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Monogenean parasites of Africa's most cultivated fish, *Clarias gariepinus* (Clariidae): A review

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Abstract
African catfish, *Clarias gariepinus* (Siluriformes; Clariidae) is the second most cultured fish in Africa. Apparently, monogeneans predominate the parasite community of *C. gariepinus*. Information on the biology, distribution and epizootiology of monogeneans is crucial for designing and effectively guiding aquaculture health management. The aim of this review is to systematically analyze available literature on monogeneans infesting *C. gariepinus* in Africa to better understand and identify gaps on parasite diversity and geographical distribution. From the 90 published records on monogeneans infesting *C. gariepinus* in Africa from 1960 to 2022, there are 23 Monogenea species belonging to four genera: *Gyrodactylus* Nordmann, 1832; *Macrogyrodactylus* Malmberg, 1957; *Quadriacanthus* Paperna, 1961; and *Paraquadriacanthus* Ergens, 1988. Species of genus *Macrogyrodactylus* and *Quadriacanthus* are the most reported while *Paraquadriacanthus* sp. is the least. Unlike Paraquadriacanthus which shows strict host-specificity, most monogenean genera exhibit a broader host spectrum. Most monogenean genera are moderately distributed across Africa except *Paraquadriacanthus* which is localized along the Nile in Egypt. Unlike Egypt and southern Africa, there is a scarcity of information on monogeneans infesting *C. gariepinus* from other parts of Africa. Reliance on only microscopic morphology for parasite identification is obsolete and incapable of yielding reliable insights into species diversity and geographical distribution of monogeneans infesting *C. gariepinus*.

Keywords: Biogeography, clariidae, ectoparasites, host-specificity, ichthyoparasitology, microhabitat, platyhelminthes

1. Introduction
The class Monogenea are hermaphroditic, mainly ectoparasitic flatworms of fresh, brackish and marine water fishes (Buchmann & Bresciani, 2006; Whittington & Chisholm, 2008) [41]. Monogenea are diverse in morphology (Francová *et al.*, 2017; Paperna, 1979, 1996) lifestyle (Cribb *et al.*, 2002) [51, 73] and host-specificity (Whittington *et al.*, 2000). The class is divided into two subclasses based on feeding behaviour; namely: Monopisthocotylea (Polyonchoinea) consuming epithelial cells and mucous, and Polyopisthocotylea (Heteronchoinea) that strictly feed on blood (Buchmann & Lindenstrøm, 2002) [42]. The Polyonchoinea consists of six orders Dactylogyridea, Gyrodactylidea, Lagarocotylidea, Montchadskyellidea, Capsalidea and Monocotylidea consisting of species frequently parasitizing wild and cultured fishes (Paperna, 1991; Reed *et al.*, 2012). Members of Heteronchoinea parasitizing mostly marine fishes are distributed into two infrasubclasses: Polystomatoinea containing one order (Polystomatidea) and Oligonchoinea with three orders (Mazocraeidea, Diclybothriidea and Chimaericolidea) (Boeger & Kritsky, 2001; Ogawa, 2015) [31, 133]. Several members of the subclass Polyonchoinea are highly pathogenic and frequently linked to fish mortalities in capture fisheries and aquaculture (Whittington & Chisholm, 2008). Most monogeneans parasitizing Africa's freshwater fish belong to families Dactylogyridae and Gyrodactylidae (Scholz *et al.*, 2018) [156, 161, 186, 187].

Clarias gariepinus, commonly known as the African catfish, is recognized as one of the most widely distributed freshwater fish species in Africa, occurring naturally in eight out of the continent's ten ichthyofaunal regions (Roberts, 1975; Skelton *et al.*, 1994; Snoeks & Getahun, 2013) [159, 171]. Despite being naturally absent in certain regions such as the Maghreb, Upper and most of the Lower Guinea, and the southern region of the Southern Cape

ichthyofaunal provinces (Skelton & Teugels, 1992), *C. gariepinus* remains highly valued for its versatility and economic accessibility, making it a preferred choice for aquaculture (Brummett, 2008b; Hecht *et al.*, 1996; Oké & Goosen, 2019) [38]. This species showcases remarkable adaptability, thriving across a spectrum of African freshwater habitats, including rivers, lakes, swamps, reservoirs, wetlands, and anthropogenic water bodies such as irrigation canals and ponds (Isyagi, 2007; Skelton, 2012) [90]. The geographical range of *C. gariepinus* spans from the Nile River system in North Africa down to the Limpopo River in South Africa, encompassing major river basins like the Nile, Niger, Congo, Orange and Zambezi, as well as numerous African lakes such as Lake Victoria, Lake Tanganyika, Lake Malawi, Lake Chad, Lake Turkana in Kenya, Lake Tana and Lake Awassa in Ethiopia, Lake Upemba in the Democratic Republic of Congo, and Lake Kariba in Zimbabwe (IUCN, 2018; Skelton, 1994; Truter *et al.*, 2023b) [92]. Additionally, *C. gariepinus* can inhabit coastal regions such as estuaries and mangrove swamps (Van Wilgen, 2012) [180]. Studies further illustrate the species distribution across diverse aquatic habitats, such as the Nile delta in Egypt (Paperna, 1979), the Olifants & Elands Rivers in South Africa (Madanire-Moyo *et al.*, 2012) [105], the Okavango Delta in Botswana (Bruton *et al.*, 2018) [39], the Siba river in Uganda (Paperna, 1973), as well as streams in Mozambique (Prikrylová *et al.*, 2012). Recent translocations have extended the distribution range of *C. gariepinus* outside the species natural geographical range such as to the rivers of the Cape province in South Africa (Skelton & Teugels, 1992), in northern Algeria as well as parts of Central Africa Republic, Lesotho, Gabon, Cameroon and Burundi where the species was not native (Fishbase, 2024; Mulega *et al.*, 2022) [70, 118]. This wide range of habitats underscores *C. gariepinus*' adaptability to varying ecological conditions, emphasizing its ecological significance and integral role in African aquatic ecosystems.

C. gariepinus is the second most economically important freshwater fish in Africa (Adeleke *et al.*, 2020; de Graaf & Garibaldi, 2014; FAO, 2020b) [6]. The species is highly preferred for aquaculture due to desirable production attributes including fast growth rate, reaching an average of 0.4 kg within three months and nearly 1 kg after 7 - 9 months (Brummett, 2008a; Opiyo *et al.*, 2017) [37], versatility under culture conditions (Fleuren, 2008; Oké & Goosen, 2019) as well as acceptance and utilization of artificial feeds (Chepkirui-Boit *et al.*, 2011; Hecht, 2013; Skelton, 2001) [71]. The adoption of simple artificial reproduction and hatchery management technologies that enhance seed production have further accelerated *C. gariepinus* culture (Abdulraheem *et al.*, 2012; Adebayo & Popoola, 2008; Amoah *et al.*, 2020; de Graaf *et al.*, 1995; de Graaf & Janssen, 1996; Müller *et al.*, 2018) [11]. As such, *C. gariepinus* is easy to produce in a variety of culture environments and systems including earthen-ponds with minimal resource input required for rapid fish growth, thus becoming a desirable species for small-scale rural farmers (Anetekhai, 2013; Isyagi, 2007; Isyagi *et al.*, 2009; Williams *et al.*, 2008) [13]. Consequently, the production of *C. gariepinus* is relatively cheaper compared to other cultivated fish species (Brummett, 2008a) [37], hence a potential alternative source of animal protein and an ideal candidate to improve food security in Africa (Obiero *et al.*, 2019) [2, 5, 52, 53, 54, 81, 82, 83, 90, 119, 132, 141, 165-169, 188].

