EFFECTS OF STOCKING DENSITY AND SEASONALITY ON DIGENEAN TREMATODE AND MONOGENEAN INFECTIONS IN NILE TILAPIA (*Oreochromis niloticus,* Linnaeus 1758) REARED IN CAGES IN UHANYA BEACH IN LAKE VICTORIA, KENYA

BY

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DECLARATION

DECLARATION BY THE STUDENT

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I devote this project to my parents (Davis and Elizabeth Bwoga), my aunt Mary Gati, and my siblings (Bella and Dorcus Bwoga, Desmond Kerario and Esther Bhoke) for their love, support and prayers all through.

ABSTRACT

There exists a balance between, parasites, their fish hosts and the environment. However, when this balance is broken parasites spread rapidly in culture facilities inducing severe epizootics. This study was conducted from December 2017 to May 2018 with an objective of highlighting stocking density and seasonality as drivers of monogenean and digenean trematode parasitism in *Oreochromis niloticus* in cages in Uhanya Beach, Lake Victoria, Kenya. The study adopted a systematic random sampling technique to sample an aggregate 600 fish during the rainy and dry seasons. Parasites isolated from the sampled fish were the monogenean *Dactylogyrus* and the digeneans; *Tylodelphys*, *Clinostomum* and *Neascus. Dactylogyrus sp.* was predominantly abundant in the fish from all the 10 cages. Mann-Whitney U-test revealed that mean intensity of *Dactylogyrus sp*. infestation considerably augmented with higher stocking density of fish (p < 0.05; df =298). On the contrary, *Clinostomum* sp., *Tylodelphys sp*. and *Neascus sp.* exhibited significantly reduced infestation with increased stocking densities (p < 0.0001). Temperature significantly differed between the seasons (df = 28; p < 0.0001). All the individual fish showed allometric growth and the general fish condition as depicted by condition factor (*Kn*) was significantly better in cages with stocking densities of 2500 individuals/ Cage (df = 298; p < 0.05). Kruskall-Wallis test indicated significant variation in prevalence of attack between the parasite species both in wet season (H = 17.793; df = 3; p < 0.0001) and dry season (H = 30.226; df 3; p < 0.0001). There was a general positive correlation between water temperatures and mean parasite intensity, however, this relationship was weak in all the parasite species ($r^2 < 0.5$). The relationship between intensity of parasite infestation and fish condition factor was not also weak and significant in all the parasite species (*Dactylogyrus sp*.: $r^2 = 0.017$; *Clinostomum sp*.: $r^2 = 0.001$; *Tylodelphys sp*.: $r^2 = 0.008$; & *Neascus sp*.: $r^2 = 0.026$). The study recommends proper site selection for cages, water quality management and sourcing of fish seed from certified hatcheries to prevent the spread of parasitic diseases.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Tilapia is a unique aquatic species grown by farmers in developing countries around the world (Fitzsimmons, 2010), with its culture expanding across the globe (Fitzsimmons *et al.*, 2011). Tilapias are extremely successful fishes, largely attributed to their high growth rate, high fecundity, high nutritional value and tolerance to harsh environmental conditions. Tilapias are classified into the taxonomic groups (genus) namely: Tilapia, *Oreochromis* and *Sarotherodon* (Trewavas, 1982) species from the genus Tilapia are substrate spawners, *Oreochromis* species are maternal brooders whereas the genus *Sarotherodon* is made up of maternal and paternal brooders. The tilapias originated from Palestine, in the Nile adjacent to West Africa in Lakes Rudolf (Turkana) and Albert in East Africa (Lowe-McConnell, 1958). Tilapia is the succeeding most farmed fish worldwide after the Chinese and Indian carps and considered as the food fish of the 21st century (Pradhan *et al.*, 2020).

The world aquaculture production of tilapia in live weight was 106 million metric tonnes in 2015, with a total projected first-sale price of US$163 billion (Tacon, 2020). China has been the prime producer of tilapia in the world since 1990s (Menaga & Fitzsimmons, 2017). Worldwide tilapia production through aquaculture augmented from 1.19 MT to 6.031 MT between 2000 and 2018 with its stake in the aggregate cultured and captured tilapia production growing from 63.6 percent to 87.6 percent (FAO, 2020). The major tilapia producing countries comprise of China (23.61 % of the total production), Indonesia (18.76 %) and Egypt (17.04 %), among others (FAO, 2020). Aquaculture production in Africa is growing at a slow rate (~2.7%) though noticeably growing with greater investments in Egypt, Nigeria, Uganda and Ghana producing significant amounts of fish (FAO, 2020).

There has been a major deterioration in fish catches in Lake Victoria whereas fish demand has been on the increase (Njiru *et al.*, 2019); to increase fish production in order to meet the gap in demand, farmers have ventured into cage culture for job creation and enhancement of economic wellbeing. Cage culture of *O. niloticus* in Lake Victoria has significantly grown in the previous 5 years with a production of twelve million kg of fish in each production cycle (approximately 8 months) (Opiyo *et al.*, 2018), this has greatly increased fish production in riparian counties along Lake Victoria. The Nyanza Gulf is a large shallow bay of Lake Victoria suffering from Eutrophication by human activities (Roegner *et al.*, 2020). Pollutants can cause sub lethal physiological stress to hosts and hence reduce their capacity to withstand parasite invasion and/or proliferation, potentially increasing infection levels indirectly (Cable *et al.*, 2017). Anthropogenic impact on the environment of Lake Victoria has caused a dramatic decline in fish species diversity (Kudhongania *et al.*, 2019). Further pressure on the ecological functioning of the lake was compounded by exotic species stockings (Balirwa, 1995). With a highly polluted lake, introduction of cage culture will likely worsen the situation.

Fish live in equilibrium with parasites, nonetheless this balance can be ruined by ecological disturbances, amongst which the alterations in the water quality (Lafferty *et al.*, 2015) partake a pertinent role as well as inadequate supervision (Plumb, 2018) and high stocking densities of fish (Mishra *et al.*, 2017). Monogeneans, digeneans, leeches and certain groups of parasitic copepods are the most common parasites of tilapia and can be extremely numerous in cultured fish leading to secondary bacterial and fungal infections or fish mortalities (Hutson *et al.,* 2018). Neodermata is a clade of Platyhelminthes that comprises of Digeneans, Aspidogastrea, Monogenea and Cestoda (Brusa *et al.,* 2020). The trematodes comprise of two subclasses: Aspidogastrea and Digenea (Panyi, 2020). The subclass Digenean trematode forms the leading and utmost successful parasite group of internal metazoan with above eighteen thousand nominal species that belong to 150 documented families and nearly 2700 genera (Bakhoum *et al.,* 2017).

Digenetic trematodes are common parasitic platyhelminthes worms commonly known as white grub (White, 2019). The eye flukes are metacercariae larval stages of the *Diplostomoidea* genera that parasitize the eyes of fish (Blasco *et al.,* 2017). Each species of digenetic trematode necessitates an intermediate host which is typically a molluscan species as (Waki *et al.,* 2018). The *Clinostomidae* is a diverse genera of digeneans predominant in freshwater and estuarine environments globally (Calhoun *et al.,* 2019). Its life cycle comprises a number of stages and three different hosts. The diversity in the Digenea is as a consequence of recolonisation of host by taxa arising from an association with tetrapods (Gauffre-Autelin *et al.,* 2017) and taking on novel sites within the fish hosts. It is also characterized by the adoption of new diets and feeding mechanisms; adaptations relating to the exploitation of ecologically similar groups of fishes and second intermediate hosts (Gauffre-Autelin *et al.,* 2017); and variations relating to the exploitation of molluscan phylogenetic lineages. On the other hand, monogenean diversity is principally related to morphological specialization for attachment by the haptor (Klapper *et al.,* 2017).

Digenean parasites poses a sequence of phases with a distinctive appearance, mode of reproduction and lifestyle that together establishes their well-known complex life cycle (Gonchar *et al.,* 2019). Their most common life cycle comprises of three hosts; the eggs exit the vertebrate host in faeces and by applying several strategies infects the first intermediary host usually a snail, either passively or actively (Hutson *et al.*, 2019). After penetration of the snail, the miracidium transforms into a simple, sac-like mother sporocyst (Ataev & Tokmakova, 2018). *Cercariae* are infectious to the subsequent host in the life cycle (Nikolaev *et al.*, 2017), and contagion may transpire inactively when fish ingests the cercaria or lively as soon as the cercaria infiltrates the fish (Żbikowska & Żbikowski, 2015). The metacercariae is present in the gut of its conclusive host's in retort to variability in physical and chemical signals such as the pH levels of the gut, digestive enzymes and temperature (Morley, 2015). For digeneans temperature seems to be the key extrinsic element prompting the metacercariae to excyst (Ayoub *et al.*, 2020).

Monogeneans form one of the richest classes of fish parasites species (Blahoua *et al.*, 2016). The four most frequently diagnosed monogenean families in aquaculture are the; *Gyrodactylidae*, *Dactylogyridae* (Vanhove *et al.*, 2018), *Ancyrocephalidae* (marine), and *Capsalidae* (marine) (Cardoso *et al.*, 2018). The monogenean genera include the *Gyrodactylus*, *Dactylogyrus*, *Cichlidogyrus* and *Cleidodiscus* genus which parasitize the gills and skin of both farmed and wild tilapia (Enyidi & Uwanna, 2019). The *Gyrodactylus* is a genus of parasitic monogeneans in the family *Gyrodactylidae* (Tu *et al.*, 2019); monogeneans of the genus *Gyrodactylus* are important pathogens triggering massive deaths in captured and farmed fish. A Majority of the gill flukes belong to the family *Dactylogyridae* (Vanhove *et al.*, 2018), represented by the largest genus the *Dactylogyrus* which includes over 900 species (Benovics *et al.*, 2017). The *Dactylogyrus* typically attaches itself to the gills of fresh water fishes (Daghigh *et al.*, 2020) and reproduces by laying eggs (Tekmedash *et al.*, 2016). This parasite is often resistant to chemical treatment (Restiannasab *et al.*, 2016).

Fish parasites and diseases pose a huge challenge on aquaculture production (Mukwabi *et al.*, 2019), however, in Kenya, diseases and parasites are viewed as a minor problem in the tilapia culture industry because of its subsistence and semi-intensive levels of production (Maina *et al.*, 2017). Cage culture of *O. niloticus* in Lake Victoria is faced with massive and frequent fish kills due to incidences of diseases and parasites (Njiru *et al.*, 2019), especially in light of pollution in the lake. Recent efforts to intensify production to meet high demand for food fish are grappling with incidences of diseases and parasites (Akoll *et al.*, 2012). For instance, in Lake Victoria Kenya where fish landings by fishermen has dwindled rapidly due to overfishing, pollution (Van Hoof, & Steins, 2017) and use of illegal fishing gears (Mkumbo & Marshall, 2015), local fishermen and fish farmers have resorted to intensive cage culture of monosex tilapia in the lake. Adoption of cage culture in the lake as an ideal culture method for Nile tilapia has led to an increase in the total number of cages from 1,663 in December 2016 to 3,398 in July 2017 (Anjejo, 2019).

The study examined stocking density and seasonality effects on digenean trematode and monogenean infections in caged *O. niloticus* in Uhanya Beach in Lake Victoria, Kenya. Specifically, the study identified digenean trematodes and monogeans and their intensity of infection on *O. niloticus* reared in cages in Uhanya Beach in Lake Victoria, Kenya. The association between fish stocking density and seasonality as drivers of digenean trematode and monogenean infections in *O. niloticus* reared in cages was determined. The study evaluated the effects of water physical-chemical variables on prevalence and intensity of digenean trematode and monogenean infections and the impact of digenean trematode and monogenean infections on fish condition factor were assessed.

1.2 Problem Statement

With the expansion of aquaculture, diseases arises as a result of movement of live fish and its products, farming of exotic species, in addition to inadequate biosecurity (Stentiford *et al.*, 2017). Parasitic infections are overwhelming in cultured organisms as compared to wild populations due to the stressful circumstances related to overcrowding as well as general water quality drop (Sakala, 2017). They spread not only inside a system but also to adjacent culture units in the case of shared facilities (Lieke *et al.*, 2020). Eutrophication in Lake Victoria arising from extreme nutrient introduction is an important stressor in cage culture (Onyango *et al.*, 2020). It is linked to raise intermediate host densities, parasite productiveness and augmented prevalence of certain pathogen infections (Shields, 2017). The high stocking densities in cage culture and water quality deterioration provides a perfect condition for parasite transmission and proliferation (Maina, 2017) especially for trematodes and monogeneans (Santos *et al.*, 2017). Fish infested with parasites lose its aesthetic value resulting to consumer rejection and a significant decrease in market value (Adugna, 2020). The well-being of cage cultured *Oreochromis niloticus* may be compromised by factors such as overcrowding, water quality decline and parasitic infections (Plumb, 2018) which as a result may have significant influence on its welfare resulting to a lower condition factor (Cooke, 2016). Intensification in aquaculture alters the environment for fish hence new infections crop up due to increased stress levels and reduced immunity (Murugami *et al.*, 2018). The regulation and deterrence of disease occurrences therefore depends on awareness about its spread (Lafferty *et al.*, 2015).

1.3 Justification

Fish parasites are sources of deadly diseases to fish actively or passively (Saha & Bandyopadhyay, 2017) consequently affecting fish production, destabilizing the biodiversity and ecosystem functions (Adamba *et al.*, 2020). Monogeneans are ubiquitous and less understood parasites that generate a stressful environment to cultured Nile tilapia through destruction of the immune system as a result making the fish vulnerable to diverse infections (Kaur *et al.*, 2018). The occurrence, tenacity, and extermination of infectious diseases every so often is influenced by the density of hosts (Krkošek, 2017); therefore, prolonged stress brought up by elevated stocking densities in cage culture may perhaps have substantial implications for fish immune-competence. Even though elevated host densities have potential to endorse greater parasite densities, there may be a drop in quantity of conspecific organisms per host (Lagrue & Poulin, 2015).

There's scarcity in evidence on manifestation, contagion dynamics and distribution of trematodes and monogeneans in diverse fish hosts in diverse ecological environments (Leung *et al.*, 2015). This information is vital in recognising the interactions of mentioned parasites with their hosts and useful for development of control measures to parasitic outbreaks (Assefa & Abunna, 2018). Understanding parasite diversity and transmission (Shaw *et al.*, 2019) is key to the development of relevant intervention measures aimed at reducing fish loss to parasitic diseases (Lim *et al.*, 2016). Understanding infection dynamics of the monogenea and digenean trematode parasites is key with particular interest on stocking density, seasonality and water quality and their effects on parasitism and host fish condition factor.

1.4 Study Objective

1.4.1 Overall Objective

The overall objective of the study was to investigate the effects of stocking density and seasonality on Digenean trematode and Monogenean infections in Nile tilapia (*Oreochromis niloticus*) reared in cages in Uhanya beach, Lake Victoria, Kenya.

1.4.2 Specific Objectives

1. To identify the digenean trematodes and monogeans infecting *O. niloticus* reared in cages in Uhanya beach, Lake Victoria, Kenya.
2. To determine the mean intensity and prevalence of infection by digenean trematodes and monogeans in *O. niloticus* reared in cages in Uhanya Beach, Lake Victoria, Kenya.
3. To determine the relationship between stocking density and prevalence of digenean trematode and monogenean infections on *O. niloticus* reared in cages in Uhanya Beach, Lake Victoria, Kenya.
4. To determine the relationship between seasonal variation in water physico-chemical parameters and prevalence of parasites in *O. niloticus* reared in cages in Uhanya Beach, Lake Victoria, Kenya.
5. To assess the relationship between mean intensity of digenean trematode and monogenean infections on fish condition factor of *O. niloticus* reared in cages in Uhanya Beach, Lake Victoria, Kenya.

