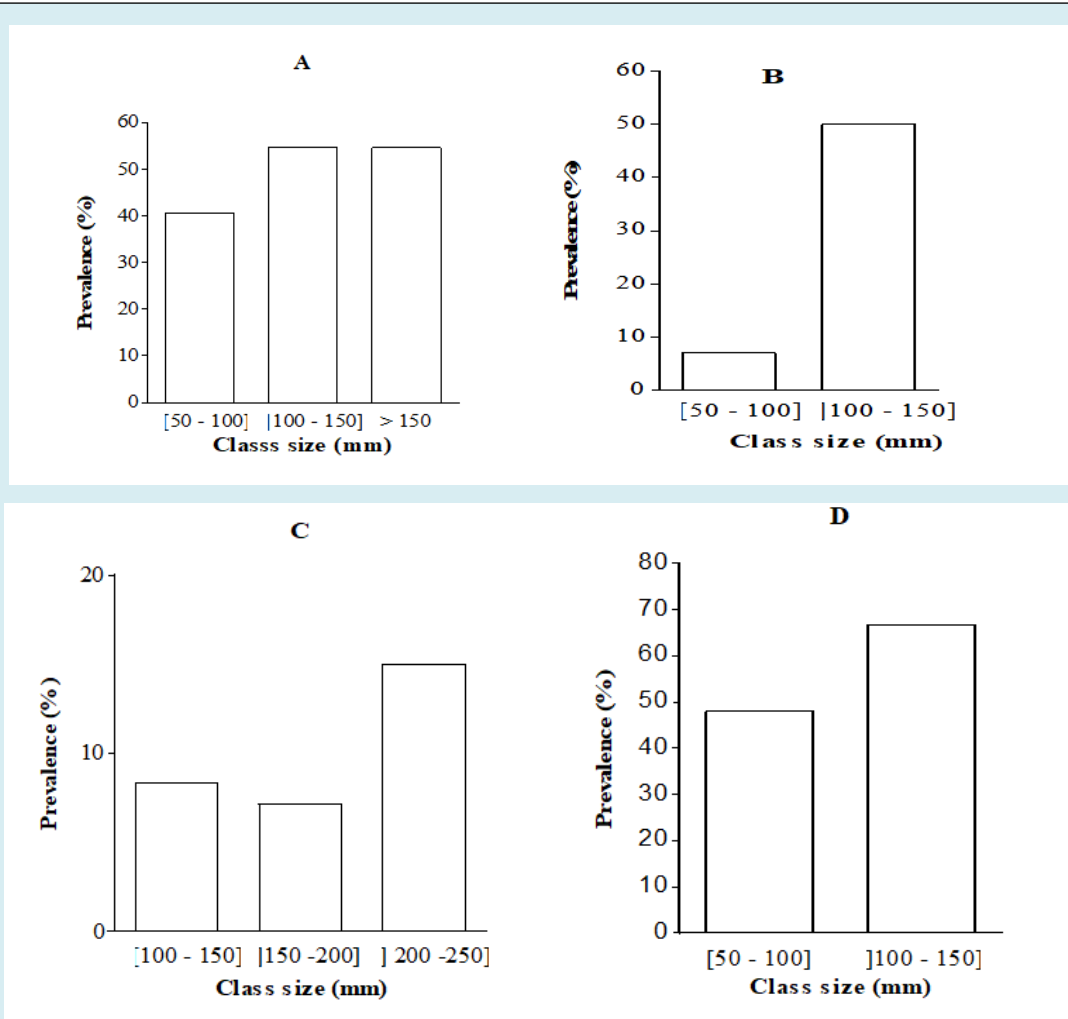
