



## Community Structure and Species Diversity of Ectoparasitic Helminthes and their Impact on Condition Factor of *Clarias gariepinus* and *Oreochromis niloticus* in Degraded Aquatic Ecosystems at Nile Delta, Egypt

Mohamed H. Gadalla<sup>1</sup>, Ahmed M. El-Naggar<sup>1</sup>, Ahmed M. Alraesi<sup>2</sup>, Hanaa T. El-Bahnasy<sup>1\*</sup>

<sup>1</sup>Zoology Department, Faculty of Sciences, Mansoura University, Egypt

<sup>2</sup>Department of Geology, Faculty of Sciences, United Arab Emirates University, United Arab Emirates

\*Corresponding Author: [Hanaa.Tawfik.2012@mans.edu.eg](mailto:Hanaa.Tawfik.2012@mans.edu.eg)

### ARTICLE INFO

#### Article History:

Received: Nov. 13, 2024

Accepted: March 3, 2025

Online: March 8, 2025

#### Keywords:

Community structure,  
Condition factor,  
Monogenean parasites,  
Environmental  
degradation,  
*Clarias gariepinus*,  
*Oreochromis niloticus*

### ABSTRACT

This research dealt with the ectoparasitic helminth communities infesting the African sharp-tooth catfish, *Clarias gariepinus* Burchell, 1822 and the Nile tilapia *Oreochromis niloticus* Linnaeus, 1758 inhabiting the degraded aquatic environments of the Nile Delta, Egypt, from summer 2021 to spring 2022. The study was carried out in four interconnected locations: Nezam Drain, a typical agricultural drainage system; Amlak Drain, which is heavily polluted from multiple sources; and two smaller agricultural drains (MAS-1 and MAS-2) linked to Amlak and Nezam Drains, respectively. Amlak Drain notably releases water into Manzala Lake, a crucial habitat for local fish populations. The investigation involved 246 specimens of *C. gariepinus*, which yielded 6,361 monogenean worms across six species. In comparison, 124 specimens of *O. niloticus* produced 450 pathogenic microorganisms, comprising six monogenean and one digenean species. Using Jaccard's index, the study found complete similarity ( $S_j=100\%$ ) in monogenean communities of *C. gariepinus* across all habitats and a high similarity ( $S_j=87.5\%$ ) for *O. niloticus* between MAS-1 and MAS-2. The research evaluated both intraspecific and interspecific aggregation indices, uncovering non-random distribution patterns among monogenean species and indicating a stronger interspecific aggregation that suggests coexistence dynamics. The condition factor (K), which indicates fish health, showed that higher parasite loads adversely affected fish welfare; those with better condition factors (Class III) had lower parasite intensities than those in poorer health classes (I and II). These results emphasize the negative impact of ectoparasitic infections on fish health and highlight how environmental degradation influences the structure of parasite communities. The findings advocate for effective management strategies to address these issues in the Nile Delta's aquatic ecosystems.

### INTRODUCTION

Fish serve as an essential protein source for humans and animals, accounting for nearly 40% of protein consumption for two-thirds of the global population (Osuiwe & Obiekezie, 2007). They also play a significant role in alleviating poverty of various communities in developing nations (Obosi and Agbeja, 2015; Efole *et al.*, 2016; Agbebi

**& Adetuwo, 2019**). Nevertheless, improving fish production means increasing the intensity of production, which has been linked to the spread of parasites and deterioration in water quality (**Osuiigwe & Obiekezie, 2007**). Parasites can harm fish by causing physical damage (such as the fusion of gill filaments and replacement of tissues), physiological harm (including cell growth, immune system changes, altered growth patterns, and negative behavioral reactions), and reproductive harm (**Bamidele *et al.*, 2007, Akinsanya *et al.*, 2008, Bamidele *et al.*, 2015**). Ectoparasites, in particular, are highly destructive and have been a major cause of death in farmed fish species (**Shalaby & Ibrahim, 1988**).

Identification of the factors influencing the composition of parasite communities has been a fundamental aspect of ecological parasitology for a long time (**Holmes, 1987; Poulin, 2001; Thompson *et al.*, 2020; Brian & Aldridge, 2023**). It is commonly assumed that parasite communities are usually positioned on a spectrum ranging from interactive to isolationist, i.e. from species-rich assemblages, where interspecific interactions significantly shape the community, to species-poor assemblages, with a fewer number of species and less interaction. This idea has emerged as a key paradigm in the ecology of parasite communities. The level of interaction within parasite communities is a key theme of modern parasite ecology. The concept of isolationist versus interactive communities was introduced by **Holmes and Price (1986)**. As postulated by **Rohde (1979)** and **Koskivaara and Valtonen (1992)**, certain species can expose their host fish to infection from a new species by reducing the host's immune response. **Rohde (1979)** suggested that a new species is more likely to cause a more severe and exhaustive infection if it is present alongside two or more other species on the same host. **Gutierrez and Martorell (1999)** observed no interaction between monogenean species. This output supports the theory introduced by **Rohde (1979, 1994)** and postulated that the most common species (*D. paravalenciennesi* and *D. uncusvalidus*) had a positive interaction.

**Louizi *et al.* (2023)** surveyed three native cichlids (*Oreochromis aureus*, *Coptodon zillii* and *Coptodon guineensis*) from Morocco and recovered 1328 monogenean worms from 56 cichlid fish comprising two monogenean species (family Dactylogyridae and genus *Cichlidogyrus*): *Cichlidogyrus cubitus* was recovered from *C. guineensis* and three phenotypes of *Cichlidogyrus cirratus* were isolated from *O. aureus* and *C. zillii*. These authors attributed the species-poor monogenean communities of the cichlid hosts to the enemy release hypothesis (**Heger & Jeschke, 2014**), and likely facilitated the lateral movement of parasites in wild populations between *O. aureus* and *C. zillii*, as well as the syngeneic diversification of *C. cirratus*. **Oliveira *et al.* (2019)** found similar species richness and community structure of the monogeneans from two populations of *Cichla monoculus*, suggesting a broad spread of these pathogens across their range in the biome of Amazon. However, the structure of communities of these parasites showed variations in abundance and prevalence, as well as dominance. The monogenean communities

exhibited a high qualitative similarity (87.5%). Similarly, the structure of parasite communities varied based on the definite circumstances of each environment, as noted in other host-parasite systems (**Santana-Pineros et al., 2012; Marcogliese et al., 2016**).

Ecological interactions among cohabitant monogeneans differ from one host-parasite model to another, for example character displacement (**Rohde, 1991**), coexistence (**Simkova et al., 2000, 2002**), competitive coexistence (**El-Naggar & El-Tantawy, 2001**), and competitive exclusion (**El-Naggar, 2012**). **Poulin (2001)** hypothesized that monogenean species possessing similar copulatory tools tend to segregate over space (microhabitat patches), however monogeneans possessing divergent copulatory organs coexist calmly. **Poulin (2001)** concluded that niche segregation is not induced by competitive interactions, but possibly by fortifying reproductive barriers. **Rohde and Hobbs (1986)** hypothesized that monogenean species resident over the same microhabitat patch might possess similar organs of clinging or attachment, however these cohabitatnts must possess divergent copulatory organs, in terms of morphometric features. This pattern of coexistence, facilitated by variability in shape and size of copulatory organs, likely reinforce the reproductive barriers of congeneric and cohabitant monogeneans.

The condition factor (K) measures the physical condition of a fish in relation to its overall welfare (**Anani & Nunoo, 2016**). It is frequently applied to assess how abiotic and biotic factors impact the health or general welfare of population of fish (**Otieno et al., 2014; Dambatta et al., 2017; Saber et al., 2020**). Additionally, the K value provides insights when comparing two populations of fish under definite feeding, climate, and population density circumstances (**Golam & Al-Misned, 2013**). A K value of 1.00 indicates the fish is in poor health, thin, and long, while a value of 1.40 suggests the fish is in good health and well-proportioned (**Barnham & Baxter, 1998**). The average condition factor (K) of the fish in the study conducted by **Ngueguim et al. (2020)** was above one (>1), indicating healthy fish, adequate feeding, and suitable environmental conditions (**Ayode, 2011; Ujjania et al., 2012**). The average condition factor for parasite-free fish was notably higher than that of infected fish, suggesting that the presence of parasites did not promote growth or survival. The impact of environmental conditions on the growth and survival of fish has been previously explored (**Nehemia et al., 2012; Olopade et al., 2015**). **Ngueguim et al. (2020)** identified a considerable disparity in the condition factor between parasite-free and parasite-infected fish. These findings are in line with previous research (**Zouhir et al., 2010**) that has shown the pathogenicity of parasites is influenced by factors such as the host (size, age, and health), the parasite (stage of development and size), and the environment (stress, isolation, pollution).

**Kouadio et al. (2023)** conducted a study on the seasonal association between the health status of fish and density of monogeneans parasites in *Heterobranchus isopterus* and *Clarias gariepinus* caught from the Bagoue River. These authors calculated the correlation coefficient to explore how the health status of fish was related to the total

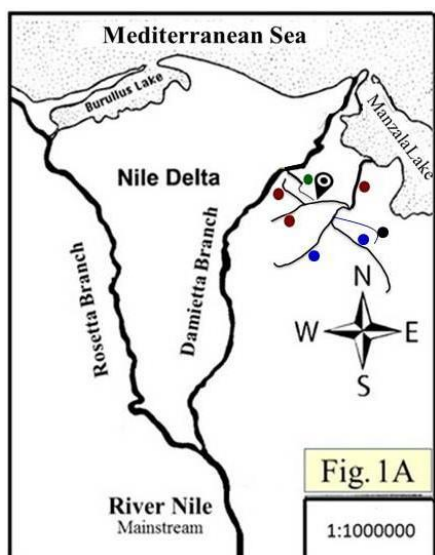
parasite count. They found a significant positive relationship between the health status of fish and parasite burden in both host species during the rainy season. Conversely, during the dry season, there was a negative relationship between the health status of fish and parasite count in both fish hosts. **Guidelli *et al.* (2011)** concluded that most ectoparasites were negatively associated with the condition factor of their fish hosts.

