INFLUENCE OF ARTISANAL FISHING GEARS USE ON WATER PHYSICO-CHEMICAL PARAMETERS AND FISH COMMUNITY STRUCTURE IN FERGUSON'S GULF OF LAKE TURKANA, KENYA

BY

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DECLARATION

Declaration by the Candidate

I declare that this Ph.D thesis is my original work and that it has never been presented for award of any degree or academic work in this University or in other institution of higher learning.

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ABSTRACT

The artisanal fishing sector provides approximately 45% of the world's fisheries and nearly a quarter of the world catch. It is vital to livelihoods and food security. However, the decline of fish resources have been linked to artisanal fishing gears. Despite the widespread use fishing gears in Ferguson's Gulf, the information linking their use to water physico-chemical parameters and fish community structure is lacking. The main objective of the study was to investigate the influence of artisanal fishing gears use on physico-chemical parameters and fish community structure in Ferguson's Gulf of Lake Turkana. The specific objectives were to: establish the difference in characteristics and fishing effort of artisanal fishing gears; determine the difference in the level of dissolved oxygen, water transparency, total dissolved solids, salinity, conductivity, temperature, and pH when artisanal fishing gears are used; examine the difference in fish biomass and species diversity from the artisanal fishing gears and; establish the difference in fish bycatch and discard from the artisanal fishing gears. Observational longitudinal research design was used for this study. This study sampled 162 fishing gears so as to obtain data on characteristics, fishing effort, fish biomass, species diversity, bycatch and discard. Data on physico-chemical parameters was obtained from 12 sampling points in Ferguson's Gulf. Differences in fishing gears characteristics, fishing effort, physico-chemical parameters, fish biomass, species diversity, bycatch and discard were established by one way ANOVA and post hoc mean separation by Duncan's Multiple Range Test significant at $\alpha = 0.05$. Results indicated that the mean number of nets in beach seine gears (11.39±5.82) was significantly higher than purse seine (7.29±5.55) and gill net gears (4.11±2.83); ANOVA, $\alpha = 0.05$, $F_{(2,159)} = 29.642$, p=0.0001. Higher mean mesh sizes were recorded in gill net gears (3.37±0.65); ANOVA, $\alpha = 0.05$, $F_{(2, 159)} = 12.273$, p = 0.0001. Purse seine gears recorded the highest mean number of hauls per day (22.8±1.64) while gill net gears recorded the lowest number of hauls (1.39±0.49); ANOVA, $\alpha = 0.05$ $F_{(2, 159)} = 4139.39$, p=0.0001). The longest mean time per haul in minutes recorded in gill net gears (934.44±635.04); ANOVA, $\alpha = 0.05$ $F_{(2, 159)} = 111.594$, p=0.0001. The differences in fishing effort and characteristics of fishing gears implied lack of uniformity. The highest mean dissolved oxygen (9.13±0.77 mg/l) was recorded in purse seining sites. The mean total dissolved solids (1922.1±105.9 mg/l), conductivity (4,764±532 µS/cm) and salinity (2.18±0.29 g/kg) were recorded in gill netting sites. The difference in physico-chemical parameters implied variation of these parameters. The highest mean fish biomass was recorded in purse seine gears (13,692±12,703.8 g); ANOVA, $\alpha = 0.05$, $F_{(2,159)} = 6.672$, p =0.002. A significantly higher Shannon-Wiener index was recorded in beach seine gears (0.4871±0.0912); ANOVA, $\alpha = 0.05$, $F_{(2,159)} = 891.33$, p =0.0001. *Oreochromis niloticus* dominated the biomass in all the fishing gears. The highest mean bycatch (2,278±629 g) and discard (2,301±574 g) were recorded in purse seine gears; thus purse seine gears were the most non-selective. These findings could help fisheries managers to formulate policies for sustainable management of fish resources in Ferguson's Gulf.

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LIST OF ACRONYMS AND ABBREVIATIONS

CORDIO	Coastal Oceans Research and Development Indian Ocean
DFO	Fisheries and Oceans Canada
DFO	Fisheries and Oceans Canada
DMRT	Duncan's Multiple Range Test
DO	Dissolved Oxygen
EEC	European Economic Community
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GPS	Global Positioning System
ICIPE	International Centre for Insect Physiology and Ecology
ICLARM	International Center for Living and Aquatic Resources Management
IDRC	International Development Research Centre
ILVO	Institute for Agricultural and Livestock Research-Belgium
IUCN	International Union for Conservation of Nature
KEBS	Kenya Bureau of Standards
KMFRI	Kenya Marine and Fisheries Research Institute
LVFO	Lake Victoria Fisheries Organization
MRAG	Marine Resources and Fisheries Consultants
NAP	National Academic Press

NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
TDS	Total Dissolved Solids
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNISWA	University of Swaziland
USGS	United States Geological Survey
WCMC	World Conservation Monitoring Centre
WHO	World Health Organization

WORKING DEFINITION OF TERMS

Artisanal fishing: Means small scale fishing carried out for subsistence or commercial purposes in which the fishers are directly involved in the day-to-day management of the fishing enterprise.

Artisanal fishing gears: Gears used by artisanal fishers for catching, trapping or getting fish. For this study they refer to beach seines, purse seines and gill nets.

Bycatch: For this study, refers to incidental capture of non-target fish species by beach seine, purse seine and gill net fishing gears.

Discard: Refer to fish caught by beach seine, purse seine and gill net gears which is thrown away for whatever reasons.

Fish community structure: Refers to characteristics of fish community such as species diversity, biomass and other attributes with cascading influence such as bycatch and discard.

Biomass: Refers to the measure obtained through weighing of fish expressed in grams.

Fish species diversity: The number of fish species in a sample of standard size including inequality in relative abundance and incorporates the evenness (equitability) of abundance.

Physico-chemical parameters: Physical and chemical characteristics of water. For this study they refer to pH, conductivity, salinity, dissolved oxygen, water transparency, total dissolved solids and temperature.

Gill net: A rectangular stationary net, set at particular locations and designed to intercept and capture swimming fish by their gills.

Beach seine: A long net consisting of many nets of different mesh sizes sewn together without a bag in the centre and usually staked at one end to the beach, then, from a boat or rafts, set around a school of fish. The other end is then hauled onto the beach, leadline first, and the captured fish school removed from the net.

Purse seine: For this study it refers to a large wall of netting without a bag (purse) in the centre deployed around an entire area or school of fish. A boat or craft encircles the school with the net and hauls it onboard.

Fishing effort: The fishing effort is a measure of the amount of fishing. For this study refer to number of fish hauls and time per haul of beach seine, purse seine and gill net gears.

Characteristics of fishing gear: The Attributes of fishing gears. For this study it refers to mesh size and number of nets joined together.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Artisanal fisheries are small-scale fisheries for subsistence, small markets, generally using traditional fishing techniques and small boats. They occur around the world and are vital to livelihoods and food security particularly in developing nations in Asia, Africa and Latin America (Scripps Institution of Oceanography, 2016). UNEP (2005) reported that artisanal fishing sector provides direct and indirect employment to tens of millions of people worldwide translating into 90% of all fishing jobs worldwide. It accounts for approximately 45% of the world's fisheries, and nearly a quarter of the world catch (UNEP, 2005). Therefore the importance of artisanal fisheries contribution to economic development and to global fish catches from both marine and freshwater environments cannot be overemphasized. However, FAO (2010) identified fishing gears used as responsible for substantial decline of inland fisheries resources.

Previous study by Jacquet and Pauly (2008) pointed out that artisanal fisheries has significant impacts on aquatic ecosystem with potential effect on water quality and changes in the ecosystems' components which could result into ultimate depletion of fish stock. In order to prevent this, an urgent need to obtain ecological data on the impact of artisanal fishing gears aquatic ecosystems is needed. However, studies carried out on the influence of artisanal fishing gears use on water physico-chemical parameters are qualitative and have concentrated on marine fisheries; thus necessitated this study.

Gill net is ranked as the most important and widely used fishing gear in artisanal fishery and its dominance has been traced back to the mid 1970's (Ogundiwin, 2014). Gill nets are efficient, relatively inexpensive and capable of catching higher amount of economically valuable fish than other artisanal gears. Fishermen attach two nets vertically or horizontally to form long panels, with mesh sizes in order to increase the surface area in gill net gears (Ligrone, 2014). According to Ogundiwin (2014) gill nets are placed early in the evening and removed early the next morning and hauling is done daily to prevent catch spoilage. These studies have illustrated important highlights regarding the mesh sizes, number of nets, haul time and number of hauls of gill net gears. While these studies indicate efficiency and affordability of gill net gears, pointing to significantly potential high use intensities, their characteristics and fishing effort need to be determined and compared to those of other gears used in inland artisanal fisheries.

According to Sigana, Tuda and Samoilys (2008), beach seines have been used in artisanal fisheries in many parts of the developing world for a very long time. Beach seine have been used several thousands of years ago and on every continent, including Africa, North America and elsewhere (Haln, Bailey, & Ritchie, 2007). Beach seines consist of robust nets made of multifilament nylon with variable but small mesh sizes (Raab & Roche, 2005; Oguttu-Ohwayo, Twongo, Wandera, & Balirwa, 1994; Samoilys, Maina & Osuka, 2011; DFO, 2010). Beach seine gears are hauled out of the water on to the beach manually or by means of a tractor, vehicle or winch (Solarin, Udolisa, & Ambros, 2003; Etcheri & Lebo, 1983). These studies provided insights into widespread use, characteristics and operation of beach seine gears. These studies nevertheless could not empirically establish the characteristics and fishing effort of beach seine gears in relation to other fishing gears.

Purse seine is one of the most advanced types of fishing gears and it has been used for more than 200 years while the modified purse seine started to evolve only 100 years ago (NAP, 1992). Purse seine is still widely used by fishers in almost every part of the world although with various modifications. They are strong nets made of multifilament nylon with variable but small mesh size created by joining six or more small mesh nets (McClanahan & Mangi, 2004). The purse seine is set and hauling is done within 4 to 8 minutes using motor boat and for large purse seines hauling may take around 15 to 20 minutes (Ben-Yami, 1994). However, these studies did not establish the mean number of nets attached together, mesh sizes and number of hauls by purse seine gears. Moreover, time taken per haul using non-motorized fishing vessels widely used in world artisanal fishery is unknown.

Studies conducted globally have established the influence of use of beach seine nets, set gillnets purse seine nets and set long lines during operation on water physico-chemical parameters such as water transparency, dissolved oxygen, conductivity, total suspended solids, and pH during their operation, with reported low primary productivity and changes in fish species diversity, structure and biomass (Coen, 1995; Churchill, 1989; Kumar & Deepthi, 2006; Johnson, 2002). However, these studies investigated the influence of fishing gears to water physico-chemical parameters in marine fisheries and moreover, did not compare them to other fishing gears; particularly beach seine, gill net and purse seine gears. However, despite the widespread use of beach seine, gill net and purse seine gears in Ferguson’s Gulf, there is no information linking the use of these fishing gears to water physico-chemical parameters and fish community structure. Therefore, this study was conducted to fill this gap in knowledge.

Globally, the use of artisanal fishing gears has been known to alter the fish community structure (IUCN & UNDP, 2007; McClanahan, 2004; Mangi & Roberts, 2007; Jones, Gray, & Umponstira, 2009). This has been attributed to capture of high number of fish species and biomass, bycatch and discard. McClanahan and Mangi (2004) and McClanahan, Sebastian, Cinner, Maina, Wilson and Graham (2008) noted that the capture and landing of high biomass and species diversity by beach seines, purse seines and gill nets could result in decline in herbivorous fishes, with serious consequences for recovery and resilience of the ecosystem. Kumar and Deepthi (2006) pointed out that bycatch and discard could lead to trophic shifts due to loss of biodiversity and depletion of keystone species in the aquatic ecosystem resulting. Ocean Health Index (2012), Decoster (2001) and McClanahan and Mangi (2004) associated the use of selective fishing gears with low bycatch and discard rates and less selective fishing gears with high bycatch and discard rates. These studies were conducted in coastal fisheries and their findings could not be applied to the inland fishery due to difference in fish species assemblages and ecological dynamics.

In Africa, the main fishing gears are gill nets, beach-seine nets, purse seine, hooks, lines and traditional spears (de Boer, van Schie, Jocene, Mabote, & Guissamut, 2001). In Uganda for instance, majority of the fishermen use gill nets, followed by the use of trap, drag net, cast net, mosquito nets, baited lines and hook/line as well as synthetic materials for fishing (Ssebisubi, 2011). Studies that have been done in freshwater environments by among others Ibrahim, Auta and Balogun (2009), Saeed and Shaker (2008) and Osman and Claos (2010), have focused mainly on monitoring of water quality for human consumption and determination of heavy metal pollution. While the widespread use of fishing gears is reported in artisanal fisheries of Africa, the information on influence of fishing gears use on water physico-chemical parameters such as dissolved oxygen, salinity, conductivity, temperature, total dissolved solids, water transparency and pH in freshwater fisheries is lacking. Therefore this study investigated the influence of artisanal fishing gears use on water physical chemical parameters of Ferguson's Gulf and compared them a cross gears so as to provide crucial information necessary for effective management of fish resources and aquatic ecosystem.

Most studies done in Africa by Ocean Health Index (2012), Taiwo (2013), Narozanki, Belle, and Steer (2011) and McClanahan et al. 2008), on the differences in fish biomass, species diversity, bycatch and discard from fishing gears have been done in marine fisheries with hardly any research conducted in freshwater fisheries. Of much concern is that purse seine and beach seine gears are largely less selective in the families they target, catching whatever is in the way with gill nets, being highly selective with highest diversity and yields of catch (Frontier Madagascar, 2009). Moreover, the amount of discard and bycatch found in Africa depends on the fishing gear used with higher proportions recorded in non-selective gears compared to selective gears (Ocean Health Index, 2012). In Antsiranana Bay of Madagascar minimal bycatch and discard rates were associated with the use of gill nets and purse seine gears (Taiwo, 2013; Narozanki et al. 2011). These studies provided information on bycatch and discard rates in fishing gears based on selectivity. However, these studies were carried out in coastal artisanal fisheries not in inland artisanal fisheries where this study was conducted.

According to Zimmerhackel et al. (2015), fisheries bycatch is a significant fisheries conservation issue as valuable fish are wasted and protected species harmed with potential negative ecological and socio-economic consequences. It is widely assumed that measures to eliminate the capture of fish which will subsequently be discarded will never be perfect and that some considerable quantity of fish will always be discarded and with more appropriate marketing that fish could be used for human consumption (Clucas, 1997). Bycatch, anything that a fisher does not intend to catch but that still ends up in the net or gear and therefore discarded, is a perfect example of a potential loss of food and natural resources that can be turned into a gain with the right practices and management. Therefore, when bycatch is effectively managed and utilized, it can contribute to food and nutrition security and constitute an important source of food and livelihoods for local populations. It is therefore important that bycatch and discards from the artisanal fishing gears used in Ferguson's Gulf should be utilized for food security in this arid area with frequent and prolonged droughts and severe famine.

In Kenya, studies by Samoilys et al. (2011), McClanahan et al. (2008) and Lwenya and Abila (2004) noted the widespread use of purse seines, beach seines and gill net gears in Kenyan inland and coastal artisanal fisheries. LVFO (2013) pointed out that the main threats from artisanal fisheries emanated from use of less selective fishing gears such as beach seines and undersized gill nets; thus, calling for an urgent need to ban beach seine gears and enforcement of mesh size regulations. According to McClanahan and Mangi (2004) and Mangi and Roberts (2006) beach seines and purse seines account for the highest biomass, species diversity, discard and bycatch compared to gill nets. Studies conducted in Coastal artisanal fisheries have established that bycatch and discard is a major concern in fisheries management in Kenya. Currently, there is no existing data on biomass, species diversity, bycatch and discard of Kenyan inland artisanal gears since previous studies have been conducted in coastal fisheries.

Compared to other large African lakes, Lake Turkana has relatively low fish species richness, providing habitat for about 50 species, 11 of which are endemic (Hopson, 1982). Lake Turkana's aquatic fauna is dominated by Nilotic riverine fish species (Lowe-McConnell, 1993). The endemic cichlids include three haplochromine species adapted for deep water habitat. They include *Haplochromis macconneli, H. rudolfianus, and H. turkanae.* Other species endemic to Lake Turkana include *Barbus turkanae, Brycinus ferox, B. minutus, Labeo brunellii, Lates longispinis, Neobola stellae* and *Chrysichthys turkana.* However, according to Mušvka, Vašek, Modrý, Jirku, Ojwang, Malala, & Kubečka (2012), Lake Turkana's artisanal fisheries has greatly grown and concentrates on littoral zone with unknown consequences on fish community structure and water physico-chemical parameters. Moreover, fisheries in Ferguson's Gulf have developed rapidly over the last two decades due to the increased use of imported fishing nets. Therefore the findings of this study would facilitate the formulation of policies and regulations for sustainable management of fish resources in Ferguson's Gulf.

The uniqueness of Ferguson's Gulf a rises from its location in Lake Turkana relative to the direction of the wind. Unlike Winam Gulf (also referred as Nyanza Gulf) that experiences heavy storms due to its location on wind ward side of Lake Victoria and (Osumo, 2001& Ochumba, 1990), Ferguson's Gulf is a sheltered area located on the leeward eastern shore of Lake Turkana. The fact that it is the only larger sheltered locality on the wind exposed side makes it one of the most important Tilapia fishing grounds in Lake Turkana (Kolding, 1993b). Kolding (1993a) reported that due to it being a sheltered area, it has different algal flora compared with the main Lake. The Gulf is dominated by rich populations of Blue green algae (Cyanobacteria) with a stable production rate exceeding any of those found in the open water and among the highest production rates on record. Kolding (1993a) attributed the potential proliferation of *Oreochromis niloticus* was to the very high primary productivity of Ferguson's Gulf. According to Gikuma-Njuru, Guilford, Hecky and Kling (2013) low primary productivity Winam Gulf is caused by high mineral turbidity that result into limited algal photosynthesis due to light penetration in the water column (Gikuma-Njuru, Guildford, Hecky & Kling, 2013). Nile Perch *(Lates niloticus)* and Nile Tilapia *(Oreochromis niloticus)* form the bulk of the fisheries catch in Winam Gulf (Ochumba, 1990). According to Watson, Zeller and Pauly (2013), for fisheries to be sustainable, the extractive process of fishing requires biomass renewal via primary production driven by solar energy. Therefore, high primary productivity of Ferguson's could explain the sustained fishing activity and widespread use of artisanal fishing gears, therefore warranting the choice of Ferguson's gulf as the study area.

Despite the widespread use of beach seine, purse seine and gill net gears in artisanal fisheries, studies undertaken in inland Gulfs in Kenya are lacking. In Winam Gulf, studies conducted, have reported massive fish kills, primary productivity dynamics, effects of water hyacinth on water quality, distribution and food web transfer of mercury and declining commercial catches (Ochumba, 1990; Osumo, 2001; Gikuma-Njuru, Gildford, Hecky & Kling, 2013; Campbell, Hecky, Muggide & Dixon, 2013; Omwoma, Owuor, Ongeri, Umani, Lalah and Schramm, 2014). Studies undertaken in Ferguson's Gulf by Harbbot (1982a), Harbbot, Ferguson and Hopson (1982b), Hopson (1982), Kolding (1989), KMFRI (2007), and Mušvka et al. (2012) in Lake Turkana have provided information on fish resources, limnology and productivity, inshore pelagic fish assemblage. Therefore, the information on influence of artisanal fishing gears use on water physico-chemical parameters and fish community structure remain unknown. Thus, this study was conducted to bridge this gap in knowledge.

1.2 Statement of the Problem

Despite the importance of artisanal fisheries, fishing gears use has been established as responsible for substantial decline of inland fisheries resources. However, lack of ecological data could exacerbate this problem and lead to depletion of fish resources. Nevertheless, studies carried out on the ecological impact of using fishing gears in artisanal fisheries have concentrated on marine fisheries and not on influence of artisanal fishing gears use on water-physico-chemical parameters and fish community structure in freshwater ecosystem.

Studies conducted globally have established the individual influence of beach seine, purse seine, and gillnets gears on water physico-chemical parameters resulting to changes in fish species diversity and biomass. However, these studies were conducted in coastal fisheries but similar data are lacking in freshwater ecosystem such as Ferguson's Gulf of Lake Turkana.

The bycatch and discard is a major concern for fisheries management globally and Kenya in particular. However, bycatch research focusing on freshwater fisheries represents only about 3% of the total bycatch data as opposed to the marine fisheries which 97% of the bycatch data belongs. Consequently, there is no data with which to quantify the bycatch and discard of Kenyan inland artisanal gears.

Despite the fact that many of the world's threatened species live in freshwater, little information exists on the biomass, species diversity, bycatch and discard associated in fishing gears in freshwater environments. Moreover, the increased number of fishers using beach seine and purse seine gears has led to even higher catch biomass, bycatch and discard at high fishing effort. However, the information linking the use of artisanal fishing gears and water physico-chemical parameters and fish community structure is unknown. Furthermore, studies conducted on characteristics and fishing effort of purse seine, beach seine and gill net gears do not give information on time taken per haul, the mesh sizes, and number of nets as well as fish hauls per day in non-motorized artisanal fisheries, which this study provided.

Several studies undertaken by Harbbot (1982a), Harbbot, Ferguson and Hopson (1982b), Hopson (1982), Kolding (1989), KMFRI (2007), and Mušvka et al. (2012) have provided information on fish resources, limnology, productivity and inshore pelagic fish assemblage of Ferguson's Gulf. However, no information exists on the influence of artisanal fishing gears use on water physico-chemical parameters and fish community structure in Ferguson's Gulf.

1.3 Objectives of the Study

The overall objective of this study was to investigate the influence of artisanal fishing gears use on water physico-chemical parameters and fish community structure in Ferguson's Gulf of Lake Turkana. The specific objectives of the study were to:

1. Establish the difference in the characteristics and fishing effort of fishing gears used in Ferguson's Gulf;
2. Determine the difference in the level of dissolved oxygen, water transparency, total dissolved solids, salinity, conductivity, temperature and pH when fishing gears are used in Ferguson's Gulf;
3. Examine the difference in fish biomass and species diversity from fishing gears used in Ferguson's Gulf; and
4. Establish the difference in bycatch and discard from fishing gears used in Ferguson's Gulf.

1.4 Research Hypotheses

1. **H_O 1:** There exists no significant difference in the characteristics and fishing effort of fishing gears used in Ferguson's Gulf;
2. **H_O 2:** There exists no significant difference in the level of dissolved oxygen, water transparency, total dissolved solids, salinity, conductivity, temperature and pH when fishing gears are used in Ferguson's Gulf;
3. **H_O 3:** There exists no significant difference in fish biomass and species diversity from fishing gears used in Ferguson's Gulf; and
4. **H_O 4:** There exists no significant difference in fish bycatch and discard from fishing gears used in Ferguson's Gulf.

1.5 Justification of the Study

In the context of degrading aquatic ecosystems, increasing fishing effort; the impact of artisanal fisheries on aquatic ecosystems has become significant globally. Furthermore, a good understanding of the link between artisanal fishing gears use and water physico-chemical parameters and fish community structure is fundamental to the management of Lake Turkana multi-gear artisanal fishery. Since Lake Turkana has low species diversity, knowledge on the influence of artisanal fishing gears on fish community structure could be used to recover conserve fish species diversity and recover populations of endangered fish species. Furthermore, Ferguson's Gulf, in particular has recorded increased fishing gears use and activity with rapidly developing fish market, therefore warranting the choice of the study area.

The Lake Turkana artisanal fishery greatly contributes to food security in Turkana County due to the collapse of pastoralism occasioned by frequent and severe droughts. Consequently artisanal fisheries of the Ferguson's Gulf have been embraced as an alternative livelihood inorder to mitigate the negative effect of drought. Provision of resources such as seed capital, fishing gears and vessels by several stakeholders has seen increased fishing gears use and recruitment into artisanal fisheries of Ferguson's Gulf. This is exacerbated by the fact that Lake Turkana's artisanal fishery is an open access resource where the entry of fishermen is not regulated. Therefore, the result of this study would provide knowledge necessary for managing the fishery resource to sustain this important livelihood. Moreover, the determination of water physico-chemical parameters associated with the use of fishing gears is important in finding out whether these values are within optimal or the lethal range for survival of fish species.

The results of this study would be of greater importance to the Lake Turkana artisanal fishers and Fisheries managers since it contains suitable information for facilitation and/or adoption of gear-based fisheries management policies and programs for the Lake Turkana Ecosystem.

1.6 Scope and Limitations of the Study

The data on sediments was not part of this study since the measurement of physico-chemical parameters was done on pelagic zone of the lake. Moreover, the analysis of the nature and composition of the inorganic and organic dissolved and particulate matter in the water column was outside the scope of this study. Data on bycatch and discard was obtained from the artisanal fishermen operating the beach seine, purse seine and gill nets. The fishing effort was limited to time per haul and number of hauls while characteristics of fishing gears was also limited to mesh sizes and number of nets joined together.

1.7 Assumptions of the Study

This study was based on the following assumptions:

1. There was no interaction between the fishing gears in Ferguson's Gulf since they were operated in their exclusive sites. The recorded variation in water physico-chemical parameters was therefore attributed to the influence of an individual gear.
2. There existed no spatial limnological differences in Ferguson's Gulf; thus the changes recorded in different fishing sites were attributed to fishing gears used.
3. The choice of exclusive fishing sites by beach seine, purse seine and gill net fishermen was based solely on the ease of operation of these gears in Ferguson's Gulf.

