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ASSESSMENT OF DAGAA (*RASTRINEOBOLA ARGENTEA*) STOCKS AND EFFECTS OF ENVIRONMENT IN LAKE VICTORIA, EAST AFRICA

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ABSTRACT

The abundance of dagaa (*Rastrineobola argentea*) in Lake Victoria has been reported to fluctuate over the long period. Several studies have accounted for this fluctuation being caused by predation, natural mortality and fishing pressure. This study examines the possible influence of climatic (rainfall, temperature and wind stress) and physicochemical (chlorophyll a and secchi depth) variables on dagaa abundance in Lake Victoria. Data for climatic, physicochemical and abundance recorded 1999 – 2014 were correlated and their trends examined. Analysis was done separately in three depth strata, deep (>40m), coastal (20 – 40m), inshore (< 20m), and two gulfs, Emin Pasha and Speke Gulfs. Population growth parameters of the species were also estimated in FiSAT II. The highest concentration of dagaa were found in the inshore shallow waters ≤40m, excluding the gulfs. Wind stress has significantly increased in Lake Victoria and was found to be the major driver that influenced the distribution of dagaa. In addition, the offshore waters are increasingly becoming important for dagaa. This could also be related to increase of wind stress in Lake Victoria that has increased the suitable habitat for dagaa. However, a limited correlation was found between other climatic and environmental factors with dagaa abundance, possibly due to the large volume of the lake with long flushing time, hence it is difficult to detect some effects with the short time series data available. The highest biomass densities of dagaa were found during the rainy season, which also coincided with the highest landing records. The estimated growth parameters (K, L_∞) showed a continued decreasing trend towards smaller size. A big difference in the values of K and L_∞ were also observed among the different localities of study, possibly due to the differences in exploitation rates and climatic conditions exhibited by these gulfs. Based on the yield per recruit plots, dagaa is not over exploited but matured at a smaller size compared to the previous studies. Dagaa being a short lived species, its commercial catch is possibly based on response to both environmental changes and exploitation rate. Although this study found a limited relationship with most of the climatic and physicochemical factors with dagaa, there is possibility that they play a great role in the complex ecosystem of Lake Victoria, hence important factors to be considered when planning management policies.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Lake Victoria is situated in equatorial East Africa between 0°20′N and 3°00′S latitude, and 31°39′ – 34°53′ E longitude (Figure 1). It is the second largest freshwater lake in the world after Lake Superior of North America and the largest in Africa with 2760 km^3 water volume. It covers a surface area of 68,800 km^2 and is shared by three countries, Kenya (6% of area), Uganda (43%) and Tanzania (51%). It has a catchment area of ≈195 000 km^2 that also includes Rwanda and Burundi. The lake is relatively shallow, with a maximum depth of 79 m, mean depth of 40 m and one quarter of the lake surface area is estimated to have a depth less than 20 m (Njiru *et al.*, 2005).

Lake Victoria climatic seasons are based on yearly monsoon cycles (Cornelissen *et al.*, 2015). The northern part of the lake, exhibits two main rainy seasons, March – May and August – November, and two dry seasons that occur December – February and June – July (Mkumbo, 2002). The southern part of the lake exhibit one major long rainy season that occur January – May, a dry season from June – August, and a transition period with calm weather and short rains occurs September – December (Cornelissen *et al.*, 2015). In Lake Victoria winds are generally low (0-3.5m/s) due to protection of mountains and rift valley escarpments (Taabu-Munyaho, 2014). The low wind speed reduces mixing and enables formation of a gradient that causes temperature differences between the surface and bottom waters. This gradient declines at the end of the rainy season when wind speed and evaporative cooling increase, leading to mixing and oxygenation of the deeper waters. Wind speeds are highest during the dry season when southerly winds exceed of 15 m/s, causing high evaporation rate, water mixing and decrease of surface temperature (Taabu-Munyaho, 2014). The strongest stratification in Lake Victoria occurs from January – March (Cornelissen *et al*., 2015).

The fishery of Lake Victoria currently is supported by three major commercial fish species, Nile perch (*Lates niloticus*), dagaa (*Rastrineobola argentea*) and Nile tilapia (*Oreochromis niloticus*) (LVFO , 2014). Nile perch was introduced into Lake Victoria in the late 1950s, and fishery for this species developed rapidly in the 1980s (Witte, 1992). Nile perch is a top predatory and the development of the stock has led to a decline of some of the endemic fish species in Lake Victoria (Figure 2). The lake consisted of more than 500 haplochromines, of which 99% were endemic (Witte *et al.*, 2012). Nile perch was introduced in order to boost the commercial fishery of Lake Victoria by converting the trash fish of less economic importance (haplochromines) through predation to large and more valuable Nile perch (Kayanda *et al*., 2009). It was not until in the 1980s that it began to appear in substantial amounts in catches (Witte, 1992). At the same time rapid changes in the Lake Victoria ecosystem occurred. The populations of haplochromines decreased as the population size of the introduced Nile perch increased. The decline in haplochromines was associated with predation by Nile perch and strong eutrophication of the lake (Witte *et al.*, 2012). Nile tilapia is the most important tilapia, also introduced into the lake almost at the same time as Nile perch. There is evidence of Nile tilapia stock declines in some areas especially in Tanzanian side of the lake (CAS, 2015).

Dagaa, a small pelagic cyprinid is the only indigenous species that is still abundant and form an important part of the food web, preyed upon mainly by tertiary predators such as Nile perch, birds and man (Wanink, 1998). The contribution of dagaa to the fishery was not significant until in the 1980s. However, Ntara (2015) reported that in the early 1960s dagaa was caught and used as poultry feeds along the lake side at individual homes. Moreover, the riparian community started consuming dagaa towards the late 1960s and early 1970s. The recent abundance of dagaa in the lake has been associated with the decline of the predatory Nile perch, increase in fresh water shrimp (*Caridina nilotica*) which is the major diet component of Nile perch and recovery of haplochromines which were thought before to be reduced by predation pressure of Nile perch (Tumwebaze, 2007).

The Lake Victoria ecosystem has been experiencing water quality fluctuations and considerable habitat degradation due to human influence (Kairu, 2001; Gichuki, 2010). The major threats facing Lake Victoria are eutrophication, over-exploitation of fish stocks especially Nile perch and Nile tilapia, introduction of exotic species such as the water hyacinth (*Eichhornia crassipes*), increased illegalities, habitat degradation and climate change (Kashindye, 2011; IPCC, 2014; Witte *et al.*, 2012; LVFO, 2014). Clearing of vegetation for firewood, settlements and agricultural development throughout the watershed has exposed the land to erosion resulting in sedimentation in the lake. Furthermore, there has been an increase of discharge of raw wastes from urbanized areas and factories. Atmospheric wet and dry depositions remain major contributors of N and P loading into the lake (Table 1). The increase in the N and P loading has resulted in eutrophication which in turn has resulted in widespread of algal blooms (Kolding *et al.*, 2008) and rapid expansion of the water hyacinth. Bays and gulfs are highly vulnerable to this kind of pollution and because of that they exhibit low fish densities compared to offshore clearer water (Manyala, 2007; Kashindye, 2011).