Despite the enormous water resources and better fish growth attributes, the proportion of *C. gariepinus* to total aquaculture production in Africa is drastically declining since 2015 (Cai & Leung, 2017; FAO, 2019) [46]. Several initiatives have focused on improving production of *C. gariepinus* through breeding (Abdulraheem *et al.*, 2012; Adebayo & Popoola, 2008; Huisman & Richter, 1987), genetics (Alal *et al.*, 2021; Barasa *et al.*, 2017), feeding (Chepkirui-Boit *et al.*, 2011; Marimuthu *et al.*, 2010; Okomoda *et al.*, 2019; Remilekun *et al.*, 2021) and enhancing culture environment (Hossain *et al.*, 1998; Isyagi, 2007; Mahlatji, 2014; Oké & Goosen, 2019). However, limited effort has been invested in infectious agents including parasites which constrain fish productivity through deteriorated health and mortalities (Adeleke *et al.*, 2020; Akoll, 2005; Akoll *et al.*, 2012; Barber & Poulin, 2002; Obiekezie & Taege, 1991; Tchokote & Olufemi, 2012), thus lowering the quality and quantity of seed (Atukunda *et al.*, 2018; Charo-karisa *et al.*, 2008; Matsiko & Mwanja, 2008) [2, 5, 6, 7, 10, 19, 23, 48, 49, 86, 88, 90, 109, 111, 113, 131, 135, 158, 172].

The parasite communities of *C. gariepinus* in aquatic systems of Africa consists of Protozoa, Myxozoa, Nematoda, Cestoda, Digenea, Monogenea, Acanthocephala and Crustacea (Kibet *et al.*, 2019; Schaeffner, 2018; Scholz *et al.*, 2018), dominated by monogeneans (Akoll *et al.*, 2012; Akoll & Mwanja, 2012; Kibet *et al.*, 2019). The direct lifecycle of monogeneans (Bakke *et al.*, 2007) [20] as well as the conditions typical of intensive *C. gariepinus* aquaculture such as the high-stocking density (Oké & Goosen, 2019), poor water quality (Boyd, 2017) [35] and the indiscriminate movement of seed and broodstock within and across borders (Huchzermeyer & van der Waal, 2012; Mwanja *et al.*, 2015), possibly enhance parasite transmission, proliferation and pathological effects on the host, consequently lowering fish productivity. Therefore, the drastic decline in Africa's *C. gariepinus* production can be attributed to the high fry mortality linked to parasitic infections in hatcheries (Akoll, 2005; Akoll *et al.*, 2012; Walakira *et al.*, 2014), which ultimately limits the supply of fingerlings of the required quality and quantity to the outhgrowers. Currently, there is a gap in effective fish disease management largely due to the limited information on the diversity and distribution of the parasites infecting *C. gariepinus*, especially the dominant monogeneans [7, 134, 160].

Previous reviews on parasites of Africa's freshwater fish have focused on the occurrence and diversity in individual countries (Adebambo, 2020; Flourizel *et al.*, 2019; Kibet *et al.*, 2019; Mahmoud & Abdalla, 2022), on particular regions (Akoll & Mwanja, 2012; Francová *et al.*, 2017), or on specific parasite genera across several countries (Prikrylová *et al.*, 2012) [4, 7, 72, 73, 87, 98, 110, 123, 183]. However, detailed information on parasite biology especially conditions associated with reproduction, distribution (local area or widespread), host-specificity, site predilection, parasite specific pathology and management of monogeneans in culture systems in Africa remain scattered. Therefore, a comprehensive review of the existing information on monogenean parasites of *C. gariepinus* in Africa is crucial to guide the designing of monitoring and control programs for these least studied parasites of fish. This review focuses on analyzing and compiling information on diversity, host ranges, infestation-site preference and geographical distribution of monogeneans parasitizing *C. gariepinus* in Africa. The review contributes to a better understanding of monogenean parasites infesting *C. gariepinus* in Africa, and provides substantial data to guide future planning and boost *C. gariepinus* productivity and biosecurity.

Methods: The systematic literature search was conducted on research articles, books, dissertations, theses and conference abstracts published on parasites of *C. gariepinus*. The literature search strategy involved browsing in published web-based resources including Science Direct, Google Scholar, PubMed, Web of Science and Scopus using a combination of keywords: "fish parasites, "African catfish", "*Clarias gariepinus*", "monogenea", "ectoparasites", "freshwater fish", and "Africa". Conference proceedings and doctoral theses were also collected from various libraries using the online catalogue. No limit was put on the number of years searched. The search results were screened and selected by title relevance to the present review, concerning biology, diversity, distribution, pathology and epizootiology of monogeneans infesting *C. gariepinus* in Africa.

Results: A systematic review of 98 publications including peer-reviewed articles, theses and conference abstracts revealed 23 species of class monogenea infesting *C. gariepinus* in Africa (Table 1). Overall, 23 monogenean species were reported on/in *C. gariepinus* from aquatic systems in Africa. Most monogenean species recorded seemed to exhibit a strict host-specificity to *C. gariepinus*, with predilection for the gills. The most frequently encountered monogenean parasite species was *Macrogyrodactylus clarii* (Fig. 1).

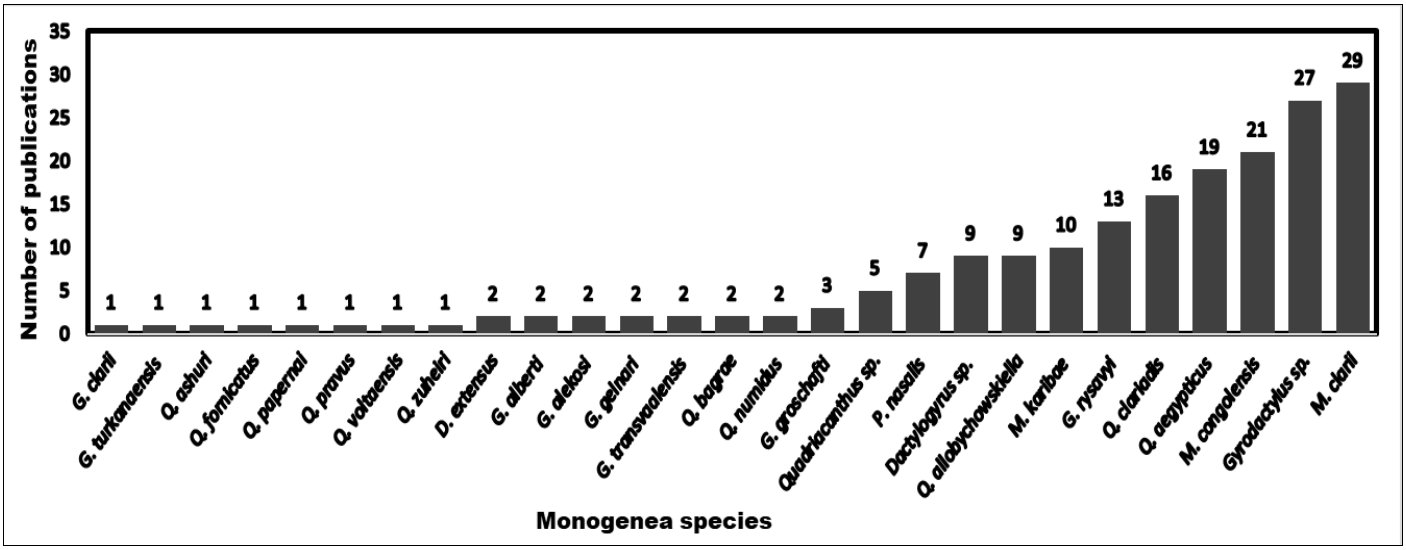

Fig 1: Diversity and publication statistics of Monogenea species parasitizing *C. gariepinus* in Africa

At country level, the highest species richness of monogeneans parasitizing *C. gariepinus* was recorded in Egypt with 16 species (Fig.2).