CHAPTER TWO

LITERATURE REVIEW

2.1 Characteristics and Fishing Effort of Artisanal Fishing Gears

Studies by McClanahan and Mangi (2004), DFO (2010) and Samoilys et al. (2011) have established difference in characteristics and fishing effort of beach seine, purse seine and gill net fishing gears. McClanahan and Mangi (2004) observed that beach seine, purse seine and gill net gears used in artisanal fishery of the Kenya Coast were supported with lines of floats at the top with a weighted leaded rope at the bottom with significant difference in mesh sizes. They consist of either panels of mono-filament or multi-filament nets ranging from 3 to 5 inches 25 m long and 1.5 m high, while beach seine and purse seine were strong nets made of multifilament nylon with variable but small mesh size of 1 inch measuring 100-200 m long 3-4 m deep in beach seine and mesh nets of 0.5-3 inches measuring 30 by 300 m in purse seine (Raab & Roche, 2005; Oguttu-Ohwayo et al., 1994; Samoilys et al., 2011; DFO, 2010). Beach seine and purse seine gears dominantly consist of long strong and high nets with small mesh sizes while gill net gears consist of large mesh sizes and short nets.

However, Oguttu-Ohwayo et al. (1994) and Samoilys et al., (2011) pointed out that the length of fishing gears depended on the number of nets joined together. However, these studies on mesh sizes and number of nets of beach seine, gill net and purse seine gears were conducted in coastal artisanal fishery. The characteristics of freshwater artisanal fishing gears, therefore, remain unknown. It is imperative that mesh sizes of nets of beach seine, purse seine and gill net gears used in artisanal fishery be determined for effective fisheries management since they determine the size and biomass of fish species captured as well as bycatch and discard.

Several studies have established that beach seine, gill net and purse seine gears consist of nets attached together vertically or horizontally so as to increase the total surface area for fish capture (McClanahan & Mangi, 2004; Ligrone, 2014; DFO, 2010). In gill net gears, fishermen attach two nets vertically or horizontally to form gill net panels of 50 or 60 m long, with mesh sizes ranging from 11 to 40 cm, depending on the targeted species (Ligrone, 2014 & DFO, 2010). In addition, purse seine and beach seine gears are created by joining six or more small mesh (2.5 cm) nets, each 25 m long and 3–4 m deep (McClanahan & Mangi, 2004). However, these studies were undertaken in coastal artisanal fisheries which differ from inland artisanal fisheries in terms of target fish species and extent of target area, thus the length of these fishing gears could be significantly affected by these factors and therefore cannot be generalized. While these studies have established the number of nets joined together in beach seine, purse seine and gill net gears used in the coastal industrial artisanal fisheries, the number of nets joined in these gears used in inland artisanal fisheries remain unknown.

Notable difference in fishing effort, particularly time taken per haul and number of fish hauls has been reported in beach seine, gill net and purse seine gears. Research by Ogundiwin (2014) conducted at Kainji Lake Lower Basin, pointed that gill nets were placed early in the evening and removed early the next morning and hauling was done daily to prevent catch spoilage. The average time taken to haul gill nets was estimated at 12 hours translating to a minimum of one and a maximum of two fish hauls per day. However, in coastal fisheries of Kenya, as reported by Samoilys et al. (2011), fishers stayed with the set net for up to 4 hours and then hauled the catch towards the moving boat.

However, in artisanal fishery of Panama, Raab and Roche (2005) observed that the nets were set in the evening between 4 and 6 pm, and then collected after darkness between 8 and 11 pm or set between 11 pm and midnight, and collected in the early morning after sunrise, from 6:30am to 10 am translating to 4-6 haul hours. The process of setting and hauling the nets could vary in duration depending on the number of nets, environment, and the working force and therefore could vary in different artisanal fisheries. Moreover, these studies were undertaken in gill net fishery where motorized fishing vessels were used for casting and hauling the set nets resulting into relatively higher fishing effort. Therefore, this study determined the time per haul taken by gill net gears using non-motorized vessels in Ferguson's Gulf to bridge the knowledge gap.

Furthermore, beach seines are set in semi-circle in the water and manually pulled or dragged with the aid of the towing rope attached to each of the wings (Solarin, Udolisa, Omotoyo, Lebo and Ambros, 2003; Etcheri & Lebo, 1983). In the process the cod end is gradually drawn close to the shore and finally hauled out of the water on to the beach. The longer the hauling lines and the wings, the larger the fishing area covered with the seine and the longer the haul time. The hauling may be done either manually or by means of a tractor, vehicle or winch. The long hauling ropes and the wings of the seine nets herd fish into the centre part of the seine body (Tietze, Lee, Siar, & Moth-Poulsen, 2011). However, these studies did not empirically determine the time taken per haul of beach seine mostly used in artisanal fisheries which is the focus of this study.

Purse seines are set in the water at the surface and extend down the water column; a fishing vessel is used to encircle an aggregation of schooling fish at maximum speed and hauling is done within 4 to 8 minutes using motorized fishing vessel (Samoilys et al., 2011; DFO, 2010). Conversely, Ben-Yami (1994), reported that for large purse seines hauling time may take around

15 to 20 minutes using motor boat. However, the time taken to haul the purse seine gears using non-motorized means is unknown. Moreover, most of the studies have focused on purse seine gears with a bag (purse) at the center than the equivalent consisting of a large wall of netting without a bag in the centre. Therefore, the study aimed at determining the time taken per haul by purse seine gears without bags and hauling time by non-motorized fishing vessels used in Ferguson's Gulf of Lake Turkana.

2.2 Fishing Gears Use and Influence on Water Physico-chemical Parameters

The study of physical and chemical characteristics of water provides a considerable insight into the quality of water of an aquatic ecosystem which in turn determines its faunal diversity (Valentina, Sigh, Ajit, & Robindara 2015). According to Osman and Klaos (2010), the quality of water may be described in terms of the concentration and state, the organic and inorganic material present in the water, together with certain physical characteristics of the water. Chapman and Chapman (1996) pointed out the principal reason for monitoring water quality is the need to verify whether it is suitable for intended uses particularly drinking. However, water quality monitoring has evolved to determine trends in the quality of the aquatic environment as is affected by the release of contaminants, by human activities, and/or by waste treatment (Saeed & Shaker, 2008). The link between fishing gears use and variation of water physical chemical parameters has tended to receive only little attention.

The aquatic environment with its water quality characteristics is the main factor controlling the state of health and disease in wild fishes (Saeed & Shaker, 2008). Since fish growth and survival are determined to a greater extent by water quality, the information linking fishing gears use and water physico-chemical parameters of aquatic ecosystem is vital. Moreover, the presence of environmental stresses such as low dissolved oxygen and high temperature reduces the ability of organisms to maintain its internal environment and could lead to death (Adeogun, Fafioye, Olaleye, & Ngobili, 2005). However, the fishing gears use and variation of water physico-chemical parameters in inland fisheries has received little attention since most studies have focused on fishing gears used in coastal fisheries. Thus, determining the link between water physico-chemical parameters and the use of fishing gears, particularly gill net, beach seine and purse seine gears, is important for fish survival and ecosystem management in Ferguson's Gulf of Lake Turkana.

Physico-chemical influence of fish gears use on aquatic ecosystems has been noted by several authors. According to Rueda and Defeo (2003), gill net causes significant increase in suspended particulate matter after fishing activity which could lead to potential cascade impacts on physico-chemical parameters of aquatic ecosystem. According to Kaiser, Collie, Hall, Jennings, and Poiner (2001) chronic fishing disturbance by fishing gears leads to changes in water physico-chemical parameters and subsequent changes in the composition of the resident fish fauna with implications on overall species diversity. The fishing disturbance potential of fishing gears is determined by fishing effort and the population of fishermen exploiting the fish resource in a given place at a time. This study determined and compared the number of hauls and time taken per haul in artisanal fishing gears in order to provide information on potential disturbance of these gears on water physico-chemical parameters and fish community structure.

Re-suspension of particulate matter by fishing gears have a variety of influence including: releasing nutrient; exposure of anoxic layers; release of contaminants; increasing biological oxygen demand; and smothering of feeding and respiratory organs affecting fish survival (Rueda & Defeo, 2003). This study provided insight into the effect of suspended matter on water column due to action of fishing gears. However, information on the cascading effect on the DO, pH, water transparency, temperature, total dissolved solids, conductivity and salinity when gill net, purse seine and beach seine fishing gears are used is not empirically known. This study aimed at providing this crucial informing which is missing.

The suspension of particulate matter occurs as fishing gear is dragged in the water column which reduces water transparency thus affecting primary production and predation by fish (Johnson, 2002). Occurrence of re-suspension over a large enough area can cause large scale redistribution of particulate matter due to upward flux of dissolved nutrients (Messieh, Rowel, Peer, & Cranford, 1991; Black & Parry, 1994). The influence are likely more significant in waters that are normally clear compared with areas that are already highly perturbed by physical forces (Kaiser, 2000). Suspended particulate matter and resulting turbidity affects aquatic organisms, depending on exposure with unknown effect on dissolved oxygen, temperature, salinity, conductivity, pH, water transparency and total dissolved solids. However, these studies did not determine and compare the water physico-chemical parameters resulting from use by fishing gears; thus necessitated this study.

According to Coen (1995), species reaction to turbidity depends on life history characteristics of the species. Mobile organisms can move out of the affected area and quickly return once the disturbance dissipates. Even if species experience high mortality within the affected area, species with short life history stages and high levels of recruitment or high mobility can repopulate the affected area quickly. Furthermore, according to Churchill (1989) chronic re-suspension of particulate matter may lead to shifts in species composition by favoring those species that are better suited to recover or those that can take advantage of the pulsed nutrient supply. These studies focused on the influence of water physico-chemical parameters on biomass and distribution of fish species. However, this study provided information linking the use of fishing gears and variation of water physico-chemical parameters in Ferguson's Gulf so as to bridge this gap in knowledge.

According to Reimann and Hoffmann (1991), fishing can cause a decrease in oxygen due to the mixing of reduced particles. In their study Kumar and Deepthi (2006) also established that the dragging of trawl nets decreased dissolved oxygen due to the mixing of reduced products such as methane and hydrogen sulphide or the re-suspended bacteria attached to sediments exerting an increase in oxygen demand in the water column. Furthermore, trawling was also found to flush out nutrients and contaminants, with possible rise in lethal gases such as ammonia, methane and hydrogen sulphide, affecting the life of organisms in water. These studies illustrated the dissolved oxygen dynamics due to action of trawl nets on bottom sediments. The information on changes in dissolved oxygen due to action of fishing gears on water column is missing. To bridge the knowledge gap, this study determined the dissolved oxygen dynamics due to the action of fishing gears on water column in Ferguson's Gulf of Lake Turkana.

2.3 Fish Biomass and Species Diversity from Artisanal Fishing Gears

Studies conducted worldwide have demonstrated that artisanal fishing gears have negative effects on the fish biomass that include decline in fish stocks (IUCN & UNDP, 2007). However, this study was carried out in the marine environments leading to paucity of information on the effect of artisanal fishing gears on fish biomass in freshwater environments. Several studies have mostly focused on influence of fishing gears on mean trophic level, biomass of target fish species, dominance, species composition and distribution (Rueda & Defeo, 2003; McClanahan, 2004; Jones et al., 2009) and not on fish biomass and species diversity. However, the present study focused on differences in species diversity and biomass in the beach seine, gill net and purse seine in freshwater environment.

More common types of artisanal fishing gears, such as purse seines and beach seines are known to harm substrate and target juvenile fish (McClanahan, 2004), leading to serious stock declines and trophic shifts. Jones et al. (2009) also reported a decline in piscivores and carnivores in fish stocks with a notable reduction in fish density on all target families. In addition, disproportionate catches of higher trophic species and increase in the ratio of juveniles to mature fish was noted suggesting the early stages of over-fishing and trophic shift. However, other aspects of the community structure such as species diversity and biomass associated with the use of these fishing gears were not included in these studies. Whereas, these studies investigated the effects of purse seines and beach seines on fish community structure, this study determined the species diversity and fish biomass in purse seines and beach seine gears and compared to those of gill net gears to fill this gap in knowledge.

A review of literature on the influence of fishing gears on benthic habitats by Johnson (2002) attributed the depletion of fish stocks to the introduction of trawler fishing techniques which scrape the bottom of the sea and end up catching juvenile fish. Fishing equipment can determine what species they catch as different types of gears used target different families of fish. Hook and line method target mainly resident families where as gill nets target transitory or schooling families Frontier Madagascar (2009). In addition, seine nets are largely unselective in what families they target, catching whatever is in the way while hooks and lines, in contrast, are highly selective as they are used to catch whatever the fisherman wants. This study illustrated the type of fish families targeted by different fishing gears depending on their selectivity. The information on fish biomass and species diversity from gill net, purse seine and beach seine fishing gears is lacking. This study provided this important information by determining the difference in fish biomass and fish species diversity in beach seine, purse seine and gill net gears used in Ferguson's Gulf of Lake Turkana.

Selective fishing gears such as gill nets have the highest diversity and yields of catch, but could also result in decline in herbivorous fishes, which has serious consequences for recovery and resilience of the ecosystem (McClanahan et al., 2008). This high diversity of catch was pointed out by this study as responsible for the rapid decline in catch at high levels of fishing effort in Kenyan Coastal artisanal fisheries. Nevertheless, the high diversity of catch allowed could allow more resources to be utilized but the ultimate consequence of this versatility would be a potential total fisheries collapse at high levels of fishing effort. Rueda and Defeo (2003) reported that the catch of large, long-lived, carnivorous species declined after the introduction of the encircling gillnet whereas catch rates of smaller, shorter-lived, and lower trophic level species increased in a tropical estuarine lagoon. The smaller mesh mostly used in beach seine and purse seine gears also increased the risk of a critical reduction in the spawning stock of target species. However, this study instead investigated the fish biomass and species diversity in gill net, beach seine and purse seine gears and compared them across these gears.

McClanahan and Mangi (2004) also observed that beach seines accounted for the highest number of fish landed as well as smaller fish compared to gill nets. Furthermore, beach seines recorded the highest number of species while most other gears caught four to five species per day with no differences between gears. However, this study was carried out in coastal artisanal fisheries of Kenya contrary to the inland fisheries which this study is focused on. Therefore, this study was conducted to provide empirical information on the difference in fish biomass and species diversity from gill nets, purse seines and beach seines in inland artisanal fishery to bridge this knowledge gap. A study done by Bianchi, Gislason, Graham, Hill, Jin, Koranteng, Manickchand-Heileman, Payá, Sainsbury, Sanchez and Zwanenburg (2000) on the impacts of fishing on size composition and diversity of demersal fish communities revealed that the number of fish species responded in a consistent way to changes in exploitation levels. In most areas studied, changes in fish size composition toward a relative decline in larger fish were observed. However, no evidence was found of any decline in number of species, while changes in species diversity were attributed to either by changes in patterns of dominance or by changes in the number of species. Therefore, this study investigated the fish biomass and species diversity in artisanal fishing gears with a view to determining their differences across the fishing gears.

Link and Garrison (2002) also noted that heavily exploited species declined in biomass, their spatial ranges and degree of overlap with other species declined. The converse was true for weakly exploited species whose populations have increased. They concluded that exploitation strongly modified species interactions through alterations in species composition. The study instead investigated the effect of exploitation levels on biomass and species diversity but not the difference in biomass and species diversity in artisanal fishing gears which is of interest to this study.

According to Mangi and Roberts (2006) fishing grounds where beach seines were used had a significantly lower fish density than where beach seining was not used. The study concluded that beach seines had the most impact on species diversity and biomass compared to gill net and purse seine gears. However, Etcheri and Lebo (1983) attributed the large scale indiscriminate mortality of juveniles and adult fish in marine fisheries to the use of fish chemical poisons. Whereas these studies established the state of fish density, species diversity and fish biomass of fishing grounds in marine environment where beach seine, purse seine and gill net gears were used, the information on fish biomass and species diversity from these gears is not known. This study therefore provided this crucial information by determining the difference in fish biomass and species diversity from gill net, purse seine and beach seine gears used in freshwater artisanal fishery of Ferguson's Gulf so as to bridge this gap in knowledge**.**

2.4 Bycatch and Discards in Artisanal Fisheries

2.4.1 Definition of Bycatch and Discards

In the world fisheries, the term bycatch has meant and continues to mean different things to different investigators and operational definition of its meaning is frequently not available in the published literature (Alverson, Freeberg, Pope & Murawski, 1994). Murawski (1992) adds that the use of the term bycatch adds considerable confusion to a topic that is already complex to both scientists and managers. Particularly, the term is relatively imprecise in that it constitutes a value judgment and may be inaccurate when used over any extended time to describe an element within a multi-species catch. Bycatch has customarily been used to identify (1) species retained and sold, (2) species or sizes and sexes of species discarded as a result of economic, legal, or personal considerations, and (3) non-targeted species retained and sold, plus all discards (Murawski, 1992). McCaughran (1992) defined bycatch as discarded catch plus incidental catch. In the context of fisheries, the term discarded catch or in short discards, means the portion of the fish catch that is thrown away or released back to the sea for whatever reasons (e.g. economic, legal, or personal reasons) (Alverson et al., 1994; Clucas, 1997). It is important to note that no discard or its part is retained by the fisherman for utilisation or for whatever reason. Therefore for this study the term bycatch has been used to mean incidental capture of non-target fish species by beach seine, purse seine and gill net fishing gears, while discard refers to fish caught by beach seine, purse seine and gill net gears which is thrown away on land or lake for whatever reasons. As most fishing gears are not guaranteed to catch whatever targeted fish species, non-fish species or sizes of fish that are desired by fishers, a large portion of the catch will be discarded, whether the catch is still alive or dead (FAO, 2010c).

2.4.2 Reasons for Bycatch and Discards

The reasons for discarding fish by artisanal fishermen include technical, legal, political and economic. Some species have no commercial value locally or seasonally while other species caught in unmarketable sizes are often discarded as marketing is difficult (Manojkumar & Panthran, 2012). Moreover, Weissenberger (2013) observed that due to lack of local market, or collection and transports, fish crushed or damaged, or fish subject to other pre-market selection with the aim to maximize returns, commercial fish stocks can be thrown overboard. However, little is known about reasons for fish discard, particularly from beach seine, purse seine and gill net gears in freshwater artisanal fishery.

Zimmerhackel et al. (2015) and Johnson (2006) noted that fish could be regarded as bycatch and discard due to regulatory restrictions (regulatory discard) e.g., protected species or certain sizes). Such regulatory-led discard may concern notably: - by-catches of fish without fishing possibilities (e.g. no quota or exhausted quota), or - by-catches of fish not complying with some technical rules (e.g. size, season, closed area, unauthorized gear) for the species concerned. Clucas (1997) summarized the main reasons for fish discard: fish caught are of the wrong species, size or sex, or the fish are damaged, incompatible with the rest of the catch (from the point of view of storage), poisonous, spoil rapidly (i.e. before it is brought on board), lack of space on board, high grading, quotas reached, catch was of prohibited species, in prohibited season or fishing ground, or with prohibited gear. However, these studies did not provide determinants for bycatch and discard from different fishing gears, particularly gill net, purse seine and beach seine gears mostly used in artisanal fishery. This study provided this information so as to bridge the knowledge gap

2.4.3 Utilization of Bycatch and Discard for Food Security

Fisheries bycatch is a significant fisheries conservation issue as valuable fish are wasted and protected species harmed with potential negative ecological and socio-economic consequences (Zimmerhackel et al., 2015). According to Clucas (1997), it is widely assumed that measures to eliminate the capture of fish which will subsequently be discarded will never be perfect and that some considerable quantity of fish will always be discarded and with more appropriate marketing that fish could be used for human consumption. Consequently, the FAO Code of Conduct for Responsible Fisheries suggests that states should improve the use of bycatch as long as doing so is consistent with responsible fisheries management and this is considered as an option in many deliberations concerning policy on fisheries management and mitigation of the discards problem (FAO, 1995).

Food security is increasingly about ensuring that the food that is produced is consumed or utilized, or in the case of fishing, that the fish that are caught are eaten (FAO, 2010). Bycatch, anything that a fisher does not intend to catch but that still ends up in the net or gear, is a perfect example of a potential loss of food and natural resources that can be turned into a gain with the right practices and management. Therefore, when bycatch is effectively managed and utilized, it can contribute to food and nutrition security and constitute an important source of food and livelihoods for local populations. However, when it is discarded, it represents a significant loss of potential food and revenue. Ajayi (2015) noted that lack of sustainable fishing practices is impacting food security and livelihoods in low-income, food deficient countries. The fishing gears used in such countries are unselective resulting into wastage associated with the bycatch and discard. This leads to the suboptimal use of the resource, with significant consequences for the population's food security.

However in Guyana, more of the bycatch is being processed for human consumption due to development of processing technologies that turn discarded fish into valuable food products for human consumption (IDRC, 2017). According to Zimmerhackel et al. (2015), bycatch, when discarded, causes significant waste of natural resources and of particular concern are the negative economic impacts of foregone income due to discards of undersized individuals of commercially valuable species. Alverson's et al. (1994) analysis of the Northwest Atlantic groundfish fishery found that $50 million of income was forgone to the local trawl fisheries as a result of the premature harvest and discard of the 1987 year class of yellowtail flounder. The value of the Gulf of Maine fisheries could double if discarding could be eliminated. NRC (1991a) estimated the value of the prohibited species (crab and halibut) losses in the Bering Sea groundfish fisheries as $160 million at the first wholesale level. Losses due to discards in the Bering Sea crab fisheries contributed an additional $50 million loss.

Earlier evaluation (NRC, 1990) placed the value of non-target removals of crab, halibut, and salmon in Gulf of Alaska fisheries lost because of regional discards at between $20 million and $30 million per year. The aggregate Bering Sea and Gulf of Alaska losses of commercially harvested species resulting from discards have thus been in excess of $250 million annually. Therefore, the utilisation of bycatch for income generation could assure households of food security through increased disposable income. FAO (2017) observed that responsibly managed fisheries actually improve livelihoods and increase food security by boosting both productivity and income, both in the medium and long terms. Healthy aquatic ecosystems with ecologically appropriate genetic diversity provide a greater source of food and livelihoods than degraded, overfished habitats. Therefore to assure food security, sustainable management of aquatic ecosystems and artisanal fisheries should be done.

2.4.4 Bycatch and Discards from Artisanal Fishing Gears

FAO (2005) estimated that the discard worldwide total to at least 27 million tonnes per year, equivalent to one third of fish landings. Bycatch from marine commercial fisheries has been regarded as a global conservation concern for decades (FAO, 2005). Though some headway has been made in mitigating bycatch and discard problems in marine fisheries (Graham, Colotelu, Blouin-Demers, & Cooke, 2011), freshwater yields comprise 11% of the global bycatch. FAO (2005) noted that bycatch and discard in freshwater commercial fisheries have been relatively understudied, since research focusing on freshwater fisheries in this regard represents only about 3% of the total bycatch literature. This paucity of research is particularly alarming given that so many of the world’s threatened species live in freshwater environments. It is the need to augment the scant knowledge on bycatch and discard in freshwater artisanal fisheries that motivated this study.

As pointed out by Horsten and Kirkegaard (2002) bycatch is an old fisheries problem, but a relatively new topic in fisheries management. However, the recent increase in awareness is credited to rapid growth of world fisheries and the rise in conservation and environmental movements, but also a more recent understanding that aquatic resources are exhaustible, and that worldwide fishing effort are excessive and threatening to marine stocks. The bycatch of non-target species may be discarded if it has little economic value or if retention is illegal and the effect can be great on endangered species incidentally caught (Alverson & Hughes, 2002). There is seldom enough information available to evaluate the influence of artisanal fishing gears on non-target (bycatch) species (including those that have commercial value). Moreover, the vital information on impact of bycatch and discard in artisanal fisheries has been premised on studies conducted in marine fisheries, thus bycatch and discard in freshwater artisanal fisheries is little known. This study therefore provided information on bycatch and discard from gill net, purse seine and beach seine gears in Ferguson's Gulf so as to bridge this gap in knowledge.

A great deal of concern has been expressed by fishery managers and conservation/environmental groups that bycatch and discards may be contributing to overfishing and altering the structure of marine ecosystems. However, FAO (1996) pointed out that such claims are frequently based on observations of large numbers of discards and high discard ratios or rates from industrial marine fisheries but hardly from fishing gears used in freshwater artisanal fishery. Furthermore, Horsten and Kirkegaard (2002) found out that many fishing gears are extremely detrimental to benthic communities, which often provide food and refugia for marine organisms. These gears tend to be more common of less-selective fisheries, and could produce much bycatch (and discards) of benthic species. This habitat disturbance could indirectly but strongly affect benthic assemblages, and eventually reduce the yield of a fishing ground. This study highlighted the ecological effects of the use of many fishing gears on marine ecosystems. The information linking gill net, beach seine and purse seine gears to bycatch and discards is missing. This study was conducted in marine industrial fisheries which markedly differ in fish species assemblages and ecological dynamics. Therefore, this study provided this missing information determining bycatch and discards from gill net, purse seine and beach seine gears used in freshwater artisanal fisheries of Ferguson's Gulf of Lake Turkana.

High discard rates of undersized target species in the Gulf of Maine in USA have been identified as a causal factor in population declines observed in the region (FAO, 1996). The discard practices also impact on species diversity and energy transfers within aquatic ecosystems and the magnitude of the bycatch associated with artisanal fishery depends on the fishing gear used (FAO, 2005). Decoster (2001) and Narozanski et al. (2011), pointed out that in trawl fishery, bycatch rates were unacceptably high, and estimated that, at times, bycatch constituted 90 per cent of the total catch while minimal bycatch and discard was associated with the use of gill nets. These studies did not provide empirical information from bycatch and discard from gill net, beach seine and purse seine gears. Moreover, information on comparison of these empirical data on bycatch and discard from gill net, beach seine and purse seine gears is lacking. In order to provide this crucial information, this study established and compared bycatch and discard from gill net, beach seine and purse seine fishing gears used in Ferguson's Gulf of Lake Turkana.

According to Kumar and Deepthi (2006), lack of selectivity of the fishing gears result into capture of a huge quantity and diversity of non-target species, including endangered species; thus raising concerns on sustainability of artisanal fisheries. Moreover, Emanuelsson (2008) reported that in artisanal shrimp gears, the pulled hand net contribute minimally to the total catch due to high bycatch incidences compared to the dominant fishing forms of double fixed net and driftnet. However, this study is focused on determining the bycatch from all the categories of gill nets used in Ferguson's Gulf. Ocean Health Index (2012) concluded that the non-selective fishing gears have a higher potential for bycatch than those that allow the fisher to identify the species and size. It is noteworthy that these studies are non-empirical and were conducted in marine fisheries and not in freshwater artisanal fishery. Thus, there is need to determine the quantity of bycatch and discard from beach seine, purse seine and gill net gears in artisanal fishery.