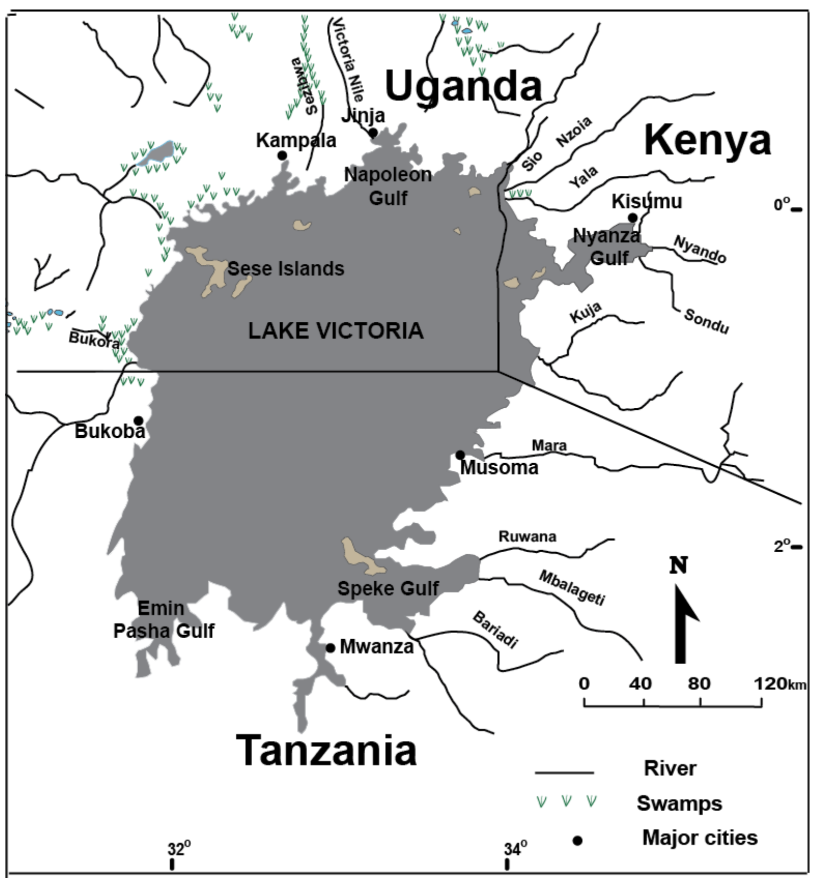

Figure 1: Map of Lake Victoria showing different places cited in the report.

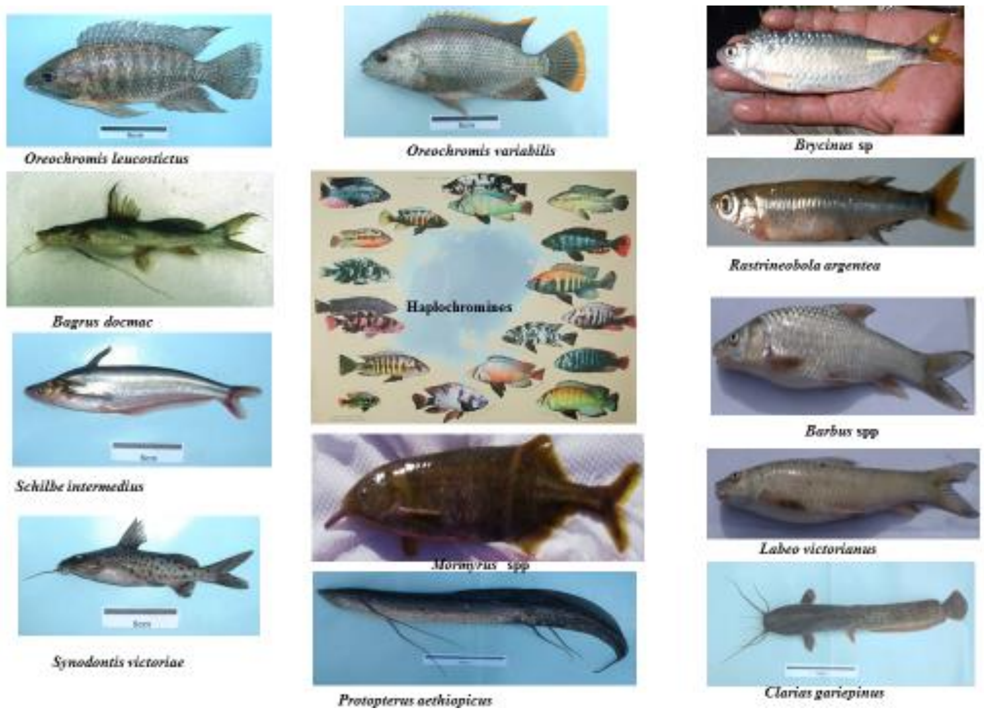

Figure 2: Some of the original fish fauna of Lake Victoria (Graham, 1929). Pictures obtained from Dr. Robert Kayanda (Tanzania Fisheries Research Institute, Centre director, Mwanza, 2015).

Table 1: Estimated nutrient loading to Lake Victoria in tones per year (Results adapted from (LVEMP., 2003)

Source of pollution	**Nitrogen loading(t/year)**	**Phosphorus loading(t/year)**
Domestic wastes	3,505 (1.68%)	1,624 (4.24%)
Industrial sources	414 (0.21%)	342 (0.89%)
River basin	49,509 (23.78%)	5,693 (14.86%)
Runoff from cultivated land	22,966 (11.03%)	2,297 (6.00%)
Runoff from non-cultivated land	29,615 (14.23%)	3,949 (10.31%)
Atmospheric wet deposition	62,601 (30.08%)	11,831 (30.89%)
Atmospheric dry deposition	39,550 (18.99%)	12,567 (32.81)
Total	208,160 (100%)	38,303 (100%)

