PREVALENCE OF PARASITIC INFECTION IN FARMED NILE TILAPIA, *Oreochromis niloticus (*LINNAEUS, 1758) AND OTHER SELECTED ENVIRONMENTAL FACTORS ASSOCIATED WITH THEIR TRANSMISSION IN WINAM GULF OF LAKE VICTORIA

BY

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environmental Biology of the Department of Agronomy and Environmental Sciences, Rongo University

2021

DECLARATION

Declaration by the candidate

This thesis is my original work and has not been submitted for any academic award in any institution; and shall not be reproduced in part or full, or in any format without prior written permission from the author and/ or Rongo University.

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(PEB/6001/2015)

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DEDICATION

This work is dedicated to my loving wife Jonish Kilori and our two sons Jayden Watson Omari and Jarvis Davis Omari who encouraged me to pursue this course to the end.

To my very dedicated supervisors: Prof. Okeyo Owuor JB and Dr. Pamela Were Kogogo who were always there for me for consultation and guidance throughout the study period and lastly to my postgraduate colleagues for their moral support and encouragement throughout the study period.

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ABSTRACT

The general objective of the study was to assess the level of parasitic infection and farmer management practices in farmed Nile tilapia (*Oreochromis niloticus)* and some of the selected environmental factors associated with their transmission in Winam Gulf of Lake Victoria, Kenya. Selected water quality parameters from the 20 ponds, 30 cages and wild were measured *in-situ* using electronic meters and parasitological examination done according to standard procedures. A total of 96 questionnaires supplemented with direct observations were administered to fish farmers to assess the status of fish farming and management practices that could influence the occurrence of fish parasites. A total of 720 fish were purchased from fishermen, cage and pond farmers and examined for parasites. Temperature, DO, TDS and Salinity differered significantly in the different study areas ($p<0.05$) while pH registered an insignificant difference between the culture systems (pond and cage) and the wild ($p>0.05$). This was attributed to the homogeneinity of the study area experiencing the same climatic conditions. The environmental variables were within FAO's recommended limits for fish production. The class trematoda which included: *Gyrodactylus* spp., *Dactylogyrus* spp., *Tylodelphys* spp., *Diplostomum* spp., *Clinostomum* spp. and *Naescus* spp. were the most common and prevalent parasites in both ponds and cages of the Winam Gulf while *Amirthalingamia* spp. and *Diplostomum* spp. were the most common and prevalent in the wild. This was due to the presence of piscivorous birds seen more often around and overstoking, which increases the spread and transmission of parasite from one fish to another. The parasitic infestation rate was not significantly different between the ponds and cages ($p>0.05$) while there was a significant difference between the two culture systems and the wild fish of Winam Gulf. Parasitism or parasitic infestation did not affect the fish condition factor in all the study areas. This was due to very low mean intensities recorded and shorter period of exposure to parasitic infestation as most farmers have not been to fish farming for a very long time especially the cage farmers. Some management practices identified as possible risk factors for occurrence of fish parasites included: overgrown vegetation, overstocking, failure to change water within a production cycle, cleaning and treatment after harvesting, poor quality feeds and feeding, sharing of farm equipments and materials, lack of awareness on fish parasitism and signs of the infected fish. For Kenyan national government to explore on blue economy and achieve the vision 2030 on food security and poverty reduction by 2030, efforts to promote commercial cage and pond fish culture enterprises in Winam Gulf of Lake Victoria and other water bodies must be enhanced on condition that the cages are sited in deep waters of the gulf with low cage concentration in a particular site and reduced stocking densities in order not to compromise the environmental quality.The farmers should also be equipped with proper management practices to maintain acceptable water quality and avoid transmission of fish parasites.

TABLE OF CONTENTS

DECLARATION i

DEDICATION ii

ACKNOWLEDGEMENTS iii

ABSTRACT iv

TABLE OF CONTENTS v

LIST OF TABLES ixx

LIST OF FIGURES x

LIST OF PLATES xiii

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS xivv

CHAPTER ONE 1

1.0 INTRODUCTION 1

1.1 Background information 1

1.2 Problem statement 5

1.3 Objectives 6

1.3.1 General objective of the study 6

1.3.2 Specific Objectives 6

1.4 Research Hypotheses 7

1.5 Scope of the Study. 7

1.6 Justification of the study 8

1.7 Significance of the study 9

1.8 Conceptual framework 10

1.9 Operational Definition of terms 11

CHAPTER TWO 14

2.0 LITERATURE REVIEW 14

2.1 Global Aquaculture production 14

2.2 Status of aquaculture in Africa 16

2.3 Aquaculture production and Food security in Kenya 20
2.4 Nile tilapia and aquaculture 22
2.5 Environmental factors affecting Aquaculture production 23
2.5.1 Temperature 24
2.5.2 Turbidity (TDS) 25
2.5.3 Dissolved oxygen 25
2.5.4 Hydrogen ion concentration (pH) 26
2.5.5 Conductivity 26
2.6 Fish parasites and Diseases 27
2.6.1 Protozoa 30
2.6.2 Metazoa 32
i) Myxozoa 32
ii) Platyhelminthes 33
iii) Nematoda 36
iv) Acanthocephala 37
v) Crustacea 38
2.7 Impacts of fish parasites and diseases in aquaculture 39
2.8 Fish parasites and Indices 40
2.8.1 Effect of parasite infection on host body condition and growth 42
CHAPTER THREE 57
3.0 MATERIALS AND METHODS 57
3.1 Study Area 57
3.2 Biophysical characteristics of the Gulf 58
3.2.1 Climate 59
3.2.2 Geology 59
3.2.3 Soils and soil types 60

3.3 Research Design and Sample size 62
3.4 Sampling Technique 64
3.4.1 Physico-chemical Water Quality Parameters 64
3.4.2 Fish sampling 64
3.4.3 Parasitological Examination 65
a) Parasite Prevalence Rates 65
b) Mean Intensity Levels of Parasites 66
3.4.4 Taxonomic Identification 66
3.5 Data Analysis 66
CHAPTER FOUR 68
4.0 RESULTS 68
4.1 Experimental Objectives 68
4.1.1 To assess and compare selected environmental parameters in the Winam Gulf68
4.1.2 Identification and comparison of parasites in *O. niloticus* in sampling sites 73
4.1.3 Occurrence, abundance and diversity of external and internal parasites 77
4. 1.4 Effects of parasitism on fish body condition and growth in the study areas 86
4.1.5 Effects of the dominant parasite taxa on *Oreochromis niloticus* fish sizes....... 88
4.1.6 The association between parasitic infections and the selected environmental factors 92
4.2 Socio-economics Objective 101
4.2.1 Distribution of respondents and response rate 101
4.2.2 Fish species and Culture systems 103
4.2.3 Source of fingerlings and Water 104
4.2.4 Fish feeds used 105
4.2.5 Pond and cage drainage and treatment after harvesting 106
4.2.6 Predatory animals and vegetation around the culture systems 107

4.2.7 Presence of parasites or abnormalities, production cycle and stocking density108
4.2.8 Challenges faced by fish farmers 110
CHAPTER FIVE.. 111
5.0 DISCUSSION 111
5.1 Environmental Parameters 111
5.2 Common *O. niloticus* parasites in the study areas 117
5.3 Prevalence, Intensity and Diversity 118
5.4 Fish parasitism and its influence with the Environmental factors 131
5. 5 Socio-economic characteristics and management practices of farmers within the Gulf 137
CHAPTER SIX 147
6.0 CONCLUSION AND RECOMMENDATIONS 147
6.1 Conclusion 147
6.2 Recommendations 148
REFERENCES... 149
APPENDICES.. 184

LIST OF TABLES

Table 4.1 Mean Monthly (± SEM) of physico-chemical water quality parameters measured in cages, ponds and wild during the study period…………………..................71

Table 4.2: Shows Taxon's presence/absence in different study sites (P=Present, -=Absent)…………………….......……………………………………………………….....75

Table 4.3: Shows the most dominant group and taxon in different study sites (√-dominant species)……………………………………………………………………………….…..77

Table 4.4: ANOVA Table showing the effect of parasitism on condition factor of *O. niloticus* in Cage, Pond and Wild (p= 0.05). ………………………………......………...87

Table 4.5: Spearman rank (rs) correlation between parasite prevalence and water quality parameters in the study sites (* Indicates significant correlations; p =0.05..……..........94

Table 4.6: Sources of fingerlings for fish farmers in Winam Gulf and its shores……….……………………………………………………………………………..105

Table 4.7: Animals seen in and around the cages and fish ponds in the gulf (Only birds apply to both the rest were only recorded in ponds)……………………….....………...108

Table 4.8 Farmers knowledge on signs of fish parasitism and abnormalities…………………………………………………………………………109

Table 4.9: Challenges faced by fish farmers in Winam Gulf and its shores…………………………………………………………………………….......110

LIST OF FIGURES

Fig. 1.1: The conceptual framework of the study that shows how fish interacts with the environment and infection of parasitic disease……………………………………………11

Fig. 3.1: A map showing Winam Gulf and major rivers draining into it and the open waters… 61

Fig. 4. 1: Mean Variations in water quality physico-chemical parameters inside the cages, 10, 20 and 30m away from cage during the study period……………..........................73

Fig. 4.2 Mean Variations in mean intensities in cage, pond and wild during the study period……………………………………………………………………………78

Fig. 4.3 Variations in Shannon Weaver and Simpson's diversity indices in cage during the study period………………………………………………………..................79

Fig. 4.4 Variations in Shannon Weaver and Simpson's diversity indices in pond during the study period…………………………………………………………………..…79

Fig. 4.5 Variations in Shannon Weaver and Simpson's diversity indices in wild during the study period…………………………………………………………………………80

Fig. 4.6 Indices of parasite diversity in cage, pond and wild during the study period…..……………………………………………………………………,,,80

Fig. 4.7 Variation in parasite prevalence rates (%) in cages during the study period…….……………………………………………………………………....83

Fig. 4.8 Variation in parasite prevalence rates (%) in ponds during the study period…….………………………………………………………………..….83

Fig. 4.9 Variation in parasite prevalence rates (%) in wild during the study period………..84

Fig. 4.10 Variation in parasite prevalence rates (%) in cages, ponds wild during the study period……………………………………………………………………………………….84

Fig. 4.11. Shows the overall mean parasitic prevalence rate among the study sites…………………..……………………………….……………………………………….85

Fig. 4.12 The relative abundance (%) of parasites in different study sites……………………………………………………………………………………………86

Fig. 4.13. Length-Weight Relationship of O. niloticus in cages and open waters in Winam Gulf……………………………………………………………………………………….88

Fig. 4.14 Scatter plot of correlation of dominant taxa intensities with fish size in cages during the study period…………………………………………………..…………89

Fig. 4.15 Scatter plot of correlation of dominant taxa intensities with fish size in ponds during the study period……………………………………………………...……...90

Fig. 4.16 Scatter plot of correlation of dominant taxa intensities with fish size in wild/open waters during the study period………………………………………………..91

Fig. 4.17 Cluster Analysis of various fish parasites in cages, ponds and wild during the study period…………………………………………………….……………………...92

Fig. 4.18 Canonical Analysis (CA) showing the loading rates of wild parasites and their relationships with the physico-chemical water quality parameters……………………..….96

Fig. 4.19 Canonical Analysis (CA) showing the loading rates of pond parasites and their relationships with the physico-chemical water quality parameters……………………..….97

Fig. 4.20 CA showing the loading rates of cage parasites and their relationships with the physico-chemical water quality parameters……………………….................................98

Fig. 4.21 Canonical Analysis (CA) factor map of showing parasite groupings and water quality effects in pond……………………………………………………………………99

Fig. 4.22 Canonical Analysis factor map of showing parasite groupings and water quality effects in cage…………………………………………………………………………...100

Fig. 4.23 Canonical Analysis factor map of showing parasite groupings effects in wild…..101

Fig. 4.24 Other non-farm enterprises that farmers are engaged in within the Gulf………………………………………………………………………………..102

Fig. 4.25 Fish farmers' education levels along Winam-Gulf of L. Victoria……………………………………………………………………….……..103

Fig. 4.26 Culture systems practiced by farmers within and along the shores of the Gulf………………………………………………………………………………..104

Fig.4.27 Type of feeds used by farmers within the gulf of L. Victoria……………………………………………………….…………………106

LIST OF PLATES

Plate 1: *Naescus* species on the skin muscle of the *Oreochromis niloticus*……………….74

Plate 2: Total blindness due to Tylodelphys species infection within the vitrous humor of *Oreochromis niloticus*…………………………………….…………………...…74

Plate 3: *Dactylogyrus* species found attached at the gills of a caged fish……………….76

Plate 4: Tail and skin rot which are signs of parasitic infection in *Oreochromis niloticus*……………………………………………………………………………..76

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ALCOM	Aquaculture for Local Communities
ANOVA	Analysis of Variance
CA	Canonical Analysis
CAN	Calcium ammonium nitrate
CCA	Canonical Correspondence Analysis
Cm	Centimeter
DAP	Di-ammonium phosphate
DO	Dissolved Oxygen
DoF	Department of Fisheries
ESP	Economic Stimulus Programme
FAO	Food and Agriculture Organization
FFEPP	Fish Farming Enterprise Productivity Programe
Fig.	Figure
FZT	Fish-borne zoonotic trematodes
GIS	Geographical Information System
GoK	Government of Kenya
ICAR	Indian Council of Agricultural Research
ITCZ	Inter Tropical Convergence Zone

LVEMP	Lake Victoria Environmental Management Programme
Mg/l	Milligram per litre
MI	Mean Intensity
MT	Metric tons
MTy^{-1}	Metric tons per year
NSPFS	National Special Programme for Food Security
PCA	Principal Component Analysis
pH	Potential Hydrogen
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SE	Standard Error
SEM	Standard error of mean
TDS	Total Dissolved Solids
Temp.	Temperature

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Aquaculture which is defined as culturing of fin fish and shell fish together with other aquatic organisms such as molluscs, crustaceans, and aquatic plants (Ahmed and Lorica, 2002). Aquaculture is fast growing in the world and it is second to biotechnology (Drucker, 2002). Aquaculture is a fast-expanding mode of food production in the world. Currently, fish farming accounts for more than one-quarter of the total fish directly consumed by humans, using about 220 finfish and shellfish species. In comparison with the rest of the world`s aquaculture production, Africa`s contribution is insignificant (FAO, 2007). The continent as a whole contributes a mere 0.9% to the world aquaculture production (FAO, 2003). This production, however, increased from 37,000 tonnes in 1984 to 189,000 tonnes in 1998 (FAO, 2003). In 2002, the total aquaculture production of Africa amounted to 451,537 tonnes and the major fish species cultured include the freshwater Carp and Tilapia (FAO, 2003). Leading producers are Egypt (376, 296), Nigeria (30,663), Zambia (4,200), South Africa (4,177), Madagascar (7, 966), Ghana (6,000) and Uganda (4,915) all in tonnes. These figures reveal the low-level intensity of aquaculture in sub-Saharan Africa as compared to 553,933 tonnes produced by Norway (FAO, 2003). Aquaculture activities can provide sources of supplementary high protein food and additional income to rural communities in developing countries (Fioravanti *et al.,* 2007).

FAO (2003) reports that aquaculture is still essentially a rural, secondary and part-time activity that is taking place in small farms in small freshwater ponds. Extensive to semi-intensive cultural systems produce limited fish yields which are mostly consumed directly, bartered or sold locally as a cash crop. From the 20 different species known to be cultured, only three species (Nile Tilapia, African Catfish and common Carp) are mostly farmed throughout Africa (FAO, 2003).

Whereas small-scale inland fisheries or aquaculture has been supported and well managed, fish-related activities play a critical role in generating wealth and sustaining economic growth (DFID/FAO, 2000). For example, research in the Zambezi floodplain reveals that inland fisheries generate more cash for households than cattle rearing in most cases and more than crop production in some cases. In Sri Lanka recent economic valuations have put the value of fisheries at about 18% of total economic returns to water in irrigated paddy production (Foeken and Owuor, 2008). This capacity of small-scale fisheries to generate cash, however, is still poorly recognized by both academics and decision makers. In addition, because fishers and, to a lesser extent, fish-farmers, can access cash year-round by selling fish, fisheries provide a "bank in the water" for remote rural populations that lack access to formal financial systems. This contrasts with agriculture, where farmers have to invest and then wait for harvest before earning cash returns.

Aquaculture is a relatively new industry with significant potential for innovation. Most species that are grown are not much different from their wild counterparts, nor have they been domesticated to a greater extent (Mbugua, 2008). Aquaculture innovation produces a higher capital return to the farmer than traditional farming practices do, and such innovation can also be a natural way of managing aquaculture production to become more sustainable.

In developing economies, the development of commercial aquaculture is yet to become popular or widespread (Quagrainie *et al.*, 2009). This is as it is widely recognized that the persistent inherent uncertainties, which result in wide variation in production yield in aquaculture, fisheries industries, are caused by adverse weather conditions and pest and disease outbreaks. Considering the production risk in inputs in the empirical analysis of firm behaviour and productivity change, (Oladele and Fawole, 2007) observes that, risk-averse producers choose input levels, which differ from the optimal input levels of risk-neutral producers. Secondly, risk-averse producers will be concerned about risk properties when they consider the adoption of new technologies; thus, they may not necessarily choose the technology with the highest mean output (Oladele and Fawole, 2007).

The Kenya Vision 2030 is the country'current development agenda covering the period 2008 to 2030 and it aims at transforming Kenya into a newly industrialized middle-income country providing a high quality life to all its citizens by the year 2030 (FAO, 2016). In a bid to realize vision 2030 strategic plan, the Kenyan government injected 70 million U.S. dollars between 2009 and 2013 financial years to invest in fish farming for food security under the social economic pillar (FAO 2016). Under the Kenya Economic Stimulus Programme (FAO, 2016) whose aim was to jumpstart the Kenyan economy towards long term growth and development**,** the Ministry of Agriculture, Livestock and Fisheries Development launched fish farming project, with a main theme of mproving nutrition and creating over 120,000 jobs and income opportunities has been one of the more successful components of ESP. In Kenya, cage and pond culture system is probably the latest and most developed systems of fish farming and since Kenya targets to export her stock to European countries to improve the economy, information on occurrence, prevalence and pathogenicity of fish parasites and diseases is very essential as it is mandatory that the exports EU coutries must be free from any disease and parasite. This information is therefore key to fish farmers as it enables them to practice proper fish husbandry.

Some of the fish parasites are zoonotic and they include helminthes such as anisakid nematodes *Anisakis simplex*; *Pseudoterranova decipiens*, cestodes of the genus *Diphyllobothrium* spps. and digenetic trematodes of the families Heterophyidae, Opisthorchiidae and Nanophyetidae (Adams *et al.,* 1997; Noga, 2010; Robert, 2012). Factors associated with zoonotic helminthes include feeding animal resevoir hosts (dogs, cats, pigs, chicken, ducks) with live infested fish, humans feeding on undercooked or raw fish and by handling infested fish (Noga, 2010). Presence of snails and addition of vegetation from other farms have also been listed as risk factors (Phan *et al.*, 2010). The snails (families Thiaridae and Bithynidae) act as intermediate hosts for Fishborne Zoonotic Trematodes (FZT) while the vegetation could contaminate the ponds with FZT eggs from other farms (Clausen *et al.,* 2012). Various factors including; the length of the host, size, parasites intensity and prevalence, environmental variables, such as size, shape and type of water body, temperature, salinity, oxygen content and pH have been shown to affect parasitism in fish (State and State, 2009; Lagrue *et al.*, 2011; Ali *et al.*, 2014). The success of cage culture system in L. Victoria has not been achieved as the system is associated by massive fish kills according to (Njiru *et al.*, 2019). In one occasion, Sakala 2017 reported that more than 5,000 fish died in cages in L. Victoria as a result of high stocking density. These need to be investigated to document factors that contribute to low aquaculture productivity in Winam Gulf of L. Victoria and most likely to threaten human health and achievement of the country's Vision 2030 on food security and poverty alleviation.

1.2 Problem statement

According to FAO (2010), demand for fish in the world has been on the increase, while the supply of fresh water fish from capture fisheries has been on the decline in the first decade. As world fish catches continue to decline and population increases, aquaculture has great potential for growth in Kenya to produce the critical volumes of fish to fill the growing gap between National fish supply, demand and food security as outlined in vision 2030 (FAO, 2018). Owing to its prominence to bridge this gap, the Kenyan Government in the 2009/2010 financial year under the Economic Stimulus Programme (ESP) introduced commercial fish farming in Kenya (FAO, 2016). The success of this new Government initiative brought about renewed strength on fresh water fish farming in Kenya. Aquaculture activities are capable of creating an industry employing and supporting a substantial number as fish farmers, feed manufactures, fish processors, traders and other actors. Hecht and Endemann (1998) reported that one of the serious challenges found to reduce the rate of fish production include water quality, fish parasites and diseases. Data on fish parasites, their distribution, abundance, composition, diversity and intensity is very vital for proper farm management (Akoll *et al.*, 2012). Fish farmers in the Lake Victoria region are struggling to increase their production through pond and cage culture since the inception of ESP initiated by by the Kenya Government in 2009/2010 FY in order to satisfy the local, national, regional and international demand in the absence of relevant information on diseases and parasite prevalence and management. Limited research has been done to document the types of parasites and diseases affecting cultures tilapia in the region and literature on mitigation of fish diseases and parasites in order to enhance economic development and vision 2030 is still scanty. The success of cage culture initiative has not been achieved as they register high mortalities, high production cost and low growth rate. Their success will depend on the availability of and access to relevant information on management strategies both biotic and abiotic factors that influence aquaculture production. While socio-economic factors have been fairly well studied, information on socio-economic together with parasite infestation is still scanty and sporadic within the Lake Victoria region especially the Winam Gulf, Kenya and its riparian (Fioravanti *et al.,* 2007). This study is therefore imperative to address this knowledge gap.

1.3 Objectives

1.3.1 General objective of the study

The general objective of this study is to assess the type of farm management practices, prevalence and risk factors associated with parasitic infestation of farmed Nile tilapia as compared to wild population in Winam Gulf of Lake Victoria- Kenya.

1.3.2 Specific Objectives

1. To determine and compare selected environmental parameters in the cages and open waters (wild and pond) in Winam Gulf.
2. To identify and document the variation between common *O. niloticus* parasites in the cages and open waters in Winam Gulf.
3. To determine the prevalence, intensity and diversity of fish parasites in the cages and open waters in Winam Gulf.
4. To determine the effect of parasitism on fish body condition as influenced by environmental factors in the cages and open waters in Winam Gulf.

5. To assess the types of management practices undertaken by fish farmers in the Winam Gulf and its surrounding.

1.4 Research Hypotheses

1. Ho-There is no difference in the selected environmental parameters between the cages and open waters in Winam Gulf.
2. Ho- There is no difference in the identification of the common *O. niloticus* parasites between the cages and open waters in Winam Gulf.
3. Ho- There is no difference in parasitic prevalence, mean intensity and diversity of both external and internal parasites between the cages and open waters in Winam Gulf.
4. Ho- There is no difference in the effect of parasitism on the fish body condition as influenced by the environmental factors between the cages and open waters in Winam Gulf.
5. Ho-There is no influence of management practices on prevalence and intensity of parasitic infection of farmed *O. niloticus* in cages and open waters of Winam Gulf.

1.5 Scope of the Study.

The study was restricted to Winam Gulf of Lake Victoria, Kenya where over 500 cages are located and ponds at the shore of the lake. The study was carried out from the month of September 2017 to August 2018. This period covered the two harvesting seasons in cages There was only one species under the study i.e. *Oreochromis niloticus.*

1.6 Justification of the study

Kenya is currently facing a major challenge in feeding her citizens (Aura *et al.*, 2017) and with more than 30% of Kenya's children classified as undernourished and about 10 million people overall suffering from chronic food insecurity and poor nutrition, food security which is defined as improved health through food sufficiency, quality and safety, is clearly key to Kenya's economic and social development (Aura *et al.*, 2017). According to Abila (2003), food security is affected by availability, access to, supply, and quality or nutritional state of food. Climate change, droughts, environmental degradation, loss of biodiversity, livestock diseases and declining fisheries due to over-exploitation and habitat change, have increased food insecurity and malnutrition in the Lake Victoria and its basin. Lake Victoria is classed as a unique natural food resource (Njiru *et al.*, 2018) and plays a vital role, dominating Kenya's inland fish production and providing a major nutritional source for communities around the lake (FAO, 2013b). Lake Victoria shares its waters between Kenya (6%), Uganda (43%) and Tanzania (51%) with 35% of the total fish production landed on the Kenyan portion of the lake. However, demand is outstripping production through overfishing and is threatened by anthropogenic pollution e.g. waste / sewage and mining in the region (Munguti *et al.*, 2014a). Kenya's huge aquaculture potential, particularly the quick growing tilapia, is being exploited to boost food security (Njiru *et al.*, 2018).

While the World Bank (2000) has identified aquaculture as a route to eradicating poverty and hunger by increasing production through utilizing fast growing non-native tilapia (*Oreochromis niloticus*) farmed in cages on the lake and freshwater ponds according to Aura *et al.*, (2017), ecto-parasites and endo-parasites infestation can be a very dangerous fish disease of fish which can cause high fish mortality and morbidity and this acts as a barrier to poverty and hunger eradication. These parasites mostly infect key organs in fish such as eye, intestine, gill therefore rendering the fish unreproductive. Information on occurrence and parasitic infection of both internal and external parasite in freshwater bodies in Kenya is very scanty. This work was worth study because fish farming plays an integral role in Kenya's economic development as it stands to be the main source of food to many rural communities. It is therefore important to carry out a study to investigate potential risks that might affect its growth.Fish diseases and other related parasitic infestation is normally a threat to maximum fish production in any aquaculture set up. Since capture fisheries can no longer satisfy the needs of the country in terms of fish supply, aquaculture production is therefore important to bridge the ver growing gap between fish demand and supply. It is critical for the information on fish parasites and diseases and how they affect production to be available to enhance the probability of achieving the Sustainable Development Goal and Vision 2030 on poverty and hunger.

1.7 Significance of the study

Fish farming as has been reported (Ducker, 2002) is very key given its contribution in improving the countryis GDP and being key source of food to many people more so the rural poor. Since aquaculture development has been in the right trajectory in the last one decade, this has brought with it serious challenges and one of the constraints to majority of the fish farmers is how to prevent and control fish parasites which causes massive fish death in various aquaculture units within the culture systems.

Furthermore, fish is an important form of food for the communities around L. Victoria and the country as a whole; hence, the study addresses an important area of food safety and food security. Creating evidence-based parasitic control policies that are required to protect humans and animal health which requires understanding and the interaction between people and aquatic organisms with their environment and the transmission of diseases between them. This will be useful and key in addressing ecosystem balance in the Lake hence increasing its productivity. This information will be useful not only to the author but also to the community around the Winam-gulf, entire Lake Victoria, government of Kenya and both national and international stakeholders within the fish value chain. The same results can also be applied in other water bodies where the same practice is carried out.

1.8 Conceptual framework

This study was developed from the concept shown below (Fig. 1.1). The conceptual framework was composed of three main parts which were assessed and these components include the following: fish, environment and parasites. Fish is affected with the environment in which it lives; the environment is composed of both biotic and abiotic factors which either directly or indirectly affect fish physiology and behaviour. Fish productivity success is highly influenced by its ecology and imn most natural environment, parasites are known to live in equilibrium with their host. However, in aquaculture unit where the fish movement is restricted such as cages and ponds there are significan stress factors that are in play due to compromised water quality, high stocking density, poor handling which make fish to be highly susceptible to parasite nfection then occurrence of a parasitic diseases.

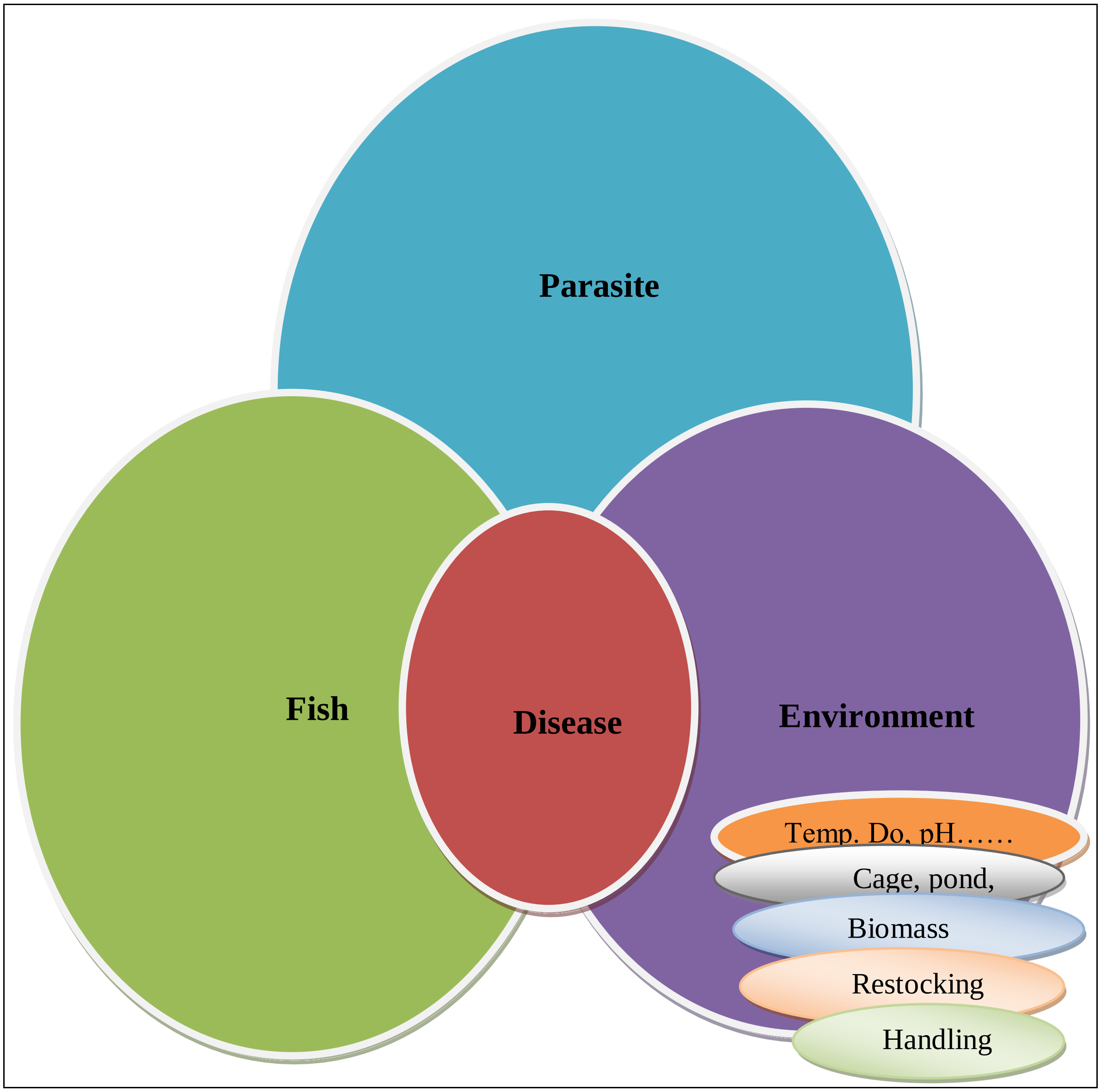

Fig. 1.1: The conceptual framework of the study shows how fish interacts with its environment and disease infection (Adopted from Otachi. 2009).

1.9 Operational Definition of terms

Allogenic parasites: Allogenic parasites are those that have indirect life cycles i.e. some of their life they spent in aquatic environment while a later development stage is normally spent in a terrestrial environment (Díaz & Muñoz, 2010; Criscione, 2005).

Aquaculture production Aquaculture production refers to output from aquaculture activities, which are designated for final harvest for consumption.

Brackish water culture: The cultivation of aquatic organisms where the end product is raised in brackish water, such as estuaries, coves, bays, lagoons and fjords, in which the salinity may lie or

generally, fluctuate between 0.5% and full-strength seawater.

Economic Stimulus Programme Federal government programme designed to counteract weak economic activity with stimulus in form of government spending on infrastructure and other initiatives, tax breaks, and subsidies.

Fish Farming Fish farming involves raising fish commercially in tanks or enclosures, usually for food.

Fishery Refers to an activity leading to catching, taking or harvesting of fish. It may involve capture of wild fish or raising of fish through aquaculture.

Fresh water culture Cultivation of aquatic organisms where the end product is raised in freshwater, such as reservoirs, rivers, lakes, canals and groundwater, in which the salinity does not normally exceed 0.5%.

Relative abundance (R.A.) was calculated as the proportionate percentage (by numbers) of each taxon in a sample. The relative abundance was calculated according to Roy, *et al.*, (2001) as:

$$RA = {}^{n}/_{N}\ 100\ (= p_i\ x\ 100)$$

Where n = Number of individuals of one taxon; N = Total number of individuals in a station; p_i = Proportion of the *i*th species and 100 =Percentage conversion

Zoonosis: any infectious or parasitic disease able to be transmitted from animals, both wild and domestic, to human or *vice versa*.

Ectoparasites: These are fish parasites, which only attack and affect the external body parts of the host fish such as skin, tail, fin among others

Endoparasites: These are fish parasites, which only attack and affect the internal body parts of the host fish such as intestines

Infracommunity level: Infra-communal level of parasites are those that spent their entire developmental stages in a single host (Zander, 1998; Poulin, 2006).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global Aquaculture production

To feed a world whose population is expected to grow to 9.6 billion by 2050, current agricultural production from crops, livestock, fisheries and aquaculture must increase by over 60% (FAO, 2014b). To meet these increasing demands, the contribution from sustainable aquaculture production would be fundamental. Aquaculture farming now represents the fastest growing animal food producing sector of the world, with an annual average growth of 8.6% over the last decade. The sector also remains an important source of essential nutrients, accounting for over 17% of the global population's consumption of animal protein (FAO, 2014a). In 2012, the total global aquaculture production was estimated to be over 90.4 million tons (FAO, 2014b) with freshwater fish representing the bulk. In the same year, the total production from inland aquaculture of both herbivorous and omnivorous finfish species was estimated to be 42 million tons (FAO, 2014b).

Aquaculture is a vital economic activity and provides livelihood to many people in the world. It especially provides a good alternative source of income for rural communities (World-bank, 2013). In 2012, 4.4% of the 1.3 billion people economically active in the broad agriculture sector worldwide were active in aquaculture, with women dominating the sector (FAO, 2014).

The FAO estimates that, overall, fisheries and aquaculture support the livelihoods of 10 – 12% of the world's population. In 2012, its production was estimated at 1.4 million tons with Egypt being the major producer while sub-Saharan Africa produced 359,790 tons in 2010, only 0.6% of the world production (FAO, 2014a). Smallholder aquaculture production accounts for 95% of the total aquaculture production. Of these, Nile tilapia farming contributes 40% (Jamu and Brummett, 2004) and is largely characterized by semi intensive production systems using earthen ponds with low and few inputs and diverse farming conditions (El-Sayed, 2006).

For many years, fish catches per unit effort increased rapidly over the past hundred years due to improved technological know-how, which provided more powerful machines, engines and modern sonar equipment. As a result of this technological advancement in fisheries, most parts of the world recorded an increased rate of over fishing and this caused a worldwide decrease in wild stocks. As a result, the growth in fish catches stopped some 20 years ago due to depletion of fish stock in most lakes around the world. This called for the need to increase fish production by farming that became an urgent matter (FAO 2008). In the previous year (2007), FAO had reported that top producers of aquaculture were found in countries such as China, India, Viet Nam, Indonesia and Thailand. China, which produces one-fifth of the world's population, accounts for two-thirds of the worlds reported aquaculture production. China's 2005 reported harvest was 32.4 million tonnes, more than 10 times that of the second-ranked nation, India, which reported approximately 2.8 million tonnes (FAO, 2009). Shinn *et al.,* (2015) reported that since 2002, China had been the world largest exporter of fish and fish products in the whole world. In 2005 for instance, exports, including aquatic plants, were valued at US$7.7 billion, with their main source of market in the following countries: Japan, the United States of America and the Republic of Korea. In the same year 2005, the total approximated number of fish farmers world-wide was estimated to be about 12 million with China accounting for 4.5 million people employed full time in aquaculture industry. In the past before the generation of the new technologies in the country, fish culture in

China had been a family business with traditional techniques passed from generation to generation. However, in the late 1960s and early 1970s the Chinese government began a move to the modern induced breeding technologies such that fish grow rapidly and has a high feed conversion rate, which has resulted in a rapid expansion of freshwater aquaculture in China De Silva *et al.,* (2006).

2.2 Status of aquaculture in Africa

Aquaculture development started in Asian continent and was first introduced to Sub-Saharan Africa in the 1950s with main objectives of improved nutrition in rural communities, generation of additional income within the poor, diversification of agricultural activities to reduce risk of crop failures during dry season and excess rainfall and the creation of employment in rural areas which was entirely jobless (Hecht, 2006). It has been reported that about 43% of the African continent is assessed as having the potential for farming tilapia, African catfish and carp (Shitote *et al*., 2012). Africa had the same potential for aquaculture production just like other areas in the world that were already recording very high production rate and even though aquaculture had grown strongly in those regions of the world where the potential existed, it had not done so in Sub-Saharan Africa (FAO 2004). In spite of various efforts since the 1950s to improve the production in Africa, returns on government and international aquaculture investments in African countries appeared to be insignificant (FAO, 2004) with less than 5% of the suitable land area being used (Mwaura, 2006 and Ngodhe *et al.,* 2013). The challenges were enormous which required an immediate action for the better returns. In 2006, it was reported that Sub-Saharan Africa contribution to world aquaculture production was less than 1% (Hecht 2006). During the same period, there was an increase in the number of people in Africa states which increased the demand for fish but unfortunately, this increase in population exerted more pressure on capture fisheries which resulted into low catches per unit area (Noga, 2010). To support and sustain future nutritional needs, capture fisheries will need to be sustained and if possible enhanced through advanced technological inputs as well as sustainable capture fisheries development, and aquaculture developed rapidly (Orina *et al.*, 2014). However, a number of reasons have been suggested for the poor rate of growth in aquaculture development in the Sub-Saharan Africa. The reasons according to Food and Agricultural Organization in their 2006 report included causes relating to fish consumption preferences, the general level of economic development in rural areas, the policy and governance environment, and limiting social factors (FAO, 2006), together with a lack of access to available information.