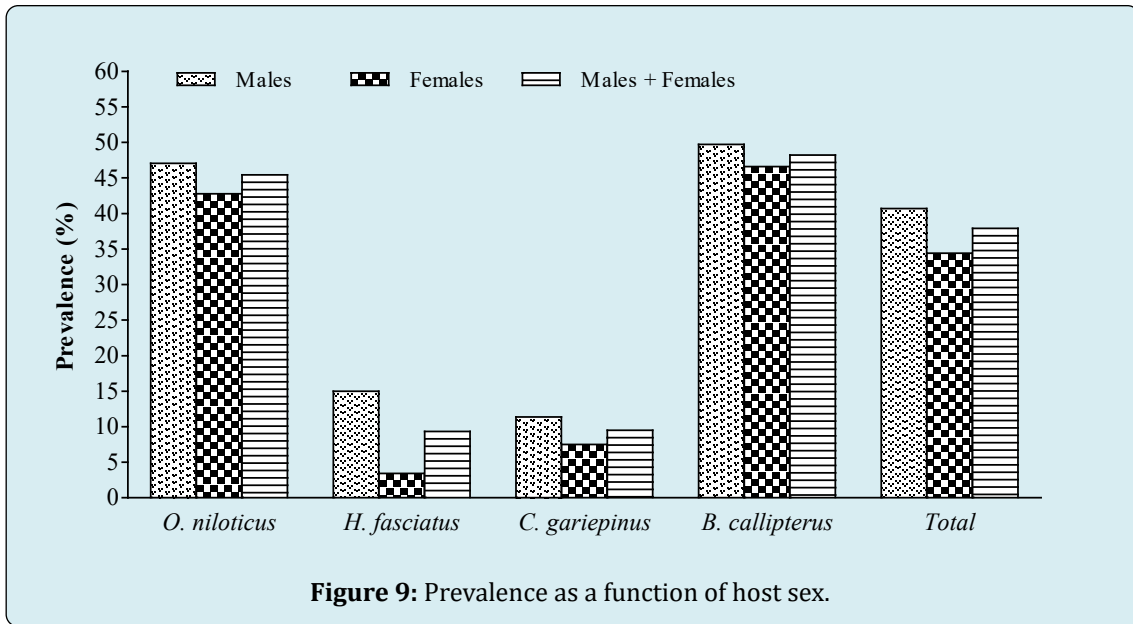
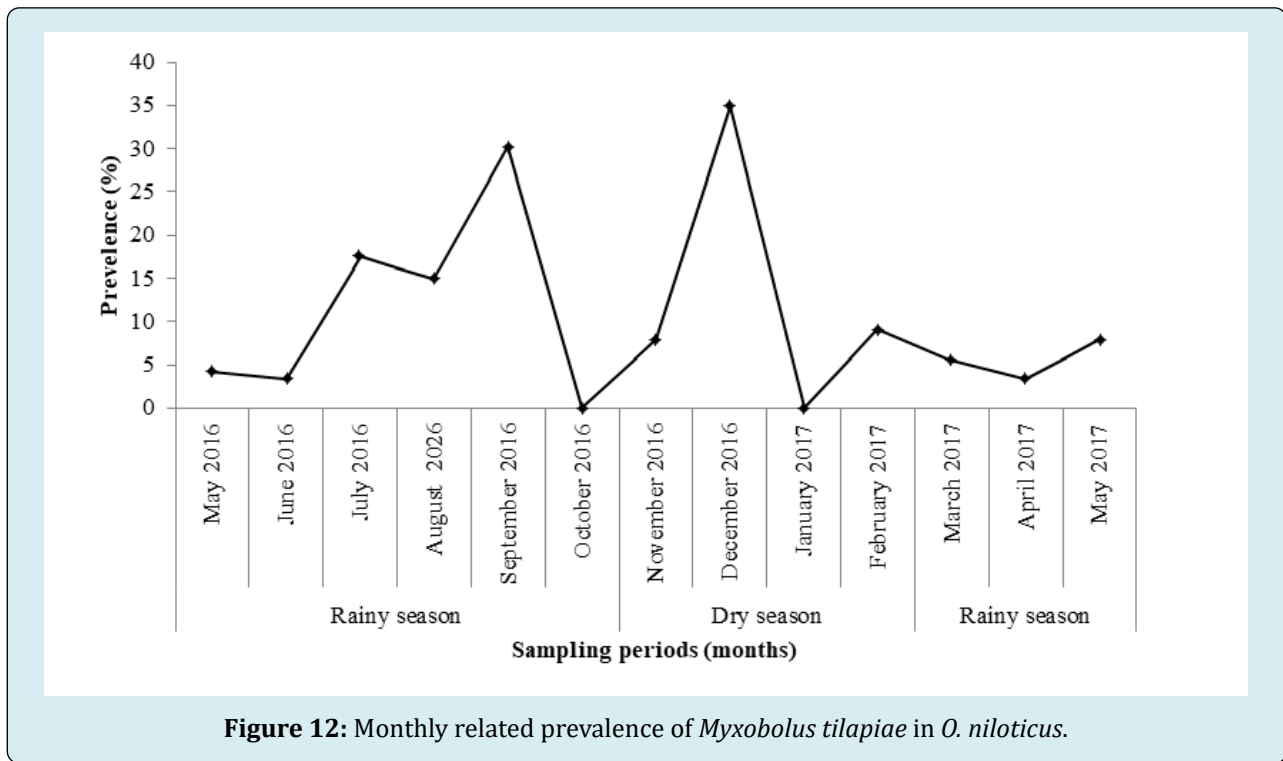