1.1 Statement of the problem

Despite the ecological and economic importance of dagaa in the lake, little assessment attention has been given to the species (Wandera, 1995; Manyala & Ojuok, 2007; Tumwebaze, 2007), more attention is given to the valuable Nile perch. A precautionary approach was proposed by the stock assessment scientists for management of the dagaa fishery in Lake Victoria. The proposed approach was to increase fishing effort to catch the already abundant dagaa in the lake, but with close monitoring of its stock. They further proposed continued enforcement of the current legal mesh size of 8-10 mm as stipulated in the Fisheries Regulations of 2009 (LVFO, 2014). Unfortunately, the legal mesh size has poorly been enforced by all the riparian states. In addition, Uganda and Kenya still recognize 5 mm as legal mesh size and still in use. Biological data for dagaa is very scanty and rarely collected in Lake Victoria. For this reason, there is scarce information on the population dynamics of the species and how it adjusts to a changing environment (Manyala & Ojuok, 2007; Sharpe *et al.*, 2012). Since dagaa has a short life cycle, its commercial catch is largely based on the new recruitment influx of each year, this increases the chance that their growth can be influenced by response to both short and long term environmental changes. Short lived species are reported to have a rapid growth rate with high fluctuations in their abundance and distribution, largely influenced by environmental conditions (Mannini, 1992; Chifamba, 2000). Fisheries managers face many challenges in the management and prediction of future abundance of such species.

1.2 Significance of the study

Despite of environmental fluctuations in Lake Victoria, dagaa has been much more successful than other groups of fish (LVFO , 2014; Manyala & Ojuok, 2007; Tumwebaze, 2007). However, the continued environmental degradation raises concern to many fisheries stakeholders on the sustainability of this fishery. Dagaa plays an important role in the ecosystem through transferring of energy from zooplankton to top predators (Tumwebaze, 2007). Thus, any change in abundance of this species can have a significant impact on the rest of the Lake Victoria ecosystem, especially Nile perch (Pitcher *et al.*, 1996). Furthermore, the dagaa fishery employs a significant number of people who earn their daily income as fishers, traders, vendors, processors and many other related activities. In addition, it is an important source of cheap source of protein to many households in the riparian region. It is therefore of very important to shed as much light as possible on the life history of dagaa, population dynamics and how it adjust to the changing environment of Lake Victoria and provide sound management advice for the species. The findings from this work will assist fisheries managers to better understand the biology of dagaa, trends in biomass and catch for better management of the resource.

1.3 Dagaa fishery

Dagaa of Lake Victoria has become very important for the region, both in terms of total catch and contribution to the economy. Although dagaa biomass is the highest of all the species in the lake (LVFO , 2014), the species ranks the second after Nile perch in terms of economic importance. Acoustic surveys indicate that the dagaa biomass has increased substantially in recent years (Figure 3), for example there has been an increase from approximately 0.93 million tons in 2011 to 1.29 million tons in 2014 (LVFO , 2014). According to LVFO (2014), the dagaa fishery of Lake Victoria is not overexploited. Stock assessment scientists recommends a sustainable harvest for the species of up to 70% of biomass, which if followed will not compromise the ability of the stock to replenish (Kayanda, 2009).

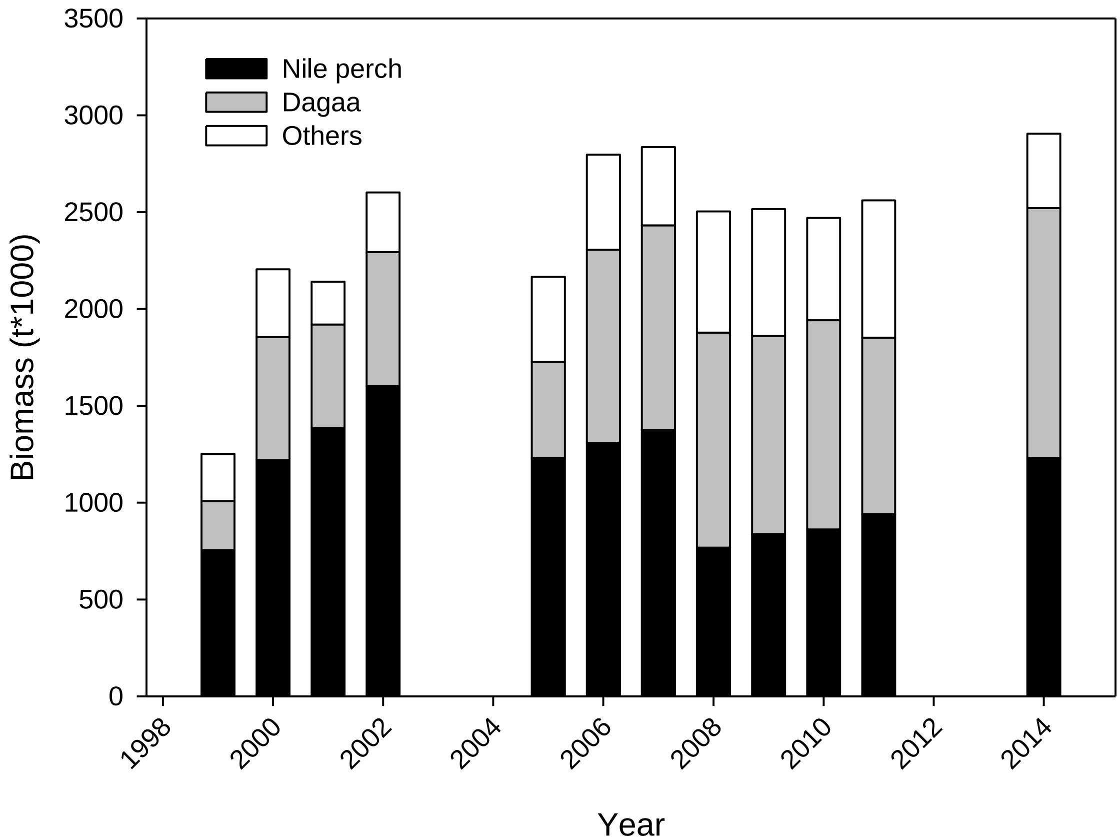

Figure 3: The Estimated biomass of Lake Victoria fish estimated in hydro acoustic surveys (figure adapted from LVFO stock assessment report 2014).

When compared to other commercial species like Nile perch, high catches of dagaa were reported in early 1980s during the Nile perch upsurge and reached its peak in 1990, from 1991 to 2005 its catch remained fairly stable, its catches peaked again from 2006 – 2014. While Nile perch reached its peak in the late 1980s and since then its catch has remained stable (Figure 4). Currently, dagaa constitutes about 60% of the total catch, while the value is only 16 %(CAS, 2014). The growth of the dagaa fishery is demonstrated by the growth of its international market centre at Kirumba and many other collection centres located in other districts in Tanzania (Ntara, 2015). Furthermore, the dagaa fishery has promoted the establishment of a milling industry in Kenya for transformation of dagaa into fishmeal (Ntara, 2015; Manyala, 1992). In addition, dagaa is sold in regional markets such as to Democratic Republic of Congo, Rwanda, Burundi, Zambia and South Sudan (Ntara, 2015). Dagaa remains a cheap source of protein for households in many parts of the Eastern and Central Africa.