Egypt is the leading nation in aquaculture production in Africa and it has built the largest aquaculture industry in Africa, accounting for four out of every five fish farmed on the continent, according to FAO, (2008). In the same report (FAO 2008), further reveals that Egyptian fish farms produce over 650,000 tons of finfish per year, or about 60 per cent of the country's total freshwater and marine fish production, providing a cheap source of protein for the country's estimated 80 million people. The aquaculture industry has witnessed explosive growth over the past decade. Total aquaculture production in Egypt has continued to grow at a very high rate due to increase investment in the industry and it has grown by approximately 500 percent since 1998 due to a shift from semi-intensive to intensive rearing methods and faster growing species such as tilapia, Al-Ahram (2010). Aquaculture sector acts as a source of employment and livelihood to many citizens as it employs about 164,000 people, representing 3.07 percent of employment in agriculture and additional 20,000 people in supporting services and industries (FAO, 2008). Fisheries contribution to agriculture production was 7.34% of agricultural production and 20.9 % of total livestock and poultry production by value in 2002 (Oduor, 2000). Aquaculture has the same objective as agriculture, namely, to increase the production of food above the level that would be produced naturally. Today, according to FAO, aquaculture is responsible for an ever-increasing share of global aquatic food production, which has increased from 3.9 percent in 1970 to 31.9 percent in 2003 (FAO, 2005).

Out of the total global quaculture production, Africa continent contributes just 3 % of global aquaculture production for the year 2009, whereby the greatest percentage of this contribution was from Egypt (FAO, 2011). Considering the global trajectory, the aquaculture production trend in Africa has been on the increase, even though at a low pace. Historically Aquaculture in Africa began around 1920's with introduction of trout farming in Eastern Africa (Toguyeni, 2010). Lately other regions started culturing other fish species although tilapia remains to be the dominant species cultured across Africa.

Because of insufficient finances to invest in national as well as regional aquaculture associated programmes, the aquaculture industries in many Southern African states have not been experiencing any growth and this contradicts with other states (Hempel, 2007). For diverse reasons according to Gupta *et. al.,* (2004) a huge proportion of government aquaculture facilities are deserted or presently dysfunctional. In Africa, the notable rise and growth in aquaculture production has been since 1998. Moreover, in Africa, Egypt is the highest aquaculture producer with a production rate of seven hundred and five (705) tonnes in 2009/2010 financial year as recorded by FAO (2011). Some of the explanations given for poor growth in aquaculture include inadequate utilization of native species for farming as well as the unsatisfactory understanding of fish parasites and diseases. Several authors powerfully recommend that governments have promoted aquaculture growth based on native/indigenous species (Toguyeni, 2010 FAO 2011 FAO 2005, FAO 2007a, and Oduor 2000). Southern Africa has a broad range of indigenous fish species, a number of which have been studied and utilized in aquaculture production for example *Oreochromis* species. Species of fish to culture in aquaculture depend mainly on ecological conditions of the site and the intensity of the culture system. Subsistence fish farmers who normally are small-scale farmers largely use species supported by aquaculture authorities as reported by Van der Mheen (1994).

Introduction of non-native fish species will call for government to ensure that adequate infrastructures are put in place to avoid unnecessary failures, and have the skilled and experienced personnel and extension officers who are able to deal with any source of calamity (FAO 2003 and Stickney, 2000). Historically research has been based on the adaptability of the non-native species to the present environmental conditions, but has since changed to technological development of native culture methods Van der Mheen and Haight (1994).

In Botswana for example, aquaculture industry development has been one of their major objectives in trying to create more job opportunities as wellas increase their sources of income as a nation (ACP, 2011). The government has been supporting this sector and small-scale fish farming was started in various sections of the country. The government has assisted in developing a first class hatchery facility in order to generate more than 500, 000 mixed sex *Oreochromis niloticus* and *Clarias gariepinus* fingerlings to improve on the fingerling production rate for stocking in freshwater dams and other aquaculture systems (Oduor, 2000). Aquaculture sector in Botswana is still at an extremely premature phase as in many Southern African countries and growth is negatively affected by disputes including reasonably elevated capital expenses, insufficient technical expertises and inadequate knowledge in fish farming (ACP, 2011, ALCOM, 1999 and 1996).

2.3 Aquaculture production and Food security in Kenya

Aquaculture is the only viable alternative source of fish especially at this time when the natural stocks of fish are declining. Kenya is one of the African countries which have great potentials for aquaculture growth because it is endowed with climatic diversity, natural features and other resources that favour the culture of a wide variety of aquaculture species. According to Ngodhe *et al.,* (2013) it was indicated that their conditions in Lake Victoria Basin, Kenya were within the optimal range of aquaculture production as described by Boyd (1998).

Aquaculture in Kenya can be categorized into three broad divisions. These are warm fresh water aquaculture dominated by the production of various species of tilapia and the African catfish (*Clarias gariepinus*) mainly under semi intensive systems using earthen ponds and cold fresh water aquaculture involving the production of rainbow trout under intensive systems using raceways and tanks and finally marine water aquaculture which is underdeveloped GoK (2009). The Tilapine species constitute about 90% of aquaculture production in Kenya. Polyculture of the Tilapines with the African catfish is under mixed sex culture systems (GoK (2009)).

Identifying aquaculture as an avenue of the many possible alternatives for refurbishing the nation's food sector, the Kenyan government established the Economic Stimulus Program in (ESP) 2009 to promote the economic growth, reduce hunger, and imrove on regional development Nyonje *et al.*,(2011). The Fish Farming Enterprise Productivity Program under the ESP established to impart entrepreneurial skills on subsistence fish farmers in order to upgade to commercial fishing which would spur economic growth. Charo-Karisa and Gichuri (2010) reported that program's main objective is to improve on fish production from an initial 4,000 Metric Tons (MT) to over 20,000 MT in the short term and further expressed the need to even improve it to 100,000 MT in the medium term. The program started with construction of 200 fish ponds in each of the 140 sub counties with more than 27,000 fish ponds nationally Karisa and Gichuri (2010). This initiative came along with it new demands such as quality and certified seeds and feeds which were not available within the country even on private sector (Musa *et al.,* 2012). The program motivated farmers to construct their ponds, this put more pressure on the already unavailable certified seeds and feeds to over 100 million and 100,000 MT, respectively (Charo-Karisa and Gichuri, 2010; Musa *et al.*, 2012, Manyala, 2011).

Indeed, as at 2011 Nyonje *et al.*, (2011) reported that total national aquaculture production, including ESP and other private farms is approximately 12,000 MTy^{-1}, equivalent to 7% of the total production and valued at $21 million Nyonje *et al.*, (2011). During the analysis, the production was estimated to hit 20,000 MTy^{-1}, which is about 10% of the total fish production by the year 2016 Nyonje *et al.*, (2011). This gives a rewarding chance for aquaculture expansion and investment opportunities in the feed and seed fish sectors, which unluckily still suffer from under exploitation. Comparing the production before and after ESP, it is vividly shown that before the introduction of ESP the production was too low despite the fact that there was high potential for production as was the case after the programme. Even after the introduction of the programme, the production rate has not reached its peak since the factors of production have not been fully utilized due to lack of proper research, linkages and collaboration between and among the key stakeholders.

Globally, Nile tilapia (*Oreochromis niloticus*), and its hybrids, are the most cultivated and widely farmed fish freshwater species after carps. Nile tilapia is the most important species, accounting for more than 90% of the total tilapia production (Fitzsimmons, 2016). Farmed Nile tilapia production has increased significantly. In 2015, the production was estimated at 5.5 million tons and but the production is projected to exceed 8 million tons by 2026 (Fitzsimmons, 2016). Cultured Nile tilapia are herbivorous and accept a wide range of diets ranging from natural organisms, garden wastes and greens to formulated feeds (Axelrod *et al.*,1985, Trewavas, 1983, Axelrod, 1993, Fryer and Iles, 1972; Guerrero, 1980; Charo-Karisa 2006). Principally, production of cultured Nile tilapia takes place under extensive and semi intensive systems using earthen ponds, cages and tanks in tropical areas with water temperatures well above 20°C (Leo and Schofield, 2008, El-Sayed, 2006).

2.4 Nile tilapia and aquaculture

Oreochromis niloticus (Linnaeus, 1758) is characterized by its compressed body form and an interrupted lateral line (Omondi *et al.*, 2011). This fish can grow to a standard length of 39.5 cm (Njiru *et al.*, 2012). The dorsal fin contains both spinous (16-17) and soft rays (11-15). During spawning season, the coloration of their fins change into red. *O. niloticus baringoensis* may be found in various freshwater habitats in Africa, with a wide and tolerant temperature regime (Omondi *et al.*, 2011). This sight-feeding fish prefers to live in pelagic zones with a diet dominated by phytoplankton and benthic algae (Stickney 2000). In aquaculture, the Nile Tilapia is ranked first among the species of choice for culture because of its characteristics. These include the fact that this fish is a fast grower, acceptable by consumers, accepts and thrills on readily, locally available supplemental feeds, eury-tolerant to environmental conditions and reproduces well in captivity. However, this species has a problem of over-reproduction which leads to "Runding" hence monosex culture is recommended and is vulnerable to diseases and parasites (Kaggwa *et al.*, 2011).

2.5 Environmental factors affecting Aquaculture production

Hossain *et al.*, 2007 on their study on physico-chemical parameters such as water temperature, alkalinity, ammonia concentration, dissolved oxygen (DO), pH and total hardness found out that there is a very strong effect of these parameters on fish health and their resistance and resilience against the disease-causing agents. In a different study, Aguilar *et al.*, 2005, indicated that disease transmission can be greatly favored and influenced by environmental conditions for instance low concentration in dissolved oxygen, high stocking density, poor hygienic conditions, temperature differences, and presence of secondary and definitive hosts in aquaculture systems and other surrounding aquatic ecosystems.

The nature and characteristic of parasitic infestation of fish community structure in any restricted ecosystem is influenced by both living and non living factors. Some of the most common abiotic factors which are recognized to have a very strong influence on parasitic infestation in any confinement include: temperature, pH, DO content, alkalinity, conductivity among others (Otachi, 2009). According to Gaffar, 2007, the impact of temperature on fishes also affects the parasitic infection in water bodies. For instance, different species of fish parasites have various behaviours and react differently to changes in water temperature where they are found. According to Marcogliese and Cone (1996), the composition structure, abundance, diversity and richness of the parasitic community of eel (*Anguila rostrata*) was seriously affected by water pH. When the pH of water increases, the snails which are the secondary host of digenean trematods get infected and the trematode parasites might be restricted from proliferation. A different study by Dzika and Wyżlic, 2009 found out that gammarids which is an intermediate host of acanthocephalan developed and metamorphosized more intensely and more acanthocephalan parasites could prevail. Halmentoja *et al.,* (2000) further did a study on the reactions and response of parasites of *Lates niloticus* in two different man-made lakes in Finland and their result showed that a decrease in the number of metazoan parasite species and in their abundance in low pH waters. However, very high species diversity was observed in more alkaline waters as compared to lakes with approximating neutral pH.

2.5.1 Temperature

Most of the aquatic organisms, especially fish, are sensitive to temperature changes in any aquatic ecosystem (Karisa, 2006, Delwar *et al*., 2011, Ngaira, 2006). Each species of fish has an optimum or preferred water temperature. Fresh water fish tolerates a temperature of 20^0C and 30^0C. Fish can sense very small changes in temperature, and when temperature exceeds their optimum, they are forced to move elsewhere in the stream. If the water temperature shifts too far from the optimum, the fish suffers. Some fish are more tolerant of changes in temperature, since they can survive in greater range of temperature. The varied acceptance levels of different fish results in competition between fish that are more tolerant, as they are often more abundant in areas with harsher temperatures. Water temperature varies daily, seasonally and annually. Water temperature does not change as fast as air temperature, but because of this, smaller increases in water temperature can have more of a negative impact on the water quality and ecosystems that depend on water (Arle, 2002).

2.5.2 Turbidity (TDS)

Turbidity in water is a measure of the clarity that is affected by the presence of solids, small particles, sediments, or pollutants. The more sediment in the water, the more turbid the water is; so, our drinking water is low in turbidity compared to water in great lakes. Materials that are suspended in water allow less light to pass through the water, and so this increases the temperature of water because suspended particles hold more heat (Omondi *et al.*, 2011). As such, suspended particles can clog fish gills, which results in reduced resistance to disease, decreased growth rates, and affects egg and fish larval development (Wahlberg *et al.,* 2003). As particles settle, they can blanket the stream bottom and smother fish eggs and aquatic insects. Sources of increased turbidity include soil erosion, waste water discharge, urban runoff, eroding stream, banks and excessive algal growth.

2.5.3 Dissolved oxygen

Dissolved oxygen is defined as the amount of oxygen dissolved in the water. Aquatic invertebrates and fish need sufficient dissolved oxygen to survive and thrive. Aquatic ecosystems gain oxygen from the atmosphere and from plants as a result of photosynthesis (Oduor, 2000). The amount of dissolved oxygen can be affected by a range of factors and processes going on in the ecosystem. If more oxygen is consumed than is added or produced, dissolved oxygen levels decline and some sensitive aquatic animals may move away, weaken or die. Dissolved oxygen levels fluctuate seasonally and over a 24-hour period. A dissolved oxygen concentration of 4-7mg/l is good for many aquatic animals. Aquatic organism exposed to low dissolved oxygen concentrations may be more susceptible to adverse effects of other stressors such as disease and toxic substances (Omondi *et al.,* 2011).

2.5.4 Hydrogen ion concentration (pH)

The pH level is a measurement of the acidity or alkalinity of water. Level of pH can indicate chemical changes in water, and the biological availability of nutrients in water. The pH scales ranges from 0 to 14. A safe level of pH of water ranges between 6.5 and 8.5 units. pH levels higher than 8.5 become highly basic, while pH below 6.5 become highly acidic for water quality. Largest varieties of fresh water aquatic organisms prefer a pH range between 6.5 to 8.0. The pH values in the stream water change due to human activities or due to submerged plants and animals (Oduor, 2000). The affluent discharges that come from industry, storm water and waste water treatment plants and quarries may have higher or lower pH values that in turn change the pH of the stream water. High acidity or alkalinity deteriorates water quality for both aquatic and recreational purposes and may cause irritation or damage to skin or eyes. Prolonged exposure of aquatic species to higher or lower pH may sometimes have fatal consequences.

2.5.5 Conductivity

This is a measure of the capability of a solution such as water in a stream to conduct an electric current. This is an indicator of the concentration of dissolved electrolyte ions in water. It does not identify the specific ions in the water. Fresh water ecosystems ideally should have conductivity between 150 to 500 µs/cm to support diverse aquatic life. However, significant increase in conductivity may be an indicator that polluting discharges have entered the water (Jason *et al.,* 2002).

2.6 Fish parasites and Diseases

Marcogliese (2001) describe parasitism as a process that negatively affects the host's life condition whereby one or more individual organisms derive nutritional benefits at the host's expense, usually without killing the host. Anyamba *et al.,* (2001) who further stated that overdependence of the parasites from the host might sometimes kill the host also supported this description. Parasitic infection always utilizes the host's energy, which would otherwise be available for the host's growth, sustenance, development, establishment and reproduction and as such may harm their host in a number of ways and affects the hosts production (Marcogliese, 2002; Barber, 2004)). In another study by Luoma and Rainbow (2008), it was reported that pathological effects due to parasites was worse in more polluted waters than in clean waters, as the pollutants act as irritants stressed the fish by reducing their immune system and this reduces their resistance to infection and other diseases. The parasitic infections increased the stress level and invariably weakened the immune system. There are other biotic and abiotic factors that affect parasite distribution in fish hosts. Some of the biotic factors according to (Pouder *et al.,* 2005) include but not limited to host age, size, weight, maturity, sex and parasite life cycle while abiotic factors are temperature, season, oxygen, pH and depth of water among others (Pouder et *al.,* 2005).

According to Anyamba *et al.,* (2001), it is difficult to isolate and quantify the effects of any single factor on parasitized fish population in the natural water bodies. However, studies of fish under culture or in captivity conditions have provided much information about the effects of parasites on fish survival (Pouder *et al.,* 2005). In a separate study by Sures (2008), it was reported that parasites can sometimes act as severe pathogens, causing direct mortality or rendering the fish more vulnerable to predators. Effects of parasite on fish according to (Poulin 2006) include muscle degeneration, liver dysfunction, interference with nutrition, cardiac disruption, nervous system impairment, castration or mechanical interference with spawning, weight loss and gross distortion of the body. Other severe pathological disorders include inflammation and atrophy of the viscera, resulting from compression of organs by the parasites, often together with accumulation of blood-stained ascetic fluid (Poulin, 2006). Parasitic infection is more likely to occur in natural water bodies, affecting fish growth, development, resistance to other infections and reproduction. These diseases, in addition to other factors, cause steady decline in fishery resources both in culture systems and open waters (World book, 2001). Parasites are also incriminated in severe pathological disorders in the affected fish, resulting in their economic and nutritive devaluation leading to rejection by buyers both locally and internationally (Marcogliese (2001). Parasitism is a phenomenon that the farmers need to deal with decicively in order to increase their rate of production and reduce the mortality rate in their ponds, cages and other culture systems (Shinn *et al.*, 2015). In a separate study by Otachi (2009), it was reported that parasitic infection in Oreochromis niloticus is rampant in culture systems and this lowers their economic value. According to Iwanowicz (2011), parasites are usually at equilibrium with their host aquatic organisms thus their roles in fish health are sometimes overlooked. However, destabilization of this equilibrium by factors like intensification of aquaculture, deficient management practices and lack of biosecurity plans leads to establishment of parasitic diseases (Paredes-trujillo *et al.*, 2016).

Parasites normally infect fish in various aquatic ecosystems. They range from very small microscopic types to big ones Lewis, (1991). According to Maria *et al.*, (2005), the well being of fish or fish health is highly influenced by the intensity of parasitic infection of *O.*

niloticus (Linnaeus, 1758) from Guarapiranga reservoir found in Sao Paulo state in Brazil. In their study the analysis of the hematocrits and the differentiated leukocyte counts were done. The occurrence and composition of various parasites were found to be related with temperature of water along with dissolved oxygen level. The leukocyte and hematocrit cells proportion displayed slight variation during the entire study period. Just basophil revealed high variation betwenn monthly mean values. The proportion of eosinophils was advanced in fish samples infested with *Ichthyophthirius multifiliis* and *Cichlidogyrus* spp. than in non-infested fish.

Generally, there are two main categories of parasites based on their body sizes according to (Marcogliese, 2005) i.e. micro parasites and macro parasites. The micro parasites are the tiny microscopic parasites that can not be seen through the naked eye but by the help of a high-resolution microscope. These include viruses, bacteria, fungi, protozoans, microsporidians and mixozoans. In the same study he reported that surveys for micro parasites in fish host, most often consider only protozoans (Marcogliese, 2005). Macro parasites are multicellular organisms which can be seen and identified without the use of a microscope and mainly comprised of the helminths and arthropods. On the basis of where they infect in the host's body (location), they are divided into ecto parasites and endo parasites. Ecto parasites are those found on the external surface such as the fins, skin or gills while endoparasites are the internal ones housed within the internal organs or cavities of a host (Marcogliese, 2002). Water pollution directly interferes with fish health and well being thus it can change the location, composition, pattern and distribution of parasite in the water hence spatial variation of parasitic infection in fish (Poulin, 2006). In a study to Investigate the effects of pollution on parasitic communities in aquatic environment by (Orina *et al.*, 2014), it was reported that parasitic infection is rare and seldom in Kenyan waters both open and culture systems. But recently increasing interest has been observed among scientists in this field for their awareness about environmental pollution which has been in the increase due to environmental degradation and its negative impact on world biotic fauna (Arle, 2002).

Generally, there are some parasites that have been observed to cause serious challenge in tropical regions in Africa (Otachi, 2009). These parasites include ectoparasites such as protozoans (*Ichthyophthirius multifiliis*, *Chilodonella* spp., *Trichodina* spp.), monogeneans (*Dactylogyrus* spp. and *Gyrodactylus* spp.). These parasites composed of vary dangerous internal and external types ranging fro protozoans to crustaceans amongs many other types. According to Otachi (2009), these parasites are known to reduce the production rate per unit area in any culture unit hence threat to sustainable aquaculture. Parasites' infection result into major economic effects on fish production which include massive fish death, rejection of fish infected by consumers in situations where parasites and/or lesions look noticeable; and more prominently, reduced and slow fertility rates, impaired growth and weight loss in infested fish (Otachi, 2009; Lagrue *et. al.*, 2011; Paredes-trujillo *et. al.*, 2016). Therefore, they represent a key constraint to production, sustainability and economic viability (Shinn *et. al.*, 2015). The major taxonomic groups commonly reviewed are as follows:

2.6.1 Protozoa

Protozoan parasites are unicellular eukaryotic organisms that belong to Kingdom Protista, and comprise of members of the phyla Sarcomastigophora (flagellates), Ciliophora (ciliates), Apicomplexa and Microsporea, with consideration to fish parasites. According to (Lucy and Ernest, 1994; Woo, 1995), their behaviour vary from independent organisms to different types of supported organisms to fully dependednt organisms at the expense of the host such as plants, animals and macro and microorganisms like protozoans. Biologists/parasitologists have widely studied interactions between parasitic organisms and their hosts and so far above sixty five thousand (65,000) different species have been sampled and analyzed and out of thi, more than two thousand four hundred (2,400) out of more than ten thousand (10,000) species know to infect fish are grouped as either internal or external fish parasites (Lucy and Ernest, 1994).

Several authors have studied and described some biological characteristics of protozoan parasites known to infect fish (Woo, 1995; Overath *et. al.*, 1999; Lom and Noble 1984; Lom and Dyková 1992; Lucy and Ernest 1994). Reproductive biology of these parasites will change from one ecological system to the other and that is why their reproductive success rate varies from one culture unit to the other depending on environmental conditions (Overath *et al.*, 1999 and Kreier, 1994). Even though majority of the protozoan parasites depict direct life cycle, some also have indirect life cycles (Woo, 1995; Overath *et al.*, 1999 and Mehlhorn, 1988). In the case of direct life cycle, protozoan parasite normally release either via wastes especiall for intenal parasites or when the primary host dies and spores or cysts can fall directly to water through leisons. These can find their way into a new host through direct ingestion or attachment. A part from this life style, protozoan parasites with an indirect life cycle like haemoflagellates normally need a secondary host and in most cases, this is usually very dangerous parasites Overath *et al.*, (1999).

2.6.2 Metazoa

i) Myxozoa

Fish parasites that belong to this group are differentiated from other parasitic groups by tiny openings, which composed of various cells that are transfigured into shell valves categories. Out of these categories, 2 to 7 nematocysts-like polar capsules comprise of an extrudible filament with a firm attachment (Lom and Dyková, 1992). They are familiar multicellular parasites found mostly in cold-blooded vertebrates, particularly fish. They portray diiferent complex development stages within their primary and secondary hosts and majority of them exploit alternative development inside an annelid worm at some point in their life cycle. Several species are exceedingly pathogenic in commercially important fish, mainly in aquaculture. According to (Lom and Dyková, 1992), myxozoans infect high diversity of fish parts and other internal organs of fish host. Gbankoto *et al.,* (2001a) carried out a study to investigate the myxozoan gill infection of the two fish species in Senegal for two years (i.e. 1987-1989). In this study, they evaluated the relationship between the host sex and growth rate of fish together with seasonal variation in parasite infection rate. They reported no significant effect showed for the dissimilar myxosporean parasites. On seasonality, a distict pattern was displayed for *Myxobolus zillii,* whereas as an effect on the growth rate of the fish host was established for *Myxobolus dossoui*. In their second, study i.e. Gbankoto *et al.,* (2001b), they now investigated *Myxobolus dahomeyensis* parasitic infection effect in tilapia species' ovaries from West Africa (Benin). In this study, they reported that the prevalence rates in ovaries varies from 18.3% to 31.6% in *Sarotheredon melanotheron melanotheron* and observed a very serious infection effect on reproductive success of this species.

El-Mansy (2005) carried out a follow-up study on *Myxobolus heterosporus* which was done by Baker 1963 (Syn. *Myxosoma heterospora*) (Myxozoa: Myxosporea) in African collections making use of specimens segregated from plasmodia found in the infected cornea of *Oreochromis aureus*. Besides this, he studied how the parasites affect histological parts on the infected tissue. The plasmodium's growth resulted in compaction and union of the cornea tissue's epithelial lining and inhabitted a broad region of the cornea tissue.

ii) Platyhelminthes

The phylum Platyhelminthes is composed of organisms, which are also known as "flatworms" and posses very distinct characteristics. They are the largest and the most common groupof parasitic infections in freshwater and marine ecosystems (Cribb *et al.*, 2002). Sveral studies (Myers *et al.,* 2005, El-Mansy 2005, Williams and Jones, 1994; Cone, 1995) identified and described Platyhelminthes as a phylum composed of four major classes namely: Monogenea, Trematoda, Cestoda and Turbellaria. The phylum composed of over 25,000 species found in all aquatic ecosystems (i.e. marine and freshwater ecosystems) and some inhabit terrestrial ecosystems and this make this group of parasites to be the largest group with no coelom of which some are independent (free living) while others are parasitic in nature. The class turbellaria consists of about 3000 species found in marine and brackish environments even though some are also found in freshwater ecosystems, e.g. Planarians. According to (Campbell, 2001) he stated that although majority of the members of this group are free living, some of them have been observed to be parasitic in nature such as order Temnocephalida. The monogeneans which usually exhibits a direct life cycle is comprised of roughly fifty families besides thousands of studied and unstudied species that mostly attack gills and skin of the host fish. Cribb *et al.,* (2002) in their study reported that monogeneans do not have fully developed systems such as circulatory, skeletal among other systems. They have also an uncomplicated digestive system comprising of a mouth opening having a pharynx with muscles together with an intestine without terminal opening. According to Cribb *et al.*, (2002), they are also hermaphroditic having functional organs of reproductive of both sexes, which occur in a single individual, and they possess a head section containing concentrated sense organs.

Depending on the location and complexity of their haptor, monogenean parasites are divided into 2 major subdivisions i.e. monopisthocotylea comprises of one major component to the haptorand Polyopisthocotylea with several components to the haptor (Woo, 1995). The class Monogenea plays a vital role as it has a high economic value concerning fish health and fish farming worldwide. Cribb *et al.*, (2002) in their study noted that this class is dominated with 2 families of Dactylogyridae and Gyrodactylidae as the two are widely studied and documented as the dominating species. Mauricio *et al.,* (2002) described issues of fish diseases in Sao Paulo State in Brazil from January 1999 to December 2000 in their fish health study. In 1999, the monogenean parasites recorded the highest relative abundance (72.9%) of all other classes studied. A separate study by Laurent *et al.,* (2006) on systematic of fourteen (14) monogenean species (Ancyrocephalidae) parasites of gill from West African tilapiine hosts (Cichlidae) by the use of genetic and morphological data reported that this type of parasites are very particular to the type of host they infest. They undergo a very simple and straightforward life cycle where their eggs are hatched into an independent larva normally called Oncomiracidia. These free-living larvae infect fish directly or in some cases, an embryo hatched from an adult monogean is transmitted directly by the adult monogean into nearby hosts (Ronald, 1978). Trematodes is another class of Platyhelminths, which is composed of two main orders i.e. Aspidogastrea and order Digenea. The total number of identified and described trematodes according to Cribb *et al.*, (2002) is about 9000 parasitic species which are know to attack and invade both both tropical and sub-tropical vertebrates. Unlike digenean, the members of Aspidogastrea is widely found in coastal and salty ecological systems and are known to infect the marine gastropods (Myer, 2001; Cribb *et. al.,* 2002). According to Ronald (1978) on his study on the parasitic life cycles of dominant parasites affecting fish species, he reported that Trematodes have intertwined and complicated type of life cycle where atleast one intermediate host must be present for the cycle to be complete. He further reported in the same study that adult trematodes are not independent and still fully depend on their host for survival. Exception (*Aporocotyle* genus), digeneans undergo most or all of their larval development stages in mollusks (Ronald, 1978).

Extremely a small number of fully developed digeneans are very dangerous and causes an enormous threat to their host whereas the larval (metacercarial) stages seriously affect the reproductive and survival success of their host, and in some cases these effects are transmitted to human beings (Woo, 1995). All cestodes are endo parasites of vertebrates with more than five thousand (5000) species until now are identified and described. Majority of them need a minimum of 1 intermediate host before they move to the definitive host where they complete their life cycle as adults. According to Woo, 1995, two life cycle stages are represented in fish: in most cases the adult parasite attach themselves in the intestinal wall of the host, and plerocercoid larvae of similar or dissimilar parasite species are located in the musculature and viscera; the larvae at the very initial stage (procercoids) are usually found to inhibit aquatic crustaceans.

Morphologically, the mature cestodes are powerfully leveled dorso-ventrally, the body part is segmented and composed of the three main parts i.e. head, neck and the body and the head usually composed of several serial parts known as proglottids. Not all cestodes are segmented but there are also few unsegmented cestodes, which are additinally described from fish (*Khawia*, *Caryophyllaeus*, etc.). Scolex which is the head is an connection organ employed to fasten and hold firm the parasite to the intestinal mucosa of the host, and therefore it is normally offered with clutch structures including bothria and suckers, and moreover proboscids and/or hooks. Cestodes lack intestine, the food is absorbed via the tegument casing the entire body surface area. Most of the cestodes are hermaphroditic (both male and female gonads) with very few exceptions. According to Woo (1995), every proglottid with its personal set of female and male gonads. Lenta (2002) examined the terms related to the nomenclature of metacestodes or larval and the diverse morphological as well as developmental personalities employed to describe diverse forms of larval cestodes. Most of the cestodes are known to cause disease in fish (mainly at a initial stages of their live cycle) and in several cases may be spread to human beings, like for the *Diphyllobothrium* spp., which cause a severe fish-borne zoonosis known as Diphyllobothriasis.

iii) Nematoda

This is the most common and available' taxon having more than eighty thousand varying described and identified species (more than 15,000 of the species are not free living but depend on their host for a living). They are found in almost all existing ecosystems: in terrestrial, freshwater bodies, marine as well as coastal ecosystem. In a study by Jadwiga (1991), it described the taxon as consisting of both free ling and parasitic organisms found in both animals and plants, including fish. Additionally, they are famously known as "roundworms" because of their morphology as they posses cylindrical, lengthened body, and round in section. Jadwiga (1991) studied this phylum and described it as unsegmented parasites, bilaterally symmetric having a full digestive system comprising of 3 sections: middle (intestine), posterior (rectum) and anterior (oesophagus) and finally ending with the anus/cloacae. The taxon does not contain parenchyma as in other parasites such as Platyhelminthes but posses pseudocoel, which play very crucial role in proper functioning of the parasite. In the same study, they further described the phylum as dioecious, having males regularly but not always smaller as compared to females. These parasites mostly are associated with infectin the alimentary canal of their host (Jadwiga, 1991). They have a very indirect and a complex life cycle, which composed of a primary host and one or two secondary host(s) depending on their availability. During its life cycle, the larva passess through 4 different larval stages before becoming sexually and reproductively mature adult. In this phylum, fish can either be primary or secondary host depending on their availability. According to Jadwiga (1991), fish as the intermediate host of the nematodes usually have birds or mammals as their final host. During its life cycle, the first secondary host is normally an aquatic crustacean or aquatic vertebrate. Some nematodes parasitising fish during larval stage are spread to humans through eating unboiled fish that is infected and bring serious diseases such as Anisakiasis (Jadwiga, 1991).

iv) Acanthocephala

Acanthocephalans mostly called as "thorny or spiny-headed worms", they are from the separate distinct phylum Acanthocephala having approximately twelve hundred species (1,200) classified into 3 separate classes, consisting of: Eoacanthocephala, Palaeacanthocephala and Archiacanthocephala. All of them are intestinal parasites as they mostly attack the intestinal parts of the host fish. This taxon has different hosts including some of their main hosts include fish, birds, mammals and amphibians (Jadwiga, 1991). According to Woo (1995) who described the morphological description as they are very slim in size,hooked on the posterior section, with no digestive system hence they take up food matters with the entire body's surface area. The acanthocephalans are dioecious, having females generally bigger than males, and oviparous. They display an in direct life cycle having the crustaceans as their intermediate hosts. Acanthocephalans are transmitted through food ingestion, which is infected with their larva. Mostly *Oreochromis niloticus* species appear to hosts a number of species. Mahmoud *et al.*, (2006) on their study on the characteristics of this type of parasites on three different fish species found out that high prevalence and mean instensity of this parasite results into serious pathogenicity which results to fish death and mass mortality in the long run.

v) Crustacea

The crustacean is one of the largest groups of parasitic organisms. They are consisting of roughly fifty-two thousand (52,000) sampled, described and identified species worldwide, and are normally taken as a distinct sub-phylum of its own. They are commonly known as arthropods and mostly found in lentic aquatic ecosystems such as ponds, lakes, oceans and swamps. Most of the crustaceans are aquatic (occupying mostly lentic ecosystems). They mostly inhabit both freshwater and marine ecosystems but some groups are also adapted to survive in terrestrial environments (Jadwig, 1991). Many crustaceans are free ling and very mobile, stirring around actively and separately, although some taxonomic units are parasitic in nature and can not move about independently and therefore survive close to their hosts (comprising tongue worms, sea lice, anchor worms among others) (Jadwiga, 1991). Crustacea parasites on fish are several as species and abundant as individuals as well, displaying different structural adjustments to adapt in the host. There are 3 main categories of Crustacea in the field of fish parasitology and they include: Branchiura, Isopoda and Copepoda, with the Isopoda and copepoda mainly found in marine and coastal environments (Woo, 1995). Most of the two thousand (2,000) species having been termed as parasites to fish belong the class Copepoda making them the largest group. The group is extremely heterogeneous, displaying diverse adaptations to different locations and resproductive success to different parasitic organisms; they vary from the free-living ones to fully parasitic organisms (Woo, 1995).

The copepods undergo a simple and direct life cycle with no complexities, in most cases; they have many different larval and adult stages during their life cycle. They are dioecious, and their females bigger than males. Their females are bigger in size than the males and the females hatch their eggs into a specific larva that shall experience numerous moults to diverse larval stages (species-based). The crustacean parasites negatively affect fish host in three different ways: interfers with the soft tissue thus causes biological damageon the rest of the organs at the expense of the parasitic organisms (Jadwiga, 1991).

2.7 Impacts of fish parasites and diseases in aquaculture

Most of the cichlids such as *Oreochromis niloticus* are known to be to be less susceptible to stress and diseases and possess a wider range of environmental conditions, not like other fish species for example *Serranochromis* species. Despite tilapia being categorized as disease resistant species, the level of water pollution generally performs a vital function in the process in dseases control and management (El-Sayed, 2006). Noga,

(2010) noted that fish parasites and diseases is a major area that challenge that negatively affect fish production worldwide. One of the major considerable diseases in tilapia culture globally, and mostly in an enclosed culture systems, is brought by *Streptococcus* bacteria. El- Sayed (2006) reported that this is an opportunistic bacterium since it would affect fish when the level of pollution rises and the fish is stressed. It has thus been liable for major losses in tilapia fisheries. Parasites form a major source of diseases constributiing to high risk in aquaculture production globally (Nicholas, 2000). The parasites generally influence the growth rate of profitably produced fish from aquaculture units, therefore raising an alarm in public health, particularly in areas where smoked or raw fish are consumedas this may lead to diseases being transmitted to human beings (Paperna, 1996). In aquaculture systems, likelihoods of high pathogenic infection can arise, contributing to high fish mortalities and financial or economic losses, whereas in natural systems, parasites can negatively influence the diversity and abundance of native fish species (Douëllou, 1992; Paperna, 1996). Information on parasites and disease in aquaculture fish species in Africa have been sporadic in entire Africa and particularly sub-Saharan Africa (South Africa being the exception) (Hecht & Endemann, 2007). It is majorly because of the low-level passion of aquaculture in the area. Presently the missing research on fish diseases in Africa is never observed as an aspect that will negatively influence aquaculture development and so is not a focus research area (Hecht & Endemann, 2007).

2.8 Fish parasites and Indices

Concerning the African continent, although productive and technological advances have been recently achieved in the tilapia farming in Egypt, the aquaculture activities undertaken in East African countries are still under-developed for several reasons, among which the lack of know how both in productive and commercial areas is of great importance (Chapell *et al.*, 1994; Muzaffar and Helaludin, 2001).

Diseases could represent an important constraint to aquaculture production, causing both production losses and public health problems. Therefore, the knowledge of the diseases of major concern in a fish farming system is necessary in order to assess the risk factors influencing their introduction/spreading and define the measures useful to their prophylaxis and control. Although several scientific papers and books have been published in the past on pathology of wild and farmed fish from Africa (Chapell *et al.*, 1994), the collection of new data was necessary to identify the diseases of major concern in fish farming, mainly in reference to the risk factors influencing diseases outbreaks in the cage farmed fish, their influence on productive parameters and their possible public health implications.

Fish in their natural environments are typically subjected to numerous stressors including unfavorable or fluctuating temperatures, high water velocities and sediment loads, low dissolved oxygen concentrations, limited food availability and other episodic variables. In addition, anthropogenic stressors such as contaminant loading add to problems that fish may already experience in many systems. All these factors individually or together, can impose considerable stress on physiological systems of fish and impair their health (Aloo, 2002). The effect pollutants on fishes depend on several abiotic factors such as; water, pH, temperature and biotic factors such as; fish size, age, life cycle, feeding habits & reproductive cycle. The effects of pollutants are manifested in different ways and can be determined using several indices. Fishes have often been used as bio-indicators of pollutants in aquatic environments (Raburu, 2003). In his study, Raburu (2003) reported that different species of fish expresses varied pollutant tolerant levels and therefore it is very important to use a norrow pollutant range for biomonitoring purposes.

2.8.1 Effect of parasite infection on host body condition and growth

In fish species, “condition parameters or factors” (condition factor; hepatosomatic, gonadosomatic, and splenosomatic indices) are mostly used to evaluate the overall well being of fish and energy allocation to different biological functions (somatic growth, reproduction, immune responses). The value of the hepatosomatic index reflects the nutritional state of the fish. In the fish liver, energy is stored (in the form of glycogen) during periods of high energy intake (Schreck and Moyle, 1990). These energy reserves can be utilized by fish during periods of low energy intake (starvation) (Hilton, 1982). The gonadosomatic index is an indicator of energy allocation to gonad development (Hilton, 1982). It can be also used as an indicator of fish reproductive maturity (Schreck and Moyle 1990). The splenosomatic index may point to the increased activity of the fish immune system. The spleen is the main immunological and hematological organ in fishes (Dalmo *et al.,* 1997).