Several studies have indicated difference in discarding rates among fishing gears. As reported by Faltas, Akel, and Abdallah (1998), El-Mor, El-Etreby, Mohammad, and Sapota (2002), Atar and Malal (2010) and Taiwo (2013) bottom scrapping non-selective fishing gears are usually characterized by high discarding ratios in relation to other fishing gears. However, the estimated level of longline discard is highest, both in terms of the proportion of the total catch and biomass of the catch (MRAG Americas, Inc., 2002). Bailey, Williams, and Itano (1996) also reported that tuna discard levels in the various pole and-line fisheries are likely relatively minor. Although, these studies were carried out in coastal fisheries, they did not empirically determine the discarding rates from beach seine, gill net and purse seine gears. To bridge this gap in knowledge, this study empirically determined the bycatch and discard amount of artisanal fishing gears in freshwater artisanal fishery of Ferguson's Gulf of Lake Turkana.

2.5 Policies and Regulations on Fisheries Management in Kenya

The United Nations General Assembly at its 49th session in resolution number 49/118 recognized that in relevant provisions of the United Nations Convention Law on the Sea (UNCLOS), States are called upon to take consideration the effects on associated or dependent species when establishing conservation or management measures (Everett, 1995). It also agreed to promote and develop and use selective fishing gears and practices that minimize bycatch of non-target fish and target fish species. Kenya being a signatory state to UNCLOS is under obligation to put into place laws and regulations to ensure compliance to it. However, no regulations have been put into place to minimize bycatch of non-target and target fish species in artisanal fisheries.

In 1995, the *Code of Conduct for Responsible Fisheries* (FAO, 1995) of the Food and Agriculture Organization (FAO) of the United Nations was adopted by 80 countries, including Kenya. The Code provides principles and standards for the sustainable use of aquatic ecosystems. Among other provisions, the Code calls on States to adopt measures to minimize catch of non-target species, waste, and discards that include, to the extent practicable, the development and use of selective, environmentally safe and cost effective fishing gear and techniques. Despite the Code, there is growing concern internationally that levels of bycatch mortality from fishing threaten the long-term sustainability of many fisheries, the maintenance of biodiversity, and even food security in some areas. This has led to the development of FAO *International Guidelines for Bycatch Management and Reduction of Discards* (FAO 2010), which were adopted in February 2011. The voluntary international guidelines provide assistance to States, including Kenya, in implementing the Code and an ecosystem approach to fisheries through effective management of bycatch.

The Kenya Fisheries Policy (2005) provides for Sustainable utilization of fishery resources. In order to realize economic efficiency and empowerment, Kenya Fisheries Development Authority (KDFA), in consultation with other fisheries stakeholders and other arms of government, specify access rights to all fisheries, determine the optimal harvest, and encourage sustainable utilization of under-exploited stocks. Further, the Fisheries Management and Development Act (2016) under section 42 prohibits the use of unlicensed fishing gears, monofilament net for the purpose of fishing, a gill net, whether drifting or set, in any river or body of water forming part of the riverine system a gill net, whether drifting or set, in any river or body of water forming part of the riverine system if the mesh of the net is less than forty-five millimeters (1.7 inches) in stretched diagonal length; a seine net the mesh of which is less than forty-five millimetres (1.7 inches) in stretched diagonal length and a beach seine net for the purpose of fishing. A person who contravenes any of these provisions commits an offence and shall be liable on conviction to a fine not exceeding one hundred thousand shillings or to imprisonment for a term not exceeding three months or to both in respect to artisanal fishing. However, sustainable management of the Kenyan artisanal fisheries depends on the ability and effectiveness of the relevant stakeholders to enforce these provisions.

2.6 The Conceptual Framework

Driver-Pressure-State-Impact-Response (DPSIR) framework initially proposed by Rapport and Friend (1979) was used as conceptual framework for this study. It is based on the concept of causality that human activities exert pressures on the environment which can induce changes in their state/quality. Society responds to these changes through environmental, governance, economic and sectoral responses (policies and programmes). Using DPSIR framework to highlight the cause-effect relationships can help decision makers and the public see how environmental, economic, societal and other issues are interconnected. In the fishing sector, different types of fishing gears are incorporated and therefore the fishing sector driving force has been divided into subdriving forces, taking into account the different fishing gears. Depending on the type of fishing gears used, the fishing activities affect the aquatic environment in different ways. Each sub-driving force embraces the different types of fishing using the different gears considered. The different fishing gears cause similar pressures over the key elements and the states; its measure is what makes pressures different. Fishing has environmental effects on many aquatic ecosystems and it can exert pressure in a number of different ways. First, harvesting of the fish resources at a higher rate than its capacity to regenerate is the most direct pressure (Ojeda-Martinez et al., 2007). This is not only unsustainable in economic terms, but also has significant effects elsewhere in the ecosystem. Generally, impacts are the causes that evoke responses and fishing activities usually cause a decrease in the abundance, biomass and size of commercial and non-commercial species and species diversity, the measure of these parameters being a good indicator for the state of fisheries (Jennings and Kaiser, 2008). As the target species decline due to over fishing, other species become more dominant and the whole structure of the ecosystem and typically the fishery targets altered leading to increased incidence of bycatch.

Over time, fish stocks become exploited so there is a decrease in total catch of the initial high trophic level target species, but as in the case of some low trophic level target species, fishing down the food chain can for a time increase total catch (McClanahan et al. 2008). Secondly, the effect of fishing gear on the non-target species and communities can produce discards. Substantial change in habitat quality by fishing gears can occur due to changes in water physico-chemical parameters as a result of their impact on water column when sediments are resuspended (Rueda and Defeo, 2003; Coen, 1995). High discarding rates lead to loss of species diversity and keystone species due the resultant capture of a huge quantity and diversity of non-target species (Ocean Health Index, 2012). Depending on the type of gear used, the impacts on fish community structure and water physico-chemical parameters occurs in different ways. Responses to these impacts typically take the form of programme activities, such as the number of inspections done, or number of people working in the surveillance of fishing sector, establishment of new laws and regulations to recover the fish stock and ecosystem health.

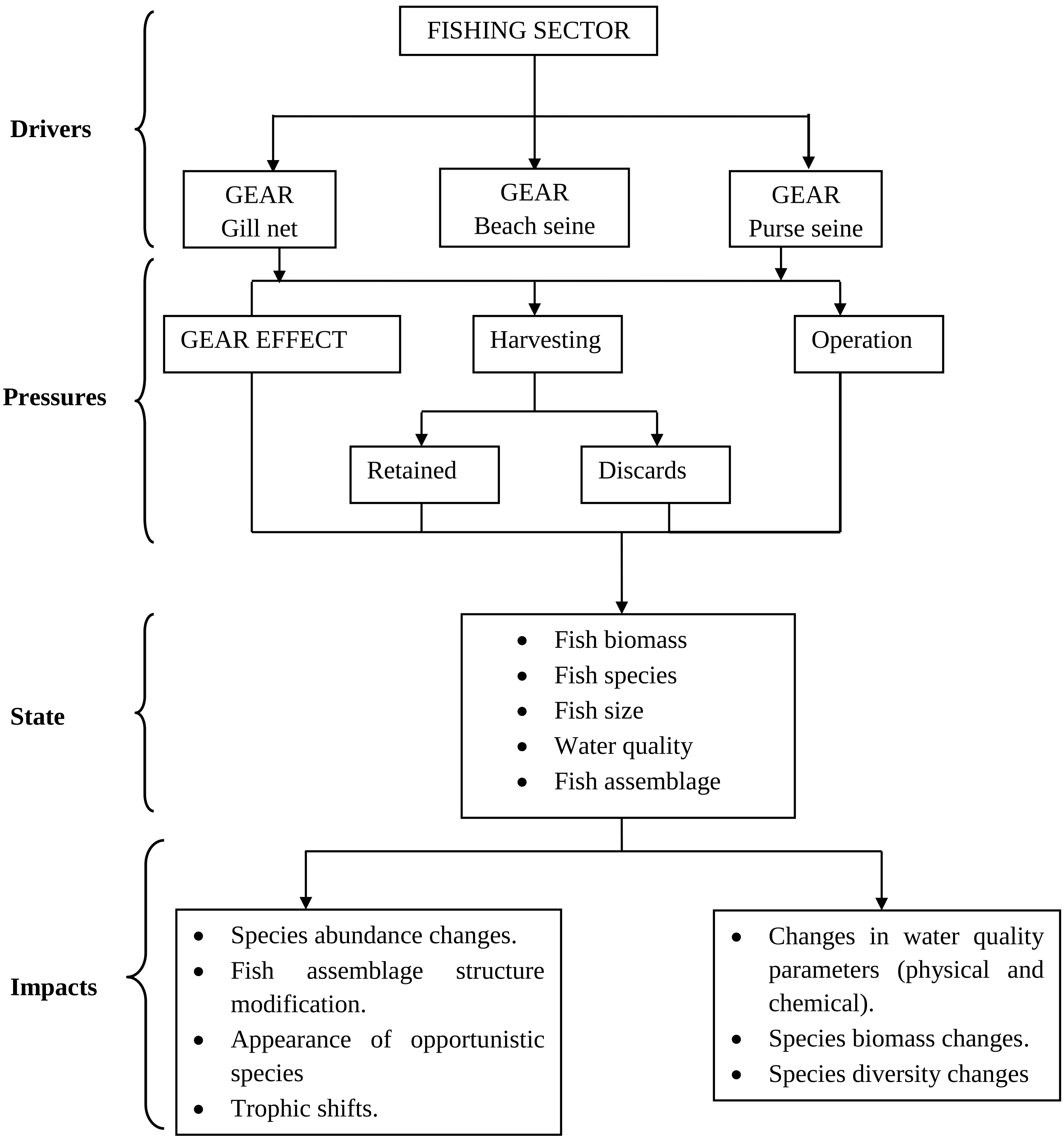

Figure 3.1: Conceptual framework on relationships among components related with effects on fishing sector.

Source: Modified from Ojeda-Martinez et al. (2007)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Lake Turkana is the largest lake among the most northerly of the Eastern Rift Valley lakes; its watershed extends into Ethiopia, Kenya, South Sudan and Uganda. The lake is 250 km long, 15–30 km wide, has an area of nearly 7,000 km^2. Turkana is the world's largest desert lake with maximum depth of 125 m and an average depth of 35 m (Avery, 2010). It is found in the Eastern arm of Great Rift valley located in a closed basin stretching from $35^0$50' to $36^0$40' East and $2^0$27' to $4^0$40' North, in the arid North western Kenya, at an altitude of 360.4 m above sea level and is the largest water body in Kenya. On the northern shore of the lake is Turkana North Sub-County the Southern shore is Turkana South Sub-County and the Northern-most tip of Samburu County, the eastern shore is Marsabit County and the Western shore is in Turkana Central Sub-County.

Ferguson's Gulf of Lake Turkana where the present study was conducted is located about mid-way along the western shore of Lake Turkana stretching from 0328.28 North and 03550.50 East (Stewart, 1988). It is 4 km from Kalokol and the most accessible part of Lake Turkana. It is fringed with doum palms, and grass with the *Prosopis juliflora* colonizing the western side. It can be accessed by murram road from Lodwar Town which is the Headquarters of Turkana County located 56 Km West of Ferguson's Gulf. Presently, the Ferguson Gulf has increasing artisanal fishers with increased fishing activity and rapidly developing fish processing and marketing.

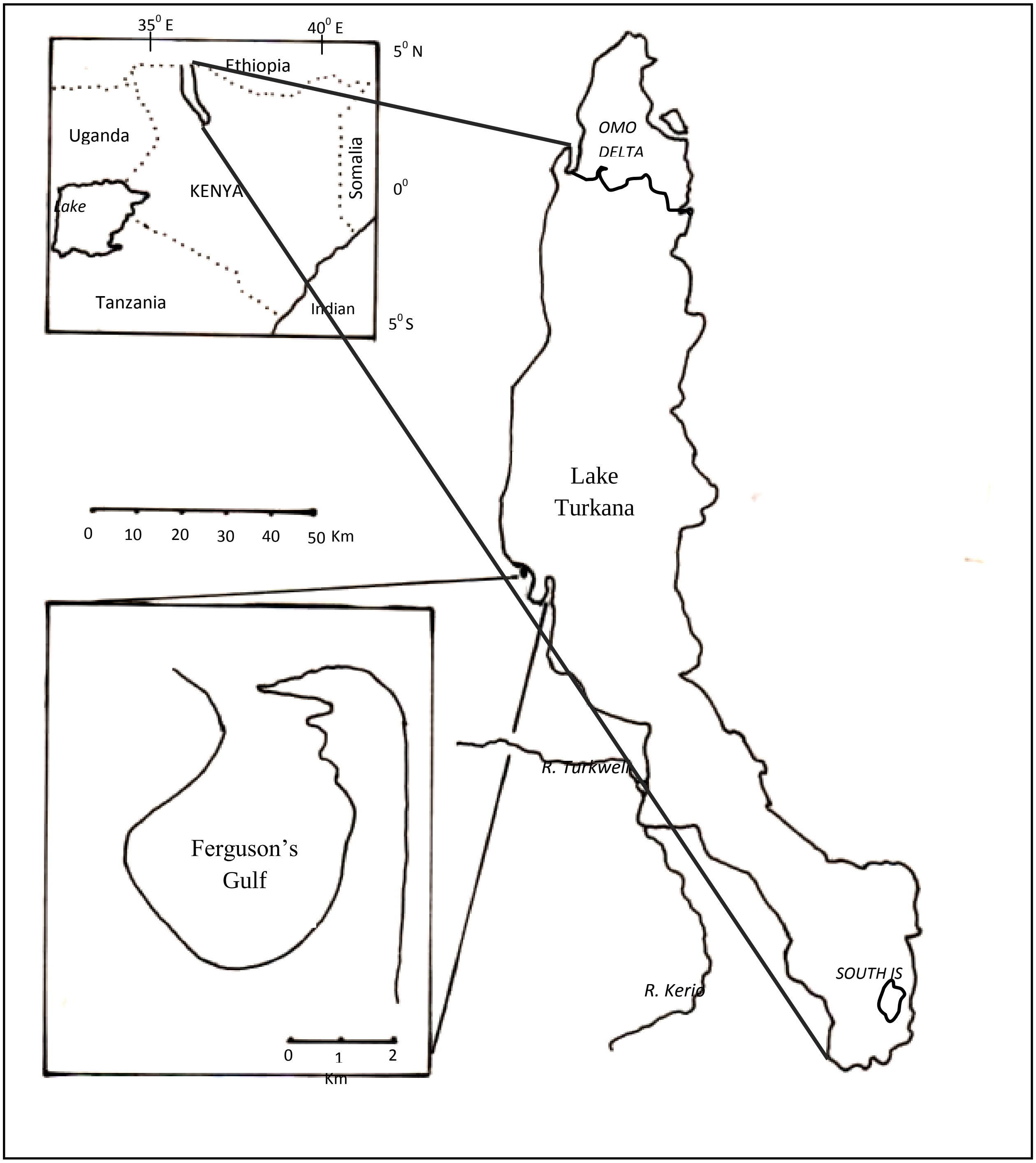

Figure 3.1: Map of Kenya (Upper Inset) showing location of Lake Turkana and Ferguson's Gulf (Lower Inset).

Source: Adopted from Hopson (1982)

3.1.1. Climate

Lake Turkana is in an arid zone and experiences very hot and dry climate throughout the year (Kolding 1993a). The mean annual rainfall in most of the lake surroundings is less than 250 mm. The occurrence of rainfall is very erratic. The lowest occur temperatures is 19.5^{o}C in July-August and highest at 39.9^{o}C during the month of October to January and a mean daily temperature of 29.26^{o}C (Kaijage and Nyagah, 2009).

3.1.2 Vegetation

The area is sparsely vegetated with characteristic bush and scrub, and scattered stunted trees (Avery, 2010). The vegetation along the lake shore is dominated by doum palm, *Hyphaene compressa* and grass, *Chrysopogon aucheri.* The introduced invasive plant, *Proposis julifora* is slowly becoming dominant and an increasing threat to fishing and navigation at Ferguson's Gulf.

3.1.3 Drainage and Hydrology

Lake Turkana is lying in a low closed basin at approximately 365 metres above sea level and is situated primarily in northwestern Kenya, with only its northernmost end, the Omo Delta, inside Ethiopia (Hughes and Hughes, 1992). With no surface outlet, the water budget of the lake is a balance between river and groundwater inflow and evaporation. River Omo which drains the southwestern portion of the Ethiopian Massif and flows through the Rift Valley into Lake Turkana is its only perennial inflow, supplying over 90% of the lake's water. The seasonal Turkwel and Kerio rivers are the largest contributors on the Kenya side and enter the lake along its western edge and in its southern half.

3.1.4 Socio-economic Activities

The predominant inhabitants of the Ferguson's Gulf area are the Turkana people. Other communities include Luo, Abagusii and Abaluhya who have migrated from other regions of Kenya and are mainly involved in fishing, fish processing and marketing (Kaijage & Nyagah, 2009). The Turkana people are primarily pastoralists and notable for livestock keeping and handicraft. Due to erratic rainfall and prolonged drought, more Turkana people have turned to fishing as a source of livelihood thereby raising concerns over the sustainability of Lake Turkana fish resources.

3.2 Research Design and Sampling Procedure

This study used observational longitudinal research design where empirical data on characteristics, fishing effort, fish biomass, species diversity, bycatch, discard, water physico-chemical parameters was collected for a period of 6 months (June to November, 2014) during the dry period as no rainfall was recorded due to the aridity of Lake Turkana region. In order to obtain this data, a sampling frame consisting of a population of 208 fishermen was obtained from Longech and Natirae Beach Management Units. Stratified sampling was used to categorize the fishermen into those using beach seine (64), gill net (66) and purse seine gears (78). For analysis of data using One-way ANOVA, a minimum sample size of 156 or approximately 52 per group was needed (Statistics Solutions, 2016). This study used a sample size of 162 fishing gears or 54 gears per group. Simple random sampling was used to obtain respective sample sizes for beach seine, purse seine and gill net gears and indicated in Table 3.1.

Table 3.1: Study population and sample size per fishing gear

Fishermen per fishing gear (s)	Number	Sample
Beach seine	64	54
Purse seine	78	54
Gill net	66	54
Total	**208**	**162**

For water physico-chemical parameters, nine sampling sites consisting of exclusively beach seine, gill net and purse seine fishing areas were identified in Ferguson's Gulf. Three sampling sites at the mouth of the gulf were included as reference sites where no fishing took place. As shown in Figure 3.2, points 1, 2, 3 represent the gill netting sites, points 4, 5, 6 represent purse seine seining sites, points 7, 8, 9 represent beach seining sites and points 10, 11 and 12 represent reference sites. Three replicate measurements were obtained in-situ from 12 sampling sites where beach seine, purse seine and gill net fishing gears and reference sites for 6 sampling months resulting into 216 measurements for each water physico-chemical parameter for the entire study. The researcher did not manipulate the fishing gears instead relied on the gears used by the fishermen. The fishing gears were not used in all the fishing sites but in their exclusive sites. The mean of the water physico-chemical parameters were obtained and compared so as to establish significant differences between purse seine, beach seine and gill net gears.

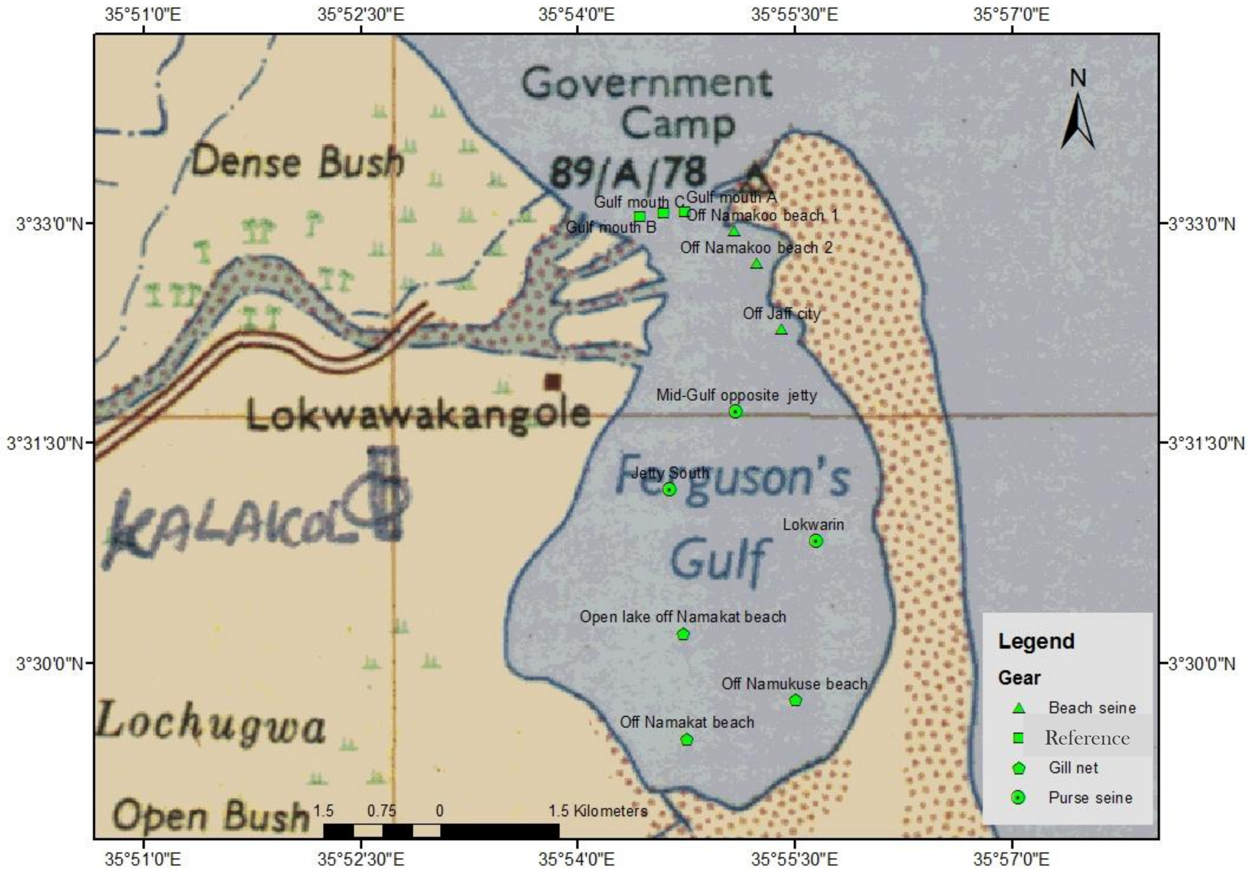

Figure 3.2: Map of Ferguson's Gulf showing sampling points for water physico-chemical parameters.

3.2.1 Sample Collection and Processing

The data on fish biomass, species diversity, bycatch and discard was obtained from gill net, purse seine and beach seine gears used by fishermen resulting into 54 measurements for each variable from each gear. The number of hauls and time per haul were estimated based on inquiries made to fishermen and observation respectively. The number of nets was estimated by counting the number of nets joined together while mesh size was measured using tape measure to obtain the full mesh distance between the centres of the two opposite knots of a stretched mesh (FAO, 1990). For each haul obtained from the fishing gears, the total biomass and number of the fish landed was determined and further sorted into the target, bycatch and discard. The total biomass and number for each individual category was recorded and then put in separate boxes for determination of species diversity.

3.2.2. Measurement of Water Physico-chemical Parameters

Water sampling was done during the wind speed of less than 2km/h referred to as calm condition characterized by "mirror-like" condition of the Lake as cited by Rowlett (2011). Except for water transparency, dissolved oxygen, pH, conductivity, salinity, total dissolved solids and temperature were measured in situ at a depth of 20 cm between 12 noon-1 pm after the fishing gears were hauled out of water. Three replicate measurements were obtained in-situ from 12 sampling sites where beach seine, purse seine and gill net fishing gears and reference sites for 6 sampling months resulting into 216 measurements for each water physico-chemical parameter for the entire study. The GPS coordinates for each sampling site were determined using *Garmin* GPS equipment.

Conductivity, salinity, water temperature and total dissolved solids were measured using HACH Sension 5 and HANNA HI 9835 meters while pH was determined using HANNA Ph/ORP H19025C meter. Dissolved oxygen was measured in mg/l using Adwa AD 630 meter while water transparency was measured from a Water transparency obtained using a standard black and white disc of diameter 20 cm, with quadrants shaded alternately.

3.2.3 Determination of Fish Species Diversity, Biomass, Bycatch and Discard

As soon as the fish were landed, identification was done to the species level with assistance of reference materials and, Experts from Kenya Marine and Fisheries Research Institute (KMFRI). Fish species diversity was determined using the Shannon-Weiner Diversity index (Shannon, 1949) which combines richness and evenness:

$$H' = - \sum_{i=1}^{S} P_i \ln P_i$$

Where: H' = Shannon-Wiener Diversity Index

S =Total number of species

P_i = proportion of total sample belonging to species *i*

The biomass, bycatch and discard were obtained by weighing the fish captured by each fishing gear per sample taken to the nearest 0.1g and recorded in Appendix II. The gill net, purse seine and beach seine fishers identified the fish regarded as bycatch and discard and gave reasons for such categorization.

3.3 Data Analysis and Presentation

One-Way ANOVA at $\alpha = 0.05$ was used to test for significance differences in characteristics and fishing effort of artisanal fishing gears, water physico-chemical parameters, biomass, species diversity, bycatch and discard. For differences that were found significant at $\alpha = 0.05$, post hoc separation of means was done by Duncan's Multiple Range Test. Species diversity was assessed using Shannon-Wiener diversity (H') index. Descriptive statistics was used to summarize the data presented as means, percentages and standard deviations. The qualitative data was analyzed by coding and organizing the data into themes and sub-themes relevant to the study objectives.