Fishing of dagaa is normally done at night by using small seine nets and attraction lights (Katunzi, 1992). The number of small seines have been reported to increase in the lake in recent years. The first lake wide frame survey recorded 16,936 small seines in 2000, while the recent survey recorded

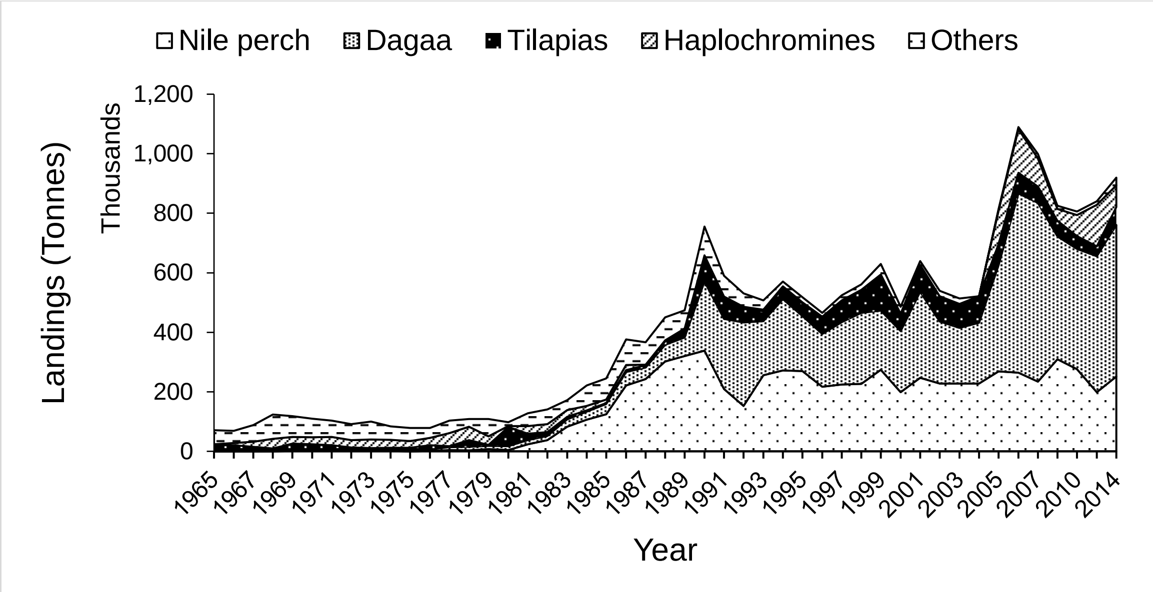

Figure 4: Fish landings in Lake Victoria by species (Adapted from LVFO stock assessment report 2014).

a total of 22,122 small seines in 2014 (LVFO, 2014). The dagaa fishery in Lake Victoria is mainly a near-shore fishery in which paddled sesse boats are the most important crafts (Tumwebaze, 2007). However, in recent years there has been an increasing shift from paddled sesse boats to motorized crafts and sail boats (LVFO, 2014). Motorized crafts and sail were reported to have high catch rates due to their ability to access offshore waters where the fish are increasingly becoming abundant (Tumwebaze, 2007; LVFO, 2014). Muhoozi, (2002) found that motorized boats which fish in offshore waters landed about double the catch of manually propelled boats which fished inshore sheltered areas, although both used gears of the same size. Dagaa harvest peaks during dark nights, when the effect of artificial attraction to light is maximised (Ojwang, 2014).

1.4 Scope of the study

The study is designed to quantitatively assess the population dynamics of dagaa in Lake Victoria. In addition, the relationship between dagaa biomass and catches with dissolved oxygen, chlorophyll a, secchi depth, temperature, wind stress and rainfall will be examined.

1.5 Objectives of the study

The overall objective is to assess the status of dagaa of Lake Victoria and correlate with environmental variables.

The specific objectives were;

1. To review trends in the biomass and catches of dagaa in Lake Victoria and describe the spatial and temporal abundance of the species in Lake Victoria.
2. To examine whether the abundance of dagaa is influenced by environmental variables.
3. To examine the population biology of the species, by estimating parameters of growth, recruitment, mortality and exploitation rate.

2 BIOLOGY AND ASSESSMENT OF DAGAA IN LAKE VICTORIA

2.1 Distribution and breeding of Dagaa

Rastrineobola argentea is a small, slender, silvery, zooplanktivorous, pelagic, and schooling fish species endemic in Lake Victoria (Mannini, 1992; Njiru , 1995; Wanink, 1998). It is locally known as dagaa in Tanzania, omena in Kenya and mukene in Uganda. The species has a short lifespan of 1-2 years and has a maximum total length of 100 mm (Wanink, 1989). However, declines in maximum lengths of dagaa has been reported in different areas of the lake. For instance, Chitamwebwa (1992) reported the maximum length for dagaa was 70 mm SL, with modal length ranging from 35 – 55mm SL in Mwanza gulf. The decrease in sizes of the species was related to intraspecific competition for food and abrupt change of the environment (Katunzi, 1992)

Dagaa is widely distributed throughout the pelagic zone (Marshall, 2003). Between the years 1999 – 2001 the highest densities of dagaa were reported in off shore in deep waters (Tumwebaze, 2007). The littoral and shallow areas are normally used as breeding and nursery grounds for dagaa (Wanink, 1999). Adult dagaa populations are reported to stay near the bottom during the day and move up to the surface at night while juveniles prefer mid waters at sunset (Wanink, 1999). This diurnal behavioural pattern has been associated with depth-related biotic and abiotic factors, like availability of dissolved oxygen in the water column, light penetration, food abundance, competition, predation and parasitization (Katunzi, 1992).

Several authors have reported dagaa to be heavily predated by Nile perch and birds (Mannini, 1992; Manyala & Ojuok, 2007; Tumwebaze, 2007), but so far it is the only native fish in the lake found in appreciable quantities (LVFO, 2014). Its small size and short life span suggest that the fish should have a high turnover rate and be resilient to heavy predation and exploitation (Nikolsky, 1969). Short lived species like dagaa tend to expand their population rapidly when feeding and spawning conditions are favorable, but decline rapidly when environmental conditions deteriorate. So far dagaa seems to be the only indigenous fish species that has succeeded in withstanding heavy predation by the introduced Nile perch predator and environmental fluctuations.