The aims of this study were to (1) analyze the ectoparasitic communities of the catfish, *Clarias gariepinus* and the Nile tilapia, *Oreochromis niloticus* inhabiting polluted aquatic habitats, (2) demonstrate the relationship between ectoparasitic communities and condition factor of the two host species, and (3) illustrate the comparative degree of intraspecific versus interspecific aggregation of individuals within the investigated monogenean species.

## MATERIALS AND METHODS

### 1. Area of investigation

This research dealt with the ectoparasitic helminth communities infesting the African Sharptooth catfish, *Clarias gariepinus* Burchell, 1822 and the Nile tilapia *Oreochromis niloticus* Linnaeus, 1758 in the north range of the Nile Delta in Dakahlia Governorate, Egypt (Fig. 1A). The present study was conducted over four consecutive seasons (from summer 2021 to spring 2022). Four varying water quality habitats were explored, namely Nezam Drain (a typical agricultural drain), Amlak Drain (multisource polluted drain), two minor agricultural drains (MAS-1 connected to Amlak Drain and MAS-2 connected to Nezam Drain) (Fig. 1B). Amlak Drain joins Nezam Drain and flows northwards to dump huge quantities of water into the southern sector of Manzala Lake (Fig. 1A), one of the highly productive ecosystems and animal protein sources in the Nile Delta. MAS-1 terminates close to Amlak Drain and receives its outflow through a pumping unit. MAS-2 terminates close to Nezam Drain and receives its outflow through a pumping unit (Fig. 1B).



**Fig. 1A.** Hand drawn map of the Nile Delta, Egypt showing: MAS-1 (green solid circle), MAS-2 (black solid circle) and Amlak Drain (red solid circles) and Nezam Drain (blue solid circles). Note directions on the compass. 📍 indicates the junction between MAS-1 and Amlak Drain



**Fig. 1B.** Google Earth map of the explored aquaic semi-ecosystems. The sampling and fishing site is located between the red solid circles. Note that the this dirty network of contaminated water sources irrigates vast agricultural lands that meet the growing demand of highly populated suburban area. MAS-1, minor agricultural stream; MAS-2, minor agricultural stream; blue arrowhead, pumping unit. Scale bar = 50m

## 2. The condition factor (CF)

The condition factor (CF) reflects the overall fish health prominence and is considered as a pointer of the quality of the surrounding environment. CF is estimated according to **Fulton (1904)**; the distinctive weight of the fish (g) is relative to the cube of its length (cm). As fish become lengthier, they become heavier. This association is formulated as follows:  $K = 100 (W/L^3)$  (**Richter et al., 2000**). The total length of fish was measured in centimeters with the aid of an ordinary ruler and the total body weight was estimated with the aid of an ordinary balance. The viscera were weighed with a balance.

## 3. Community structure of helminth parasite species

In accordance with **Bush et al. (1997)**, the ecoparasitological indices of prevalence, mean intensity, and abundance of the helminth parasite species of the catfish and the Nile tilapia were computed. As a statistical concept, prevalence (% of infection) refers to the number of people in a given population who are infected with a parasite species at any given moment. Mean intensity (MI) is the total number of worms of a particular parasite species divided by the number of hosts infected with that parasite; prevalence (P%) is the number of host individuals infected/infested by one or more individuals of that parasite species divided by the number of hosts examined for that parasite species; and the total

number of individuals of a specific parasite species divided by the total number of hosts (both infected and non-infected) of that species under examination is known as abundance (A).

The indices describing the structure of the community included mean intensity, prevalence, dominance and abundance. **Roohi *et al.* (2016)** computed the dominance of helminth parasite species as follows:

$$D = N_{\max} / N_{\text{total}}$$

$N_{\text{maximum}}$  = the total number of members of the dominant species,

$N_{\text{total}}$  = total number of individuals belonging to various species.

#### 4. Dominance index (Simpson index)

A measure of diversity that considers both the total number of species and their relative abundance is Simpson's diversity index (D). Diversity rises in tandem with species richness and evenness. **Dodge (2008)** states that the following formula is used to determine Simpson's diversity index (D). Simpson index was calculated as follows:

$$1/D = 1/\sum p_i^2$$

Where, p is the species i proportion in the community. According to **Krebs (1999)** and **Magurran (2004)**, the diversity index is sensitive to changes in the most common species and gives changes in unusual species less weight.

Simpson's diversity index is a formula designed to measure the diversity of species in a biological community (**Simpson, 1949**). Designated as *D*, this index was calculated as follows:

$$D = \sum n_i (n_i - 1) / N(N - 1)$$

Where:

$n_i$ : The number of organisms that belong to species *i*,

N: The total number of organisms that belong to different species in the community.

Simpson's diversity index runs from 0 to 1. A greater value corresponds to diminished diversity.

Ecologists frequently compute Simpson's index of diversity, also known as a dominance index and computed as  $1 - D$ . The diversity of species increases with an index's greater value. Ecologists can also compute Simpson's reciprocal index, defined as  $1/D$ . The minimum value for this index is 1, while the maximum value corresponds to the total number of species. The Simpson diversity index spans from 0 to 100%, where 0 indicates unlimited diversity and 1 signifies no diversity; thus, a higher D number corresponds to reduced diversity. Consequently, the Simpson index is typically represented as its inverse ( $1/D$ ) or its complement ( $1-D$ ), commonly referred to as the Gini-Simpson index. Simpson evenness is designed as follows:

$$E1/D = (1/D)/S$$

Where, S is the species number in the sample (CCR). According to **Magurran (2004)**, this index provides a scale (0-1) regarding the evenness of the various parasite species in the component community.

## 5. Community similarity (similarity coefficients for binary data):

### 5.1. Sorenson's coefficient (coefficient of community)

The range of Sorenson's coefficient level is 0 to 1. The two communities are completely unlike when the coefficient value gets close to zero. On the other hand, there is an overlap between the two communities when the coefficient value is around 1. According to **Hammond and Pokorný (2020)**, the formula below is used to estimate this coefficient:

$$S_s = 2c / (S_1 + S_2)$$

$S_s$  = Sorensen's similarity coefficient.

$c$  = number of parasite species shared by both communities.

$S_1$  = number of parasite species unique to the first community.

$S_2$  = number of parasite species unique to the second community.

### 5.2. Jaccard's index

When comparing the variety and similarity of two sample groups (binary data), a statistic known as the Jaccard's index (Jaccard similarity coefficient) is used (**Jaccard, 1901**). It primarily depends on whether a live thing is present locally or not. Jaccard's equation was calculated as follows:

$$S_J = 100c / (a + b - c)$$

$S_J$  = Jaccard's similarity coefficient.

$c$  = number of parasite species shared by both communities.

$a$  = number of parasite species unique to the first community.

$b$  = number of parasite species unique to the second community.

### 5.3. Intraspecific aggregation index

Intraspecific aggregation index ( $J_k$ ) was calculated as follows:

$$J_k = \frac{\sum_{i=1}^p \frac{n_{ki}(n_{ki} - 1)}{m_k} - m_k}{m_k} = \frac{V_k}{m_k} - 1$$

Where,  $n_{ki}$  means the number of parasite species  $k$  on host individual  $i$ ,  $m_k$  and  $V_k$  represent mean numbers and variance in numbers of parasitic species  $k$ , respectively. When  $J$  equals 0, individuals of the target species exhibit a random distribution.  $J$  value of 0.75 signifies a 75% increase in the anticipated number of conspecifics inside an environmental patch relative to a random distribution pattern (**Morand et al., 1999; Simkova et al., 2000**).

#### 5.4. Interspecific aggregation index

Interspecific aggregation index ( $C_{kl}$ ) was calculated as follows:

$$C_{kl} = \frac{\sum_{i=1}^p \frac{n_{ki}n_{li}}{m_k P} - m_l}{m_l} = \frac{Cov_{kl}}{m_k m_l}$$

Where, Cov means the covariance between two species (k and l),  $n_{ki}$  and  $n_{li}$  represent the mean numbers of the parasite species k and l on host individual I,  $m_k$  and  $m_l$  represent mean numbers of the parasite species k and l, and P means the number of host species. The positive associations between the two species are indicated by  $C > 0$ . However, negative associations are indicated by  $C < 0$  (Simkova *et al.*, 2000).

#### 5.5. Relative strength of Intraspecific vs. Interspecific aggregation index

Relative strength of Intraspecific vs. Interspecific aggregation index ( $A_{kl}$ ) was calculated as follows:

$$A_{kl} = \frac{(J_k + 1)(J_l + 1)}{(C_{kl} + 1)^2}$$

Where,  $J_k$  means the intraspecific aggregation index of species k and  $J_l$  means the intraspecific aggregation index of species l.  $C_{kl}$  represents the interspecific aggregation index between individuals of the parasite species k and l. Intraspecific aggregation becomes stronger than interspecific aggregation when  $A_{kl} > 1$ . However, interspecific aggregation becomes stronger than intraspecific aggregation when  $A_{kl} < 1$  (Simkova *et al.*, 2000).