3.4 Validity and Reliability of the Data

3.4.1 Validity of the Data

According to Heale and Twycross (2015), validity is defined as the extent to which a concept is accurately measured in a quantitative study. Mbambo (2009) refers validity of an instrument to the extent to which it measures what it is designed to measure. On the other hand, Ellis and Levy, (2009) refer validity to a researchers' ability to draw meaningful and justifiable inferences from scores about a sample or population. Therefore to be able to make accurate inferences on whether to adopt or reject the null hypotheses, the validity of the data collected in this study was integral. Further, Golafshani (2003) describes the validity in quantitative research as construct validity. Construct validity is the degree to which an instrument measures the trait or theoretical construct that it is intended to measure and it utilizes a hypothetical construct for comparison rather than criterion (Oladimeji, 2015). In this study, construct validity was considered. The construct was the initial hypothesis that determined the data to be gathered and how to be gathered. Construct validity are ensured by obtaining convergent validity, discriminant validity, hypothesis testing and known group validity (Oladimeji, 2015; Trochim, 2006).

Correlation analysis undertaken between measures of water physico-chemical parameters that should be theoretically related to each other (Vaishali & Punta, 2013) and Scannell & Jacobs, 2001), such as salinity and, conductivity ($p<0.01$, $r=0.927$), salinity and Total Dissolved Solids (TDS) ($p<0.01$, $r=0.830$) showed convergent validity. Conversely, since the waters of Ferguson's Gulf exhibited high alkalinity, correlation between pH and temperature should not be significant (Green, 1949). A product moment correlation analysis showed no significant correlation between pH and temperature ($r= 0.074$), indicating discriminant validity. The positive correlation between salinity and conductivity; salinity and Total Dissolved Solids (TDS) indicated convergent validity while the no significant correlation between pH and temperature indicated discriminant validity which strongly indicated that the data collected was valid (Table 3.2).

Table 3.2: Correlations co-efficients of water physico-chemical parameters measured in Ferguson's Gulf

Parameters	Salinity	Conductivity	pH	Temperature
Salinity	1			
Conductivity	**.927****	1		
pH	.525**	.384**	1	
Temperature	.144*	.141*	**.074**	1
TDS	**.830****	**.844****	.376**	-.027
**. Correlation is significant at the 0.01 level (1-tailed). *. Correlation is significant at the 0.05 level (1-tailed).				

The hypotheses of the study were tested using one way ANOVA at $\alpha = 0.05$. All the null hypotheses for the four study specific objectives were rejected; an indicator of validity of data. In order to ensure known group validity, the measurement of water physico-chemical parameters was done in reference sites where fishing gears were not used and compared with measurements obtained from areas where fishing gears were used in Ferguson's Gulf.

3.4.2 Reliability of the Data

Reliability is defined as the consistency with which a measuring instrument yields a certain results when the entity being measured hasn't changed (Ellis and Levy, 2009). If a study and its results are reliable, it means that the same results would be obtained if the study were to be replicated by other researchers using the same method. According to Darko-Ampem (2004) pretesting is the best way to identify problems with the data collection instrument and find possible solutions. It also identifies problems with the data collection instruments and to find possible solutions. The pilot study also helped to assess the ability and willingness of the respondents to provide the needed information. Pilot study was done by administering instruments to a sample size of approximately 10% of the fishermen of the total sample size targeted by the study as recommended by Wuensch (2012). A pretest utilizing beach seine, purse seine and gill net fishers excluded from the actual research, was conducted to determine the clarity of the items and consistency of the responses. A split-half technique of testing reliability was employed by splitting the pilot questionnaires into two halves. A Pearson correlation coefficient of 0.88 was obtained. According to Motheral (1998), a coefficient of 0.80 is considered as the acceptable minimum, which indicated that instruments were reliable and fell within the recommended range. To ensure reliability in the instruments used for measurement of water physico-chemical parameters, the meters were calibrated using distilled water so as to obtain accurate recordings. Test –retest reliability method was used where the set of physico-chemical parameters were measured in the sampling sites at different times during the study period. In order to determine the reliability of the data, Pearson correlation coefficient of 0.9 was obtained. According to Andale (2017) a coefficient of 0.8 is the acceptable reliability which indicated that instruments had excellent reliability.

3.5 Ethical Issues

This study was initiated by the researcher and approved by the School of Graduate Studies (SGS), Maseno University, Kenya. Permission to carry out the study within Ferguson's Gulf was obtained from the County Fisheries Officer, Kenya Marine and Fisheries Research Institute Beach Management Units and Chiefs, where applicable. Verbal consent was sought from artisanal fishers before carrying out data collection on biomass, species diversity, bycatch, discard and characteristics and fishing effort of beach seine, purse seine and gill net gears.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characteristics and Fishing Effort of Artisanal Fishing Gears

The study established that beach seine gears recorded the highest mean (11.39±5.82) number of nets joined together than purse seine (7.29±5.55) and gill net (4.11±2.83) gears. One-Way ANOVA, at α =0.05 ($F_{(2,159)}$ = 29.642, p=0.0001) revealed significant difference in number of nets joined in beach seine, purse seine and gill net gears, with Duncan's Multiple Range Test showing significant differences in the mean number of nets joined of beach seine, gill net and purse seine gears. As shown in Table 4.1 below, the lowest (4.11±2.83) number of nets was recorded in gill net gears while the highest (11.39±5.82) number of nets was recorded in beach seine gears.

Table 4.1: Mean number of nets and mesh sizes of fishing gears used in Ferguson's Gulf

	Characteristics (Mean±SD)	
Fishing gears	**Number of nets**	**Mesh size (inches)**
Gill net	$4.11±2.83^{A}$	$3.37±0.65^{B}$
Purse seine	$7.29±5.55^{B}$	$2.89±0.48^{A}$
Beach seine	$11.39±5.82^{C}$	$2.85±0.66^{A}$
Means with different superscripts in the same column are significantly different at α= 0.05 (Means separated by DMRT)		

Considering the number of nets per fishing gear of fishing gears separately, majority (38.9%) of gill net gears consisted of 2 nets followed by 3 nets (11.1%), 4 nets (11.1%), 5 nets (11.1%) and 10 nets (11%). The least proportion consisted of 1 net (5.6%) and 9 nets (9%). However, in purse seine gears, the highest (24%) proportion of gears consisted of 4 nets, followed closely by 22.2% made up of 3 nets, the lowest proportion (1.9%) comprised of 15 nets and 18 nets per fishing gear. Others included 5 nets (11.1%), 6 nets (11.1%), 20 nets (11%), 7 nets (5.6%), 10 nets

(5.6%) and 12 nets (5.6%). A relatively high (16.7%) proportion of beach seine gears was made up of 18 nets followed by 12 nets (16.7%), 17 nets (11%), 6 nets (11%), 3 nets (11%), 16 nets (5.6%), 8 nets (5.6%), 4 nets (5.6%), 20 nets (5.6%), 5 nets (5.6%) and using 10 nets (5.6%) per fishing gear of beach seine gears (Figure 4.1).

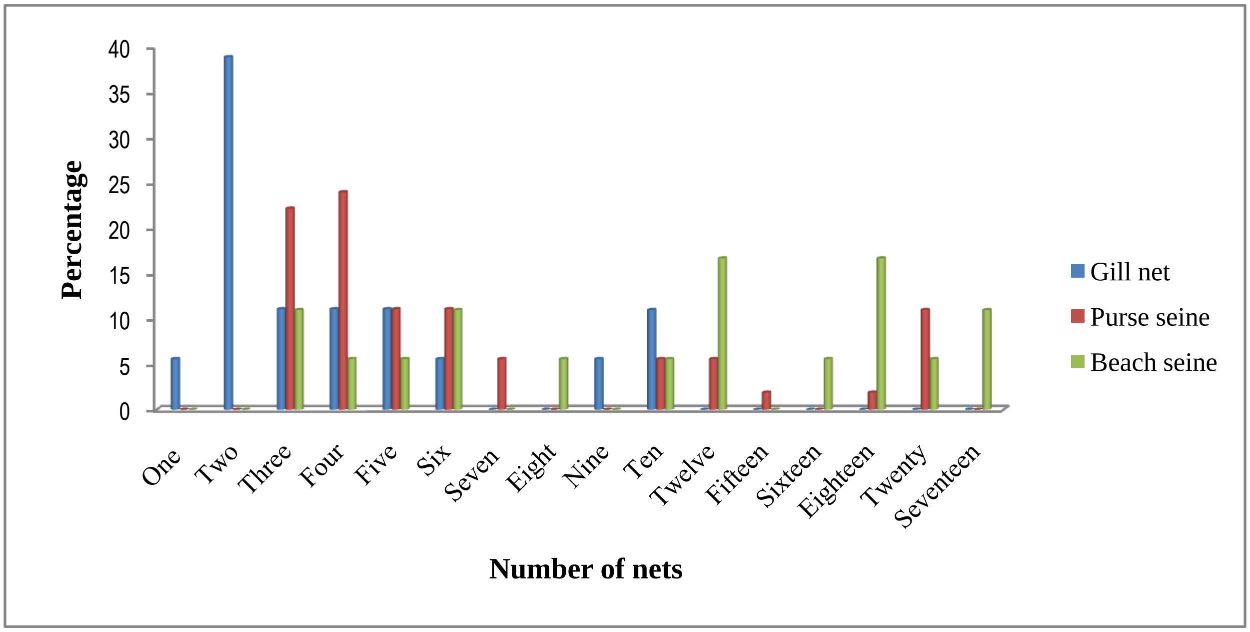

Figure 4.1: Number of Nets joined per fishing gear in Ferguson's Gulf.

As shown in Table 4.1, the difference in the number of nets joined together across the fishing gears implied the complex nature of multi-gear artisanal fisheries interms of properties of fishing gears and potential catch yields. The high number of nets joined together in beach seine gears, was attributed to the need to maximize the biomass of fish per haul as it was labour intensive since it was operated manually. However, the least number of nets in gill net gears was attributed to the fact that gill net gears concentrate on catch yield interms of size than the number of fish captured as opposed to beach seine and purse seine gears. The findings on difference in number of nets in gill net, purse seine and beach seine gears were consistent with DFO (2010), Misund, Kolding and Pierre (2008), Okeyo (2010) and Mc Clanahan and Mangi (2004) that found out that beach seine, purse seine and gill net gears used by artisanal fishers consisted of varying number of nets joined together so as to increase the surface area for fish capture resulting into high fish biomass. Okeyo (2010) stablished that non-selective fishing gears such as beach seines and purse seines recorded the highest number of nets so as maximize the number of fish captured in the artisanal fisheries of the Kenya's South Coast. Further, the hand gill nets mostly used by artisanal fishermen consisted of the lowest number of nets due to the fact that the fishermen use only number of gill nets of a chosen mesh size; concurrent to the findings of this study.

As shown in Table 4.1, gill net gears had larger (3.37±0.65 inches) mean mesh sizes than purse seine (2.89±0.48 inches) and beach seine gears (2.85±0.66 inches). There was significant difference in mesh sizes among fishing gears (One-way ANOVA, α =0.05 ($F_{(2,159)}$ = 12.273, p = 0.0001). DMRT further confirmed that mean mesh sizes of beach seine gears differed significantly from mean mesh sizes of gill net gears but not from mean mesh sizes of purse seine gears. Gill net gears had the larger (3.37±0.65 inches) mean mesh sizes than purse seine (2.9±0.47 inches) and beach seine (2.9±0.67 inches) gears. The mean sizes of mesh nets of the fishing gears is presented in Figure 4.2 below.

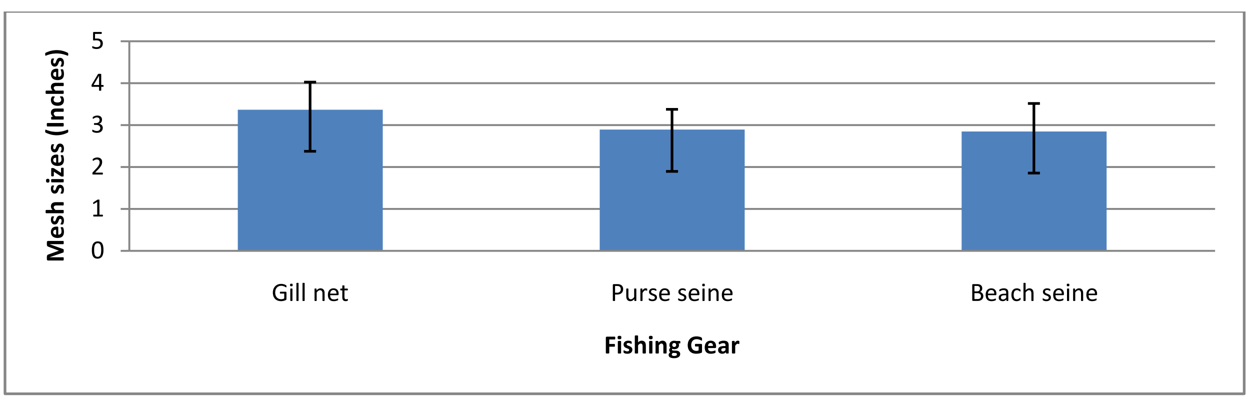

Figure 4.2: Mean mesh sizes of gill net (n = 54), purse seine (n = 54) and beach seine (n = 54) gears used in Ferguson's Gulf. Error bars represent standard error of the mean from Table 4.1.

The study also revealed that the 3" mesh size nets were dominant in gill net (n = 54) and purse seine gears (n =54) accounting for 55.9% and 42.6% respectively. Nonetheless, 2.5" mesh size nets were dominant in beach seine gears representing 44% of the total (N = 54). This was followed by 3.5" (16.1%) in gill net, 2.5" (36.9%) in purse seine and 3" (18%) in beach seine gears. The largest 5" mesh size nets were only found in gill net gears but missing in purse seine and beach seine gears as illustrated in Figure 4.3 below.

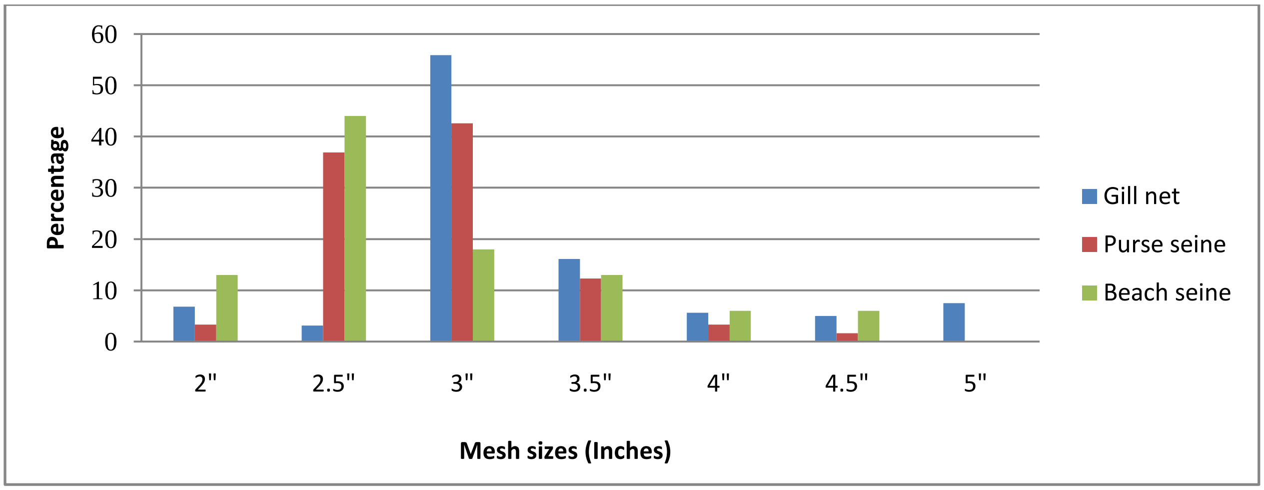

Figure 4.3: Mesh sizes of fishing gears used in Ferguson's Gulf. The 3'' mesh size nets dominated the gill net (55.9%) and purse seine gears (42.6%), while the 2.5'' (44%) mesh size nets dominated the beach seine gears.

The larger mean mesh size in gill net gears as shown in Table 4.1, implied that they are size selective and catches mainly larger sized and mature fish species than beach seine and purse seine and beach seine gears. The fact that gill nets are selective and could be easily controlled for capture of specific fish species and sizes to meet the market and personal preferences accounted for large mean mesh size in gill net gears. This study revealed that, a a negative relationship between mean mesh sizes and the mean number of nets joined together in gill net, purse seine and beach seine gears. Thus, the higher the mean number of nets joined together, the smaller the mean mesh size. This could stem from the difference in the yielding potential of gill net, purse seine and beach seine gears. In gill net gears, the catch yield could be maximized by using larger mesh sizes while increasing the number of nets joined per gear and using small mesh sizes could potentially increase the catch yield in purse seine and beach seine gears.

As established by the study, purse seine and beach seine gears consisted of relatively small mesh size nets compared to gill net gears (Table 4.1). Therefore, the gill net gears used in Ferguson's Gulf were size selective compared to purse seine and beach seine gears. The small mesh sizes in beach seine and purse seine gears implied potential capture of small-sized fish by these gears which could lead to recruitment overfishing in Ferguson's Gulf in long term. These findings concurred with Maina (2012) that reported the use of a wide range of nets with varied mesh sizes in the Kenyan artisanal fishery with small mesh sizes recorded in purse seine and beach seine gears and large mesh sizes recorded in gill nets. Further, Okeyo (2010) and Mc Clanahan and Mangi (2004) also found out that beach seine and purse seine gears consisted of small mesh size nets in artisanal fishery of the Kenyan Coast similar to the findings of this study. Studies by Oguttu-Ohwayo et al. (1994) and Hoorweg, Wangila and Degen (2009) also reported use of small mesh-sized beach seine gears in artisanal fisheries of Lake Victoria and Lamu. Furthermore, the use of large mesh size nets in gill net gears also agreed with the findings of Lopes and Gervasio (2003), Okeyo (2010), Oguttu-Ohwayo et al. (1994) and Misund et al. (2008) that gill net gears consist of larger mesh sizes.

The small mesh sizes of purse seine and beach seine gears used in artisanal fishery could have implications for management of fish resources in Ferguson's Gulf. During the study it was observed that such gears caught virtually everything that it enclosed and was unselective while the highly selective gill nets caught only the right size of fish which got stuck in the meshes. Therefore to manage the fish resources of Ferguson's Gulf, appropriate minimum mesh sizes should be recommended for beach seine and purse seine gears. The use of larger mesh sizes in gill net gears allowed some of the fish to escape through the larger meshes and have time to grow older and larger resulting into lower catch rates. As pointed out by Sary, Oxenford and Woodley (1991), Garrod (1987) and FAO (1984), in long-term, the delayed capture would lead to a useful increase in the stock size, thereby improving the spawning stock and future yields of Ferguson's Gulf.

Concerning the fishing effort; the number of hauls undertaken by beach seine, purse seine and gill net gears in Ferguson's Gulf were recorded per day. The highest (22.8±1.64) mean number of hauls was recorded in purse seine gears while the lowest (1.39±0.49) mean was recorded in gill net gears, with beach seine gears recording mean of 8.3±1.3 hauls per day. There was significant difference in mean number of hauls of fishing gears (One-way ANOVA, α =0.05, $F_{(2,159)}$ = 4136.38, p=0.001), with DMRT showing significant difference in the mean number hauls of purse seine, beach seine and gill net gears (Table 4.2).

Table 4.2: Mean number of hauls and time per haul recorded in fishing gears used in Ferguson's Gulf

	Fishing Effort (Mean±SD)	
Fishing gears	**Number of hauls per day**	**Time per haul (Minutes)**
Gill net	1.39±0.49^{A}	934.44±635^{A}
Purse seine	22.8±1.64^{B}	17.65±8.10^{B}
Beach seine	8.3±1.3^{C}	25.11±9.49^{C}
Means with different superscripts in the same column are significantly different at α=0.05 (Means separated by DMRT)		

The proportionate composition of number of hauls per fishing gear indicated that, in purse seine gears, majority consisted of twenty five (27.7%) hauls followed by twenty six (16.7%), twenty three (16.7%), twenty eight (11.1%), twenty seven (5.6%), twenty one (5.6%) and twenty

(5.6%). Likewise, in beach seine gears the number of hauls consisted of eight (27.7%), twelve (27.7%), eleven (11.1%), thirteen (11.1%), fourteen (5.6%), ten (5.6%), nine (5.6%) and seven (5.6%). In addition, the number of hauls in gill net gears consisted of one (61%) and two (39%) only (see Figure 4.4).

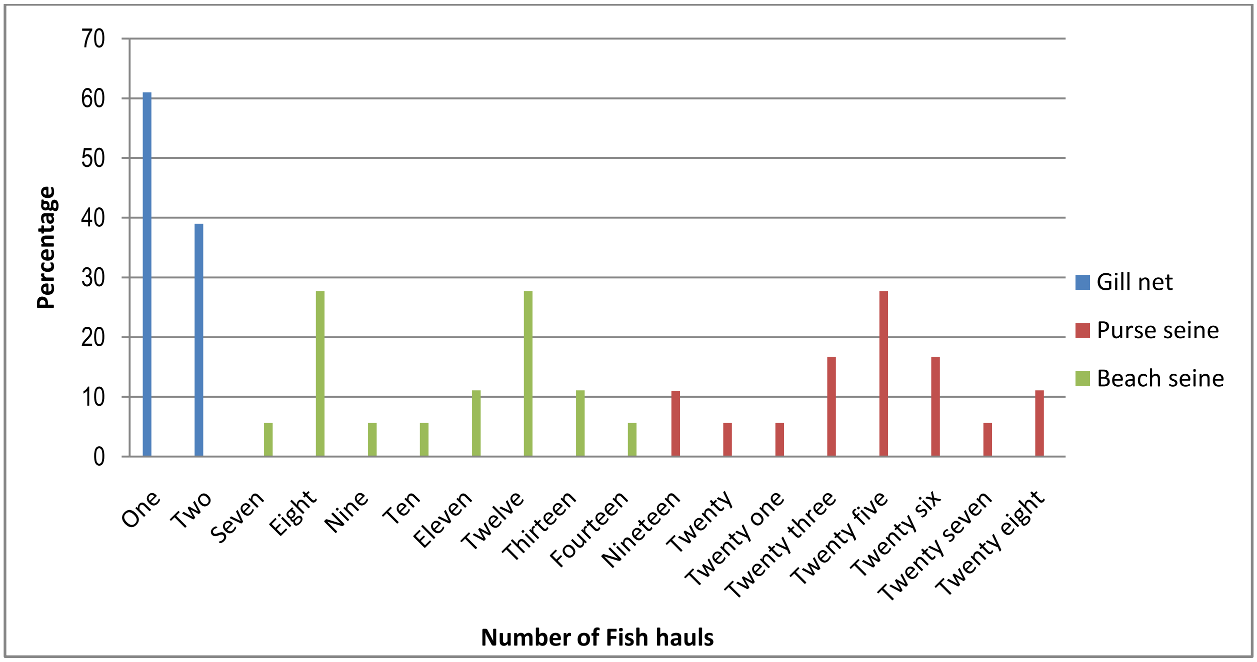

Figure 4.4: Number of hauls per day by fishing gears used in Ferguson's Gulf. In gill net and purse seine gears, majority consisted of one (61%) and twenty five (27.7%) hauls respectively. Highest number of hauls consisted of eight (27.7%) and twelve (27.7%) in equal proportions in beach seine gears.

The time per haul by beach seine, purse seine and gill net fishing gears was established by the study and recorded in minutes as the time interval starting when the fishing gear was cast and ending when completely out of water. The highest mean time (934.44±635.04 minutes) taken per haul was recorded in gill net gears while the lowest mean time (17.65±8.10 minutes) was recorded in purse seine gears and 25.11±9.49 mean time per haul in minutes was recorded in beach seine gears. There was significant difference in mean time per haul of beach seine, purse seine and gill net gears (One-way ANOVA, $F_{(2,159)}$ = 111.594, p=0.0001). DMRT established significant difference in mean time per haul in all fishing gears. As shown in Table 4.2 above, the longest (934.44±635 minutes) time taken per haul was recorded in gill net gears while the shortest time (17.65±8.10 minutes) was recorded in purse seine gears. The mean time taken per haul per fishing gears are illustrated in Figure 4.5 below.

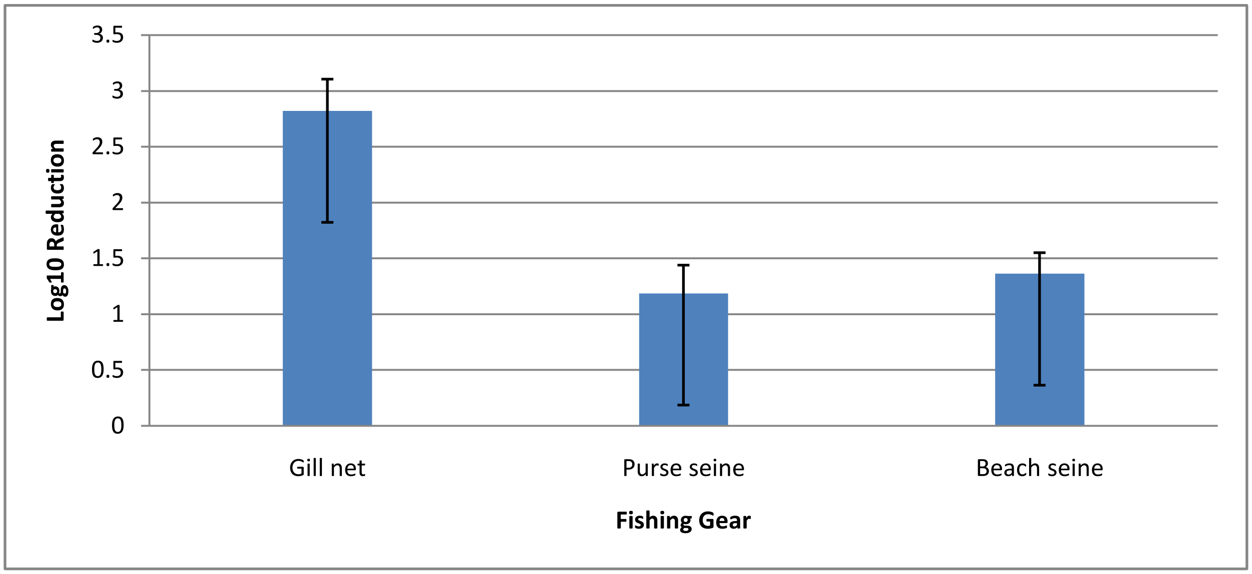

Figure 4.5: Mean time taken per haul in the log reductions of minutes by fishing gears used in Ferguson's Gulf. Gill net (n = 54), purse seine (n = 54) and beach seine (n = 54) gears took mean times of 934.44±635 minutes, 17.65±8.10 minutes, 25.11±9.49 minutes respectively.