Malek (2001) revealed that increasing numbers of trematode *Labratrema minimus* in the liver and muscles of fish species *Pomatoschistus minutus* decreased the hepatosomatic and gonadosomatic indices of the host. However, in another fish species, *Pomatoschistus microps,* the opposite effect of this parasite species on the hepatosomatic index was found. According to the author, it was probable that the trematode might reduce liver weight (hepatosomatic index) in both fish species; however, the weight of the large number of parasites in the liver of *P. microps* actually caused an increase in the hepatosomatic index (the trematode was localized predominantly in the liver of *P.*

microps but predominantly in the muscles of *P. minutus*). *Cryptocotyle concavum*, a trematode species found in the peritoneum of *P. microps*, was found to reduce the hepatosomatic index of its host, supporting the idea that the increase in hepatosomatic index in relation to *L. minimus* did not represent objective evidence of parasite effect on liver weight. Lefebvre *et al.*, (2004) did not confirm the expected effect of a non-native nematode species *Anguillicoloides crassus* on liver mass in European eel (*Anguilla anguilla*), but the authors found that parasite infection caused a significant increase in fish spleen mass. These results were explained by the system of energy storage in eels (energy is predominantly stored as lipids in muscle tissue) and the bloodsucking activity of the parasite. Spleen enlargement was probably caused by the hypersynthesis of blood cells to compensate for the blood loss and also by the synthesis of immune cells against the parasite. Brouder (1999) found a negative correlation between the length or weight of roundtail chub (*Gila robusta*) and the abundance of an introduced tapeworm (*Bothriocephalus acheilognathi*). The author also revealed that infected fish were significantly shorter than uninfected fish, indicating that the infection with tapeworms may have slowed fish growth. However, it was not clear whether these results indicated a "cause and effect relationship" (i.e. tapeworms cause slower growth). It was suggested that the differential diet among the size classes of chub may have played a role. Small fish are more likely to feed on cyclopoid copepods (intermediate hosts of the parasite) than larger fish and they are probably also more susceptible to infection. When a small fish becomes infected, its growth may slow, which increases the likelihood of continued feeding on copepods and the likelihood of further infection (i.e. tapeworms may slow fish growth and slower growth may increase infection). A negative effect of parasites on host growth was also demonstrated experimentally (under natural conditions) when comparing bird nestlings (finch *Geospiza fortis*) infected with introduced fly larvae (*Philornis* *downsi*) and nestlings with an artificially decreased infection level Oladebo, (2004) and Koop *et al.,* (2011). The less infected nestlings had longer primary feathers and also tended to have higher body mass and longer tarsi compared to naturally infected nestlings. These differences were considered to affect the fledging success of nestlings and their further survival.

In some instances, parasite infection was found to enhance host growth. Parasite induced somatic growth enhancement (gigantism) may be associated with parasite-induced castration of the host (see the next chapter). In a few cases, however, growth enhancement was recorded in hosts infected with non-castrating parasites. For example, Arnott *et al.,* (2000) found in an experimental study that fish (*Gasterosteus aculeatus*) infected with cestode plerocercoids (*Schistocephalus solidus*) grew faster (i.e. had higher weight increments) and had a similar or better condition than uninfected fish. Infected fish had a heavier spleen (which did not cause the difference in total body weight between infected and uninfected fish) but gonad weight was comparable between infected and uninfected fish. The faster growth of infected hosts was found surprising, as the hosts must have suffered energy loss due to parasite growth (*S. solidus* plerocercoids gain a relatively huge body size and weight in fish hosts) and probably also due to immune response (demonstrated by spleen enlargement). It was suggested that enhanced growth might represent a host response (e.g. increased food intake or reduced activity) that decreases the risk of starvation over winter, i.e. in an energetically demanding period, or that it might be controlled by the growing parasite, which needs enough space or needs the host to be larger and thus more vulnerable to predation (host manipulation by *S. solidus*). A review by Barber *et al.,* (2008) indicated that the impact of *S. solidus* infections on *G. aculeatus* biology is strongly influenced by rearing conditions. When access to food is unrestricted (which is possible under experimental rather than natural conditions), infected fish are able to sustain high growth rates, fuel parasite growth, and still lay down energy reserves. When infected fish are reared under competition for limited food resources, or are fed a restricted diet, a negative impact of the parasite on host growth and energetics can be found, corresponding with the impact in natural populations (lower body condition in infected fish).

Johnson and Dick (2001) found a significant negative effect of three parasite species (microsporidian *Glugea* sp., larval digenean of *Apophallus brevis* and larval nematode of *Raphidascaris acus*) on the growth, reproductive potential, and survival of yellow perch (*Perca flavescens*). Each parasite species affected host biology in a specific way. It was demonstrated that the impact of the parasite on the host is determined by interactions among parasite and host characteristics (e.g. parasite location in the host and a way of parasite transmission; host age, size, sex, and trophic status). The expressions of parasite effects on the host were related to the fish overwintering period and the period of sexual maturation.

2.9 Socio-Economics factors affecting fish production

Fish is a popular diet all over Africa as stated in a report by the Food and Agriculture Organization (FAO) on the State of World Fisheries and Aquaculture (2008), and further that the fish sector is a source of income and livelihood for millions of people around the world (FAO, 2008). Employment in fisheries and aquaculture has grown substantially in the last three decades, with an average rate of increase of 3.6 per cent per year since 1980. It is estimated that, in 2008, 44 million people were directly engaged, full time or, more frequently, part time, in capture fisheries or in aquaculture and at least 12 per cent of these were women (Foeken, *et al.*, 2008). On average, each jobholder provides for three dependants or family members. Thus, the primary and secondary sectors support the livelihoods of a total of about 540 million people, or 8.0 percent of the world population (FAO, 2008).

One of the Sustainable Development Goal (SDGs) calls for a reduction of 50% between 1990 and 2015 in the number of people who suffer from hunger and whose income is less than US$1 per day (Foeken and Owuor, 2008). Further, the number of people living in poverty is estimated to have risen from 11 million or 48% of the population in Kenya to 17 million or 56% in 2001 (Foeken and Owuor., 2008). Consequently, urban poverty is rising fast. As a result, new strategies for coping with poverty have to be revised to cope with the dire situation for example multiple sourcing of cash incomes and fresh water fish farming (World Bank 2000; Foeken and Owuor, 2008). According to Halwart *et al.*, (2007), a number of subsistence-level fish farmers have turned into small-scale commercial fish farmers to produce for both the local and export markets hence making a significant contribution to both food security and foreign exchange earnings in Kenya and in the year 2008, Foeken and Owuor (2008) reported in their study that in Kenya there are several factors and challenges facing the aquaculture industry. In their study they listed some of the challenges facing the industry as follows: lack of capital, land tenure system, quality feeds and seeds, lack of insurance cover, insufficient training among the farmers and other stakeholders along the value chain among others. This was also supported by Mwangi, 2008 whose study listed a good number of challenges affecting the industry. In his study he highlighted the significance of aquaculture to the country's economy and gave recommendations for sustainable aquaculture (Mwangi, 2008; Osure, 2011). For instance, the demand for fingerlings to stock the fast-growing number of fishponds has skyrocketed from 1 million to 28 million in less than a year, forcing the government to lean heavily on private industry. Ngugi *et al.,* 2007 reported that insufficient availability and quality of fingerlings for stocking is one of the key challenges facing the development of aquaculture in Kenya. As of 2007, according to Ngugi *et al.,* 2007, the ministry of Agriculture, Livestock and Fisheries reported that the yearly demand for *Clarias gariepinus* fingerlings in Lake Victoria was 10 million annually for fish farming and 18 million for bait. Three years later, Charo-Karisa and Gichuri, (2010) reported that the total demand for both *Clarias gariepinus* and *Oreochromis niloticus* fingerling is estimated at 100 million yr^{-1}. The demand for fish fingerlings is unattainable despite the government's support hence there is need for heavy investimate on private hatcheries to bridge the the demand and supply gap (Ngugi *et al.,* 2007). Additionally, the quality of the fingerling supplied should be certified as some of the suppliers supply substandard fingerlings. To attain the right quality fingerlings, the authority together with all stakeholders in the fisheries sector should promote measures to acquire same-sex fingerlings with the use of hybridization and sex reversal techniques to curb the problem of inbreeding in culture facilities. Conversely, those initiatives are still not popular amongst fish farmers because of the technical knowledge as well as facilities needed (Charo-Karisa and Gichuri, 2010). These are various areas in which private investors in Kenya may connect to sustain fish farming. The Kenyan government via the aquaculture functioning grouping which brings together fisheries officers, researchers, fish farmers, Kenya Bureau of Standards (KBS), and other stakeholders has further legalized fish hatcheries countrywide and they have drafted seed fish quality standards, which are projected to bring solutions to problems of inferior seed fish in the aquaculture market in the country (Charo-Karisa and Gichuri, 2010; Ngugi *et. al.,* 2007).

Because of this scenario coupled with other numerous challenges there is no significant growth in fish farming industry and the farmer is left confused by many extension officers who visit and give varying information as some of them do not have the right knowledge on fish farming (Ngugi and Manyala, 2004). Furthermore, there are no adequate comprehensive policies, legal framework and guidlines on fish farming and legislation are inadequate too (Mwangi, 2008; Osure, 2011). Because of this gap, policy makers have accorded low priority to fish farming as an economic activity. Subsequently the sector has operated for a very long time without a comprehensive policy and legislation. This coupled with other constraints according to Mwangi (2008) and Ngugi *et al.*, (2007) has reduced management and research effectiveness, discouraged investment in fish farming and constrained production and growth. Most farmers have not yet embraced the technology for producing high quality seed as they claim its very expensive and the end result is also unknown (MOFD, 2011 and Nicholas, 2000). In the same study the ministry reported that commercially produced feeds are hard to come by and when available they are expensive for most farmers to afford. Inadequate training programmes for farmers and extension workers have retarded the growth of the fisheries sector in the country. The inadequacy in provision of extension services has been a major challenge to development of fish farming in Kenya. This situation results from lack of resources and technical staff (MOFD, 2011). Inadequate outreach programmes and inefficiency in dissemination and transfer of technology to farmers also play a key role and constrains the development of aquaculture sub-sector in Kneya (Musa *et al.*, 2012). Many farmers with good land within a suitable area for aquaculture that can be put into fish farming are not even aware of this potential due to lack of knowledge on fish farming. Most if not all farmers do not take fish farming as an enterprise and therefore do not keep records of their income and expenditure together with inefficient statistical data collection among the fish farmers have seriously impeded information dissemination on fish farming (Munguti and Charo-Karisa, 2011). Low funding of the sub- sector activities by the Government and coupled with low investment by the private sector are some of the major constraint to this sector. Government of Kenya through the ministry of fisheries in the year 2011 stated that poor quality fish feed paused a challenge to the development of aquaculture in the country (Musa *et al.,* 2014; MOFD, 2011). Many of other studies shows that fish feed is very critical when it comes to aquaculture business because fish feeds account for more than 40-50% of the total production cost (Craig and Helfrich, 2002; Munguti and Charo-Karisa, 2011 and 2006). Munguti *et al*., (2012) and Musa *et al*., (2012) indicated that one of the most serious challenges in aquaculture set up is quality feeds, seeds, extension officers to advise and guide farmers on the best practices. In reaction to the ESP project, the Kenyan fish feed sector experienced a shortage of 14,000 MTy^{-1} (Charo-Karisa and Gichuri, 2010). Since then, the aquaculture industry has been growing continuously and the demand has increased tremendously to about 50,000 MTy^{-1}(Charo-Karisa, 2011). Due to the increased demand for fish feed, unscrupulous dealers sometimes sell feed of compromised quality, prompting the government to initiate efforts to establish national standards for fish feeds (Munguti and Charo-Karisa, 2011). The feed challenge originated from the raw materials used for feed formulation (Munguti *et al.,* 2012). The bulk of raw materials used in fish feed production are waste products from agricultural production of human food, such as maize bran, rice bran, wheat bran and sunflower cake. These crops are produced as rain-fed agriculture with yields depending on weather conditions and affected by climate change. Besides this, these ingredients also face stiff competition from other livestock production systems, mainly poultry and dairy feed production units. These formulated feeds from the agricultural raw materials are deficient in macro- and micronutrients and have anti-nutritional factors and poor palatability, leading to low fish growth that limits fish yields per unit area (Munguti *et al.,* 2014b). Other factors that come into play and affect the overall yield include issues regarding quality, quantity, timely supply and affordability as they have affected the robustness of the supply chain (Munguti *et al.,* 2014b). An inventory by Gitonga (2014) shows that there are numerous livestock feed manufacturers, but very few have taken up fish feed manufacture as fish industry has not been well developed to attract more investors. Scarcity of fish feed limits timely supply to the farmers as many farmers stay without feeds for a longer time even after the order. In addition, since some of the materials (e.g. cotton seedcake) are sourced from the neighbouring countries, specifically Uganda and Tanzania, the cost of feed production goes up, making it unaffordable to the small-scale producer (Nalwanga *et al.*, 2009).

The Fish Farming Enterprise Productivity Programe (FFEPP) which was an initiative to enhance fish production in Kenya triggered an increase in demand for feed from about 10,000 tonnes to about 50,000 tonnes per year (Munguti *et al.,* 2014a); the lack of fish feed was a key challenge in the FFEPP implementation as the implementation stage took longer than expected, because of the the lack of established fish feed manufacturers in the country it forced the farmers to make feed themselves even though they did not have the technological know-how with no formal training, this resulted to poor quality due to the poor quality of ingredients used (Gitonga 2014). Despite the presence of the Kenya Bureau of Standards (KEBS: a statutory body charged with enforcement of standards and certification), there is still a challenge in ensuring quality of animal feed in the country, particularly of fish feed as most feed processors still supply poor quality feeds. Most of the smaller feed processors are unregistered, unregulated and difficult to trace, therefore evading the oversight of KEBS (Gitonga, 2014). Furthermore, most feed ingredients are not fully standardized, so manufacturers have challenges in complying with set overall feed regulations and standards (Gitonga 2014; Ogello *et al.*, 2013).

Lack of market access, market demand and fish prices too are factors of concern in aquaculture development in Kenya (MOFD, 2011). Markets for farmed fish are not robust, even though there is potential for increased demand due to dwindling catches in the capture fisheries (Liti *et al.*, 2005; Ngugi and Manyala 2004). Though it is believed that farmed fish can compete favourably in the market with capture fish, what consumers actually want is not properly known, and fish and fish products that target different market segments require different handling, processing and packaging (Liti *et al.*, 2006). In addition, the market segmentation for farmed fish is less well understood than that for capture fisheries (Ngugi & Manyala 2009). One of the bottlenecks that limit the marketing of aquaculture products is the relative ignorance of the Kenyan consumer when it comes to particular fish species (Ruthuis *et al.*, 2011). Sometimes consumers are sold fish species that are incorrectly labelled as tilapia; this creates a negative image if the fish consumed does not live up to the expectations. Also, value addition by traders such as fishmongers is limited, as are consumer fish preparation and cooking skills (Rothuis *et al.*, 2011). Lack of cold storage facilities to store fish after harvest has limited marketing of farmed fish. Since fish is a highly perishable commodity, farmers risk post harvest losses if they harvest all their fish from their ponds or any other culture system without a ready market. Unlike the captured fish market, where processing – such as smoking – to increase shelf life takes place at the lakeside point of capture, in the farmed fish supply chain the fish processing segment is not well established (Shitotel *et al.*, 2012). Despite the high demand for fish, market linkages for farmed fish are not as established as they are in the horticulture and dairy milk supply chains. Farmers therefore need to focus on high potential market areas. Studies show that in the top 10 fish farming countries in the world, small to medium enterprise fish farming success is due to strong and active markets; access to quality fingerlings, feed, credit and transport; and a focus on profits (Shitote *et al.*, 2013). The government of Kenya through the ministry of fisheries in the year 2013 reported that challenges for markets in aquaculture are based on lack of market information; low value addition strategies; threats from imported fish, particularly from China; competition from capture fisheries; and inability of farmers to consistently produce enough fish to sustain market demands (MOALF 2013). The high demand for fish in Kenya is mostly being met by capture fisheries, which contribute about 86% of the total fish production in the country (MOALF 2013). It is a challenge for fish farmers to enter and sustain production for these markets. The niche that fish farmers could occupy that is to supply is also difficult to access due to marooning of water hyacinth, as farmers in some areas have to compete with illegal fishers who poach during the closed season and sell their fish very cheaply (Shitote *et al.*, 2013). Rothuis *et al.*, (2011) identified market segmentation for fish ranging from rural to urban, low income to high income and from low consumption to high consumption and even tourists. The results are as follows: For low income segments in urban areas (often slums), relatively small portions of fish (100– 150 g) are preferred as they are less expensive. People buy either whole, small tilapia or small pieces of tilapia or catfish. On the other hand, middle income families will prefer size ranges of 250–350 g, while high-end markets will prefer sizes above 350 g. Prices can go up to USD 1.87/kg in major cities such as Eldoret and other parts of the country; and for major towns surrounding the aquaculture production centres, markets for fish are assured (Quagrainie *et al.*, 2010).

Given that small-scale production is done in cycles of 6–8 months, it is difficult for the farmers to maintain a regular supply of fish as they need time to prepare their farm for the next production cycle and especially when they do not have cooling facilities for fish preservation (Quagrainie *et al.,* 2010). In addition, Kimathi *et al.,* (2013) reported thatthere is no contract farming in fish farming industry similar to that common in sugar and rice farming. Farmers have been encouraged by the GoK and NGOs to form clusters from which they can increase production via shared learning and common purchase of inputs as this will reduce their production costs as they will purchase the farm inputs in bulk. Cluster farmers have been helped by the Aquaculture Association of Kenya (AAK) to link to markets in urban centres. According to Kimathi and others in their study reported that when organised in clusters, the farmers can plan the stocking, production and harvest to ensure consistent supply of fish once market linkages have been made. Learning institutes and health facilities can provide regular markets as long as these clusters can maintain production and a regular supply throughout the year (Kimathi *et al.*, 2013). Obiero *et al.*, (2014) further stated that forming of clusters is an opportunity for farmers to have joint investments in cold storage or processing facilities as well as marketing through gathering and sharing price information. However, it is important that farmers start viewing aquaculture as a commercial activity instead as a subsistence activity.

In addition, aquaculture challenges facing most farmers are compounded by inadequate entrepreneurship skills by the farmers and lack of credit facilities. Nonetheless, although it has not been scientifically quantified, Kenya has enormous potential for fish farming in the agricultural rural zones (MOFD 2011 and DOF 2012). In fact, extensive water bodies provide great potential for food and incomes for rural population (Obiero *et al.*, 2014;

Ngodhe *et al.,* 2013). Munialo (2011) and Ngodhe *et al.,* (2013) stressed that the potential for growth and expansion is high given the many favourable physical endowments of the region. The physical features include; adequate rainfall, a well distributed network of rivers, streams, dams, satellite lakes and wetlands as well as suitable climate and suitable soil type. The Kenya Integrated Household Survey of 2005/06 indicated that 46% of the rural population living near perennial and seasonal water bodies fall below the poverty line. All these happen despite the potential these water bodies hold. In reaffirming the potential of the region Munialo (2011) explains; other advantages include favourable physical features such as the vast gently sloping land, fertile soil with high water retention capacity, and regional and international markets. The potential of fish farming can be tapped to increase fish production through fish farming. Lake Victoria which is an existing natural water body can be used for cage and pen culture to increase fish production (Mwangi, 2008; FAO, 2007a; Munialo, 2011; Ngodhe *et al.,* 2013). In another study, conducted by (Ahmed and Lorica 2002), they sought to provide a framework for examining aquaculture's linkages to food and nutritional security by highlighting key role of aquaculture in household food and income systems in developing countries. Examples were taken from Asian countries and it was established that there was a steady growth over the last decade with regard to employment, income and consumption. From the study that was conducted there was clear evidence of positive income and consumption within households. There is increased recognition for improved and balanced nutrition, including critical vitamins and minerals in the diet and the need for improved sanitation, hygiene and living environment, which are related to income and purchasing power improvement. Ahmed and Lorica (2002), in their recommendations, they indicated that there is a wide scope for more empirical studies to be carried out on the varied opportunities that aquaculture would provide to improve the income, employment and food consumption within households. Since food insecurity mainly affects poorer communities, (Ahmed and Lorica 2002), targeted small subsistence-oriented farmers in their study. They looked at the key socio-economic and policy factors affecting aquaculture adoption and its impact on poor and asset less people. They reported that even though there is high potential for fish farming in Africa, very few governments have a long-term plan for aquaculture and this makes it difficult for them to quantify their production targets as far as fish farming is concerned (Ahmed and Lorica 2002). The development and wider adoption of aquaculture can be seen as a significant basis for improving household food security and general household welfare (Munialo, 2011; Ahmed and Lorica, 2002). Aquaculture has the potential to contribute to the food and nutritional status of people in at least three ways (adoption-income linkages; adoption-employment linkages; and adoption consumption linkages) (Ngodhe *et al.*, 2013; Rivera and Cary, 1997; Ahmed and Lorica 2002).

The aquaculture sector in Kenya lags behind developments in other parts of the world and even further behind the sectors in Nigeria and Egypt, where there has been great advancement in fish production as a result of hybridization, genetic selection, application of all-male tilapia culture, formulated diets, biofloc technology ponds, cages, tanks and recirculation systems (Gitonga 2014). Small-scale fish farming is challenged by increasing competition for land and water, lack of efficiency in the supply chain and relatively high production costs, all of which suggest that a shift from small-scale production towards intensification is necessary (Munguti *et al.*, 2014b; Gotonga 2014). Fish farming in Kenya, however, is stuck at low levels of intensity, except for a few farmers on the outskirts of major towns and cities who practice production in recirculation systems (Munguti *et al.*, 2013a). Kaliba *et al.*, (2007) reported that when farming takes place in ponds larger than 600 m^2, rearing the recommended all-male tilapia population, the gross profit margins increases (Munguti *et al.*, 2014a). Intensive fish farming is unpopular with most fish farmers due to the high cost of investment and operational costs and the challenges associated with managing the technology. Munguti *et al.*, (2014a) reported that there is scarce data available on production of tilapia and catfish from cages, recirculation systems and raceways in Kenya.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was conducted in Winam Gulf of Lake Victoria, Kenya as shown in figure 3.1. Lake Victoria is at altitude of 1135 m above the sea level and covers an area of 69,485 km^2 and it is the second largest freshwater lake globally. Its waters is shared by Kenya (6 %), Uganda (45 %) and Tanzania (49 %) Kendall (1979). According to Williams *et al.*, (2007), the lake is located within a shallow depression between the Great Rift Valley and the western Albertine Rift, and has an average and maximum depth of 132 m and 265 m, respectively. It receives majority of its water (85%) from direct precipitation, and only about 15% from several small tributaries. Similarly, evaporation accounts for 85% of all water loss, and only a minor output is through its only outlet, the Victoria Nile in the north (Albright *et al.*, 2004). The lake's surface level varies by up to 3 m, mostly in response to rainfall, to a smaller extent due to managed outflows (Awange and Ong'ang'a, 2006). Pelagic waters in Lake Victoria are stratified, seasonally variable and receive nutrients mainly through diffuse atmospheric deposition (Njiru *et al.*, 2012).

Winam Gulf of Lake Victoria is a 1400 km^2 big bay having a 550 km shoreline situated in the northeast of Lake Victoria entirely in Kenya (Williams *et al.*, 2007). It is joined to the focal basin by the three kilometres broad Rusinga channel. A deeper but narrower channel situated south of Rusinga Island was allowing for improved transmission although it was blocked by a walkway erected in 1980 (Njiru *et al.*, 2012). Maximum and average depth in the Winam Gulf of Lake Victoria are 68 m and 6 m, correspondingly. In the Winam Gulf, the physico-chemical state of affairs is extremely different from ones in the main basin's pelagic area (Albright *et al.*, 2004). The water is excessively shallow to be continuely stratified, and the 4 main tributaries going into the Winam Gulf response for 37.6% of entire surface water flowing into the entire Lake Victoria, plus huge amounts of terrigenous components. In the area around the Winam Gulf, fertilization and agriculture are broad (Awange and Ong'ang'a, 2006. A rise in nutrient and sedimentation content in the gulf was observed in the 1^{st} decades because of surface run-off, land degradation as well as erosion of soil whereas a planned rise in atmospheric deposition stays disagreed as reported by Gordon *et. al.* (2009). Massive ferilization of farms forming the gulf catchment continued to be reported as these results into periodic water quality problems within the gulf (Njiru *et. al.,* 2012)

3.2 Biophysical characteristics of the Gulf

The gulf serves as an important reservoir for the region and for the larger Nile Basin. Because the lake is shallow, its volume is substantially less than that of other African Great Lakes, which have much smaller surface areas (Fusilli *et al*., 2013). Its total volume is about 2,760 km^3, only 15% of the volume of Lake Tanganyika, even though the latter has less than half its surface area. In the Winam Gulf of Lake Victoria, 8.1 billion m^3 of water comes from rainfall over its surface and in-flowing rivers contribute 9.2 billion m^3 (Cheruiyot *et al.,* 2014). The rivers, which originate from and enter the Lake in the Kenyan catchment contribute 38% of the total river discharge entering Lake Victoria from land catchment, however River Mara, which enters the lake in Tanzania and contributes about 5% is mainly from the Kenyan catchment, therefore total contribution of Kenyan catchment is estimated at about 42% of land catchment input. Consequently, activities in Kenya catchments potentially affect a substantial portion of the river discharge to the lake and especially in Winam Gulf (Cavalli *et al.,* 2009). The main rivers and their discharge percentages are: Nzoia - 39%, Gucha-Migori - 20%, Sondu - 14%, Yala - 13%, Nyando - 6% and Sio-4%. The remaining 4% comes from various streams such as Awach Seme, Awach Kibos, Awach Kano (clustered as North Awach) and Awach Tende and Awach Kibuon (clustered as South Awach) (LVEMP, 2002). There are also several seasonal rivers and streams originating from areas with high rainfall.

3.2.1 Climate

The gulf and its catchment has an equatorial climate with the temperatures modified by the relatively high elevation of the Lake Victoria basin and its mountains e.g. Mt. Elgon. Temperatures and rainfall are lower than typical equatorial conditions and therefore the area is classified as sub-humid with temperatures ranging between 20°C to over 35°C (Sitoki *et al*., 2012). The rainfall ranges between 1000 mm and 1500 mm with no distinct dry season in the year. The rainfall has two major peaks with the first in March to May (long rains) and the second in October-December (short rains) (Fusilli *et al*., 2013). The rainfall is controlled by the movement of the ITCZ (Inter Tropical Convergence Zone) (Fusilli *et al*., 2013). There are considerable spatial variations in rainfall in the area, mainly due to the location of the highlands and nearness to lakeshores (Fusilli *et al*., 2013). The temperature, rainfall and wind regimes in the immediate vicinity of the Gulf provide a hot, humid tropical climate and these affect the ecology of the lake (Prepas and Charette, 2005).

3.2.2 Geology

Winam Gulf occurs in Western Kenya and consists of Precambrian formations, which comprise slightly metamorphosed volcanic and sedimentary deposits belonging to the Nyanzian and Kavirondian Systems (Okongu *et al.*, 2005). The area where these rocks are exposed is structurally known as the Tanzanian Shield. Lake Victoria is perched high on the East African Craton in a tectonic sag between the two rift valleys of East Africa (Cavalli *et al.*, 2009). The rocks of the Bukoban System constitute a platform cover on the East African Craton. In Western Kenya, the rocks consist of Precambrian volcanic and sedimentary deposits of the Kisii Series Cavalli *et al*., 2009). The major rock types are basalts, phonolites, andesites, dacites, conglomerates, grit, tuffs and rhyolites. The terrain is also characterized by Archean granite/greenstone formations in which gold mineralization occurs as well as Cenozoic carbonatite complexes (Okongu *et al.*, 2005). There are also areas of Quaternary sediments in the region and the main rock types are clays, diatomites, shales and silts some of which were deposited when Lake Victoria stood at higher elevations (Sitoki *et al.*, 2012).

3.2.3 Soils and soil types

Soil types that occur in the Winam Gulf and the Lake's basin are varied and include Cambisols, Planosols, Vertisols, Regosols, Arenosols and Ferralsols (Awange and Ong'ang'a, 2006).. In the Kano plains are found the Gleysols commonly associated with swamps, on the slightly elevated grounds and piedmont plains are Planosols and its complexes, which are of moderate fertility (Awange and Ong'ang'a, 2006). On the upland are Cambisols and Luvisols of volcanic origin, which have low fertility. There are various types of soils in the sugar belt e.g. heavy black cotton soils (Williams *et al*., 2007).

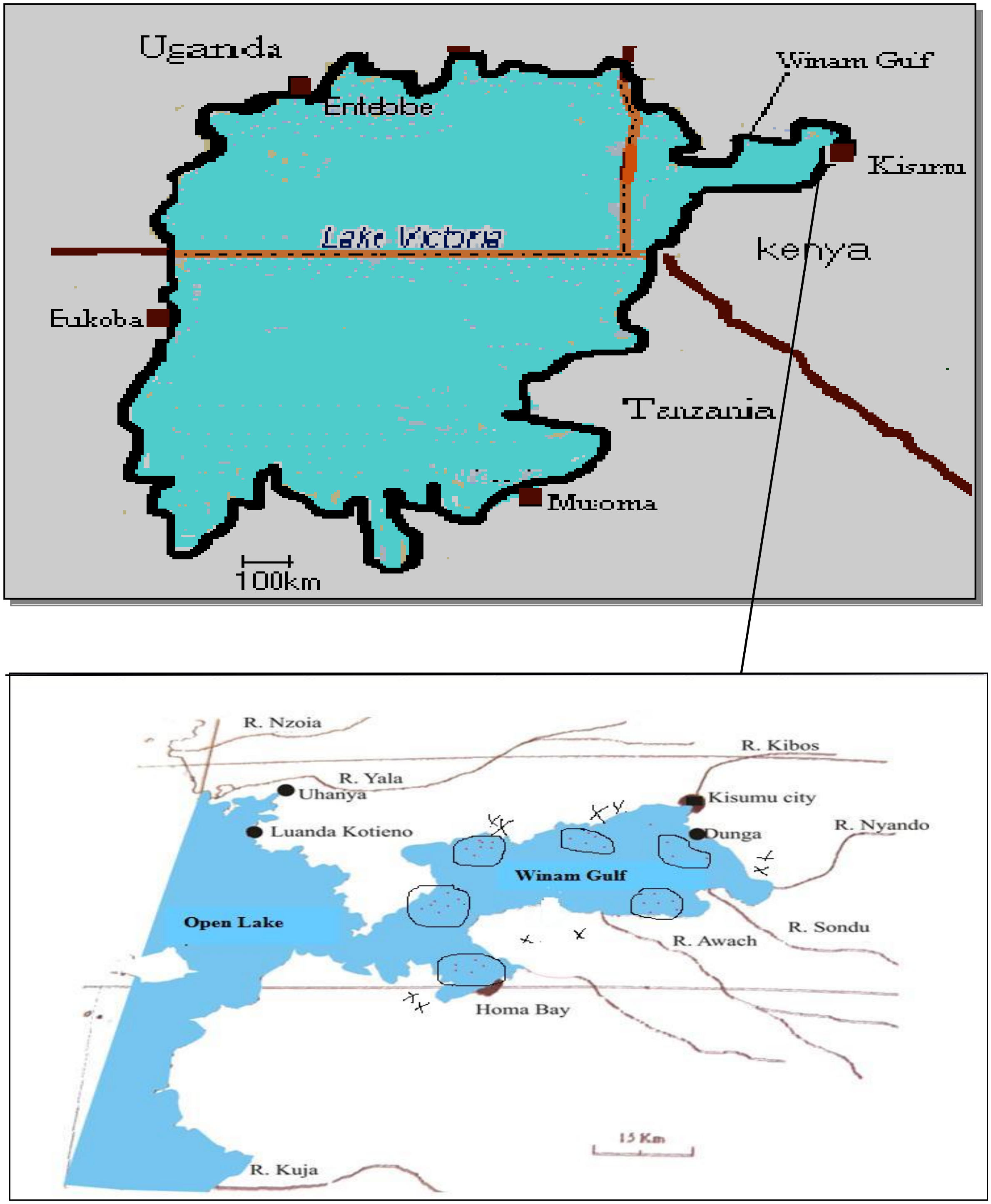

Fig. 3.1: A map showing L. Victoria, Winam Gulf and drainage system (Source: Osumo 2001)

NB: Circled dots (.) indicate areas covered by cages while crosses (x) along the shore shows pond location

3.3 Research Design and Sample size

The study adopted a systematic random sampling technique. In Cages, two production cycles were considered for study where each cycle had three sets of cages each set had five cages measuring (2m by 2m by 2m). In each cycle, the first cage sampled was 200m from the shore of Winam Gulf and the subsequent cages were selected after every 10m from the previous cage with approximately 3m above the lake bottom. Sampling was done for the last 4 months before harvesting during the two cycles. Seven hundred and twenty fish samples were studied in the entire study period. Two hundred and fourty (240) fish samples each from the wild, cages and ponds. The total number of cages and ponds sampled were 30 and 20 respectively. Ponds were located within 100m from the shores of Winam Gulf. The number of cages, ponds and sample sizes were calculated using Yamane (1967) formula. In the wild, fish samples were bought from fishermen while still fishing.

For qualitative data, households were the sample units used. A list of farmers who owned at least one fishpond within 100 meters from the shores of Winam Gulf was obtained from the County Governments (Homa Bay and Kisumu). The list of 62 pond and 34 cage farmers formed the sampling frame with 300m^2 and 8m^2 pond and cage size respectively. A semi-structured questionnaire (Appendix 1) was prepared, reviewed, pretested and a final version incorporating the pre-test results was produced. The questionnaires were administered through face-to-face interviews by the researcher with the help of four enumerators and complimented with direct observations. The farmers were purposively selected with the assistance of the sub-county fisheries officers depending on their availability and willingness to participate in the study.

The sample size was arrived using the formula by Yamane (1967) as shown below:

$$n = \frac{N}{1+N(e)^2}$$

Where n is the sample size, N is the population size, e is the sampling error, which is approximately 10%.

Questionnaires were assessing brief history of the farm (duration of fish farming, fish species kept, culture system practiced, type of farming system practiced, types of ponds, sources of fingerlings, source of pond water), management practices (frequency of changing pond water, pond drainage after harvesting, pond treatment after harvesting, pond fertilization, type of feed used, sharing of fishing nets, cleaning of fishing nets, animals found in and around the pond and management of vegetation around the ponds), disease history in the farm (fish abnormalities seen in the farm, fish losses due to fish diseases, frequency of fish deaths), disease control measures and knowledge on fish parasites. Other factors assessed were feeding fish to other animals, consumption of fish by the household members, fish preparation method and cooking duration, symptoms experienced after consuming fish and challenges encountered in fish farming. Basic information about the farm, the owner and the respondents were also recorded. Ninety six (96) questionnaires were administered (34 Cage farmers and 62 pond farmers) within Winam Gulf and its shores.

3.4 Sampling Technique

3.4.1 Physico-chemical Water Quality Parameters

Triplicate temperature, dissolved oxygen (DO), salinity, total dissolved solid (TDS) and pH readings were taken *in situ* by water quality multi-probe meter, (OAKTON^{R}, Model pH/Mv/ºC METER, Singapore) at a depth of 10 cm below the water surface for each of the sampling sites in cages, ponds and wild.

3.4.2 Fish sampling

A seine net was used to sample selected ponds at the shores of the Gulf. This was done by the help of two individuals holding the opposite edges of the the net and seine along the pond from one end to the other end. Cages were sampled using hand net, which was used to scoop fish from the sampled cages to obtain the caged fish while wild fish were bought from the fishermen while fishing.

Total length was measured using fish measuring board to the nearest centimeter & weight was measured by electronic balance of 0.1g accuracy. The total length & weight relationship was determined by equation W = aLb given by Le Cren (1951), where 'a' is the intercept (initial growth coefficient) & 'b' is the exponent or the slope (growth coefficient). The equation was transformed into the logarithmic form, Log W = Log a + b Log L. The values of 'a' & 'b' were determined empirically. The parameters a and b of Length-Weight Relationships were estimated by linear regression analysis (least-squares method) on log-transformed data. The allometry coefficient was expressed by the exponent b of the linear regression equation. Relative condition factor also called Fulton's Condition factor (Kn) was determined by using equation, $K = (W/L^{b}) \times 100$ as described by Le Crens, 1951 and Fulton, 1911; where K is condition factor, W is body mass and L is body length.

3.4.3 Parasitological Examination

All parasites observed were identified, counted and recorded. Parasitological examination was conducted using standard necropsy procedures (Thoesen, 1994). Internal examinations were done through stretching out the intestines and stomach in a Petri dish and cutting open longitudinally. The contents were examined under a compound microscope at a magnification of X100. Internal organs were also examined by cutting a small piece from each, put on glass slide, squashed by use of a cover slip and observed under the compound microscope in the field. Metacercariae of trematodes were released from their cysts for better examination by teasing them out of the membranous coat. Isolated parasites were fixed and stored in 70% alcohol and preserved in 10% formalin (Paperna, 1996) for laboratory identification. Staining and mounting of parasite specimens were done by procedures described by Pritchard and Kruse (1982). Specimens were then passed through a graded series of concentrations of alcohol from 70, 50, 35% and finally in distilled water to bring them to the level of the stain. They were stained using Mayer's hematoxylin stain then dehydrated through a series of graded alcohol concentrations of 35, 50, 70, 85, 95 and absolute alcohol. Clearing of specimens were done with xylene after which they were mounted on glycerin. Further identification of parasites was done by use of morphological features and identification keys described by Paperna (1996) and Khalil *et al.*, (1994).

a) Parasite Prevalence Rates

Prevalence levels of tilapia parasites were quantified according to Bush *et al.,* (1997) as follows:

$$Prevalence = \frac{\begin{array}{c}Number\ of\ hosts\ infected\ with\ one\ or\ more\ individuals\\ of\ a\ particular\ parasite\ species\ or\ taxonomic\ group\end{array}}{number\ \ of\ hosts\ examined\ for\ that\ parasite} \times 100$$

b) Mean Intensity Levels of Parasites

Mean intensity (MI) of parasites were determined according to Bush *et al.*, (1997) as follows:

$$MI = \frac{Total\ number\ of\ individuals\ of\ a\ particular\ parasite\ species}{number\ of\ hosts\ infected\ with\ that\ parasite}$$

3.4.4 Taxonomic Identification

During this study, taxonomical identifications did not go past genus level this since the larval stages and the initial stages of the parasites could not be identified and distinguished by species. According to Hoffman (1967), most of the larval form do not have visible diagnostic characteristics, such as sex organs, and therefore cannot be differentiated with certainty among taxa. Moravec (1998) stated that in the cases of the trematode metacercariae and cestoda larvae, differentiating them on the level of their supragenus, genus or species is already too difficult and leads to poor description more so misidentifications. Because of these reasons, species identification to the lowest taxonomic level was not possible. *Contracaecum* sp., *Diplostomum* sp., *Clinostomum* sp. and *Gyrodactylus* sp. among others were all not easy to correctly identify on a species level in their early stages.