1.5 Research Hypothesis

Ho: There is no significant relationship between fish stocking density and prevalence of digenean trematodes and monogenea infection in *O. niloticus* reared in cages in Uhanya beach, Lake Victoria, Kenya.

Ho: There is no significant relationship between seasonal variation and prevalence and mean intensity of digenean trematode and monogenean infections in *O. niloticus* reared in cages in Uhanya beach, Lake Victoria.

Ho: Water physical-chemical variables do not affect the prevalence and mean intensity of digenean trematode and monogenean infections in *O. niloticus* reared in cages in Uhanya beach, Lake Victoria.

Ho: Intensity of parasite infection does not have an effect on fish condition factor of *O. niloticus* reared in cages in Uhanya beach, Lake Victoria, Kenya.

Ho: Water physical-chemical variables do not affect the mean intensity of parasites

1.6 Operational definition of significant terms

Abundance: The quantity of entities of a given parasite in a single host varying from zero to infinity.

Definitive host: this refers to an organism where the parasite spends its final developmental stage until maturity is attained.

Ecto-parasite: This term refers to a parasites that lives on the external surface of hosts.

Endo-parasite: This terms defines a parasite that lives in the tissues and interior organs of their hosts.

Host: This is defined as an organism harboring a parasitic, mutualistic or commensalist guest providing it with nourishment and shelter.

Infection: The process of parasite invading the body of animal or making an animal ill or diseased.

Infestation: The presence of remarkably large amounts of parasites with potential to effect damage or cause disease.

Intermediate host: an organism harboring a sexually immature parasite vital for the parasite to go through its development and complete its life cycle.

Mean Intensity: The overall amount of individuals of a specific parasite in a sample of a host species divided by the quantity of infected individuals of the host species in the sample.

Prevalence: The number of characters of a host species infested with a specific parasite species divided by the number of hosts examined.

CHAPTER TWO

LITERATURE REVIEW

2.1. Global Aquaculture Production of *O. niloticus*

In 2011, the global aquaculture production of food fish reached 62.7 million tonnes. This was an increment by 6.2% from 59 MT in 2010 with a projected value of USD 130 billion (FAO, 2010). The global aquaculture tonnage of (*Oreochromis niloticus*) was approximately 71% of the total tilapia production at 4,207,900 metric tons with an estimated value of US$ 6,923 million in 2012 (Fitzsimmons, 2013). In 2014, the global tilapia production was valued at 4.5 million tons and expected to surge to 7.3 MT by 2030 (FAO, 2014). The total global tonnage from culture stood at 73.8 MT in 2014 valued at approximately 160.2 billion US dollars (FAO, 2016). The FAO aquaculture statistics recorded a worldwide aquaculture production of one hundred and six million tonnes in 2015 formed of live weight of tilapia with a total estimated value of US$163 billion (Zhou, 2017). The total reported global aquaculture output was 53.4 MT in 2017 with a yearly progression in fish production of 5.7% since 2000 with in excess of 208 different fish species reported in 2017, priced at US$139.7 billion (Tacon, 2020).

Tilapia (*O. niloticus*) is commonly farmed and universally traded fish for nutrition in the world. It was produced at an estimated 1.45 million tons in China in 2013 (Li *et al.*, 2017). The leading suppliers of farmed tilapia are China, Philippines, Taiwan, Indonesia and Thailand altogether producing approximately 1.1 million MT of fish in 2001, forming about 76% of the total aquaculture production of tilapia worldwide (Fessehaye, 2006). Global tilapia production was estimated to be 2.8 million tonnes in 2008 (FAO, 2010) and exceeded 3,078,000 metric tons in 2009 and is expected to reach 3,200,000 metric tons in

2010 (Fitzsimmons, 2010). The worldwide production of tilapia was estimated to be 5.67 million MT in 2015 (FAO, 2018) and expected to reach 7.3 million MT by 2030. Global Tilapia production quickly amplified and was 5.6 million tons in 2015 (Yue *et al.*, 2016). Nonetheless, tilapia consumption remains still low at only two fish per capita per year (Fitzsimmons, 2016). Reduced tolerance to changes in temperatures during seasons has constrained tilapia production to south China and great expenditure encountered due to long-distance transportation have limited local consumption of tilapia (Zhang *et al.*, 2017).

Fish contributes over twenty five percent of overall animal protein consumption globally particularly in small income earning countries (Bondad-Reantaso *et al.*, 2005). Egypt has one of the world's major aquaculture sectors which plays a significant role in income generation, job creation and in promoting food security as a result of aquaculture production of Nile tilapia (Eltholth *et al.*, 2015). Egypt is as well the 2nd main producer globally of cultured tilapia subsequently China (Mur, 2014). *O. niloticus* is the core cultivated fish in Egypt comprising 75.5 % of the countries production. The country has a production capacity of 1.05 million tonnes (Rothius *et al.*, 2013). Nile tilapia is the main cage cultured species particularly in the Nile Delta region at semi-intensive and intensive levels (Soliman & Yacout, 2016).

Kenyan aquaculture is characterized by emphasis on 2 focal aquaculture species: the Nile tilapia (*O. niloticus*) and the African catfish (*Clarias gariepinus*) (Opiyo *et al.*, 2018). *O. niloticus* is the most cultured and available fish in Kenyan because of its great consumer preference (Wanja *et al.*, 2020). Changing technology such as aquaculture production in net cages has been the key motivating force for growing the aquaculture sector in the time of diminishing open water stocks (Bundi *et al.*, 2018). Recent rapid developments in the aquaculture sector in Kenya demanded a surge in production of quality fish seed in fish hatcheries resulting to a production output of 23 million of *O. niloticus* fingerlings and 2 million of *C. gariepinus* annually (Nyonje *et al.,* 2018). Cage culture of monosex *O. niloticus* has dominated the Kenyan aquaculture sector with over three thousand net cages producing above three million tilapias valued at US$ 12 million (Njiru *et al.,* 2019).

In the recent past, aquaculture development in Kenya increased due to Government support (Ngugi *et al.,* 2019); nevertheless, evidence on its influence on water quality is scanty. Since 2004, Kenya has experienced a histrionic increase in aquaculture production with an increase from about 1000 tons to more than 23000 tons from 2004 to 2013 (Wambua & Jóhannesson, 2018). The nutritive shortage levels continue high amongst a substantial section of the Kenyan populace. With aggregating food production bottlenecks such as declining wild stocks and effects of climate change becoming more renowned, therefore, fish culture has been acknowledged as an imperative chance to augment household food security (Ogello & Munguti, 2016). Aquaculture production is however faced by challenges including fish diseases and pollution (Mukwabi *et al.,* 2019). The extensive development of cage farming in Lake Victoria warranties monitoring of fish health (Opiyo *et al.,* 2018). Other challenges faced in fingerling production comprises; huge mortalities during larval stages, poor supply of hatchery inputs and equipment, high costs quality feeds and lack of technical advice on emergent technologies (Nyonje *et al.,*2018). Few studies have been conducted in Kenya with regards to parasites of importance such as the digeneans and monogeneans which have great impact on human and fish health. Therefore this study addresses the issue of parasitic disease outbreaks in cage cultured tilapia in order to reduce fish losses to these parasites of economic importance.

2.2. Digenean Trematodes and Monogenean Infections of Tilapia

Digenea

Among the fish-borne parasitic diseases, infections by digenetic trematodes are the most common (Faruk, 2018). They possess complex life cycles encompassing developing stages in one or additional intermediate hosts and an adult stage in definitive hosts (Mesquita *et al.,* 2020). The backbone of digenean systematics is morphological scrutiny of sexual adults from vertebrates (Bakhoum *et al.*, 2017). To spread to a vertebrate host and dependent on the species, the cercariae either infiltrates directly through skin or mature into adults (Nation *et al.,* 2020). Eggs released by the mature worm inside the vertebrate host gets to the environment. The miracidium may perhaps hatch and swim away or the egg may have to be ingested by the next host depending on the species (Carvalho *et al.*, 2019). The metacercariae enters a second intermediate host, and wait to be ingested or it attaches to vegetation by metacercariae secrete a resistant cyst wall, and waits to be eaten (Halstead *et al.,* 2018).

Trematode fluke larvae are widespread in fish, and they usually encyst as metacercariae within species-specific locations (Stumbo *et al.,* 2012). The larval stage of these flukes constitute a phase in which the capacity to preserve its cycle and infect definitive hosts is maintained and prolonged over a long time (Tatonova & Besprozvannykh, 2019). Metacercariae infectivity is passive, happening only when the parasite is consumed by the target host and is at its highest at low temperatures (Zimmermann *et al.*, 2017). Clinostomum digenean trematode is among the most widespread and common trematodes present both in freshwater and estuarine habitats with a life cycle comprising of a number of stages in several hosts (Aghlmandi *et al.,* 2018; Calhoun *et al.,* 2019). The metacercariae of *Clinostomum* are found mostly under the skin of the fish. This genera of trematodes sometimes infects humans through the consumption of raw fish (Sohn *et al.,* 2019).

Clinostomum complanatum, the "yellow grub", is a digenean trematode which forms cysts in the body cavity, visceral organs and muscles of fish; the eggs of these worms once released into the water by definitive hosts, commonly birds, infect fish (Song *et al.,* 2018). Incidences of ichthyozoonotic infections from fish to humans, though rare, occur from the consumption of raw fish such as *Oreochromis niloticus* or *Lates niloticus* and can cause laryngeal or pharyngeal infections in humans (Kim *et al.,* 2019). *Neascus spp* can be distinguished by the formation of black spots on location where the larvae are encysted as a result of pigment mobilization; its infectivity can vary with water temperature (Matondo & Mtalika, 2018).

There exists a diversity in the morphology of adult digenean parasites, with most having a ventral sucker in the mouth region and also in the acetabulum (Pelegrini *et al.,* 2016). These suckers are important both for locomotion and for attachment to host surfaces (Krupenko, 2019). The vast preponderance of digeneans are endoparasitic and hermaphroditic, an adaptation to the limited availability of hosts that permits the continuance of their life cycle (Mandavi & Bray, 2018). Protandry with two testes is common among the Digenea. Some however, have more than over 100 in some flukes (Kearn & Whittington, 2015). Most digenean species inhabit the intestine as adults, as they frequently consume the contents in the stomach of the hosts. Some however colonize other tissues and don't restrict their presence only to the intestines (Toledo & Fried, 2017).

Blood parasites also referred as the blood flukes are those parasites feeding exclusively on blood (Skelly *et al.,* 2014). Examples include; spirorchiids and sanguinicolids. Parasitic infection results in the alteration of the phenotypic characteristics of the host and therefore influencing the pressures affecting their populations (Stumbo & Poulin, 2016). *Schistosomiasis,* a devastating tropical disease is caused by parasitic flatworms of the genus *Digenea Schistosoma mansoni* (Contenti *et al.,* 2020). The phenomena of parasitic parasites influencing their hosts to improve trophic transmission is common and diversified (Ruehle & Poulin, 2019); the metacercariae phase of the *Diplostomidae flukes* infect a wide variety of fish species whith their area of infection being mostly the eyes. The larval-stage of *Tylodelphys sp.* are a common infection in the eyes of fish host populations (Stumbo, 2017); These genera of parasites complete their life cycle in the gut of an intermediate host bird upon it consuming the fish (Ruehle *et al.,* 2020). Most flukes appear as dormant cysts in the host species they attack. This however not the case for *Tylodelphys sp.* which stays active, roaming around inside the fish's eye. The species lives in the vitreous liquid between the lens and the retina of its host, where it actively feeds on the vitreous humour fluid, which provides energy for its early growth and activity (Stumbo, 2017). Eye flukes are known to affect fish in various ways including; inducing cataracts, causing partial blindness as well as a variety of behavioral abnormalities in the intermediate host (Flink *et al.,* 2017); which in the long run impairs vision in fish crucial in the detection and avoidance of aerial predators.

Trematode species belonging to the *Diplostomidae* family, specifically those in the genera *Austrodiplostomum, Diplostomum, and Tylodelphys* cause ocular diplostomiasis in the eyes of the fish (Rosser *et al.,* 2016). These infections may be fatal (Horak *et al.,* 2019) and are characterized by impaired vision and/or blindness (Rosser *et al.,* 2016). Trematode *Tylodelphys* spp. has caused blindness to of *Oreochromis niloticus* at Lake Koftu, Sebeta ponds in Ethiopia (Mitiku, 2017). The digenetic trematodes (Clinostomum spp, Diplostomum spp., and Neascus), have been reported to cause diseases in Nile tilapia (*Oreochromis niloticus*) leading to low aquaculture production (Adugna, 2020).

A study aimed to establish the prevalence, intensity and pathological lesions caused by the digenean metacercariae in *Oreochromis niloticus* (Mathenge, 2010), showed the least prevalent helminth among the fish samples was the Clinostomum (8%) and the Neascus spp. (9.7 %). The *Clinostomum, Diplostomum* and *Neascus* species were listed under aquatic diseases of importance during the risk assessment exercise on fish diseases and parasites conducted in the Eastern corridor (Kenya, Rwanda and Uganda) to understand their potential impact on fish trade in the Sub-Saharan Africa (Walakira, 2016). Most parasitology studies have not compared digenean parasite prevalence during different seasons; this study thus fills this gap by comparing intensity of parasite transmission and prevalence during both the rainy and dry reasons.

Monogenea

There are two sub classes of monogeneans based on the intricacy of their haptor; the monopisthocotyleans (one haptor formed as hooks for attachment) (Zhang *et al.*, 2018) and the polyopisthocotyleans (numerous sections of the haptor). Fish parasitic polyopisthocotylean monogenean parasites are extremely host specific and have been used as a model to research host-parasite co-evolution (Tambireddy *et al.,* 2016). Polyopisthocotyleans are mostly found dwelling in gills and feed on blood (Weston, 2018)

Monopisthocotyleans, on the other hand, utilize the gills, skin, and fins as places of attachment. (Oroga, 2019). Examples of these monopisthocotyleans include those of the Genus *Gyrodactylus*, which have no eyespots and are viviparous in nature (Zhang *et al.*, 2020). The *Dactylogyrus* is a genus of monopisthocotyleans monogeneans in the Dactylogyridae family, commonly known as gill flukes and is usually found on the gills of Cyprinid fishes (Zhang *et al.*, 2019).

A large number of monogeneans are browsers that travel around the body surface feeding on cutaneous mucus and gill detritus (Petchimuthu *et al.*, 2018). They are equipped with a series of hooks for attachment during feeding (Garvey, 2020). Most monogenean species are host and site specific (Benovics *et al.*, 2020) and require only a single host to complete its entire life cycle; some may even permanently remain attached to the host on a single site. Monogeneans are found in both fresh and marine fishes (Mendoza *et al.*, 2018) and they have the ability to reproduce within a wide range of temperatures. They are able to attach to their host by the aid of the hook-like structures collectively termed the prohaptor (Zahradníčková *et al.*, 2016), while the posterior ones termed the opisthaptor. The parasite has a direct life cycle (Hutson *et al.*, 2018) making it possible to trace the source of the parasites and through application of relevant morphological and molecular techniques. Monogenean ectoparasites have been reported to have significant potential as sentinels in the assessment of environmental health (Gilbert & Avenant, 2016); Metals have been reported to have detrimental effects on monogenean infrapopulations, with aluminium being proven to have a detrimental influence on gyrodactylid survivability. Monogenean is considered as one of the important and sensitive parasites to any changes in water quality (Mbokane *et al.*, 2019).