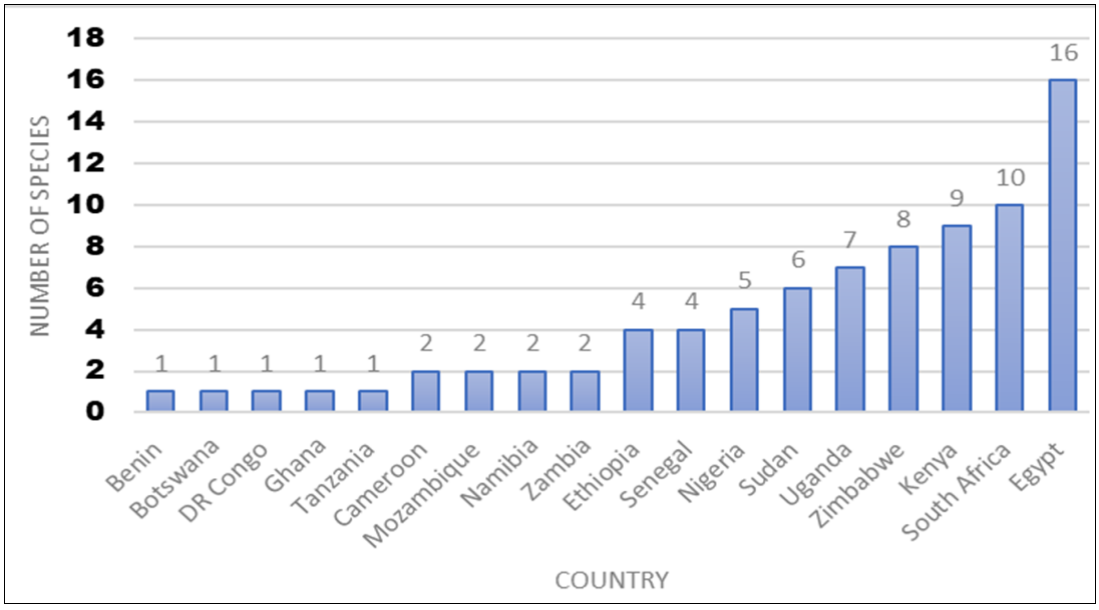

Fig 2: Monogenean Species richness by country across Africa

Correspondingly, a remarkably high number of publications (77) were published in Egypt (Fig.3).

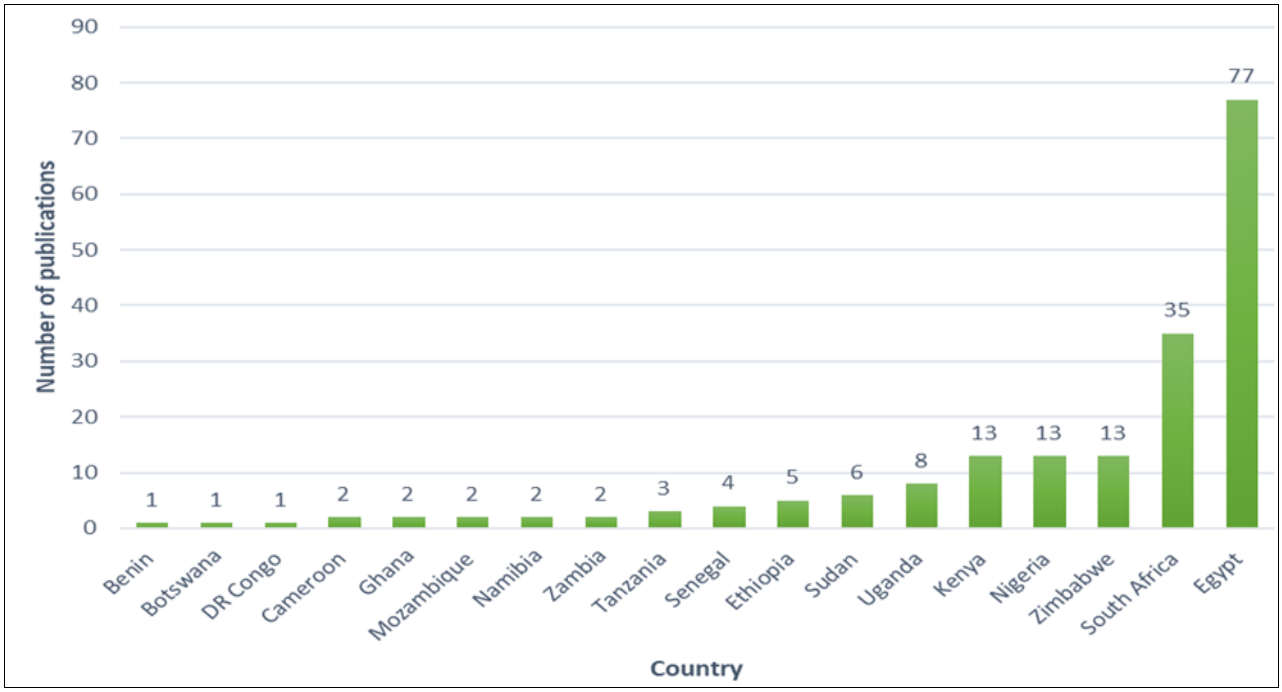

Fig 3: Number of encountered records on monogeneans infesting *C. gariepinus* across Africa

On regional scale, nearly half of the records on monogeneans infesting *C. gariepinus* originated from Northern Africa (44%) compared to other regions (Fig. 4).

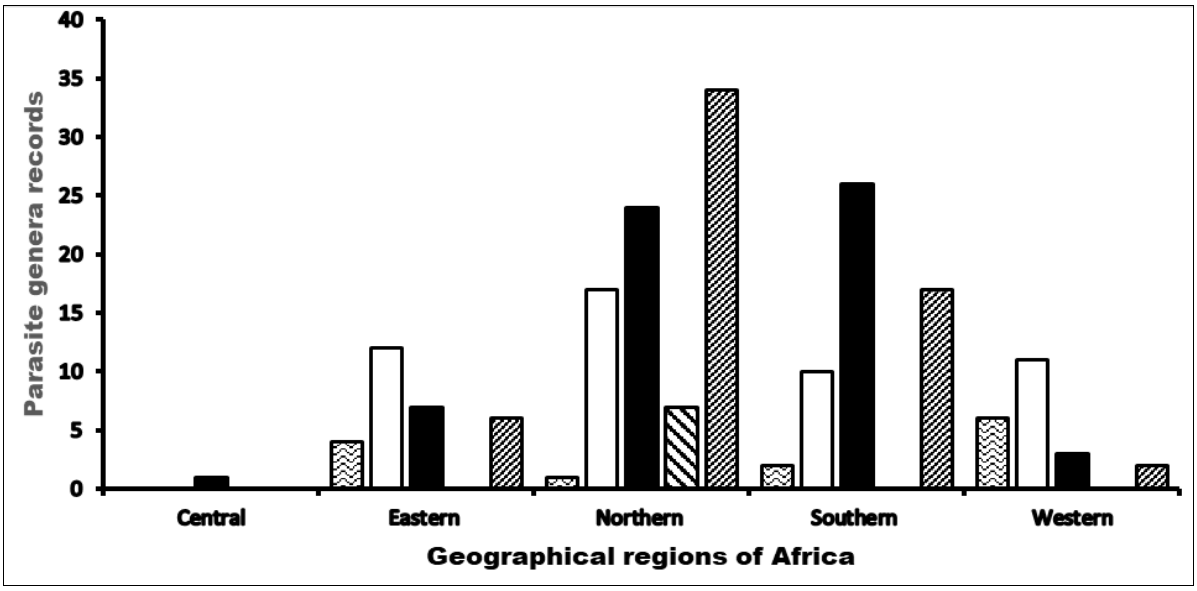

Fig 4: Geographic distribution of Dactylogrus (zig zag graph), Gyrodactylus (open graph), Macrogyrodactylus (black graph), Paraquadriacanthus (downward diagonal) and Quadriacanthus (upward diagonal) infesting *C. gariepinus* across Africa

Discussion: Overall, 23 monogenean species were reported on/in *C. gariepinus* from Africa, consistent with recent review of Truter *et al.* (2023). The recorded species belong to four genera: *Gyrodactylus* von Nordmann, 1832; *Macrogyrodactylus* Malmberg, 1957; *Quadriacanthus* Paperna, 1961; and *Paraquadriacanthus* Ergens, 1988, in the class of Polyonchoinea [65].