3.5 Data Analysis

Qualitative data was captured and stored in Statistical Package for Social Scientists (SPSS) version 17 where descriptive analysis was done and mean, mode, percentages and frequencies were computed to show the level of farm management practices and the state of affairs. Inferential analysis was also done to show statistically significant relationships between variables and in the testing of the specific objectives. Water quality physico-chemical parameters were summarized for the study period as mean ± SE values for each sampling station. Spatial variation in physico-chemical parameters between cage, pond and wild was tested using a two-way ANOVA at 95% confidence limits.

Analysis of variance (ANOVA) was used to determine the effect of parasitism on fish condition factor and general growth. The relationship between the fish size and the parasite mean intensity was done by a simple correlation analysis while association between the parasitic prevalence and the water quality parameters was done by spearman's rank correlation. More quantification analysis were done using the Shannon-weaver, Simpsons' species biological diversity index and Sorensen‟s coefficients of species similarity as described by James and Jerrold (1977). Canonical Correspondence Analyses (CCA) (Shostak *et al.*, 1987; Flores & Baccala, 1998) of water quality parameters and parasites were used to determine parameters affecting fish health (production) in each of the study area. These analyses were done using MINITAB™ version 14.0 and Statgraphics 2.1 statistical programs. All statistical significances were tested at 95% levels.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the analysis and findings of the study as per the five study objecives and presented in the subsequent sub-sections below:

4.1 Experimental Objectives

4.1.1 To assess and compare selected environmental parameters in the Winam Gulf

The mean monthly physico-chemical water quality parameters in cages, ponds and wild/open water from the month-1, January to month-8, August 2018 is presented in Table 4.1. In the cages physico-chemical water quality parameters showed no significant difference between the sampled months. The highest mean (26.8±0.41ºC) temperature was recorded in January and the lowest mean (24.8±0.29ºC) was registered in the month of May 2018. The mean temperatures for the rest of the months fell within the ranges for January and May. The highest dissolved oxygen (DO) concentration (mean of 5.6±0.14mg/l) was recorded in March 2018 and the lowest mean (4.1±0.11 mg/l) was in February 2018. Similar to DO, the highest mean pH (7.3±0.18) was recorded in both March and May while the rest of the months registered significantly lower pH value of 7.1-7.2±0.15. The study found that water salinity was quite low being between 0.14ppt and 0.12ppt for January, February to April but in May salinity value recorded was high being 7.2±0.15ppt. Total dissolved solids (TDS) were highest in the month of January (mean of 28.8±0.45 mg/l) and lowest in February (mean of 18.4±0.32 mg/l). Table 4.1 presents the values for the rest of the months.

Whereas in ponds, there were no significant differences on the water quality physico-chemical parameters between January and August 2018. Just like in cages, ponds registered the highest mean temperature in the month of March 28.5±0.60 ºC and the lowest during the month of June 24.8±0.45 ºC. Similarly, DO was also highest in the month January recording a mean of 5.4±0.16 mg/l and lowest during the month of March and July with a monthly mean of 4.2±0.12 and 4.2±0.16 mg/l respectively. The month of August recorded the highest value of pH with a mean of 7.6±0.15 and the lowest pH recorded during the month of April and May 7.1±0.15 and 7.1±0.13 respectively. The highest salinity concentrations 2.8 ±0.10ppt were recorded from the month of April throughout to August while the lowest concentrations of 2.1 ±0.10ppt were recorded in January and February. Concentrations of TDSs were very high all through the sampling period. The highest was recorded during the month of March 480±10.1 mg/l and the lowest in January and February 360±8.52 and 360±7.99 mg/l respectively.

In the wild/open water, temperature was highest during the months of January, February, March and April that recorded 26.2 ±0.53, 26.5 ±0.45, 26.0 ±0.37 and 26.5±0.43ºC respectively and lowest in the rest of the months where the mean values were all 25.0ºC. The highest concentrations of DO was recorded in the month of August with a mean of 7.0±0.15mg/l and the lowest recorded during the month of June with a mean of 5.5±0.12mg/l. pH had a range between 7.0 in the months of May, June and August and 7.2 in the months of January, April and July. Salinity did not change significantly with the ranges between 0.14±0.02 ppt in January and 0.12±0.01 ppt in March while TDS concentration was highest in the month of June (mean of 24.0±0.5 mg/l) and lowest in February recording (mean 16.8±0.22 mg/l) as presented in (Table 4.1).

The mean temperature varied considerably with study sites as follows: the highest mean temperatures at respective sites are: 26.85±0.84 ^{0}C for ponds, (26.45±0.65 ^{0}C for wild/open water and 25.88±0.67^{0}C) in cages. There was a significant difference between these mean temperatures ($p=0.02$). Also there was slight variation on DO values between cages and ponds while in the wild/open water there was high mean DO concentration (5.98±0.96mg/l) compared to that in the cage (4.98±0.20 mg/l), The pond registered the lowest mean (4.80±0.66 mg/l). There was no significant variation in pH values where lowest value was recorded in the wild/open water (7.09±0.39) and the highest in the pond (7.45±0.26). Salinity concentrations were low in both cage and wild/open water with a mean concentration of 0.13±0.02 and 0.12±0.03 ppt respectively while ponds registered the highest mean value (2.64±0.55 ppt). There was a significant difference in salinity values between pond and cage and pond and wild ($p=0.01$; $p=0.014$) respectively. The TDS recorded the highest variance with the pond recording a mean concentration of 447.15±10.63 mg/l with cage coming a distant second with a mean concentration of 25.49±0.85 mg/l followed closely with the wild recording a mean of 19.39±0.98 mg/l. There was a significant statistical difference between the study sites ($p=0.01$)

Table 4.1 Mean Monthly (± SEM) of physico-chemical water quality parameters measured in cages, ponds and wild during the study period

Month /Site	**Jan. (1)**	**Feb. (2)**	**Mar. (3)**	**April (4)**	**May (5)**	**June (6)**	**July (7)**	**Aug. (8)**	**Mean**
Cage									
Temp.	26.8±0.41	26.6±0.39	25.4±0.46	24.5±0.38	24.8±0.29	25.5±0.42	26.5±0.35	26.2±0.45	25.88±0.67
DO	4.4±0.12	4.1±0.11	5.6±0.14	5.3±0.13	5.1±0.15	4.9±0.11	5.2±0.13	5.3±0.15	4.98±0.20
pH	7.2±0.15	7.1±0.13	7.3±0.18	7.1±0.16	7.3±0.14	7.1±0.12	7.1±0.14	7.1±0.17	7.17±0.35
Sal	0.12±0.02	0.12±0.01	0.14±0.02	0.12±0.01	0.13±0.02	0.14±0.02	0.14±0.01	0.14±0.02	0.13±0.02
TDS	28.8±0.45	18.4±0.32	26.4±0.35	25.5±0.43	26.5±0.55	24.5±0.44	27.5±0.48	26.6±0.46	25.49±0.85
Pond									
Temp.	28.4±0.48	27.8±0.57	28.5±0.60	26.8±0.42	25.5±0.44	24.8±0.45	25.2±0.55	26.5±0.50	26.85±0.84
DO	5.4±0.16	5.3±0.14	4.2±0.12	4.8±0.13	4.5±0.14	4.8±0.15	4.2±0.16	4.4±0.13	4.80±0.66
pH	7.5±0.19	7.3±0.16	7.6±0.18	7.1±0.15	7.1±0.13	7.5±0.17	7.4±0.14	7.6±0.15	7.45±0.26
Sal	2.1±0.10	2.1±0.10	2.7±0.10	2.8±0.10	2.8±0.10	2.8±0.10	2.8±0.10	2.8±0.10	2.64±0.55
TDS	360±8.52	360±7.99	480±10.1	420±9.55	450±9.65	460±9.75	450±8.97	450±9.66	447.15±10.63
Wild									
Temp.	26.2±0.53	26.5±0.45	26.0±0.37	26.5±0.43	25.7±0.44	25.5±0.48	25.7±0.47	25.8±0.36	26.45±0.6
DO	6.4±0.15	5.9±0.11	5.8±0.14	6.2±0.16	5.8±0.17	5.5±0.12	6.2±0.18	7.0±0.15	5.98±0.96
pH	7.2±0.16	7.1±0.13	7.1±0.12	7.2±0.10	7.0±0.12	7.0±0.15	7.2±0.13	7.0±0.13	7.09±0.39
Sal	0.14±0.02	0.14±0.01	0.12±0.01	0.13±0.01	0.13±0.02	0.14±0.02	0.14±0.01	0.14±0.02	0.12±0.03
TDS	19.3±0.33	16.8±0.22	19.5±0.36	19.5±0.31	18.5±0.24	24.0±0.53	22.5±0.46	18.6±0.33	19.39±0.98

In order to determine effect of cage culture on physico-chemical water quality the measurements were taken at 10, 20 and 30m away from the cage. There was no significant difference in temperatures recorded at 10m (27.1±0.82), 20m (27.2±0.65) and 30m (27.0 ±0.78^{0}C) away from the cage. There was a significant difference (p=0.04) between temperatures inside and outside cage. The same trend was shown in DO concentration where inside cage had a mean of 4.98±0.20mg/l while outside had 5.8±0.96, 6.0±0.76 and 6.1±0.84 mg/l at 10, 20 and 30m respectively. There was a significant difference between the inside and outside cage (p=0.03). There was no significant difference between inside and outside the cage in pH values (p=0.15). Inside cage had 7.17±0.35 while outside the cage recorded 7.08±0.31, 7.09±0.25 and 7.14±0.28 at 10, 20 and 30m, respectively. In terms of salinity, the concentration also followed a similar trend with inside cage recording 0.13±0.02 ppt and outside cage registered a mean of 0.11±0.01. Just like the pH, salinity concentration also revealed an insignificant difference between the inside and outside cage (p=0.46). TDS was higher inside the cage (25.49±0.85mg/l) than outside. There was a mean of 22±0.65, 20±0.39 and 20.5±0.45mg/l at 10, 20 and 30m respectively. There was a significant statistical difference between the inside and mean outside the cage except for the pH (p=0.025) (Fig. 4. 1).

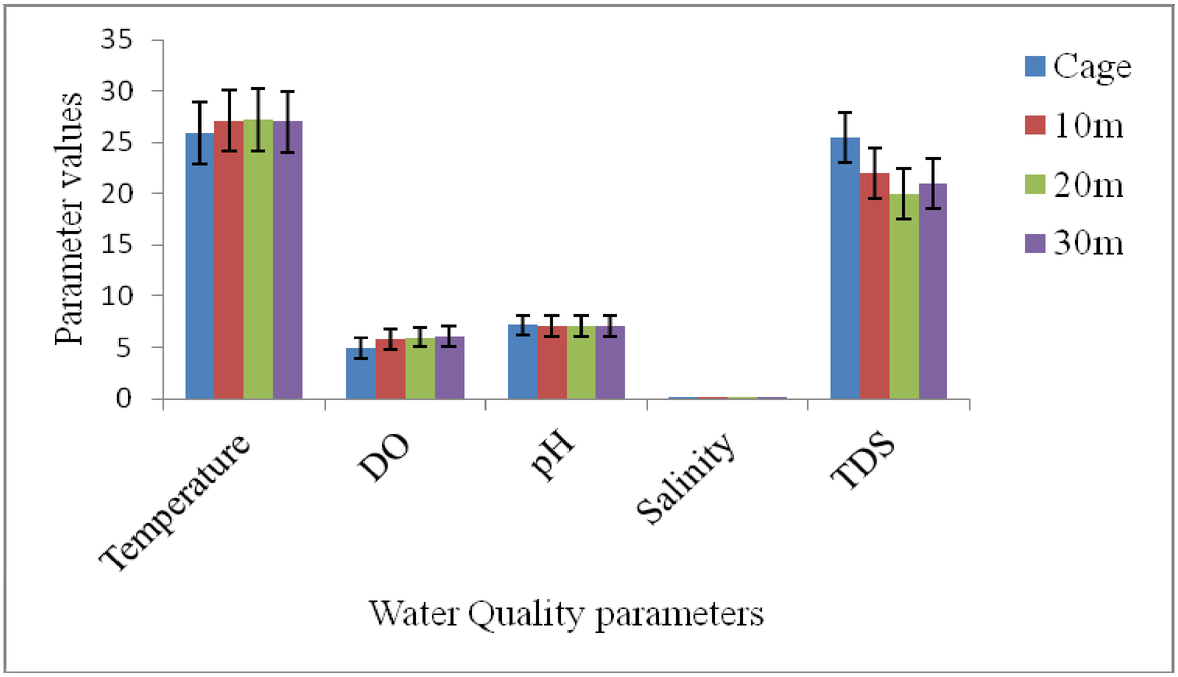

Fig 4. 1: Mean Variations in water quality physico-chemical parameters inside the cages, 10, 20 and 30m away from cage

4.1.2 Identification and comparison of parasites in *O. niloticus* in sampling sites

A total of 12 parasitic taxa namely *Acanthocestis spp, Armirthalingamia spp, Clinostomum spp, Crustacean, Dactylogyrus spp, Gyrodactylus spp, Diplostomum spp, Naescus spp, Trichodina spp, Myxobolus spp, Contraceacum spp and Tylodelphys spp.* were recorded in different sampling sites i.e. ponds, cages and wild/open water. All the 12 taxa were represented in pond while in cage 11 taxa were recorded. In cage only *Crustacean* was absent. In the wild/open water, 4 out of the 12 taxa were absent namely *Contraceacum spp, Gyrodactylus spp*, *Myxobolus spp* and *Tylodelphys spp*. (Table 4.2). During the study period some of the infections were found externally for instance *Naescus* spp. Were found at the skin muscles (Plate 1) and *Tylodelphys* spp commonly dominated the vitrous humor (Plate 2) leading to partial blindness.

Plate 1: *Naescus species* on the skin muscle of the *O. niloticus*

Plate 2. Total blindness due to *Tylodelphys species* infection within the vitrous humor

Table 4.2: Shows Taxon's presence/absence in different study sites (P=Present, - =Absent)

Parasite	Pond	Cage	Wild
Acanthocestis spp.	P	P	P
Armirthalingamia spp.	P	P	P
Clinostomum spp.	P	P	P
Contraceacum spp.	P	P	-
Crustacean spp.	P	-	P
Dactylogyrus spp.	P	P	P
Diplostomum spp.	P	P	P
Gyrodactylus spp.	P	P	-
Myxobolus spp.	P	P	-
Naescus spp.	P	P	P
Trichodina spp.	P	P	P
Tylodelphys spp.	P	P	-

Table 4.3 shows that seven (7) parasitic taxa were common in all the 3 study systems. These were: Acanthocephala, Cestoda, Trematoda (*Monogenic and Digenic*), Nematoda, Crustacean, Myxozoan and Protozoan. The most common group in all the study sites is the class trematoda especially the digenic group that was represented by *Clinostomum* spp., *Tylodelphys* spp., *Naescus* spp. and *Diplostomum spp.* The monogenic trematodes were represented by the *Gyrodactylus* spp., and *Dactylogyrus* spp. The rest of the parasitic groups were represented by a single taxon for instance Acanthocephala was represented by *Acanthocestis* spp. while Cestoda was *Armirthalingamia* spp.; Nematoda group was represented by *Contraceacum* spp. Crustacean was represented by an unidentified *crustacean spp*. On the other hand, Myxozoan and Protozoan groups were represented by *Myxobolus* spp. and *Trichodina* spp., respectively.

There were 3 dominant taxa in the cage i.e. *Dactylogyrus* spp., *Tylodelphys* spp. and *Diplostomum* spp. In ponds, the most dominant parasite taxa were *Tylodelphys* spp. and *Diplostomum* spp. In the wild, the parasitic infection was only dominated by *Diplostomum* spp. It is important to state that *Diplostomum* spp. is the only taxon that dominated all the three study sites (Table 4.3). A sample photo of *Dactylogyrus* spp. at the gills of mostly cage fish is shown below (Plate 3) and tail rot due to parasitic infection (Plate 4).

Plate 3. *Dactylogyrus* species found attached at the gills of a caged fish

Plate 4: Tail and Skin rot which are signs of parasitic infection in *O. niloticus*

Table 4.3: The most dominant group and taxon in different study sites (√-dominant species)

Parasite group	**Taxon**	**Cage**	**Pond**	**Wild**
Acanthocephala	*Acanthocestis* spp.			
Cestoda	*Armirthalingamia* spp.			
Monogenic Trematoda	*Dactylogyrus* spp.	√		
	Gyrodactylus spp.			
Digenic Trematoda	*Clinostomum* spp.			
	Tylodelphys spp.	√	√	
	Naescus spp.			
	Diplostomum spp.	√	√	√
Nematoda	*Contraceacum* spp.			
Crustacean	*Unidentified Crustacean* spp.			
Myxozoan	*Myxobolus* spp.			
Protozoan	*Trichodina* spp.			

4.1.3 Occurrence, abundance and diversity of external and internal parasites

Occurrence, abundance and diversity of parasites at different study sites over the entire study period is summarized in the subsequent figures. In cages, the monthly abundance and mean intensity increased from January 2018 to April 2018 before dropping in May (1.5±0.3). It then started to increase reaching highest peak (5.1±0.5) in the 8th month, which was the last sampling date for this study. In ponds, there was a slight but steady increase in mean intensity from February (1.3±0.3) to July (3.2±0.4) before it dropped to (3.0±0.5) in August 2018. Samples in the wild/open water site did not show a systematic pattern in terms of mean intensity of the parasites throughout the study period (Fig. 4.2).

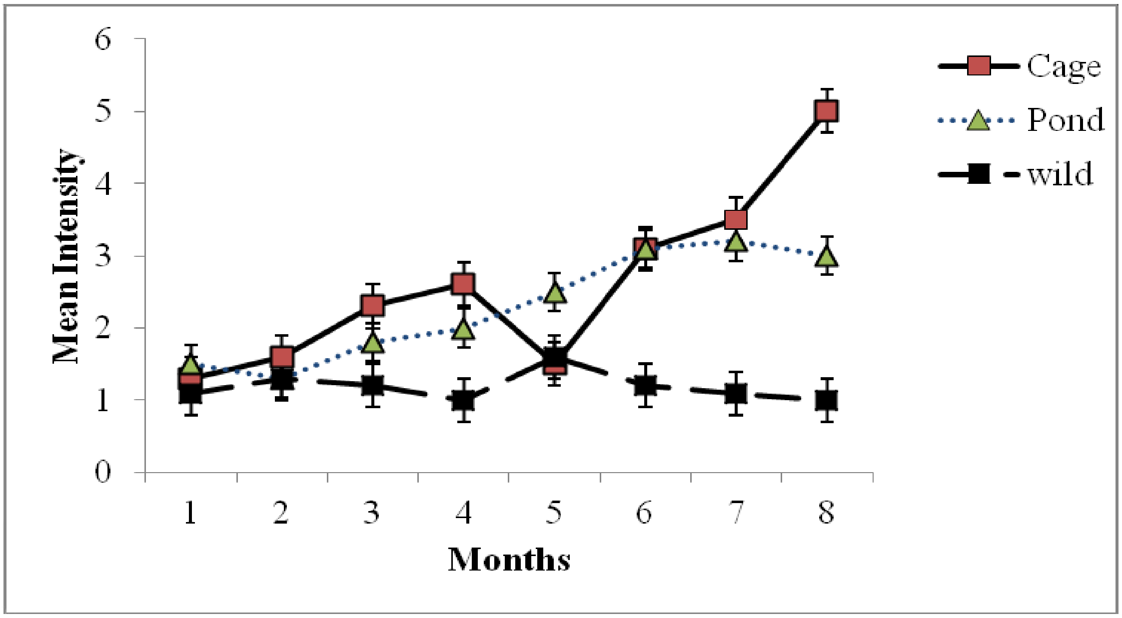

Fig. 4.2 Variations in mean intensities in cage, pond and wild during the study period

Two diversity indices (Shannon-Weaver (H') and Simpson's (1-D)) were used to show the diversity of various taxon during the study period. In cages, both indices revealed an up and down trend showing a steady increase from month-1 (0.76 and 0.18) to month-4 (1.85 and 0.50), respectively. There was a decrease in month-5 (0.88 and 0.21) before another increase till its peak in the last month of sampling (2.50 and 1.53) respectively, (Fig. 4.3). Pond recorded a continuous increase of both indices from January 2018 (month 1) to August (end sampling). In the first month Shannon Weaver and Simpson's diversity indices were 1.29 and 0.53, respectively. These values increased every month until they reached the highest peak of 1.65 and 0.74 respectively, (Fig. 4.4).

Unlike results from cage and pond, there was no consistency in species diversity in the case of wild/open water. Shannon Weaver diversity index dropped to its lowest (0.49) in the months of March and April while Simpson's was lowest (0.37) in the month of April. Both indices reached their highest peak (0.63 and 0.42) respectively in the last month (Fig. 4.5). The mean Shannon-weaver and Simpson's diversity indices in the study sites during the entire study period are shown in Fig. 4.6. Cage and pond showed no significant difference in both indices (p value 0.207 and 0.178) while cage and wild (p value 0.001 and 0.000) just like pond and wild (p value 0.000 and 0.002) showed a significant difference in Shannon-weaver and Simpson's indices, respectively. Cage, pond and wild recorded a mean Shannon weaver index of 1.52 ±0.2, 1.48± 0.2 and 0.56±0.1, respectively while the Simpson's diversity index recorded were 0.67±0.09, 0.63±0.08 and 0.38±0.06, respectively (Fig. 4.6)

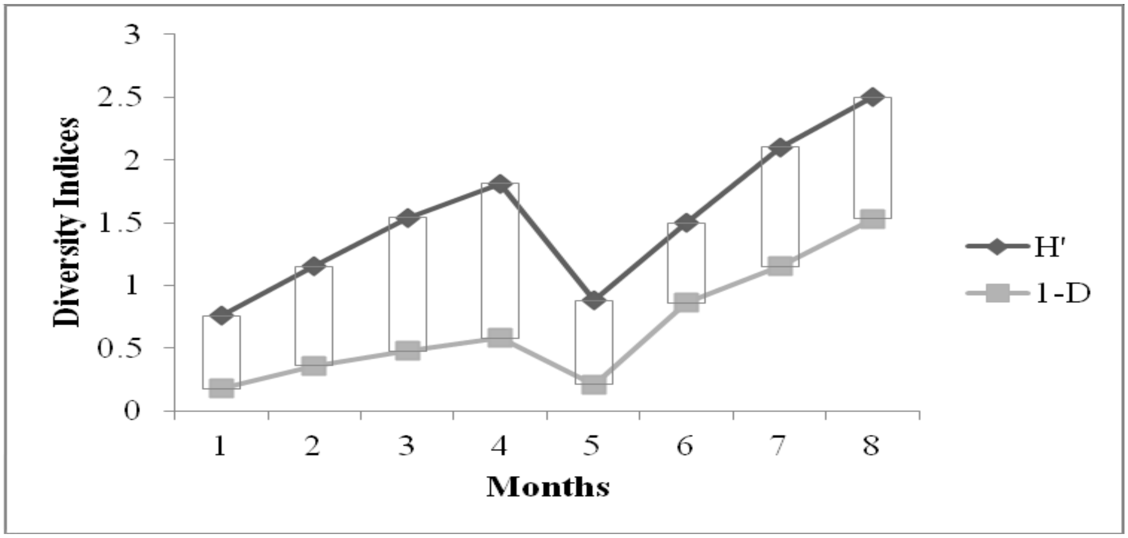

Figure 4.3 Variations in diversity indices (H' and 1-D) in cages during the study period

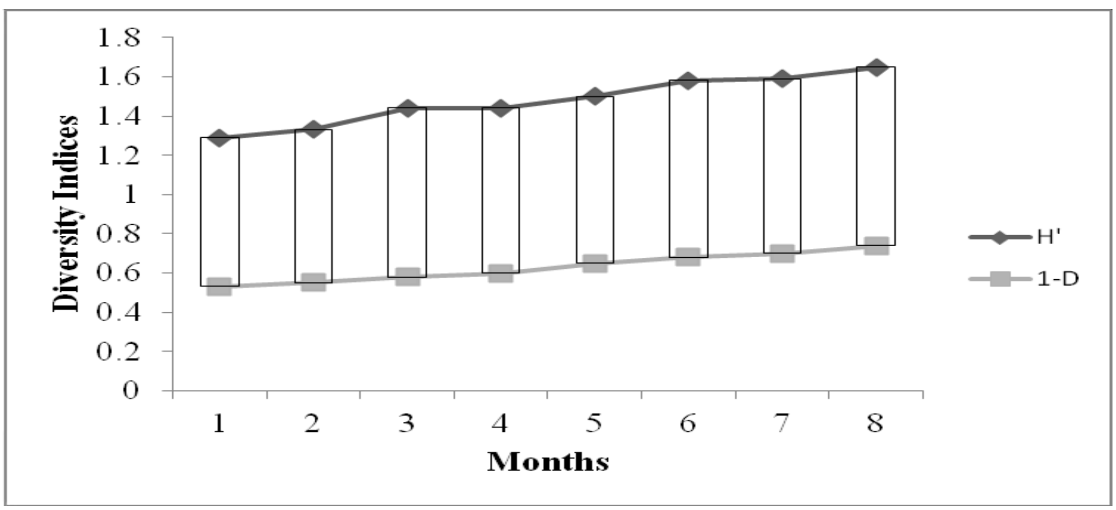

Fig. 4.4 Variations in diversity indices (H' and 1-D) in ponds during the study period

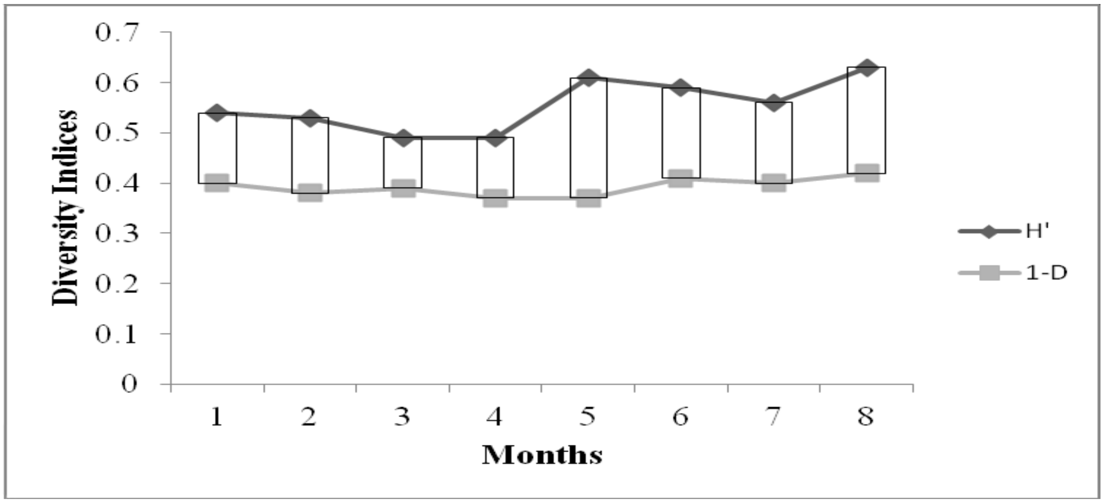

Fig. 4.5 Variations in diversity indices (H’ and 1-D) in wild during the study period

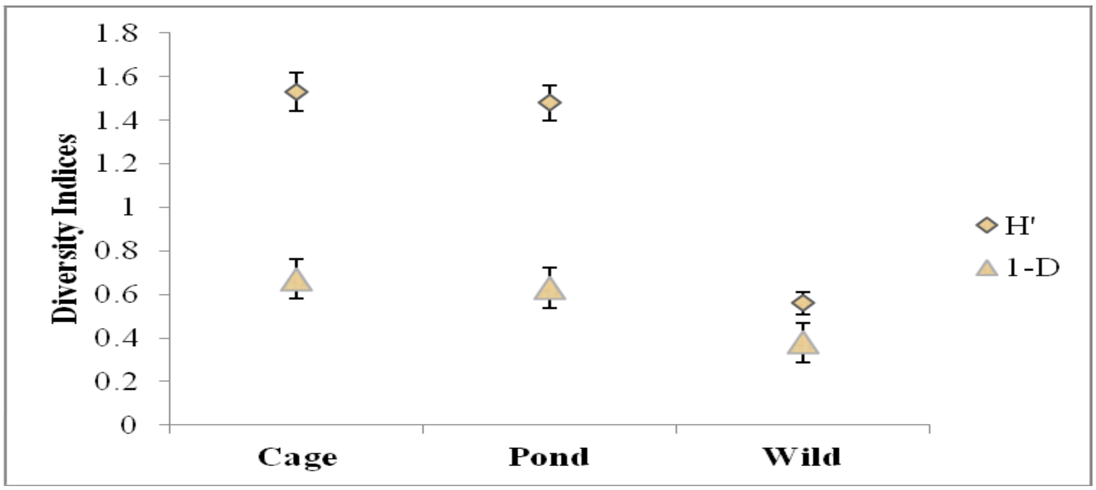

Fig. 4.6 Indices of parasite diversity in cage, pond and wild during the study period

Sorenson’s community similarity coefficient between cage and pond system were found to be 0.91, which is close to 1 indicating that similar parasites species occurred in both cage and pond sites i.e the probability of finding a particular parasite species in both pond and cage in a random sampling is 91%. On the other hand, probability of finding a similar individual parasite in random sampling from cage and wild is 33% and that of pond and wild is 31%.

The study found that *Tylodelphys* spp. (33.3±3.2%) was the most prevalent parasitic, followed by *Dactylogyrus* spp. (28.8±2.5%) and *Diplostomum* spp. (20.8±1.8%). The remaining taxa occurred as follows: *Trichodina* spp. (14.1±2.0%), *Gyrodactylus* spp. (12.5±1.8%), *Clinostomum* (10.4±2.2%). The others occurred in the following order while *Naescus* spp. (9.6±1.2%) followed by *Contraceacum* and *Myxobolus* both (3.8±0.5%). *Amirthalingamia* (2.1±0.3%) and *Acanthocestis* spp. (1.7±0.1%) (Fig. 4.7).

Most of the fish parasite species encountered during the study period were present at different prevalence rates in cages. The highest parasitic prevalence was *Tylodelphys* spp. (33.3±3.2%), followed by *Dactylogyrus* spp. (28.8±2.5%), *Diplostomum* spp. was the next in prevalence with (20.8±1.8%). These 3 taxa were the most prevalent among the fish species. The other taxa had the following prevalence rates: *Trichodina* spp. (14.1±2.0%), *Gyrodactylus* spp. (12.5±1.8%), *Clinostomum* spp. (10.4±2.2%) while *Naescus* spp. (9.6±1.2%) then *Contraceacum* spp. and *Myxobolus* spp. both (3.8±0.5%). The least prevalent taxa were *Amirthalingamia* spp. and *Acanthocestis* spp. at (2.1±0.3%) and (1.7±0.1%) respectively (Fig. 4.7). All the species encountered were present in pond samples although at different prevalent rates. The most prevalent species of parasites include: *Tylodelphys* spp. (50.8±5.2%), followed by *Diplostomum* spp. (40.8±3.2%), *Trichodina* spp. recorded a mean prevalent rate of (20.8±2.8%) followed by *Clinostomum* spp. and *Dactylogyrus* spp. both had a mean rate of (11.2±2.0%). *Gyrodactylus* spp. had (4.5±0.3%) while *Naescus* spp. recorded (3.8±0.2%) and *Acanthocestis* spp. (3.3±0.1%). The least prevalent species were *unidentified Crustacean* spp. (2.1±0.1%), then *Myxobolus* spp. (1.6±0.1%), *Contraceacum* spp. (1.25±0.1%), and finally *Amirthangamia* spp. (0.4±0.1%) (Fig. 4.8). Some of the parasites that were present in both cage and pond not only had lower prevalence rates but were completely missing. The most prevalent parasite species include: *Diplostomum* spp. (37.5±3.5), then *Amirthalingamia* spp. (17.5±1.6), *Dactylogyrus* spp. (7.9±0.5) followed by *Acanthocestis* spp. (4.2±0.3) while *Clinostomum* spp. had a mean of (2.1±0.1), *Trichodina* spp. (1.25±0.1), both *Naescus* spp. and *Crustacean* spp. had (0.4±0.1) (Fig. 4.9).

The highest parasitic prevalence in both cages and ponds was *Tylodelphys* spp. (33.3±3.2%) and (50.8±5.2%), respectively while the highest prevalence in wild was *Diplostomum* spp. (37.5±3.5%). Prevalence for *Diplostomum* spp. in cage and pond were (20.8±2.8%) and (40.8±3.2%), % respectively. In cages prevalence for *Dactylogyrus* spp. and *Gyrodactylus* spp. were (12.5±1.8%) and 28.8±2.5%) while their prevalence in ponds was (11.2±2.0%) and (4.5±0.3%) respectively. *Amirthalingamia* spp. had a prevalence of (2.1±0.1), (0.4±0.1) and 17.5±1.6) in cages, ponds and wild respectively. *Trichodina* spp. (14.1±2.0%), (20.8±2.8%) and (1.25±0.1) in cage, pond and wild respectively while *Clinostomum* spp. (10.4±2.2%), (11.2±2.0%) and (2.1±0.1%) in cages, ponds and wild, respectively. *Naescus* spp. in cages, ponds and wild were (9.6±1.2%), (3.8±0.2%) and (0.4±0.1%), respectively while *Acanthocestis* spp. was (1.7±0.1%), (3.3±0.2%) and (4.2±0.3%) in cages, ponds and wild (Fig. 4.10). Fgure 4.11 shows the overall prevalence rates in the three study sites during the study period. The highest parasitic prevalence rate was 71±8.5% in cages followed by 67±6.3% in ponds and finally 33.8±4.1% in wild. There was no statistical difference in percentage parasitic prevalence between the cages and ponds ($p=0.91$) while there was a difference between cage and wild and also pond and wild ($p=0.023$ and $p=0.021$) respectively (Fig. 4.11)

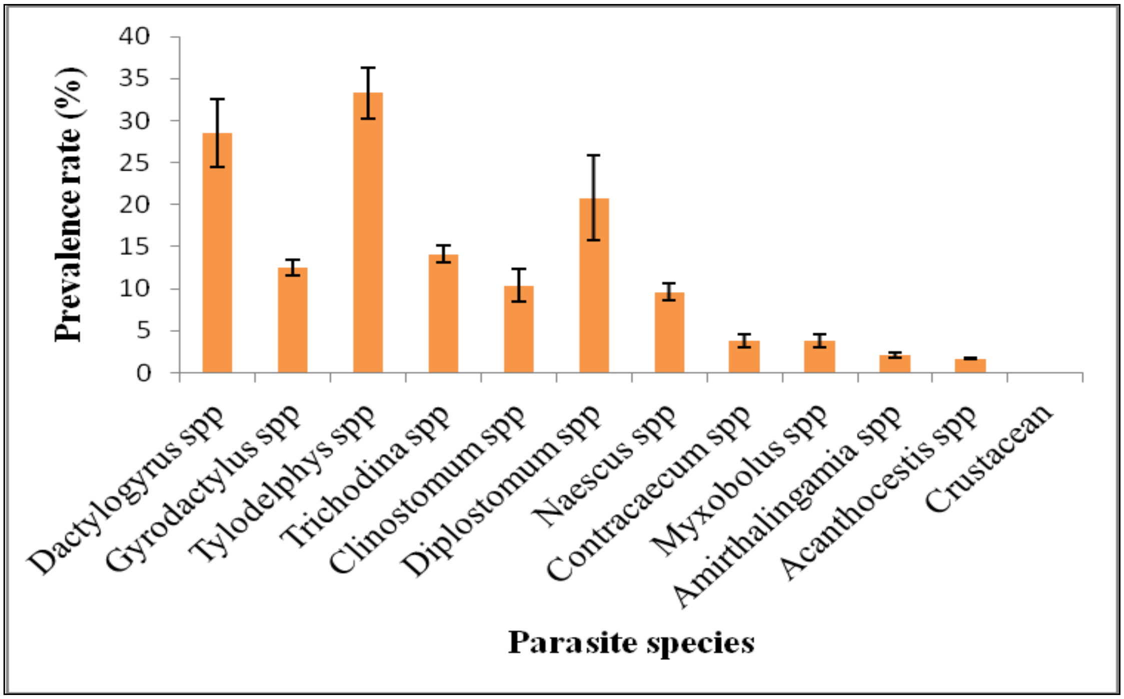

Figure 4.7 Variation in parasite prevalence rates (%) in cages during the study period

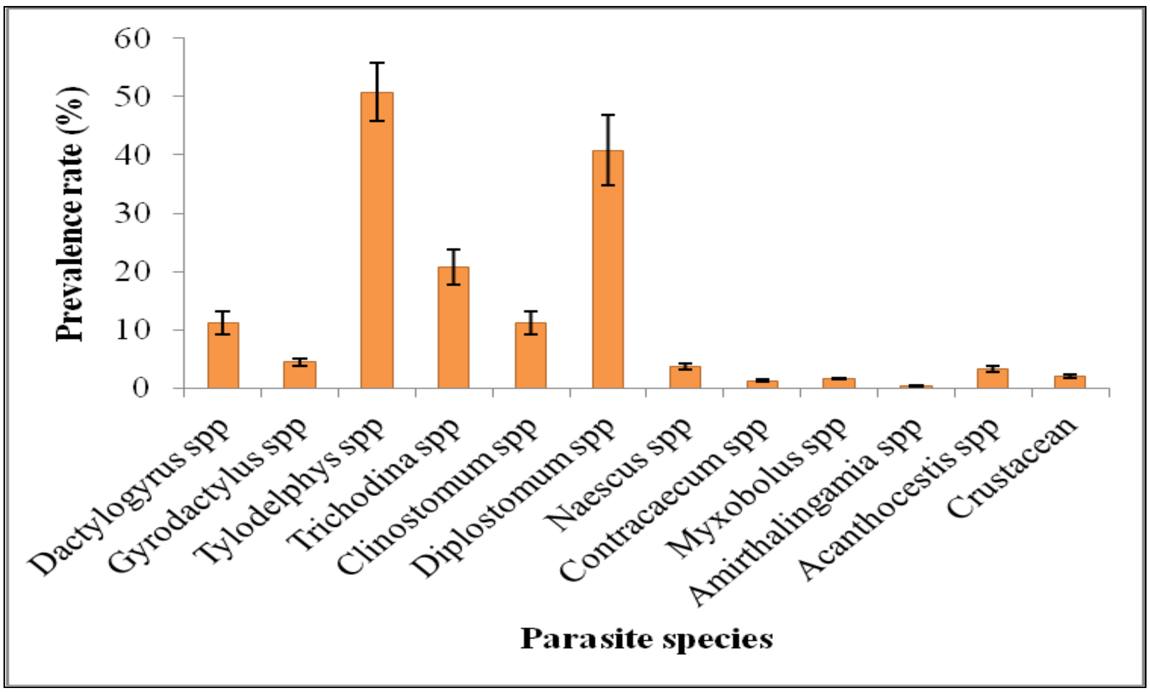

Figure 4.8 Variation in parasite prevalence rates (%) in ponds during the study period