The *Dactylogyrus* and the *Gyrodactylus* differ in their reproductive strategies (Trujillo *et al.,* 2018) and preferred sites of attachment (Hardi & Handayani, 2017). The Dactylogyrus typically attaches itself to the gills of fresh water fishes (Daghigh *et al.,* 2020) and reproduces by laying eggs (Tekmedash *et al.,* 2016). This parasite is often resistant to chemical treatment (Restiannasab *et al.,* 2016). *Gyrodactylus* on the other hand, is usually found on fins of freshwater fishes (Heglasová *et al.*, 2020). It produces live young and is hermaphroditic in nature (Huyse *et al.*, 2017). Viviparous taxa generate live progeny that can infect the same or nearby hosts directly (Hutson *et al.*, 2018). Benedeniella is a large monogenean parasite that may create long-term disease issues in marine environments and is difficult to eradicate once established. (Kumar *et al.,* 2016). Excessive parasite loads cause morbidity and mortality outbreaks in farmed fish.

Fish infested with monogeneans become lethargic, display detached scales and marbled gill swim near surface, lose appetite and can be seen on sides rubbing their bodies against the holding facility (Aly *et al.,* 2020). Heavy infestations lead to respiratory diseases (Kumar *et al.,* 2016), the gill swells and become pale. Excess mucus secretion, epithelial injury, hemorrhages (Pimentel et al., 2019), osmotic difficulties, and gill atrophy may all result from further monogenean invasions.. This increases the rate of respiration and the fish becomes less tolerant to low oxygen levels causing the fish to gulp for air at the water surface resulting in distress (Filipsson *et al.,* 2017).

Severe monogenean infestations may result in significant losses through damage or mortality (Denholm *et al.*, 2016). Monogenean damages result to secondary bacterial and fungal infections (Doan *et al.,* 2020). This infestation leaves the fish host susceptible to viral and bacterial infections due to the inflicted injuries caused by anchoring and during feeding (Lim *et al.,* 2016); on infection, the gills produce copious mucus decreasing respiratory efficiency. The irritation caused by the infestations by monogenea induces stress on fish thus causing skin ulcers or focal reddening (E Mahmoud *et al.*, 2020). This leads to excessive mucous secretion to relieve the irritating inflammatory reaction caused by continuous irritation by the monogeneans (Gado *et al.*, 2017) thus creating an opening for bacterial attack. Potassium permanganate, when used repeatedly for a week after exposure, has the best preventative effectiveness against monogenean parasites. (Aly *et al.*, 2020).

High mortality rates of farmed Nile tilapia caused by hyperplasia was reported in the northwestern Mexican Pacific coast (Grano *et al.*, 2018) caused by the presence of the monogenean *Gyrodactylus cichlidarum* attached to the filaments. An assessment of the potential risks of fish mortality, disease transmission, and the suitability of pond water for rearing fish in Kirinyaga County, Central Kenya, found an infestation of *Diplostomum spp.*, *Dactylogyrus spp.*, *Clinostomum spp*., and *Piscicola* leeches in pond cultured *Oreochromis niloticus* (Wanja *et al.*, 2020). Two monogenean species; *Gyrodactylus cichlidarum* and *Cichlidogyrus sclerosus*, typically found infesting the body surface and gills of Nile tilapia (*O. niloticus*) have caused significant financial losses in intensive tilapia farming (Grano *et al.,* 2018). The monogenean *Cichlidogyrus tilapiae* has caused acute toxicity in tilapia juveniles leading to significant mortalities and expressive financial losses to fish farmers (Meneses *et al.,* 2018). The parasitic monogenean worm *Gyrodactylus cichlidarum* induces high mortality in Nile tilapia fry, indicating a link between the infection rates and parasite loads (Zhi *et al.,* 2020). Information on parasites of monosex tilapia cultured in cages in the tropics in lacking, this study thus fills this gap by addressing the impacts of monogenean infections in cage cultured tilapia in Lake Victoria. It consequently addresses the need to source fingerlings from authenticated hatcheries to avoid parasite transfer from the hatchery to culture facilities especially in relation to parasites like the monogeneans which have direct life cycles.

2.3. Stocking Density and Seasonal variation in Prevalence of Digenean Trematodes and Monogenean Infections

Cage cultured fish are susceptible to high disease incidence because of the high fish stocking densities as compared to that in pond culture (Yarahmadi *et al.,* 2016). In order to achieve high production while maintaining sustainability, cage fish farmers stock as high number of fish per cage as possible (Debortoli *et al.,* 2016); however, fish cultivated under high densities often experience disease outbreaks. The overcrowding in cages causes stress and makes it easier for disease-causing germs to spread quickly (Mishra *et al.,* 2017). Therefore, increasing fish stocking density has a negative impact on feed utilization and deleterious effects on external wellbeing, as it leads to fin damage and formation of eye cataracts (Calabrese *et al.,* 2017).

Cage fish farming is economically viable (Aswathy & Joseph, 2019); it allows for a high stocking density and has significant positive influence on fish production. However, poor quality of feeds, poor water quality and increased stocking densities may lead to parasitic disease outbreaks (Alhassan *et al.,* 2018) in cage culture systems. Extremely high stocking densities of cage cultured tilapia reduce the sustainability and efficiency of the cage culture system (Monteiro *et al.,* 2016). Aquaculture practice is becoming more intensive, and the greater stocking densities and feed inputs that arise in closed aquaculture systems might cause water quality changes and/or degradation (Romano & Sinha, 2020).

Survival of fish, growth, health, water quality, gene expression, and productivity are all directly influenced by stocking density in the culture systems (Long *et al.,* 2019); it has a remarkable influence on the Food Conversion Ratio. Nile tilapia stocked at high stocking densities experience a decrease in dissolved oxygen (Zaki *et al.*, 2020) which in turn stresses fish, leading to decreased growth and survival thus making fish susceptible to parasitic infections. Behavior is a reaction to the environment as fish perceive it and is therefore a critical factor of fish wellbeing (Castanheira et al., 2017); High stress responders have been demonstrated to be more negatively affected by high stocking densities causing a reduction in growth after exposure to stress. Increased fish stocking densities therefore lowers growth and survival rates in fish culture (Paul *et al.,* 2016).

Increased stocking density of *Oreochromis niloticus* lowers blood total cholesterol, triglyceride, and total protein concentrations, causing growth inhibition, loss in meat quality, and changes in various serum biochemical markers, making the fish susceptible to parasites and diseases (Wu *et al.*, 2018). High stocking density of juvenile Nile tilapia, *Oreochromis niloticus* affects the albumin levels in fish serum; Tammam et al., (2020) found that fish reared at 70 m^3 had the best growth rates, feed efficiency, body composition, immune response, and overall health status, with immunoglobulin (IgM and IgG) values that were relatively higher than fish reared at 90 m^3, indicating that lower stocking densities result in better immunity response.

Fish farm production and profitability are heavily influenced by stocking density and disease management (Engle et al., 2017). In tilapia, high fish density raises plasma cortisol levels, which is typically cited as confirmation of chronic stress (Ellison *et al.,* 2018). According to Qiang *et al.,* (2016), juvenile GIFT tilapia (*Oreochromis niloticus*) cultured in high-density treatments (600 and 750 g/m^3) exhibit significantly higher post-challenge mortality; high stocking density decreases the immune capability and therefore intensifies fish susceptibility to *Streptococcus iniae* (*S. iniae*), which is a secondary bacterial infection caused by stress from parasitic infections. Increased rearing density of Nile tilapia results in a considerable reduction in growth parameters; high stocking density affects both hemoglobin (Hb) levels and red blood cell (RBC) count, resulting in greater cortisol and glucose levels (Dawood *et al.*, 2020).

Sailaja et al., (2017) reported a significant seasonal pattern in the prevalence and severity of infection, seeing greater parasite loads during the warmer summer months and extremely low or no infection during the colder winter months. Gill monogenean infestation of Tilapia zillii exhibited seasonal fluctuation where the maximum intensities of parasite infection were recorded in the rainy seasons and the minimum in the dry seasons (Etile & N'douba, 2018). Susceptibility of fish to parasite infestation varies and is dependent on a variety of factors, including morphology, immunological characteristics, and physiology, as well as the parasite's host-specificity and distribution. As a result, the intensity of the fish parasite is greatly influenced by season (Al-Azizz *et al.*, 2017).

Disease proceeds more quickly and has a larger cumulative death rate in lower latitudes, especially in the early phases of life and in shellfish (Leung & Bates, 2013). Trematodes are extremely sensitive to changes in temperature; temperature and rainfall are important factors controlling the seasonal prevalence of parasites (Koiri & Roy, 2016). Observations of parasitic infection prevalence and abundance in various culture systems, fish stocks, and sampling seasons have shown trematode parasites to be more prevalent in the spring and summer, coinciding with a period of rising temperatures and higher infection levels in larger-sized fish (Schade *et al.,* 2016). The influence of temperature on infectivity is likely to alter disease risk in many parasite-host systems as a result of climate change (Goedknegt *et al.,* 2015). For trematode parasites in general, a small increase in temperature will result in a significant increase in cercarial emergence from the first intermediate host (snails), with little to no loss in transmission efficiency, and this may also boost the local effect of trematodes (Kalinda et al., 2017).

Monogeneans reproduce all year, with two peaks in the short rainy season and in January (when hosts are more concentrated in low water levels) (Jacques *et al.*, 2020). *O. niloticus* was sampled in both the rainy and dry seasons and analyzed for monogenea; the total prevalence was 55.90%, with the rainy season having the highest prevalence, abundance, and intensity (Sinare et al., 2019). A similar study on Monogeneans in *O. niloticus* shows the highest prevalence and intensity of the infection in the long rainy season and lowest in the dry season. Prevalence of fish borne zoonotic trematodes (FZT), metacercariae stage in the wet season is significantly higher than in the dry season (Thien *et al.,* 2019). This study identifies disease management in tilapia culture as a significant factor contributing to the success of cage culture. The study focuses on the need for an optimum stocking density to control disease spread within culture facilities and also describes the effects of seasonal variation on parasite spread to create a better understanding on prevention and control of digenean and monogenean outbreaks in cage culture.

2.4. Impact of Digenean Trematodes and Monogenean Infections on Fish

In Brazil, Monogenea is one of the most common fish parasites; the size of the host, however, has little bearing on the quantity of monogeneans. (Ferreira & Tavares, 2016). Female *Oreochromis niloticus* are somewhat more infected by parasitic infections as compared to their male counterparts (Mgbemena *et al.*, 2020); in terms of size, fishes of higher lengths and weight for both *Clarias gariepinus* and *Tilapia zillii* were more prevalent to parasitic infection (higher % infection) than their counterparts with lower lengths and weights. Monogenean parasites were the most common fish hosts in Eastern Brazil, however the parasites showed an aggregated dispersion pattern (Oliveira *et al.*, 2017).

Several studies have found that parasite richness increases with host age, and that parasite aggregation is regulated by age and/or size-related recruitment (Adeogun *et al.,* 2013), and have indicated that the Ectoparasite infection was more common in smaller fish than in larger ones (Kamislin, 2017). Tilapia zillii shows a significant difference in relation to host size-related *Cichlidogyrus* parasite incidence (Etile & N'douba, 2018) whereby there's an increase in parasite prevalence with increase in size. Similarly, there is a positive relationship between host size, prevalence, and mean intensity of infection with monogenean Paramazocreas thrissocles, with larger fish carrying heavier infections (Sailaja et al., 2017) than small-sized fish.

The condition factor (k) is a vital parameter used to express the well-being of the fish in their habitat and is determined using Fulton's condition factor, expressed by the length-weight factor (Githukia *et al.*, 2015); the value of k estimates the change in nutritional condition of examined fish. The length and weight of O. *niloticus* have a significant positive correlation (r>0.8), and the condition factor (K) of infected and uninfected fishes shows that the K factor of uninfected *O. niloticus* is greater than that of infected *O. niloticus* (Abdulhamid *et al.*, 2018). Parasite feeding activities may have adverse effects on the health status of hosts, however at extremely low prevalence; they lack a significant effect on the condition factor of the fish (Amuzie & Okwodu, 2019). Confinement causes stress in fish, which can result in tissue damage and reduced productivity, Steckert et al., (2018) found no production loss and no effects of tissue alterations on the relative condition factor (Kn) in farmed tilapia in their histopathological investigation, suggesting excellent health.

Parasitic infections are perceived as harmful to the hosts; however, their effects are dependent on a variety of conditions, including the host's bodily state, parasite load, and life cycle (Maceda *et al.*, 2016). Parasites can change the physiology, appearance, reproduction, and behavior of their hosts (Timi & Poulin, 2020). Parasites need their hosts for development and replication (Rynkiewicz *et al.*, 2015), which has a detrimental impact on hosts by depleting host resources and causing direct tissue damage. Individual health changes caused by infection (raising expensive immune responses, or altering host mobility, foraging, or social behavior) might have an impact on fitness and population sustainability (Sánchez *et al.*, 2018). This study therefore describes the effect of parasitic outbreaks in cage culture on the health of the host fish. This information is useful to understanding the control of spread of these parasites through breaking the parasite cycle thus improving the health of fish.

2.5. Impact of Water Quality on Digenean Trematode and Monogenean Infection

Parasites modify several features of their hosts; particularly, manipulative parasites produce phenotypic abnormalities in their intermediate hosts in order to boost their chance of transmission (Labaude *et al.,* 2020). Temperature fluctuations have been proven in several studies to have a major impact on parasite population dynamics (Gehman *et al.,* 2018); although host–parasite systems have tightly connected life cycles, each interactor can respond to changes in environmental variables in various ways. Many fish infections are considered to have emerged as a result of climate change, notably increased temperatures (Strepparava *et al.,* 2018); Increased temperature alters parasite transmission chances by lengthening the parasite transmission stage, altering parasite distribution and establishment in a wider variety of rivers. Biological processes of aquatic invertebrates such as the Monogenea may be influenced by a variety of environmental factors (Marchiori *et al.,* 2015); the addition of 9 g/L sodium chloride concentration in the water reduces the survival of the monogenea parasite and the viability of the eggs, making it an effective preventive therapy. Parasite assemblages vary with the water quality parameters (Ojwala *et al.,* 2018).

Water quality has a significant influence on the biology and physiology of fish, and hence on the health and productivity of a fish culture system (Abaho et al., 2020); as seen in cases where there is low DO levels within experimental cages that might be related to high stocking densities within these systems. Monogenean prevalence in Egyptian tilapia hatcheries was high during the period of April to September 2017; water temperature had a significant influence on monogenean parasitism. A moderate increase in temperature is likely to amplify parasites' impact on aquatic ecosystems; thus, as temperatures rise, poikilothermic animals (such as fish) increase their activity, potentially increasing parasite encounters and infection risk (Gopko *et al.*, 2020). Warmer water temperatures have an impact on the intensity and form of biotic interactions, such as parasitism; this is also linked to environmental and biotic circumstances that promote parasite prevalence in fish (Schaaf *et al.*, 2017).