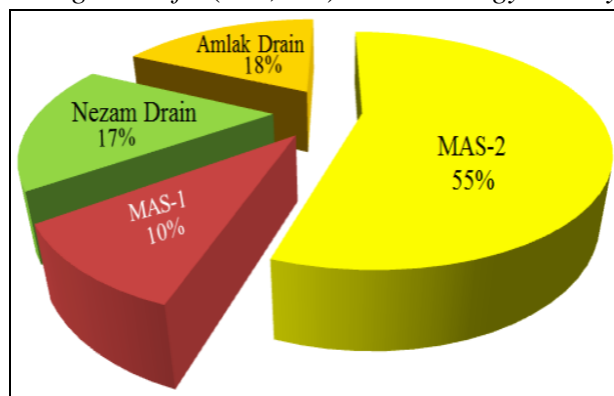
## RESULTS

### 1. Parasite community structure

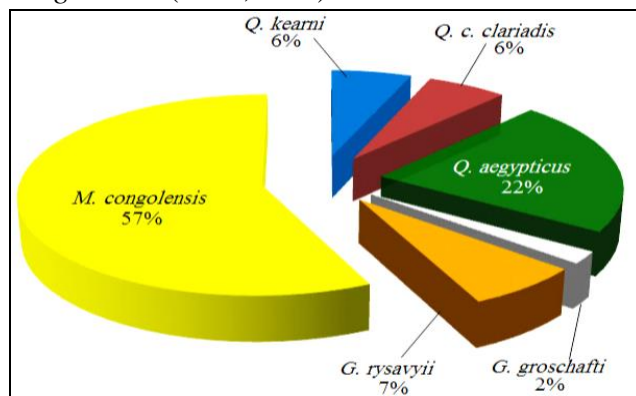
Out of 246 specimens of the African sharptooth catfish, *Clarias gariepinus* Burchell, 1822 caught from Nezam Drain (51), MAS-2 (74), Amlak Drain (69) and MAS-1 (52), a total of 6361 monogenean worms were isolated from the skin and gills during the period from summer 2021 to spring 2022. The community comprised 6 monogenean species, namely *Gyrodactylus groschafti* Ergens, 1973; *Gyrodactylus rysavyi* Ergens, 1973; *Macrogyrodactylus congolensis* (Prudhoe, 1975) Yamaguti, 1963; *Quadriacanthus aegypticus* El-Naggar and Serag, 1986; *Quadriacanthus clariadis clariadis* Paperna, 1979 and *Quadriacanthus kearni* El-Naggar and Serag, 1985. The load of these pathogenic microorganisms was affiliated as follows: Nezam Drain (number=1084, sharing ratio= 17%), MAS-2 (3471, 55%), Amlak Drain (1140, 18%) and MAS-1 (666, 10%) (Fig. 2). Figs. (3- 6) illustrate the sharing ratios of the skin and gill monogenean species of *C. gariepinus* inhabiting Amlak Drain, Nezam Drain, MAS-1 and MAS-2, respectively. Data pooled from all investigated habitats revealed that the



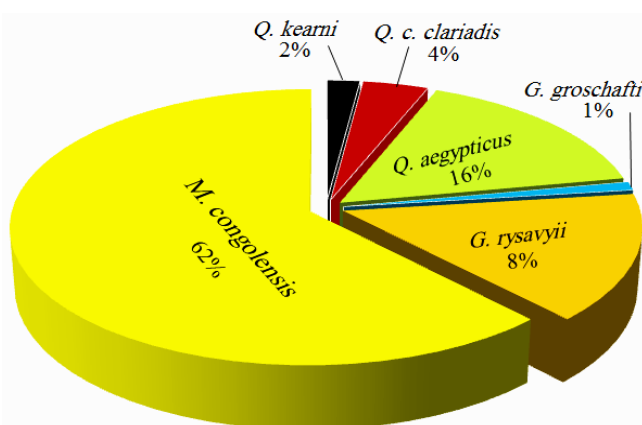
monogenean community is structured as follows: *Quadriacanthus aegypticus* (number=1084, sharing ratio= 17%), *Quadriacanthus clariadis clariadis* (253, 4%), *Quadriacanthus kearni* (166, 3%), *Gyrodactylus rysavyi* (717, 11%), *Gyrodactylus groschafti* (101, 2%) and *Macrogyrodactylus congolensis* (4071, 64%).



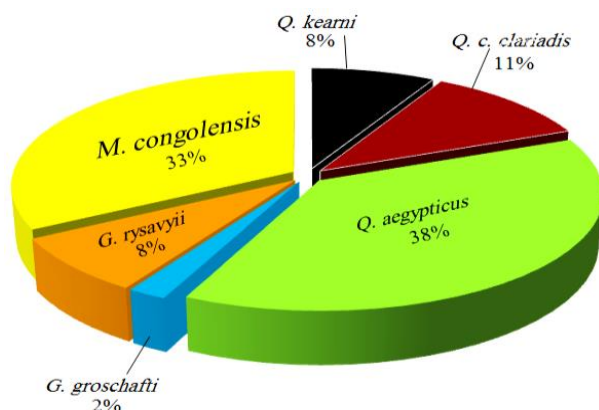
**Fig. 2.** Pie chart showing ratios of the total skin and gill parasitic load of the catfish, *Clarias gariepinus*



**Fig. 3.** Pie chart showing the ratios of the skin and gill parasites of the gill parasites of the catfish, *Clarias gariepinus* inhabiting Amlak Drain



**Fig. 4.** Pie chart showing the ratios of the skin and gill parasites of the gill parasites of the catfish, *Clarias gariepinus* inhabiting Nezam Drain

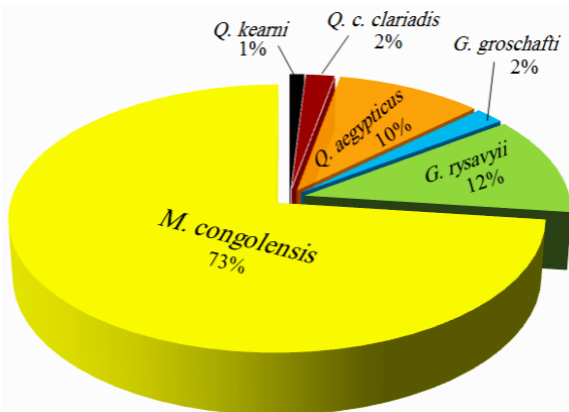


**Fig. 5.** Pie chart showing the ratios of the skin and gill parasites of the gill parasites of the catfish, *Clarias gariepinus* inhabiting MAS-1

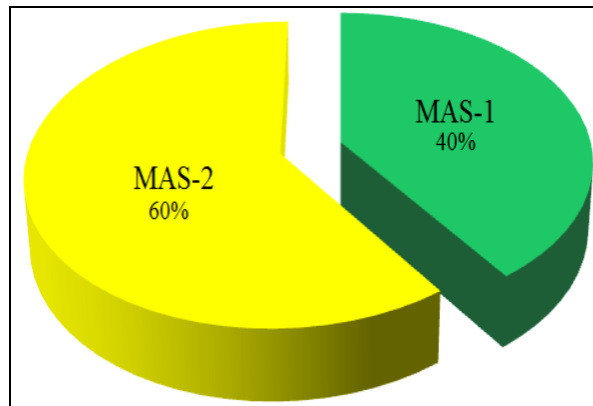
The greatest number of *Macrogyrodactylus congolensis* was computed at Nezam Drain (number=2533, sharing ratio= 62%), *Gyrodactylus rysavyi* at MAS-2 (424, 12%), *Gyrodactylus groschafti* at Amlak Drain, Nezam Drain and MAS-2 (59, 58%), *Quadriacanthus aegypticus* at MAS-1 (362, 38%), *Quadriacanthus clariadis clariadis* at MAS-1 (76, 11%) and *Quadriacanthus kearni* at MAS-1 (73, 8%) (Figs. 3 - 6). In contrast, the lowest number of *Macrogyrodactylus congolensis* was computed at MAS-1 (number=220, sharing ratio= 33%), *Gyrodactylus rysavyi* at Amlak Drain (52, 7%),

*Gyrodactylus groschafti* at Nezam Drain (10, 1%), *Quadriacanthus aegypticus* at (178, 10%), *Quadriacanthus clariadis clariadis* at (43, 2%) and *Quadriacanthus kearni* at MAS-2 (16, 1%).

Out of 124 specimens of the white tilapia, *Oreochromis niloticus* Linnaeus, 1758 caught from MAS-1 (62) and MAS-2 (62), a total of 450 pathogenic microorganisms were isolated from the gills during the period from summer 2021 to spring 2022 (182 from *O. niloticus* at MAS-1 and 268 from the same host at MAS-2). The community comprised 6 monogenean species and one digenean species, namely *Cichlidogyrus ergensi* Dossou, 1982; *Cichlidogyrus halli typicus* (Price and Kirk, 1967) Paperna, 1979; *Cichlidogyrus thurstonae* Ergens, 1981; *Gyrodactylus cichlidarum* Paperna, 1968; *Macrogyrodactylus clarii* Gussev, 1961; *Scutogyrus longicornis longicornis* Paperna and Thurston, 1969; and the digenean *Centrocestus formosanus* (Nishigori, 1924) Price, 1932. The load of these pathogenic microorganisms was affiliated as follows: MAS-1 (number=182, sharing ratio= 40%) and MAS-2 (268, 60%) (Fig. 7). Figs. (8, 9) illustrate the sharing ratios of the gill monogenean species of *O. niloticus* inhabiting MAS-1 and MAS-2, respectively. Data pooled from the two habitats revealed that the monogenean community is structured as follows: *Cichlidogyrus halli typicus* (number=206, sharing ratio= 46%), digenean cysts (*Centrocestus formosanus*) (147, 33%), *Cichlidogyrus ergensi* (34, 7%), *Gyrodactylus cichlidarum* (26, 6%) and *Cichlidogyrus thurstonae* (26, 6%). Other monogenean species (*Scutogyrus longicornis longicornis*, *Cichlidogyrus tiberianus* and *Macrogyrodactylus clarii* are represented by few individuals (3) and minor sharing ratios (1%). The cichlid host, *O. niloticus* from MAS-2 harbored greater numbers of *C. halli typicus* (120), *C. ergensi* (31) and *C. formosanus* (92); however, *O. niloticus* from MAS-1 harbored fairly more worms of *G. cichlidarum* (17) and *Scutogyrus longicornis longicornis* (4). The oviparous monogenean, *C. thurstonae* scored the same number at both habitats (13 worms).