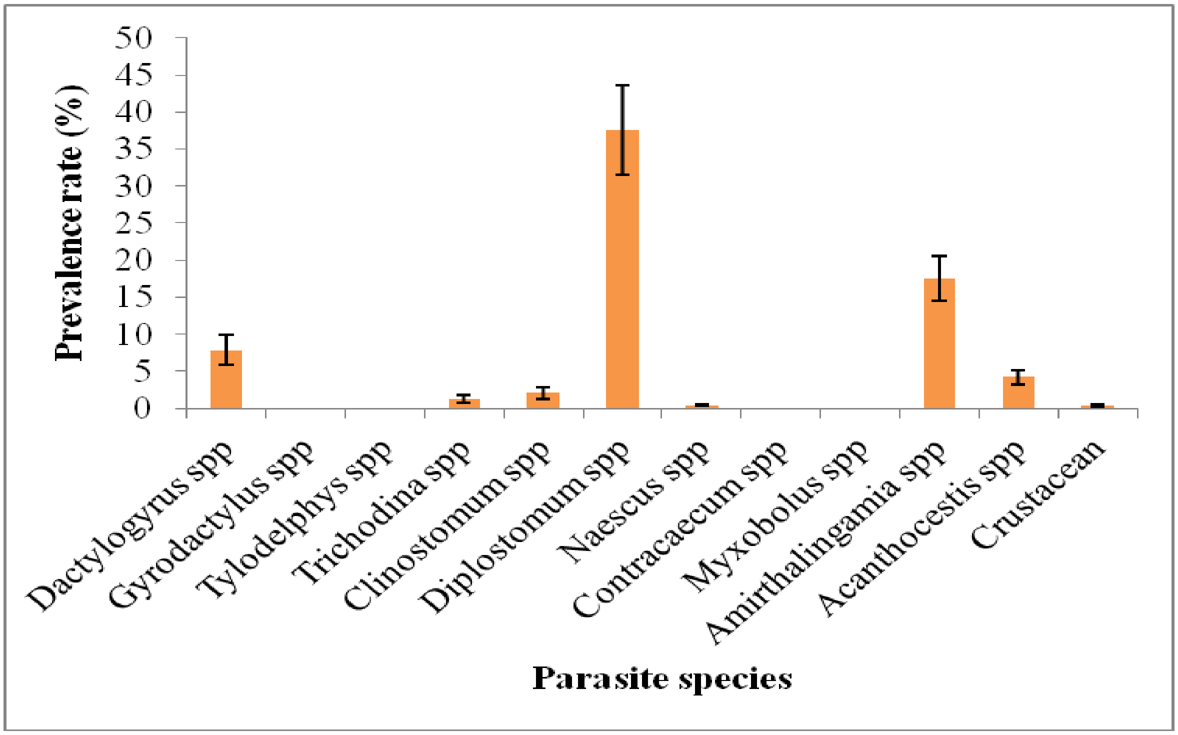

Figure 4.9 Variation in parasite prevalence rates (%) in wild during the study period

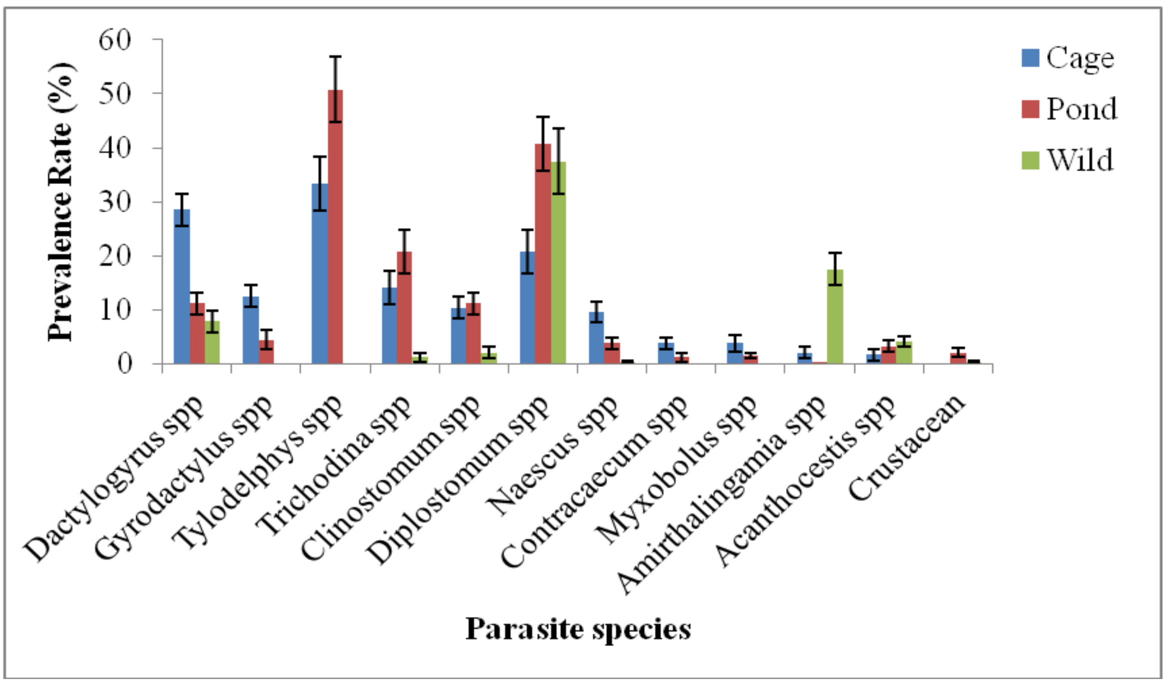

Fig 4.10 Variation in parasite prevalence rates (%) in cages, ponds wild during the study period

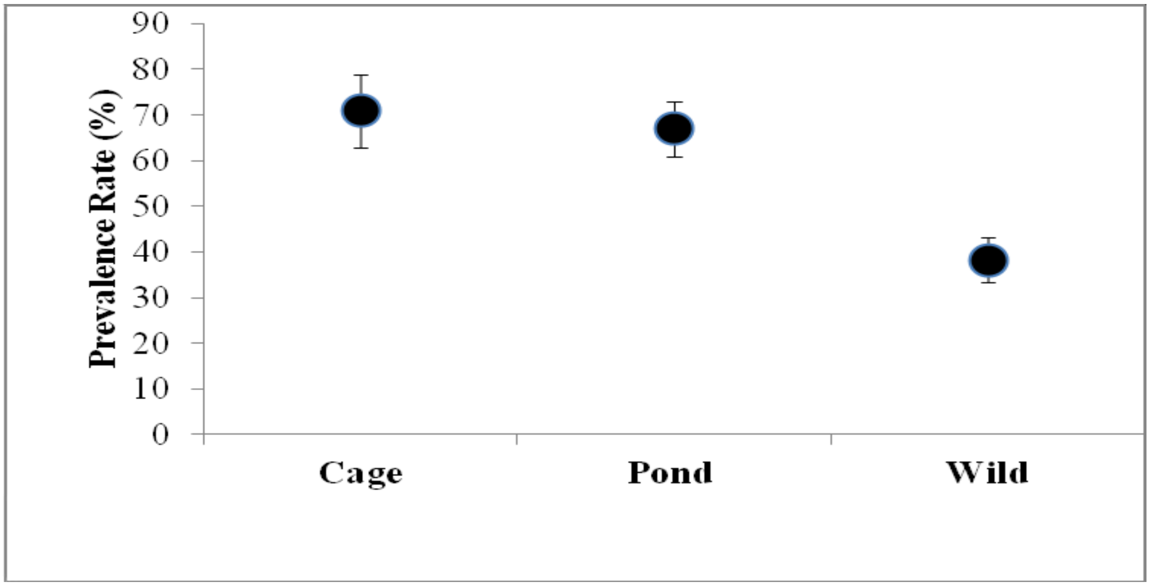

Fig. 4.11. Overall mean parasitic prevalence rate among the study sites

Relative abundance level of each taxon per study area was calculated as the proportionate percentage (by numbers) of each taxon per study area. *Acanthocestis* spp. registered a relative abundance of 31%, 44% and 25% in cages, ponds and wild respectively. *Amirthalingamia* spp. had higher relative abundance in the wild 69% than culture system i.e. cages and ponds while *Clinostomum* spp. in cages and ponds had almost the same relative abundance (49% and 44%) respectively with only 7% in the wild. *Contraceacum* spp., *Gyrodactylus* spp., *Myxobolus* spp. and *Tylodelphys* spp. were all missing in the wild but had a relative abundance of (70% and 30%), (80% and 20%), (72% and 28%) and (56% and 44%) respectively in cages and ponds respectively. *Dactylogyrus* spp., *Diplostomum* ssp., *Naescus* spp. and *Trichodina* spp. recorded different relative abundances (75%, 15% and 10%), (20%, 44% and 36%), (60%, 38% and 2%) and (39%, 58% and 3%) respectively in cages, ponds and wild respectively. Crustacean had a relative abundance of (90% and 10%) in ponds and wild respectively as it was missing in the cages (Fig. 4.12).

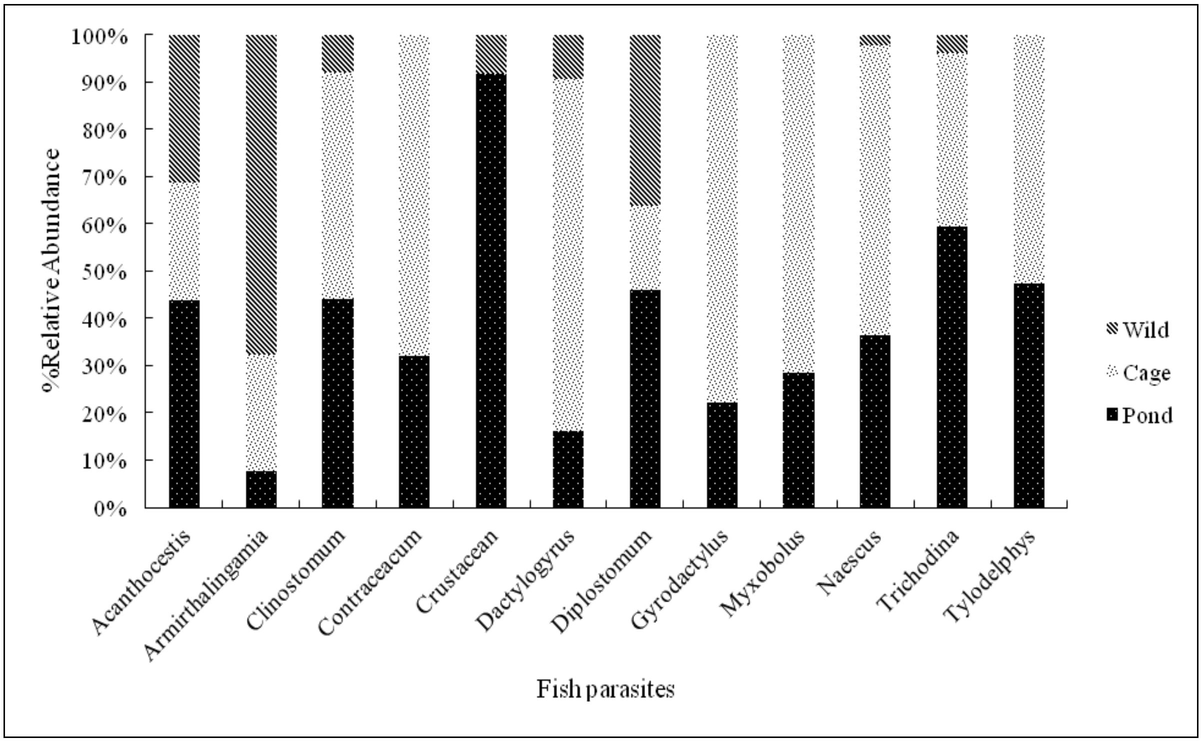

Fig 4.12 The Relative abundance (%) of parasites in the study areas during the study period

4. 1.4 Effects of parasitism on fish body condition and growth in the study areas

The effect of parasitic infection on the condition factor of fish was influenced by different culture systems (Table 4.6). In cage, parasitic infection was mostly associated with higher condition factor of fish than in ponds and wild. *Datylogyrus* spp. (F=5.197, p=0.085), *Tylodelphys* spp. (F=8.181; p=0.149), *Diplostomum* spp. (F= 24.691; p=0.042) and *Trichodina* spp. (F= 3.281; p=0.144). Only *Diplostomum* spp. had an insignificant effect on fish condition factor in cages. Ponds also indicated a similar scenario with only *Diplostomum* spp. (F=38.642, p=0.044) having a slight significant effect on body condition factor. Other infections which did not affect the condition factor in ponds included: *Dactylogyrus* spp. (F=1.175; p=0.271), *Tylodelphys* spp. (F=1.174; p=0.151) and *Trichodina* spp. (F=0.189; p=0.135). Wild fish parasitic infection had the least association with the condition factor and none of them recorded a significant effect. *Dactylogyrus* spp.

(F=0.935; p=0.254), *Diplostomum* spp. (F=1.214; p=0.272) while *Amirthalingamia* spp. (F=0.899; p=0.396) and *Acanthocestis* spp. (F=1.554; p=0.085) as presented in (Table 4.4).

Table 4.4: ANOVA Table showing the effect of parasitism on condition factor of *O. niloticus* in Cage, Pond and Wild (p= 0.05).

	Dactylogyrus	*Tylodelphys*	*Diplostomum*	*Trichodina*	*Amirthalingamia*	*Acanthocestis*
Cage						
F	5.197	8.181	24.691*	3.281	-	-
p	0.085	0.149	0.042	0.144	-	-
Pond						
F	1.175	1.174	38.642*	0.189	-	-
p	0.271	0.151	0.044	0.135		
Wild						
F	0.935	-	1.214	-	0.899	1.554
p	0.254	-	0.272	-	0.396	0.085

The mean condition factor of the 3 study cultures over the study period revealed that wild fish recorded the highest mean condition factor (K), 1.48±0.1 this was closely followed by pond (mean 1.45±0.1) and the least in mean condition factor was cage (mean 1.38±0.1). Results from Chi square for trend showed that the differences of body conditions among infested fish were not statistically different (p>0.05).

Results for length-weight relationship showed that *O. niloticus* recorded a positive allometric growth (*b*>3) in all the three study sites (Fig 4.13). The highest value of the regression slope *b* was recorded in ponds (3.18) and the lowest in cage fish (3.09) while the wild fish had (3.16). The regression slope *b* was not significantly different between the sites (p=0.21).

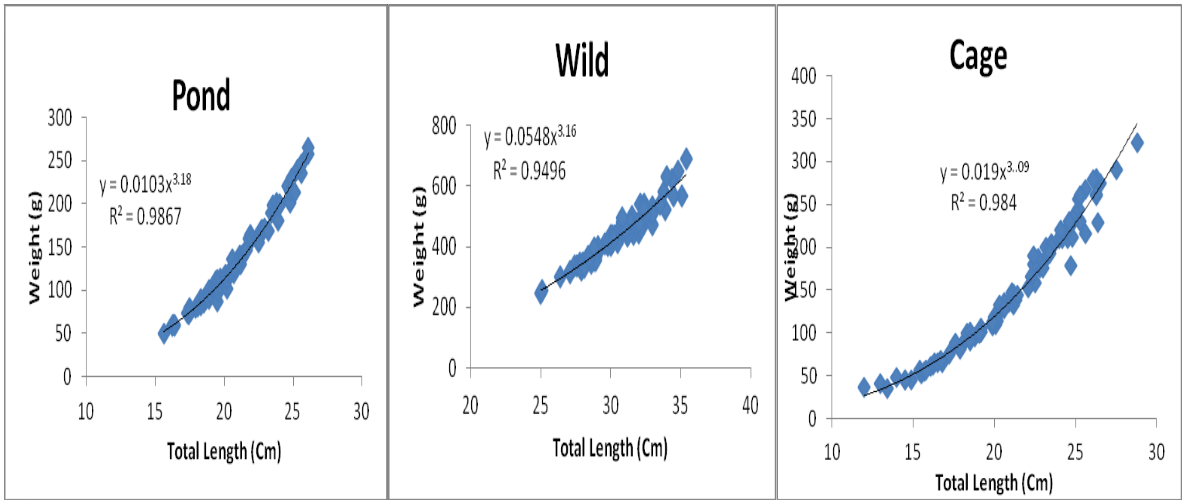

Fig. 4.13 Length-Weight Relationship of *O. niloticus* in cages, ponds and open waters

4.1.5 Effects of the dominant parasite taxa on *Oreochromis niloticus* fish sizes

The intensity of infestation of the most prevalent and abundant parasites showed relationship with the size of the host *Oreochromis niloticus*. In cages, the four dominant taxa included: *Tylodelphys* spp., *Dactylogyrus* spp., *Diplostomum* spp. and *Trichodina* spp. *Tylodelphys* spp. in cages revealed a strong positive correlation but was not statistically significant (r =0.84, slope = 0.27 and p = 0.13). The parasitic load of *Tylodelphys* spp. increases with increase in the host's total length. On the other hand, *Dactylogyrus* spp. also revealed a strong positive correlation between it and the total body size (slope=0.198, r =0.7893, p = 0.45). The increase in mean intensities of *Dactylogyrus* spp. as the body size also increases in the cages did not reveal any statistical significance difference among the fish in cages. *Trichodina* spp. showed a very weak positive correlation (r = 0.69, slope = 0.087, p = 0.72) between. infection and the fish size. As the mean intensity was increasing so as the size of fish but the association was very weak. There was no significant difference in the parasitic load increase of *Trichodina* ssp. with increase in fish size in cages. Similar to *Dactylogyrus* spp., *Tylodelphys* ssp. and *Trichodina* spp., *Diplostomum* spp. also revealed a positive correlation though a weak one with the general fish size in the cages (r =

0.71, slope = 0.127, p = 0.01). The only difference from the above correlations is that

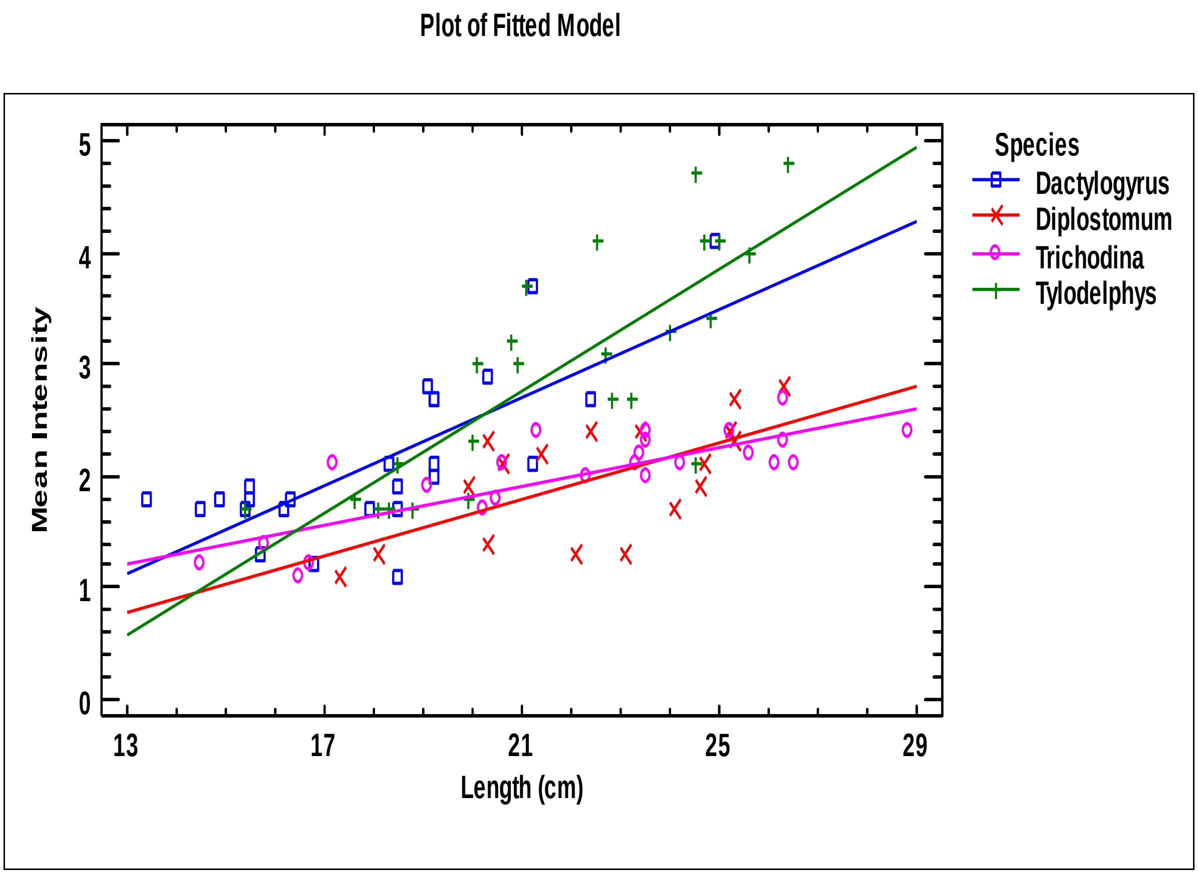

Fig. 4.14 Scatter plot of correlation of dominant taxa intensities with fish size in cages

Correlation analysis between the mean intensites of the dominant taxa and the fish size showed a mixed result in ponds just like what was recorded in cages. The same dominant taxa in cages were also dominant in ponds and they included *Tylodelphys* spp., *Diplostomum* spp., *Dactylogyrus* spp. and *Trichodina* spp. There was a moderate positive correlation which did not show any statistically significant difference (slope=0.179, r =0.674, p =0.06) between the size of the host fish and the mean intensity of parasitic infestation of *Tylodelphys* spp. in ponds. Similar to *Tylodelphys* spp., *Trichodina* spp. in also showed a moderate positive correlation (slope=0.178, r =0.609) between the size of the fish and the intensity of parasitic infestation. This increase in mean intensity with total length also did not reveal any statistically significant diffence (p=0.094). The intensity of infestation of *Diplostomum* spp. showed a weak positive correlation (r =0.674, slope = 0.1417) and just like in cages, there was a statistical significant difference (p value 0.0029). *Dactylogyrus* spp. followed a similar trend as *Tylodelphys* spp. and *Trichodina* spp. with a positive correlation between the mean intensity and the total length of *O. niloticus* in ponds

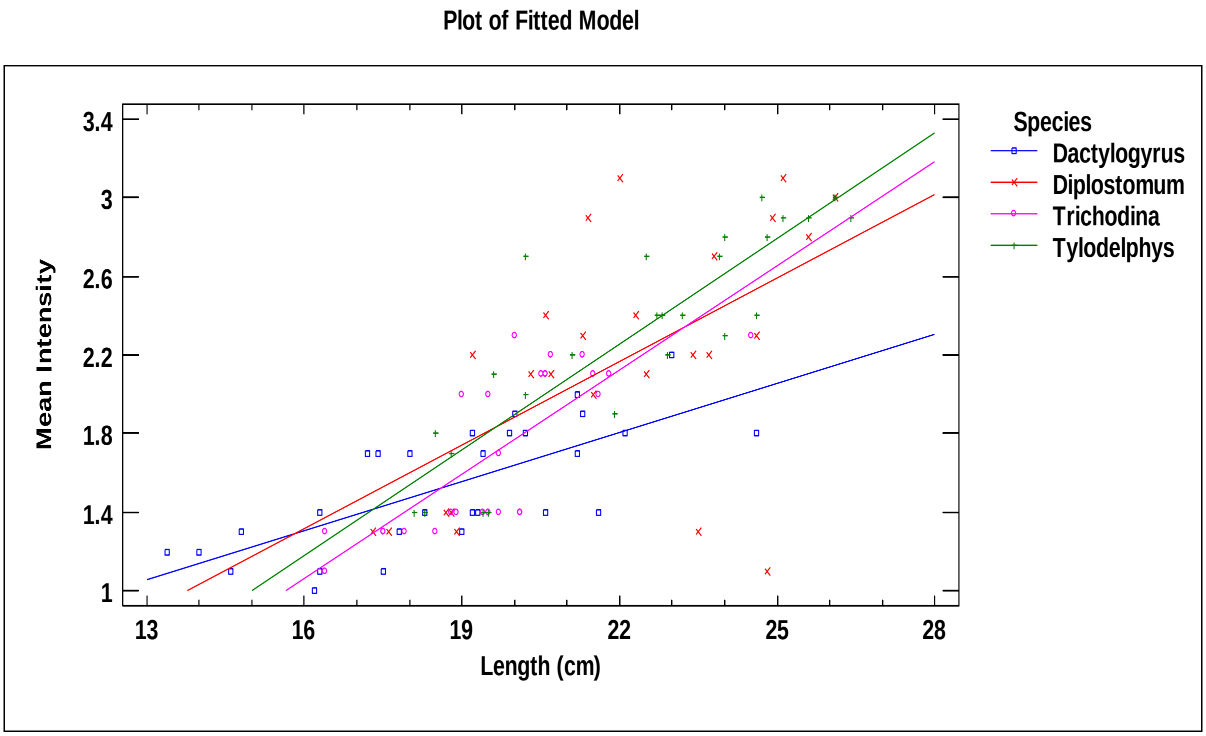

Fig. 4.15 Scatter plot of correlation of Dominant taxa intensities with fish size in ponds

In the wild/open waters the following taxa were the most dominant*:* *Diplostomum* spp., *Armirthalingamia* spp., *Dactylogyrus* spp. and *Acanthocestis* spp. *Diplostomum* spp. which was the most prevalent did not show a statistical significance in its infection and the size of the fish even though the correlation was strongly positive (r = 0. 674, slope =0.073 and p =0.18). *Dactylogyrus* spp. on the other hand recorded a similar positive correlation with the fish sizes in the wild though not as strong relationship as was the case of *Diplostomum* spp. An increase in fish size resulted to an increase in *Dactylogyrus* spp. parasitic infestation.

This relationship was not statistically significant (slope=0.043, r =0.568, p=0.703). *Acanthocestis* spp. showed a weak positive correlation with the size of fish in the wild. Its mean parasitic intensity increases with an increase in fish sizes though this correlation was statistically insignificant (slope=0.040, r=0.314, p=0.135) while the intensity of *Amirthalingamia* spp. infestation on the other hand showed a moderate positive correlation

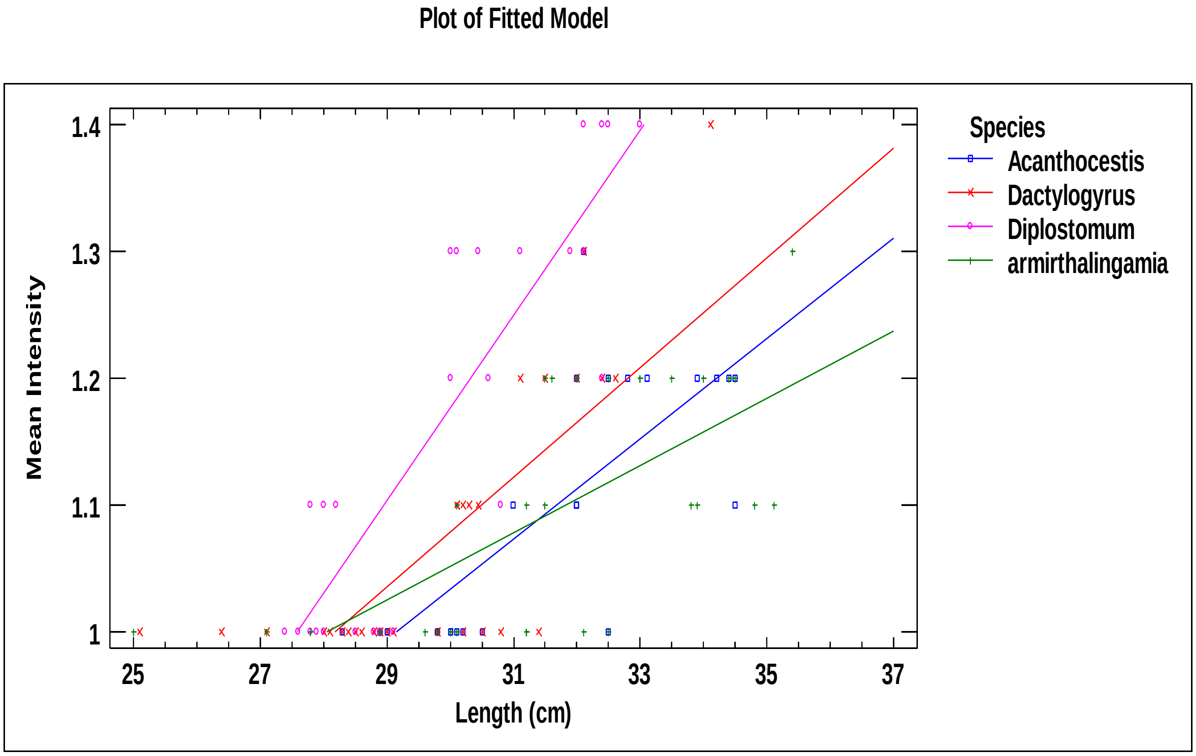

Fig. 4.16 Scatter plot of correlation of Dominant taxa intensities with fish size in the wild

Cage and pond were grouped closely in terms of parasites composition and prevalence by cluster analysis, with wild being the most distant from the two culture systems (Figure 4.17). Cage and pond also must have differed in the prevalence of *Dactylogyrus* spp., *Diplostomum* spp., *Trichodina* spp., *Clinostomum* spp., *Acanthocestis* spp., *Naescus* spp. and *Amirthalingamia* spp. parasite with the wild. Other parasites which were prevalent in cages and ponds but were missing in the wild such as *Gyrodactylus* spp., *Tylodelphys* spp., *Myxobolus* spp. and *Contraceacum* spp. must have pushed the wild further away from the cages and ponds as cluster analysis have indicated (Fig. 4.17).

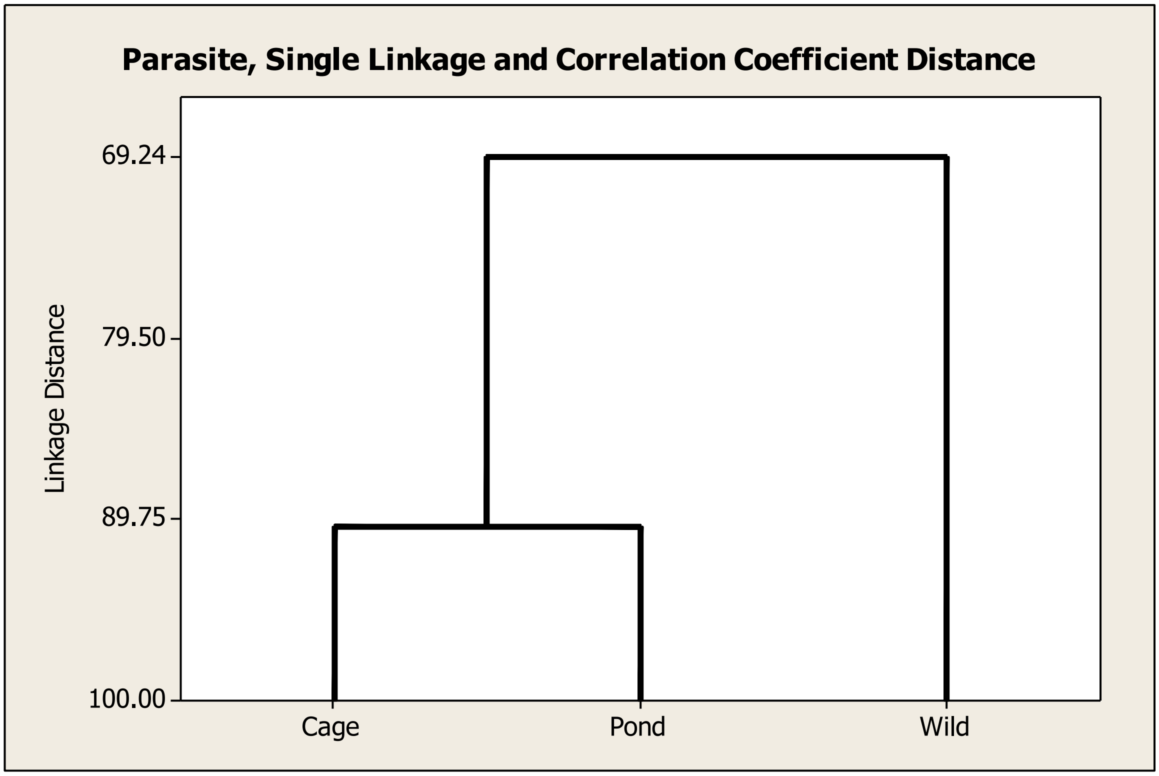

Fig. 4.17 Cluster Analysis of various fish parasites in cages, ponds and wild

4.1.6 The association between parasitic infections and the selected environmental factors

Mixed correlations between parasitic prevalence levels and some water quality parameters were observed in cages, ponds and wild during the study period. In cage, *Dactylogyrus* spp. showed a statistically significant negative correlation with DO (rs= -0.89 p=0.01) and statistically insignificant negative correlation with TDS and pH (rs=-0.28, p=0.95 and rs=0.24, p=0.10). It also showed a statistically insignificant correlation with temperature (rs=0.51, p=0.15) and salinity (rs=0.04, p=0.81). *Tylodelphys* spp. and *Trichodina* spp. had significant positive correlation with temperature (rs=0.84, p=0.03 rs=0.14, p=0.02) respectively. *Tylodelphys* spp. not significant with DO (rs=0.18, p=0.75) and TDS (rs=0.43, p=0.71) while *Trichodina* spp. also had an insignificant positive correlation with DO (rs=0.64, p=0.13), pH (rs=0.12, p=0.84) and TDS (rs=0.18, p= 0.62) with a negative insignificant correlation with salinity (rs=-0.22, p= 0.88). *Diplostomum* spp. had a very strong positive correlation with temperature (rs=0.85, p=0.45), DO (rs=0.67, p=0.72) and TDS (rs=0.77, p=0.67). It showed a very weak positive correlation with salinity (rs=0.07, p=0.25) and a very strong negative correlation with pH (rs= -0.86, p=0.93).

In ponds, *Dactylogyrus* spp. had a strong positive correlation with temperature (rs=0.56, p=0.25) which was not statistically significant. It had a weak significant positive correlation with DO (rs=0.11, p=0.03) and an insignificant weak positive correlation with salinity (rs=0.07, p=0.25) and TDS (rs=0.15, p=0.53). The only negative correlation was with pH (rs=-0.18, p=0.16). *Tylodelphys* spp. in ponds also had mixed correlations with a significant one with temperature (rs=0.48, p=0.01) and insignificant positive correlations with DO (rs=0.34, p=0.66), salinity (rs=0.18, p=0.11) and TDS (rs=0.62, p=0.57) and finally a weak negative correlation with pH (rs=-0.28, p=0.76) which was not statistically significant. *Trichodina* spp. showed an insignificant positive correlation with temperature (rs=0.09, p=0.33), DO (rs=0.42, p=0.81), salinity (rs=0.03, p=0.88) and TDS (rs=0.14, p=0.32). This taxon also had a negative correlation with ph (rs=-0.31, p=0.19) which was not significant. *Diplostomum* spp. was positively correlated to all the parameters i.e. temperature (rs=0.19, p=0.71), DO (rs=0.28, p=0.01), pH (rs=0.41, p=0.50) and significantly correlated with TDS and DO. Salinity had a positive correlation (rs=0.04, p=0.22) and TDS (rs=0.18, p=0.00). There was mixed correlation between the different taxa and the water quality parameters and TDS, DO and temperature had a significant correlation with *Diplostomum* spp., *Tylodelphys* spp. and *Dactylogyrus* spp. respectively (Table 4.5).

In the wild, *Dactylogyrus* spp. had positive correlations with temperature (rs=0.38, p=0.14), salinity (rs=0.12, p=0.67) and TDS (rs=0.21, p=0.41) with negative correlations with DO (rs=-0.28, p=0.58) and pH (rs=-0.42, p=0.13). *Diplostomum* spp. had a significant negative correlation with temperature (rs=-0.18, p=0.02), but not significant with DO (rs=-0.15, p=0.88) and pH (rs=-0.67, p=0.11) with a positive one with salinity (rs=0.10, p=0.97) and TDS (rs=0.24, p=0.78). The only significant correlation was with the temperature. *Amirthalingamia* spp. had a significant positive correlation with Temperature (rs=-0.24, p=0.03) but not significant with DO (rs=0.36, p=0.18), pH (rs=0.21, p=0.57) and salinity (rs=0.18, p=0.48) with a negative correlation with TDS (rs=-0.15, p=0.17). *Acanthocestis* spp. had all positive correlations with the parameters i.e. temperature (rs=0.42, p=0.23), D (rs=0.05, p=0.28), pH (rs=0.17, p=0.38), salinity (rs=0.03, p=0.23) and TDS (rs=0.16, p=0.54). The wild only recorded a significant correlation with temperature (Table 4.5).

Table 4.5 Spearman rank (rs) correlation between parasite prevalence and water quality parameters in the study sites (* Indicates significant correlations; p =0.05).