The impact of fish diseases may differ in each culture system (Woo & Gregory, 2014). Cage culture is the most effective method of rearing fish as it entails growing fish in existing water bodies while being contained in a net cage that enables free exchange of water and other materials (Ignatius, 2016). Site selection is critical to the performance and sustainability of any aquaculture enterprise; offshore sites give greater space area and typically higher water quality, both of which are required to improve the production of healthy fish (Chu *et al.*, 2020). Huge amounts of silt deposited in cage sites from stormwater may clog cage nets, resulting in low dissolved oxygen and degradation of water quality within cages, thus leading to disease outbreaks and associated problems (Chitmanat *et al.*, 2016).

Cage fish farming is still being applauded for its important role in achieving sustainable development by creating jobs, increasing wages, and providing food security for fishing communities. (Anjejo, 2019). Fish cage culture allows for intensive production in water bodies without conventional preparation for aquaculture (Wu *et al.*, 2019); Cages set in regions that are located in deep, well-flushed waterways have the most desired water quality. Monosex culture of tilapia, *Oreochromis niloticus* on semi-intensive fish farming system is increasing (Cai *et al.*, 2017), however, farmers face challenges such as; high prices of fish feed, low fry survival, fish health issues and challenges in fish processing and marketing. Nile tilapia is cultured in ponds and cages for Kenyan consumers, and therefore, any tilapine parasites or diseases deprive them of the valuable source of protein (Wanja *et al.*, 2020). Water quality plays a significant role in monogenea and digenean growth, reproduction and transmission, this study thus attempts to show the effects of different water physico- chemical variables on digenean and monogenean parasite prevalence and intensity.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

The study took part in Uhanya Beach, Yimbo in Siaya County from December 2017 to May 2018. Siaya County is located at south west Kenya and is adjoined to Kakamega and Vihiga Counties to the northeastern part and Kisumu to the southeast (Odindo *et al.,* 2014). Uhanya beach is located in Usenge sub-location, Bondo Sub-County, Siaya County in West Yimbo location with a total population of 21,931 (SCSP, 2019). The county lies at latitude 0° 26' to 0° 18' N and longitude 33° 58' E and 34° 33' W (GOK, 2015; Abura *et al.,* 2017). Siaya County has a bimodal rainfall season between March to May (long rains) and September to December (short rains) with precipitation peaks occurring in April and November respectively (Ochieng, 2018). There is an overall 3,696 fish cages on the Kenyan side of Lake Victoria, used for the culture of *O. niloticus*, of which its bulk (n=3141; 85%) is located in Siaya County (Aura *et al.,* 2018).

3.1.1. Study Sites

The Uhanya Fish Cage Enterprise in Uhanya beach, Usigu ward was selected based on the number of cages (300), close proximity to the road infrastructure and financial considerations. A total of 10 fish cages measuring 6 Meters squared were systematically selected to form the sample cages. Five of these cages were stocked at a density of 2,000 monosex *Oreochromis niloticus* fingerlings whereas the additional 5 had 2,500 fish provided by the fish cage management and reared for eight months. The cage farm lies between latitude of 0° 5.40' to 0° 5.70' south and on longitude 34° 4.62' to 34° 4.86' east (Figure 1).

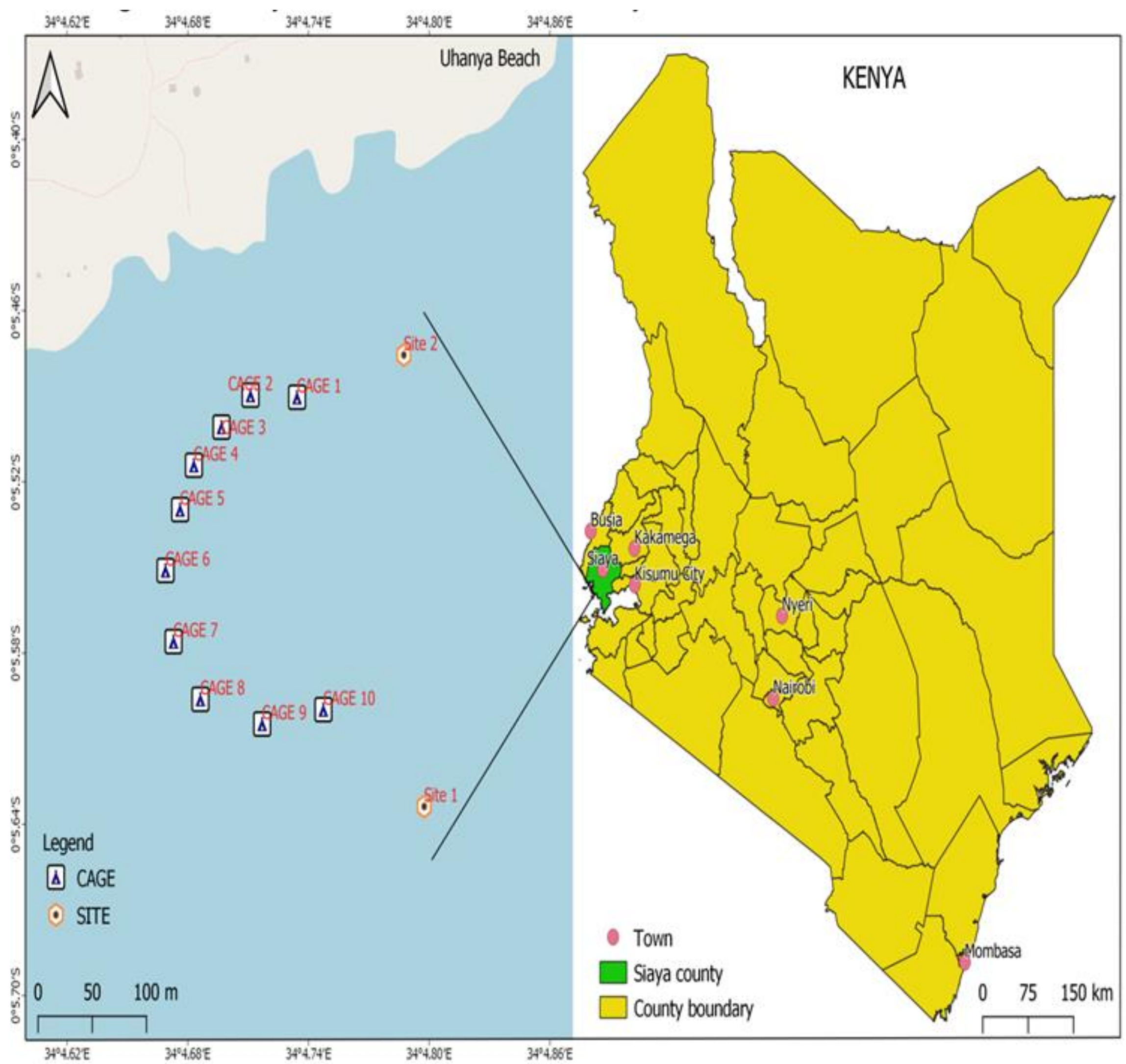

Figure 1: Position of cages at the study site in Uhanya Beach, Siaya County (Source: Author, 2021)

3.1.2. Study Design

A reconnaissance study of the cage site was conducted. With the help of the farm manager, identification of the operational cages, cage sizes, fish stocking densities and distances between the cages was established. The study focused on cages stocked with 2500 and 2000 monosex *O. niloticus*. Sampling was conducted during the wet (March 2018 to May,

2018) and dry seasons (December 2017 to May 2018), to determine the correlation of number of fish per cage and seasonality on parasite prevalence and its effect on fish condition factor. The GPS coordinates of the farm was recorded and cages systematically selected to form sample cages for this study using a systematic random sampling technique.

3.1.3. Sampling Design

Systematic random sampling technique was utilized in this assignment. The initial cage sampled was 300 metres off shore of the lake and the subsequent cages were selected after every 50 meters from the previous cage and at least 4 metres above the lake bottom. From a total of 246 fish cages, 124 cages measured 2 x 2 x 3 metres of which 64 had a stocking density of 2,500 and the remaining 60 had a stocking density of 2,000 monosex *O. niloticus.* Out of these, 10 cages were sampled. Five of these cages were stocked at a density of 2,000 monosex *O. niloticus* fingerlings whereas the other 5 were stocked at a density of 2,500 fish and reared for eight months. To achieve randomization, a scoop net was used to randomly pick 30 fish from each study cage, stocked at a density of 167fish/m3 and 208fish/m3 respectively. The fish were carried in buckets and labelled according to name, location and stocking density of cage then taken to a field laboratory for parasite isolation, observation and analysis. A total of 600 fish were collected from 10 cages, 300 fish collected during the dry (December 2017 to February, 2018) and 300 fish collected during the rainy season (March 2018 to May 2018) aimed at establishing the influence of seasonality on digenean trematode and monogenean parasitism.

3.1.4. Isolation and Identification of Parasites from Fish Samples

The fish samples were examined for both the internal and external parasites through observation and microscopy. Fish were killed humanely by dislocating the cervical vertebrae as defined by Matvienko *et al.,* (2015) preceding parasitological examinations. Gross inspection of the skin, fin and gills was done using a magnifying lens of a magnification of ×10 to determine the presence of fish ectoparasites. A cover slip was used to make skin and gill scrapings and thereafter a wet mount prepared on a microscope slide and observed under a dissecting microscope at a magnification of ×100. For the endoparasites, the samples were dissected and the eyes, kidney, intestine, swim bladder and body cavity were inspected. Parasites isolated were categorized as either monogeneans or digenean trematodes. Monogenean and digenean parasites were recognized based by observing the morphological features and with the help of standard identification keys and illustrative picture guides (Pouder *et al.*, 2011; Scholz & Choudhury, 2014). Parasite counts were recorded. The effect of monogenean and digenean trematodes on the healthiness of the fish host was scrutinized through Fulton's condition factor (k-factor).

3.1.5. Determination of Parasitic Indices

The following parasitic indices were determined the mean intensity, prevalence and abundance in accordance to recommendations by Bush *et al.* (1997) and calculated as follows;

Parasite abundance = the quantity of parasite entities of a particular parasite in a single host

$$Prevalence\ (\%) = \frac{Number\ \ of\ fish\ infested\ \ \times 100}{Total\ Number\ of\ fish\ examined}$$

$$Mean\ intensity = \frac{Total\ Number\ of\ individual\ of\ a\ parasite\ species}{Total\ Number\ of\ infested\ host}$$

3.1.6. Determination of Fish Condition Factor

The collected fish samples were weighed using the scientific weighing balance (Mettler Toledo PL-E Portable Balance) and the length measured using the standard metre rule. The length and weight of each sample was then recorded. Total lengths of the specimen were taken from tip of mouth extending towards the caudal fin using a measuring metre rule calibrated in centimeters. Length and weight relationship was calculated using Le Cren (1951) equation: $w = aL^b$. The data were transformed into logarithms to determine the growth pattern thus: Log W = Log a x b Log L, where W = body weight of fish (g), L = standard length of fish (cm), a = constant, b = exponent (Odedeyi *et al.*, 2007). The condition of the fish was expressed by Fulton's condition factor (K), calculated by the formula: K = 100W/ L3. Where K is the condition factor, W is the weight of the fish in grams (g), L is the total length of fish in centimeters (cm). A b value of higher than 1.0 proposes fish is in good health condition and indicates an isometric growth, which is desirable in fish farming (Anani & Nunoo, 2016).

3.1.7. Water Quality Variables

Physico-chemical variables of water were taken *in situ* during the course of the sampling period using a YSI multi-probe water quality meter (556 MPS, Yellow Springs

Instruments, Ohio, USA) at each cage and the two off-cage sites. These parameters included concentrations of; dissolved oxygen concentration (DO), pH, Total Dissolved Solids (TDS), salinity and temperature. These physico-chemical variables were measured at depths of 1, 2 and 3 metres levels below the surface.

3.2. Data Analysis

Data sets were first scrutinized aimed at testing for parametry (normality) and outliers were excluded from the datasets before being subjected to univariate statistics both descriptive and inferential using SPSS (version 16) and advanced tools of MS Office Excel (2016).

Mann-Whitney U-test tested for significant differences in water quality parameters between the two stocking densities (167fish/m^3 and 208fish/m^3) monosex *O. niloticus* respectively, during both the dry and wet seasons.

Kruskall-Wallis test was then used to examine the relationship between water quality parameters such as; dissolved oxygen, water temperature and Total dissolved solids) and mean intensity of parasitic attack (*Dactylogyrus sp*., *Clinostomum sp*., *Tylodelphys sp*. and *Neascus sp*.).

CHAPTER FOUR

RESULTS

4.1 Monogenean and Digenean Parasite species infecting *Oreochromis niloticus* reared in cages in Uhanya Beach, Lake Victoria, Siaya County

The monogenean parasites identified were of the genus *Dactylogyrus* while the digeneans were of the genera *Tylodelphys*, *Clinostomum* and *Neascus*. The *Dactylogyrus sp.* parasite was found attached on gill filaments. They were identified by the presence of eye spots and a series of hooks on the anterior end. *Tylodelphys sp.* was in the eye vitreous fluid. The *Clinostomum sp.* (Plate 1) had encysted in the buccal cavity of the fish. *Neascus sp.* (Plate 2) larvae were encysted on the skin where they formed black spots as a result of pigment mobilization on the skin of *O. niloticus*.