**Fig. 6.** Pie chart showing the ratios of the skin and gill parasites of the gill parasites of the catfish, *Clarias gariepinus* inhabiting MAS-2

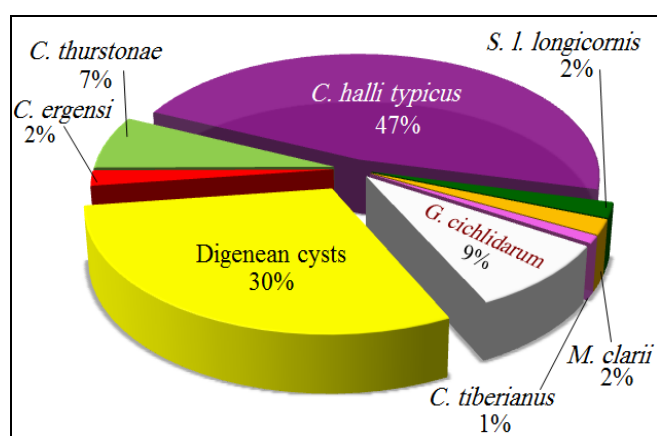


**Fig. 7.** Pie chart showing ratios of the total gill parasitic load of the white tilapia, *Oreochromis niloticus*

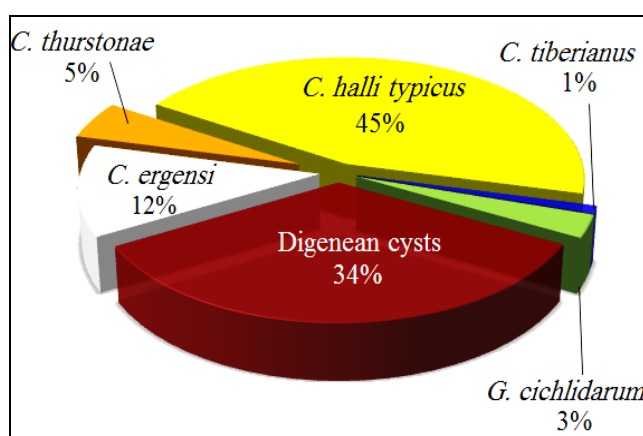
## 2. Dominance index and Simpson's diversity index

Fig. (2) shows the proportions of the monogenean load on *C. gariepinus* from different study sites. It can be seen that the catfish dwelling MAS-2 harbored the heaviest monogenean burden (55%) compared to the monogenean burden on *C. gariepinus* in other localities. Concerning the monogenean community of *C. gariepinus* inhabiting Amlak Drain, the skin viviparous monogenean *M. congolensis* was the most dominant, followed by the oviparous gill monogeneans *Q. aegypticus* and *Q. c. clariadis* (Fig. 3). Regarding the monogenean community of *C. gariepinus* dwelling Nezam Drain, the skin viviparous monogenean *M. congolensis* was the most dominant, followed by the oviparous gill monogenean *Q. aegypticus* and the skin viviparous monogenean *G. rysavyii* (Fig. 4). At MAS-1 habitat, *Q. aegypticus* scored the highest dominance level, followed by *M. congolensis* and *Q. c. clariadis* (Fig. 5). On the other hand, at MAS-2 habitat, *M. congolensis* dominated the community, followed by *G. rysavyii* and *Q. aegypticus* (Fig. 6).

Fig. (7) shows the proportions of the ectoparasitic load on *O. niloticus* from the two investigated habitats. It is obvious that the cichlid fish host dwelling MAS-2 habitat harbored the heaviest monogenean burden (60%) compared to the ectoparasitic burden on the same host in MAS-1 habitat. Concerning the monogenean community of *O. niloticus* dwelling, the oviparous gill monogenean *C. halli typicus* was the most dominant, followed by the cysts of the digenean *C. formosanus* and the oviparous monogenean *C. ergensi* (Fig. 8). Concerning the monogenean community of *O. niloticus* inhabiting MAS-2 locality, the oviparous gill monogenean *C. halli typicus* was the most dominant, followed by the cysts of the digenean *C. formosanus*, the viviparous *G. cichlidarum* and the oviparous *C. thurstonae* (Fig. 9).



**Fig. 8.** Pie chart showing the ratios of the gill parasites of the white tilapia, *Oreochromis niloticus* inhabiting MAS-1



**Fig. 9.** Pie chart showing the ratios of the gill parasites of the white tilapia, *Oreochromis niloticus* inhabiting MAS-2

### 3. Community similarity indices

Jaccard's index revealed complete similarity ( $S_j=100\%$ ) of the monogenean communities of the catfish *C. gariepinus* among habitats (Nezam Drain, Amlak Drain, MAS-1 and MAS-2). On the other hand, Jaccard's index indicated high similarity ( $S_j=87.5\%$ ) of the monogenean communities of tilapia *O. niloticus* between MAS-1 and MAS-2.

Similarly, Sorenson's coefficient scored complete similarity ( $S_s=1$ ) of the monogenean communities of the catfish *C. gariepinus* among habitats (Nezam Drain, Amlak Drain, MAS-1 and MAS-2). On the other hand, Sorenson's coefficient showed high similarity ( $S_s=0.94$ ) of the monogenean communities of tilapia *O. niloticus* between MAS-1 and MAS-2.

### 4. Intraspecific aggregation index

For *Macrogyrodactylus congolensis* from *Clarias gariepinus* in Amlak Drain, Nezam Drain, MAS-1 and MAS-2, index of intraspecific aggregation (J) values were 0.05, 0.36, 0.05 and 0.54, respectively. Index of intraspecific aggregation (J) for *Gyrodactylus rysavyii* from Amlak Drain, Nezam Drain, MAS-1 and MAS-2 were 0.99, 1.04, 0.13 and 2.47, respectively. Estimated J values for *Quadriacanthus aegypticus* from *C. gariepinus* were 0.64, 1.73, 0.63 and 1.00, respectively. Obtained J values for *Q. c. clariadis* from *C. gariepinus* in the above mentioned habitats were 1.66, 0.08, 1.80 and 1.81; and for *Q. kearni* were 1.33, 1.08, 0.57 and 3.79, respectively. These findings indicate that individuals of monogenean species exhibit non-random distribution.

Computed values of the index of intraspecific aggregation (J) for monogenean microfauna *Cichlidogyrus halli typicus*, *C. thurstonae*, *Scutogyrus longicornis longicornis* and *C. ergensi* of *Oreochromis niloticus* inhabiting MAS-1 were 0.90, 0.48, 7.38 and – 20.83, respectively. On the other hand, at MAS-2, estimated values of J for the above mentioned monogenean species were – 0.32, 2.10, 100 and 1.46, respectively, except for *C. ergensi* at MAS-1 and *Cichlidogyrus halli typicus* at MAS-2. These findings indicate that individuals of monogenean species exhibit non-random distribution.

### 5. Interspecific aggregation index

Regarding the cohabitants *Macrogyrodactylus congolensis* and *Gyrodactylus rysavyii* from the skin of *Clarias gariepinus*, computed values of the index of interspecific aggregation ( $C_{12}$ ) were 4.50, 4.50, 9.00 and 9.00 in Amlak Drain, Nezam Drain, MAS-1 and MAS-2, respectively. On the other hand, concerning the gill resident monogeneans belonging to genus *Quadriacanthus* from Amlak Drain, Nezam Drain, MAS-1 and MAS-2, estimated values of the index of interspecific aggregation ( $C_{12}$ ) for *Q. aegypticus*–*Q. c. clariadis*, *Q. aegypticus*–*Q. kearni*, and *Q. c. clariadis*–*Q. kearni* were >1. Concerning the monogenean gill parasites of *Oreochromis niloticus* inhabiting MAS-1 and MAS-2, computed values of the index of interspecific aggregation ( $C_{12}$ ) for

*Cichlidogyrus halli typicus*–*C. thurstonae*, *C. halli typicus*–*S. l. longicornis*, *C. halli typicus*–*C. ergensi*, *C. thurstonae*–*S. l. longicornis*, *C. thurstonae*–*C. ergensi*, and *S. l. longicornis* –*C. ergensi* were >1. These data indicate that all monogenean pairs exhibit positive associations.