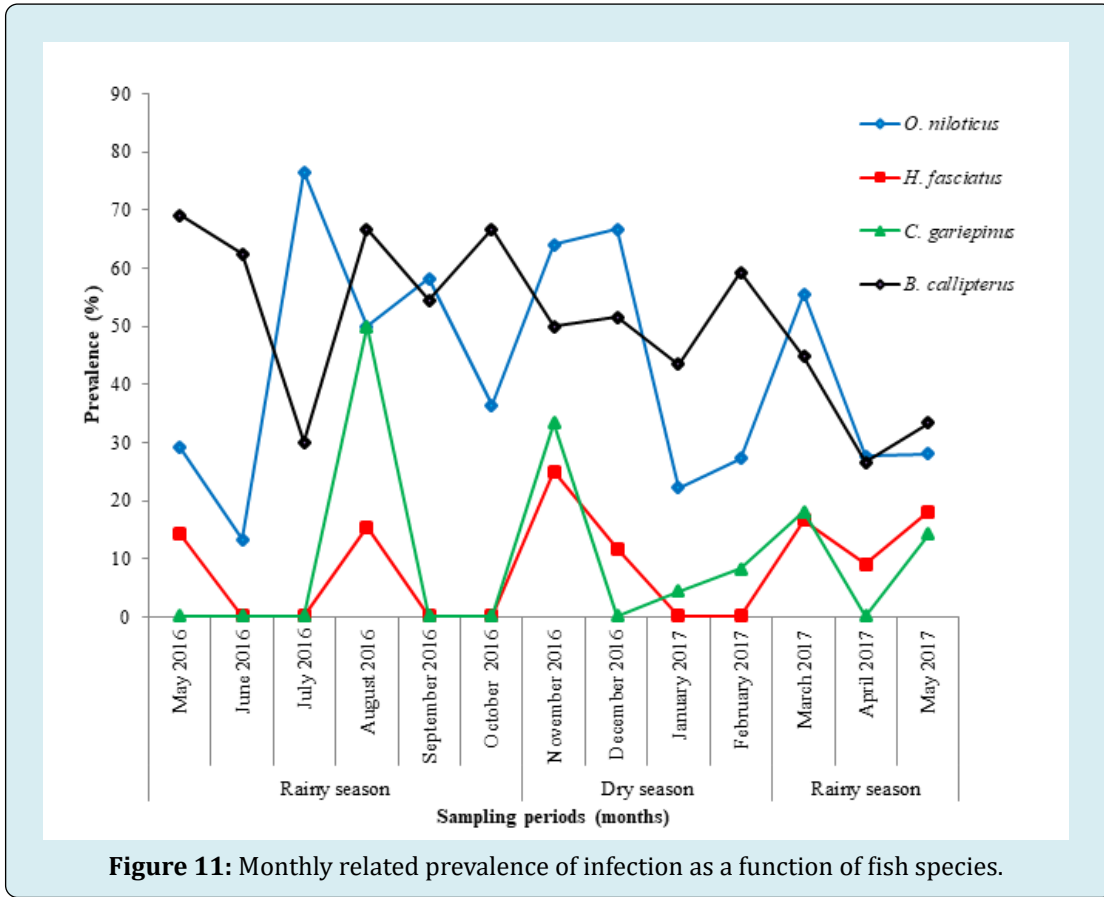