The difference in the fishing effort (see Table 4.2) of the fishing gears indicated the variation in daily fish yields of these gears. The highest mean number of hauls in purse seine gears implied highest fish yields per day, while the lowest number of fish hauls in gill net gears denoted the lowest fish yields interms of biomass. The results of this study revealed that the mean number of hauls in fishing gears could be explained by the mean time taken per haul. Thus, fishing gears such as gill net which recorded longer mean haul time had least mean number of hauls and purse seine gear which recorded the shortest mean haul time had the highest mean number of hauls per day.

The difference in hauling time and number of hauls per day as shown in Table 4.2, could be explained by the nature and the operation of these gears. In Ferguson's Gulf, purse seines were set at the surface and extended down into the water column and non-motorized fishing vessel was used to encircle an aggregation of fish. Once the cycle is complete, the net was brought a board the vessel by hauling it, thus took a shorter time per haul. Moreover, purse seine gears were set off shore and in relatively deeper waters of Ferguson's Gulf therefore the need to maximize the catch by increasing the number of hauls unlike beach seine and gill net gears. On the other hand, beach seines were most often set from the rafts; one end remained on shore, while the rest of the net was set in a curved path and brought back to the beach within a shorter time. Therefore, given shorter time per haul, the beach seine and purse seine gears recorded relatively higher number of hauls per day in Ferguson's Gulf. The findings in Table 4.2 are supported by Okeyo (2010) that reported high number of hauls and shorter time per haul by beach seine and purse seine gears used in artisanal fishery of Kenya's South Coast.

However, in Ferguson's Gulf, gill nets were passively set at the water surface and remained relatively stationary with the use of weights. The fish were usually caught either when trying to swim through a mesh or when becoming wedged ("gilled") or when becoming entangled in the netting. The period taken to capture the targeted fish species could be longer depending on the fish movement, leading to longer time taken by gill net gears per haul and least hauls recorded per day as established by this study. This concurred with Raab and Roche (2005) and Ogundiwin (2014) that reported longer haul time and fewer hauls respectively, of gill net gears used in artisanal fisheries of Pedro González in Panama and Kainji Lake Lower Basin, Nigeria, respectively.

In Ferguson's Gulf, beach seine and purse seine gears operated more or less in competition with one another with the main objective of maximizing the catch without limits on the quantity of fish caught and the number of hauls. Therefore the fishermen continued fishing until yields are so low as to be not worth the effort expended. Thus, so long as the number of fish hauls and hauling time is unlimited, in the long term, the spawning fish stock could be reduced to the point where there could be a possibility of the fish stock collapse in Ferguson's Gulf. FAO (1984) also associated the high number of hauls by purse seine and beach seine gears with a decline in the catch and an increase in the quantities of small fish of economically important species worldwide. However, the use of large mesh sizes in gill net gears of Ferguson's Gulf, could not only offer increased potential yields, but also reduce the likelihood of stock collapse, and leaves a larger mature stock as a buffer against the periods when the fish stock is low. It is therefore important that the number of hauls by beach seine and purse seine gears predominantly consisting of small mesh sizes and high number of nets should be regulated so as to avert possible fishery collapse.

4.2 Use of Artisanal Fishing Gears and Influence on Water Physico-chemical Parameters

The highest mean pH of 9.34±0.63 was recorded at reference sites while the lowest mean pH of 8.86±0.45 was recorded in beach seine gear sites. Gill net and purse seine gear sites recorded 9.19±0.61 and 9.27±0.22 mean pH respectively. Significant difference in pH was established in all fishing and reference sites (One-way ANOVA, $F_{(3,212)} = 9.431$, $p = 0.0001$), with Duncan's Multiple Range Test showing that mean pH of reference sites differed significantly from beach seine gear sites but not from purse seine and gill net gear sites. Separation of means by DMRT indicated highest (9.34±0.623) mean pH value in reference sites and lowest (8.86±0.45) mean value in beach seine gear sites (Table 4.3).

Table 4.3: Mean measurements of water physico-chemical parameters in fishing and reference sites of Ferguson's Gulf

Sampling Site	Water physico-chemical parameters (Mean±SD)						
	pH	Salinity (g/kg)	Conductivity (µS/cm)	Water transparency (cm)	TDS(mg/l)	DO (mg/l)	Temp. (ºC)
Gill netting	9.19 ± 0.62^{B}	2.18 ± 0.29^{A}	4764 ± 532^{A}	21.6 ± 4.2^{A}	1922.1 ± 105.9^{C}	8.05 ± 0.49^{A}	31.5 ± 1.1^{A}
Purse seining	9.27 ± 0.22^{B}	2.13 ± 0.33^{A}	4690.6 ± 646^{A}	25.5 ± 2.1^{BC}	1888.7 ± 109.2^{C}	9.13 ± 0.77^{B}	31.2 ± 1.6^{B}
Beach seining	8.86 ± 0.45^{A}	1.99 ± 0.32^{B}	4364.6 ± 615^{B}	24 ± 6^{B}	1840.9 ± 114.5^{B}	8.51 ± 0.62^{C}	31.4 ± 1.1^{A}
Reference	9.34 ± 0.63^{B}	1.58 ± 0.24^{C}	3122 ± 228^{C}	26.9 ± 7.6^{C}	1681.5 ± 51.7^{A}	7.62 ± 0.38^{D}	31.0 ± 0.7^{B}
Means with different superscripts in the same column are significantly different at α= 0.05 (Means separated by DMRT)							

The highest pH recorded in reference sites indicated presence of higher level of carbonates. However, the lowest mean pH at the beach seine gear sites implied suspension of reducing matter and low quantity of carbonates. The potential presence of high quantity of reducing matter produced high concentrations of dissolved carbon dioxide which lowered the pH of beach seine gear sites by increasing the carbonic acid (H_2CO_3) concentration in the water (Nirmala et al., 2012; Winter, Harvey, Franke & Alley, 2013). The low pH recorded in beach seine fishing sites, study agreed with Johnson (2002) that reported low pH in fishing sites where gears are dragged along the lake floor; characteristic of the operation of beach seine gears. Therefore, the operation of beach seine gears in Ferguson's Gulf could flush nutrients and reducing matter resulting into low pH.

Table 4.3 shows that the highest (2.18±0.291g/kg) mean salinity was recorded in gill net sites while the lowest value of 1.58±0.24 g/kg was recorded in reference sites. Beach seine and purse seine gear sites recorded mean salinity values of 1.99±0.32 g/kg and 2.13±0.33 g/kg respectively (see Figure 4.6a). Significant differences in salinity was established in all the fishing and reference sites (One-way ANOVA, $F_{(3,212)}$ = 45.172, p= 0.0001). Duncan's Multiple Range Test showing significant difference in mean salinity values of gill net gear sites from reference and beach seine gear sites but not purse seine gear sites with high mean salinity recorded in gill net gear sites while the lowest mean was recorded in reference sites. The mean salinity values are illustrated in Figure 4.6a below.

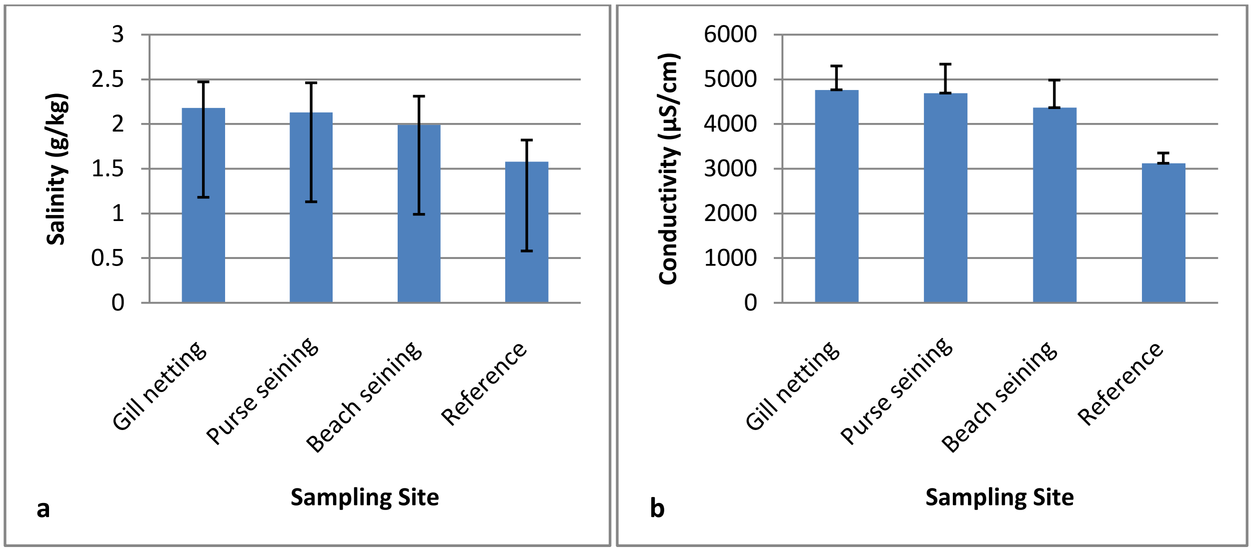

Figure 4.6: Mean (a) salinity (n = 54) and (b) conductivity (n = 54) measurements recorded in fishing and reference sites. Error bars represent standard error of the mean from Table 4.3.

As shown in Table 4.3 above, conductivity differed significantly in all the fishing and reference sites (One-Way ANOVA, $F_{(3,212)} = 116.43$, $p = 0.0001$). The lowest conductivity of 3123±228 µS/cm was recorded in reference sites while the highest conductivity of 4764±531 µS/cm was recorded in gill net gear sites (See Figure 4.5b above). Conductivity values of 4364.6±615 µS/cm and 4690.6±646 µS/cm were recorded in beach seine and purse seine gear sites in that order. DMRT established significant difference in conductivity of gill net gear sites from reference and beach seine gear sites but not purse seine gear sites.

According to the findings of this study, high salinity and conductivity mean values were recorded in gill net sites while the least mean values were recorded in reference sites corresponding to high and low TDS respectively. The mean higher conductivity and salinity values in gill net gear sites implied presence of high concentration of salts dissolved in water contrary to reference sites. This could be explained by the fact that in aquatic ecosystems, TDS is positively correlated to conductivity and salinity (Vaishali & Punta, 2013; Scannell & Jacobs, 2001; Mbalassa, Bagalwa, Nshombo & Kateyo, 2014).

Reference sites recorded the highest (26.97±7.57 cm) mean water transparency while the lowest (21.63±4.20 cm) mean was recorded in gill net gear sites. Further, purse seine gear and beach seine gear sites recorded 25.5±2.1cm and 24±6 cm water transparencys respectively (Table 4.3). There was significant difference in water transparency in all fishing and reference sites (One-way ANOVA, $F_{(3,212)} = 9.6$, $p = 0.0001$). DMRT showed that beach seine gear sites differed significantly from gill net gear sites and reference sites but not purse seine gear sites. The water transparency mean values measured in fishing and reference sites are presented in Figure 4.7 below.

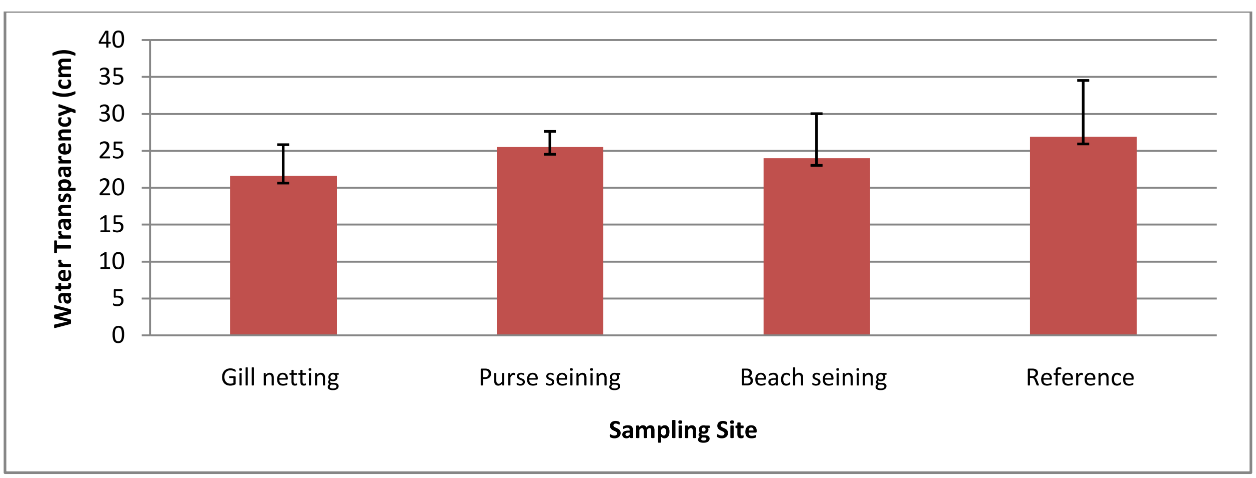

Figure 4.7: Mean water transparency with error bars representing the standard error of the mean from Table 4.3 (n = 54).

The lowest mean water transparency in gill net gears, implied low light penetration into the water column. The lowest water transparency value at the gill net gear sites was attributed to high TDS and presence of littoral vegetation which produced and added organic matter into the water. The high value at reference site was due to low TDS and less pertubation; an indication of clear waters with high light penetration. The low water transparency in gill net fishing sites was contrary to Churchill (1989) that established low water transparency in gill net fishing sites and high water transparency in beach seining sites. The high TDS in gill net fishing sites in Ferguson's Gulf could be explained by the fact that gill net gears were used in the sites with high proximity to littoral vegetation which could have produced and added more organic matter into the water column. This explanation is supported by Raspopov et al. (2002) that reported low water transparency on the littoral zone habitats of the Lake Ladoga due high TDS. The low transparency value of gill net gear sites could have implications for fish movement and distribution. Fuller and Minnerick (2007), observed that fish rely on sight and speed to catch their prey; therefore they could be affected by low water transparency and migrate from the affected areas to new territories. Lee, Jones-Lee and Rast (1995) similarly observed significant reduction in biomass of top predators in water bodies with transparency of less than 150m. Therefore the biomass of top predators could be severely reduced or totally absent in gill net gears used in Ferguson's Gulf due to very low water transparency recorded in gill netting sites

As shown in Table 4.3, the lowest (1681.5±51.77 mg/l) mean TDS was recorded in reference sites while the highest (1922.15±105.93 mg/l) mean TDS value was recorded in gill net gear sites. The mean TDS value of 1888.7±109.2mg/l, was recorded in purse seine gear sites while 1840.9±114.5 mg/l mean TDS was recorded in beach seine gear sites. TDS varied significantly in all the fishing and reference sites (One-way ANOVA, $F_{(3,212)} = 62.968$, p =0.0001). DMRT showed that purse seine gear sites differed significantly from beach seine gear and reference sites but not gill net gear sites. Log reduction of mean TDS values was done and presented in Figure 4.8 below.

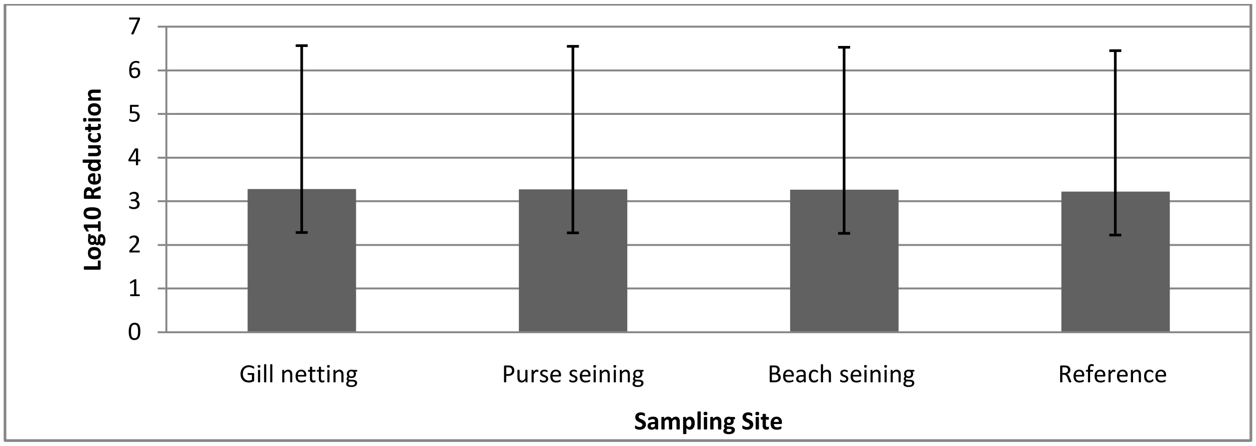

Figure 4.8: Mean TDS in the log reductions of mg/l of fishing and reference sites in Ferguson's Gulf. The gill net (n = 54), purse seine (n = 54) and beach seine (n = 54) gears recorded mean TDS of 1922.15±105.93 mg/l, 1888.7±109.2mg/l, 1840.9±114.5 mg/l and 1681.5±51.77 mg/l respectively.

The highest TDS recorded in gill net gear sites indicated high concentration of cations and anions in water as well as organic matter characteristic of hardwater or high salinity. The highest TDS value at gill net gear sites was attributed to suspension of high concentration of dissolved solids in the water column. However, this finding was contrary to the Kumar and Deepthi (2006) that reported low TDS levels in the gill net sites. This difference could be explained by the fact that gill net fishing sites were in close proximity to vegetated Ferguson's Gulf shore fringed by littoral macrophytes and *Prosopis juliflora.* Littoral vegetation could have produced organic matter contributing to the increased total dissolved solids. This finding concurred with Raspopov, Adamec and Husak (2002) and Murphy (2007) that reported high amount of total dissolved solids in sections of water bodies inhabited by littoral vegetation due to action of microbes on dead organic matter on the littoral zone habitats of the Lake Ladoga, Russia.

The mean TDS values of gill net gear sites (1922.1±105.9 mg/l) was above the maximum permissible limit for surface water set at 1000mg/l by KEBS (2007) (Appendix); thus, not suitable for the survival of most fish species with narrow range of tolerance to TDS. According to Scannell and Jacobs (2001), excessive TDS level could produce toxic effects on fish and fish eggs, showing reduced hatching and egg survival rates, shrinking the cells of fish and affecting its ability to move in a water column causing it to float or sink beyond the normal range. Thus, there could be increased difficulty in movement, fecundity and survival of fish species due to high TDS level in Ferguson's Gulf.

The highest mean DO of 9.13±0.77 mg/l was recorded in purse seine gear sites while the lowest mean DO of 7.62±0.38 mg/l was recorded in reference sites. Mean DO values of 8.51±0.62 mg/l and 8.05±0.49 mg/l were recorded in beach seine gear and gill net gears sites respectively. Dissolved oxygen (DO) significantly differed in all the fishing and reference sites (One-way ANOVA, $F_{(3,212)} = 66.689$, p =0.0001). DMRT showed significant difference of mean DO in all the fishing gears and reference sites. The mean Do values recorded in fishing and reference sites are shown in Figure 4.9.

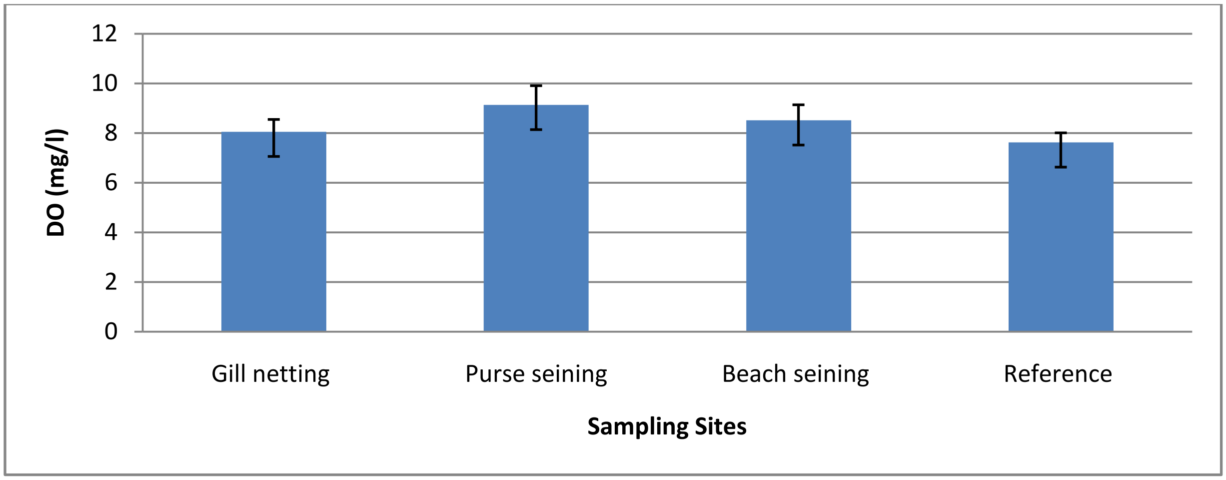

Figure 4.9: Mean Dissoved Oxygen measurements recorded in fishing and reference sites with Error bars represent standard error of the mean (n = 54).

The high mean dissolved oxygen concentration in purse seine gear sites implied high amount of gaseous oxygen (O_2) dissolved in water. This was caused by the agitation of water by purse seine fishers using water using oars and feet inorder to drive fish into the set nets. The lowest dissolved oxygen level in reference sites was due to undisturbed state resulting from lack of fishing activity. The above findings were similar to EPA (2012) that found increased dissolved oxygen concentration with agitation of a water body and relatively low dissolved oxygen concentration in undisturbed water bodies. Therefore, unlike gill net and beach seine gears, the use of purse seine gears resulted into increased dissolved oxygen in purse seine fishing sites of Ferguson's Gulf. Nevertheless, the mean dissolved oxygen level of 9.13±0.77 mg/l measured in purse seine gear sites fell within the optimal range of 6-9 mg/l, reported by Bisht, Ali, Rawat and Pandey (2013) needed for survival of fish.

The highest mean temperature of 31.5±1.1ºC was recorded in gill net gear sites while the lowest mean of 31.0±0.7 ºC was recorded in reference sites. Purse seine gear and beach seine gear sites had 31.2±0.6 ºC and 31.4±1.1ºC mean temperature respectively. There was existed significant difference in mean temperature of all fishing and reference sites (One-way ANOVA, $F_{(3,212)}$ = 2.672, p =0.012). DMRT showed significant difference of reference sites from beach seine gear and gill net gear sites but not purse seine gear sites (see Table 4.3). The mean high temperature recorded in gill net gear sites was attributed to high TDS and suspension of high load of organic matter in the water column. The high quantity of organic matter added by littoral vegetation accounted for high TDS load in gill net fishing sites. This finding agreed with Washington State Department of Ecology (1991), Mbalassa, Bagalwa, Nshombo and Kateyo (2014) and EPA (2012) that reported increased temperature of the surface water in littoral zone due to absorption of solar radiation by suspended matter in the water column.

4.3 Fish Biomass, Species Diversity and Artisanal Fishing Gears Use

Data on Fish biomass and species diversity was obtained from gill net, purse seine and beach seine gears and presented separately under respective sub-sections below.

4.3.1 Fish Biomass and Artisanal Fishing Gears

Fish biomass differed significantly in beach seine, purse seine and gill net gears (One-Way ANOVA, $F_{(2,159)} = 6.672$, $P = 0.002$), with DMRT further showing significant differences in mean biomass of purse seine gears from gill net gears but not beach seine gears. The highest (13,692.2±12,703 g) proportion of biomass was recorded in Purse seine gears and the least (7,788.8±5,443.7 g) was recorded in gill net gears (Table 4.5).

Table 4.4: Mean biomass of fish from fishing gears in Ferguson's Gulf

Fishing gear	**Fish biomass (g) (Mean±SD)**
Gill net	$7,788.8 \pm 5,443.7^{A}$
Purse seine	$13,692 \pm 12,703.8^{B}$
Beach seine	$12,060.3 \pm 5,884.7^{B}$

Means with different superscripts in the same column are significantly different at α =0.05 (Means separated by DMRT).

The significant difference in the mean biomass of fish from gill net, purse seine and beach seine gears implied difference in the yield potential of these gears in Ferguson's Gulf. According to data in Table 4.5, purse seine gears contributed the highest proportion (49%) of fish biomass while beach seines contributed 47% and gill nets contributed the least proportion (4%). Gill net gears caught small quantity of fish per haul than beach seine and purse seine gears. The high biomass in purse seine and beach seine gears was attributed to smaller mesh sizes and high number of nets per fishing gear. However, low number of nets and large mesh sizes accounted for low biomass in gill net gears.