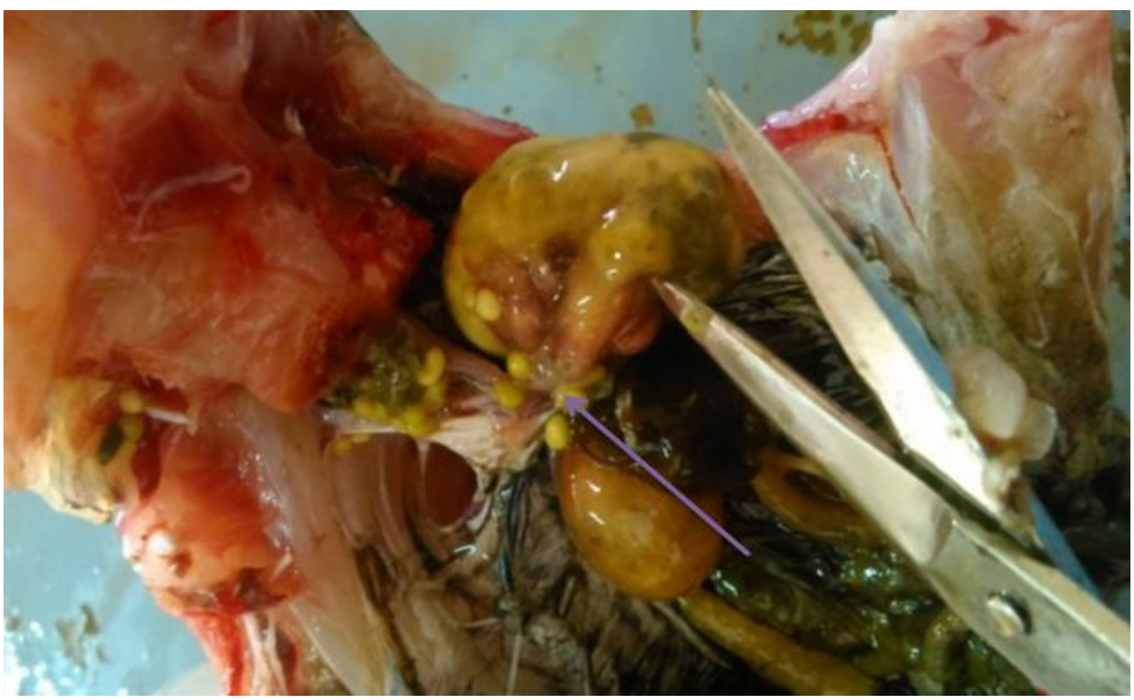

Plate 1: Metacercariae of *Clinostomum sp.* (a) encysted in the buccal cavity of cage cultured monosex *O. niloticus* in Uhanya Beach, Lake Victoria, Siaya County (Source: Author, 2018)

Plate 2: Metacercariae of *Neascus sp.* encysted on the skin of cage cultured monosex *Oreochromis niloticus* in Uhanya Beach, Lake Victoria, Siaya County (Source: Author, 2018)

4.2. Mean Intensity and Prevalence of infestation of digenean trematodes and monogeans in *Oreochromis niloticus* at different stocking densities

Mann-Whitney U-test revealed that mean intensity of *Dactylogyrus sp.* infestation significantly increased with increased fish stocking density (U = -1.94: $p < 0.05$; df = 298). On the contrary, *Clinostomum sp.*, *Tylodelphys sp. and Neascus sp*. exhibited significantly reduced infestation with increased stocking densities (U = 5.18; df = 298; $p < 0.0001$; U = 1.83: $p < 0.05$; df = 298 and U = 5.10: $p < 0.0001$; df = 298 respectively) (Fig.2). The Kruskall-Wallis H test indicated significant variation in prevalence of attack between the parasite species both in wet season (H = 17.793; df 3; $p < 0.0001$) and dry season (H = 30.226; df 3; $p < 0.0001$) (Fig.3)

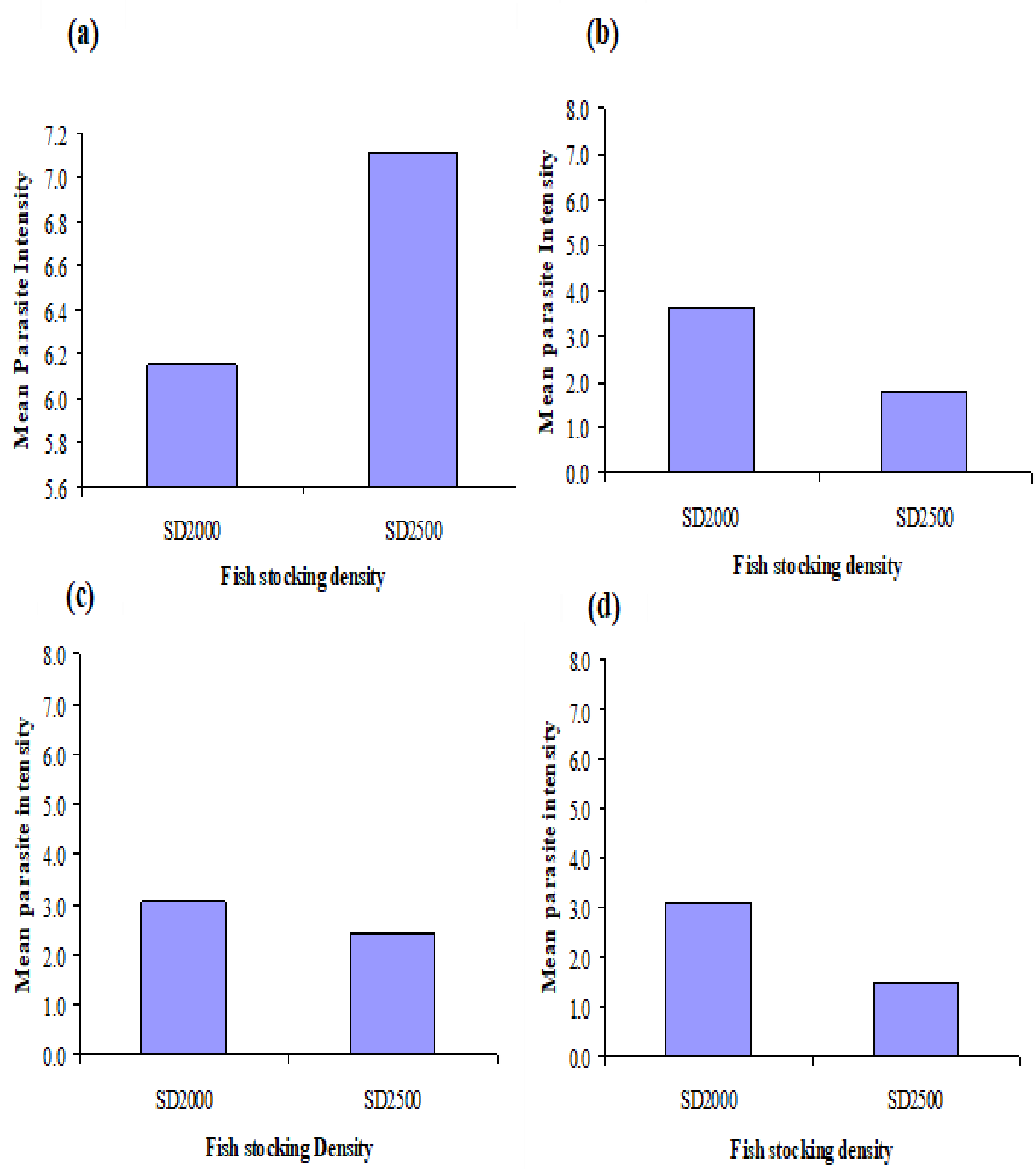

Figure 2: Mean (± SE) intensity infestation by fish parasite: (a) *Dactylogyrus sp.;* (b) *Clinostomum sp.;* (c) *Tylodelphys sp.;* and (d) *Neascus sp*. across different stocking densities in fish cages inUhanya Beach of Lake Victoria

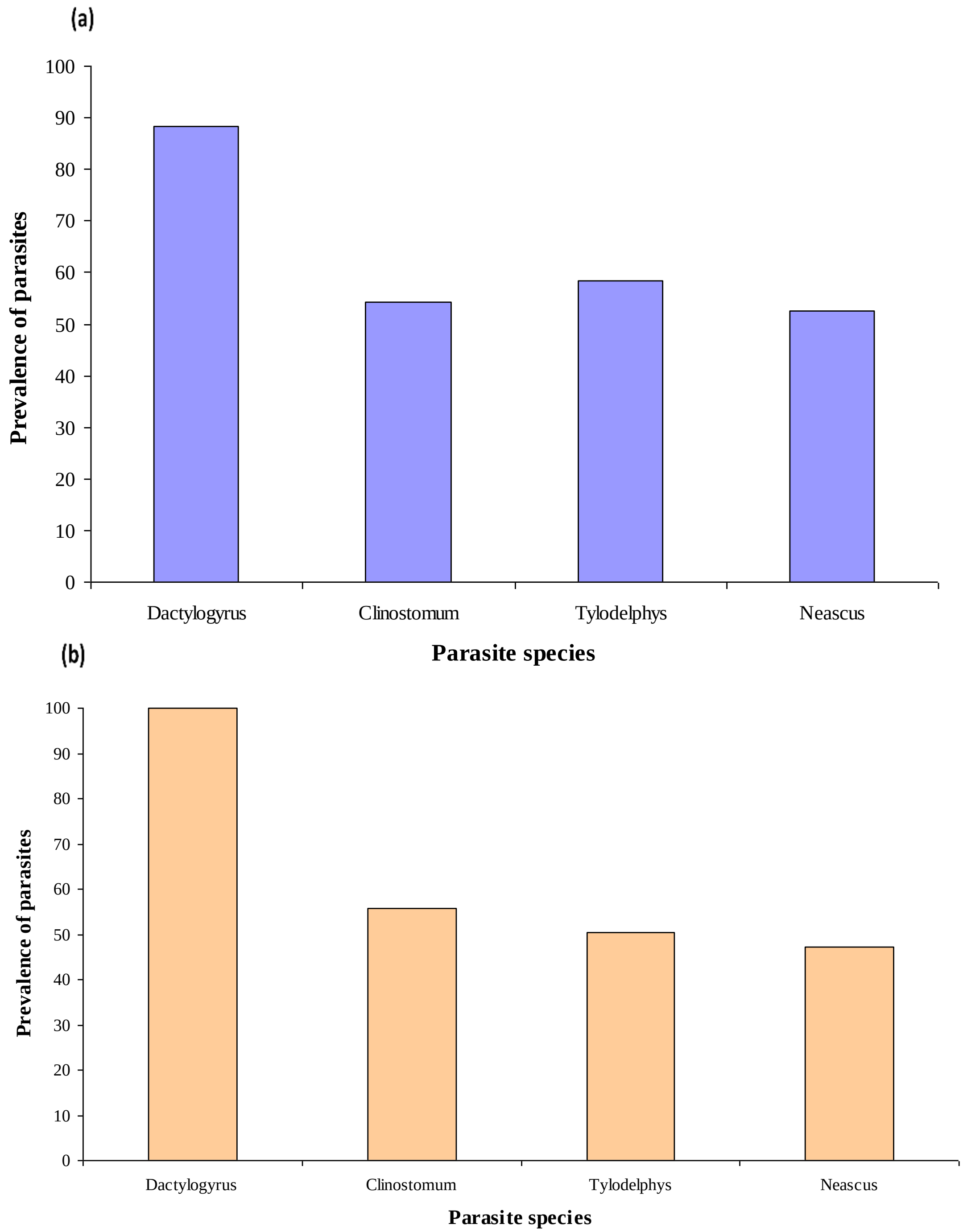

Figure 3: Prevalence of parasite (*Dactylogyrus sp.*, *Clinostomum sp.*, *Tylodelphys sp*. and *Neascus sp*.) infestation on Cage cultured *O. niloticus* in Uhanya Beach of L. Victoria in wet (a) and dry (b) seasons

4.3. Relationship between stocking density and prevalence of digenean trematode and monogenean infections on *Oreochromis niloticus* reared in cages in Uhanya Beach, Lake Victoria, Siaya County

Dactylogyrus sp. was predominantly abundant in the fish from all the 10 cages, the intensity of infestation by this monogenean escalated with increased stocking density. On the contrary, the mean intensity of *Clinostomum* sp., *Tylodelphys sp*. and *Neascus sp.* reduced with increased stocking densities. In both stocking densities (2000 and 2500 fish/cage) and during both dry and wet season, Dactylogyrus *sp.* exhibited the highest prevalence of attack (Figure 4).

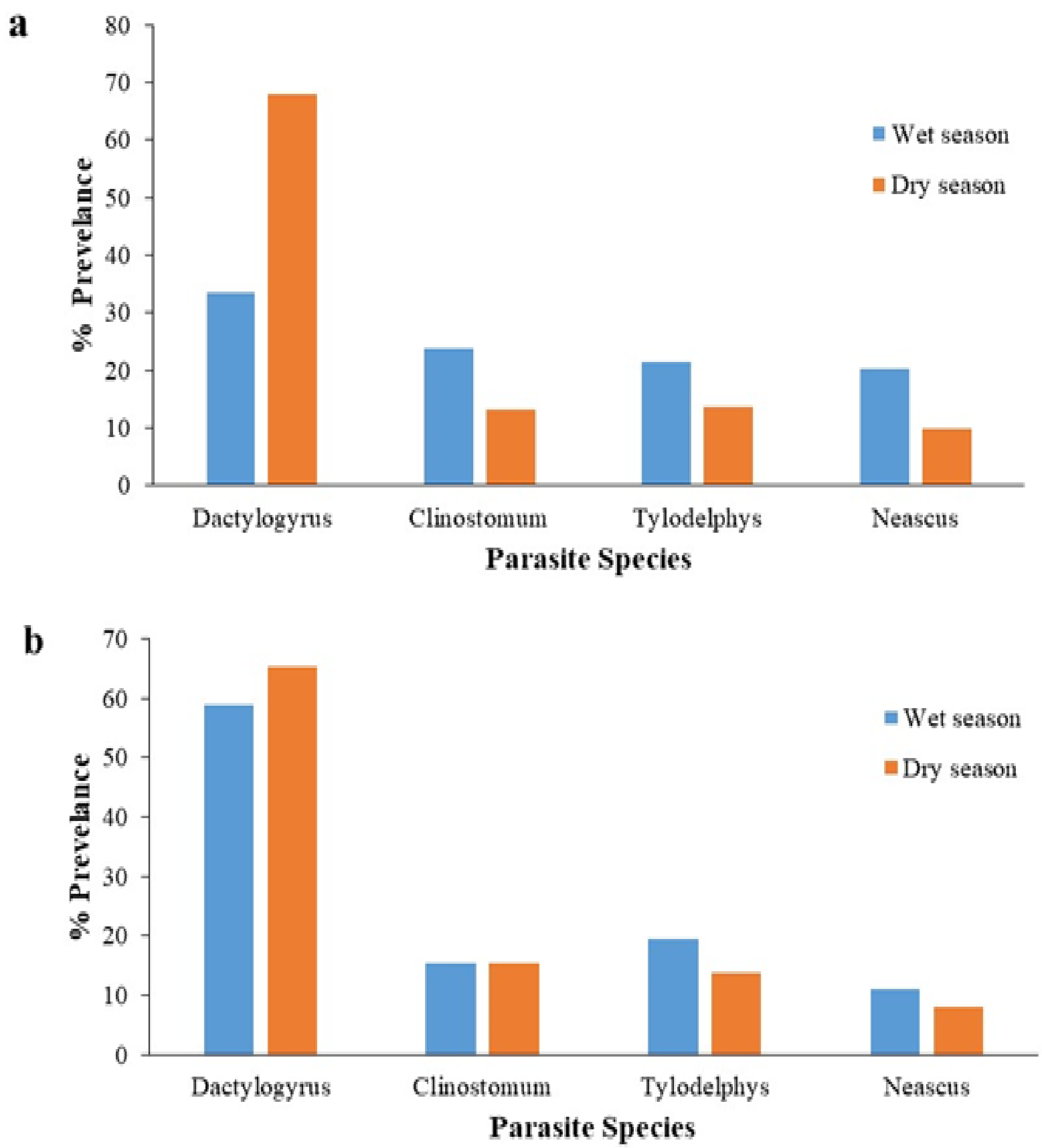

Figure 4: Prevalence of *Dactylogyrus sp.*, *Clinostomum sp.*, *Tylodelphys sp.* and *Neascus sp.* parasites in *O. niloticus* reared in cages at stocking density of 2000 fish/cage (a) and 2500 fish/cage (b) during the Wet and Dry seasons in Uhanya Beach of L. Victoria, Siaya County

To determine whether differences exist among the means groups multiple comparison (Table 1) was used. It shows the parasite composition by prevalence from the 10 cages at different stocking densities during the wet and dry seasons.