***Gyrodactylus* von Nordmann, 1832:** Gyrodactylus are small monogeneans ranging from 0.4 to 1.5 mm long (Pugachev *et al.* 2010) with fusiform body shape. Members of the genus belong to the family of Gyrodactylidae in the Order: Gyrodactylidea, Subclass: Polyonchoinea under the class: Monogenoidea. Anteriorly, the prohaptor has two small cephalic lobes forming a characteristic "V-shaped" process (Whittington *et al.*, 2000) and lack eye spots. Posteriorly, the parasite has a haptor (formerly opisthaptor) armed with 16 marginal hooks located on the periphery, a pair of centrally located anchor hooks (hamuli) supported by a membranous ventral bar and sclerotized dorsal bar (Pugachev *et al.*, 2010). Gyrodactylus are viviparous species, characterized with the presence of fully developed embryo in the uterus (Bakke *et al.*, 2007; Boeger *et al.*, 2003) [20, 32]. A healthy worm, up to three generations developing in another within the parent

uterus embryo (Cable *et al.*, 2002; Cable & Harris, 2002) [44], a phenomenon called hyperviviparity. As a result of hyperviviparity, worms exhibit a rapid generation time that consequently leads to an explosive population growth (Bakke *et al.*, 2007; Cable & Harris, 2002; Philip D. Harris, 1993) [20, 44, 79, 80]. The hyperviviparity reproductive strategy among Gyrodactylus increases survival of offspring; reduced mortality during transmission and accelerated establishment of reproductively active population (Boeger *et al.* 2003) [32]. Among temperate species, survival time of individuals detached from the host ranged from 3.7 days to 5 days maximum between 10 and 25 °C (Cable *et al.*, 2002; Lester & Adams, 1974; Scott & Anderson, 1984) [44]. When attached on the host at 10 °C, Gyrodactylids survive up to 24.5 days (Cable *et al.*, 2002) [45]. During the lifetime, Gyrodactylus give birth twice (Cable *et al.*, 2002) [45] and mature within 24 hours at 25 °C. The rapid generation time can result in exponential parasite population growth on a single host.

Several other water quality parameters including dissolved oxygen, pH, electrical conductivity, and total dissolved solids have shown pronounced impacts on the survival and reproduction of gyrodactylid parasites (Cavalcanti *et al.*, 2020; Gilbert & Avenant-Oldewage, 2021; Waruiru *et al.*, 2020) [185]. Unlike temperature whose increase is known to enhance gyrodactylid reproduction; low levels of dissolved oxygen have been shown to reduce parasite survival while acidic conditions can inhibit parasite reproduction (Scott & Anderson, 1984) [162]. Furthermore, the electrical conductivity and the total dissolved solids appear to positively influence the mean intensity of values of gyrodactylids (A. A. El-Naggar *et al.*, 2017). With regard to feeding, *Gyrodactylus* feed on mucus and epithelial cells (Cable *et al.*, 2002) [44, 47, 76, 103, 162].

Occurrence and identification

The review revealed that eight species, namely, *Gyrodactylus clarii, G. turkanaensis, G. alekosi, G. alberti, G. gelnari, G. groschafti, G. transvaalensis* and *G. rysavyi* occur on/in *C. gariepinus* in Africa (Table 1). With regard to identification, several previous studies published information on monogeneans identified only genus level (Mavuti *et al.*, 2017; Murugami, 2017; Murugami *et al.*, 2018; Mwita, 2014; Mwita & Nkwengulila, 2004, 2008; Akoll, 2005;) [7]. Importantly, the present review revealed the challenge associated with identification of species under the genus Gyrodactylus. In this regard, nearly half of all the gyrodactylid records were identified to genus. Besides, the identity of *G. clarii* described from *C. gariepinus* in Uganda (Paperna, 1973), was subsequently considered a synonym of *G. rysavyi* (Paperna, 1979). Likewise, *G. alberti* previously reported in Egypt (El-Naggar *et al.*, 2001) was later on re-described as *G. rysavyi* (Arafa *et al.*, 2007). Morphological identification of monogeneans generally relies on the hard parts of the haptor (Hodneland & Nilsen, 1994; L. F. Khalil & Mashego, 1998; Pugachev *et al.*, 2010) [97]. Consequently, the occurrence and identity of *Gyrodactylus* species in Africa remains questionable. Therefore, the review highlights the urgent need for further investigations into monogeneans utilizing appropriate tools particularly molecular techniques to improve species identification. So far, next generation sequencing has been utilized to delineate gyrodactylids (Vanhove *et al.*, 2018) [85, 114, 120, 121, 124, 125, 126, 181].

The distribution of gyrodactylids infesting *C. gariepinus* across Africa is linked to the habitat range of host within the African ichthyofaunal provinces of Congolese, Eastern - Coast, Nilo-Sudanian, Southern, and Zambezian (Nelson *et al.*, 2016; Snoeks & Getahun, 2013; Teugels, 1996; Van Steenberge *et al.*, 2020) [129, 171, 179]. However, some parasite species including *G. clarii, G. alberti and G. turkanaensis* have been recorded once each in Uganda and Kenya both in Eastern - coast province (Fig. 1). *G. groschafti* has been recorded twice Egypt and Nigeria both within Nilo-Sudanian. *G. gelnari* and *G. alekosi* occurred at least in three provinces but have not yet been recorded in Congolese and Nilo-Sudanian provinces and Congolese and Eastern - coast respectively. Meanwhile, *G. transvaalensis* and *G. rysavyi* have a wider distribution in Africa, occurring in four provinces except Eastern - coast and Congolese respectively. The true picture of the distribution of the gyrodactylids remains uncertain due to the a) limited number dedicated studies conducted in various African countries, b) challenges of identification using morphological structure and c) the limited sampling effort [173].

Host and site specificity: The review revealed that 62.5% (5/8) of the gyrodactylids described appeared specific to *C. gariepinus*, consistent with general observation, that monogeneans are usually oioxenous (Bakke *et al.*, 2002; Giorgi *et al.*, 2004; Whittington *et al.*, 2000). Meanwhile, three species, *G. gelnari, G. rysavyi* and *G. transvaalensis*, have been recorded to parasitize both *C. gariepinus* and *C. anguillaris* (Beletew *et al.*, 2016; Prikrylová *et al.*, 2012; Schaeffner, 2018) [29, 77]. With the available information, *G. gelnari*, G. rysavyi and *G. transvaalensis* could be considered stenoxenous, until addition records suggest otherwise. The occurrence of *G. gelnari, G. rysavyi* and *G. transvaalensis* on more than one host, increases the potential threat to fish health. With two or more hosts, a parasite is capable of utilizing any of the alternative host to survive in the environment in absence of principle host, and as such, sustain the organism in the system [160].

Concerning preferred sites for attachment, most members of genus *Gyrodactylus* infesting *C. gariepinus* appear to prefer gills with sporadic occurrence on the skin and fins. Although limited studies have explored niche preference selection among Gyrodactylus species of *C. gariepinus* in Africa, the choice of microhabitats among gyrodactylids can change depending on the level of infection (Buchmann & Bresciani, 1997; Heinecke *et al.*, 2007; Jensen & Johnsen, 1992; Pie *et al.*, 2006) [40, 93], host species (Heinecke *et al.*, 2007; Pie *et al.*, 2006) [84], and to some extend environmental conditions especially water temperature (Blažek *et al.*, 2008) [30]. It is also noteworthy that viviparous gyrodactylids probably migrate to the skin as a behavioral strategy to enhance transmission (P D Harris & Tinsley, 1987). Although, the current review revealed that some species were recorded only in one host and at one site, the available information is insufficient to affirm the host and site specificity. For instance, *G. transvaalensis* was recorded on the skin (Prudhoe & Hussey, 1977), on the gills (Mushagalusa Mulega *et al.*, 2023), and on fins of *C. anguillaris*,(Prikrylová *et al.*, 2012), which may suggest preference of different sites with respect to prevailing conditions. As such, dedicated research effort committed to collecting more specimens from various regions of Africa to ascertain the host-site specificity of gyrodactylids in *C. gariepinus* is urgently needed [79, 80, 118, 122, 149, 150, 153].