Figure 10: Prevalence in relation to class size in *O. niloticus* (A), *H. fasciatus* (B), *C. gariepinus* (C) and *B. callipterus* (D).



Prevalence of Myxosporeans Genera

The myxosporeans fauna of fishes (Figure 3) was composed of 21 species belonging to the genera *Myxobolus* (17 species), *Myxidium* (2 species), *Henneguya* (1 species) and *Thelohanellus* (1 species). The prevalence of myxosporeans genera as illustrated in Figure 4 reveals that irrespective of the host species, the highest ($X^2=58$; $P < 0.001$) infection rate (37.11%) was recorded for the genus *Myxobolus*. On the contrary the less prevalent genera were in the decreasing order of infection rate *Myxidium* (1.87%), *Thelohanellus* (0.70%) and *Henneguya* (0.35%). Moreover, *Myxobolus* spp infected all host species with the highest and significant prevalence ($X^2=87.00$; $P < 0.001$) in *B. callipterus* (45.90%) and *O. niloticus* (15.43%). The genus *Myxidium* was only found in two fish species namely *C. gariepinus* and *B. callipterus* with low prevalence i.e. 1.19 and 4.92% respectively. In addition, *Henneguya* and *Thelohanellus* were specific to a single host (*B. callipterus*). Meanwhile, the genus *Myxobolus* infected two host species namely *O. niloticus* and *H. fasciatus*. *B. callipterus* was the sole host to be infected by all the four myxosporeans genera.

Fish Species as a Risk Factor

As shown in Figure 5, all the four fish species were infected and the overall prevalence was 37.92% regardless of the fish species. The prevalence varied very remarkably with host species ($X^2=92.00$; $P < 0.001$). Although *B. callipterus* seemed to be more infected (48.20%) than *O. niloticus* (45.43%), no significant difference ($X^2=0.50$; $P = 0.479$) was found between prevalence. Furthermore, *H. fasciatus* was the less infected fish (9.32%).

Host Related Prevalence of Myxosporean Infection

The host related prevalence of myxosporean infection (Figure 6) reveals that parasite species were scarce or intermediate. *B. callipterus* and *O. niloticus* harbored more myxosporean species (13 and 12 respectively) than *H. fasciatus* and *C. gariepinus*, each of them being infected by four species. In *O. niloticus*, the prevalence significantly ($X^2=118.80$; $P < 0.001$) ranged from 0.86 to 15.14% for *M. pharyngeus* and *M. tilapiae* respectively. As for *B. callipterus*, *M. pseudodispar* exhibited the highest prevalence ($X^2=145.90$; $P < 0.001$) while *M. muelleri* and *M. pharyngeus* were the least occurring (0.65%). Although the parasites prevalence did not vary significantly in *H. fasciatus* and *C. gariepinus*, *Myxobolus camerounensis* remained the most prevalent.

Prevalence in Relation to Infection Sites and Host

The prevalence in relation to infection sites and host as shown in Figure 7 reveals that, regardless of the fish species 12 organs were parasitized. *O. niloticus* and *B. callipterus* exhibited the highest number of infected organs i.e. 10 and 7 organs respectively. *C. gariepinus* and *H. fasciatus* had respectively 3 and 6 parasitized organs. Besides the fact that kidneys were the sole commonly infected organs to all fish species, their infection frequencies were the highest ($P < 0.001$) whatever the host species.

The prevalence of parasite species as a function of infection sites (Figures 8A, 8B & 8C and Table 3) illustrates that kidneys harbored 91.67% of species (11 species over 12) in *O. niloticus* (Table 3), 100% in *B. callipterus* (13 species over 13) and 75% (3 species over 4) for *H. fasciatus* and *C. gariepinus*. In *H. fasciatus* kidneys (Figure 8A), *M. israelensis* and *M. brachysporus* were evenly present and five time less prevalent ($P = 0.01$) than *M. tilapiae*. As for *C. gariepinus* (Figure 8B), muscles and gall bladder were infected with *M. camerounensis* and *Myxidium petrocephali* respectively having the same infection rate (1.19%). In *O. niloticus*, kidneys, liver and spleen harbored more parasite species (11; 7 and 4 respectively). *Myxobolus kainjiae* seemed to be specific to *O. niloticus* ovaries. Moreover, a broad spectrum of target organs was noticed with *M. camerounensis* (6 infected organs over 10) with prevalence ranging from 0.86 to 3.14% in the gills and kidneys respectively. Whatever the parasite species, the prevalence differed significantly from one infection site to another ($P < 0.05$). *Myxobolus tchoumbouei* appears to exhibit a broad spectrum of target organs (5 infected organs over 7) in *B. callipterus* (Figure 8C).

Host Sex Related Prevalence of Myxosporean Infection

The host sex related prevalence of myxosporean infection as illustrated in Figure 9 reveals that whatever the host species and irrespective of the parasite species, males tended to be more infected than females except in *H. fasciatus* where males were significantly ($P = 0.001$) more infected than females. Whether in males or females, the lower prevalence ($P < 0.05$) was recorded in *H. fasciatus* and *C. gariepinus*.