These findings on significant difference in biomass of fish caught by purse seine, beach seine and gill net gears in Ferguson's Gulf were similar to Ibrahim et al. (2009) that reported significant difference in the mean biomass of fish for beach seine, purse seine and gill net gears with high fish biomass recorded in purse seine gears. Studies by Fondo (2004), Mc Clanahan and Mangi (2004) and Brown, Auster, Lauk, Liz & Coyne (1998) conducted at Kenyan coast and Gulf of Mexico respectively, also recorded the highest catch for purse seine gears followed by beach seine gears and least in gill net gears. In addition, Okeyo (2010) reported the high biomass in purse seine gears used in artisanal fishery of Kenya's South Coast concurrent with this study.

Therefore, purse seines and beach seines used in Ferguson's Gulf accounted for high biomass of fish landed. This was attributed to the fact that purse seine and beach seine gears effectively trapped any encircled fish with higher biomass compared to other fishing gears. This could lead to subsequent decline in fish stocks and trophic shifts with serious consequences for recovery and resilience of Ferguson's Gulf ecosystem. Purse seine gears harvested pelagic (surface-dwelling) species which contributed significantly to most of the fish landed interms of biomass in Ferguson's Gulf concurrent with the findings of DFO (2010). Therefore purse seine gears were the most rewarding due to high biomass and thus could be the most preferred to gill net and beach seine gears in the artisanal fishery of Ferguson's Gulf from a commercial perspective. However, Okeyo (2010) noted that purse seine and beach seine gears were responsible for the decreasing catches because of their small mesh sizes in Kenyan Coastal artisanal fishery. Despite these implications on fish resources, purse seine and beach seine gears are currently used in Ferguson's Gulf without regulations, raising the question of sustainability of Lake Turkana fish resources.

Table 4.5: Inventory of fish species and biomass based on fishing gear type used in Ferguson's Gulf

Fish species	Biomass (g) per fishing gear			
	Gill net	**Purse seine**	**Beach seine**	**Total biomass**
Oreochromis niloticus	526,875	8,580,750	7,879,088	16,986,713
Hydrocynus forskalii	1,792	9,518	18,540	18,540
Schilbe uranoscopus	163,256	2,236	22,487	174,229
Bagrus bayad	6,384	5,320	2,712	14,416
Labeo horie	2,781	14,008	92,856	109,645
Synodontis schall	8,512	16,704	3,730	28,946
Chrysichthys turkana	264	660	660	1,584
Tetraodon lineatus	-	-	648	648
Sarotherodon galilaeaus	-	3,920	205,380	209,300
Clarias gariepinus	-	-	5,216	5,216
Citharinus citharus	2,125	2,772	1,650	6,547
Lates niloticus	1,700	2,608	5,805	10,113
Alestes baremoze	38,665	7,514	17,200	63,379
Distichodus niloticus	-	1,875	11,250	13,125
Tilapia zillii	-	4,508	15,480	19,988
Total biomass	752,354	8,652,393	8,282,702	17,662,389
Dash (-) denote absence of fish species				

Analysis of the data shown in Table 4.5, indicated that *Oreochromis niloticus* dominated the biomass in all the fishing gears constituting 70% in gill net, 99% in purse seine and 96% in beach seine gears. *Hydrocynus forskalii* (0.24%), *Schilbe uranoscopus* (22%), *Bagrus bayad* (0.85%), *Labeo horie* (0.3%), *Synodontis schall* (1.1%), *Chrysichthys turkana* (0.04%), *Citharinus citharus* (0.28%), *Lates niloticus* (0.23%), *Alestes baremoze* (5.1%) constituted the remaining 30% in gill net gears.

The remaining 1% of biomass in purse seine gears consisted of *Hydrocynus forskalii* (0.1%), *Schilbe uranoscopus* (0.03%), *Bagrus bayad* (0.06%), *Labeo horie* (0.16%), *Synodontis schall* (0.16%), *Chrysichthys turkana* (0.01%), *Sarotherodon galileaus* (0.05%), *Citharinus citharus* (0.2%), *Lates niloticus* (0.03%), *Alestes baremoze* (0.09%), *Distichodus niloticus* (0.02%) and *Tilapia zillii* (0.05%).

Schilbe uranoscopus (0.27%), *Hydrocynus forskalii* (0.22%), *Bagrus bayad* (0.03%), *Labeo horie* (1.12%), *Synodontis schall* (0.05%), *Chrysichthys turkana* (0.01%), *Sarotherodon galileaus* (2.48%), *Citharinus citharus* (0.02%), *Lates niloticus* (0.07%), *Alestes baremoze* (0.21%), *Distichodus niloticus* (0.14%), *Tilapia zillii* (0.19%), *Tetraodon lineatus* (0.01%) and *Clarias gariepinus* (0.06%) constituted the remaining 4% in beach seine gears. The biomass of fish species catches by beach seine, purse seine and gill net gears was reduced by Log10 and presented in Figure 4.10 below.

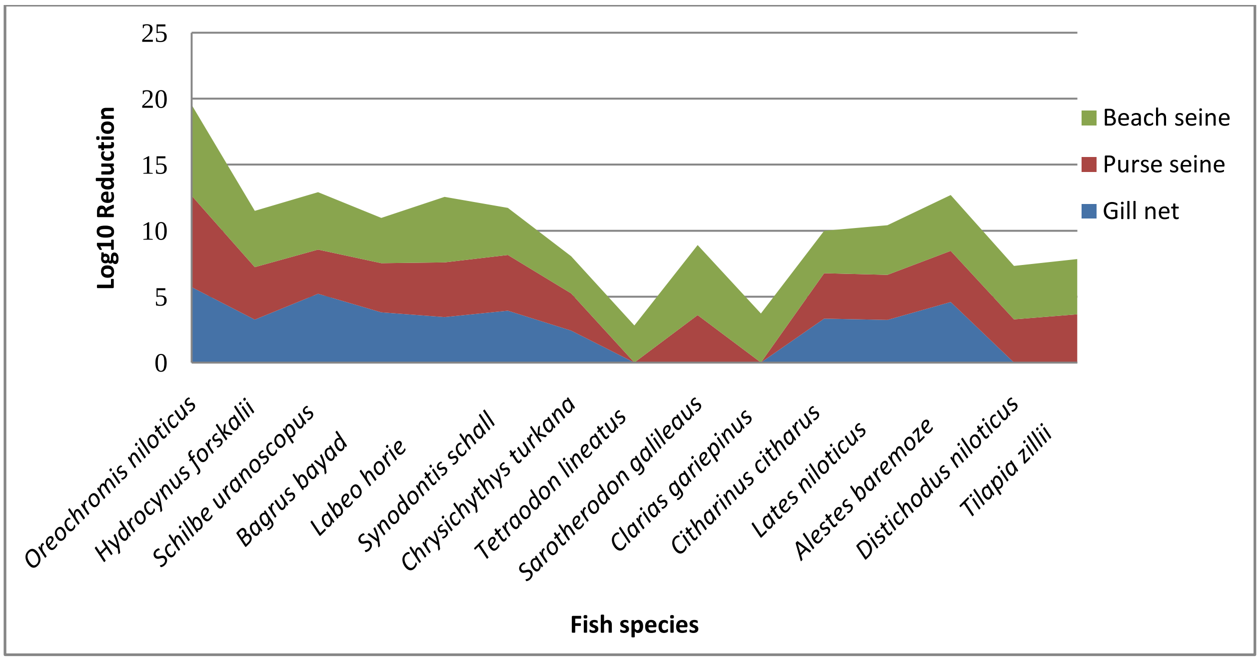

Figure 4.10: Biomass in the log reductions of grams of fish from fishing gears. The biomass of fish species landed in Ferguson's Gulf from Table 4.6.

Overaly, biomass was dominated by *Oreochromis niloticus* constituting 96% while *Hydrocynus forskalii* (0.1%), *Schilbe uranoscopus* (0.1%), *Bagrus bayad* (0.08%), *Labeo horie* (0.6%), *Synodontis schall* (0.16%), *Chrysichthys turkana* (0.01%), *Sarotherodon galileaus* (0.19%), *Citharinus citharus* (0.04%), *Lates niloticus* (0.06%), *Alestes baremoze* (0.4%), *Distichodus* *niloticus* (0.07%), *Tilapia zillii* (0.11%), *Tetraodon lineatus* (0.004%) and *Clarias gariepinus* (0.029%) formed the remaining 4% (Figure 4.11).

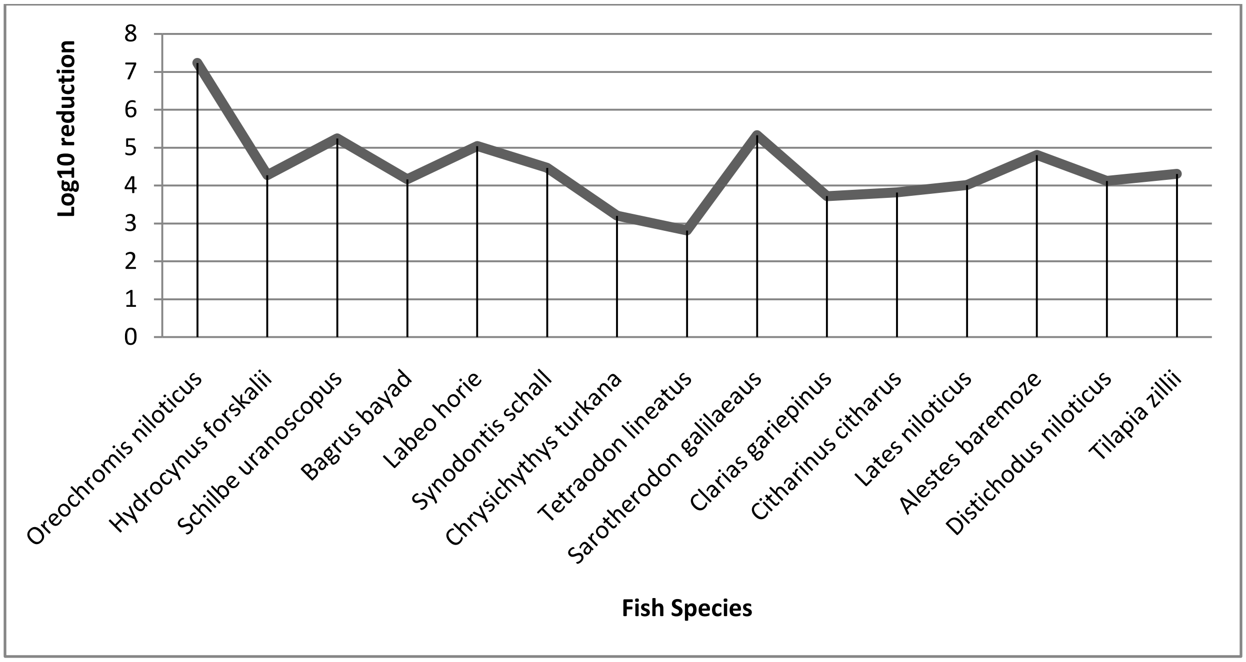

Figure 4.11: Total biomass in the log reduction of grams of fish species captured by fishing gears in Ferguson's Gulf. The fish biomass consisted of *Oreochromis niloticus* (16,986,713g), *Hydrocynus forskalii* (18,540g), *Schilbe uranoscopus* (174,229g), *Bagrus bayad* (14,416g), *Labeo horie (*14,416g), *Synodontis schall* (28,946), *Chrysichthys turkana* (1,584g), *Tetraodon lineatus* (648g), *Sarotherodon galilaeaus* (209,300g), *Clarias gariepinus* (5,216g), *Citharinus citharus* (6,547g), *Lates niloticus* (10,113g), *Alestes baremoze* (63,379g), *Distichodus niloticus* (13,125g) and *Tilapia zillii* (19,988g).

The dominance of fish biomass by Nile Tilapia, *Oreochromis niloticus*, implied high productivity and existence of eutrophic conditions. The existence of high conductivity, salinity and low water transparency, favourable for survival of *Oreochromis niloticus* also accounted for its dominance in Ferguson's Gulf. This agreed with Novaes & Cavalho (2001) that reported dominance of *Oreochromis niloticus* in water bodies with low water transparency and high salinity and conductivity. Moreover, Novaes and Cavalho (2001) pointed out that *Oreochromis niloticus* is an opportunistic species with an exceptional ability to adjust to environmental conditions unfavourable to other species. Thus, the comparative high salinity, conductivity and low water transparency levels in Ferguson's Gulf could have caused the dispersal or depletion of fish species with low tolerance to these conditions leading to high populations of *Oreochromis niloticus.*

As shown in Table 4.5, possible high biomass of dominant, *Oreochromis niloticus,* or removal of too many reproductive individuals from a population, by purse seine and beach seine gears, confounded by high hauls and small mesh sizes, may have far-reaching ecological effects in fish community structure of Ferguson's Gulf. According to Brown et al. (1998) removing a dominant species could cause predator populations dependent on the harvested species to decline. This could therefore explain the low overall species diversity and low biomass of top predators such as *Lates niloticus* and *Hydrocynus forskalii* in Ferguson's Gulf which formed a minute 0.16% of the overall biomass.

According to the data in Table 4.5, all the fish species caught were native species consisting of only one endemic fish species, *Chrysichthys turkana. Oreochromis niloticus, Schilbe uranoscopus, Hydrocynus forskalii, Citharinus citharus, Bagras bayad, Labeo horie, Chrysichthys turkana, Lates niloticus, Alestes baremoze* and *Synodonitis schall* occurred in all fishing gears. *Clarias gariepinus* and *Tetraodon lineatus* occurred in beach seine gears only while *Sarotherodon galilaeus, Tilapia zillii* and *Distichodus niloticus* occured in both purse seine and beach seine gears. The capture of native species, few cichlids and one endemic species pointed to the little to ichthyofaunal modification of Lake Turkana with low level of endemicity and few cichlids. These results agreed with Odada et al. (2003) that reported low number of endemic fish species, few cichlids and high number of native fish species in Lake Turkana. Furthermore, previous research by Kolding (1989) in Lake Turkana reported *Clarias gariepinus* as sparsely distributed and occuring in benthic habitats and very rare in gill net gears and mostly caught by beach seine gears, which is consistent with this study.

The capture of *Clarias gariepinus* and *Tetraodon lineatus* only by beach seine gears was attributed to the ecology and habitat requirements of these species. They are benthic fish species mostly found on shallow waters near the shore and can survive in low pH levels and relatively high turbidity, characteristic of beach seine gear fishing sites of Ferguson's Gulf. Purse seine and gill net gears used in Ferguson's Gulf only targeted pelagic fish species, therefore accounting for the absence of *Clarias gariepinus* and *Tetraodon lineatus* which are benthic fish species. Although *Tetraodon lineatus* could be regarded as widely distributed, it is suspected that the species may be extirpated from the water bodies, since it no longer appears in commercial catches (FishBase, 2004). This supports the findings of this study which established rarity of this species interms of distribution and total biomass as it accounted for a paltry 0.004% of the total biomass in Ferguson's Gulf. The rarity of the Cichlids, *Sarotherodon galilaeus* and *Tilapia zillii* as established by this study was supported by Kolding (1989) and Lae (1995) also observed that, *Sarotherodon galilaeus* and *Tilapia zillii* were less abundant in Lake Turkana and River Niger compared to *Oreochromis niloticus*. The dominance of *Synodontis schall*, *Lates niloticus* and *Schilbe uranoscopus*, *Hydrocynus forskahli* in the fish biomass captured by gill net gears was supported by Mušvka et al. (2012) that established that these species dominated the gill net fishery of Lake Turkana.

4.3.1 Fish Species Diversity and Artisanal Fishing Gears

Of the 15 species recorded in all the fishing gears, 10 species were recorded in gill net gears, 13 in purse seine gears while all the 15 species were recorded in beach seine gears representing twelve families: Cichlidae, Alestidae, Cyprinidae, Clariidae, Bagridae, Claroteidae, Latidae, Schilbeidae, Mochokidae, Citharinidae, Distichodontidae and Tetraodontidae. Fish species; *Oreochromis niloticus, Schilbe uranoscopus, Hydrocynus forskalii, Citharinus citharus, Bagras bayad, Labeo horie, Chrysichthys turkana, Lates niloticus, Alestes baremoze* and *Synodonitis schall* occured in all the fishing gears. *Clarias gariepinus* and *Tetraodon lineatus* occurred only in beach seine gears. As shown in Table 4.6 above, the Cichlids, *Sarotherodon galilaeus* and *Tilapia zillii*, only occurred in purse seine and beach seine gears but not in gill nets.

One-way ANOVA ($F_{(2,159)} = 40.935$, $p = 0.0001$), showed significant difference in the number of fish species among beach seine, purse seine and gill net gears. DMRT showed significant differences in the number of fish species of beach seine gears from gill net and purse seine gears. The highest (2.46±1.16) mean number of fish species was recorded in beach seine gears and the lowest mean (1.15±0.359) in gill net gears (Table 4.6).

Table 4.6: Fish species richness in artisanal fishing gears in Ferguson's Gulf

Fishing gear	**Number of Fish species (Mean±SD)**
Gill net	1.15 ± 0.359^{A}
Purse seine	1.33 ± 0.549^{A}
Beach seine	2.46 ± 1.16^{B}

Means with different superscripts in the same column are significantly different at α=0.05 (Means separated by DMRT).

Shannon-Wiener diversity index (H) showed significant difference among beach seine, purse seine and gill net gears (One-way ANOVA, $F_{(2,159)} = 891.33$, $p = 0.0001$). DMRT established significant differences in mean Shannon-Wiener diversity indices among beach seine, purse seine and gill net gears. The highest (0.4871±0.0912) mean Shannon-Wiener diversity index value was observed in beach seine gears and the lowest (0.053±0.008) observed in gill net gears (Table 4.7).

Table 4.7: Mean Shannon-Wiener Diversity indices of artisanal fishing gears used Ferguson's Gulf

	Fishing gear		
Parameters (Mean±SD)	Gill net	Purse seine	Beach seine
Shannon-Wiener Diversity Index (H')	0.1865 ± 0.0244^{A}	0.053 ± 0.008^{B}	0.4871 ± 0.0912^{C}

Means with different superscripts in the same row are significantly different at α =0.05 (Means separated by DMRT).

The high Shannon-wiener diversity index in beach seine gears implied that beach seine gears captured a higher number of relatively abundant fish species. This was attributed to non-selectivity and the ability of these species to target both demersal and pelagic fish species. The low fish species diversity in purse seine and gill net gears was attributed to the fact that these gears only targeted pelagic species. However, despite the high species diversity, most (96%) of the catch was dominated by *Oreochromis niloticus;* implying low overall species diversity of Ferguson's Gulf. This greatly explained why the Shannon-wiener diversity index calculted for gill net, purse seine and beach seine gears was less that 1 as shown in Table 4.7 above. A further indication that only one fish species was present in Ferguson's Gulf with no uncertainty as to what species each individual would be. The overall low shannon-wiener diversity index for fishing gears was attributed to the dominance of *Oreochromis niloticus* due to extremely low populations of other fish species in Ferguson's Gulf.

The results of the study on difference in species diversity of fishing gears was supported by (2012) that reported relatively high species diversity in beach seine gears compared to purse seine and gill net gears in artisanal fishery of Kenya's Coast. Concurrent to this study, Okeyo (2010) and Lloret et al. (2010) also reported low fish species diversity of gill net gears and attributed to its large mesh sizes. Moreover, FAO (2003) also reported that in multispecies fisheries, all fishing gears are species and size selective where one type of gear may catch a set of species. This means that beach seine, purse seine and gill net fishing gears caught a certain portion of the multispecies fish community present in the entire Ferguson's Gulf. Therefore, there could be more fish species in Fergusons's gulf other than the ones recorded by this study.

In conclusion, the area of operation of a gear, the behaviour of the fish relative to the gear, and the size of the fish determined the fish species caught by fishing gears in Ferguson's Gulf. Interestingly, McClanahan et al. (2008) pointed out high diversity of catch as responsible for rapid decline in catch at high levels of fishing effort with a potential consequence of total fisheries collapse in Kenyan Coastal fisheries. The relatively higher number of hauls, shorter time per haul and small mesh sizes indicated the destructive potential of purse seine and beach seine gears on fish resources of Ferguson's Gulf, hence the need to manage the widespread use of purse seine gears observed in Ferguson's Gulf in order to avert the collapse of the Lake Turkana fishery.

4.4 Bycatch, Discard and Artisanal Fishing Gears

Data on bycatch and discard was obtained from gill net, purse seine and beach seine gears used in Ferguson's Gulf.

4.4.1 Bycatch in Artisanal Fishing Gears

There was significant difference in bycatch from different fishing gears (One-way ANOVA, $F_{(2,159)}$ = 75.196, p =0.0001) used in Ferguson's Gulf. Duncan's Multiple Range Test showed significant differences in the mean bycatch of purse seine gears (2,278±629 g) from beach seine (1,078.4±55.5 g) and gill net (1,461.6±324.5 g) gears. The highest mean bycatch was recorded in purse seine gears (2,278±629g) and the lowest (1,078.4±55.5 g) was recorded in gill net gears (Table 4.8).

Table 4.8: Mean biomass of bycatch from artisanal fishing gears used in Ferguson's Gulf

Fishing gear	Bycatch (g) (Mean±SD)
Gill net	$1,461.6±324.5^{C}$
Purse seine	$2,278±629^{B}$
Beach seine	$1,078.4±55.5^{A}$

Means with different superscripts in the same column are significantly different at α=0.05 (Means separated by DMRT).

Table 4.9 shows that the highest proportion (49,116 g, 49%) of bycatch was recorded in purse seine gears while gill nets recorded 32% (31,729 g) of the total bycatch. The least (19,192 g, 19%) proportion of bycatch was recorded in beach seine gears.

Table 4.9: Fish species composition and bycatch in artisanal fishing gears used in Ferguson's Gulf

Bycatch (g) per artisanal fishing gears					
	Family and Species	**Gill nets**	**Purse seines**	**Beach seines**	**Total biomass**
1	**Cichlidae**				
	Tilapia zillii	-	258	-	258
	Sarotherodon galilaeaus	-	128	-	128
2	**Alestidae**				
	Hydrocynus forskalii	4,905	22,275	1,266	28,446
	Alestes baremoze	215	-	-	215
3	**Cyprinidae**				
	Labeo horie	876	-	8,514	9,390
4	**Mochokidae**				
	Synodontis schall	6,500	6,616	-	13,116
5	**Bagridae**				
	Bagrus bayad	5,369	7,021	-	12,390
6	**Citharinidae**				
	Citharinus citharus	624	-	2,760	3,384
7	**Claroteidae**				
	Chrysichthys turkana	132	264	1,584	1,980
8	**Clariidae**				
	Clarias gariepinus	-	-	2,000	2,000
9	**Schilbeidae**				
	Schilbe uranoscopus	12,763	12,104	708	25,575
10	**Latidae**				
	Lates niloticus	345	-	-	345
11	**Tetraodontidae**				
	Tetraodon lineatus	-	-	648	648
12	**Distichodidae**				
	Distichodus niloticus		450	1,500	1,950
	Total Biomass	31,729	49,116	18,980	99,825

The high number of bycatch in purse seine gears implied highly unselective capture of fish species interms of size and species type resulting into high biomass of otherwise non-target fish species. The high fish biomass recorded in purse seine gears per haul in this study relative to beach seine and gill net gears accounted for high bycatch. This was consistent with Brown et al. (1998), Fondo (2004) and Polet and Depestle (2010) that reported greater bycatch of purse seine gear in artisanal marine fisheries United States of America, Kenya and the North Sea in that order, than beach seine and gill net gears.

A shown in Table 4.9, *Oreochromis niloticus* was the target fish species across all fishing gears and therefore not regarded as bycatch. This was attributed to the high biomass, developed market and relatively high commercial value of *Oreochromis niloticus* compared to other fish species. However, in beach seine gears, *Oreochromis niloticus* was considered as target species along with other fish species. The high fish species diversity of beach seine gears could account for increased number of targeted fish other than *Oreochromis niloticus.* The finding on the dominance of *Oreochromis niloticus* agreed with Kolding (1989) that reported this species as the most dominant of the fish landings and most expensive of the Lake Turkana's cichlids with developed market niche, therefore, the mostly targeted of the fish resources from commercial point of view. The high number of target species in beach seine gears was attributed to the fact that beach seines targeted both demersal and pelagic fish species, consequently, provided fishers with a range of species that could be utilized for commercial and subsistence purposes, concurrent with (FAO, 2015).

4.4.1.1 Composition of Bycatch from Fishing Gears

As indicated in Table 4.10 above, most (40.2%) of the bycatch in gill net gears was composed of the taxa Schilbedae (*Schilbe uranoscopus*) followed by Mochokidae (*Synodontis schall*) (20.5%), Bagridae *(Bagrus bayad)* (17%), Alestidae consisting of *Hydrocynus forskalii* and *Alestes baremoze* (16%), Citharinidae (*Citharinus citharus*) (2%), Cyprinidae (*Labeo horie*) (2.8%), Latidae (*Lates niloticus*) (1.1%) and Claroteidae (*Chrysichthys turkana*) (0.4%) as shown in Figure 4.11 below.

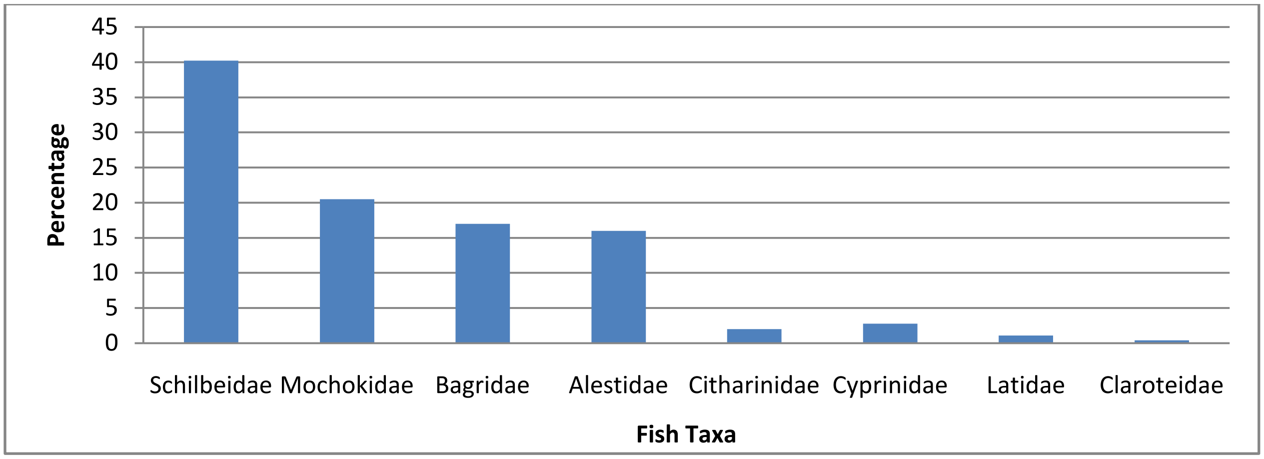

Figure 4.12: Fish taxa composition by biomass of bycatch in gill net gears used in Ferguson's Gulf. Bycatch consisted of Schilbedae (12,763g), Mochokidae (6,500g), Bagridae (5,369g), Alestidae (4,905g), Citharinidae (624g), Cyprinidae (876g), Latidae (345g) and Claroteidae (132g) fish taxa.