Sites	Temperature		DO		pH		Salinity		TDS	
Cage	**rs**	**p**	**rs**	**p**	**rs**	**p**	**rs**	**p**	**rs**	**p**
Dactylogyrus spp.	0.51	0.15	-0.89	0.01*	0.24	0.10	0.04	0.81	-0.28	0.95
Tylodelphys spp.	0.84	0.03*	0.18	0.75	-0.11	0.58	-0.10	0.33	0.43	0.71
Trichodina spp.	0.14	0.02*	0.64	0.13	0.12	0.84	-0.22	0.88	0.18	0.62
Diplostomum spp.	0.85	0.45	0.67	0.72	-0.86	0.93	0.07	0.25	0.77	0.67
Pond										
Dactylogyrus spp.	0.56	0.25	0.11	0.03*	-0.18	0.16	0.02	0.36	0.15	0.53
Tylodelphys spp.	0.48	0.01*	0.34	0.66	-0.28	0.76	0.18	0.11	0.62	0.57
Trichodina spp.	0.09	0.33	0.42	0.81	-0.31	0.19	0.03	0.88	0.14	0.32
Diplostomum spp.	0.19	0.71	0.28	0.01*	0.41	0.50	0.04	0.22	0.18	0.00*
Wild										
Dactylogyrus spp.	0.38	0.14	-0.28	0.58	-0.42	0.13	0.12	0.67	0.21	0.41
Diplostomum spp.	-0.18	0.02*	-0.15	0.88	-0.67	0.11	0.10	0.97	0.24	0.78
Amirthalingamia spp	.-0.24	0.03*	0.36	0.18	0.21	0.57	0.18	0.48	-0.15	0.17
Acanthocestis spp.	0.42	0.23	0.05	0.28	0.17	0.38	0.03	0.23	0.16	0.54

The correlation between parasitic infection and water quality parameters during the study period was explored using a multivariate analysis. CA dimension 1 accounted for 91.5% of the total variance and correlated with most of the parasites e.g. CA revealed that there were strong and weak positive loadings of *Trichodina* spp. and *Naescus* spp. in the wild respectively during the January and August. Their prevalence was influenced by salinity and DO. *Crustacean* spp., *Clinostomum* spp., *Dactylogyrus* spp. and *Diplostomum* spp. revealed different loading strengths with a very strong loading of *Crustacean,* then *Clinostomum* spp., *Dactylogyrus* spp. and then a very weak loading of *Diplostomum* spp. during the month of February and May samplings. Temperature was the main water quality parameter affecting their prevalence. *Acanthocestis* spp. and *Amirthalingamia* spp. loadings were influenced mainly by TDS during March and July sampling. There was no any loading of parasites during the April sampling. Dimension 2 of the CA only accounted for 4.1% of the total variance and did not show any clear correlation between the two variables (Fig. 4.18).

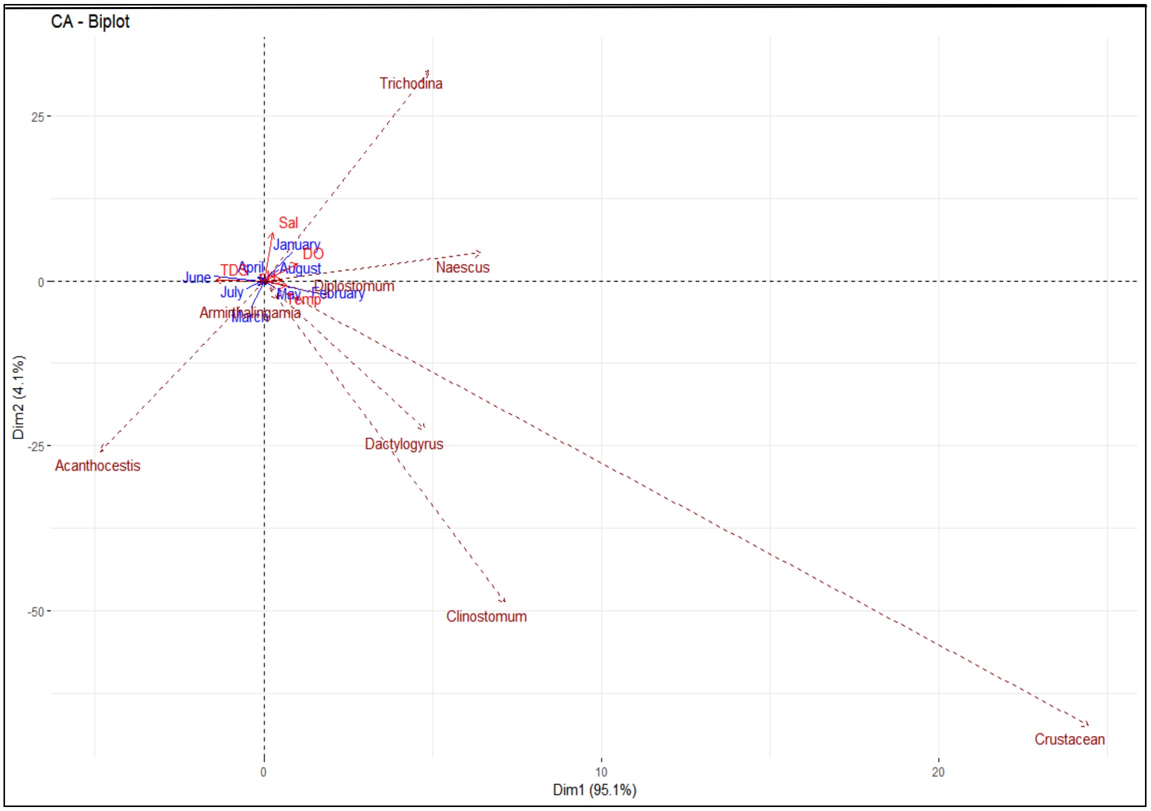

Fig 4.18 CA showing the loading rates of wild parasites and their relationships with the physico-chemical water quality parameters

In the ponds, CA dimension 1 accounted for 96.2% of the total variance and correlated with all the parasites except *myxobolus* spp. and *contraceacum* spp. which were correlated with the dimension 2 which accounted for 1.1% of the total variance. Parasites such as *Trichodina* spp., *Diplostomum* spp., *Naescus* spp., *Dactylogyrus* spp. and *Amirthalingamia* spp. revealed different strength of loadings in the month of January with *Amirthalingamia* spp. and *Diplostomum* spp. showing the strongest and weakest loadings respectively. The loadings were influenced by mainly temperature and pH. *Acanthocestis* spp. had a strong loading while *Gyrodactylus* spp. and *Clinostomum* spp. revealed weak loadings during the month of February and March. Their prevalence was weakly influenced by temperature and TDS. *Contraceacum* spp. had strong loading towards dimension 2 while Crustacean and *Tylodelphys* spp. recording weak loadings during the months of May, July and August with none of the physico-chemical water quality parameter affecting their prevalence. *Myxobolus* spp. showed moderate loadings during June and April samplings and its prevalence was weakly affected by salinity (Fig. 4.19).

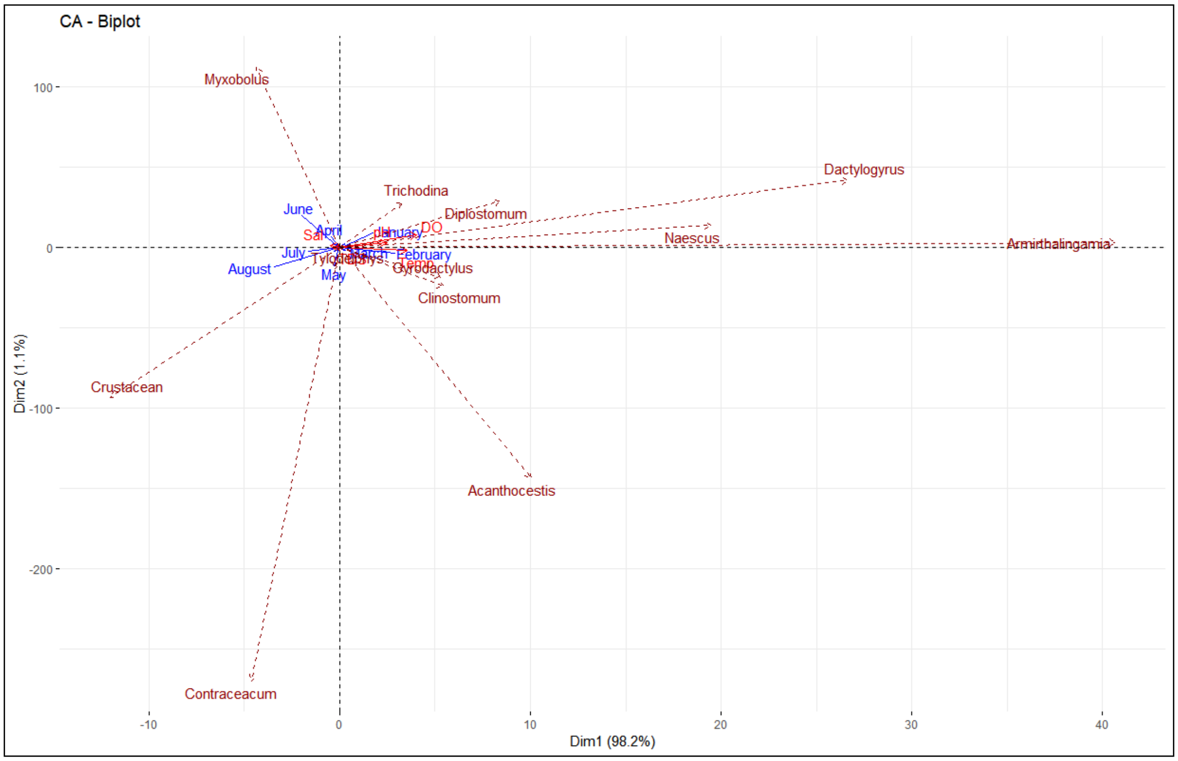

Fig. 4.19 CA showing the loading rates of pond parasites and their relationships with the physico-chemical water quality parameters

In the cages, CA dimension 1 and 2 accounted for 83.3% and 14.9 % of the total variance respectively and correlated with most of the parasites *Acanthocestis* spp. and *Clinostomum* spp. had very strong and weak loadings respectively during the months of February, March and August. Their prevalence was weakly affected by pH. In the month of June, *Diplostomum* spp., *Trichodina* spp., *Gyrodactylus* spp., *Myxobolus* spp. and *Contraceacum* spp. had different strength of loadings as *Contraceacum* spp. recording the strongest and *Diplostomum* spp. the weakest. The prevalence was influenced by temperature. During January, May and July, *Tylodelphys* spp. registered not very strong loading and its prevalence was weakly influenced by TDS. *Amirthalingamia* spp., *Naescus* spp. and

Dactylogyrus spp. were influenced by DO and salinity and recorded various loading strengths.

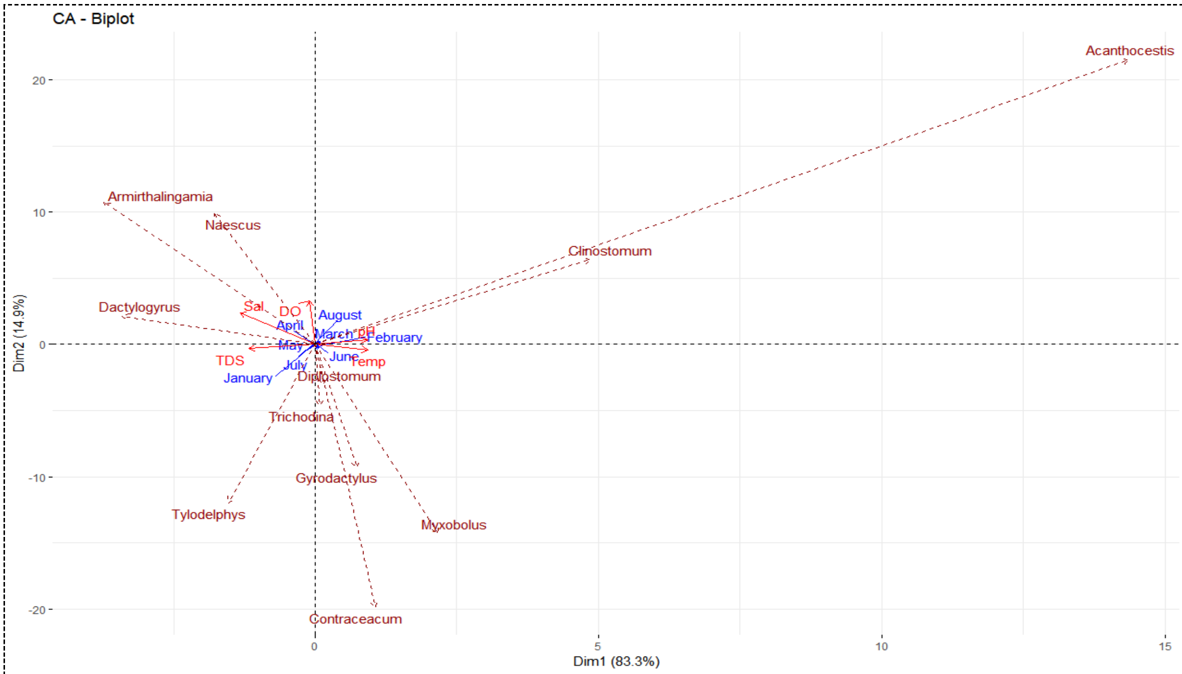

Fig. 4.20 Canonical Analysis and Biplot showing the loading rates of cage parasites and their relationships with the physico-chemical water quality parameters

Canonical Analysis factor map grouped variables with the similar influence on various fish parasites together. In ponds, *Amirthalingamia* spp., *Dactylogyrus* spp., *Diplostomum* spp. and *Naescus* spp. prevalence were similar and therefore they were positively loaded on the map with a positive correlation with DO and pH. *Gyrodactylus* spp. and *Acanthocestis* spp. also had a similar response towards change in temperature and TDS. *Contraceacum* spp., *Clinostomum* spp., *Crustacean* spp. and *Tylodelphys* spp. were also grouped together by the factor map indicating a similar change in their prevalence while *Trichodina* spp.and *Myxobolus* spp. were also affected similarly (Fig 4.21).

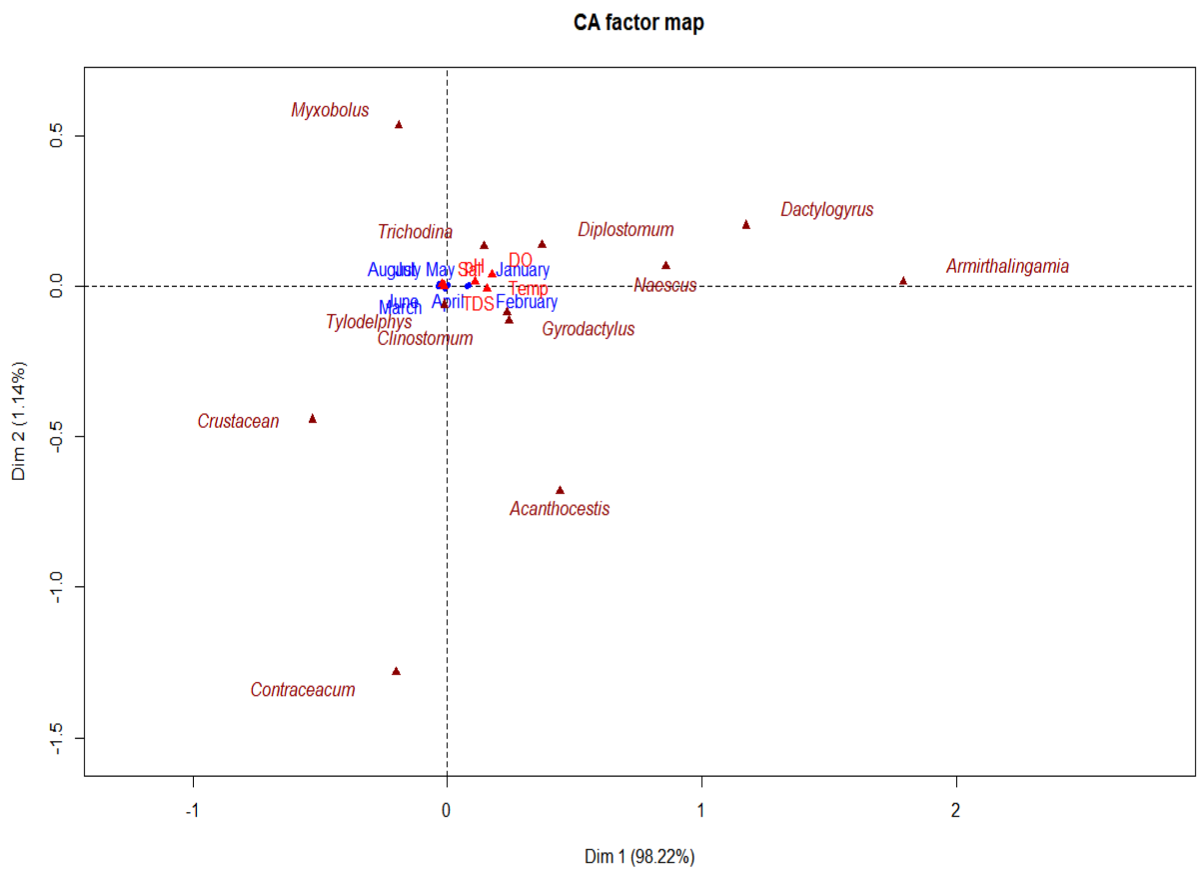

Fig. 4.21 Canonical Analysis factor map of showing parasite groupings and water quality effects in pond

In cages, *Acanthocestis* spp. and *Clinostomum* spp. were grouped together as *Armithalingamia* spp.and Dactylogyrus also responded similarly with *Naescus* showing an independent response. *Diplostomum* spp. and *Myxobolus* spp. had a similar behavior regarding the temperature change while *Trichodina* spp., *Gyrodactylus* spp., *Tylodelphys* spp. and *Contraceacum* spp. all grouped together (Fig 4.22)

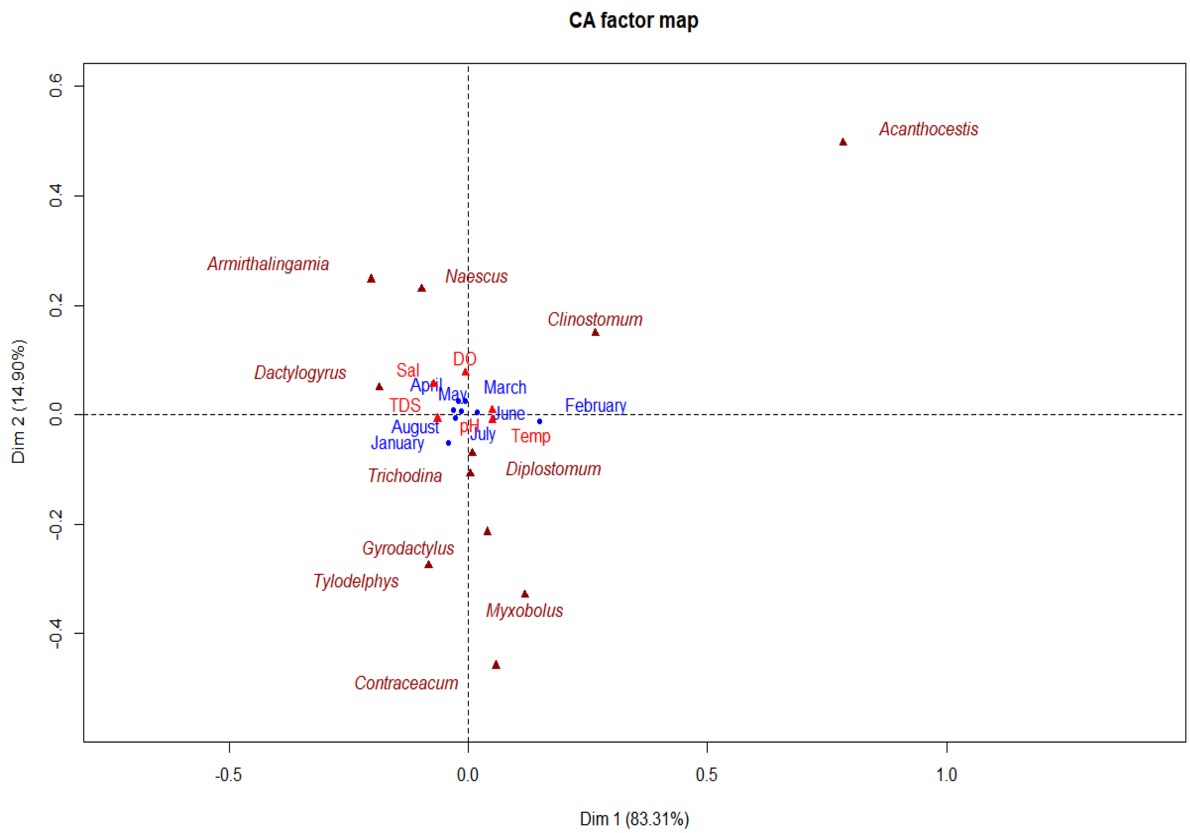

Fig. 4.22 Canonical Analysis factor map of showing parasite groupings and water quality effects in cage

In the wild, *Naescus* spp. and *Trichodina* spp. were distantly grouped together and they responded similarly to various DO concentrations while *Diplostomum* spp., *Dactylogyrus* spp., *Clinostomum* spp. and *Crustacean* spp. also clustered together with *Acanthocestis* spp. and *Amirthalingamia* spp. also behaved similarly in response to environmental changes (Fig. 4.23).

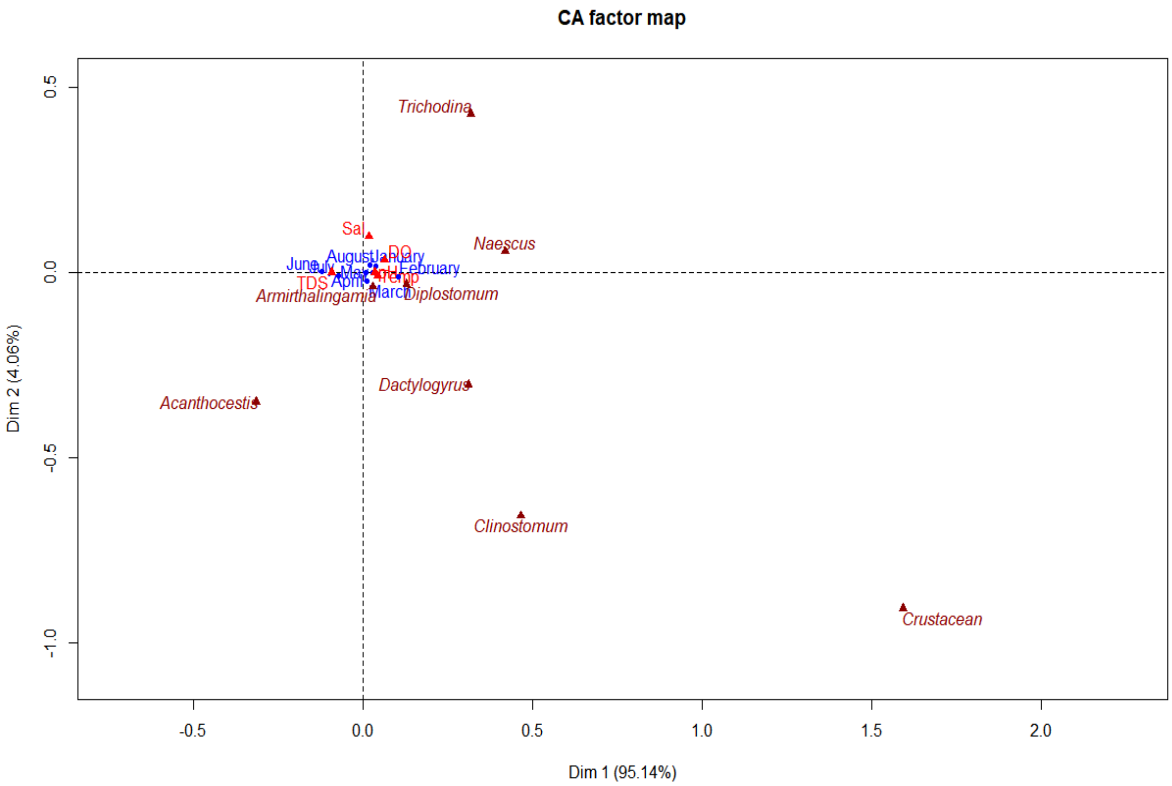

Fig. 4.23 Canonical Analysis factor map of showing parasite groupings effects in wild

4.2 Socio-economics Objective

4.2.1 Distribution of respondents and response rate

A total of 96 fish farmers were interviewed in Winam Gulf. These farmers were unevenly distributed along the gulf. Out of the 96 farmers, 34 (35.4 %) were either cage owners or cage managers while the remaining 62 (64.6%) were either pond owners or pond managers. Majority of the farmers were males (78%) and they were over 50 years of age (74.5%). Most ponds and cages were managed by the owners (71.6%) while some were managed by farm workers (18.4%) and spouses (10%) and children (0.7%) to the fish farm owners who were also respondents in some farms.

Of the fish ponds and cages studied, 38.3% of the farmers were involved in fish farming as their main occupation while others were involved in business (23.2%) and some were salaried employees (30.5%) while 8% did not specify their main occupation (Fig. 4.24). Almost all (90%) of the farmers went through formal education where most of them (38.2%) attained secondary level of education followed by primary certificate holders at 24.8 % (Fig.4.25). Majority (53.8%)of the farmers have been practicing fish farming for more than 5 years (and out of this 90% are pond farmers with only 10% cage farmers) while 25% have been in farming for between 2 and 5 years while the remaining farmers (21.2%) have just been into farming for less than 2 years.

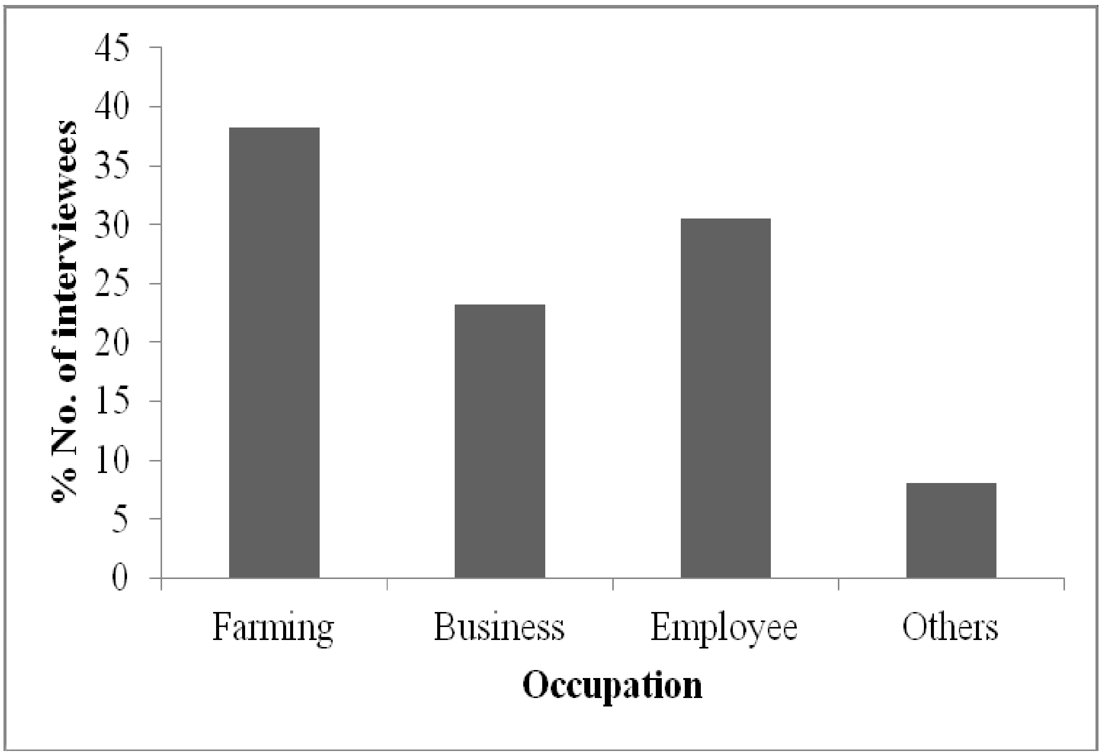

Fig 4.24. Other non-farm enterprises that farmers are engaged in within the gulf

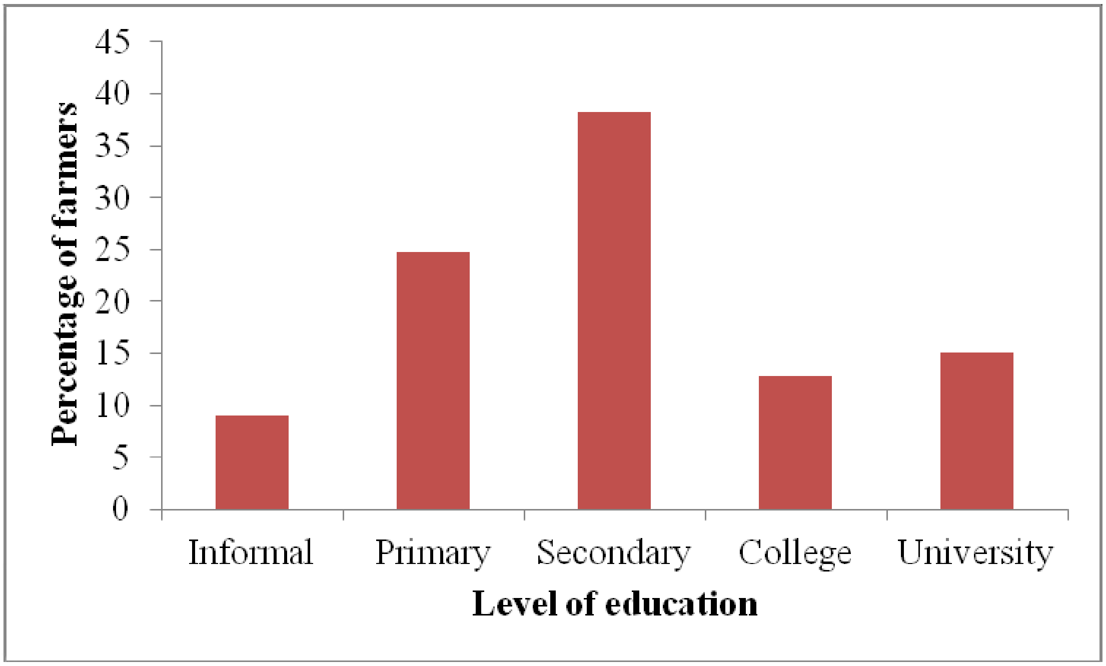

Fig. 4.25 Fish farmers' education levels along Winam-Gulf of L. Victoria (NB: College: Diploma and certificate holders while University: Degree holders)

4.2.2 Fish species and Culture systems

Nile tilapia is the main species being cultured within the gulf and 91.3% of the farmers' culture mono sex tilapia while 6.2% stocked both tilapia and catfish and 2.5% stocked mixed sex tilapia. Even though majority of the farmers stocked mono sex tilapia, they still encountered some breeding taking place within the ponds and cages. This was evident during feeding and sampling as fingerlings could still be seen amongst the adult fish. Cages were only stocked with mono sex tilapia. These are the only species cultured within the gulf and its shores. Semi intensive farming system was practiced by majority (236.9^0) of the farmers mainly in earthen ponds (73.9%). Other farming systems practiced included: extensive system and intensive system practiced by 82.8^0 and 40.3^0 (all in cages) of the farmers, respectively (Fig. 4.26). Only 22.8% of the ponds had liners while 3.3% of the ponds were concrete.

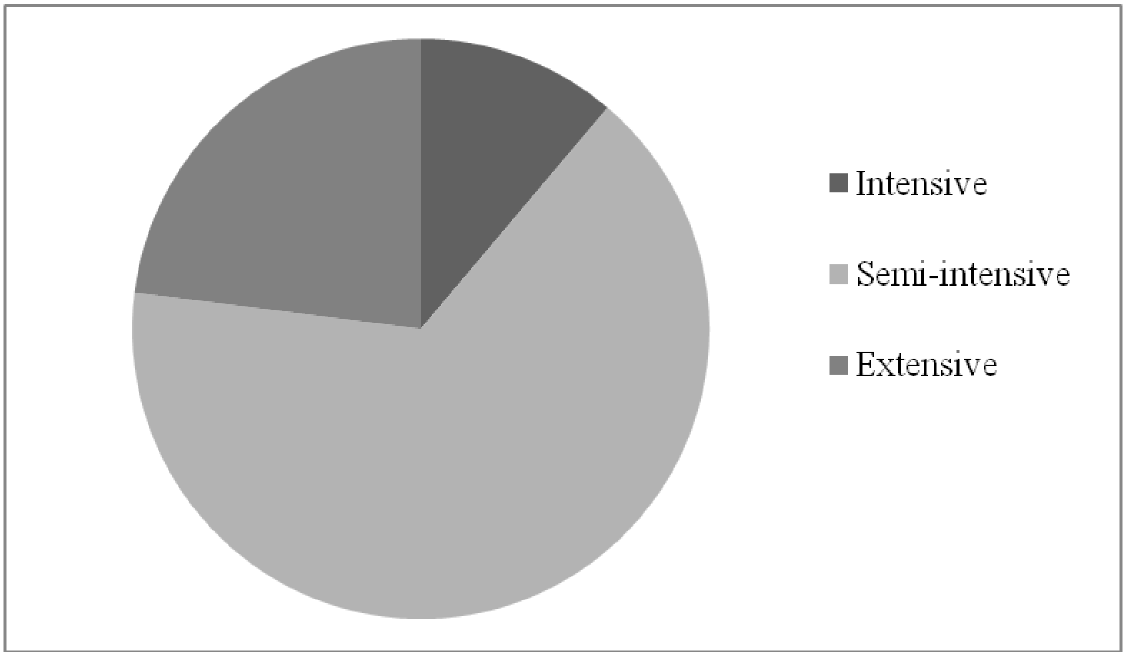

Fig. 4.26 Culture systems practiced by farmers within and along the shores of the Gulf

4.2.3 Source of fingerlings and Water

Majority of farmers around the gulf sourced their first stock of fingerlings from private farms (55.8%) others source from government agencies hatchery (29.5%) and 10% of the farmers got from their own breeding ponds while only a few (4.7%) sourced from the wild. No farmer was importing fingerlings from outside the country. The number of farmers who restocked from private and government hatcheries were (25.6% and 20%) respectively while a considerable number of farmers (26.4%) left the fish to inbreed in the ponds without sourcing fingerlings from outside for restocking while the 28% sourced from their own separate ponds and the wild (Table 4.6). Out of these overall percentages, all the cage farmers sourced their fingerlings either from the private hatcheries (62.8%) or government hatcheries (37.2%).

Table 4.6 Sources of fingerlings for fish farmers in Winam Gulf and its shores

Source	**Percentages**	
	Initial	**Restocking**
Private hatchery	55.8	25.6
Government hatchery	29.5	20
Inbreeds	0	26.4
Own pond	10	20.5
Wild	4.7	7.5
Import	0	0

Rivers which accounted for 40.9% were the major sources of water for the ponds followed very closely by wetlands or lake shores (38.4%) and finally boreholes (13%). Other water sources included dams (5.9%) and harvested rain water from the roof (1.8%). About 79.7% of the farmers which were the majority did not change or refill water in the fish ponds during a production cycle. Only approximately 20.3% changed or refilled water at various intervals including once per month (5%), twice per month (7%) and once for an entire production cycle (8.3%). There was no change of water in the cages as all the cages were erected at the Winam Gulf of the L. Victoria, Kenya.

4.2.4 Fish feeds used

Commercial fish feeds were used by majority (55%) of farmers followed by home-made formulation (21.7%) of farmers. Other feeds used include vegetables (6.8%) and kitchen leftovers (3.3%). Majority (91.5%) of the cages used commercial feed while the rest used both commercial and home-made. However, 13.2% of the farmers were not feeding the fish (Fig. 4.27). Majority 90.2% of the farmers using commercial feeds fed ponds and cages twice a day while the remaining number of farmers fed fish ones. The rest of the feeds were given randomly without proper timing and location. There was no standard measure of feeds given to the fish.

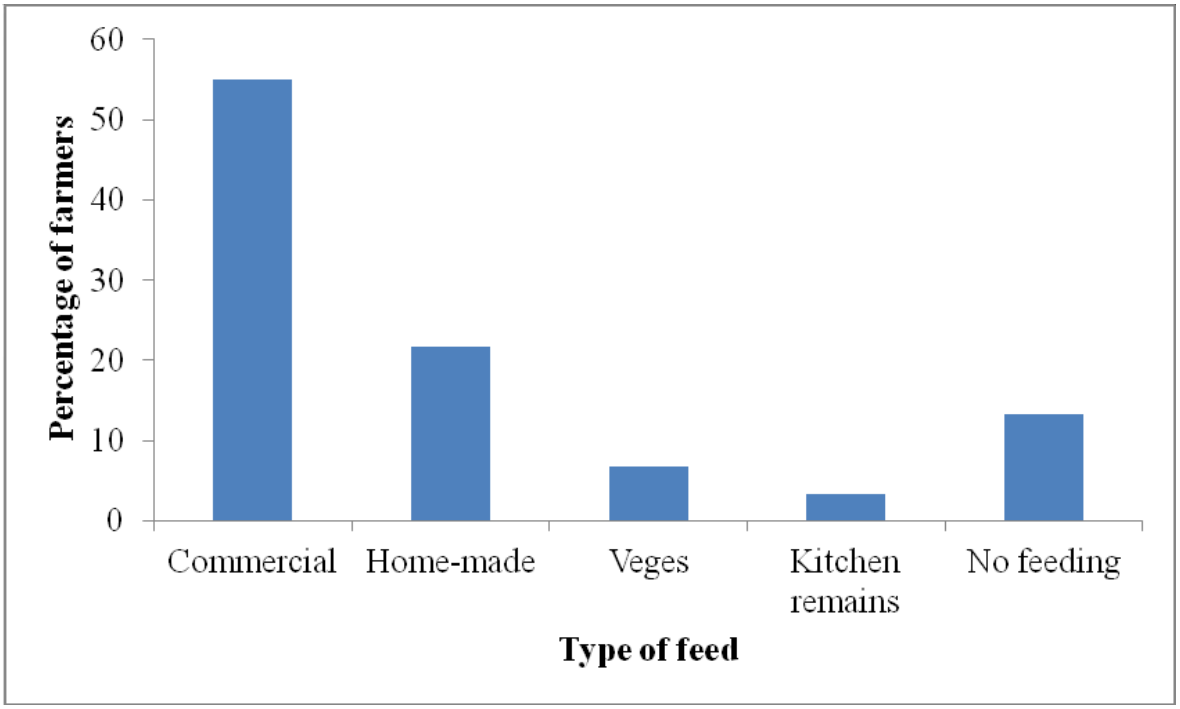

Fig. 4.27 Type of feeds used by farmers within the gulf during the study period

4.2.5 Pond and cage drainage and treatment after harvesting

During the study only 20.3% of farmers were draining their ponds during harvesting and out of these, 56.8% applied agricultural lime and fertilizers as a means of pond treatment after draining while 43.2% allowed the ponds to sun-dry without liming and fertilization. Over 90% of the farmers use livestock manure for fertilization with less than 10% using chemical fertilizers (di-ammonium phosphate (DAP) and calcium ammonium nitrate (CAN)). The farmers did not have a specific proportion of lime and manure to be applied since they were just estimating the amount to be applied. A greater percentage of the farmers (79.7%) did not drain their ponds and this means their ponds were not limed, fertilized or sun-dried before restocking. No farmer recorded cage disinfection and cleaning after the production cycle. However, the frequency of pond fertilization and liming varied with 41.8% of farmers never added manure within a production cycle, while 14.6% added when the green color fades off. Others added manure at various intervals including once every three months (25.4%), once a month (10.9%), once for every two months (5.1%) while 2.2% added twice per month. Majority of the farmers knew that fish eats manure and that is why they apply it frequently. Majority of the farmers (80.6%) did not have their own fishing nets and therefore were forced to share with other farmers while 97.1% of the farmers with more than one pond and cage used the same net between ponds and cages. After using the nets, farmers had various ways of washing them. Majority of the farmers (81.4%) washed them with pure water only while, 5.7% dried the nets on the sun and use them later without cleaning but 2.1% cleaned them using water with a disinfectant. However, 10.8% of the farmers did not clean the fishing nets at all but use them continouosly.