Pathology: Gyrodactylids are principally ectoparasitic

worms, attaching and feeding on mucus, epithelial cells, and blood from the host's skin, fins, and gills of fish (Bakke *et al.*, 2007; Reed *et al.*, 2012). The gills are a primary target for gyrodactylid attachment (Akoll *et al.*, 2012) [7, 20]. Gyrodactylids use specialized structures, including hooks and a haptor (attachment organ), to firmly anchor themselves to the host fish (Beletew *et al.*, 2016; Reed *et al.*, 2012) [29, 156]. In gill-parasites, the characteristic strongly curved hamulus shafts of gyrodactylids often penetrate the gill tissue (Bakke *et al.*, 2007) [20]. On the skin, studies have observed non-penetrating attachment strategy of *Gyrodactylus* to the host (Bakke *et al.*, 2007; Shinn *et al.*, 2003) [20], thus inflicting minimal damage on the host epithelium Continuous feeding activities can lead to tissue damage and disruption of the host's protective mucosal layer. As gyrodactylids feed on gill tissue and mucus, they cause physical damage to the delicate respiratory epithelium (Akoll, 2005; Paperna, 1996). This damage can impair the function of gills, leading to respiratory distress in fish (Klinger & Floyd, 2013). Reduced oxygen uptake due to compromised gills can result in hypoxia and further stress on the fish (Akoll, 2005) [7]. Gyrodactylid infestations weaken the fish's immune defenses at the attachment sites (Kabata, 1985; Thoney & Hargis, 1991), making the fish more susceptible to secondary infections by bacteria, fungi, or other parasites (Bandilla *et al.*, 2006; Kabata, 1985; Kotob *et al.*, 2016; Xu *et al.*, 2007) [22]. Opportunistic pathogens can exploit the compromised tissue and cause additional damage and disease. The presence of gyrodactylids triggers an inflammatory response in the fish's tissues that involves the recruitment of immune cells to the site of attachment (Whittington & Chisholm, 2008). Chronic inflammation can lead to swelling, hyperplasia (increased cell growth), and potentially irreversible tissue damage over time (Okunade *et al.*, 2023; Olubiyo *et al.*, 2023). Fish infested with gyrodactylids may exhibit abnormal behavior, such as flashing (rapidly rubbing against surfaces), lethargy, or reduced feeding activity (Barber *et al.*, 2000; Boyd, 2017; Whittington & Chisholm, 2008) [35]. These behavioral changes are indicative of discomfort and stress caused by the parasite's presence. Severe gyrodactylid infestations can negatively impact fish growth and reproductive performance. Reduced feeding efficiency due to gill damage can lead to stunted growth and poor overall condition. In some cases, heavy parasite loads may directly affect reproductive organs, impairing the fish's ability to spawn or reproduce successfully (Barber, 2007) [24, 94, 99, 100, 136, 138, 163, 186, 187, 190].

***Macrogyrodactylus* Malmberg, 1957:** This is the largest gyrodactylid, attaining a maximum length of approximately 1.5-2 mm. Similar to Gyrodactylus, Macrogyrodactylus possesses a haptor armed with one pair (two) of hamuli, ventral and dorsal bars and 16 marginal hooks, and lack eye-spots. The head region is notched anteriorly to form two lobes. Each lobe has a single adhesive area, located anteroventrally near the distal extremity and terminates in a single spike-like process.

Posteriorly, the haptor consists of one pair of hamuli, eight pairs of marginal hooklets, two different connecting bars and a pair of accessory sclerites. The ventral bar consists of a Y -shaped sclerite and two pairs of relatively long, posteriorly directed, rod-like sclerites, a pair of long ventral bar rods (M. M. El-Naggar & Serag, 1987; Maduenyane *et al.*, 2022a). The dorsal bar consists of two sclerites appear to articulate with each other at the inner borders with straight or V-shaped arrangement. In addition, there are two slightly curved plate, the accessory sclerites, in each of the anterolateral region of the haptor, in close proximity with the anterolateral marginal hooklets [107].

The haptor has 16 marginal hooklets, consists of a rod-like handle and a sickle. Two marginal hooklets occur on the anterolateral lobes while the rest on the posterior edge of a separate fan-shaped tegumental flap. The tegumental flap extends posteriorly forming fourteen finger-like processes through which the marginal hooklets protrude into the ventral surface of the haptor. There is a domus-like structure originating from near the tip of the blade of the sickle and extending proximally as far as the middle region of the handle.

The Macrogyrodactylus species are viviparous with the parent containing up to 4 generations on embryos. In this regard, the second embryo inside the uterus of the first generation has the third generation also carrying fourth generation (L. F. Khalil, 1964) [96]. Macrogyrodactylus species can survive up to 10 days off the host at between 13°C and 30°C without changing the water (L. F. Khalil, 1964) [96]. Apparently, information on survival time of the species detached from the host is lacking, yet critical in estimation of risk associated with used of water from contaminated facilities.

Like other monogeneans, macrogyrodactylids are highly sensitive to fluctuations in water quality parameters due to their intimate association fish and the aquatic environment. Understanding the influence of the various water quality parameters is crucial since macrogyrodactylids are one of the most geographically spread monogenean genera infesting *C. gariepinus* (Truter *et al.*, 2021, 2023b). Fluctuations in DO, temperature, pH, and TDS appear to influence the physiology of these worms especially when outside the optimum ranges, and thus could be useful indicators of water quality. Low levels of DO, temperature and pH have been shown to reduce parasite survival and proliferation (A. A. El-Naggar *et al.*, 2017; Madanire-Moyo *et al.*, 2010) [106].

The feeding behavior of macrogyrodactylids is specialized and adapted to their mode of attachment and habitat on fish hosts. As ectoparasites, macrogyrodactylids primarily feed on the surface tissues of their hosts, particularly on the skin and gill epithelium (M. M. El-Naggar *et al.*, 1999; Mashaly *et al.*, 2019). These worms use specialized attachment structures, including hooks and clamps on their haptoral (attachment) apparatus, to firmly anchor themselves onto the skin or gills of fish hosts (Arafa *et al.*, 2009; M. M. El-Naggar, Arafa, *et al.*, 2019). The feeding site is typically localized to the area of attachment, where the parasite directly contacts the host's epithelial cells. Macrogyrodactylids feed primarily by grazing on the surface tissues of fish hosts, and can use a combination of physical attachment and suction to secure themselves and access nutrients (Arafa *et al.*, 2009). The parasites use specialized structures, such as the anterior attachment organ (prohaptor) and clamps, to hold onto the host's tissues while feeding. Macrogyrodactylids primarily feed on mucus, epithelial cells, and blood from the host's skin and gill tissues (M. M. El-Naggar *et al.*, 2001; Mashaly *et al.*, 2019). Mucus, which serves as a protective layer on the host's skin and gills, provides a nutrient-rich substrate for macrogyrodactylid feeding. Continuous feeding by macrogyrodactylids can lead to physical damage and disruption of the host's epithelial tissues. The parasites may cause erosion, ulceration, or hyperplasia (increased cell growth) at the feeding site, which can compromise the integrity and function of the host's skin and gills (Arafa *et al.*, 2009). The feeding activities of macrogyrodactylids can induce host immune responses and

inflammation, contributing to tissue damage and potential secondary infections (Barber & Poulin, 2002). The parasites rely on the continuous production of mucus and shedding of epithelial cells by the host for sustained feeding and survival. Macrogyrodactylids exhibit distinct feeding behavior patterns, including attachment, detachment, and repositioning on the host's body surface. The parasites may migrate within the host's gill arches or move between different body regions to optimize feeding opportunities and avoid host responses (L. F. Khalil, 1964; Mashaly *et al.*, 2019) [96, 112].

Occurrence and identification: Species of *Macrogyrodactylus* Malmberg, 1957 (Gyrodactylidae) are endemic to Africa (L. F. Khalil & Mashego, 1998; Truter *et al.*, 2021) [97], and often implicated in fish diseases (Barson *et al.*, 2008; M. M. El-Naggar *et al.*, 2016; Paperna, 1991). Among the nine *Macrogyrodactylus* species known (Truter *et al.*, 2021) [27], only three species namely, *M. clarii, M. congolensis, and M. karibae* occur on *C. gariepinus* (Table 1). Among the macrogyrodactylids infesting *C. gariepinus*, *M. clarii* is the most frequently reported across Africa (50%), although *M. congolensis* and *M. karibae* are moderately reported (Fig. 1). Although less diverse, species of genus Macrogyrodactylus are the most encountered (31.6%) monogenean parasitizing *C. gariepinus* across Africa (Fig. 1, Fig. 4), and thus pose a significant threat to fish health and productivity. Such parasite species deserve more attention especially under intensive *C. gariepinus* aquaculture [55, 56, 57, 58, 59, 60, 61, 62, 63].