## 6. Relative strength of Intraspecific versus Interspecific Aggregation index

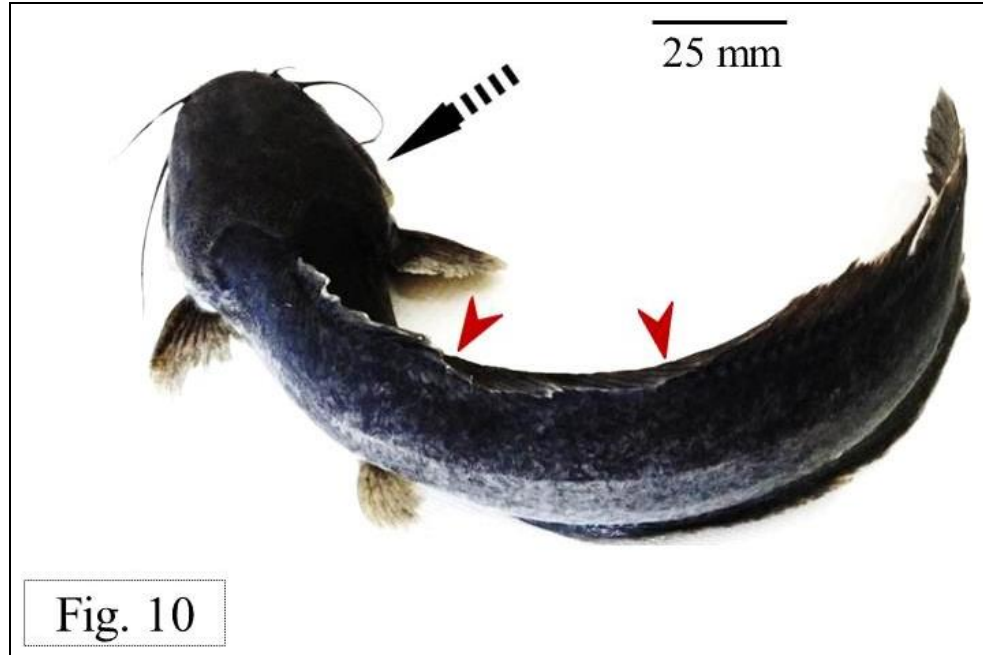
Regarding the cohabitants *Macrogyrodactylus congolensis* and *Gyrodactylus rysavyii* from the skin of *C. gariepinus*, computed values of the index assessing the relative strength of intraspecific aggregation versus interspecific aggregation ( $A_{12}$ ) were 0.07, 0.09, 0.01 and 0.05 in Amlak Drain, Nezam Drain, MAS-1 and MAS-2, respectively. On the other hand, concerning the gill resident monogeneans belonging to genus *Quadriacanthus* from Amlak Drain, Nezam Drain, MAS-1 and MAS-2, estimated values of  $A_{12}$  for *Q. aegypticus*–*Q. c. clariadis*, *Q. aegypticus*–*Q. kearni*, *Q. c. clariadis*–*Q. kearni* were all < 1.

Concerning the monogenean gill parasites of *O. niloticus* inhabiting MAS-1 and MAS-2, computed values of the index assessing the relative strength of intraspecific aggregation versus interspecific aggregation ( $A_{12}$ ) for *Cichlidogyrus halli typicus*–*C. thurstonae*, *C. halli typicus*–*S. l. longicornis*, *C. halli typicus*–*C. ergensi*, *C. thurstonae*–*S. l. longicornis*, *C. thurstonae*–*C. ergensi*, and *S. l. longicornis* –*C. ergensi* were all < 1.

## 7. Relationship between mean intensity of ectoparasite species and condition factor of *C. gariepinus* and *O. niloticus*.

Regarding the monogenean microfauna of *C. gariepinus* at Nezam Drain, the overall mean intensity values on condition factor classes I, II and III were 10.27, 7.42 and 3.00 worms per infested fish, respectively. At Amlak Drain, the overall mean intensity values on condition factor classes I, II and III were 21.64, 8.73 and 8.00 worms per infested fish, respectively. Concerning the monogenean microfauna at MAS-1, the overall mean intensity values on condition factor classes I, II and III were 13.55, 8.04 and 2.50 worms per infested fish, respectively. At MAS-2, the overall mean intensity values on condition factor classes I, II and III were 10.58, 10.47 and 15.83 worms per infested fish, respectively. Fig. (10) shows an individual catfish, *C. gariepinus* belonging to condition factor (Class I) experiencing weight loss in response to high parasite load and high pollution level in all investigated habitats.

For the monogenean microfauna of *O. niloticus* at MAS-1, the overall mean intensity values on condition factor classes I, II and III were 8.32, 5.13 and 3.56 worms per infested fish, respectively. At MAS-2, the overall mean intensity values on condition factor classes I, II and III were 6.16, 12.00 and 2.33 worms per infested fish, respectively.



**Fig. 10.** Photograph showing an individual catfish, *C. gariepinus* belonging to condition factor (Class I) showing weight loss in response to monogenean load and environmental pollution. Note the broad head region (intermittent arrow) and the slim trunk region (red arrowhead)

## DISCUSSION

Ectoparasite communities of *C. gariepinus* (6 species) and *O. niloticus* (7 species) are dominated by a few species, indicating that these assemblages are isolationist in nature (non-interactive). The skin viviparous gyrodactylid *Macrogyrodactylus congolensis* was the core species in monogenean communities of *C. gariepinus* inhabiting MAS-2, Nezam Drain and Amlak Drain (73, 62 and 57%, respectively). However, at MAS-1, the core species was *Q. aegypticus* (38%), followed by *M. congolensis* (33%). Regarding the monogenean communities of *O. niloticus*, the oviparous ancycrocephaline monogenean *Cichlidogyrus halli typicus* was the core species on this cichlis host at both MAS-1 and MAS-2 habitats (47 and 45%, respectively). It is worth noting that the digenean cysts encapsulated into the cartilaginous support of the gill arches attained relatively high sharing ratio in the buildup of the gill ectoparasitic community of *O. niloticus* in MAS-1 and MAS-2 (30% and 34%, respectively).

Survey of the monogenean assemblages on *C. gariepinus* revealed that the skin viviparous monogeneans (*M. congolensis* and cohabitant *G. rysavyii*) are more abundant than the gill oviparous monogeneans (*Quadriacanthus* spp.). This higher abundance may be attributed to differences in the physical activity, feeding reproductive potential, duration of the life cycle, nature of the microhabitat and body size of pathogen. **El-Naggar et al. (2001, 2004)** highlighted the amazing physical activity of *M. congolensis*

and *G. rysayii*. Both species were observed to practice leech-like, upside down leech-like locomotion, searching and prolongation and shortening movements. Unlike *M. congolensis*, *G. rysayii* swims actively across the water column for a brief time. Unlike *G. rysayii*, *M. congolensis* conducts pendulum-like movement. However, the gill monogeneans (*Cichlidogyrus* and *Scutogyrus* spp.) only translocate in a leech-like movement. Scutogyrid and cichliogyrid pathogens are oviparous monogeneans (egg-laying), while skin gyrodactylids are viviparous (live-holding). Oviparous species release eggs into water, whereas viviparous species release larvae, which directly attach to the same host individual or a neighboring one. Furthermore, skin viviparous monogeneans are larger in size and exhibit higher reproductive potential than gill monogeneans. While oviparous gill monogeneans generally lay one egg per 24 hours, viviparous skin monogeneans may give birth up to 3 or 4 overlapping generations per 24 hours.

According to **Bromagen (2022)**, the body size reveals features of the biography, ecology, and evolution of the living organism. This plays a critical role in success or failure during biological interactions (e.g. competition, reproduction, microhabitat selection, etc.). Usually, there is a negative association between body size and population density in nature (**Bromagen, 2022**). This assumption is in line with our data; the abundance of adult stage of the oviparous *Quadriacanthus* species was higher than those of the cohabitants (*Macrogyrodactylus*, *Gyrodactylus* and *Ergasillus*). On the other hand, the abundance of encysted metacercaria topped other gill residents. Yet the gill biotope is regarded as a food- and space-rich resource, other drivers may play a pivotal role in the survival of these tiny pathogens.

Monogenean parasitic communities have been categorized mostly as non-interactive or isolationist in nature, in terms of interspecific interactions between different species (**Koskivaara & Valtonen, 1992; Rhode et al., 1994; Simkova et al., 2000; Karvonen et al., 2007**). However, **Karvonen et al. (2007)** argued that the majority of these studies were conducted at scales improper for investigation, in terms of low parasite abundance (**Koskivaara & Valtonen, 1992; Simkova et al., 2000**) or microhabitat level (**Mouillot et al., 2005**). On the other hand, **Salgado-Maldonado et al. (2020)** proposed that the majority of fish parasite communities are made up of a limited number of species, suggesting that interactions between different species are not crucial in shaping these communities. They also suggested that competition between different species could still occur in these communities, that the presence of other species could influence the diversity of the community, and that grouping of individuals within the same species could help different species live together by reducing the overall competition.

**Mendoza-Franco et al. (2019)** examined interactions among low-diversity monogenean parasitic populations, concentrating on *Astyanax aeneus*, a tropical freshwater fish. Their research indicated that interactions between different species (interspecific interactions) could be a significant factor in the organization of low-diversity parasite communities. Interactions structuring low-diversity can



occasionally lead to the exclusion of one species, but there are different mechanisms by which different species can coexist (**Morand *et al.*, 1999**). The way species share resources can reduce the overall competition and is crucial for the diversity of parasite (monogenean) communities in fish (**Simkova *et al.*, 2000**).

In the present study, indices of the aggregation indicated that individuals of monogenean species exhibit non-random distribution, all monogenean pairs exhibit positive associations, and interspecific aggregation is stronger than intraspecific aggregation. **Karvonen *et al.* (2007)** found no evidence for competitive exclusion among the monogeneans of the genus *Dactylogyrus* (*D. formosanus*, *D. intermedius* and *D. wegneri*) on the scale of the gill filaments of the crucian carp, *Carassus carassus* existing in dense populations in lentic water of ponds, where circumstances are optimum for population proliferation and transmission of monogeneans that exhibit direct and simple life cycle. Moreover, these authors observed that individual of each *Dactylogyrus* species attain high aggregation trend over the gill filaments, indicating that these microorganisms actively search for conspecifics residing in the same microhabitat patch.

**Olubiyo *et al.* (2023)** explored how parasites impact the development of African catfish (*Clarias gariepinus*) in Omi Dam, located in Kogi State, Nigeria. Typically, fish that were not infected with parasites showed a positive allometric growth pattern, with a condition factor greater than 1.5. Conversely, fish infected with parasites demonstrated a negative allometric growth pattern, with a condition factor less than 1. The influence of parasites in the lives of parasite-loaded *C. gariepinus* was identified as a possibly significant factor contributing to the weight loss observed in individuals of this group, which in turn affected certain morphometric values, such as those related to body weight.