4.2.6 Predatory animals and vegetation around the culture systems

Predatory birds (60.8%) were the major animals seen around the ponds and cages (Table 4.9) followed by otters (13.6%). Domesticated dogs (7%) and cats (5.7%), snakes (6.1%), aquatic snails (1.9%) and monitor lizard (4.9%). Predatory birds and otters were reported by majority of the farmers to occur frequently and some farmers say they see them throughout the day and it forced them to continuously chase them away. Dogs, snakes, monitor lizard and cats occurred less frequently while; snails were reported to be rare (Table 4.7). The following birds were spotted during the survey which was confirmed by farmers as follows. Kingfishers were the major (25.3%) predatory birds followed by Ibis (20.5%), herons (16.6%) and egrets (7.3%). Other predatory birds seen include: marabou stork, cormorants, hamerkop, fish eagles, wild ducks, pelicans and crows. Majority of the ponds were heavily vegetated (56.2%) with 20.5% less vegetated and the rest moderately vegetated.

Table 4.7. Animals seen in and around the cages and fish ponds in the gulf (Only birds apply to both the rest were only recorded in ponds)

Animals	**Frequency (Percentage of farmers)**			
	% of responses	**frequently**	**less frequent**	**Rare**
Birds	60.8	78.3	14.7	7
Otters	13.6	63.7	26.1	10.2
Monitor Lizard	4.9	27	68.5	4.5
Snails	1.9	2.6	6.4	91
Snakes	6.1	12	38.5	49.5
Cats	5.7	22.5	67.2	10.3
Dogs	7	20.5	72.5	7

4.2.7 Presence of parasites or abnormalities, production cycle and stocking density

Only 5.4% of farmers reported that their fish had been infested by parasites. Of the farmers interviewed, 82.6% did not know any sign of fish parasitism and fish abnormality while the others mentioned various signs and abnormalities which included: skin discoloration (1.5%), poor feeding (3.6%), slow growth (5.8%), swollen belly (1.8%), erratic swimming (2.2%) and bend tail (2.5%) as the main signs (Table 4.8).

Majority (32.8%). of the farmers harvested fish at the age of 7-9 months. Other farmers harvested at varying ages including; 10% of the farmers (all cage) harvest after 6 months weighing around 250g other pond farmers (55.8%) harvest at 10-12 months and the rest of the farmers harvested randomly. Majority of the farmers (90.8%) could not ascertain the weight of harvested fish during harvesting since they sold in sizes as opposed to in weight. It was also interesting to note that majority of the farmers (70.5%) experience fish losses but could not give reasons for the mortality while 29.5% were not very sure of any fish loss.

Most of the pond farmers (43.5%) did not know their stocking densities since they kept on adding the fingerlings from other ponds within their farms while 30.9% of the farmers had an initial stocking density of 1000 fingerlings in 300 sq. meter pond but realized a lot of inbreeding within the ponds which could raise the density to above the initial density. Other farmers 25.6% had an initial density of 1500 and above fingerlings in 300 sq. meter pond. Most farmers operated small cages (2 x 2 x 2) in which 90.3% of farmers had an initial stocking density of 2000 fingerlings and 9.7% stocked 2500 fingerlings. Just like in ponds, there was inbreeding in cages as the fingerlings could be spotted during sampling session. This makes it hard for farmers to exactly know the fish biomass in the cages and ponds at a given time. This was seen as a serious threat to fish production. Since Nile tilapia is a prolific breeder, it is always advisable for farmers to go for male-only fingerlings and since majority of the farmers had no access to quality and certified hatcheries, they ended up stocking mixed sexes which resulted to serious inbreeding in various culture systems

Table 4.8 Farmers knowledge on symptoms of fish parasitism and abnormalities

Fish abnormality	**% of respondents**
No abnormality	82.6
Stunted growth/Retardation	5.8
Bend tail	2.5
Erratic swimming	2.2
Swollen belly	1.8
Skin discolor	1.5
Poor feeding	3.6

4.2.8 Challenges faced by fish farmers

Fish feed in general was a major challenge to all farmers. Twenty-five-point seven percent of the farmers were saying the cost are very exorbitant, quality compromised and they are also unavailable and a greater percentage (21.1%) said the cost of fish fingerlings were high, poor quality and not easily accessible. Other challenges reported were fish predation (10.4%), water shortage (4.7%), theft (5.2%), slow growth of fish (10.6%), limited extension services (10%), theft (3.3%) and finances (9%), (Table 4.9).

Table 4.9: Challenges faced by fish farmers in Winam Gulf and its shores

Type of Challenge	**% of respondents**
Feed (Expensive, poor quality and unavailability)	25.7
Fingerling (Expensive, poor quality and unavailability)	21.1
Fish predation	10.4
Water shortage	4.7
Stunted growth	10.6
Limited extension services	10
Theft	5.2
Financial shortage	9

CHAPTER FIVE

5.0 DISCUSSION

5.1 Environmental Parameters

5.1.1 Temperature

Temperature is a very important physico-chemical variable in fish farming that affects fish metabolic rate (FAO, 2006). It also affects the toxicity and the reaction rate of other chemicals such as ammonia, which are very detrimental to fish besides influencing the solubility of gases in water including atmospheric oxygen, which is only useful in a solution. Kiran, (2010) observed that temperature fluctuation also affects the development of natural food sources of fish such as phytoplankton and zooplankton hence impacting negatively on fish productivity. High temperatures in any aquatic ecosystem lead to increase in metabolic activity of aquatic organisms and at the same time reduces the concentration of dissolved oxygen in water (Afzal *et al.*, 2007 and Reshid *et al.*, 2014). The recommended ranges for good performance of warm water fish according to FAO, (2006) is between 25 and 32^{o}C. Very low temperatures causes stagnation of fish growth and at times kill the fish while very high temperatures also reduces the solubility of atmospheric oxygen and contributes to stress in fish, which may also lead to fish death.

During the entire period of study, surface water in the Winam Gulf exhibited a narrow range of temperature 24.5-26.8^{o}C, 24.8-28.8^{o}C and 25.5-26.5^{o}C in cage, pond and wild, respectively. This may be due to almost the same intensity of solar radiation experienced during the study period in the gulf and absence of micro-climatic variations in temperatures during the study period. On a different study by Escalera-Vazquez and Zambrano (2010), a similar trend was reported where they indicated that majority of the tropical lakes shows a relatively constant solar radiation which results in narrow seasonal ranges of both air and water temperatures. Winam Gulf surface water temperature showed a slight rise and fall from January to April, a slight drop in May followed by another change in the subsequent months. There was generally high solar radiation over the Gulf region during the period when surface water temperature was observed to rise and that is why the wild and cage temperature showed a similar trend since it's the same ecosystem. The heat content and temperature in the water column were higher from January to March than April to August, which could be attributed to difference in cloud clarity, which is directly affecting the intensity of the solar radiation incident to the lake surface. There was rarely a cloud cover from November 2017 to March 2018 and this is why the temperature at this time was higher than the periods that experienced some slight rains i.e. April till September 2018. This is not in agreement with the study done by Ayroza *et al.,* (2013) who stated that higher temperatures in the rainy season have been associated with deep reservoirs that have a long residence time; favoring thermal and chemical stratification in the rainy season. This may be because they only study the thermal difference in a small water body and only during the rainy season unlike this study that considered both ponds and open waters of the Winam Gulf. A comparison between this study and Kaggwa *et al.,* (2011) and Denny *et al.,* (2006) revealed the same trend where they both agree that the smaller the surface area exposed to solar radiation the higher the temperature.

In each month when measurements were made, water temperatures in the open waters and cages were nearly the same during the study period. Different sampled ponds also showed the same temporal variation but with a higher value than the gulf. The high temperature in ponds could be as result of the smaller surface area exposed to solar radiation than the area in open waters of the gulf. This could be also as a result of depth as most ponds are barely

1m deep as compared to gulf where some points are too deep. Other possible reasons for the slight variations include: Some sampled areas were more enclosed with vegetation than others and their temperature tended to be slightly lower, e.g. areas around Kendu-Bay; influence by the inflowing rivers such as R. Nyando, Awach, Sondu-Miriu and Kibos that enter the Gulf also could have lowered its temperature when it rains. Ingole *et al.,* (2009) alluded that differences in temperature in any culture system is influenced by environmental variables such as air temperature, humidity, wind and solar energy.

5.1.2 Dissolved Oxygen

The dissolved oxygen concentrations in the Winam Gulf surface water and the nearby inland ponds were relatively high. The mean concentrations varied very little between the cages and open waters during the present study period. This relatively high concentration of dissolved oxygen in the gulf could be as a result of high phytoplankton densities which was very evident by the greenish colour of the water and also the atmospheric oxygenation which was evident by the wind that blows from the lake towards the shore. The high photosynthetic biomass is ecologically accompanied by high photosynthetic rates. The high phytoplankton biomass could be as a result of increased nutrient inputs into the gulf through the flowing rivers especially during the rainy season. The shallowness of the gulf also renders it prone to stirring of the water by winds causing nutrients to be released from the sediments into the water thus leading to increased productivity (Magagula *et al.,* 2010). The concentrations of DO in the cages and ponds in the entire gulf and its shore were lower and this was attributed to high stocking density of *Oreochromis niloticus* in the cages. The fish consumes the available dissolved Oxygen and could as well deplete it If the concentration is low. There could also be the cage-net effect on free circulation of water which could have also lowered the rate at which the atmospheric oxygen dissolves in water.

This augmented by excess feeds and fish waste together with other wastes that get into the gulf and ponds rendered the concentration at the cages and ponds lower than the open waters. The concentration in the entire gulf and surrounding ponds were relatively lower during some rainy period than dry spell this was attributed to the introduction of organic matter through the rivers and run-off from agricultural lands hence lowers the oxygen content of the water due to the consumption of oxygen during decomposition. This is supported by Mwaura (2006) who stated that lack water circulation and other pollutants in water negatively affect the rate at which atmospheric oxygen dissolves in water. The numerous car wash and open air garages within the shores of Lake Victoria also play a part in the reduction of oxygen in the gulf. With the blocked storm drains in the town, engine oil emanating from these car wash and garages is washed into the lake during the rains. Various patches of oil films are a common feature associated by urban centres especially during the rainy season. Such films reduce the aeration process of the water and thus lower oxygen content.

5.1.3 pH, Salinity and TDS

Just like temperature, pH according to ICAR (2006) has been reported to affect the metabolism and the physiological processes of aquatic organisms as well as affecting the toxicity rate of ammonia. In the current study, the water pH remained fairly constant in open waters of the gulf, cages and also the ponds over the period of the present investigations with values ranging between 7.0 and 7.6. There was, however, a marked trend of a slight increase in pH values during the rainy season which was not statistically significant. This is mainly due to the effect of dilution of the gulf water by direct precipitation and runoff. River run-off normally has a lower pH than the lake water while rain water has a pH of about 7.0. During the rainy season, the effect of dilution outweighs the effect of Carbon dioxide released during respiration by fish and other aquatic biota which would lower the pH. The relatively higher algal and zooplankton densities in open waters and ponds could have resulted into the release of more carbon dioxide into the water, thereby lowering the pH. Distribution of pH was nearly uniform throughout the water surface and column. The pH of the Winam Gulf does not appear to change considerably over a long period. This is because of the homogeneity of the physico-chemical parameters (i.e. rainfall pattern, water depth, amount of dissolved and suspended particles, chemical pollutants among others) in the entire gulf and its surrounding. This study is in agreement with Mkare *et al.,* (2010) and LVEMP (2005) who found out that shallow, tropical water bodies are often characterized by homogeneity in physico-chemical parameters due to complete mixing within the water column.

Biologically, as carbon dioxide is removed, carbonate accumulates and gives away hydroxyl ions leading to pH increase. Aquatic vegetation and plants can continue to use the small amounts of carbon dioxide available at pH values above 8.3, and bicarbonate may be absorbed by plants and some of the carbon from bicarbonate used in photosynthesis thus low pH. Mwaura (2006) and Denny *et al.,* (2006) also points out that the type of soil and lacustrine sediments can be associated with bicarbonate and carbonate ions could also affect the pH either by raising or lowering it depending on the soil and sediment type.

Salinity values were generally low during the study period. The low salinity of Lake Victoria can be attributed to high precipitation and high inputs of fresh water by the inflowing rivers. The much lower precipitation in some other lakes Specially in the Rift

Valley, the seasonality of the rivers that feed them, underground seepage and the high rates of evaporation cause high salinity in the lake water through concentration of ions (Voutilainen *et al.*, 2008; Njuguna, 1982).

The slightly high salinity concentrations in ponds (2-3mg/l) could be due to surface run-off which brings dissolved salts from the rocks over which it flows together with nutrients from agricultural land, especially during the rainy season. When water evaporates, the dissolved salts remains and their concentration increases and since the pond surface area is smaller than the open waters, the evaporation rate becomes higher and more intense in ponds than in open waters. This could have been the reason why the salinity in ponds was high as compared to the gulf.

Agricultural practice has been shown to influence nutrients and total dissolved solids (TDS) in water. Human activities such as fertilization and cultivation could have contributed to high, total dissolved solids and turbidity as this result into increased phytoplankton biomass according to Johnson *et al.*, (1997) and Esch *et al.*, (1993).

It is most likely that high concentration of total dissolved solids in ponds could have been as a result of pond fertilization which is recommended for algal growth. Most ponds were over-fertilized and therefore realized algal bloom as a result of high nutrient concentration. It could also have been increased by the soil particles eroded river banks getting into the ponds via run-off during rainy season. Unlike in open waters where there is high rate of dilution and the entry of these particles usually settle in the deeper layers of the lake. The differences in depth and the surface area exposed to TDS caused the statistical difference in the TDS concentration between open water and the ponds.

5.2 Common *O. niloticus* parasites in the study areas

In the present study, 12 taxa were registered in all the study areas. Cage and pond the composition did not differ as the case in the wild. Parasitism, as defined by Marcogliese (2001) reflects a life condition whereby one or more individual organisms derive nutritional benefits at the host's expense, usually without killing the host. All parasites utilize resources that are required for the host's growth, sustenance, development, establishment and reproduction and as such may harm their host in a number of ways and affect the hosts' production (Barber, 2004). A previous study reported that pathological effects due to parasites was influenced by the level of pollutants whereby the ecosystems with same level of pollutants are likely to be infested by the same type of parasites and the more an ecosystem is polluted the higher the diversity of parasites (Marcogliese, 2002). It has also been reported that the pollutants acting as irritants stressed the fish and reduced their resistance to infection as proposed by Luoma and Rainbow (2008). This could have been the reasons as to why the same parasitic infections were recorded in the two culture systems since they recorded the same environmental conditions and pollution extent but different from the wild or open waters which was less polluted. The infections increased the stress level and invariably weakened the immune system. There are other biotic and abiotic factors that affect parasite distribution in fish hosts. Biotic factors include host age, size, weight, maturity, sex and parasite life cycle while specific abiotic factors are temperature, season, oxygen, pH and depth of water among others according to (Pouder *et al.*, 2005) and therefore these factors could have also played a role in distribution of the parasite taxa in different environments during the study period.

Fish during this study were infested with parasites of the genera *Diplostomum* spp., *Clinostomum* spp., *Gyrodactylus* spp., *Dactylogyrus* spp., *Tylodelphys* spp., *Naescus* spp., *Trichodina* spp. and *Acanthocephalus* spp. The occurrence of these parasites have been observed elsewhere in Kenya and other countries in both farmed and capture fish (Aloo, 1999; Florio *et al.*, 2009; Otachi, 2009; Diana *et al*., 1997; Mathenge, 2010; Mavuti *et al.*, 2017b). In this study, the lack of significant statistical difference in occurrence of these parasites is also supported by the above studies as they did not show any difference in distribution of these parasites within different ecological zone within the country. It is stated that freshwater fish are infected by a restricted helminth parasite fauna according to Ochieng *et al.*, (2012) and this could also have been the case in this study.

This difference between the culture systems and the wild is linked to the fact that since fish in culture environments are held under controlled conditions, with compromised water quality conditions, they are easily affected by more parasites than those in the wild whose stocking density is too low, water is continuously aerated, temperature is favorable, enough space for movement among other environmental conditions.

5.3 Prevalence, Intensity and Diversity

This study has shown that cage, pond and wild fish in open waters of Winam Gulf of Lake Victoria in Kenya are often infected with different classes of parasites that cause both gross and microscopic pathological changes when they occur in high intensities. The taxa found during the entire period of study were: *Acanthocestis* spp., *Armirthalingamia* spp., *Clinostomum* spp., *Unidentified Crustacean* spp., *Dactylogyrus* spp., *Diplostomum* spp., *Naescus* spp., *Tylodelphys* spp., *Gyrodactylus* spp., *Contraceacum* spp., *Myxobolus* spp. and *Trichodina* spp. Overally, the parasitic prevalence was 71 % for the pond fish while the cage fish had a prevalence of 67% and finally wild fish recorded the lowest prevalence of 33.8%. The high prevalence of parasitic infection in the caged fish could have been attributed to high stocking density which led to high degree of body contact and compromised water quality parameters within the cages while in ponds it may have been attributed to surrounding vegetations observed in most ponds which offered good conditions for the propagation of the intermediate hosts, the snails. This condition may further attract the definitive hosts, the piscivorous birds (Baker, 1963; Paperna, 1980). This is in agreement with the study by Mathenge (2010) who reported that the presence of weeds and other vegetations in the ponds at Sagana fish breeding farm whose presence contributed to the high prevalence of helminthes parasites found in the fish from that farm. He further illustrated that the overgrown vegetation provides a good environment for parasites such as crustacean copepods or leeches and snails that are vectors/intermediate hosts for various parasites. The mud can be a reservoir for cysts of dinoflagellates and invertebrates' intermediate hosts for digenean trematodes such as snails (Komar and Wendover, 2007). These conditions may further attract the definitive hosts, the piscivorous birds, (Barson, 2004) as quite a number of birds were also reported to have been around both the ponds and cages. The deterioration of water quality in both cages and ponds could have been the reason as to why there was no significance difference in their prevalence since they recorded same ecological conditions given no altitude and latitude differences.

As reported in Jadwiga (1991*),* *Dactylogyrus* spp. and *Gyrodactylus* spp. spps are monogenic trematodes with a simple and straightforward life cycle and needs only one host's gills and skin where they attach their hooks and suckers. They are external monogenetic trematodes mostly found in African water bodies as reported from Uganda and Ethiopia (Florio *et al.,* 2009). He further illustrated that their high prevalence can be explained by the life cycle pattern. They are monoxenous parasites, and the risk factors favoring its spread such as warm tropical temperatures, low water exchange, poor bottom hygiene, and short water column depth among among other environmental factors, which could have been the reason why there was high prevalence in cages and ponds with very low if any in the wild. *Gyrodactylus* spp. was conspicuously missing in the wild and this could be associated with the rare fish-to-fish contact in the wild unlike in the culture systems, more frequent in farmed fish than the wild. This is not in line with the studies from other parts of the East Africa, for instance, the study by Florio *et al.*, 2009 found out the the highest prevalence in wild fish was 63.35% compared to the cultured fish which is 31.7% from Uganda but in agreement with the Martines *et al.*, (2015) who elaborated on how the ect-parasites have higher reproductive success in aquaculture units where there is high stocking density than the wild. They are also known to reproduce faster and transmit from one fish to the other in aquaculture systems than in natural environmental conditions (Martines *et al.*, 2015). Extreme limited water movement and poor bottom quality due to excessive eutrophication as well as very high stocking density are some of the main risk factors enhancing spread of infestation and according (Florio *et al.*, 2009) can develop to heavy gill infestation and other organs' infestation in farmed fish. Generally, the prevalence, mean intensity and abundance values in cages and ponds were more less the same, although caged fish portrayed a higher value for both *Dactylogyrus* spp. and *Gyrodactylu*s spp. This might have been because of restrictive movement of fish due to high stocking density per unit area therefore enhancing fish-to-fish transmission of *Gyrodactylogyrus* spp. and invasion by oncomiracidia of *Dactylogyrus* spp. besides influence from both biotic and abiotic factors. Additionally, it is more likely that caged fish to have injuries due to congestion than any other culture unit or wild. This is supported by Otachi *et al.*, (2009) who stated that when the stocking density is extremely high, fish would get injuries because of fish-to-fish fin contact, which makes them highly vulnerable to parasitic infection if carelessly handled. Studies by (Aloo, 1999; Otachi, 2009; Mathenge, 2010) on fish parasites also agree with these findings. These two common monogean parasites have been observed elsewhere in Kenya and other countries in both farmed and in rare cases capture fish (Mavuti *et al.*, 2017b). It can therefore be concluded that monogenic external parasites have higher probability of survival and reproduction success in fish farms, where they spread very fast to multiple hosts because of the overcrowding than in the wild. External parasites usually develop, transmit and reproduce faster in aquaculture systems than in natural conditions where they live in equilibrium with their hosts, perhaps explaining why infection rates of these parasite groups may be low in the wild. They were recorded in low intensities with most of the fish registering a value less than 2. Since it has been stated that more parasites infest on fish in highly polluted ecosystems with very high intensities, the low intensity recorded was related to an overall good environmental conditions observed with all the physico-chemical water quality parameters sampled were above the required levels for fish to thrive and therefore there was no suitable conditions for parasites to multiply. In an interview with the cage farmers, it was very evident that the productivity in both cages and ponds were decreasing with time. This could be related to accumulation of parasites over time hence high intensities. The cages and ponds sampled had not stayed for a very long time and therefore the parasite accumulation over time was low. This may explain the low appearance and intensity of ectoparasitic species found in this study. The low intensity has been supported by Gichohi *et al., (*2008) who said that there was a higher prevalence and intensity in a new aquaculture set-up than the one that has stayed for a while this he said could be due to the accumulation of the worms over a longer period.

Digeneans always reveal a very complex life cycle and their occurrence and distribution in fish follows the presence or absence of intermediate and definitive hosts. Digeneans i.e *Tylodelphys* spp., *Clinostomum* spp., *Diplostomum* spp. and *Naescus* spp. observed in both aquaculture systems could be attributed to quite a number of physical, chemical and biological factors. Otachi (2009) also recorded a similar species of parasites during his comparative study on parasite infestations in Machakos and Sagan fish farms in Kenya. During the entire study period, the possibility and availability of the infested snails could the reasons as to why there was such an infection. During the study period, *Tylodelphys* spp., showed very minimal variation in their mean intensities between the study units or sampling sites and slightly higher prevalence values in fish ponds than cages and this could be attributed to the consequence of the muddy sediment and vegetation around the ponds besides differences observed in biotic factors such as presence of snails and piscivorous birds around both cages and ponds. Human activities around the ponds and the shore could have also influenced the water quality resulting to high prevalence of this parasite. *Diplostomum spp* was the most frequent digeneans found in *O. niloticus* from all the study areas, this could be due to suitable snail hosts habitat in all the areas under study. High prevalence levels for digenic trematodes in the culture systems were associated with presence of birds that are linked to the life cycle of some of these parasites. Some of the common birds included the cattle egret, grey heron, pelicans and cormorants which were observed frequently around the culture systems during the study period. These birds play an important role in transmission and life cycle of these parasites, hence the high prevalence levels. Piscivorous birds are definitive hosts for many metacercarial stage digenean parasites found in fish. Aquatic birds also contribute to the dispersal of aquatic snails, which serve as intermediate hosts for many digenean parasites. Records from

Paperna (1996) suggest that water bodies from the Jordan system throughout the Nile to the Rift Valley lakes share common snails such *Lymnaea* spp. and *Melanoides* spp. High prevalence of helminths are further linked to behaviour of fish in relation to habitat types and disruption of parasites transmission by water currents and depth respectively. For this reason, cages are considered to be safer for rearing fish in deep waters as parasites are in higher numbers in the bottom. These findings are in agreement with Steinauer and Font (2003) who stated that the increase of copepod intermediate hosts and increased fish foraging in the summer results into high prevalence rate and on the other hand, decline of prevalence and abundance in fall has been asociated with death of infected hosts or competitive interarctions among individual helminths.

According to Akoll *et al.,* (2012), non-seasonal fluctuations in parasites could be due to highly variable nature of the water body; with frequent, unpredictable changes in the physical conditions causing unstable populations that fluctuate unpredictably regardless of seasonal effects. Studies undertaken elsewhere have shown that prevalence of digenic trematodes are directly related to the density of the aquatic invertebrates as intermediate hosts (Voutilainen *et al.,* 2008). In addition, *Diplostomum* spp. metacercariae eye infections for instance have been found to increase the vulnerability of the affected fish to predators by changing their behavior and by coming much often to the surface, where they become easy targets for the predators (Seppala *et al.,* 2004). Due to control of predators in fish farms in contrast to the wild, digeneans infested fish will tend to survive more compared to the wild where they will certainly be predated by the piscivorous birds. During his study, Otachi (2009) relates the differences in prevalences to varying water temperature and caging. In addition, the increased stocking density in fish farms compared to the wild may enhance the infestation rates in those fish according to (Karvonen *et al.*, 2005; Violante-Gonzalez *et al.*, 2009).

In case of a vey high infection load of digenic trematodes such as *Tylodelphys* spp., this usually occupies between lenses and retina causing partial or total blindness of fish. According to Paperna, (1996) and Florio *et al.*, (2009), the severe infection could also result in to impairment of the eye ball, poor vision and total blindness. This same infection according to Florio *et al.*, 2009 results into loss of sight and prevents the fish from seeing food and enemies and is therefore resulting to stunted and very poor growth which results in to poor yields in terms of production. Besides, fish is highly susceptible to predation and other consumers as they cannot see and escape from their enemy leading to high rate of predation.

Contracaecum species have a wide range of secondary hosts to choose from and would go for the most available ones. They are normally attracted to various fish species and occur all the way across Asia, Europe to Eastern Africa, transmitted by the migration routes of piscivorous birds which are their final hosts (Paperna, 1996). It is the only nematode that was found during the entire study period. According to Zhokhov *et al.*, (2007), *Contracaecum* spp. is one of the parasites, which commonly attack *Clarias gariepinus* and *Oreochromis niloticus*. Madanire-Moyo and Barson (2010) in their study on sensitivity of this species to pollution reported that it is highly prevalent fish parasite in some cases, they are very sensitive to water pollution because of their first intermediate host copepod's vulnerability to water pollution (Madanire-Moyo & Barson, 2010) this makes them one of the best water quality bioindicators. In Comparisson, Lake Tana recorded a high prevalence of *Contracaecum* spp. infecting *Oreochromis niloticus* at a rate of 59.8%, at 51.8% in Lake

Naivasha, and 48.6% at Lake Awassa (Otachi *et al.,* 2014). This is supported by other studies such as Tadesse, (2009) and (Yimer and Enyew, 2003). These high prevalent rates were opposed to the low rates (< 10%) registered in both ponds and cages with no infection in the wild during this study. In aquaculture, fish become infected with nematodes if they feed on live foods (mainly crustaceans) containing infective larval stages or if they are farmed in culture systems that promote the growth of other animals hosting infective stages of the nematode (vector or paratenic host, and intermediate hosts). Some nematodes can be transmitted directly from fish to fish, but the common life cycle pattern of fish nematodes is indirect, with at least one intermediate host (Yanong, 2006). This could be the reason why there was presence of this parasite though low in prevalence and intensity in farmed fish but not in the wild. The following studies: Yimer and Enyew, 2003; Tadese, 2009; Florio *et al.,* 2009; Gulelat *et al.,* 2013; Reshid *et al.,* 2014 all confirm this study's finding on the low prevalent and mean intensity values of this nematode species in culture systems and its absence in the wild.

The crustacean parasite is widely distributed across Africa and it's more common in *Clarias gariepinus* species according to (Paperna, 1996). In this study, unidentified *crustacean* species was found once in pond and wild with no prevalence registered in the cages. This could be attributed to crustacean parasites of fish showing a direct life cycle which is strongly affected by environmental variables such as low water exchange, presence of algal bloom, among others. The absence of these environmental conditions during the study period could have resulted into the low prevalences and intensities in ponds and wild. This study is supported by (Yimer & Enyew, 2003) who while reflecting the records from Lake Tana, Ethopia, where this species is not endemic and is rarely found. This type of parasite is also known to be sensitive to water pollution because of their first secondary host copepod's susceptibility to water pollution (Madanire-Moyo & Barson, 2010). Similar parasites were also identified and described in caged *Oreochromis niloticus* from Wonji, L. Babogaya and Awassa but the prevalence and intensities were not high but ranging from 3.0 to 8.6% (Florio *et al.*, 2009).

Trichodina spp. which belongs to protozoan taxon was found in cages and ponds at 14% and 20% prevalence rate respectively. Martins *et al.*, 2015 revealed that *Trichodina* spp. was reported on fish in major water bodies in Eastern African cages, ponds and natural water bodies. Comparatively, there was higher prevalence rate in aquaculture systems than in natural water bodies. For instance, a comparative study conducted in Uganda in ponds, cages and natural waters, *O. niloticus* fish according to Florio *et al.*, 2009 revealed a prevalence of 34.6%, 22.2% and 1.8% respectively. According to Tadesse, (2009) a higher prevalence rate of *Trichodina* spp. in aquaculture systems in Yemlo and Wonji fish ponds with a prevalence rate of 56.67 and 46.70 % respectively eported, but registered lower prevalence in natural water bodies of Lake Awassa and Lake Babogaya with prevalence of 10% and 14.4%. In the present investigation, it also reveals a similar trend of results just like the above-mentioned studies. The prevalence in the wild was 1.25% which represented the natural water body while in the culture systems it was 14% and 20% in cage and pond respectively. The continuous unidirectional flow of stream and river water in to the wild could have resulted to low infestation of *Trichodina* spp. in the wild while the human activities within the lake and its shores besides the high stocking density of the culture species may have caused the impairment of water quality parameters due to excessive organic load which promotes the proliferation of protozoan parasites, low water levels, lack of pond drainage and treatment after every harvesting are some of the factors which allows a conducive environment for propagation of fish parasites. Paperna (1996) indicated that most of protozoan parasites are ubiquitous in aquatic systems and have high capabilities to result into poor economic returns due to parasite induced host mortality. This could have been as a result of increase in poor water quality and presence of skin and scale damage on fish body which results to stress and promote the multiplication and propagation of the parasite on fish.

During this study, only one member of myxozoan genera (i.e. *Myxobolus* spp.) was found. Prevalence values were extremely variable among sites, may be due to the different distribution of the benthic annelids which represent suitable alternate host for *Myxobolus* spp. In terms of prevalence rate, the rate of *Myxobolus* spp. observed during this study were lower than that observed by Gbankoto *et al.*, (2001a) who found a similar species in another tilapia species and by El-Mansy (2005), who reported a different species of *Myxobolus* from the eyes of *Oreochromis niloticus* in River Nile, Egypt. This could be due to different ecological conditions in the study areas. Myxozoan parasites are known to have the ability to reproduce at a very faster rate and transmit from one fish to the other in culture units than in natural water bodies. Poor water exchange together with high biomass are also the main dangerous and seems to favour spread of infestation (Florio *et al.*, 2009).

Cestodes and acanthocephalans are all parasites characterized by an indirect life cycle with crustaceans (copepods and amphipods) as intermediate host. The higher prevalence values observed in wild tilapias than the cultured can be explained with the different feeding habits, based on natural zooplankton. On the contrary, caged tilapias feed on pelleted food with a reduced intake of plankton and a consequent reduced risk of ingestion of infective larval stages of these parasites. The variation in mean prevalence and intensity of the different parasites species may be as a result of the changes in the water quality of the environments where the fish inhabit and the strength of its immunity in each study area. It could also be attributed to the abundance and composition of the crustacean, which is an intermediate host for acanthocephalans. High infestation and infection of fish with acanthocephalans results in to perforation of the gut. Therefore, according to Uhuo *et al.*, 2014, the pathogenesis of acanthocephalan is due to the attachment of adult parasites along the alimentary canal and the larval encapsulation in the fish. A fish experiencing high mean intensity and prevalence of parasites may show parasitological infections along the intestinal wall and may result in to blockage of the gut especially in fingerling fishes which in turn slows down the growth rate in fish (Paperna, 1996).

The correlation analysis which was used to show the relationship between fish size and the prevalence rate showed that there was a higher prevalence and intensity in big-size fish than young tilapia and this could be due to the accumulation of the worms over a longer period and their larger size which tend to be too big for the piscivorous bird, which will feed on small and medium sized fish (Gichohi *et al.,* 2008; Zekarias and Yimer, 2008). This is supported by Steinauer and Font (2003) who found larger fish to harbour more helminth species and more individuals of each species than smaller fish and suggests that larger and presumably older fish have a longer period of exposure to parasites. They therefore ingest more prey items than smaller fish thus increasing their probabability of exposure to intermediate hosts of these parasites. Similar findings by Khidr *et al.,* (2012) and Khanum *et al.,* (2011) show that fish with higher body weight tend to have more parasites.

Similarly, Akoll *et al.,* (2012) have shown that size and not sex of fish affects helminth infection rates, an observation explained by accumulation and prolonged exposure in larger and older fish. In helminth parasites, age of fish hosts influences the intensity of parasitism as result of repeated seasonal exposure to cercariae and to the lifespan of metacercariae;

with cases where older fish harboring fewer parasites being attributed to recent colonization of species that preferentially invade young fry (Aloo *et al.*, 2004).

The lowest parasite diversity was recorded during the first sampling in both cage and pond fish. In the cages, the Shannon weaver and Simpson's diversity indices increases from 0.76 and 0.18 during the first sampling to 1.8 and 0.5 in the fourth month respectively. There was a drop in the fifth month before a steady increase to its peak in the last month of study. The initial steady increase is related to the period of exposure to the parasitic infection and intermediate host and this means that the longer the period of exposure the more diverse the parasites become and vice versa. The drop in the fifth month could be as a result of harvesting. The cages were harvested at the end of April and new stock of grown out fish were introduced in May and therefore their exposure period from stocking to sampling for parasitic infection was short and therefore the low diversity. The diversity increases with the fish sizes along the sampling period as has been supported by various studies whereby it has been attributed to long exposure to intermediate host which transmit the parasite to fish and also the high stocking densities in aquaculture systems. In ponds, there was a steady increase in both Shannon weaver and Simpson's indices just like in cage from the first month (1.29 and 0.53) to the last month (1.65 and 0.74) respectively only that there was no drop in May since the fish were not harvested. The indices pattern in cages is almost similar compared to ponds. Lack of difference in species diversity and richness of parasites observed in two aquaculture units may probably be due to the same physical, chemical and biological conditions recorded in the two set-ups. A different study indicated a similar trend of parasite species richness in aquaculture units (i.e. cages and ponds) when compared with a separate study carried out in Kenya, Uganda and Ethopia, (Akoll *et al.,* 2012; Budak *et al.*, 2010; Otachi, 2009; Tadesse, 2009). The parasite diversity in the natural water body (wild) was low and did not record any pattern and this could be as a result of the unpredicted environmental conditions in the wild and during the study period the environmental conditions did not favor the infection of parasites and hence low diversity. Besides, habitat that plays an integral part due to variance in food resources in different habitats, also dictates the species diversity. For fish, the depth profile of the habitat also affects the survival and success of these parasites. For example, fishes that occupy the top layer of the column are usually plankton feeders and mostly found in the pelagic zone just like the case of cages and ponds, are more vulnerable to parasitic infection that have zooplankton as a secondary host for most classes of parasites especially nematodes and cestodes. Fish from the natural waters are usually not affected with high infection rates from these parasite groups, because rarely will you find zooplankton in aphotic zone with completely no light (Dogiel *et al.*, 1961). Further comparison reveals that these results were in agreement with a similar study by Hechinger and Lafferty (2005) and Marcogliese (2005) who also observed that a species richness of host and habitat variation normally result into an increase in the rate of parasitic transmission and disease propagation. This could be as a result to high species richness and high abundance of secondary hosts that enhances parasitism since most of the parasites depend on a parasitic type of relationship to get into their next host during their life cycle. The composition and abundance of parasite in a host organism shows the availability of other organisms that support the transmission from one host to another in the parasite's life cycle and trophic pathways in which the hosts participate in the life cycle. In natural water bodies, water levels with minimal regulation promotes parasitism among different species in freshwater ecosystem. Lack of wind and calm water also increases the rate of parasitism by getting hold of infectious parasites during the free flow (Marcogliese, 2005). This implies that the composition abundance of the identified parasites in Lake Baringo does not differ from the ones in other lakes in

Kenya, Ethiopia, and Uganda. However, in natural circumstances, most parasites are never stable and changes over time. Yimer and Enyew (2003) reported that ecological changes in any aquatic environment affects the secondary and final hosts'biological behaviour and appearances, thereby producing variations in parasite richness, diversity and composition. The importance of life cycle patterns including availability and infectivity of intermediate and definitive hosts in variation in occurence rates of parasites has been emphasized by Khurshid and Ahmad (2012) who argue that transmission success is a key determinant of parasite fitness in any host-parasite system, especially in complex life cycles. The most possible important explanation for the generally low parasitic diversity found in this study relates to the colonization time hypothesis, the invasion theory, and the enemy release hypothesis. Invasion theory suggests that some of a species' initial colonization success may be due to temporary release from parasites and pathogens, with fewer in the new environment than in native habitats (Torchin *et al.*, 2003). Release from parasites and pathogen is predicted to be greatest early in invasion and forms part of the enemy release hypothesis (Keane and Crawley 2002).