Host and site specificity

Unlike *M. congolensis* that has been recorded from clariid hosts *C. gariepinus* and *C. anguillaris* thus exhibiting an extended host spectrum, the review revealed that both *M. clarii* and *M. karibae* appeared host-specific to *C. gariepinus* (Table 1). Evidence of hybridization of monogenean parasites known to infest clariids *C. gariepinus* and *C. anguillaris* (Barson *et al.*, 2010; N'Douba & Lambert, 1999) enhances the possibility for an extended host range and consequently threats to fish health management especially under weak biosecurity enforcement (Huchzermeyer & van der Waal, 2012; Wanja *et al.*, 2020). Regarding preference of sites for parasite attachment, macrogyrodactylids are strictly ectoparasitic, attaching to host skin, fins and gills (Table 1). *M. clarii* and *M. karibae* appear to restrict the occurrence to gills (Barson *et al.*, 2008; L. F. Khalil & Mashego, 1998) [27, 97]. Meanwhile, *M. congolensis* has been recorded at multiple sites including the gills, skin and fins of *C. gariepinus* (Akoll *et al.*, 2012; Barson *et al.*, 2010). The ability of *M. congolensis* to infest multiple host sites is likely to increase the parasite's pathological impact on the host (Barber *et al.*, 2000). Due to the relatively large size, macrogyrodactylids are likely to cause extensive damage to the host-infestation sites and consequently secondary microparasite infections (Bandilla *et al.*, 2006; Busch *et al.*, 2003; Kotob *et al.*, 2016) thus increasing host morbidity and mortality rates [7, 22, 43, 87, 100, 127].

Geographical distribution

Species of genus *Macrogyrodactylus* are widely distributed, having been reported in all the major regions of Africa (Fig. 4). Unlike *M. karibae* that is localized to Southern Africa, *M. clarii* and *M. congolensis* are recorded across Africa (Truter *et al.*, 2021). Although *M. congolensis* was first described infesting *C. gariepinus* from Lake Upemba in the DRC (Prudhoe, 1957) [152], no further records were obtained from the DRC or any other locality in Central Africa. Generally, records on macrogyrodactylids parasitizing *C. gariepinus* from Central, East and West Africa are scarce. Meanwhile, 80 percent of the records on macrogyrodactylids infesting *C. gariepinus* were obtained from Northern and Southern Africa (Fig. 4). The high number of macrogyrodactylid records in Northen and Southern Africa could be commensurate with the level of aquaculture infrastructure development in this region (FAO, 2020a) that is likely reflected by the magnitude of the sampling efforts (Fig. 3). Although less records of macrogyrodactylids were obtained from west Africa, the occurrence of *M. clarii* and *M. heterobranchii* from a clariid host *C. anguillaris* in Nigeria (Shotter, 1980) and Senegal (Přikrylová & Gelnar, 2008) respectively creates the possibility of encountering more macrogyrodactylids in the region since hybridization of congeneric monogeneans has already been documented in Zimbabwe [164].

More so, the indiscriminate movement fish resources across boundaries is likely to enhance the possibility of parasite host-switching and hybridization (Bakke *et al.*, 2002) [20], and thus the likelihood of *M. heterobranchii* infesting *C. gariepinus* in new localities. Therefore, this call for more parasitological investigations in the region as a basis for comprehensive fish health management [151].

***Quadriacanthus* Paperna, 1961**

Members of the genus Quadriacanthus have fusiform body and belong to class Monogenoidea, subclass: Polyonchoinea, Order: Dactylogyridea in the family Dactylogyridae (Francová *et al.*, 2017; Lim *et al.*, 2001). The prohaptor has eye-spots represented by many brown, oval to spherical pigment granules scattered in cephalic area (M. M. El-Naggar & Serag, 1986; Lim *et al.*, 2001). The haptor slightly lobed and demarcated from the body by a constriction. The haptor consist of 4 hamuli with short, single root and at least 2 associated accessory sclerites. A pair of dorsal anchors/ hamuli are larger than ventral hamuli. Both dorsal and ventral anchors have small patches. The dorsal bar is robust, broad and V-shaped, with expanded mid-region as 2 posterolateral arms and funnel-like process projecting from its posterior extremity. The ventral bar is Y-shaped with 2 arms articulating at the proximal ends. Marginal hooks have dissimilar shape and size with three of 7 pairs of marginal hooklets larger than others and provided with proximal extension. In this regard pair 4 is elongated with expanded handle; and pairs 5 and 7 are short with expanded handles (M. M. El-Naggar & Serag, 1986; Lim *et al.*, 2001). Quadriacanthus species are oviparous organisms, producing eggs of different sizes and shapes (Reda *et al.*, 2003) [155].

Occurrence and identification

The genus *Quadriacanthus* Paperna, 1961 (Dactylogyridae) consists of a total of 38 species of parasites of clariids in Africa and Asia (Bouah *et al.*, 2022; Francová *et al.*, 2017; Lim *et al.*, 2001; Tripathi *et al.*, 2007) [34, 175], with almost a third parasitizing *C. gariepinus* in Africa (Scholz *et al.*, 2018) [161]. The review recorded eleven species, namely *Q. aegypticus Q. allobychowskiella, Q. ashuri, Q. bagrae, Q. clariadis, Q. fornicatus, Q. numidus, Q. papernai, Q. pravus, Q. voltaensis,* and *Q. zuheiri* infest *C. gariepinus* from African aquatic systems. Among the *Quadriacanthus* species *Q. aegypticus* are the most frequently reported across Africa.

Eight species, including *Q. ashuri, Q. fornicatus, Q. papernai. Q. pravus, Q. voltaensis* and *Q. zuheiri* have only been recorded once each (Fig. 1, Table 1). In addition, several reports have presented Quadriacanthus species identified only to genus level (Abdel Latif *et al.*, 2009; Acosta *et al.*, 2020; Beletew *et al.*, 2016; A. A. Khalil & El-houseiny, 2019; Mokonyane, 2020; Olivier *et al.*, 2009; Onojafe *et al.*, 2021; Truter *et al.*, 2023a) [137, 139, 176-178]. The existence of such single parasite species records highlights the minimal parasite survey efforts, and thus the need for more routine investigations on fish parasitology [1, 3, 29, 73, 95, 115].

Host and site specificity

Genus *Quadriacanthus* comprises mostly parasites of clariids, except *Q. bagrae* from bagrids (Paperna, 1979), *Q. anaspidoglanii* from claroteids (Schaeffner, 2018), *Q. tilapiae* from cichlids (Paperna, 1973), and *Q. euzeti* from a phylogenetically distant notopterid (Nack *et al.*, 2016). Nevertheless, the existence of *Q. tilapiae* reported from cichlids is doubtful and possibly linked to sample contamination (Nack *et al.*, 2016), accidental infection (Lim *et al.*, 2001) or the specimen was incorrectly identified and synonymized to *Q. bagrae* (Kritsky & Kulo, 1988). Amongst the *Quadriacanthus* species parasitizing *C. gariepinus* (Table 1), only *Q. bagrae* and *Q. voltaensis* are recorded to infest alternative hosts; bagriid catfish *Bagrus bajad* and *B. docmak* (Francová *et al.*, 2017; Hussein *et al.*, 2019); and a clariid catfish *C. camerunensis* (Schaeffner, 2018; Tripathi *et al.*, 2007) respectively. Having a wider host-range has significant implications in parasite management since clariids and bagrids are both endemic to Africa and share most of their habitats (Ferraris, 2002; Nelson *et al.*, 2016) [69, 89, 102, 128].