Table 1: Post hoc Multiple Comparison (Bonfenori) of mean intensity between parasites groups (1. *Dactylogyrus sp.*, *2.Clinostomum sp.*, *3.Tylodelphys sp.*, *4.Neascus sp.)*

					95% Confidence Interval	
Parasites (I)	**Parasites (J)**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**Lower Bound**	**Upper Bound**
1	2	42.647	1.028	0.000**	39.93	45.364
	3	43.284	1.028	0.000**	40.567	46.001
	4	46.818	1.028	0.000**	44.101	49.535
2	1	-42.647	1.028	0.000**	-45.364	-39.93
	3	0.637	1.028	1.000^{ns}	-2.08	3.354
	4	4.171	1.028	0.000**	1.454	6.888
3	1	-43.284	1.028	0.000**	-46.001	-40.567
	2	-0.637	1.028	1.000^{ns}	-3.354	2.08
	4	3.534	1.028	0.004*	0.817	6.251
4	1	-46.818	1.028	0.000**	-49.535	-44.101
	2	-4.171	1.028	0.000**	-6.888	-1.454
	3	-3.534	1.028	0.004*	-6.251	-0.817

4.4. Seasonal variations in physico-chemical parameters of water and mean parasite intensity in *O. niloticus* reared in cages in Uhanya Beach in Lake Victoria, Siaya County

All the water quality variables other than pH recorded greater values during the dry than the wet season. In the course of dry season advanced temperature levels were recorded in cages with 2500 stocking density while dissolved oxygen, salinity and pH recorded higher levels in cages with 200 stocking density. Higher levels of TDS were recorded in cages with fish stocking density of 2500 during both seasons (Table 2).

Table 2: Water quality parameters ranges during both seasons in cages at Uhanya Beach in Lake Victoria, Siaya County

Stocking density	Season	Temperature (^{0}C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH	TDS (mg/L)
2000	WET	24.17-26.30	5.31-6.29	0.12-0.19	7.09-7.12	24.87-34.80
	DRY	25.23-26.30	5.36-5.82	0.12-0.19	7.05-7.10	24.77-35.26
2500	WET	23.73-24.87	5.15-5.92	0.12-0.16	7.02-7.22	27.99-34.57
	DRY	25.63-26.53	5.24-6.07	0.11-0.19	7.02-7.10	29.46-34.94

During the wet season, temperature was significantly high in cages with low stocking densities (SD (p <0.01). Total Dissolved Solids (TDS) presented a general negative correlation with mean parasite intensity in all species except in *Clinostomum sp*. a positive trend (Figure 5). Dissolved oxygen (DO) significantly differed between the seasons in the similar cages ($p < 0.05$). In 2500SD, Temperature significantly differed between the seasons ($p < 0.0001$) (Figure 5). DO was significantly higher during wet season in cages with low SD (p <0.01). The difference was not observed during dry season in the same stocking densities ($p > 0.05$).

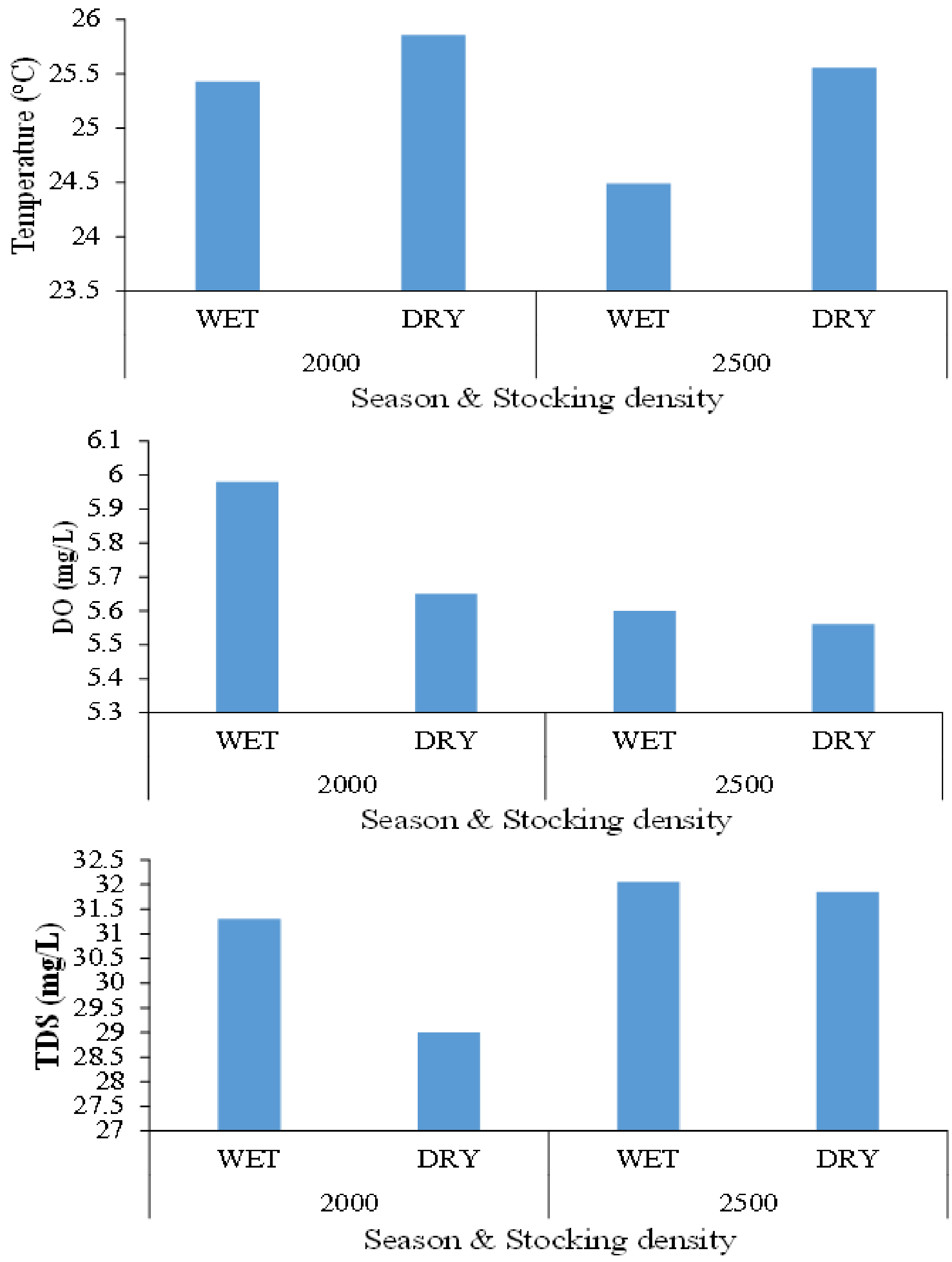

Figure 5: Variation of Temperature, Dissolved Oxygen (DO) and Total Dissolved Solids (TDS) between different stocking densities during the Wet and Dry seasons in cages at Uhanya Beach of Lake Victoria, Siaya County

Even though there was a general positive correlation between water temperatures and mean parasite intensity, this relationship was not significant in all the parasite species ($r^2 < 0.5$). Apart from *Dactylogyrus sp.* which showed negative correlation with Dissolved Oxygen (DO), all other parasite species showed a general positive correlation between dissolved oxygen and mean parasite intensity (Figure 6 & 7). These relationships were however not significant in all the parasite species ($r^2 < 0.5$). Total Dissolved Solids (TDS) on the other side showed a general negative correlation with mean parasite intensity in all species except in *Clinostomum sp*. a positive trend. Again, these relationships were just by magnitude but were not significant ($r^2 < 0.5$) (Figure 6 & 7).

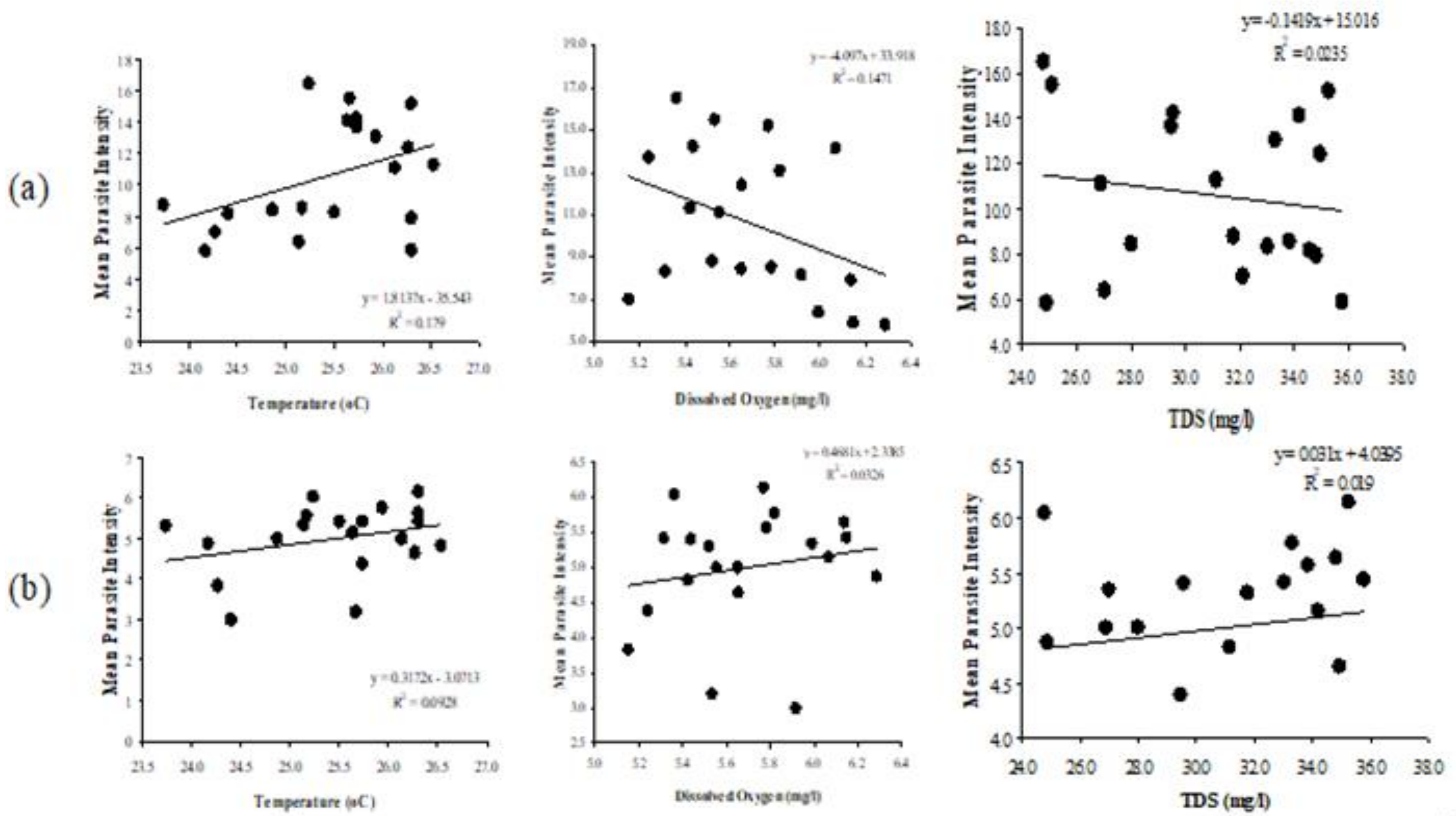

Figure 6: Effects of water quality parameters on mean intensity of parasitic by: (a) *Dactylogyrus sp*., (b) *Clinostomum sp*., in cage cultured *O. niloticus* in Uhanya Beach of L. Victoria

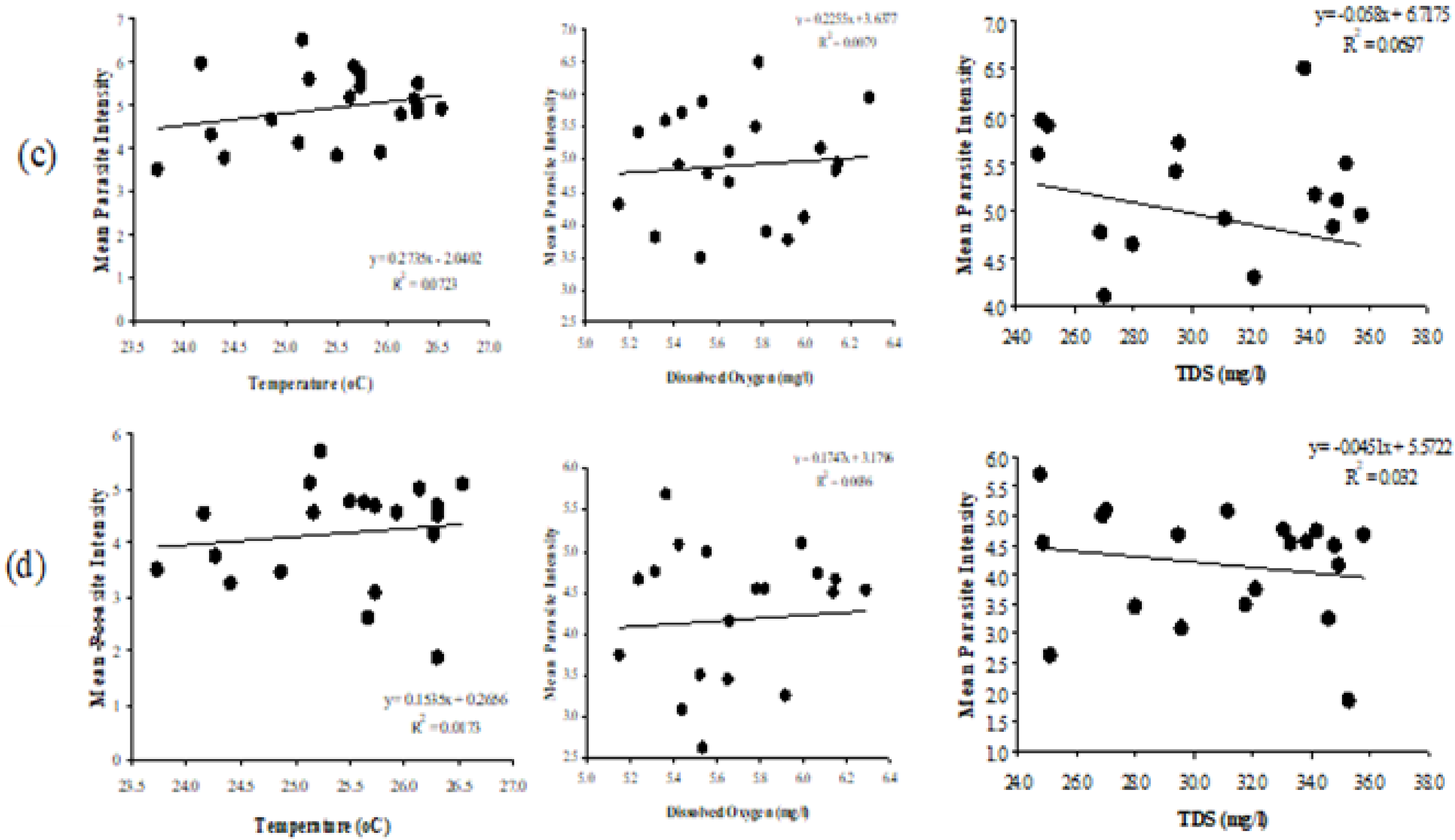

Figure 7: Effects of water quality parameters on mean intensity of parasitic by: (a) *Dactylogyrus sp.*, (b) *Clinostomum sp.*, (c) *Tylodelphys sp.* and (d) *Neascus sp.* in cage cultured *O. niloticus* in Uhanya Beach of L. Victoria

4.5. Effect of Digenean and Monogenean parasites on fish condition factor

The general fish condition as depicted by the mean condition factor (*Kn*) was significantly higher in cages of stocking densities of 2500 individuals/ Cage (U = 2.005; df = 298; p < 0.05) (Figure. 8).