In purse seine gears, as shown in Table 4.9, majority (45.4%) of bycatch belonged to taxa Alestidae, followed by Schilbedae (24.6%), Mochokidae (13.5%), Bagridae (14.3%), Distichodidae (0.9%), Cichlidae (0.8%) and Claroteidae (0.5%) as illustrated in Figure 4.12 below.

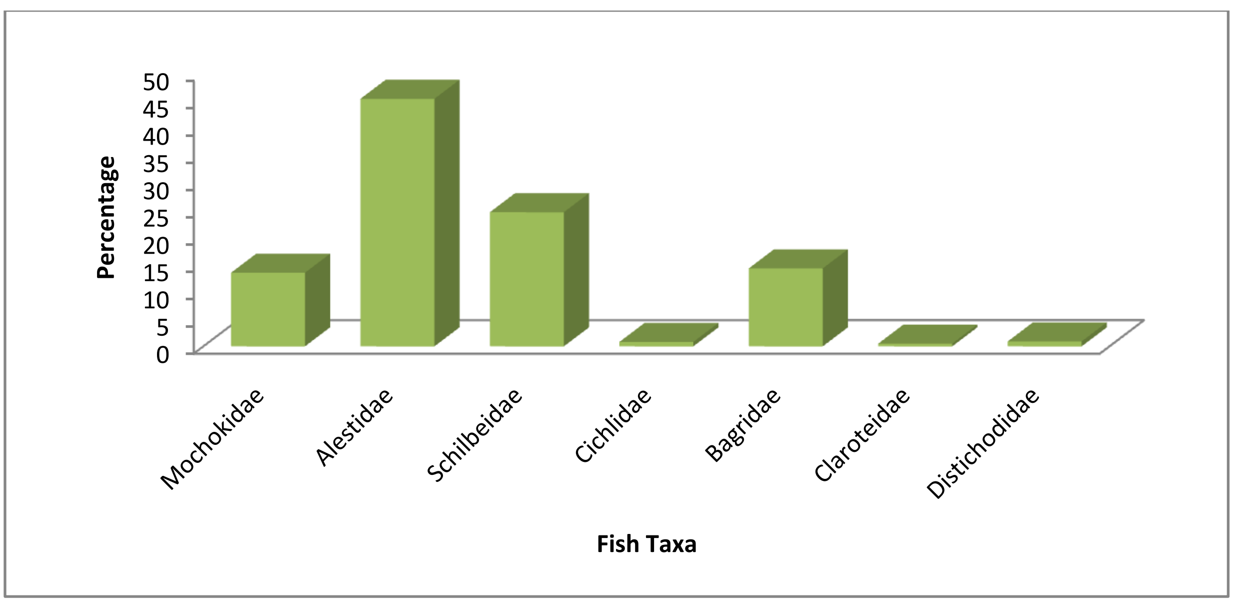

Figure 4.13: Fish taxa composition of bycatch in purse seine gears used in Ferguson's Gulf. The bycatch consisted of Mochokidae (6,616g), Alestidae (22,275g), Schilbeidae (12,104g), Cichlidae (386g), Bagridae (7,021g), Claroteidae (264g) and Distichodidae (450g).

The Taxa composition of bycatch in beach seine gears also differed proportionately (Table 4.10). Most of the bycatch was composed of fish species belonging to the Taxon Cyprinidae (8,514g, 44.8%). Others included Citharinidae (2,760g, 14.5%), Clariidae (2,000g, 11%), Alestidae (1,266g, 6.7%), Claroteidae (1,584g, 8%), Distichodidae (1,500g, 7.9%), Tetraodontidae (648g, 3.4%) and Schilbeidae (708g, 3.7%) as shown in Figure 4.13 below.

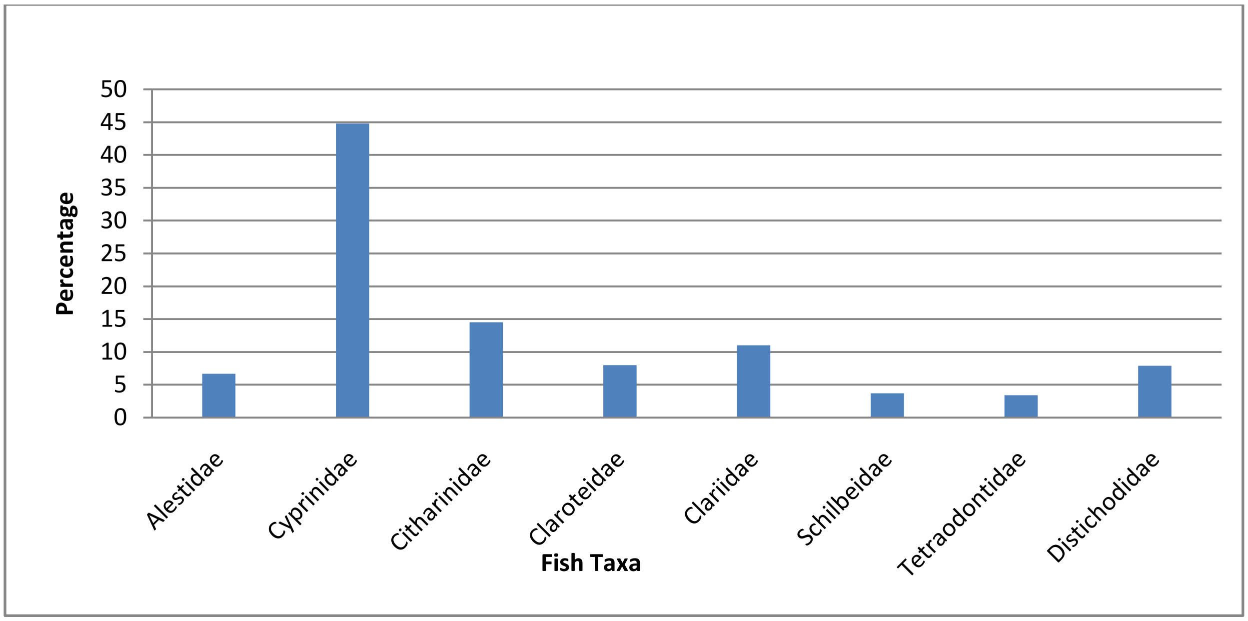

Figure 4.14: Fish taxa composition of bycatch in beach seine gears used in Ferguson's Gulf. The bycatch consisted of Cyprinidae (8,514g), Alestidae (1,266g), Schilbeidae (708g), Citharinidae (2,760g), Tetraodontidae (648g), Claroteidae (1,584g) and Distichodidae (1,500g).

The overall composition of bycatch from gill net, purse seine, beach seine fisheries established that the bulk consisted of Taxa Alesteidae (28.7%) and Schilbeidae (25.6%). Others included Mochokidae (13.1%), Bagridae (12.4%), Clariidae (2%), Cyprinidae (9.4%), Citharinidae (3.4%), Claroteidae (1.9%), Cichlidae (0.4%), Latidae (0.4%), Distichodidae (2%) and Tetraondontidae (0.7%) as shown in Figure 4.14.

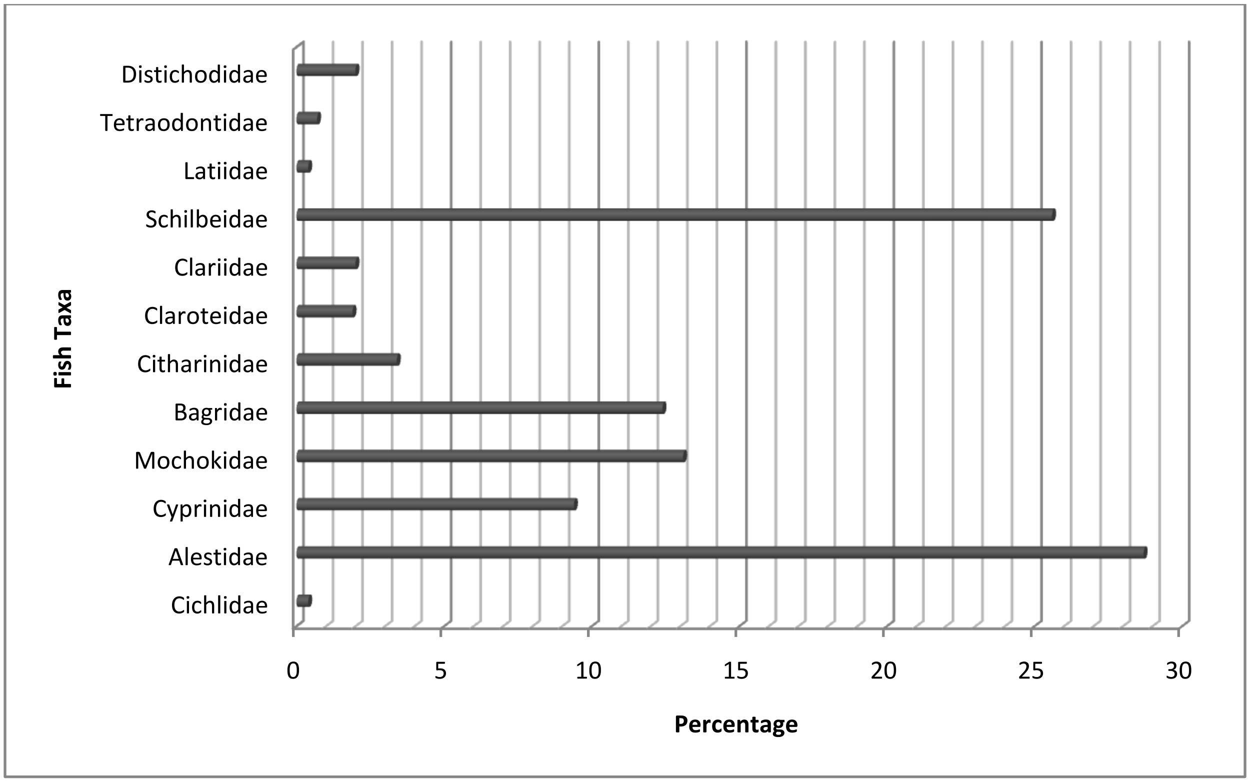

Figure 4.15: Fish taxa composition of total bycatch from artisanal fishing gears used in Ferguson's Gulf. The total bycatch was composed of Taxa Cyprinidae (9,390g), Alestidae (28,661g), Schilbeidae (25,575g), Citharinidae (3,384g), Tetraodontidae (648g), Claroteidae (1,980g), Latidae (345g), Bagridae (12,390g), Mochokidae (13,116g), Cichlidae (386g), Clariidae (2,000g) and Distichodidae (1,950g).

The high bycatch of *Schilbe uranoscopus* in gill net gears could be attributed to high biomass relative to other non-target fish species. *Hydrocynus forskalii* is pelagic dwelling fish species and forms shoals in open water near the water surface thus accounting for high proportion of bycatch in purse seine gears that targets pelagic fish species. Meanwhile, the high proportion of *Labeo horie* as bycatch in beach seine gears could be attributed to the fact that species utilizes mud and detritus as its food and its migratory behaviour is stimulated by relatively higher turbidity level resulting from the action of beach seine gears. These findings are consistent with Polet and Depestle (2010) and Kolding (1989) that reported high biomass of *Labeo horie* and *Hydrocynus forskalii* respectively, in benthic and pelagic habitats respectively, characteristic of beach seine and purse seine fishing sites. Furthermore, the established low proportions of *Chysichthys turkana* in gill net gears was due to the fact that the species is a bottom feeder and occurs in relatively deep quiet waters. But the low bycatch proportions of *Schilbe uranoscopus* in beach seine gears was attributed to its water surface-dwelling nature resulting to low biomass (FishBase, 2004).

4.4.1.2 Determinants of Bycatch

The study revealed that *Oreochromis niloticus* was the only fish species targeted by all gill net, purse seine and beach seine fishers, while *Tetraodon lineatus* was regarded as bycatch by all the fishers. However, other than *Oreochromis niloticus,* the rest of the fish species were regarded as bycatch by some fishers while at the same time as target fish by other fishers. Considering the reasons for targeting *Oreochromis niloticus* by all artisanal fishers (N = 162); Presence of ready market (f = 83) was the leading determinant, followed by the High abundance (f = 36) of the fish species in Ferguson's Gulf. Other reasons included high commercial value (f = 24) and acceptance over a wider consumer population (f = 19) as shown in Figure 4.15.

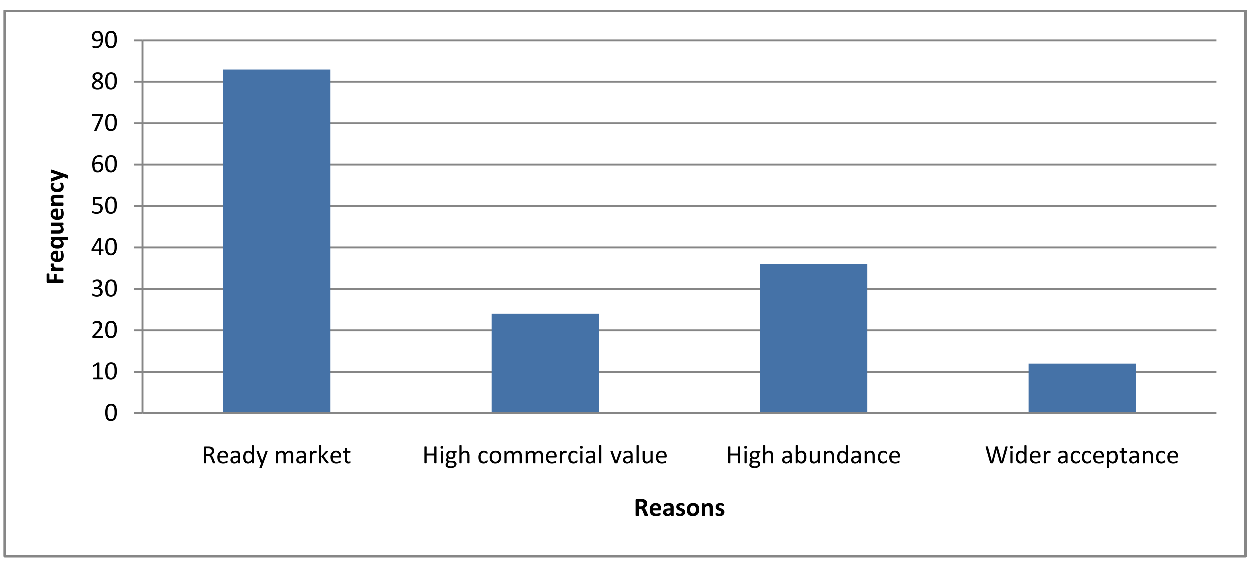

Figure 4.16: Reasons for targeting *Oreochromis niloticus* by artisanal fishers in Ferguson's Gulf (n =162).

In gill net gears, *Schilbe uranoscopus* was regarded as bycatch mainly because of low commercial value (80%) and small size (20%), while *Synodontis schall* was bycatch mostly due low commercial value (89%) and potential injury to fishers (11%). Likewise, *Citharinus citharus* and *Alestes baremoze* was regarded as bycatch due to lack of ready market while *Hydrocynus forskalii* and *Lates niloticus* was bycatch because of low commercial value and being not in the home range respectively, as it was regarded as a deep-water fish species by fishermen. *Labeo horie* was regarded as bycatch mainly because of low commercial value (55%), lack of ready market (37%) and presence of many bones in its flesh (8%). *Chrysichthys turkana* was regarded as bycatch by gill net fishers because of rarity in Ferguson's Gulf.

In purse seine gears, *Hydrocynus forskalii* was regarded as bycatch due to low commercial value (64%), lack of ready market (26%) and presence of many bones in its flesh (10%) while small body size (43%), rarity (34%), and low commercial value (23%) were the reasons for regarding *schilbe uranoscopus* was regarded as bycatch by purse seine fishers. Likewise, low commercial value accounted for 26% in *Synodontis schall*, 29% in *Bagrus bayad* and 38% in *distichodus niloticus.* Other reasons included rarity (5%) and potential injury to the fishers (59%) for *Synodontis schall* and lack of ready market accounting for 71% of *Bagrus bayad* and 62% in *Distichodus niloticus.* Moreover, *Chrysichthys turkana* was regarded as bycatch due to potential injury to the fishers (34%), rarity (22%) and lack of market (44%).

Likewise, in beach seine lack of ready market greatly determined bycatch, accounting for 62% in *Labeo horie*, 51% in *Citharinus citharus*, 57% in *Clarias gariepinus*, 45% in *Hydrocynus forskalii*, 36% in *Chrysichthys turkana*, and 68% in *Schilbe uranoscopus*. Other determinats included feminity (38%) in *Labeo horie*, not in the home range (43%) for *Clarias gariepinus*, potential injury to fishers accounting for 14% in *Hydrocynus forskalii* and 74% in *Chrysichthys turkana*. Furthermore, low commercial value accounted for 49% in *Citharinus citharinus*, 41% in *Hydrocynus forskalii*, and 32% in *Schilbe uranoscopus*. Lack of ready market (74%) and low commercial value (26%) greatly determined *Distichodus niloticus* as bycatch by beach seine fishers. The poisonous nature of *Tetraodon lineatus* accounted for 100% of bycatch in beach seine gears.

This study revealed that commercial value of a fish species and existence of market greatly determined the bycatch in the artisanal fisheries of the Ferguson's Gulf. In Lake Turkana, Kolding (1989) observed *Oreochromis Niloticus* as the main target species because of its high commercialization. However, other fish species such *Hydrocynus forskalii, Alestes baremoze, Distichodus niloticus* and *Synodontis schall* are potential but not yet commercialized species and therefore not mainly targeted in the Lake Turkana artisanal fishery. This was supported by FAO (2001) that *Oreochromis niloticus, Labeo horie, Alestes baremoze,* and *Hydrocynus forskhalii* are fish species that are of main interest to subsistence and commercial artisanal operators. As pointed out by NOAA (2015), bycatch could impact the larger ecosystem if it occurs at unsustainable levels and bycatch mortality may also impact future use of fishery resources and therefore a serious source of concern in Ferguson's Gulf.

4.4.2 Fish Discard in Fishing Gears

Significant differences in biomass of discard was recorded in beach seine, purse seine and gill net gears (One-way ANOVA, $F_{(2,159)}$ = 233.062, p =0.0001). DMRT further established significant differences in mean discard of beach seine gear (732.3±334.8 g) from purse seine gear (2,301.7±574.3 g) but not different from gill net gear (624.7±413 g). The highest mean discard biomass was recorded in purse seine gears while the lowest was recorded in gill net gears (Table 4.10).

Table 4.10: Mean biomass of fish discarded from artisanal fishing gears in Ferguson's Gulf

Fishing gears	**Discard (g) (Mean±SD)**
Gill net	624.7 ± 413^{A}
Purse seine	$2,301.7 \pm 574.3^{B}$
Beach seine	732.3 ± 334.8^{A}

Means with different superscripts in the same column are significantly different at α=0.05 (Means separated by DMRT).

The data in Table 4.11 below shows that, Purse seine gear recorded the highest proportion (205,680g, 68%) of discard by biomass while beach seines and gill nets recorded (34,748g, 20%) and (203,340g, 12%) respectively.

Table 4.11: Fish discard by artisanal fishing gears used in Ferguson's Gulf

Discard (g) per artisanal fishing gears				
Family/Species	**Gill nets**	**Purse seines**	**Beach seines**	**Total biomass**
Cichlidae				
Oreochromis niloticus	200,000	201,600	31,600	433,200
Tilapia zillii	-	200	-	200
Sarotherodon galilaeaus	-	-	-	-
Alestidae				
Hydrocynus forskalii	-	1,100	-	1,100
Alestes baremoze	-	-		-
Cyprinidae				
Labeo horie	-	1,300	2,500	3,800
Mochokidae	-			
Synodontis schall	2,000	1,100	-	3,100
Bagridae				
Bagrus bayad	400	-	-	400
Citharinidae				
Citharinus citharus	-	-	-	-
Claroteidae				
Chrysichthys turkana	-	-	-	-
Clariidae				
Clarias gariepinus	-	-	-	-
Schilbeidae				
Schilbe uranoscopus	140	380	-	520
Latidae				
Lates niloticus	800	-	-	800
Tetraodontidae				
Tetraodon lineatus	-	-	648	648
Total Biomass	203,340	205,680	34,748	443,768

The difference in amount of discard by beach seine, purse seine and gill net gears could be attributed to the fact that fishing gears were not perfectly selective or because there was pressure on fishermen to catch more of the target species than they could market. The high amount of discard by purse seine gears was due to small mesh sizes and high fish biomass while low amount of discard by gill net gears was mainly attributed to large mesh sizes and low fish biomass. This findings agreed with Ocean Health Index (2012) and Grati, Fabi and Scarcella

(2004) that reported high discarding rates in purse seine gears and low discarding rates in gill net gears of Adriatic Sea.

As shown in Table 4.11, the bulk of discard by biomass in all the fishing gears consisted of *Oreochromis niloticus*. This was attributed to the dominance of *Oreochromis niloticus* interms of biomass and small mesh sizes in purse seine and beach seine gears consistent with Kolding (1989) that reported dominance of *Oreochromis niloticus* among the fish landed by fishing gears in Ferguson's Gulf. This finding was consistent with Chen, Almatar, Alsaffar and Yousef (2013) that reported extremely high percentage of discard for the abundant fish species in Kuwait's Fishery. *Lates niloticus*, *Bagrus bayad*, *Synodontis schall*, *Schilbe uranoscopus*, *Hydrocynus forskhalii*, *Tilapia zillii*, *Labeo horie* and *Tetraodon lineatus* formed the least proportion of discard due to low relative biomass and dominance by *Oreochromis niloticus*. The discarding of *Oreochromis niloticus* in all gears was mainly due to small size of the fish species for sale and consumption. Overall, the capture and consequent discard of small sized fishes of different species by beach seine, purse seine and gill net fishing gears stemmed primarily from the violation of minimum size regulations and frequent use of mesh sizes of 2" in Ferguson's Gulf of Lake Turkana.

4.4.2.1 Composition of Bycatch from Fishing Gears

In gill net gears the bulk (99%) of fish discard consisted of Cichlidae (consisting of *Oreochromis niloticus*) (see Table 4.12 above) while Latidae (consisting of *Lates niloticus)* (0.5%), Bagridae (consisting of *Bagrus bayad*) (0.2%), Mochokidae (consisting of *Synodontis schall*) (0.2%) and Schilbeidae (consisting of *Schilbe uranoscopus*) (0.1%) formed the remaining 1%. Likewise, Cichlidae (consisting of *Oreochromis niloticus* and *Tilapia zillii*) also formed the largest (90.5%) amount of the discard by biomass in purse seine gears (see Table 4.11 above). Other Taxa included Schilbeidae (consisting of *Schilbe uranoscopus*) (5%), Alestidae (consisting of *Hydrocynus forskalii*) (3.2%), Cyprinidae (consisting of *Labeo horie*) (1.3%). Fish discard in beach seine gears (See Table 4.11) also showed a similar trend consisting mostly of Taxa Cichlidae (*Oreochromis niloticus*) (90.9%), Cyprinidae (*Labeo horie*) (7.2%) and Tetraodontidae (*Tetraodon lineatus*) (1.9%).

Overall, the Taxa Cichlidae (consisting of *Oreochromis niloticus* and *Tilapia zillii*) formed 97.7% of the total discard by biomass while Schilbedae (consisting of *Schilbe uranoscopus*), Alestidae (consisting of *Hydrocynus forskalii*), Latidae (consisting of *Lates niloticus*), Mochokidae consisting (consisting of *Synodontis schall*) and Cyprinidae (consisting of *Labeo horie*) formed the remaining 2.3%. The total discard by fish species in Ferguson's Gulf was reduced by Log10 and presented in Figure 4.16 below.