Genus *Quadriacanthus* exhibits a strict host-site specificity, infesting only the gills of *C. gariepinus* (Paperna, 1961; Kritsky & Kulo, 1988; El-Naggar *et al.*, 2017; Francová *et al.*, 2017). Heavy infestation of gills is known to cause respiratory distress and increased rate of respiration (Thoney & Hargis, 1991; El-Naggar *et al.*, 2019), leading to less-tolerance of the clariid to low oxygen conditions (Klinger & Floyd, 2013; Reed *et al.*, 2012). Gill infestation possess more challenges especially for intensive aquaculture typical of high stocking density and poor water quality which increase fish stress and susceptibility to parasite infestations (Boyd & Tucker, 1998; Whittington & Chisholm, 2008) [36, 73, 99, 102, 129, 156].

Geographical distribution

Whereas *Quadriacanthus* species are the monogenean parasites of *C. gariepinus* with the widest geographical distribution spanning across Africa and Asia (Lim *et al.*, 2001; Schaeffner, 2018; Tripathi *et al.*, 2007), majority of the genera's records available are from Egypt (Fig. 4), a fact possibly attributable to the level of aquaculture development in the country. Among the *Quadriacanthus* species encountered; *Q. aegypticus* and *Q. clariadis* are widely distributed across Africa while *Q. ashuri, Q. fornicatus, Q. papernai, Q. pravus, Q. voltaensis* and *Q. zuheiri* are geographically localized to the individual parasite's type locality. Localization of monogenean species to the type parasite locality possibly reflects absence of routine parasite surveys and thus a gap in information of the geographical spread of the parasite [160, 175].

***Paraquadriacanthus* Ergens, 1988 [65].**

Members of *Paraquadriacanthus* have elongated bodies. Anteriorly, the prohaptor of Paraquadriacanthus species have four pairs of head organs and four eye spots present as scattered granular pigments in the cephalic area. Posteriorly, the haptor is well demarcated from the body and consist of a) 4 rootless anchors with the dorsal anchors having a pair of large patches with hooked termination while ventral anchor having a pair of small triangular patches; b) two connecting bars: the undivided dorsal connecting bar has an onchium - a sclerotized anterior shield and arrow- or T-shaped posteriorly directed portion. The ventral bars are separated to form a V-shaped structure. c) 14 (7 pairs) larval type marginal hooks of similar sizes (Pugachev *et al.* 2010; Lim *et al.* 2001; Ergens 1988). In some cases, pair 4 or 6 of the marginal hooks have proximal ovate enlarged handle (Lim *et al.*, 2001) [154].

Occurrence and identification

The genus *Paraquadriacanthus* Ergens, 1988 (dactylogyridean) is a monotypic group. The genus has a single species, *Paraquadriacanthus nasalis* described from the nasal cavities of the type-host *C. gariepinus*. The preference of the, rarely examined, nasal cavity could explain the low frequency of records. Though *Quadriacanthoides andersoni* had been identified as a new Quadriacanthus species (Kritsky & Kulo, 1988), a comparison of the paratype of *P. nasalis* and the holotype of *Q. andersoni* confirmed that the two genera were synonyms, and the respective type species were conspecific (Arafa, 2012; Kritsky, 1990).

Host and site specificity

Available literature indicates that *P. nasalis* has been recorded in Nilo-Sudan ichthyofauna region on *C. gariepinus* inhabiting Nile River in Egypt (Arafa, 2012; El-Naggar *et al.*, 2017; Ergens, 1988). Unlike other monogeneans infesting the gills, skin and fins, *P. nasalis* has only been recorded parasitizing the nasal cavity of *C. gariepinus* (Arafa, 2012; El-Naggar *et al.*, 2017; Hagras *et al.*, 1999, Ergens, 1988). Though Kritsky and Kulo (1988) reported *P. nasalis* (syn. *Q. andersoni*) from the external surface of *C. gariepinus*, the parasite collection method used in the study precluded the exact determination of infestation site that could include the gills, fins, skin, nares or the mouth.

Geographical distribution: Currently, *P.* nasalis records have been geographically localized along the Nile River in Egypt (Arafa, 2004, 2012; Ergens, 1988; Hagras *et al.*, 1999; Kritsky, 1990; Kritsky & Kulo, 1988). The restricted distribution of *P. nasalis* to the Nile River in Egypt could be linked to the lack of appropriate parasite identification tools as well as sampling campaign targeting monogeneans within the Nile basin countries including Sudan, Ethiopia and Uganda and other habitat ranges of *C. gariepinus*. Investigations into the biotic and abiotic factors of the Nile River waters in Egypt could as well help to elucidate on the scarceness of the *P. nasalis* in other regions of Africa [78, 101, 102].

Identification: Molecular approaches have been considered essential in addressing the identification challenges in Monogeneans. However, the high amino acid sequence variability in the barcoding gene, cytochrome c oxidase subunit I (COI) of monogeneans coupled with high species diversity, has rendered the development of truly "universal" barcoding primers for flatworms a nightmare.

Alien monogenean parasites of *C. gariepinus* in Africa

Species of *Dactylogyrus* Diesing, 1850 (Dactylogyridae) are primarily gill parasites of cyprinid fishes (Gibson *et al.*, 1996; Molnar *et al.*, 2019). However, several fish parasite surveys in Kenya (Mavuti *et al.*, 2017; Wanja *et al.*, 2020; Waruiru *et al.*, 2020) [185], and Nigeria (Oscar *et al.*, 2015) [142] have recorded *Dactylogyrus* sp. from *C. gariepinus* although the parasite species identity was not ascertained. Some records from Nigeria (Enyidi & Uwanna, 2019) [64, 75, 114, 116] and South Africa (Smit *et al.*, 2017) have described the dactylogyrid parasites from *C. gariepinus* as *Dactylogyrus extensus* Mueller and Van Cleave, 1932. The occurrence of alien species of parasites could as well be linked to the introduction of exotic fish species in an attempt to boost aquaculture production (Hecht & Endemann, 1998; Wurtz & Simpson, 1960), for ornamental purposes (Mouton *et al.*, 2001; Waruiru *et al.*, 2020) [185], the indiscriminate movement of fish seed and broodstock across borders (Bondad-Reantaso, 2007) [33], as well as fish escapees from aquaculture into the wild (Andrew *et al.*, 2008; Huchzermeyer & van der Waal, 2012) [12]. While it is unusual for *Dactylogyrus* species to infest clariid hosts, the fact that several *C. gariepinus* specimens were examined during these studies lowers their possibility as accidental infections. Records of *Dactylogyrus* species from several specimens by different authors might suggest that the parasite species is in fact well established on the clariid host. However, since all studies reporting *Dactylogyrus* species from *C. gariepinus* relied on only microscopic morphology for parasite identification, use of appropriate parasite identification tools such as microscopic morphometry and nucleic acid-based assays as well as a combination of these techniques might provide comprehensive and reliable information on the status of dactylogyrids as parasites of *C. gariepinus* in Africa [87, 117, 170, 184, 185, 189].

Pathology of fish infested with monogeneans

Members of class Monogenea are principally ectoparasitic (Buchmann & Bresciani, 2006; Řehulková, 2018) [41], infesting the gills, skin and fins (Arafa, 2012; Ghoneim *et al.*, 2015; Mashaly *et al.*, 2019). Apparently, one species, *P. nasalis* appears to infect the nasal cavities of *C. gariepinus* (Arafa, 2004, 2012; Ergens, 1988). Monogeneans utilize humus and the marginal hooklets for attachment onto the host. The hooks and hooklets penetrate epithelial cells and generate a firm contact with the host, consequently damaging host cells and tissues (Whittington & Chisholm, 2008) [74].

Polyonchoinean monogeneans feed by breaking down newly produced epithelial and mucous cells, thereby causing significant damage to the host (Paperna, 1996). In severe infections, monogeneans elicit inflammatory reactions in the host such as hyperplasia of organs of attachment especially gills (Akoll, 2005; Arafa *et al.*, 2009) as well as skin and fin erosions (Arafa *et al.*, 2013; L. F. Khalil & Mashego, 1998) [97]. As such, the impact of the pathological effects of monogeneans on the host fish might vary according to the preferred site of parasite attachment, as well as the intensity of the parasites on that particular site, and has significant implications on fish health, productivity as well as profitability especially in aquaculture (Opiyo *et al.*, 2018; Walakira *et al.*, 2014) [7, 112, 140, 157, 183].