Prevalence in Relation to Class Size and Correlation between the Prevalence and Fish's Condition Factor (K)

The prevalence in relation to class size (Figure 10) shows that fishes of all class sizes were infected. In fishes

whose sizes ranged between 50 and 150 mm, the prevalence was significantly higher in *B. callipterus* and lower in *H. fasciatus* ($P < 0.05$). In *C. gariepinus*, the overall prevalence in the class] 200 - 250] was about twice higher ($P < 0.05$) than that recorded in the class sizes] 100 - 150] and] 150 - 200]. As for *H. fasciatus*; the prevalence was about seven times higher ($X^2 = 12.37$; $P < 0.001$) in the class size] 100 - 150] than size [50-100]. The prevalence was not correlated with the fish size except in *O. niloticus* exhibiting positive and significant correlation ($r = + 0.17$; $P < 0.01$). Table 2 reveals that whatever the fish species, the prevalence was not correlated ($P > 0.05$) with the condition factor.

Monthly Related Prevalence as a Function of Fish Species

No seasonal pattern of host infection (Figure 11) was observed. *H. fasciatus* and *C. gariepinus* were found to be infected for 7 and 6 months over 13 months respectively over the 13 months of the sampling period. *O. niloticus* and *B. callipterus* which were parasitized throughout the 13 months. The infection rate of *O. niloticus* and *B. callipterus* was higher during July and May 2016 respectively but was lower in the same order in June 2016 and April 2017. As a whole, *H. fasciatus* recorded the lowest prevalence ($P < 0.001$) during the study period.

Monthly Prevalence of *Myxobolus tilapiae* in *O. niloticus*

As earlier illustrated, *Myxobolus tilapiae* was the most prevalent parasite infecting *O. niloticus*. The latter being appreciated by households and is involved in fish farming program in Cameroon. Figure 12 shows that October 2016 and January 2017 were not favorable to the occurrence of *M. tilapiae*. On the contrary, the highest ($P < 0.05$) prevalence (34.85%) was recorded in December 2016.

Discussion

The diversity of the myxosporeans fauna is in accordance with Combes's [23] assertion as which the pathogenic effects are hardly caused by a single parasite species. The higher prevalence recorded by the genus *Myxobolus* is documented. In fact, Lom and Diková [18] estimated that the world myxosporeans fauna was composed of about 2180 species gathered within 62 genera among which the genus *Myxobolus* Bütschli, 1882 represented about 36.33% of species. This observation is in agreement with the findings of Lekeufack and Fomena [24] who recorded in the River Sangé in Cameroon 54.55% of myxosporeans of the genus *Myxobolus* infesting various hosts namely *Ctenopoma petherici*, *Clarias pachynema* and *Hepsetus odoe*. Moreover, Abakar [4] reported in Chad 60% of *Myxobolus* species. The

same observation was made in Chad By Fomena, et al. [25], then Kostoingue and Toguebaya [26]; Fall, et al. [27] in Chad, Senegal and Cameroon; Obiekezie and Okaeme [6] in Nigeria.

The genus *Myxobolus* infected all the four fish species contrary to the genera *Myxidium*, *Henneguya* and *Thelohanellus*. The broad spectrum of hosts observed with *Myxobolus* spp may be explained by the versatility (flexibility) of its metabolic pathway enabling it to get adapted to various biotopes. In addition, the genus *Myxobolus* may have a genetic background allowing it to challenge the host immune system. Although the overall prevalence (37.92%) was low, that may constitute a serious problem to the fish production. Euzet and Pariselle [28] observed that in natural milieu, the pathogenic effects of parasites are reduced because of the balance established during the evolution of host / parasite system. For a given parasite, the infection rate and the status of the parasite species vary geographically [29] according to host species [30]. In farming situation, the overall prevalence can increase because the confinement of fish, the presence of muddy vase, the low oxygenation and low depth of water enhance the transmission of the parasites [6, 31-33].

Irrespective of the parasite species *B. callipterus* and *O. niloticus* recorded the higher prevalence and harbored about thrice more parasite species than *H. fasciatus* and *C. gariepinus*. The most vulnerable host may either be due to their weak immune system or the intrinsic factors such as the feeding mode. *O. niloticus* for example feeds on algae which are carriers of actinospores. The variation of the number of parasite species per host may be explained by the proximity between fishes and oligochaetes [24] which are definitive hosts [18, 34]. The scarcity of parasite species in *H. fasciatus* and *C. gariepinus* should not be incriminated to the competition because according to Sitjà-Bobadilla [35], there is neither inter nor intra specific competition between myxosporeans. Thus, the absence of competition may be at the origin of *O. niloticus* and *B. callipterus* polyinfection. The specificity of a parasite species to a given taxon may be genetic dependent.