2.2 Effects of environment

The water budget of the lake depends mainly on the rainfall and evaporation (Table 2). The mean annual rainfall for Lake Victoria from 1950 – 2000 was between 886 – 2045 mm per year (COWI., 2002).The intergovernmental panel on climate change (IPCC) has projected that there will be likely increase in annual mean rainfall in the East African region by 2020 (IPCC, 2014). A decline or increase in rainfall will have a major impact on the water level and on the nutrient levels of the lake. Due to the large surface area of the lake the flushing time is very long; which allows high nutrient (Hecky & Bugenyi, 1992) and heat retention (Marshall, 2012). The amount of rainfall in Lake Victoria has a significant influence on the nutrient availability and productivity of the lake. Heavy rains that occurred in the 1960s led lake level to rise and flooded the shore line which released nutrients from the leaching soils and decomposed plant material (Kashindye, 2011; Mkumbo, 2002).

Table 2: Average outflow and inflow from Lake Victoria. Data adapted from (COWI., 2002).

Inflows	Through rainfall over the lake (m^3/s)	3631 (82%)
	Basin discharge (m^3/s)	778 (18%)
Outflows	Evaporation from the lake (m^3/s)	-3330(76%)
	Nile river(m^3/s)	-1046(24%)
Balance(m^3/s)		+33

The commercial catch of dagaa in Lake Victoria is based on the new generation each year. Growth of dagaa in the lake is most likely due to the response to both short and long term environmental changes. Several studies have shown a relationship between climate and physicochemical factors with fish catches. In Lake Kariba, air temperature and rainfall were found to have a strong influence on the abundance of kapenta sardine (*Limnothrissa miodon*) catches. Marshal (1982) reported that, the above normal rainfall that occurred between 1973-74 and 1977-78 did play a major role in enabling good sardine catches in Lake Kariba in the 1980s. Furthermore, Chifamba (2000) found a strong correlation of air temperature with total water inflow, lake levels and kapenta catches in Lake Kariba. In tropical lakes, temperature is an important factor that determine the productivity of the lake through the effect of nutrient cycling. However, Lake Victoria has been reported to experience increase in temperature, the lake is about 0.5°C warmer than in the 1960s (Njiru *et al*., 2008). The temperatures in Lake Victoria region is projected to warm by 1.4°C by 2050, with a warming of about 0.2°C per decade (IPCC, 2014). Magadza, 2011 found that, the increase in temperatures in Lake Kariba caused stable stratification that locked up the nutrients in the hypolimnion. In turn phytoplankton production was negatively affected in the nutrient poor epilimnion reducing the production flow up the trophic level through zooplankton to pelagic fish.

Short-lived species of the African great lakes have been shown to adapt to the changing environment and they persist in high abundance. These species include *Limnothrissa miodon* and *Stolothrissa tanganicae* in Lake Tanganyika and dagaa in Lake Victoria, however they have matured at a small size (Manyala & Ojuok, 2007; Marshall, 1987; Moreau *et al*., 1991). The small size is a life history adaptation to a relatively unstable environment, which is a typical for r-selected species, characterized by a short life cycle and early reproduction and tend to inhabit unstable and unpredictable environment (Marshall, 1987). However, so far there is scarce evidence to explain changes in population and abundance association with environmental changes (Witte, 1995; Bundy & Pitcher, 1995). Other African great lakes have already started experiencing the effect of increased temperatures on fish catches. For instance, *Limnothrissa miodon* was reported to decline in catches in Lakes Kariba and Tanganyika due to warming of water (O'Reilly *et al.*, 2003; Magadza, 2011). Manyala & Ojuok (2007) reported a significant relationship between dagaa larval density and ambient water temperature, secchi depth and dissolved oxygen in Lake Victoria.

2.3 Population growth parameters

Fishery of small pelagic fishes of African great lakes are mainly artisanal with little formal management. Although they have many similar characteristics, they exhibit different life history (Sharpe *et al.*, 2012). The growth rate of dagaa is reported to be lower than other short-lived species like *Stolothrissa tanganicae* (K= 2.58 – 2.89, $L_\infty = 138mm\ TL$) from Lake Tanganyika (Wandera & Wanink, 1995). Breeding of dagaa is not well understood in Lake Victoria, so far there is no consensus regarding the recruitment pattern of dagaa in Lake Victoria. Several studies have reported different findings regarding recruitment peaks. Wandera & Wanink (1995) reported a single recruitment peak per year for dagaa in Lake Victoria (Tanzanian and Ugandan waters), while Njiru (1995) reported two recruitment peaks for dagaa. *Eugraulicypris sardella* and *Stolothrissa tanganicae* have more than one peak during a year (Wandera & Wanink, 1995). The fluctuations and variations in life history of the small pelagic species from the African great lakes have been attributed to predation, fishing pressure and environmental factors (Sharpe *et al*., 2012; Marshall, 1987). For example, the decrease in body size, maturation at small size and increase in reproductive effort was reported for dagaa in response to predation by Nile perch and commercial fishing in Napoleon gulf of Lake Victoria (Sharpe *et al*., 2012). Likewise, limitation of food, predation by tigerfish (*Hydrocynus vittatus*) and commercial fishing were associated with the decline in mean size of *Limnothrissa* in Lake Kariba (Marshall, 1987). *Limnothrissa* was also reported to increase its growth rate and decrease its size in response to the changing conditions of Lakes Tanganyika, Kabora Bassa and Kivu lakes (Marshall, 1987).

The average size at first maturity for dagaa was reported to be 46 mm SL for male and 33 mm SL for females in the 1990s, and reached that size at almost one year (Manyala & Ojuok, 2007). The reported growth parameters of dagaa from different locations of the lake have shown a significant variation. In the 1990s the L_∞ of 52 – 67.8mm SL, K of 0.58 -3 year^{-1}, M of 0.88 – 3.2 year^{-1}, F of 1.22 -1.98, Z of 2.86 – 4.8 year^{-1}, ∅ of 1.62 -1.77 and E of 1.25 – 0.29 were reported by several authors in Lake Victoria (Table 3). The fluctuations of these parameters is quite high, reflecting that dagaa been r selected species has unstable population and undergoes high fluctuations.

Table 3: Growth parameters of dagaa from different parts of Lake Victoria estimated by various authors. Data adapted and modified from (Manyala & Ojuok, 2007).