With the exception of *G. alekosi*, *G. transvaalensis* and *P. nasalis*, all monogeneans known to infest *C. gariepinus* have been recorded from the gills (Table 1), making fish gills the most preferred site for monogenean attachment and thus infestation. Gill infestation is known to elicit a range of host responses and pathological effects including hyperplasia and oedema, and consequent gill fusion (Akoll, 2005; Arafa *et al.*, 2009) [7], that lead to decrease or loss of gill respiratory surface area, respiratory stress and subsequently death of the host (Paperna, 1991; Thoney & Hargis, 1991). Infested gills have been described to be grey-white in color, having lost the natural red color, and being covered in mucous (Kabata, 1985; Obiekezie & Ajah, 1994; Paperna, 1964; Venter, 2002) [94, 182]. The attachment of monogeneans to the fish gills elicits several pathological effects including breakdown of coating epithelium, necrosis of epithelial cells, vacuolations inside and outside of host cells, infusion of gill lamellae, rapture of blood capillaries (hemorrhage), infiltration of erythrocytes, and degeneration and fibrosis of interlamellar epithelium (Arafa *et al.*, 2009; M. M. El-Naggar, Mashaly, *et al.*, 2019). The host response to monogenean infestation includes excessive mucoid secretions, appearance of lymphocytes and hyperplasia of the tissue at the site of attachment to the gill tissues. (Arafa *et al.*, 2009) [130, 174].

Species of genus *Quadriacanthus* exhibits a strict host-site specificity, infesting only the gills of *C. gariepinus* (Francová *et al.*, 2017; Paperna, 1961) [73]. Therefore, the histopathological effects of *Quadriacanthus* species impact exclusively the gills, including compression of gill lamellae, degeneration and rapture of the outermost pavement cells, breakdown of the wall of the blood spaces, fibrosis, necrosis, reduction and desquamation of the lamellae epithelial layers, loss of innermost pavement cells, swelling and rapture of blood cells and swelling and vacuolation of the lamellar tissues at the site of hook insertion (M. M. El-Naggar, Mashaly, *et al.*, 2019; M. M. El-Naggar & Serag, 1985). Host responses to monogenean infestation include proliferation of undifferentiated epithelial cells into mucous cells, hyperplasia, and appearance of lymphocytes at the site of haptor attachment. Severe epithelial hyperplasia compromises respiratory exchange and kills the host fish through hypoxaemia, causes dysfunction of respiratory system (Crafford, 2013; Whittington & Chisholm, 2008) [50, 112].

Besides gill infestation, a few monogenean species including *G. alberti*, *G. groschafti*, *G. rysavyi*, *G. transvaalensis* and *M. congolensis* have been recorded infesting the skin, while only *G. alekosi* is recorded from the fin of *C. gariepinus* (Table 1). Skin and fin infestations cause infiltration of melanomacrophage centers into the epidermis (Akoll, 2005; Maduenyane *et al.*, 2022b) [7, 108], irritation to the host resulting into abnormal behavior such as flashing and rubbing against the pond wall in aquaculture that consequently reduces feeding time (Whittington & Chisholm, 2008), and increasing likelihood for secondary bacterial and fungal infections (Barber 2007; Kotob *et al.* 2016) [24, 100]. Other histopathological features induced by skin infesting monogeneans include copious mucous production which obscures chromatophores, making the skin appear paler than normal (Kabata, 1985; Thoney & Hargis, 1991), and consequently lowered market value. Additionally, greyish-white patches have been noted on *C. gariepinus* bearing skin-infesting macrogyrodactylid *M. congolensis*, probably as a result of the severe irritation of the skin (L. F. Khalil & Mashego, 1998; Obiekezie & Ajah, 1994; Paperna, 1996) [94, 97, 130, 143-148, 174, 186, 187].

Although monogeneans are principally ectoparasites (Bakke *et al.*, 2002; Buchmann & Lindenstrøm, 2002; Cribb *et al.*, 2002) [42], 51, *G. alberti* is reported to infest a wide range of

microhabitats on the external and internal host surfaces (El-Naggar *et al*., 2001). The infestation of multiple host sites by any parasite is likely to increase the scope of pathological disturbances incurred by the host, and ultimately amplify the magnitude of morbidity and mortality. Even if there is contention as to whether *G. alberti* is a synonym of *G. rysavyi*, (Arafa *et al.*, 2007), the predilection for multiple host sites raises interest in *G. alberti* attachment mechanism [20].

General comment on identification

Morphological method utilizes shapes, measurement and arrangement of majorly marginal hook, hamuli and bars for species identification. The structures keratin-like proteins that imparts rigidity and chemical resistance especially to proteinase digestion, hence have a stable in shape. However, present challenges to capture the subtleties of their shape.

Meanwhile, the ventral bar shape which is crucial in identifying a novel gyrodactylids, are flexible and fragile, hence easily distort by fixatives including formalin or ethanol or even in air-drying process. The processed specimen mounted using either Canada Balsam or saturated ammonium picrate-glycerin, are examined using light microscope, hence offers cheap method for identification of monogeneans. Apart from the disadvantages of fixatives and mountants (Bakke *et al.*, 2007) [20], lack of technical skills to appropriately process the specimens remain a major hindrance for most parasitologists

General Conclusions and Recommendations

The African catfish inhabiting Africa's freshwaters is host to diverse fauna of polyonchoinean monogeneans belonging to the genera *Gyrodactylus* von Nordmann 1832, *Macrogyrodactylus* Malmberg 1957, *Quadriacanthus* Paperna 1961, and *Paraquadriacanthus* Ergens 1988. Members of *Macrogyrodactylus* and *Quadriacanthus* have been encountered the most while *Quadriacanthus* is the most diverse monogenean genera parasitizing *C. gariepinus* in Africa's freshwaters. Although rudimentary, microscopic morphology of the sclerotized parts of the monogenean attachment organ is the most common method of parasite identification [65].

While most monogeneans infesting *C. gariepinus* are generally host specific, the extended host range displayed by some species enhances the likelihood for spread beyond the host's ecological niche, thus a potential threat in biosecurity. Updated information on the zoogeography of both host and parasite species is crucial in an attempt to understand the infestation and transmission patterns of parasites. Infestation of multiple hosts is also likely to enhance parasite transmission especially in the event of indiscriminate movement of seed and broodstock across geographical barriers, in polyculture, or even the occurrence of host escapees from farms to the wild and vice versa.

Although some monogeneans exhibit a wider spectrum of microhabitats, most species encountered are host-site specific, parasitizing only particular sites of predilection on *C. gariepinus*. Infestation of multiple host sites is likely to increase the scope of host pathological disturbances, intensify the magnitude of morbidity and mortality, and thus pose challenges to fish health management.

While representatives for each of the four monogenean genera parasitizing *C. gariepinus* have been encountered in all regions of Africa, only *M. clarii*, *M. congolensis*, *G. rysavyi*, *Q. clariadis* and *Q. aegypticus* display the widest geographical span across Africa, and thus require more attention for improved *C. gariepinus* health management. The impact of ecological and anthropogenic factors on the prevalence and distribution of monogeneans needs to be assessed as a possible cause for the observed parasite distribution across the continent. The clustering of most records on monogeneans infesting *C. gariepinus* to the Nile basin, Nigeria and southern Africa could be commensurate to the high level of aquaculture development and intensive parasite surveillance. The occurrence of several monogenean species of *C. gariepinus* with single records that are limited to the parasite type-locality highlights either limited number of studies or identification challenges.

Overreliance on microscopic morphology for parasite identification increases the possibility for inaccurate parasite diagnosis and misidentifications. The several records of monogeneans reported as *Gyrodactylus* sp. highlight the absence of appropriate identification tools and skills necessary to ascertain parasite species identity. The use of a combination of techniques such as microscopic morphology, haptoral sclerite morphometry and DNA sequence analysis will yield reliable information and thus provide more insights into parasite diversity, geographic distribution, microhabitat preference and host range. Since *C. gariepinus* has become one of the preferred aquaculture fish species in Africa, routine parasite surveys should be conducted especially in parasite type-localities as well as in the central, eastern, and western regions of Africa for an improved health management and the sustainability of productivity.

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