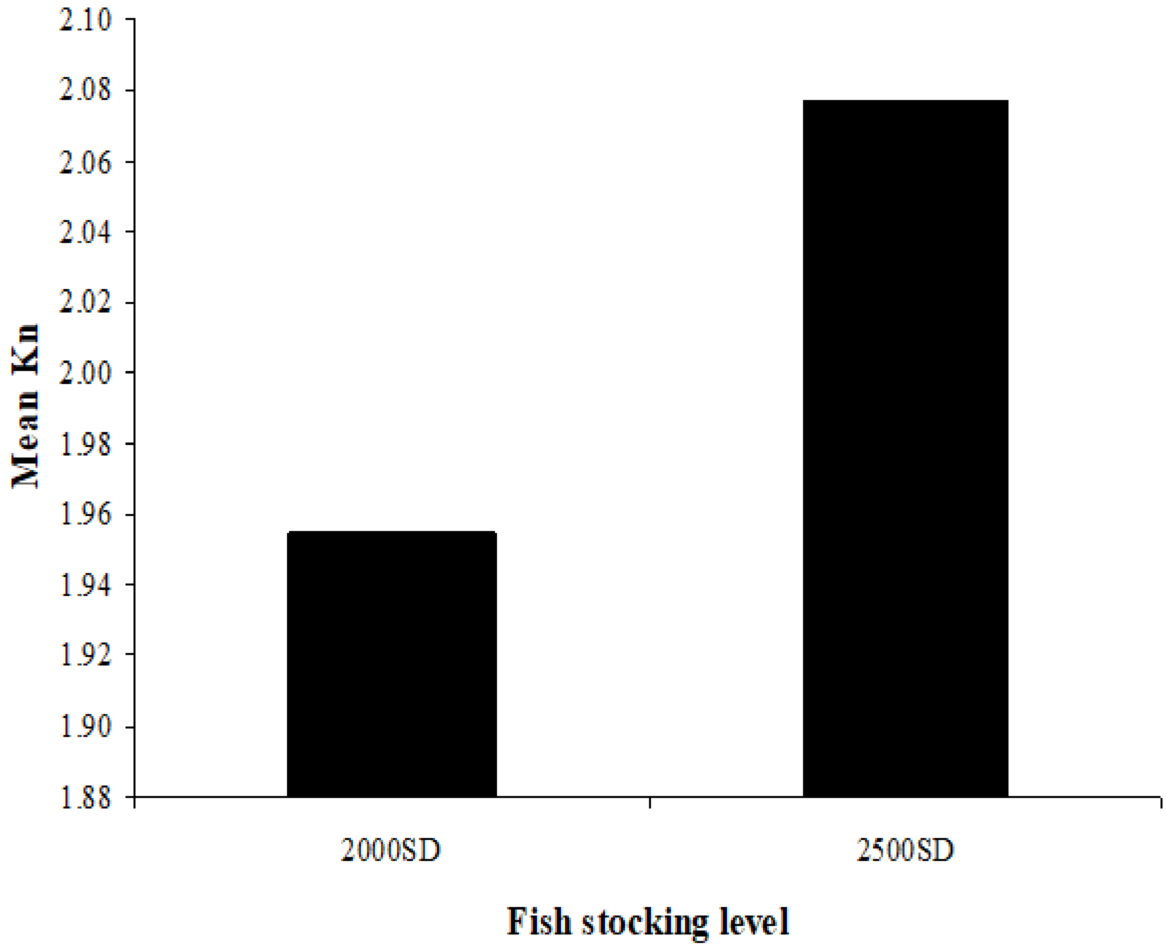

Figure 8: Mean fish health condition factor (*Kn*) across stocking densities in cage cultured *O.* niloticus in Uhanya Beach of L. Victoria

CHAPTER FIVE

DISCUSSION

5.1 Digenean Trematode and Monogenean Infections in Cage Cultured Nile Tilapia

Dactylogyrus sp. was predominantly abundant in the fish from all the 10 cages during both seasons. This corresponds with the study by Otachi *et al.,* (2014) in which the monogenean parasite *Cichlidogyrus sp.* was isolated as the dominant taxa invading 2 cichlid fishes in Lake Naivasha, Rift Valley, Kenya. Modi & Prasanna (2018) also reported *Dactylogyrus fotedari* as the most prevalent monogenean infesting gill arches of freshwater fish in India. The increased intensity of infestation with the monogenea *Dactylogyrus* at higher stocking densities witnessed in this study is in an agreement with the study by Garcia *et al.*, (2013) where it was established that applying low initial stocking densities of fish lowered the possibility of infection occurrence and therefore no drug use was required for disease control; in this mentioned study, fish deaths, disease occurrences and malformation substantially reduced with decreased stocking density. In the same study, level of dissolved oxygen within cages increased with decreased stocking density.

The prevalence of the trematode *Tylodelphys sp*. was higher during the dry season as compared to the other trematode species isolated. Trematodes are extremely sensitive to changes in temperature (Koiri & Roy, 2016), these parasites are significantly present from December through March in the tropics coinciding with a period of increasing temperature (Schade *et al.,* 2016). Monogeneans breed all through the year with 2 peaks during short rains (Jacques *et al.*, 2020). The maximum cyclical incidence, richness and numbers stood out during the rainy period (Sinare et al., 2019). Temperature acts as a major extrinsic aspect inducing metacercarial excystation for digeneans (Ayoub *et al.*, 2020). Infection by metacercariae is passive taking place simply when the target swallows the parasite, highest at low temperatures (Zimmermann *et al.,* 2017).

This study reports a case of a co-infection by both monogenea (*Dactylogyrus sp.*) and digeneans (*Clinostomum sp.* (c) *Tylodelphys sp.* and *Neascus sp*.). This is a situation where a single fish is infected by more than one parasite group. This was observed in all cages and at both stocking densities. Abdel *et al.,* (2020) also described co-infections commonly arising when two or multiple different pathogens infect the same host leading to parasitic outbreaks amongst other negative impacts. On the contrary, the reduced mean intensity of digenean trematode parasites (*Clinostomum* sp., *Tylodelphys sp*. and *Neascus sp.*) with higher stocking densities may be attributed to the dilution effect caused by rise in contact area as a result of escalated host density. In cage reared tilapia in Bangladesh, the *Tylodelphys sp.* identified could not compare to the mean intensity and prevalence of the gill monogenean *Gyrodactylus* (Doulah *et al.,* 2019) which conforms to the findings of this study. This can be explained by reduction in encounter as has been recorded in trematodes (Keesing *et al.,* 2006). These astonishing outcomes may possibly be due to elevated densities and restricted movement of these parasites. It could also result from low probability of effectively infecting a host. Eye parasites are notorious for causing detrimental effects to fish as they induce cataract or cause partial loss of sight and a number of behaviour alterations to the intermediary host (Flink *et al.,* 2017). Certain fish species can absorb parasite transmittable phases irrespective of they themselves get infected thus decreasing encounters between the competent hosts and parasites (Civitello *et al.,* 2013).

5.2 Mean Intensity and Prevalence of Digenean Trematode and Monogenean Infections at different Stocking Density in different Seasons

Mean intensity of *Dactylogyrus sp*. infestation significantly increased with increased fish stocking density. This can be attributed to the spread of monogeneans from one fish to the other transpiring primarily via direct contact, where increased stocking density increases the contact between one fish and the other (Elsheikha & Patterson, 2013). Therefore, in this regards, extremely high stocking densities of cage cultured tilapia reduce the sustainability and efficiency of the cage culture system (Monteiro *et al.*, 2016) in the long run. Andree *et al.*, (2013) demonstrates that when fish is exposed to stressors for instance variations in water temperature, low dissolved oxygen concentrations and overcrowding there is significant escalation in the pathogenicity of invading pathogens.

This study agrees with that of Zaki *et al.,* (2020) where it was observed that Nile tilapia stocked at high stocking densities experienced a decrease in dissolved oxygen which in turn stresses fish, leading to decreased growth and survival thus making fish susceptible to parasitic infections. This study identified fish suffering from partial and total blindness and tissue injuries in both stocking densities. This concurs with findings by Calabrese *et al.,* (2017) where increasing fish stocking density negatively affected feed utilization (FCR) and the external welfare of fish leading to fin damage and formation of eye cataracts (Calabrese *et al.,* 2017).

This study also contrasts with findings by Costa *et al.,* (2017) which showed that an increase in stocking density caused a decrease in the final weight of fish, standard length and survival; findings of this study instead show better condition factor in fish stocked at high stocking densities. According to Abaho *et al.,* (2020), the mean relative condition factor of fish ranged from 1.02 to 1.06, but was not significantly different ($p > 0.05$) among the stocking densities. Therefore, their study suggested a stocking density of 200 fish/m^3 of a cage as the best stocking density in terms of fish growth parameters. Pinho *et al.,* (2016) and Zahedi *et al.,* (2019) found no significant alterations in all tested plasma biochemical factors among fish under different stocking densities.

This study compares to that of Khrukhayan *et al.,* (2016) who assessed monogenean gill parasites in caged sea bass in Thailand. The dominance of gill parasites was elevated in all farms at all seasons with an increases infection rate all through the arid season; however, comparable to this study, water quality parameters displayed no major variances ($p > 0.05$). Dissolved oxygen (DO) significantly differed between the seasons in the similar cages ($U = 2.428$; $df = 28$; $p < 0.05$). This agrees with Mwamburi *et al.,* (2020) where greater external dissolved oxygen concentrations were detected in both periods, likened to the deep waters, pH also demonstrated spatial fluctuations, but lacked any weighty mean ($p < .05$) temporal differences.

Schaaf *et al.,* (2017) describes trematodes as a kind of freshwater parasites that flourish in warm water temperatures. In this study conducted in the tropical region, found monogeneans were found to be prevalent during wet and arid seasons as compared to digeneans, which is a contradiction from the study by Prakash & Verma, (2020) where the monogeans parasites were not found during monsoon season. In their study, all groups of ectoparasites showed the highest prevalence in winter followed by summer. Increased water temperature during summer is intensely linked with great digenean infections (Dumbo *et al.,* 2020). According to Etile & N'douba (2018), *Cichlidogyrus digitatus* had the highest prevalence (100%) in long rainy season, followed by 78.9% in short rainy season, 51.8% in short dry season and 49.3% in long dry season. However in the present study, there were additional digeneans during the rainy season. This study was carried on comparable fish cohorts with largely similar sizes. This study indicates significant variation in prevalence of attack between the parasite species both in wet season ($F = 17.793$; *df* 3; $p < 0.0001$) and dry season ($F = 30.226$; *df* 3; $p < 0.0001$). Jerônimo *et al.,* (2011) established high *dactylogyrids* intensity in fish from Joinville Brazil with one hundred percent prevalence, intensity and abundance of *Monogenoidea* in all seasons.

Monogeneans reproduce throughout the year with two heights during the short rains during which the female hosts lay and are frail fry also are in the environs). This is also observed in January when hosts are more concentrated in shallow waters (Jacques *et al.*, 2020). Trematodes are extremely sensitive to changes in temperature; temperature and rainfall are important factors controlling the seasonal prevalence of parasites (Koiri & Roy, 2016). For trematode parasites in general, a slight surge in temperature will lead to a noticeable surge in cercaria occurrence from the main molluscan host (Kalinda *et al.,* 2017), with minute if any drop in their transmission effectiveness, and that this may also improve the effect of trematodes. (Schade *et al.,* 2016); comparable to this study, trematode parasites are significantly present overlapping with increased temperature to high levels of infection in the larger-sized fish.

Higher temperatures every so often intensifies growth of parasite, its reproduction and infection nevertheless, it can also accelerate parasite death (Greenspan *et al.,* 2017). According to Strepparava *et al.,* (2018), raised temperature transforms the chance of parasite spread by aggregating the time of parasite transmission phase thus affecting the spread and establishment of the parasites. Sailaja *et al.,* (2017) also identified a discrete seasonal pattern in the occurrence and strength of infection and took note of developed parasite loads predominant during warmer summer months and very low or no infection during winter months. According to findings of this study, DO was significantly higher during wet season in cages with low SD ($U = 2.471$; $df = 28$; $p < 0.01$).

5.3 Water Quality Effect on Digenean Trematode and Monogenean Infections

This study found no significant variation in temperatures and total dissolved solids (TDS) between the dry and wet seasons in cages where stocking density was 2000 ($p > 0.05$). This is comparable to the study by Umaru *et al.,* (2016) in Kubanni reservoir Ahmadu Bello University, Zaria where there was certainly not a substantial difference ($p > 0.05$) in water quality parameters in all the treatments. Wu *et al.,* (2018) also found no major variances in water temperature amongst the four stocking densities in a recirculation aquaculture system. Temperature significantly differed between the seasons ($U = -6.116$; $df = 28$; $p < 0.0001$), whereas dissolved oxygen and Total dissolved solids varied insignificantly between season ($p > 0.05$). This study shows correspondence to the study by Godoy *et al.*, (2018) in Iguassu River electric plant reservoir (Paraná/Brazil) whose results revealed that fish culture did not negatively change the water quality.

However, supplementary reviews have revealed that temperature differences have a major impact on the dynamics of the parasite populations (Gehman *et al.,* 2018). High temperature alters the opportunities for parasite spread by aggregating the length of parasite transmission phase thus affecting the spread and establishment of the parasites (Strepparava *et al.*, 2018). A reasonable upsurge in temperature is expected to enrich the effect of parasites on aquatic ecosystems consequently, (Gopko *et al.,* 2020), in higher temperatures, poikilothermic animals (e.g. fish) intensify their activity resulting in further recurrent encounters with parasites hence higher risk of infection.

5.4. Impact of Digenean Trematodes and Monogenean parasites on fish condition factor

The general fish condition as depicted by condition factor (*Kn*) was significantly better in cages of stocking densities of 2500 individuals/ Cage (U = -2.005; df = 298; $p < 0.05$). Al-Azizz *et al.,* (2017) explains that vulnerability of fishes to parasite invasion differs dependent on a number of factors ranging from; morphological, immunological and physiological characteristics, as well as host-specificity and parasite distribution. Therefore parasite intensity is greatly influenced by season. Paul *et al.,* (2016) established that high stocking density decreases the rate of growth and endurance in cultured fish. Similarly, according to Yarahmadi *et al.,* (2016) high fish stocking densities in cage culture system make fish susceptible to high disease incidence. However, results of this study contrast with these findings, where the condition factor (*Kn*) was significantly better in cages of stocking densities of 2500 individuals/ Cage (U = -2.005; df = 298; $p < 0.05$).

No relationship was observed between size of fish and levels of parasitism in this study, unlike in the study by Upadhyay *et al.,* (2012) which showed a significant positive relationship between parasite and fish size, in which smaller fishes were almost free of parasites. The large quantity of monogeneans is not inclined to the size of the host (Ferreira & Tavares, 2016). Smaller size fishes were more in danger to ectoparasite infection in comparison to the bigger ones (Kamislin, 2017). Nile tilapia stocked at high stocking densities experience a decrease in dissolved oxygen (Zaki *et al.,* 2020) which in turn stresses fish, leading to decreased growth and survival thus making fish susceptible to parasitic infections. Therefore, there is better immunity response at lower stocking densities (Tammam *et al.,* 2020). High silt in water during rainfall clogs cage nets triggering a decline in dissolved oxygen and deterioration in water quality within cages leading to disease outbreaks (Chitmanat *et al.,* 2016).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

In conclusion, the monogenean Dactylogyrus was the predominant parasite identified by the study to be affecting Nile tilapia farmed in cages in Uhanya Beach, Lake Victoria. The relationship between the fish host and the parasites was more of commensalism than parasitism for the reason that the level of parasite infestation did not affect the host fish health condition. The study further established that an escalation in stocking density led to a decrease in parasite numbers in individual hosts as a result of dilution effect in host density for trematodes parasites. However, for the monogenean group, higher stocking density increased incidences of parasite attack because the parasite is transmitted by direct contact and with an increase in fish numbers in a cage, the contact chance is increased. Seasonal variations in temperature is a crucial factor affecting relative parasite abundance.