Location	**L_∞(mm)**	**K(year-^{1})**	**M(year^{-1})**	**F**	**Z(year^{-1})**	**∅**	**E**	**Author(s)**
Nyanza gulf	67.8	0.58	0.88	1.98	2.86			(Manyala, 1991)
Ugandan water	64.5	0.92	2.37	1.22	3.59			(Wandera, 1993a)
Inner Nyanza gulf	59.0	0.74	1.12	1.89	3.47			(Manyala, 1995b)
Mid Nyanza gulf	62.0	0.74	1.12	1.39	2.97			(Manyala, 1995b)
Open lake	58.0	0.63	0.99	1.77	3.35			(Manyala, 1995b)
Station G 1983	61.0	1.42						(Wanink, 1998)
Station G 1988	53.0	3.00						(Wanink, 1998)
Open water	65.0	1.4	2.7		4.8	1.7	0.29	(Njiru, 1995)
Nyanza gulf	50.0	1.8	3.2		4	1.7	0.25	(Njiru, 1995)
Mwanza gulf	65	1.08	2.6		4.4	1.66		(Wandera & Wanink, 1995)
Buvuma channel	65	0.99	2.5		3.9	1.62		(Wandera & Wanink, 1995)
Mwanza gulf	52.0	1.14						(Wanink, 1989)
Average	**60.2**	**1.20**	**1.94**	**1.65**	**3.70**	**1.67**	**0.27**	

2.4 Stock assessment of dagaa in Lake Victoria

It has generally been thought that small pelagic species do not fit well with traditional stock assessment models and related assumptions used in population dynamics studies; thus making their assessment and management difficult and even questionable (Mannini, 1992). Most of the available experiences concerning population dynamics and stock assessment of small pelagic are from marine species and generally concerns clupeids (Mannini, 1992). Information on the population dynamics and stock assessment of small pelagic fish species of the African great lakes is scarce. During the sixth session of the FAO/CIFA sub-committee for the Development and Management of the Fisheries of Lake Victoria held in 1992 in Bujumbura, the sub-committee recognized the potential for dagaa to the economy of the Lake Victoria region and promoted a rational exploitation of the fishery by assigning high priority to research on the population dynamics of dagaa (Manyala, 2007). Despite of the assigned priority by the FAO/CIFA, biological data is very scanty and rarely collected in Lake Victoria.

Stock assessment in Lake Victoria is mainly based on data collected in acoustic surveys, catch assessment surveys (CAS) and frame surveys. Most of these surveys are carried out as part of donor funded projects with gaps between them. Dagaa biomass monitoring in Lake Victoria is mainly done using acoustics. The first lake wide biomass and catch monitoring started in 1999 and 1997 respectively. The list of lake wide acoustic surveys conducted in Lake Victoria is shown in Table 4.

Fisheries Frame Surveys in Lake Victoria date back to the early 1970s, and they were conducted at country level. The first lake wide coordinated frame survey was carried out by LVFO in 2000 with the support of the GEF/World Bank funded Lake Victoria Environmental Management Project Phase One (LVEMP I) and the EU funded Lake Victoria Fisheries Research Project Phase II (LVFRP II). The second lake wide survey was carried out in 2002 with funds from LVEMP I and the third one was conducted in April, 2004. The Frame Surveys for 2006 and 2008 were conducted with financial support from the EU through IFMP. Frame survey for 2010, 2012 and 2014 were funded LVEMP II and TASP II (LVFO, 2014).

3 MATERIALS AND METHODS

3.1 Available data

The available data that is used for the assessment of dagaa in Lake Victoria are mainly the annual commercial catches from beaches, landing records, biomass estimates from acoustic and bottom trawl surveys and catch efforts data from frame surveys. Biological data which is crucial for the assessment of the species is rarely and irregularly collected. This study uses biomass estimates from acoustic surveys to evaluate trends in biomass (spatial and temporal), and correlate the observed trends with environmental variables. Also monthly catch estimates from landing records obtained from Kirumba fish market are reviewed. In addition, dagaa growth parameters will be assessed so as to understand the population dynamics. The study uses published and unpublished data which were gathered from various institutions (Table 5). The length frequency data were collected by the Tanzania Fisheries Research Institute (TAFIRI), Kenya Marine and Fisheries Research Institute (KMFRI) and National Fisheries Resources Research Institute (NaFIRRI) from commercial catches of Speke, Nyanza and Napoleon Gulfs respectively. Biomass estimates and environmental parameters were collected lake wide during hydro acoustic surveys from 2000 – 2015. Total rainfall data from 1999 - 2013 were obtained from the Tanzanian metrological agency, data being collected from the three stations located near Lake Victoria (Mwanza, Bukoba and Musoma). The u (East - West component) and v (North - South component) components of the wind were downloaded from the National Oceanic and Atmospheric Administration (NOAA) webpage (NOAA, 2015) from 2^{o} 30' S and 32^{o} 30'E, for the Tanzanian side of the Lake.

Table 4: Number of lake wide acoustic surveys conducted in Lake Victoria under the Lake Victoria fisheries Organization (LVFO).

Survey No.	Name of the Project	Month and Year
1	Lake Victoria Research Project (LVRP)	August 1999
2	Lake Victoria Research Project (LVRP)	February 2000
3	Lake Victoria Research Project (LVRP)	August 2000
4	Lake Victoria Research Project (LVRP)	February 2001
5	Lake Victoria Research Project (LVRP)	August 2001
6	Lake Victoria Research Project (LVRP)	August 2002
7	Implementation of a Fisheries Management Plan (IFMP) project	August 2005
8	Implementation of a Fisheries Management Plan (IFMP) project	February 2006
9	Implementation of a Fisheries Management Plan (IFMP) project	August 2006
10	Implementation of a Fisheries Management Plan (IFMP) project	February 2007
11	Implementation of a Fisheries Management Plan (IFMP) project	August 2007
12	Implementation of a Fisheries Management Plan (IFMP) project	February 2008
13	Implementation of a Fisheries Management Plan (IFMP) project	August 2008
14	Implementation of a Fisheries Management Plan (IFMP) project	February 2009
15	Implementation of a Fisheries Management Plan (IFMP) project	August 2009
16	Implementation of a Fisheries Management Plan (IFMP) project	March 2010
17	East African Community (EAC) Partnership Funds – Support to Resources Monitoring for Lake Victoria	September 2011
18	East African Community (EAC) Partnership Funds – Support to Resources Monitoring for Lake Victoria	September 2014
19	Lake Victoria Management Project Phase II (LVEMP II)	November 2015

Table 5: Sources and data types used in the study

Data	**Source**	**Sampling duration**	**Year**
Biomass estimates	LVFO	Once or twice per year	1999-2015
Landings records	Kirumba fish market	Daily landings	2013-2015
Length frequency data	TAFIRI	Six months	April – September 2001
Length frequency data	KMFRI	Four months	June- September 2014
Length frequency data	NaFIRRI	Nine months	2014-2015
Environmental data (chlorophyll a and dissolved oxygen, water temperature, secchi depths)	LVFO through the stock assessment regional working group	Twice per year	2000-2014
Climatic data; i) Mean monthly rainfall ii) Wind data(u and v wind components)	Tanzania Meteorological Agency. National Oceanic and Atmospheric Administration (NOAA) webpage.	Monthly Data recorded four times a day (0000, 0600, 1200 and 1800)	1999-2013 1999-2015