Parasite species which were specific to *O. niloticus* and *B. callipterus* seemed to be oïxenous (narrow specificity). Meanwhile, *Myxobolus tilapiae* and *M. brachysporus* were stenoxenous to *O. niloticus* and *H. fasciatus* since those parasite species infected hosts belonging to the same family (Cichlidae). *O. niloticus* and *B. callipterus* being too distant in the phylogenetic tree, parasite species that were common to them were therefore euryxenous (broad specificity).

Kidneys were the most infected organs probably because, since they filter blood and secrete many solutes [36], parasites converge there for the metabolites they needs. In addition, kidneys and spleen are the initiation

sites of the developmental cycle for many myxosporean species [31]. *Oreochromis niloticus* and *B. callipterus* which recorded the highest percentage of infected organs may have a weak immune system. The specificity of *Myxobolus kainjiae* to *O. niloticus* ovaries may implies that ovaries provide suitable environment for the *M. kainjiae* survive and also, this latter may be extremely competitive and therefore prevents the establishment of another parasite species. The broad spectrum of target organs observed with *M. camerounensis* and *M. tchoumbouei* in *O. niloticus* and *B. callipterus* respectively may be explained by the versatility of their metabolic pathway enabling them to get adapted to various biotopes. Ibrahim and Soliman [37] thought that the heterogeneity of biotopes generates distinct infection sites which are habitat options for parasites.

The sex did not influence the prevalence regardless of the host and parasite species. This is in agreement with the claims of Abakar [4], Milanin, et al. [38], Lekeufack and Fomena [24]. Fomena [31] didn't find any difference between the infection rate of male and female *Oreochromis niloticus* at Mélen fish ponds (Yaoundé -Cameroon) by myxosporeans of kidneys and livers. Likewise, Viozzi and Flores [39] noticed that the prevalence of *Myxobolus biliare* in *Galaxias maculatus* was sex independent and claimed to be the global situation with myxosporidiosis. In *H. fasciatus* and *B. callipterus*, males were significantly more infected than females because males lose huge amount of energy for testosterone synthesis thus weakening the efficiency of their immune system [40]. Simkova, et al. [41] underlined that the effect of fish sex on the prevalence of myxosporidiosis is not well known.

The infection of fishes of all class sizes was reported by Obiekezie and Okaeme [6] who thought that fishes of all ages are susceptible to myxosporean infection. Irrespective of the fish species, young hosts were more infected than older ones. This may be due to the small sample size of older fishes (about 30% of the total population). Tombi and Bilong Bilong [33], Viozzi and Flores [39], Abakar [4] reported that young fishes were more vulnerable to myxosporean infections than older ones. Brummer – Korvenkontio, et al. [30] made the same observation in Finland where the prevalence of infection of *Rutilus rutilus* by *Myxobolus rhodei* and *M. pseudodispar* decreased with the fish age. These authors raised the increase of the immune system response with the size (age) of fish. In contrast to our observation, Nchoutpouen, et al. [42] pointed out that, in farming situation, older *Oreochromis niloticus* were more infected than the younger ones.

Whatever the fish species, infections occurred during both the rainy season and the dry seasons. Bilong Bilong and Tombi [43], then Abakar [4] also noticed that some myxosporean species were present in fishes throughout the year. The high prevalence observed during the dry season

in *O. niloticus* and *H. fasciatus* can be explained by the high temperature of water and mud encouraging the sinking of actinospores. The latter get aging in the mud and sludge so as to infect *O. niloticus* and *H. fasciatus* feeding on them [6,44]. *Clarias gariepinus* and *B. callipterus* probably do not feed on mud during the dry season, reason why they exhibit the low infection rate.

Conclusion

The myxosporean fauna of fishes from the Sudano-guinean zone of Cameroon was diversified. *B. callipterus* and *O. niloticus* were more infected than *C. gariepinus* and *H. fasciatus*. Males of *H. fasciatus* were significantly more infected than females. The prevalence of parasite species was not correlated with the condition factor and fish size except that of *Myxobolus tilapiae* which was positively correlated with *O. niloticus* size. The season did not significantly influence the prevalence. Kidneys were the most infected organ. The recorded data are useful to fish farming and the elaboration of prevention and control strategies against myxosporidiosis.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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