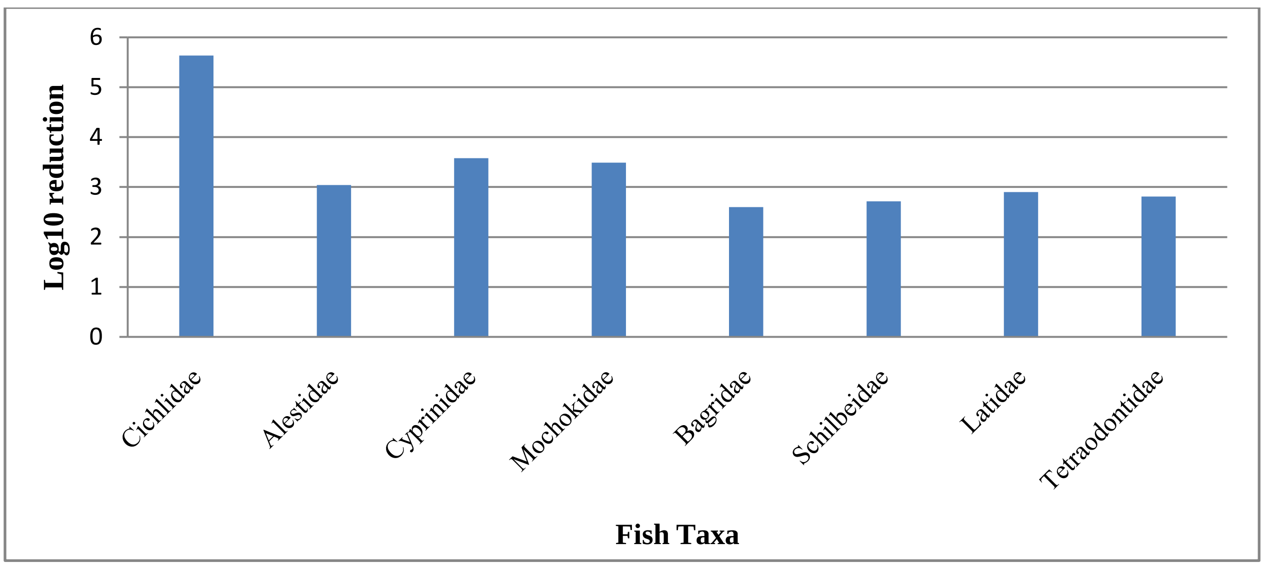

Figure 4.16: Fish biomass in the log reduction of grams of fish discarded from artisanal fishing gears Ferguson's Gulf. The Taxa Cichlidae (433,400g), Alestidae (1,100g), Cyprinidae (3,800g), Mochokidae (3,100g), Bagridae (400g), Schilbeidae (520g), Latidae (800g) and Tetraodontidae (648g) formed the total fish discarded from Ferguson's Gulf.

4.4.2.2 Determinants of Fish Discard from Artisanal Fishing Gears

Majority (83.6%) of the Cichlid, *Oreochromis niloticus* discarded in gill net gears was attributed to small size of fish captured, while spoilage, and damage by gear accounted for 12.5% and 3.6% respectively. The small size of fish greatly accounted for discard of *Schilbe uranoscopus* and *Synodontis schall* while spoilage was accounted for discard of *Bagrus bayad* and *Lates niloticus* in gill net gears. *Oreochromis niloticus* and *Labeo horie* were discarded due to their small size while *Tilapia zillii* was discarded due to lack of market. However, Lack of market, low market value and lack of ready market in that order, accounted for discarding of *Hydrocynus forskalii*, *Synodontis schall* and *Schilbe uranoscopus* in purse seine gears. In beach seine gears, *Oreochromis niloticus* was discarded mainly due to small size of the fish for sale and consumption, and *Labeo horie* was discarded as it was regarded as feminine (18%) and also had low commercial value (82%) while *Tetraodon lineatus* was discarded because of its poisonous nature.

The discarding of *Schilbe uranoscopus* in gill net gears was attributed to the fact that it is a small species with a amaximum recorded fork length of only 34 cm, and the long time of 934.44±635 minutes taken to haul the gill net catch could be responsible for spoilage of fish species caught. Kolding (1989) also observed that *Schilbe uranoscopus* was not commercially important in Lake Turkana compared to other fish species, thus mostly discarded in Lake Turkana fishery. Among the commercial species such as *Oreochromis niloticus* and *Lates niloticus*, a size-dependent discarding occurred in gill net, purse seine and beach seine gears similar to the findings of Grati et al. (2004) that reported discard of small-sized commercial species by gill net fishery in the Adriatic Sea. Pavlenko (2005) also reported that the amount of discards in gill net gears depends on the market situation, the fish condition and size concurrent with the findings of this study.

According to this study, the reasons for discarding of *Tilapia zillii*, *Hydrocynus forskalii*, *Synodontis schall* and *Schilbe uranoscopus* from purse seine gears were consistent with Kolding (1989) that reported non-commercialization of these species. It is noteworthy that *Tetraodon lineatus* contains tetrodotoxin, a neurotoxin, presenting a higher risk of severe intoxication in humans concurrent with Deshpande (2002) that reported intoxication of humans through consumption of *Tetraodon lineatus*. Although the fishers could not be ingesting the tetrodotoxin, Patocka and Stredav (2002) noted that it can enter the body through abraded skin, thus raising serious health concerns among the fishers of Ferguson's Gulf. The range of social, economic, cultural and political reasons for discarding of fish species in purse seine, gill net and beach seine gears were similar to those identified by FAO (1996) and Clucas (1997) as responsible for fish species discarded in the artisanal fishery of the world. However, discarding of fish species in compliance to fisheries regulations on the size and type of fish species to be landed was not encountered by this study implying absence of bycatch and discard regulations in Ferguson's Gulf.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

The summary, conclusions and recommendations drawn from the present study are indicated according to the specific objectives of the study as shown below:

4.1 Summary

Beach seine gears recorded highest number of nets per fishing gear while gill net gears recorded the lowest number of nets. Majority of gill net, purse seine and beach seine gears consisted of 2 nets, 4 nets and 18 nets in that order. Gill net gears had larger mesh sizes than purse seine and beach seine gears. The 3" mesh size nets were dominant in gill net and purse seine gears while 2.5" mesh size nets were dominant in beach seine gears. Furthermore, the highest number of hauls was recorded in purse seine gears while the lowest was recorded in gill net gears. In addition, gill net gears recorded longest time per haul than purse seine and beach seine gears with the shortest time per haul recorded in purse seine gears.

In the physical and chemical limnology, dissolved oxygen, salinity, conductivity, pH, total dissolved solids, temperature and Water transparency differed significantly in all fishing sites. The highest dissolved oxygen concentration was recorded in purse seining sites while the lowest level was recorded at reference site at the mouth of Ferguson's Gulf. The highest salinity and conductivity were recorded in gill netting gear sites while the lowest salinity and conductivity were recorded at reference sites. pH was higher in reference site than in purse seining and gill netting sites while the lowest value was recorded in beach seining sites. Furthermore, the highest total dissolved solids were recorded in gill netting sites than in purse seining and beach seining sites while the lowest total dissolved solids were recorded in reference site. Water transparency was lowest in gill netting sites than in purse seining and beach seining sites while the highest was recorded in reference sites.

The fish biomass differed significantly in all fishing gears with purse seine gears recording the highest proportion while gill nets contributed the least. *Oreochromis niloticus* dominated the biomass in all the fishing gears. The number of fish species was higher in beach seine gears compared to purse seine and gill nets gears. Likewise beach seine gears had a higher Shannon-Weiner diversity index value than purse seine and gill net gears; implying that beach seine gears caught more fish species than gill net and purse seine gears.

The highest proportion of bycatch was recorded in purse seine gears and the least in gill nets. *Oreochromis niloticus* was the target species across gill net, purse seine and beach seine gears. The presence of the ready market was the leading reason for targeting *Oreochromis niloticus* by beach seine, purse seine and gill net fishers in Ferguson's Gulf. Most bycatch in gill net, purse seine and beach seine gears was composed of taxa Schilbedae, Alestidae and Cyprinidae in that order.

Purse seine gears recorded the highest proportion of discard while gill net recorded the least bycatch. In gill net, purse seine and beach seine gears, the bulk of discard consisted of *Oreochromis niloticus* due to small size for consumption and sale. Overall, the taxa Cichlidae (consisting of *Oreochromis niloticus* and *Tilapia zillii* species) formed majority of the total discard from all the fishing gears.

4.2 Conclusion

1. Beach seine and purse seine gears consisted of small mesh sizes nets while gill net gears consisted of large mesh sizes nets. The highest number of hauls was recorded in purse seine gears which took the shortest time per haul and could lead to deterioration of water physico-chemical parameters and change in fish community structure of Ferguson's Gulf at higher fishing effort.
2. High TDS, temperature, salinity and conductivity was recorded in gill netting sites while the lowest values were recorded in reference sites. High pH, DO concentration and low water transparency was recorded in beach seining, purse seining and gill netting sites respectively. The use of purse seine gears contributed to increased dissolved oxygen compared to beach seine and gill net gears. Except for salinity and conductivity, all the physico-chemical parameters were within the optimal range for survival of fish species in Ferguson's Gulf.
3. Fish biomass was mainly related to fishing gear type, with purse seine and beach seine gears recording high biomass per haul. In addition, beach seine gears recorded higher fish species diversity compared to gill net and purse seine gears. *Oreochromis niloticus* was the dominant species landed and formed the bulk of biomass in all fishing gears.
4. The highest proportion of bycatch was recorded in purse seine gears and the least in gill nets. Size selective discarding of *Oreochromis niloticus* occurred in all the fishing gears mainly while at the same time considered as target species across gill net, purse seine and beach seine gears. Most bycatch in gill net, purse seine and beach seine gears was composed of taxa Schilbedae, Alestidae and Cyprinidae in that order. The highest quantity of discard was recorded in purse seine gears while gill net recorded the least.

4.3 Recommendations

1. The number of fishing hauls, nets and biomass of fish landed by purse seine gears should be limited so as to avoid possible overfishing in Ferguson's Gulf.
2. The continued use of beach seine gear, in Ferguson's Gulf, despite the ban by Fisheries Management and Development Act of 2016, points to lack of compliance to this legislation. The fisheries stakeholders should ensure that beach seine gear is not used by artisanal fishing gears in Ferguson's Gulf so as to sustainably manage the fish resources.
3. Modification of artisanal fishing gears done so as to increase selectivity and reduce the bycatch levels.
4. The utilisation of fish otherwise discarded should be done so as improve household food security situation in the dry and drought prone Ferguson's Gulf area.

4.4 Areas for Further Research

1. A study should be conducted to determine the number of nets, mesh sizes and hauls in gill net, beach seine, and purse seine gears that can ensure maximum sustainable fish yield in Ferguson's Gulf.
2. Research is needed to determine the influence of water physico-chemical parameters on fish movement, biomass and distribution.
3. A study should be done to determine the nature of the sediments suspended in the water column due to action of beach seine, purse seine and gill net gears of Ferguson's Gulf.
4. Research should be done to estimate the income losses due to discards in the artisanal fisheries of Ferguson's Gulf.

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APPENDICES

Appendix I: Water Physico-Chemical parameters data Sheet

Month	Fishing Gear	Sample	Replicates	pH	Salinity (g/Kg)	Conducti-vity (μSm^{-1})	Water transp-arency (cm)	TDS (mg/l)	DO (mg/l)	Depth (m)	Water Temp. (^0C)

Appendix II: Fishing gears Characteristics, Fishing effort, Biomass, Diversity, Bycatch and Discard data Sheet

Characteristics and fishing effort of fishing gears					**Biomass**		**Target species**			**Non-target (Bycatch) species**			**Discard**		
Fishing Gear	Number of nets	Most used Mesh size	Time per Haul	Hauls per day	Fish species landed	Number /Biomass (g)	Species	Number/ Biomass (g)	Main reason	Species	Number/ Biomass (g)	Main reason	Species	Number /biomass (g)	Main reason

Appendix III: Water physico-chemical parameters sampling sites location and description

Site	Longitude	Latitude	Description	Name
1	035º92'51.7" E	03º49'58.6" N	• Open lake with no presence of vegetation. • The shore was vegetated by littoral macrophytes including *Prosopis juliflora*, • A depth of 82 cm.	Off Namukuse beach
2	035º91'21.9" E	03º50'34.2" N	• Open lake with no presence of vegetation. • The shore was vegetated by littoral macrophytes including *Prosopis juliflora*. • A depth of 62cm	Open lake off Namakat beach
3	035º90'27.2" E	03º49'37.5" N	• Open lake with no presence of vegetation. • The shore was vegetated by littoral macrophytes including *Prosopis juliflora*. • A depth of 111cm	Off Namakat beach
4	035º91'53.1" E	03º51'85.8" N	• A depth of 218cm • Open water with no vegetation. • The shore was vegetated shore with Hippo grass. littoral macrophytes	Jetty South
5	035º91'43.6" E	03º53'03.3" N	• A depth of 143cm. • Open water with no vegetation. • Sandy shore with no vegetation cover.	Mid-Gulf opposite Jetty
6	035º93'05.6" E	03º51'21.4" N	• Depth of 159 cm. • Open water with no vegetation. • Sandy shore with no vegetation	Lokwarin
7	035º90'03.6" E	03º52'81.9" N	• Open water with no vegetation • Sandy shore with no vegetation • A depth of 162 cm.	Off Jaff city
8	035º91'81.1" E	03º54'90.8" N	• Sandy shore with no vegetation and fringed by human settlements. • Open water with no vegetation • A depth of 213cm	Off Namakoo beach 1
9	035º91'35.8" E	03º54'92.8" N	• Open water with no vegetation • Sandy shore with no vegetation and fringed by human settlements. • A depth of 189.5 cm	Off Namakoo beach 2
10	035º90'94.2" E	03º53'50.8" N	• Open water with no vegetation • Mid of gulf mouth. • A depth of 246.5 cm	Gulf mouth A
11	035º90'86.1" E	03º55'13.9" N	• Open water with no vegetation • Mid of gulf mouth. • A depth of 250 cm.	Gulf mouth B
12	035º90'71.9" E	03º55'07.2" N	• Open water with no vegetation. • Mid of gulf mouth. • A depth of 255 cm.	Gulf mouth C

Appendix IV: Fish discarded from gill net gears in Ferguson's Gulf

Appendix V: Fish discarded from purse seine gears in Ferguson's Gulf

Appendix VI: Fish discarded from beach seine gears in Ferguson's Gulf

Appendix VII: *Tetraodon lineatus* discarded at Ferguson's Gulf from beach seine gears

Appendix VIII: A fisherman agitating water using his feet to drive fish into the set purse seine gear in Ferguson's Gulf

Appendix IX: Vegetation growing at preferred gill net fishing sites in Ferguson's Gulf

Appendix X: Surface water standards (Kenya Bureau of Standards)

Parameters	**Highest desirable level**	**Maximum level permissible**	**KEBS**
Total solids	500 mgl^{-1}	1500 mgl^{-1}	1000 mgl^{-1}
Colour	5 CU	50 CU	15 CU
Taste	Unobjectable	-	Unobjectable
Odour	Unobjectable	-	Unobjectable
Turbidity	5 NTU	25 NTU	5 NTU
Chloride	200 mgl^{-1}	600 mgl^{-1}	250 mgl^{-1}
Iron	0.1 mgl^{-1}	1 mgl^{-1}	0.3 mgl^{-1}
Manganese	0.05 mgl^{-1}	0.5 mgl^{-1}	0.1 mgl^{-1}
Copper	0.05 mgl^{-1}	1.5 mgl^{-1}	1.0 mgl^{-1}
Zinc	5 mgl^{-1}	15 mgl^{-1}	5 mgl^{-1}
Calcium	75 mgl^{-1}	200 mgl^{-1}	-
Magnesium	30 mgl^{-1}	150 mgl^{-1}	NIL
Sulphate	200 mgl^{-1}	400 mgl^{-1}	400 mgl^{-1}
Total hardness	100 mgl^{-1}	500 mgl^{-1}	500 mgl^{-1}
Nitrates	45 mgl^{-1}	-	10 mgl^{-1}
Phenol	0.001 mgl^{-1}	0.002 mgl^{-1}	-
Fluoride	0.6-0.8 mgl^{-1}	-	1.5 mgl^{-1}
pH	7-8	9	6.5-8.5
Arsenic	0.05 mgl^{-1}		-
Cadmium	0.001 mgl^{-1}		-
Chromium	0.005 mgl^{-1}		-
Cyanide	0.005 mgl^{-1}		-
Lead	0.1 mgl^{-1}		-
Mercury	0.001 mgl^{-1}		-
Selenium	0.01 mgl^{-1}		-
Sodium	-		200 mgl^{-1}
Ammonia	-		0.5 mgl^{-1}
Chlorine	-		0.2-0.05 mgl^{-1}
Benzene	-		10 mgl^{-1}
1,2-dichloromethane	-		10 mgl^{-1}
1,1-dichloroethymine	-		-
Suspended solids	-		NIL

Source: Ministry of water and irrigation, Water testing Lab Manual

Appendix XI: Drinking water standards (World Health Organization)

Parameter	**WHO limit**
pH	6.5-8.5
Temperature	<35^{0}C
Salinity	600mg/l
Dissolved Oxygen	8-10mg/l
TDS	500mg/l
Electrical conductivity	500µS/cm
Arsenic	10 µg/l
Barium	10 µg/l
Benzene	10 µg/l
Boron	2400 µg/l
Chromium	50 µg/l
Fluoride	1500 µg/l
Selenium	40 µg/l
Uranium	30 µg/l
Carbon tetrachloride	4 µg/l
1,2-Dichlorobenzene	1000 µg/l
1,4-Dichlorobenzene	300 µg/l
1,2-Dichloroethene	50 µg/l
1,2-Dichloroethane	30 µg/l
Dichloromethane	20 µg/l
Di(2-ethylhexyl)phthalate	8 µg/l
1,4-Dioxane	50 µg/l
Edetic acid	600 µg/l
Hexachlorobutadiene	0.6 µg/l
Nitrilotriacetic acid	200 µg/l
Pentachlorophenol	9 µg/l
Styrene	20 µg/l
Tetrachloroethene	40 µg/l
Toluene	700 µg/l
Trichloroethene	20 µg/l
Xylenes	500 µg/l

Source: WHO (2004)

Appendix XII: The Range and Mean of water physico-chemical parameters of Lake Turkana

Parameter	**Range**	**Mean**
pH	7.8 – 9.8	8.5
Turbidity (NTU)	0.1 – 414.1	38.3
Silicates (mg/l)	9.8 – 41.8	24.0
Total soluble solids (TSS, mg/l)	16 – 6022	3095
Total dissolved solids (TDS, mg/l)	152 – 2976	1156
Chlorophyll-*a* (mg/l)	3.0 – 681.5	45.1
Water transparency (m)	0.5 - 2.55	1.09
Conductivity (µs/cm)	1,079 - 7,297	3,450
Dissolved Oxygen (DO, mg/l)	2.59 - 8.46	6.3
Temperature (^{o}C)	27 - 32	29

Source: KMFRI (2007)

Appendix XIII (a): Annotated checklist of Lake Turkana Fishes

Family	Species	Supporting Literature
Polypteridae-Bichirs	*Polypterus bichir bichir* (Geoffroy Saint Hilaire, 1802) Nile bichir	Hopson and Hopson, 1982; Boulenger, 1909
	Polypterus senegalus senegalus (Cuvier, 1829) Senegal bichir	Hopson and Hopson, 1982; Boulenger, 1909
Osteoglosidae-Bonnytongue	*Heterotis niloticus* (Cuvier, 1829) African bonytongue	Hopson and Hopson, 1982; Boulenger, 1909
Mormyridae-Snout fishes	*Hyperopisus bebe* (Lacepede, 1803) Ngai	Hopson and Hopson, 1982; Boulenger, 1909
	Mormyrus Kannume (Forsskål, 1775) Elephant-snout fish	Hopson and Hopson, 1982; Boulenger, 1909
Gymnarchidae-No suggested common name	*Gymnarchus niloticus* (Cuvier, 1826) aba aba	Hopson and Hopson, 1982; Boulenger, 1909
Cyprinidae-Barbs, Minnows and Labeos	*Barbus bynni* (Forsskål, 1775) Nile barb	Hopson and Hopson, 1982; Boulenger, 1909
	Barbus neumayeri (Fischer, 1984) Neumayer's barb	Fischer, 1984
	Barbus stigmatopygus (Boulenger, 1903) Mid spot-barb	Hopson and Hopson, 1982; Boulenger, 1911
	Barbus turkanae (Hopson and Hopson in Hopson, 1982) Turkana barb	Hopson and Hopson, 1982
	Chelaethiops biblie (De Joannis, 1835) Turkana sardine	Hopson and Hopson, 1982
	Labeo cylindricus (Peters, 1852) Redeye labeo	Hopson and Hopson, 1982
	Neobola bottegoi (Vinciguerra, 1895) Bottego's minnow	Howes, 1984
	Leptocypris niloticus (De Joannis, 1835) Nile minnow	Worthington and Ricardo,1936; Hopson and Hopson, 1982
	Labeo horie (Heckell, 1846) Assuan labeo	Worthington and Ricardo,1936; Hopson and Hopson, 1982
	Labeo niloticus (Forsskål, 1775) Nile labeo	Hopson and Hopson, 1982
	Neobola Stellae (Worthington, 1932) Turkana minnow	Hopson and Hopson, 1982

Source: Okeyo (2004)

Appendix XIII (b): Annotated checklist of Lake Turkana Fishes

Family	Species	Supporting literature
Distichodidae- **Distichodines**	*Distichodus niloticus* (Linnaeus, 1762) Nile distichodus	Günther, 1986; Hopson and Hopson, 1982
Citharinidae- **Citharines**	*Citharinus citharus* (Worthington, 1932) Turkana citharine	Hopson and Hopson, 1982
Characidae- **Characins**	*Alestes baremoze* (De Joannis, 1835) Egyptian robber	Boulenger, 1909, 1916; Hopson and Hopson, 1982
	Alestes dentex (Linnaeus, 1758) Nile robber	Boulenger, 1909; Hopson and Hopson, 1982
	Brycinus ferox (Hopson and Hopson in Hopson, 1982) Large-toothed Turkana robber	Hopson and Hopson, 1982
	Brycinus macrolepidotus (Valenciennes in Cuvier and Valenciennes, 1849) Large-scaled robber	Hopson and Hopson, 1982
	Brycinus minutus (Hopson and Hopson in Hopson, 1982) Dwarf-Turkana robber	Hopson and Hopson in Hopson, 1982
	Brycinus nurse (Rūppel, 1832) Nurse tetra	Hopson and Hopson in Hopson, 1982
	Hydrocynus forskalii (Cuvier, 1819) Elongate tigerfish	Boulenger, 1909; Hopson and Hopson, 1982
	Hydrocynus vittalus (Castelnau, 1861) Tigerfish	Boulenger, 1909; Hopson and Hopson, 1982
	Micralestes elongatus (Daget, 1957) Elongated robber	Hopson and Hopson, 1982
Bagridae- **Bagrid catfishes**	*Bagrus bayad* (Forsskål, 1775) Black Nile catfish	Worthington and Ricardo, 1936; Hopson and Hopson, 1982
	Bagrus docmak (Forsskål, 1775) Sudan catfish	Hopson and Hopson, 1982
	Auchenoglanis occidentalis (Valenciennes in Cuvier and Valenciennes, 1849) Giraffe catfish	Vinciguerra, 1898; Boulenger, 1911; Hopson and Hopson, 1982
Claroteidae- **Calaritid catfishes**	*Chrysichthys auratus* (Geoffroy Saint Hilaire, 1802) Golden Nile catfish ***renamed** *Chrysicthys turkana* **by Hardman (2008) after discovered as a new species of Chrysichthys endemic to Lake Turkana.***	Hopson and Hopson, 1982

Source: Okeyo (2004)

Appendix XIII (c): Annotated checklist of Lake Turkana Fishes

Family	Species	Supporting literature
Schilbeidae- Butter catfishes	*Schilbe uranoscopus* (Rūppel, 1832) Egyptian butter catfish	Worthington and Ricardo, 1936; Hopson and Hopson, 1982
Amphiliidae- Mountain catfishes	*Andersonia leptura* (Boulenger, 1900) Whiptailed Nile catfish	Hopson and Hopson, 1982
Clariidae -catfishes	*Clarias gariepinus* (Burchell, 1822) Common catfish	Worthington and Ricardo, 1936; Hopson and Hopson, 1982
	Heterobranchus longifinis (Valenciennes in Cuvier and Valenciennes, 1849) vundu	Hopson and Hopson, 1982
Melapteruridae – Electric catfishes	*Melapterurus electricus* (Gmelin, 1789) Electric catfish	Pellegrin, 1935; Hopson and Hopson, 1982; Golubstsov and Berendzen, 1999
Mochokidae- Squeakers and suckermouths	*Mochokus niloticus* (De Joannis, 1835) Dwarf Nile catfish	Vinciguerra, 1898; Boulenger, 1911; Hopson and Hopson, 1982
	Synodontis frontotus (Vaillant, 1895) Sudan Squeaker	Vinciguerra, 1898; Hopson and Hopson, 1982
	Synodontis schall (Schneider, 1801) Nile squeaker	Günther, 1986; Hopson and Hopson, 1982
Aplocheilichthyidae - Topminnows and Lampeyes	*Aploicheilichthys rudolfianus* (Worthington, 1932) Turkana Lampeye	Hopson and Hopson, 1982
	Aploicheilichthys Jeaneli (Pellegrin, 1935) Omo lampeye	Hopson and Hopson, 1982
Centropomidae- Nile perch and related forms	*Lates longispinis* (Worthington, 1932) Turkana perch	Hopson and Hopson, 1982
	Lates niloticus (Linnaeus, 1758) Nile perch	Worthington, 1932; Hopson and Hopson, 1982
Cichlidae- Cichlids	*Haplochromis macconneli* (Greenwood, 1974) Mc Connel's haplo	Hopson and Hopson, 1982
	Haplochromis rudolfianus (Trewavas, 1933) Rudolf haplo	Hopson and Hopson, 1982
	Haplochromis turkanae (Greenwood, 1974) Lake Turkana mouthbrooder	Hopson and Hopson, 1982

Source: Okeyo (2004)

Appendix XIII (d): Annotated checklist of Lake Turkana Fishes

Family	Species	Supporting literature
Cichlidae-Cichlids	*Oreochromis niloticus* (Trewavas, 1933) Turkana Tilapia	Hopson and Hopson, 1982
	Sarotherodon galilaeaus (Linnaeus, 1758) Galilaea Tilapia	Worthington and Ricardo, 1936; Hopson and Hopson, 1982
	Tilapia zillii (Gervais, 1758) Zill's Tilapia	Boulenger, 1915; Hopson and Hopson, 1982
	Hemichromis letourneuxi (Sauvage, 1888) Nile jewel cichlid	Hopson and Hopson, 1982
Tetraodontidae-Puffers	*Tetraodon lineatus* (Linnaeus, 1758) Nile puffer	Sterba, 1959;Hopson and Hopson, 1982

Source: Okeyo (2004)