3.2 Data Analysis

3.2.1 Spatial and temporal abundance of dagaa

This part uses acoustic surveys data that were collected in the period 1999–2015. Two surveys were conducted each year, one during the stratification period between February – March, and the other during the mixing period (August – November). The seasonal variation in biomass were addressed using data collected during these seasons. The seasonal thermal variation have influence on the distribution and availability of food and dissolved oxygen that consequently affect fish stock (Mkumbo, 2002). To address the spatial differences in biomass, this study analyzed data based on depth strata described by the LVFO, namely deep (depth >40 m), coastal (depth between 20 – 40 m) and inshore (depth < 20 m), and two gulfs namely Emin Pasha Gulf (EP) in the south west of the lake, Speke Gulf (SG) in the south east of the lake, and one island namely Sesse island (SI) in the north west of the lake (Taabu-Munyaho, 2014).

Monthly fluctuations in the landing of dagaa were also reviewed and their trends observed by using landing records from Kirumba international market which is located in Mwanza. This market is very important for the dagaa fishery as it collects dagaa from over 30 landing sites as shown in Figure 5.

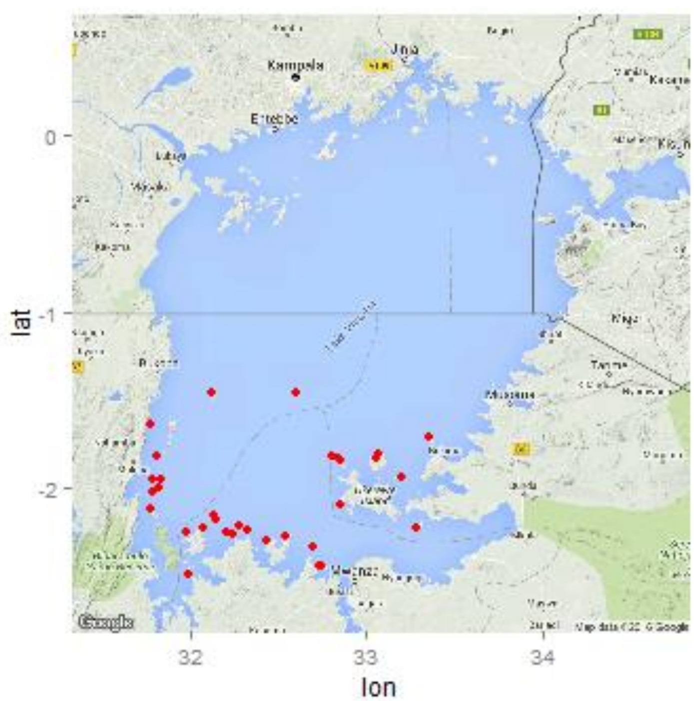

Figure 5: Map of Lake Victoria showing the location of landing sites (indicated by red points) that brings dagaa to Kirumba market.

3.2.2 Relationship between dagaa biomass and environment

This part uses data collected on the Tanzanian side of Lake Victoria. Analysis was done separately in the three depth strata and two gulfs. The analysis was conducted using mean environmental variables (chlorophyll a, dissolved oxygen, water temperature and secchi depth), climatic data (wind stress and rainfall), and biomass of dagaa. Mean values of physicochemical and biomass variables from the specific strata or gulf were used for correlations (Appendix 8). Since it was not possible to get data for climatic variables for each of the particular strata and gulf of study, mean climatic values were used to correlate with biomass of each particular strata and gulf. The total rainfall for each year collected from Bukoba, Musoma and Mwanza stations were averaged to represent the mean rainfall for the Tanzanian part of the lake for that particular year (Appendix 12). Wind stress was estimated from the u and v components of the wind as follows;

$$\tau = C_D \rho w^2$$

Where C_D is a dimensionless coefficient called the drag coefficient $10^3 C_D = 1.2$ (Large & Pond, 1981), ρ is the density of air ($\rho = 1.2 kg/m^3$), w is the wind speed that includes both the v and u wind components.

Either linear, exponential, power or polynomial models were fitted in Excel by selecting best fit. The selection of the best model was based on r^2 values.

3.2.3 Estimation of growth parameters

Data analysis was based on length frequency distributions using the Electronic Length Frequency Analysis (ELEFAN I) routine of the FiSAT II for Windows programs (Pauly, 1987). Estimation of the growth parameters was done by the von Bertalanffy growth equation expressed in the form:

$$L_t = L_\infty(1 - \exp(-K \times (t - t_0)))$$

Where L_t is the predicted length at age t; L_∞ is the maximum length the fish of a given stock would reach if they were to grow indefinitely; K is the growth coefficient and t_0 the age the fish would have been at zero length.

The asymptotic length (L_∞) and growth coefficient (K) was estimated from the von Bertalanffy generalized model in the ELEFAN I routine of the FiSAT II. ELEFAN I identified the growth curve that best fit the length-frequency data, using the best-fit value of Rn as criterion (Rn is 'goodness of fit' index of the ELEFAN I routine which = $10^{ESP/ASP}/10$; where, ESP is 'explained sum of peaks' and ASP is 'available sum of peaks' in a growth curve).

Estimation of the theoretical length at zero (t_0) for the species was computed using Pauly's empirical equation:

$$t_0 = -0.392 - 0.27 log L_\infty - 1.038 log K$$

Where K and L_∞ are the parameters from the von Bertalanffy equation.

The life span t_{max} is the approximate maximum age that a fish in the population could achieve and was calculated as the age at 95% of L_∞ using the parameters of the von Bertalanffy growth function as: $t_{max} = t_0 + 3/K$ (Taylor, 1958).

By using the asymptotic length (L_∞) the length at first maturity (L_m)of unsexed fish samples from commercial catches of three populations were estimated by applying the following empirical equation (Froese, 2000);

$$LogL_m = 0.8979 \times LogL_\infty - 0.0782$$

The length corresponding to the age group with maximum egg production (optimum length(L_{opt})) was estimated from the following empirical equation (Froese, 2000);

$$LogL_{opt} = 1.053 \times LogL_m - 0.0565$$

The age at first maturity (t_m) was calculated from the length at first maturity (Lm) using the parameters of the von Bertalanffy growth function (t_0, L_∞, K) and length at first maturity (L_m) (Froese, 2000);

$$t_m = t_0 - \ln(1 - \frac{L_m}{L_\infty})/K$$

The growth performance index ($\emptyset$) is used to compare different populations of the same or closely related species. The growth performance index was computed to compare the growth of different dagaa populations in the lake according to Pauly & Munro (1984) as follows:

$$\emptyset = \log(K) + 2\log(L_\infty)$$

Where K and L_∞ are from von Bertalanffy equation.