The grouping of conspecific individuals (intraspecific aggregation) can facilitate the coexistence of species that might otherwise be rejected. A greater number of parasite species may exist within the same host population when their distribution among host individuals is clustered (**Ives, 1988, 1991**). The host population serves as a reservoir of resource patches, within which parasites are unevenly dispersed. Generally, parasite populations are spread out in a clustered pattern among host individuals, with most host individuals harboring a few parasites and the majority of parasites are aggregated in a few host individuals (**Poulin, 1998; Poulin & Morand, 2004**). Clustering is the most distinctive aspect of parasitic infections in fish (**Poulin, 1993; Simkova *et al.*, 2000**).

The study conducted by **Ngueguim *et al.* (2020)** aimed at analyzing the impacts of ectoparasite infections on length-weight associations and condition factor of fishes in aquaculture systems of Cameroon. The findings showed that 34.87% of the fish samples were infested by ectoparasitic pathogens, specifically *Oreochromis niloticus* (34.37%), *Cyprinus carpio* (37.10%), and *Clarias gariepinus* (33.67%). The prevalence level of ectoparasite infestation varied according to fish weight and size, leading to patterns of negative allometric growth, regardless of whether the fish was infected or not. The average condition factor spanned from 1.07 to 3.01, with fish not infected showing



significantly higher condition factors than their infected counterparts. Regarding the infected group, *Oreochromis niloticus* demonstrated the highest condition levels, followed by *Cyprinus carpio* and *Clarias gariepinus*. The study concluded that ectoparasite infections had a significant influence on the length-weight associations and fish condition factor.

**Lizama et al. (2007)** study has demonstrated detrimental effects of endoparasites on the condition factor of tilapia. **Lizama et al. (2007)** demonstrated a negative relationship between the monogenean *Cichlidogyrus* sp. and condition factor of *O. niloticus*. Some investigations indicate that parasites do not influence the condition factor of tilapia (**Velloso & Pereira, 2010; Guidelli et al., 2011; Oliveira & Tavares-Dias, 2016**).

A study by **Paredes-Trujillo et al. (2021)** revealed that the Nile tilapia with fewer ectoparasites (*Cichlidogyrus* and *Gyrodactylus*) had higher energy availability compared to those with more ectoparasites. Furthermore, the Nile tilapia with more ectoparasites were found to weigh less than those with fewer. Additionally, **Paredes-Trujillo et al. (2021)** observed a notable, non-linear negative relationship between the number of ectoparasites and energy availability per fish, likely due to the increased production of gill mucus by ectoparasites, which reduced the energy available to the Nile tilapia. These monogeneans along with the protozoans *Trichodina* and *Vorticella* caused hypertrophy, hyperplasia, necrosis as well as further proliferative modifications in the epithelium, leading to respiratory issues (such as *Cichlidogyrus sclerosus*) and even death (**Del Rio-Zaragoza et al., 2010**).

The mean intensity of the monogenean gill parasites of *O. niloticus* and the skin and gill monogeneans of *C. gariepinus* showed negative impacts on the general health of fish expressed by the condition factor. Fish with high condition factor (Class III) harbored low mean intensity values, however fish with low condition factor (Class I and Class II) harbored high mean intensity. The condition factor serves as a numerical measure and an ecological index that reflects the interaction between abiotic and biotic elements in the health status of fish. It indicates the well-being of fish populations at different life stages (**Blackwell et al., 2008**). Examining the differences in this factor among populations or individuals can help identify how various parameters, like the quality of environment and availability of food, impact them (**Munyasya et al., 2015**). As a health-related metric, it can also highlight the influence of parasites on their hosts, in both wild and captive settings. **Lizama (2003)** proposed that the condition factor of fish, as a quantitative indicator of well-being, can be utilized to explore the connection association between health and natural parasitism.

Our findings reinforce the opinion that monogeneans can harm the fish host and cause severe negative impacts on the health status and length-weight relationship of the fish. Similar adverse impacts of monogeneans on the performance of their fish hosts were reported by **Hoque et al. (2018), Mladineo et al. (2023)** and **Abdel-Maged et al. (2024)**.

As observed by **Abdel-Maged *et al.* (2024)**, the monogeneans, *Pricea multae* and *Gotocotyla acanthura* triggered great damage to the gills in the marine fish host, *Scoberomorus commerson*. The features of microhabitat destruction involved partial to complete fusion and desquamation of gill lamellae (i.e. peeling of dead cells from epithelium/epidermis), with extensive loss of lamellae and infiltration of lymphocytes at the site of infestation, damage of pillar cell which support lamellae, along with clubbing of gill lamellae and hypertrophy (i.e. excessive enlargement) of the lamellar tips. **Abdel-Maged *et al.* (2024)** characterized the host response which comprised the presence of numerous scattered or shuffled lymphocytes and mucous globules at the attachment sites of monogeneans. **Hoque *et al.* (2018)** detected the cause of rapid mass mortality (more than 2000 fries in 24 hours) in farmed *Mystus gulio* infested by *Dactylogyrus* species. These authors calculated parasitological indices comprising prevalence, abundance, mean intensity and dominance, and estimated that 51 specimens of farmed *M. gulio* were infested with a total of 140 worms of *Dactylogyrus* sp. (mean intensity = 2.75 worms/infested fish). This monogenean recorded a dominance level >10%. The prevalence of *Dactylogyrus* sp. (85%) revealed that this pathogen was abundant in recently died *M. gulio*. **Mladineo *et al.* (2023)** recognized severe histopathological impacts of *Sparicotyle chrysophrii* on the gills of *Sparus aurata* and observed that clamp attachment is dynamic, distressing a series of microhabitats in the gills. The primary clinical signs of the blood feeder, *S. chrysophrii* on *S. aurata* involved lethargy and progressive anemia. The terminal stage of infestation comprised progressive emaciation and mortality.

## CONCLUSION

This study provides significant insights into the community structure and species diversity of ectoparasitic helminths affecting the African Sharptooth catfish (*Clarias gariepinus*) and the Nile tilapia (*Oreochromis niloticus*) in the degraded aquatic ecosystems of the Nile Delta, Egypt. The findings reveal a high prevalence of monogenean parasites, with *Macrogyrodactylus congolensis* and *Cichlidogyrus halli typicus* identified as dominant species in their respective hosts. The research highlights the detrimental impact of ectoparasitic infections on the health of fish, as indicated by the negative correlation between parasite load and the condition factor of both fish species.

The study underscores the importance of environmental quality in shaping parasite communities, with higher parasite loads observed in more polluted habitats, particularly Amlak Drain. The observed non-random distribution patterns of monogenean species suggest complex interspecific interactions, with evidence of stronger interspecific aggregation compared to intraspecific aggregation. This indicates a dynamic coexistence among parasite species that may influence their community structure.

Overall, the results emphasize the urgent need for effective management strategies to mitigate the impacts of pollution and ectoparasitic infections on fish health in the Nile Delta. Addressing these issues is crucial for the sustainability of local fisheries and the overall health of aquatic ecosystems. Future research should focus on the long-term effects of environmental degradation on parasite-host interactions and explore potential interventions to enhance fish health and biodiversity in these critical habitats.

## REFERENCES

- Abdel-Maged, R. R.; Rasheed, N.; Ibrahim, I.; Saad, H. M.; Batiha, G. and Abou Zaid, A. A.** (2024). New Insights on the Effects of Monogenean Gill Parasites on Naturally Infested *Scoberomorus commerson*: Host Response, Electron Microscopy, and Histopathological Studies. *Damanhour J. Vet. Sci.*, 11(1): 20-25. <https://doi.org/10.21608/djvs.2023.248877.1125>
- Agbebi, F. O. and Adetuwo, K. I.** (2019). Analysis of socio-economic factors of fish pond production in Enugu State, Nigeria. *J. Trop. Agric.*, 57(1): 27-34. <http://dx.doi.org/10.22161/ijeab/3.2.26>
- Anani, F. A. and Nunoo, F. K. E.** (2016). Length-weight relationship and condition factor of Nile tilapia, *Oreochromis niloticus* fed farm-made and commercial tilapia diet. *Int J Fish Aquat Stud*, 4(5): 647-650. <https://doi.org/10.13140/RG.2.2.14114.89288>
- Ayode, A. A.** (2011). Length-weight relationship and diet of African Carp *Labeo ogunensis* (Boulenger, 1910) in Asejire Lake South-western Nigeria. *Fish Aquat Sci*, 1816-4927. <https://doi.org/10.3923/jfas.2011.472.478>
- Akinsanya, B.; Hassan, A. and Adeogun, A. O.** (2008). Gastrointestinal helminth parasites of the fish *Synodontis clarias* (Siluriformes: Mochokidae) from Lekki lagoon, Lagos, Nigeria. *Rev Biol Trop.*, 56: 2021- 2026. <https://doi.org/10.15517/rbt.v56i4.5776>
- Bamidele, A.; Otubanjo, O. A. and Hassan, A. A.** (2007). Helminth parasites of *Malapterurus electricus* malapteruridae from Lekki Lagoon, Lagos, Nigeria. *J Am Sci.*, 3(3): 1-5.
- Bamidele, A.; Pentho, K. M.; Kayode, S. J.; Lambe, O. and David, U. U.** (2015). Condition factor and gastrointestinal parasitic fauna of three fish species as stress indicators in Lekki lagoon, Lagos, Nigeria. *Egypt. Acad. J. Biol. Sci.*, 7(1): 1– 13. <https://doi.org/10.21608/eajbse.2015.14489>
- Barnham, C. and Baxter, A.** (1998). Condition Factor K for Salmonid Fish. *Fisheries Notes*, pp. 1–3.
- Blackwell, B. G.; Brown, M. L. and Willis, D. W.** (2008). Relative weight ( $W_r$ ) status and current use in fisheries assessment and management. *REV FISH SCI*, 8: 1-44. <https://doi.org/10.1080/10641260091129161>