5.4 Fish parasitism and its influence with the Environmental factors

5.4.1 Fish parasites and Condition factor

Although infection with cercariae such as *Diplostomum* spp. compactum can produce severe damage in hosts including death. Other effects of parasites on fish hosts include muscles degeneration, liver dysfunction, and interference with nutrition and respiratory functions, cardiac disruption, nervous system impairment, castration or mechanical interference with spawning, weight loss and gross distortion of the body (Iyaji *et al.,* 2009). Eye flukes are known to cause emaciation, blindness, and death in fish ((Shinn *et al.,* 2015). Disruption of vision by different digenic trematodes in the eyes may reduce feeding efficiency, as has been indicated in the previous studies. Parasite infestations in fish causes production and economic losses through direct fish mortality; reduction in fish growth; reproduction and energy loss; increase in the susceptibility of fish to disease and predation; and through the high cost of treatment (Shinn *et al.,* 2015). In the present study, most infested fish were in good, excellent and fair body conditions. None of the infested fish had poor body condition. The analysis of variance showed that the differences of body conditions among the infested fish were not statistically significant ($P>0.05$). This shows the infestation was low and had minimal effect on the fish body condition. This could be because of the low parasites intensity recorded. In some instances, fish that were infected with trematodes such as *Gyrodatylus* spp., *Datylogyrus* spp., *Tylodelphys* spp. and *Diplostomum* spp. had a higher condition factor than un-infected ones.

Even though there were no statistically significant differences in the fish condition factor in the study areas, the fish in the wild seemed to have an excellent condition factor when compared with the two culture systems. This difference is linked to the fact that since fish in culture environments are held under controlled and restricted conditions, they are much more affected as much as those in the wild by factors such as seasonality of water quality parameters, food availability and presence of intermediate and definitive hosts. The parasitic infection can either results into poor or good body condition depending on various factors for instance study by Polacic *et al.,* (2009) indicated that increase in food availability enhances the fish immune system hence resistance to diseases hence high condition factor. Another study by Skarstein *et al.,* (2001) revealed that parasite infection can sometimes lead to better condition factor and fast growth. This is as a result of increase in weight of body organs such as spleen and gonads. When these organs become larger and bigger, they affect weight which is a variable in calculating the condition factor. Parasites also make fish to reduce its biological activity and increase food intake to cope with the situation. All these increase the growth rate and the condition factor of the infected fish and to some instances a better condition factor than the uninfected ones. When access to food is unrestricted like in the case of cage and pond systems, infected fish are able to sustain high growth rates, fuel parasite growth, and still lay down energy reserves. When infected fish are reared under competition for limited food resources, or are fed a restricted diet, a negative impact of the parasite on host growth and energetics can be found, corresponding with the impact in natural populations (lower body condition in infected fish). Skarstein *et al.,* (2001) further indicated that trematodes parasites reduces the weight of liver and causes slow growth in infected fish. These could be the reasons why fish (infected and uninfected) showed a mixed condition factor which ranged from good to excellent. Despite visible lesions caused by different groups of parasites, the presence of the parasites did not seem to affect the body condition of their host. These findings agree with those of Abebe (2010), that in natural environments, parasites are normally in a complex dynamic equilibrium with their host. However, this is only true as long as the environment is not disturbed, for example through pollution (Barros *et al.,* 2004). Ndeda (2013) also showed that the presence of parasites had no effect on condition factor of fish in culture systems when their mean intensity is low (Ndeda 2013, Anyamba *et al*., 2001).

5.4.2 Association between parasitic infection and Environmental factors

High stocking densities in aquaculture systems, lack of proper management practices and insufficient bio-security plans have resulted to massive losses in this practice as a result of heavy parasitic infection leading to massive fish kills. Environmental variables are affected by poor management conditions such as high stocking density, high concentrations of nutrients and low frequency of water exchange in culture systems. Environmental parameters affect parasitic infections in fish in various degrees as has been reported by (Paredes-trujillo *et al.,* 2016). They suggested that the high and low technology Nile tilapia farms in Mexico are known to have specific suites of ectoparasites, depending on their management and environmental variables. Martins *et al.,* (2000) also carried out a study in Brazil between 1993 and 1999 and stated that out of 393 diagnosed cases brought by fish farmers at the Aquaculture center, majority comprised various parasites whose occurrence was attributed to high organic matter content, high stocking densities and farmers' failure to clean the fish nets. During the present study, occurrence of various parasites shows a mixed kind of association whereby majority of the parasites did not seem to be significantly associated with various environmental variables. This could be attributed to the fact that most of these environmental variables were within the acceptable range for fish growth which on the other hand did not promote the parasitic infections. The environmental parameters influencing prevalence and intensity of fish parasites during the study period in all the three study areas were pH, DO, salinity, TDS and temperature. Different parasite species recorded different weak correlation with various environmental parameters. In cages, the general prevalence was not significantly correlated with pH, salinity, TDS but had a significant correlation with temperature and DO. In ponds, the significant correlations were with temperature, TDS and DO which proved to have at least some influence while in the wild only temperature affected the rate of parasitic infection. Temperature and DO even though were within the required limit during the study, were still influencing to some extent the rate at which the fish were infected with parasites in ponds and cage. This could be as a result of high stock densities in the culture systems which depleted the available dissolved oxygen which was also affected by the high temperature recorded in some of the sampling times. High stocking density has always been associated with algal bloom, which results in to low water exchange and poor atmospheric absoption.

Total dissolved solids also seemed to have affected the infection in ponds. The dissolved substances which were as a result of heavy fertilization and feeding could have favoured the survival and growth of intermediate host within and outside the ponds. In the wild temperature fluctuation as a result of differences in solar input could have affected the *amirthalingamia* spp.and other parasites infection in the open waters of the gulf. According to Khidr *et al.,* (2012), high temperature favours short induction periods, rapid growth and high egg production while high tolerance levels to pH are developed through acclimatization. Similarly El-Naggar and Khids (1986) found temperature and dissolved oxygen as the main factors affecting seasonal variation in prevalence and mean intensity of cichlidogyrids in tilapia. The role of temperature and DO in the dynamics of parasite communities has been emphasized (Ernst *et al.*, 2005) and has been cited as one of the most important abiotic factors determining the seasonal dynamics of parasites of fish (Khidr *et al.,* 2012). Variation in parasites infection recorded in this study is in agreement with a study by (Khurshid and Ahmad 2012) who found that different helminths were positively correlated with water temperature and DO and stated that due to their sensitivity, helminths can serve as stress indicators in small water bodies utilized for culture based fisheries. Seasonal cycles in water quality characteristics such as temperature, DO, nutrient load influence parasitic indices such as prevalence rates in fish as also indicated by (Khurshid and Ahmad 2012; Puinyabati *et al.,* 2013. During the drought or hot weather, water shortage which is associated with rapid water quality deterioration and low water turn-over may result in environment-related host stress; increasing susceptibility to parasites (Akoll *et al.,* 2012) and in nutrient imbalances that lead to less production of fish food organisms and higher consumption of parasitic organisms (Gupta *et al.,* 2012). Temporal variation and the stocking densities are the main reason for variation in dynamics of parasitic infection in the Czech Republic (Khidr *et al.*, 2012). Vincent and Font (2003) further attribute temporal fluctuations in helminth parasites of fish to flushing of infected hosts, intermediate hosts and free-living infective worm stages downstream by heavy rains. Results in this study was not supported by a similar study on relationship between temperature and parasitic prevalence by Buchmann and Bresciani (1997). In their study, they found out that there is no relationship in prevalence in Danish rainbow trout.This could be attributed to differences in altitude as the tropical region where this study was carried out experience higher temperatures than subtropical region where they carried out their study. In the Winam Gulf temperatures were always high in all the sampling months. Ottachi *et al.,(*2009) reported that most parasite species did not reveal seasonality in their prevalence or in their mean intensities in Sagana because there was no free flow of water in the ponds which tend to mitigate abrupt fluctuations in temperatures while in Machakos during the same study, prevalence rates and mean intensity of different parasite species varied with changes in temperature with a high mean intensity in dry season, which he said was due to high temperatures which enhances cercarial shedding by snail host. Parasites such as trematodes were present in most of the communities sampled and analysed, despite the heterogeinity of sampling sites, this was in tandem with Stables and Chappell (1986) who carried on a tudy on composition of parasitic infection in fish and the availability of eye flukes (*Tyodelphys* spp.) in both freshwater and coastal waters. Other infections such as by *Diplostomum* spp. metacercariae are known to be of negative effect on the general growth of fish hence impairing their reproductive success (Paperna, 1996, De Silva *et al*., 1993 and Moravec, 1998).

Plots for CA, factor maps and multidimensional scaling operated on similarity and distance vector matrix when all the measured parameters were combined, and the outputs depicted how factors being compared (environmental and parasites) relate with each other. Parasites which were influence with similar environmental variables were grouped together while those with dissimilar characteristics had distant linkages. In the wild temperature and DO seemed to influence the parasitic infection of fish even though they are insignificant due to uniform range of temperature and DO throughout the study period. These two parameters are very important and influence the metabolic rate and physiological activities of any organisms and therefore their slight variation due to solar energy output could have affected the rate of parasitic infection in the wild, cage and also pond. Other environmental factors seemed to have very minimal impact if any on the parasites. This is in congruence with other studies such as Akoll *et al.,* (2012), Moccia and Bevan (2000) and FAO (2006) who reported that environmental variables within recommended range for fish do not provide a conducive environment for parasitic organisms to thrive. Canonical Analysis results confirm the Pearson's correlation trend on environmental variables which seemed to have influenced the infection rate in fish.

5. 5 Socio-economic characteristics and management practices of farmers within the Gulf

A total of 96 fish farmers were interviewed along the Winam Gulf of lakeVictoria during the study period. More men than women engaged in fish farming and this biased distribution of gender in fish farming as an economic activity could be attributed to the fact that men are superior to women in households and they own majority of the registered land parcels. This is in agreement with with the study by Maina *et al.,* (2014) who recorded that over 90% of the registered land owners are men who are the head of the households. This was further confirmed by studies in other African states for instance the study by Ellen and Gardner (2009) observed that the land ownership system in Burkina Faso favors men and women face a serious challenge when it comes to fish farming.

Fish farming at the gulf and the shores of L. Victoria is practiced by different age groups. The majority of the farmers were above 50 years. This could be due to the fact that it is at this age where you find most of the retirees who engage in farming after successfully served the country as a civil servant. The youths also regard farming not like a source of employment and income and therefore majority of them move to urban centers looking for white-collar jobs hence their low number in fish farming. This finding is supported by Ngwili, (2014) who reported that over 60 years in Kiambu and Machakos counties have retired from formal employment and embarked in fish farming as an income generating activity. Oseni *et al.,* (2011) also reported a similar trend in Nigeria.

Majority of the respondents were self employed and actively involved in farming as their sole source of income. A greater percentage was in formal employment and business as they show an opportunity in fish farming besides their main sources of income. This could be attributed to the green economy which has received a lot of support from the government and other Non-Governmental Organizations and they support fish farming as a means to increase food security and reduce poverty. The available support in the sector has attracted very many individual and thus the higher number in agriculture. Economic Stimulus Program (ESP) which was initiated by the Kenyan government in the 2009/2010 financial year to support fish farming in Kenya also supported the fish farmers and this could be one of the reasons why majority are purely in fish farming as an enterprise. In the year 2010 the government of Kenya development plan (Government of Kenya, 2011) stated that over 70% of the Kenyans are self employed in the informal sector and majority of these people are in active agriculture. This finding agrees with Ngwili (2014) who also observed that majority of the farmers in Kiambu and Machakos were self employed in agriculture. Majority of the respondent were the secondary and primary school drop outs. This could be due to lack of tertiary education which could enable them get formal jobs and therefore have agriculture as the sole alternative to livelihood. This is unlike the colleges and university graduates who are in the formal employment.

Tilapia monoculture was the most common culture system around the gulf while mixed sex and poly-culture are the least in the region and those who practice it do it mainly to control the prolific breeding nature of cat fish. This agrees with the study by Ngwili (2014) and Mavuti (2017b) who observed the same in Nyeri Kiambu and Machakos counties. Farmers within the tropics prefer tilapia monoculture according to De Silva *et al.,* (2006) because they are easily bred in captivity, grow fast and are economical to culture. As food fishes, tilapias are well accepted in many regions of the world particularly in Asia, Africa and the Americas. Tilapias feed low in the food chain. They readily take natural food in the water such as microscopic plants and animals (plankton) through their efficient feeding apparatus but can also accept artificial diets. Tilapias grow to maturity in less than four months in the tropics. Breeding of tilapias can also occur throughout the year. Male tilapias grow faster than the females and are known to grow up to a size of 3 kg or more if well managed. Majority of the respondents practiced semi-intensive culture system where as a few farmers were in intensive system. This is because of the low-income level of the majority of farmers since intensive system require huge amount of capital to be invested in farming. The few who were in cage system were doing intensive as majority of them were in good employment and some got support from different quotas. Some respondents were also doing fish farming for subsistence and did not incur any cost in maintenance and inputs. This agrees with Musa *et al.,* (2012) in western Kenya region.

Most of the farmers sourced their first fingerling stock mainly from the private hatchery while a a greater percentage of farmers obtain from government agencies hatcheries which were used by the government during the ESP as reported by (MOALF, 2014, Ngwili *et al.*, 2015). This is opposed to Nigeria's case where Garcia-Rodríguez and De La Cruz-Aguero (2011) reported that majority of the farmers sourced fingerlings from government hatchery as opposed to private farms. Many private hatcheries were established after ESP to supply fingerlings to farmers and given that the government hatcheries are far away from the western Kenya farmers and the increase in private hatcheries has made majority of the farmers to source their fingerlings from the private farms to reduce the mortality rate which is affected by the distance during transportation. The few who sourced their fingerlings from the wild were not in the business of fish farming but were doing it for subsistence. Majority of the farmers sourced pond water from rivers and the wetlands because there are many permanent rivers and wetlands draining into the L. Victoria. The two water sources are the most convenient as most ponds are sited within and close to these sources to reduce the maintenance cost and this is why the majority of farmers did not refill their ponds. This is in agreement with studies by Mdegela *et al.*, (2011) in Tanzania and Mavuti *et al.*, (2017a) in Kenya where the main source of water are the rivers and the lacustrine wetlands. However, this is not supported with the study by Shitote *et al.*, (2012) in Siaya County, Kenya and Garcia-Rodríguez and De La Cruz-Aguero (2011) and Zezza *et al.*, (2010) in Nigeria who found out that farmers in those areas sourced pond water mainly from springs and boreholes, respectively.

Majority of the farmers fed their fish mostly with commercial feeds and other supplemental with the home-made formulations with very few farmers relying on vegetables and kitchen remains. Some subsistence farmers reported that they don't give anything to fish in the name of food as they believe that natural food in their environment is just enough for their survival. This is in tandem with several other studies such as Ngwili (2014) who observed that majority of the farmers in Machakos and Kiambu counties use commercial feeds while vegetables and kitchen remain were also used by subsistence farmers as other sources of food. He again in a separate study observed that 11.2% of the farmers did not feed the fish at all (Ngwili *et al.,* 2015). This is also supported by Mavuti *et al.,* (2017a) who also observed a similar trend in Nyeri County. Liti *et al.,* (2005) observed that commercial feeds give higher yield and return than home-made formulated feeds and other sources such as vegetables and kitchen remain because of the variance in nutritional composition. Healthy fish are dependent on nutrition as the nutritional status is one of the important factors that determine the ability of fish immune defenses to resist diseases (Blanco *et al.,* 2000). According to Green *et al.,* (2002), pond management practices should aim at high production and productivity. Akankali *et al.,* (2011) reported that most farmers do not give their fish the right diet and stated that feeds must be formulated in such a way that it can easily be eaten and digested by fish as big particles such as whole grains go to waste as they cannot be ingested by fish.

Majority of the farmers did not drain and treat their pond by the use of agricultural lime after harvesting and only a few farmers drain their ponds after every production cycle. This is supported by Ngwili (2014) who reported that majority of the farmers in Machakos and Kiambu counties did not drain and disinfect (lime) their ponds at all. Ngugi *et al.,* (2007) reported that when ponds are allowed for a long period of time without draining and liming then it becomes eutrophic due to accumulation of organic wastes which depletes the dissolved oxygen leading to mass mortality. They further noted that pond drainage is a vital pond management practice since it has a direct link on water quality which may affect dissolved oxygen, fish health and the overall production and productivity of the ponds.

Mavuti *et al.,* (2017a) recommended that pond drainage and treatment should be done at the end of every production cycle in order to get rid of any accumulated chemicals which may be very toxic to fish and also to break the life cycle of any parasite or disease-causing organisms which are very dangerous to fish health. They further said that it should not be too often to allow the phytoplankton which is the primary source of food to grow.

Use of traditional organic fertilizers was very common among most farmers while few used inorganic fertilizers (mostly DAP and CAN) or a combination of inorganic and organic fertilizers. These findings are in agreement with those of Mdegela *et al.,* (2011) in Morogoro Tanzania, Ngwili *et al.,* (2015) in Kiambu and Machakos counties and Mavuti *et al.,* (2017a) in Nyeri County. Pond fertilization stimulates growth of primary producers such as phytoplankton for the fish to feed on. They reported that frequency of application in the ponds varied among the farmers. The frequency of pond fertilization is a very important management practice because it enhances productivity of the pond which affects the fish growth. However, a large proportion of farmers neither used organic nor inorganic fertilizers throughout the production cycle. This leads to low concentration of phytoplankton which is very essential in the fish diet and its absence could compromise the fish nutritional state and immunity making the fish more susceptible to attack by pathogens including parasites thus less production in unfertilized ponds (Diana *et al.,* 1997). To ensure good production of plankton, fertilization of the pond should be done once every two weeks (NSPFS-FAO, 2005). Fish growth and yields are usually higher with fertilization and supplementary feeding and besides supporting high stocking density, feeding enables the farmer to observe the behavior, health status, feeding level and change in size of the fish (NSPFS-FAO, 2005). However, excessive nutrient loading can result to overpopulation of phytoplankton, especially cyanobacteria and green algae which may lead to excessive oxygen production resulting in gas bubble disease (Mdegela *et al.*, 2011).

Majority of the farmers did not own a net and therefore shared fishing net since most of them said they could not afford the net and hence request from their colleagues during harvesting. Farmers with more than one pond also used the same net between ponds as none of the farmers had more than one net. Only a small percentage of farmers washed the net, and disinfected them after use. Others sun dried the net without washing and disinfection. However, a greater percentage of farmers did not clean nor treat the net in any way. Net sharing and lack of or improper cleaning and disinfection lead to transmission of pathogens from one culture system to another. Any equipment used in a fish pond or farm should be thoroughly dried or chemically disinfected before being used in another pond or between groups of fish (Blanco *et al.*, 2000; Iwanowicz, 2011). Martin *et al.*, (2000) in Brazil reported fish mortality and behavior change, due to occurrence of parasites as a result of high organic matter content, high stocking densities and farmers' failure to clean the fish nets.

Piscivorous birds and otters were the main predatory birds frequently observed in and around the ponds. Kingfisher was the most popular piscivorous bird. This was attributed to thick vegetation cover which inhabits birds and other hosts witnessed around the ponds during the study period. This is incongruence with those of Shitote *et al.,* (2012) and DOF (2012) who reported kingfishers and other birds to be the common fish predators in Siaya County. These birds cause huge economic loss to farmers along the gulf. Majority of the farmers had not neither known nor experienced any fish abnormality in their culture systems while very few individuals have experienced the fish abnormalities and unusual behavior. Most fish abnormalities reported by the few farmers who had the information on fish parasites and diseases include skin discolouration, erratic swimming, retardation, insufficient extension services and death which were also reported by Komar and Wendover, (2007) to be signs of parasitism in fish. Fish deaths were reported to occur occasionally. Some farmers mentioned various signs of fish parasitism. Others did not know signs of parasitism in fish and most of them lacked expertise on fish management and health. This shows there's need for capacity building of fish health experts and farmers. This could enhance extension services so that farmers can recognize and report any signs of parasitism and other fish health issues. Dickson *et al.,* (2016) reported improvement in profitability of fish farming in Egypt following training on best management practices. This could also, contribute to improved production, as extension services have been shown to have a great impact on agricultural productivity (Oduro-ofori *et al.,* 2014; Dickson *et al.,* 2016). Majority of the farmers had extremely high stocking densities and this could be one of the reasons why their production cycles were very long with the majority of farmers harvesting fish weighing 200g after approximately 8 months. Too many fish per square meter results into competition for resources such as food, dissolved oxygen and other requirements necessary for fish growth. This was a major challenge to farmers as observed during the study period. The major challenges reported by majority of the farmers along the gulf include fingerling cost, quality and availability; feed, lack of extension services, stunted growth of fish and predation. These challenges affecting fish farmers have also been reported by various studies such as Shitote *et al.,* (2013); Ngugi *et al.,* (2007), GoK (2010), FAO (2007) and Mwangi (2008). In contrary to these findings, other studies by Garcia-Rodríguez and De La Cruz-Aguero (2011) in Nigeria and Ngwili *et al.,* (2015) in Kenya reported that irregular electricity supply and predation were the main challenges faced by farmers in Nigeria and Kenya respectively.

Generally, this study is in agreement with other studies like Shitote *et al.*, (2012) who studied the challenges facing fish farming in Kenya. In this study, it was reported that fish farmers faced several pond management problems including; Twenty percent (20%) of the farmers poor formulated/quality feeds, high cost of feeds (33.6%), drying up of ponds during drought (18.5%), lack of fingerlings (13.8%), flooding (10.9%) and siltation of ponds (8.9%), pond maintenance (8.6%) and poor security (5.7%). The current study is also in agreement with that of Sheheli *et al.*, (2013), who reported various pre-stocking management practices practiced by farmers such as dike repairing, removing excessive mud from pond bottom; eradicating predatory and undesired fish, lime and fertilizer application while studying fish farming management practices in Bangladesh. During his study he noted that majority of farmers did not practice the pre-stocking management practices as requires and most of them used fertilizers mainly in form of cow dung, urea and triple super phosphate (TSP) at various rates to fertilize their ponds without any standard measurement. They also took various disease prevention measures including pond drying, lime application, controlling weed, removing undesirable fish and changing dirty water (Shekara, 2004). In the same study it was reported that poor stocking density among farmers were very rampant where the majority of farmers overstocked their ponds leading to low production and productivity of their ponds. This was also in agreement with Paredes-trujillo *et al.*, 2016 who reported that too many fish per unit area in tilapia aquaculture, poor management practices and lack of biosecurity plans have led to the spread and establishment of non-native parasitic diseases. He further stated that poor management conditions such as high stocking density, fish source, and high concentrations of nitrates and low frequency of water exchange due to poor drainage in cultured tilapia have been identified as factors associated with reports of parasitic and bacterial diseases

(Paredes-trujillo *et al.,* 2016). The study by Paredes trujillo *et al.,* (2016) further suggested that the high and low technology Nile tilapia farms in Yucatán Mexico have specific suites of ectoparasites, depending on their management and environmental variables. In Brazil, 393 diagnosed cases brought by fish farmers at the Aquaculture center between 1993 to 1998, comprised various parasites whose occurrence was attributed to high organic matter content, high stocking densities and farmers' failure to clean the fish nets (Martins *et al.,* 2000).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

1. There was significant variation in selected environmental parameters between the two culture systems (cage and pond) whose water quality parameters were more compromised than the wild hence the first alternative hypothesis was accepted.

2. There was variation in common parasites between the culture systems where more reproductive success was witnessed with more taxa representation than the wild hence the second alternative hypothesis was accepted.

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3. There was a significant difference on parasitic prevalence rate, MI and diversity between the culture systems where there was higher prevalence, MI and diversity than the wild hence the third alternative hypothesis was also accepted.

4. There was no effect of parasitism on fish body condition factor between the culture systems and the wild hence the fourth null hypothesis was accepted.

5. There is influence of farm management practices on prevalence, MI and diversity of infection since the uptake aquaculture best management practices were very poor leading to higher prevalence rates in culture systems than the wild hence the fifth alternative hypothesis was accepted.

6.2 Recommendations

For Africa as a continent to achieve her sustainable development goal (SDG) on food security and poverty alleviation, the following are recommended:

1. The need for regular and continuous environmental parameters monitoring programs which must be strictly enforced for all fish culture systems.

2. There is need for continuous identification and documentation of parasitic abundance and composition in culture systems for decision making purposes.

3. Since the MI and diversity of parasites were low then efforts to promote commercial deep waters cage and pond fish culture enterprises in Winam Gulf of L. Victoria and other water bodies should proceed with regular monitoring of environmental parameters and parasitic infection.

4. Need for fish health monitoring program which encompasses preventive, regulatory and disease control measure since not all parasitic infection affects fish condition factor.

5. Awareness creation through workshop trainings on proper fish farming husbandry/management practices to prevent diseases and parasitic infection hence increased productivity.

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ii) QUESTIONNAIRE FOR FISH FARMERS ON ASSESSMENT OF RISK FACTORS ASSOCIATED WITH OCCURRENCE OF FISH PARASITES OF ECONOMIC AND ZOONOTIC IMPORTANCE IN WINAM GULF OF L. VICTORIA, KENYA

Please tick or fill the appropriate areas. The information you give will be used for research purposes only and will be kept confidential.

Background information

1. Sub-County ....Ward ---------------------Village.......................

Biodata

1. Name of the owner ………………………………………………

2. Age of the owner

[1] 20-30 years [2] 31-40 years [3] 41-50 years [4] > 50years

3. Gender of the owner? [1] Male [2] Female

4. Main occupation of the owner?

[1] Farming [2] Business [3] Salaried employee [4] Other ……… (Specify)

5. Education level of owner ……......................

[1] No Formal Education [2] Primary Level [3] Secondary Level [4] College [5] University

6. Name of respondent: ……………………………………………………………………

7. Education level of respondent?

[1] No Formal Education [2] Primary Level [3] Secondary Level [4] College [5] University

8. Relationship of respondent to owner of the fish farm?

[1] Owner [2] Spouse [3] Child [4] Worker [5] Other Specify

9. Who is responsible for the day to day management decisions of the farm?

[1] Owner [2] Spouse [3] Child [4] Worker [5] Other Specify…

10. What is the education level of the person responsible for day to day management decisions?

[1] No Formal Education [2] Primary Level [3] Secondary Level [4] College [5] University

C. Information on management

11. How long have you been a fish farmer?

[1] <1 year [2] 1-2yrs [3] 2yrs- 5yrs [4] > 5yrs

12. Do you have cages or ponds?

13. What species of fish do you keep?

[1] Tilapia [2] Catfish [3] Others (Specify)

14. What type of culture system do you practice?

[1]Monoculture one sex [2] Monoculture mixed sex [3] Polyculture [4] other specify

15. What type of farming system do you practice?

[1] Extensive [2] Semi intensive [3] Intensive [4] Others specify

16. Observe and note the type of pond(s) in the farm

[1] Earthen [2] Concrete [3] Liner [4] Others specify

17. Where did you source the first stock of your fingerlings?

Source	Please specify the name
[1]Government hatchery	
[2] Private hatchery	
[3] The wild	
[4] Import	
[5] Own pond	
[6] Others (specify)	

18. Where do you source your restocking fingerlings?

Source	Please specify the name
[1]Government hatchery	
[2] Private hatchery	

[3] The wild	
[4] Import	
[5] Own pond	
[6] Others (specify)	

19. What is the main source of water used in the pond(s)?

[1] River [2] Borehole [3] Rain [4] Dam [5] Tap [6] Others

specify

20. How frequently do you change/top up water in the pond?

[1] Twice per month [2] Once per month [3] Once every two months [4] Never [5] other

specify

21. Is the pond drained after harvesting fish?

[1] Yes [2] No

22. Is the pond and cage treated and disinfected respectively after draining and harvesting?

[1] Yes [2] No

23. How is the pond and cage treated after harvesting?

[1] Liming [2] Sun drying [3] Both [4] Others

specify

24. Is the pond fertilized and cage disinfected before restocking fingerlings?

[1]Yes [2] No

25. If yes, name the types of fertilizers and disinfectant used?

Type of fertilizer	Please specify
[1] Inorganic	
[2] Organic	
[3] Disinfectant	
[4] Others (specify)	

26. How frequently do you fertilize and disinfect the pond and cage?

[1] Once per production cycle [2] Once a year [3] once in 2-5 yrs

[5] Never [6] Others specify

27. Which feed do you give the fish?

[1] Commercial fish feeds [2] Home-made fish feed [3] Kitchen leftovers [4] vegetables [5] others (specify)

28. Do you share fishing nets with other farmers?

[1]Yes [2] No

29. Do you use the same fishing net between ponds and cages?

[1]Yes [2] No

30. How do you clean the net(s) after harvesting fish?

[1]Washing with water only [2] Washing and disinfecting [3] Drying in the sun [4] Never [5] others specify

31. Have you seen the following animals in your pond or around the cage?

Type of animal	Tick appropriately
[1] Birds	
[2] Snails	
[3] Dogs	
[4] Cats	
[5] Monitor lizard	
[6] Snakes	
[7] Otters	
[8] Others specify	

32. How frequent are the animals seen?

Type of animal	Frequently	Less frequently	Rarely	Never
[1] Birds				
[2] Snails				
[3] Dogs				
[4] Cats				
[5] Monitor lizard				
[6] Snakes				
[7] Otters				
[8] Others specify				

33. Do you deworm cats and dogs in your farm? [1] Yes [2] No

34. What is your stocking density and size of cage and pond?

35. After how long do you harvest the fish?

[1] 6 months [2] 7-9months [3] 10-12 months [4] >12 months [5] others specify

36. What is the average weight of fish during harvesting?

Age	Weight at harvesting (grams)
[1] 6 months	
[2] 7-9 months	
[3] 10-12 months	
[4] >12 months	
[5] Other specify	

37. What is the production trend for the period you have been a farmer?

[1] Increasing [2] Decreasing [3] Stagnant [4] Don't know [5] Others specify

38. Have you seen any fish abnormalities in your pond or cage?

[1] Yes [2] No

39. If yes, please specify the abnormalities you have seen?

____

_____

40. Have you experienced losses due to fish diseases?

[1]Yes [2] No [3] don't know

41. If yes, what type of losses? (*tick all that apply*)

Type of loss	Tick appropriately
[1] Poor growth rate	
[2] Death	
[3] Reduced size/weight at harvest	
[4] High cost of treatment	

[5] Others specify	

42. How often are fish deaths experienced in the farm or cage?

Frequency	No. dead
[1] Daily	
[2] Weekly	
[3] Monthly	
[4] After harvesting	
[5] Other specify	

43. Have your fish been infected by parasites?

[1]Yes [2] No [3] Don't know

44. How would you know when fish are infected by parasites?

Clinical signs	Tick appropriately
[1] Flashing while swimming	
[2] Rubbing against pond sides and other objects	
[3] Overproduction of gill and/or skin mucus	
[4] Skin or gill lesions(white spots	
[5] Fish appear bloated	
[6] Death	
[7] Loss of weight	
[8] Difficult breathing(gills move more rapidly)	
[9] Others (specify).....	

45. Do you practice the following disease control activities in your fish farm or cage?

Activity	Tick appropriately
[1] Controlling snails	
[2] Deworming of fish	
[3] Control of birds	
[4] Clearing of vegetation	
[5] Water treatment	
[6] Liming	
[7] Others specify	

46. Estimate the cost you incur in the disease control activities in your fish farm?

Activity	Estimated cost (Ksh.) per season
[1] Controlling snails	
[2] Deworming of fish	
[3] Control of birds	
[4] Clearing of vegetation	
[5] Water treatment	
[6] Liming	
[7] Others specify	

47. What challenges are you facing as a fish farmer?

____

____

____

Thank you for taking time to fill this questionnaire…….

CORRELATION ANALYSIS BETWEEN THE PARASITES MEAN INTENSITY AND THE FISH SIZE

Comparison of Regression Lines - Mean Intensity versus Length (Cm by Species) in cages

Dependent variable: Mean Intensity
Independent variable: Length (Cm
Level codes: Species

Number of complete cases: 171
Number of regression lines: 4

Multiple Regression Analysis

Parameter	*Estimate*	*Standard Error*	*T Statistic*	*P-Value*
CONSTANT	-1.4666	0.642079	-2.28414	0.0249
Length (Cm	0.198462	0.035153	5.64565	0.0000
Species=Diplostomum	0.614819	1.16224	0.528996	0.5982
Species=Trichodina	1.54101	0.850807	1.81123	0.0737
Species=Tylodelphys	-1.48084	0.960913	-1.54107	0.1271
Length (Cm*Species=Diplostomum	-0.072517	0.0554189	-1.30852	0.0100
Length (Cm*Species=Trichodina	-0.111036	0.0430588	-2.57871	0.717
Length (Cm*Species=Tylodelphys	0.073623	0.0480038	1.53369	0.1289

Coefficients

Species	*Intercept*	*Slope*
Dactylogyrus	-1.4666	0.198462
Diplostomum	-0.85178	0.125945
Trichodina	0.0744078	0.0874255
Tylodelphys	-2.94744	0.272085

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	41.3307	7	5.90439	27.21	0.0000
Residual	18.0075	83	0.216958		
Total (Corr.)	59.3382	90			

R-= 84.1527 percent
R-(adjusted for d.f.) = 83.0933 percent
Standard Error of Est. = 0.465788
Mean absolute error = 0.351569
Durbin-Watson statistic = 1.62119 (P=0.0088)
Lag 1 residual autocorrelation = 0.162209

Residual Analysis

	Estimation	*Validation*
N	171	
MSE	0.216958	
MAE	0.351569	
MAPE	16.9473	
ME	1.55675E-15	
MPE	-3.90271	

<u>Comparison of Regression Lines - Mean Intensity versus Length (cm) by Species in pond</u>

Dependent variable: Mean Intensity
Independent variable: Length (cm)
Level codes: Species

Number of complete cases: 176
Number of regression lines: 4

Multiple Regression Analysis

Parameter	*Estimate*	*Standard Error*	*T Statistic*	*P-Value*
CONSTANT	-0.0194697	0.440832	-0.0441659	0.9649
Length (cm)	0.0829003	0.0232792	3.56114	0.0006
Species=Diplostomum	-0.931625	0.73451	-1.26836	0.2077
Species=Trichodina	-1.75051	0.870708	-2.01044	0.0471
Species=Tylodelphys	-1.67275	0.7261	-2.30374	0.0233
Length (cm)*Species=Diplostomum	0.0586917	0.0353453	1.66052	0.0030
Length (cm)*Species=Trichodina	0.0940906	0.0445481	2.11211	0.0941
Length (cm)*Species=Tylodelphys	0.0964012	0.0347072	2.77755	0.066

Coefficients

Species	*Intercept*	*Slope*

Dactylogyrus	-0.0194697	0.0829003
Diplostomum	-0.951095	0.141702
Trichodina	-1.76998	0.176991
Tylodelphys	-1.69222	0.179301

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	23.1841	7	3.31201	29.14	0.0000
Residual	11.1374	98	0.113647		
Total (Corr.)	34.3215	105			

R- = 67.5498 percent
R-(adjusted for d.f.) = 65.2319 percent
Standard Error of Est. = 0.337116
Mean absolute error = 0.241881
Durbin-Watson statistic = 1.57249 (P=0.0135)
Lag 1 residual autocorrelation = 0.212143

Residual Analysis

	Estimation	*Validation*
N	106	
MSE	0.113647	
MAE	0.241881	
MAPE	13.9658	
ME	-1.54803E-15	
MPE	-3.20823	

Further ANOVA for Variables in the Order Fitted

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Length (cm)	21.1427	1	21.1427	186.04	0.0000
Intercepts	0.991385	3	0.330462	2.91	0.0384
Slopes	1.04997	3	0.349991	3.08	0.0310
Model	23.1841	7			

<u>Comparison of Regression Lines - Mean Intensity versus Length (cm) by Species in the wild</u>

Dependent variable: Mean Intensity
Independent variable: Length (cm)
Level codes: Species

Number of complete cases: 146
Number of regression lines: 4

Multiple Regression Analysis

		Standard	T	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
CONSTANT	-0.153727	0.221616	-0.693665	0.4894
Length (cm)	0.0395795	0.00704782	5.61585	0.0000
Species=Dactylogyrus	-0.0654397	0.296601	-0.220632	0.8258
Species=Diplostomum	-0.862162	0.31702	-2.71958	0.0076
Species=armirthalingamia	0.411705	0.27503	1.49694	0.1373
Length (cm)*Species=Dactylogyrus	0.00368678	0.00966202	0.381575	0.7035
Length (cm)*Species=Diplostomum	0.0334967	0.010341	3.23922	0.181
Length (cm)*Species=armirthalingamia	-0.0131284	0.00872304	-1.50503	0.1352

Coefficients

Species	*Intercept*	*Slope*
Acanthocestis	-0.153727	0.0395795
Dactylogyrus	-0.219167	0.0432663
Diplostomum	-1.01589	0.0730762
Armirthalingamia	0.257978	0.0264511

Analysis of Variance

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	1.10396	7	0.157709	32.43	0.0000
Residual	0.525265	108	0.00486356		
Total (Corr.)	1.62922	115			

R= 67.7598 percent
R-(adjusted for d.f.) = 65.6702 percent
Standard Error of Est. = 0.0697392
Mean absolute error = 0.0533558
Durbin-Watson statistic = 1.81619 (P=0.1622)
Lag 1 residual autocorrelation = 0.0883812

Residual Analysis

	Estimation	*Validation*
N	116	
MSE	0.00486356	
MAE	0.0533558	
MAPE	4.82619	
ME	3.11054E-16	
MPE	-0.351148	

Further ANOVA for Variables in the Order Fitted

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Length (cm)	0.636718	1	0.636718	130.92	0.0000
Intercepts	0.340174	3	0.113391	23.31	0.0000
Slopes	0.127068	3	0.0423561	8.71	0.0000
Model	1.10396	7			

The StatAdvisor

For instance, in cage fish size vs mean intensity' the output shows the results of fitting a linear regression model to describe the relationship between Mean Intensity, Length (Cm and Species. The equation of the fitted model is

Mean Intensity = -1.4666 + 0.198462*Length (cm + 0.614819*(Species=Diplostomum) + 1.54101*(Species=Trichodina) - 1.48084*(Species=Tylodelphys) - 0.072517*Length (Cm*(Species=Diplostomum) - 0.111036*Length (Cm*(Species=Trichodina) + 0.073623*Length (Cm*(Species=Tylodelphys)

where the terms similar to Species=Diplostomum are indicator variables which take the value 1 if true and 0 if false. This corresponds to 4 separate lines, one for each value of Species. For example, when Species=Dactylogyrus, the model reduces to

Mean Intensity = -1.4666 + 0.198462*Length (Cm

When Species=Diplostomum, the model reduces to

Mean Intensity = -0.85178 + 0.125945*Length (Cm

When the P-value in the ANOVA table is less than 0.05, then there is a statistically significant relationship between the variables at the 95.0% confidence level.

The R- statistic indicates that the model as fitted explains percentage (%) of the variability in Mean Intensity. The adjusted R- statistic, which is more suitable for comparing models with different numbers of independent variables, is also calculated. The standard error of the estimate shows the standard deviation of the residuals to be 0.465788. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu. The mean absolute error (MAE) of 0.351569 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. When the P-value is less than 0.05, there is an indication of possible serial correlation at the 95.0% confidence level.