6.2 RECOMMENDATIONS

The study recommends:

1. Use of the 2,500 stocking density for maximum profits if water quality is good and feeding is done as required of in intensive aquaculture.
2. Sourcing of fingerlings should be done strictly from certified and authenticated hatcheries in order to avoid purchasing fingerlings infested with parasites like the monogeneans that require only one host to complete its life cycle.

3. Proper site selection for cages to increase dissolved oxygen concentration through regular flow of water and to prevent water quality deterioration through anthropogenic activities on the shore.
4. Regulated feeding during wet seasons to avoid lowering dissolved oxygen concentration through decomposition of unconsumed feed.

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APPENDICES

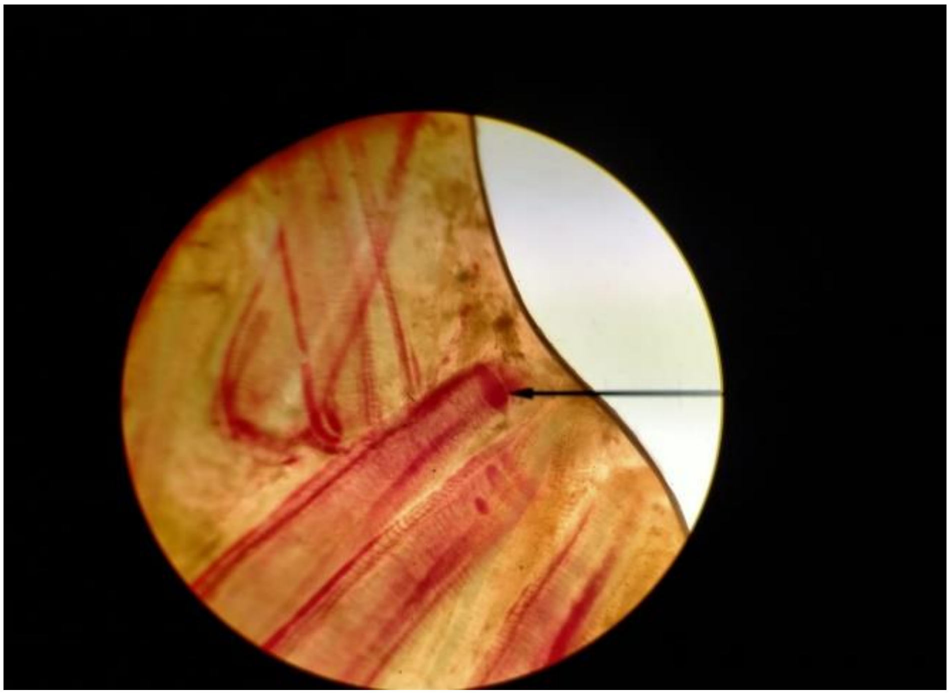
Appendix Plate I: Physico-chemical water quality *in situ* data collection

(Source: Author, 2018)

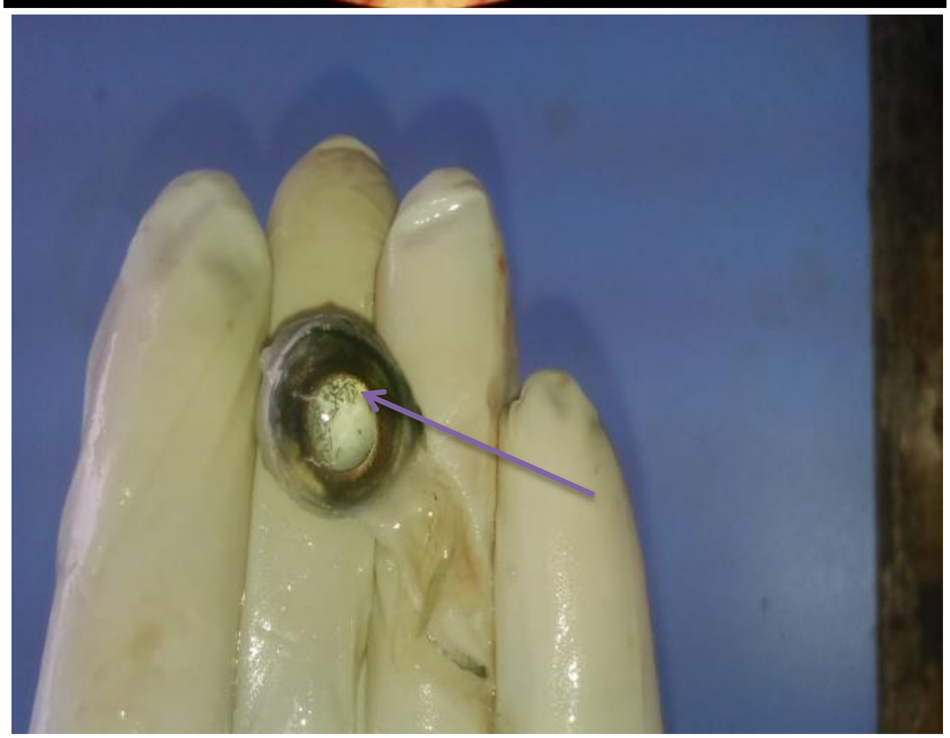
Appendix Plate II: Data recording in Uhanya Beach cages (Source: Author, 2018)

Appendix Plate III: Total blindness in Oreochromis niloticus harvested from fish cages in Uhanya Beach, Lake Victoria (Source: Author, 2018)

Appendix Plate IV: Monogenea of the genera *Dactylogyrus* attached on a gill filament (a.) and the metacercariae of the digenea *Tylodelphys* encysted in the eye vitreous humour (b.) **(Source: Author, 2018)**



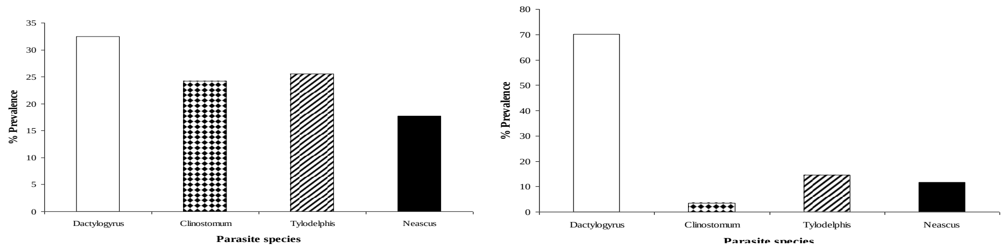
a.



b.

Appendix V: Prevalence of *Dactylogyrus*, *Clinostomum*, *Tylodelphys and Neascus* parasites in *O. niloticus* cultured in cages at stocking density of 2000 fish/cage in Wet (W) and Dry (D) seasons in Uhanya Beach of L. Victoria, Siaya County

Cage 1



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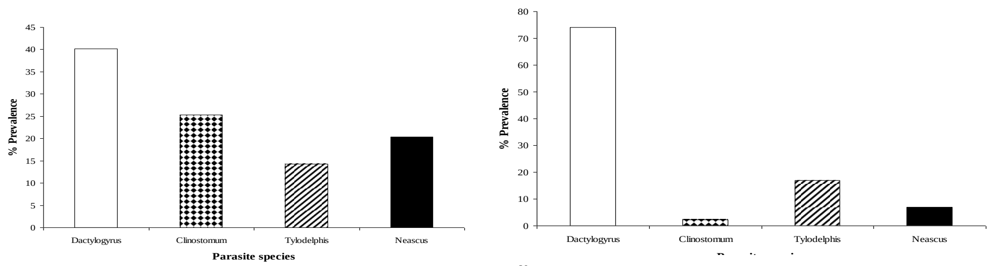

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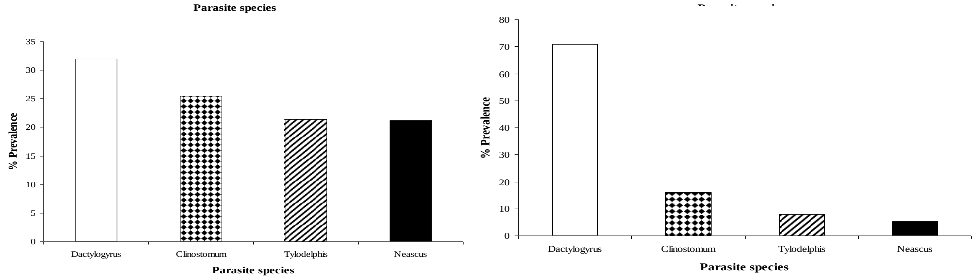

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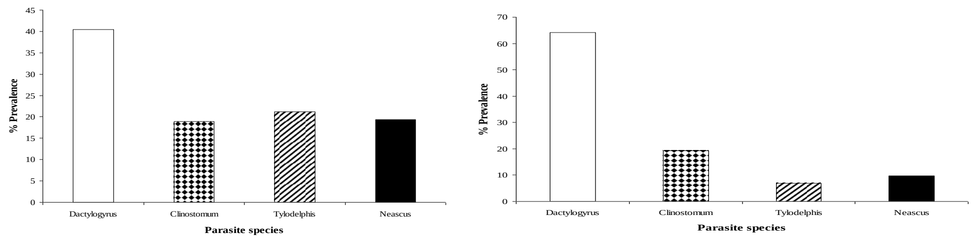

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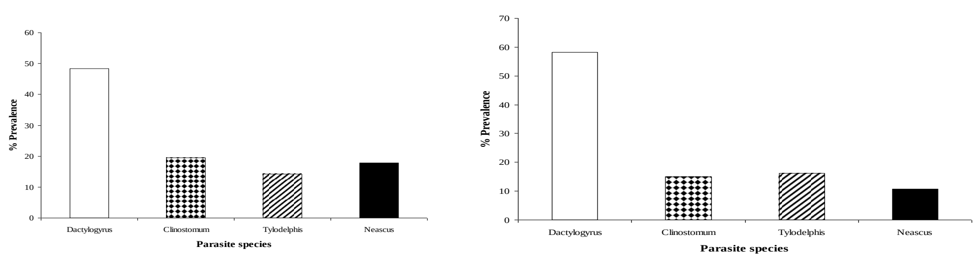
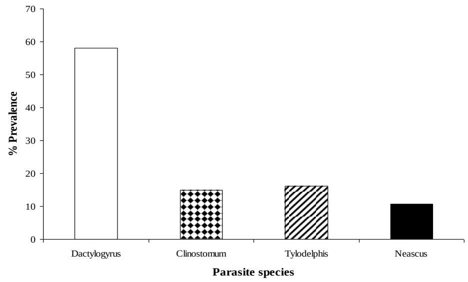
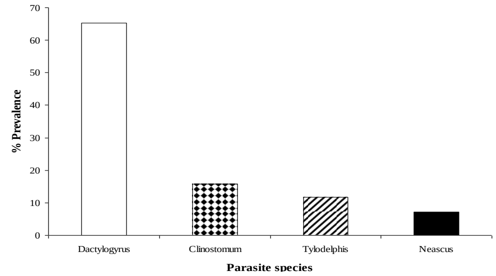


Appendix VI: Prevalence of *Dactylogyrus*, *Clinostomum*, *Tylodelphys* and *Neascus* parasites in *O. niloticus* cultured in cages at a stocking density of 2500 fish/cage in Wet (W) and Dry (D) seasons in Uhanya Beach of L. Victoria, Siaya County

Cage 6





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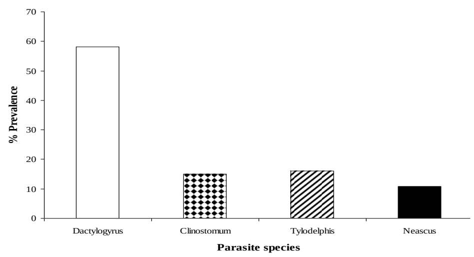

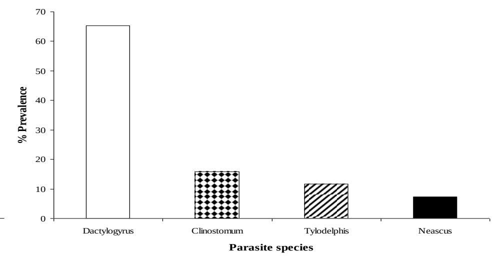

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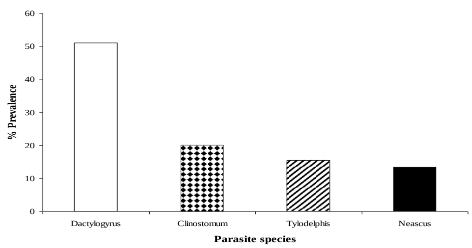

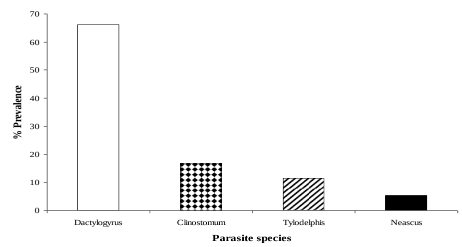

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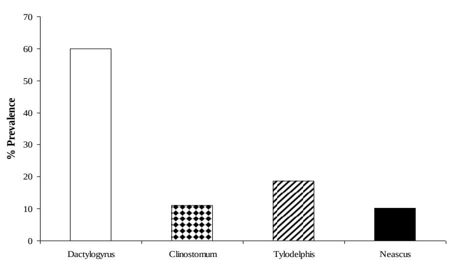

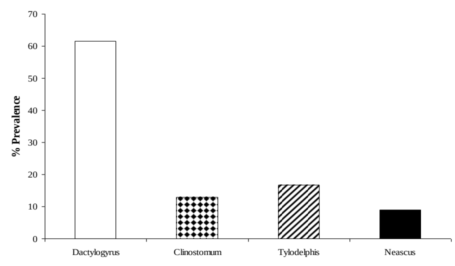

Cage
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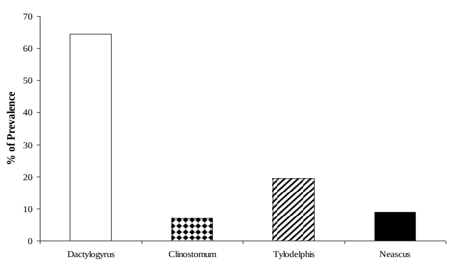

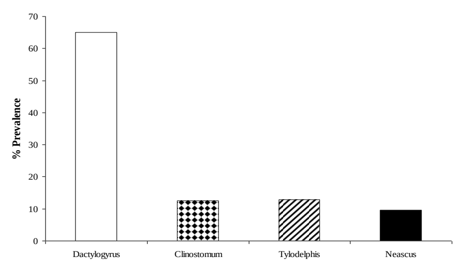

Appendix VII: Similarity report

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Turnitin Originality Report

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