- Brian, J. I. and Aldridge, D. C.** (2023). Factors at multiple scales drive parasite community structure. *Parasitology*, 147, 1375–1380. <https://doi.org/10.1111/1365-2656.13853>
- Bromagen, S. H.** (2022). Monogenean body size, but not reproduction, increases with infracommunity density. *Int. J. Parasitol.*, 52(8): 539-545. <https://doi.org/10.1016/j.ijpara.2022.03.004>
- Bush, A. O.; Lafferty, K. D.; Lotz, J. M. and Shostak, A. W.** (1997). Parasitology Meets Ecology on Its Own Terms: Margolis et al. Revisited. *J Parasit*, 83(4): 575-583. <https://doi.org/10.2307/3284227>
- Dambatta, M. A.; Bilyaminu, H.; Zakari, H. Umar, A. F.; Abdulrashed, I. and Sogbesan, O. A.** (2017). Length-Weight relationship and condition factor of *Oreochromis niloticus* in Wudil River Kano State, Nigeria. In the 7<sup>th</sup> International Conference on Biological, Chemical and Environmental Sciences; Budapest, Hungary, 3237.
- Del Rio Zaragoza, O. B.; Fajer-Avila, E. J.; Fajer-Avila, E. J. and Almazán-Rueda, P.** (2010). Haematological and gill responses to an experimental infection of dactylogyrid monogeneans on the spotted rose snapper *Lutjanus guttatus* (Steindachner, 1869). *Aquac. Res.*, 41(11): 1592 – 1601. <https://doi.org/10.1111/j.1365-2109.2009.02471.x>
- Dodge, Y.** (2008). [The Concise Encyclopedia of Statistics](#). Springer.
- Efole, T.; Mikolasek, O.; Aubin, J.; Eyango, M.; Pouomogne, V. and Ombredane, D.** (2016). Sustainability of fishpond culture in rural farming systems of Central and Western Cameroon. *International Journal of Agricultural Sustainability*, 15(2), 208–222. <https://doi.org/10.1080/14735903.2016.1211243>
- El-Naggar, A. M.** (2012). Ecological Aspects of Gyrodactylid Monogeneans from the Skin and Gills of the Nile Catfish *Clarias gariepinus* Inhabiting Nile Delta, Egypt. I. Parasite Adaptations versus Environmental Fluctuations: A Review. *GRT*, 1(XI): May (2012).
- El-Naggar, M. M.; El-Naggar, A. M. and El-Abbassy, S. A.** (2001). Microhabitat and movement of the viviparous monogeneans *Gyrodactylus alberti*, *Macrogyrodactylus clarii* and *M. congolensis* from the Nile catfish *Clarias gariepinus*. *JOBASZ*, 35(D): 169-187.
- El-Naggar, M. M.; El-Naggar, A. M. and Kearns, G.** (2004). Swimming in *Gyrodactylus rysavyi* (Monogenea, Gyrodactylidae) from the Nile catfish, *Clarias gariepinus*. *Acta Parasitol.*, 49(2): 102-107.
- Fulton, T. W.** (1904). The rate of growth of fishes. Twenty-second Annual Report. Part III, Fisheries Board of Scotland, Edinburgh.
- Golam, M. M. and Al-Misned, F. A.** (2013). Length-Weight Relationships, Condition factor and sex-ratio of Nile Tilapia, (*Oreochromis niloticus*) in WadiHanifah,

- Riyadh, Saudi Arabia. WJZ, 8(1): 106-109. <https://doi.org/10.5829/idosi.wjz.2013.8.1.7247>
- Guidelli, G.; Tavechio, W. L. G.; Takemoto, R. M. and Pavanelli, G. C.** (2011). Relative condition factor and parasitism in anostomid fishes from the floodplain of the Upper Paraná River, Brazil. *Vet. Parasitol.*, 177(1–2): 145-151. <https://doi.org/10.1016/j.vetpar.2010.11.035>
- Gutierrez, P. A. and Martorell, S. R.** (1999). The structure of the monogenean community on the gills of *Pimelodus maculatus* in Rio de la Plata (Argentina). *Parasitology*, 119: 177-182. <https://doi.org/10.1017/S0031182099004606>
- Hammond, M. E. and POKORNÝ, R.** (2020). Diversity of Tree Species in Gap Regeneration under Tropical Moist Semi-Deciduous Forest: An Example from Bia Tano Forest Reserve. *Diversity* 12(8): 301. <https://doi.org/10.3390/d12080301>
- Heger, T. and Jeschke, J. M.** (2014). The enemy release hypothesis as a hierarchy of hypotheses. *Oikos*, 123(6): 741-750. <https://doi.org/10.1111/j.1600-0706.2013.01263.x>
- Holmes, J. C.** (1987). The structure of helminth communities. *International Journal for Parasitology*, 17(1): 203-208. [https://doi.org/10.1016/0020-7519\(87\)90042-7](https://doi.org/10.1016/0020-7519(87)90042-7)
- Holmes, J. C. and Price, P. W.** (1986). Communities of Parasites. In: Anderson, D.J. and Kikkawa, J., Eds., *Community Ecology: Patterns and Processes*, Blackwell Scientific Publications, Oxford, pp. 187-213.
- Hoque, F.; Das, A.; Hussan, A.; Chakrabarty, P. and Sundaray, J. K.** (2018). Mass mortality associated with *Dactylogyrus* infection in farmed long whiskers catfish, *Mystus gulio*. *J. Exp. Zool. India*, 21(1): 227-231.
- Ives, A. R.** (1988). Aggregation and the coexistence of competitors. *Ann. Zool. Fenn.*, 25(1): 75-88. <https://doi.org/10.1006/tpbi.1997.1335>
- Ives, A. R.** (1991). Aggregation and Coexistence in a Carrion Fly Community. *Ecol. Monogr.*, 61(1): 75. <https://doi.org/10.2307/1943000>
- Jaccard, P.** (1901). Etude Comparative de la distribution florale dans une portion des Alpes et des Jura. *Bull. Soc. vaudoise sci. nat.*, 7: 547-579. <https://doi.org/10.5169/seals-266450>
- Karvonen, A; Bagge, A. M. and Voltonen, E. T.** (2007). Interspecific and intraspecific interactions in the monogenean communities of fish: A question of study scale?. *Parasitology*, 134(Pt 9):1237-42. <https://doi.org/10.1017/S0031182007002636>
- Koskivaara, M. and Valtonen, E. T.** (1992). *Dactylogyrus* (Monogenea) communities on the gills of roach in three lakes in Central Finland. *Parasitology*, 104: 263--272. <https://doi.org/10.1017/S0031182000061709>
- Kouadio, A. R. E.; Bouah, E. F.; Yao, S. S. and N'Douba, V.** (2023). Seasonal study of the relationship between the condition factor and the monogeneans parasite density of *Heterobranchus isopterus* Bleeker, 1863 and *Clarias gariepinus*

- (Burchell, 1822) fished in the Bagoue River (North-Western, Ivory Coast). Parasitol. Res., 122: 2175–2180. <https://doi.org/10.1007/s00436-023-07918-z>
- Krebs, C. J.** (1999). Ecological methodology. 2nd edition. Addison Wesley Longman. New York, pp. 620.
- Lizama, M. de los A.; Takemoto, R. M.; Ranzani-Paiva, M. J. T.; Ayroza, M. L. de S. and Pavanelli. G. C.** (2007). Host-parasite relationship in fish from fish farms in the Assis region, São Paulo State, Brazil. 1. *Oreochromis niloticus* (Linnaeus, 1757). Acta Sci. Biol. Sci., 29: 223-231. <https://doi.org/10.4025/actascibiolsoci.v29i2.594>
- Lizama, M. de los A.P.** (2003). Estudo da relação entre a comunidade parasitária, meio ambiente e dinâmica da população de *Prochilodus lineatus* (Valenciennes, 1836) e *Astyanax altiparanae* Garutti & Bristki, 2000, na planície de inundação do Alto rio Paraná, Brasil. Ph.D. Thesis, State University of Maringá, Brazil.
- Louizi, H.; Maarten, V.; Rahmouni, I.; Rkhami, O. B.; Benhoussa, A.; Van Steenberge, M. and Pariselle, A.** (2023). Species depauperate communities and low abundances of monogenean gill parasites at the edge of the natural distribution range of their cichlid hosts in northern Africa. Hydrobiologia, 850: 2461-2471. <https://doi.org/10.1007/s10750-022-05031-3>
- Magurran, A. E.** (2004). Measuring biological diversity. Blackwell Publishing. Oxford, pp. 256.
- Marcogliese, D. J.; Locke, S. A.; Gelinas, M. and Gendron, A. D.** (2016). Variation in parasite communities in spottail shiners *Notropis hudsonius* linked with precipitation. J. Parasitol., 102(1): 27–36. <https://doi.org/10.1645/12-31>
- Mendoza-Palmero, C. A.; Hsiao, Y.** (2020). *Boegeriella* nom. nov. (Monogenoidea: Dactylogyridae) for *Walteriella* Mendoza-Palmero, Mendoza-Franco, Acosta & Scholz, 2019, a junior homonym of *Walteriella* Kazantsev, 2001 (Coleoptera: Cantharidae). Syst Parasitol, 97: 857–858. <https://doi.org/10.1007/s11230-020-09957-x>
- Mladineo, I.; Volpatti, D.; Beraldo, P.; Rigos, G.; Katharios, P. and Padros, F.** (2023). Monogenean *Sparicotyle chrysophrii*: The major pathogen of the Mediterranean gilthead seabream aquaculture. Aquaculture, 16(1): 287-308. <https://doi.org/10.1111/raq.12839>
- Morand, S.; Poulin, R.; Rohde, K. and Hayward, C.** (1999). Aggregation and species coexistence of ectoparasites of marine fishes. International Journal for Parasitology, 29, 663–672. [https://doi.org/10.1016/S0020-7519\(99\)00029-6](https://doi.org/10.1016/S0020-7519(99)00029-6)
- Mouillot, D.; Mason, W. H. N.; Dumay, O. and Wilson, J. B.** (2005). Functional regularity: A neglected aspect of functional diversity. Oecologia, 142(3): 353–359. <https://doi.org/10.1007/s00442-004-1744-7>

- Munyasya, J. N.; Juma, K. K.; Burugu, M. W.; Mburu, D. N. and Okuku, E. O.** (2015). Biochemical Effects of Sewage Pollution on the Benthic Organism *Nerita polita*. J Environ Anal Toxicol., S7. <https://doi.org/10.4172/2161-0525.S7-006>
- Nehemia, A.; Maganira, J. D. and Rumisha, C.** (2012). Length-weight relationship and condition factor of tilapia species grown in marine and fresh water ponds. ABJNA, 3(3): 117-124. <https://doi.org/10.5251/abjna.2012.3.3.117.124>
- Ngueguim, D. F.; Kouam, M. K.; Tiogue, C. T.; Miegoue, E. and Awah-Ndukum, J.** (2020). Impact of Ectoparasites on Length-Weight Ratio and Condition Factor of Cultured Fish Species in the West Region of Cameroon. AJRAVS, 6(4): 41-55. <https://doi.org/10.9734/ajravs/2020/v3i4132>
- Obosi, K. and Agbeja, Y. E.** (2015). Assessing the level of aquaculture biosecurity regulations compliance in ibadan, Nigeria. DJAR, 2(3): 012-019.
- Oliveira, M. S. B. and Tavares-Dias, M.** (2016) Communities of Parasite Metazoans in *Piaractus brachypomus* (Pisces, Serrasalmidae) in the Lower Amazon River (Brazil). Rev Bras Parasitol Vet, 25: 151-157. <https://doi.org/10.1590/S1984-29612016022>
- Oliveira, M. S. B.; Adriano, E. A.; Tavares-Dias, M. and Correa, L. L.** (2019). Community of Monogenea in Populations of *Cichla Monoculus* from Two Tributaries of the Amazon River in the Northern Brazil. Helminthologia, 56(1): 1–10. <https://doi.org/10.2478/helm-2018-0043>
- Olopade, O. A.; Taiwo, I. O. and Ogunbanwo, A. E.** (2015). Length-weight relationship and condition factor of *Leuciscus niloticus* (De Joahhis, 1853) from Epe Lagoon, Lagos State, Nigeria. EgeJFAS, 32(2): 165-168. <https://doi.org/10.12714/egejfas.2015.32.3.07>
- Olubiyo, C. K.; Audu, P. A.; Adang, L. K. and Olubiyo, G. T.** (2023). Effects of parasites on growth pattern of African catfish (*Clarias gariepinus*) in Omi Dam, Omi, Yagba West Local Government Area, Kogi State. Scientia Africana, 22 (2): 107-114. <https://doi.org/10.4314/sa.v22i2.11>
- Osuigwe, D. I. and Obiekezie, A. I.** (2007). Assessment of the growth performance and feed utilization of fingerling *Heterobranchus longifilis* fed raw and boiled jack bean (*Canavalia ensiformis*) seed meal as fish meal substitute. J. Fish. Int., 2: 37-41.
- Otieno, O. N.; Kitaka, N. and Njiru, J. M.** (2014). Length-weight relationship, condition factor, length at first maturity and sex ratio of Nile tilapia, (*Oreochromis niloticus*) in Lake Naivasha, Kenya. Int. j. fish. aquat. stud., 2(2): 67-72. <https://doi.org/10.1111/lre.12417>
- Paredes-Trujillo, A.; Velazquez-Abunader, I.; Papiol, V.; Rodríguez, R. and Vidal, V.** (2021). Negative effect of ectoparasite burdens on the condition factor from farmed tilapia *Oreochromis niloticus* in the Yucatan, Mexico. Vet. Parasitol., 292(1): 109393. <https://doi.org/10.1016/j.vetpar.2021.109393>



- Poulin, R.** (1993). The disparity between observed and uniform distributions: A new look at parasite aggregation. *IJP-PAW*, 23, 937–944. [https://doi.org/10.1016/0020-7519\(93\)90060-C](https://doi.org/10.1016/0020-7519(93)90060-C)
- Poulin, R.** (1998). Large-scale patterns of host use by parasites of freshwater fishes. *Ecology Letters*, 1, 118–128. <https://doi.org/10.1046/j.1461-0248.1998.00022.x>
- Poulin, R.** (2001). Interactions between species and the structure of helminth communities. *Parasitology*: 122 Suppl: S3-11. <https://doi.org/10.1017/s0031182000016991>
- Poulin, R. and Morand, S.** (2004). *Parasite biodiversity*. Washington, DC: Smithsonian Books.
- Richter, H. C.; Luckstadt, C.; Focken, U. and Becker, K.** (2000). An improved procedure to assess fish condition on the basis of length-weight relationships. *Arch. Fish. Mar. Res.*, 48: 255-264.
- Rohde, K. and Hobbs, R. P.** (1986). Species segregation: competition or reinforcement of reproductive barriers? In: Cremin M, Dobson C, Noorhouse E, eds. *Parasites lives: papers on parasites, their hosts and their associations to honour JFA spent*. St. Lucia: University of Queensland Press, pp. 189–199.
- Rohde, K.** (1979). A critical evaluation of intrinsic and extrinsic factors responsible for niche restriction in parasites. *Am. Nat.*, 114: 648-671. <https://doi.org/10.1086/283514>
- Rohde, K.** (1991). Intra- and interspecific interactions in low density populations in resource-rich habitats. *Oikos*, 60: 91-104. <https://doi.org/10.2307/3544997>
- Rohde, K.** (1994). Niche restriction in parasites: proximate and ultimate causes. *Parasitology*, 109: S69-S84. <https://doi.org/10.1017/s0031182000085097>
- Roohi, J. D.; Ghasemzadeh, K. and Amini, M.** (2016). Occurrence and intensity of parasites in goldfish (*Carassius auratus* L.) from Guilan province fish ponds, north Iran. *CJF*, 74: 20-24. <https://doi.org/10.1515/cjf-2016-0004>
- Saber, M. A.; Shaaban, A. M.; El ganainy, A. A. and Osman, H. M.** (2020). Species composition, length-weight relationships and condition factor of commercial species grasped by trammel nets and gill nets in the Gulf of Suez, Red Sea, Egypt. *Egypt. J. Aquatic Biol. Fish.*, 24(3): 145 – 156. <https://doi.org/10.21608/ejabf.2020.89748>
- Salgado-Maldonado, G.; Caspeta-Mandujano, J. M.; Mendoza-Franco, E. F.; Rubio-Godoy, M.; Garcia-Vasquez, A.; Mercado-Silva, N.; Guzman-Valdivieso, I. and Matamoros, W. A.** (2020). Competition from sea to mountain: Interactions and aggregation in low-diversity monogenean and endohelminth communities in twospot livebearer *Pseudoxiphophorus bimaculatus* (Teleostei: Poeciliidae) populations in a neotropical river. *Ecol Evol.*, 10: 9115–9131. <https://doi.org/10.1002/ece3.6557>



- Santana-pineros, A.; Pech, D. and Vidal-martinez, V. M.** (2012). Spatial structure of the helminth parasite communities of the tonguefish, *Symphurus plagiusa* from the Campeche coast, southern Mexico. *Int. J. Parasitol.*, 42(10): 911–920. <https://doi.org/10.1016/j.ijpara.2012.07.008>
- Shalaby, S. I. and Ibrahim, M. M.** (1988). The relationship between the monogenetic trematode *Cichlidogyrus tubicirrus magnus* (first record in Egypt) and morphological lesions of gills among *Tilapia nilotica*. *J. Egypt. Com. Path. & Clinic.*, 1(1): 116-126.
- Simkova, A.; Desdevises, Y.; Gelnar, M. and Morand, S.** (2000). Co-existence of nine gill ectoparasites (*Dactylogyrus*: Monogenea) parasitizing the roach (*Rutilus rutilus* L.): History and present ecology. *IJP-PAW*, 30(10): 1077-1088. [https://doi.org/10.1016/S0020-7519\(00\)00098-9](https://doi.org/10.1016/S0020-7519(00)00098-9)
- Simpson, E. H.** (1949). Measurement of diversity. *Nature*, 163: 688.
- Thompson, P. L.; Guzman, L. M.; De Meester, L.; Horváth, Z.; Ptacnik, R.; Vanschoenwinkel, B.; Viana, D. S. and Chase, J. M.** (2020). A process-based metacommunity framework linking local and regional scale community ecology. *Ecology Letters*, 23, 1314–1329. <https://doi.org/10.1038/163688a0>
- Ujjania, N. C.; Kohli, M. P. S. and Sharma, L. L.** (2012). Length-weight relationship and condition factors of Indian major carps (*C. catla*, *L. rohita* and *C. mrigala*) in Mahi Bajaj Sagar, India. *Res. J. Biol.*, 2(1): 30 - 36.
- Velloso A.L. and Pereira, Jr. J.** (2010). Influence of ectoparasitism on the welfare of *Micropogonias furnieri*. *Aquaculture*, 310(1): 43–46. <https://doi.org/10.1016/j.aquaculture.2010.10.030>
- Zouhir, R.; Amara, R. and Trilles, J-P.** (2010). Impact des parasites sur les performances biologiques de *Mullus barbatus barbatus* L. INOC- Tischreen University. International Conference on Biodiversity of the Aquatic Environment.