Estimation of mortality

Total mortality rate (Z) was estimated by the length converted catch curve (Pauly, 1983; Ricker, 1975), with the growth parameters from the von Bertalanffy as input data (L_∞ and K). Length frequency data was converted to their corresponding ages by means of the von Bertalanffy parameters. Z was obtained by plotting a catch curve with negative slope of;

$$\ln(\frac{N_i}{\Delta t_i}) = a + b * t_i$$

Where N_i is the number of fish in length class i, Δt_i is the time needed for the fish to grow through length class i, t is the age (or the relative age, computed with t_0=0) corresponding to the midlength of class i, a is y intercept and b is the regression slope(the estimate of Z).

Natural mortality was estimated from the equation of (Pauly , 1980), linking natural mortality with the von Bertalanffy parameters; K, L_∞ and mean annual water temperature T (°C)

$$\text{Log}\,(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\,\log\,(K) + 0.4634\log(T)$$

For schooling fish like dagaa Pauly's equation was modified (Mannini, 1992), by multiplying M with 0.8 so that the estimation becomes 20% lower (Sparre & Venema, 1992).

Fishing mortality (F) was estimated from the relation Z = F + M, while the exploitation rate was calculated from E = F/Z = F/ (F + M).

Where Z is the total mortality, F is the fishing mortality and M is the natural mortality.

Calculation of probability of capture

Calculation of the probability of capture was estimated from the length converted curve by extending the line for the age groups that are not fully recruited to the fisheries (Figure 11). Assuming what the catch could be if they were fully recruited. The ratio between the fish that could be caught and that which is caught is used to estimate the probability of capture.

Recruitment patterns

The recruitment pattern is computed in FiSAT II using L_∞ and K as input parameters, from a time series of length frequency data from Pauly (1984). The recruitment was directly computed from the length converted catch curve through logistic curve, which assumes selection to be symmetrical. The procedure involves:

1. Backward projection onto the time axis of a set of length frequency data;
2. Summation of each month of the frequencies projected onto each month;
3. Subtraction, from each monthly, sum of the lowest monthly sum to obtain a zero value where apparent recruitment is lowest; and
4. Expressing monthly recruitment in percentage of annual recruitment.

Yield and prediction

Relative yield per recruit (Y'/R) was estimated by the knife edge selection model based on the Beverton and Holt of 1966. L_c/L_∞ ratio and M/K ratio were used as input parameters to the FiSAT II.

The relative yield per recruit was computed from;

$$Y'/R = E * U^{M/K}\{1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\}$$

Where;
U = 1-(L_c/L_∞), $m = (1-E)/M/K) = (K/Z)$, $E = F/Z$, E= the fraction of deaths caused by fishing (exploitation rate), F= fishing mortality per year, Z= total mortality per year, M= Natural mortality per year, K = the rate at which the length tends towards the asymptote of dimension 1/t, L_c is the length (mm) of fish at first capture, L_c is the mean length of fish would reach if they were to grow indefinitely.

The relative biomass per recruit (B'/R) was estimated from the following relationship;

$$B'/R = (Y'/R)/F$$

While E_{max}, $E_{0.1}$, and $E_{0.5}$ are estimated from the first derivative of this function.

Plots of Y'/R vs E (=F/Z) and of B'/R vs E, from which E_{max}(exploitation rate which produces maximum yield), $E_{0.1}$(exploitations at which the marginal increase of relative increase per recruit is 1/10th of its value at E=0) and $E_{0.5}$ value of E under which the stock has been reduced to 50% of its unexploited biomass) were also produced.

4 RESULTS

4.1 Spatial and temporal distribution of dagaa

The seasonal and spatial distribution of dagaa abundance is shown in Figures 6 and 7. There has been a marked increase in dagaa biomass over time. Generally, in the years 1999, 2000, 2001 and 2002 the average densities of dagaa were between 5.3-8.8 t/km^2, the highest densities of 15.9 tons/km^2 and 12.9 t/km^2 were mainly found during periods of stratification in February of 2000 and 2001 respectively (Appendix 1). During this time very few areas had densities of 20 t/km^2 or higher. From 2005 to 2015 the average densities of dagaa increased, and was between 10.1-23.6 t/km^2. During these time areas with densities of 20 t/km^2 increased. Areas with 30 t/km^2 and 40 t/km^2 densities were found to increase in many parts of the lake. Generally, the stratified periods had higher biomass than the mixing periods (Figure 8). An increasing trend was observed in all the strata over time, but the highest biomass is found in the shallow inshore and coastal strata, and the lowest being the gulfs (Figure 9). Although Kenya has small a portion of the lake, it has the highest concentration of biomass. While Tanzania and Uganda had similar biomass contribution (Figure 10).

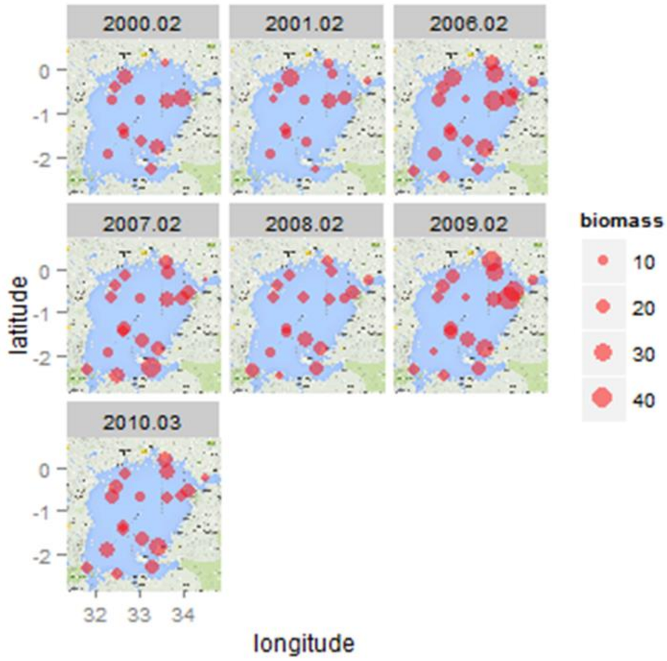

Figure 6: Distribution and abundance of dagaa (biomass in tons/km^2) in Lake Victoria from 2000 – 2010 estimated during stratification period in February and March through acoustic surveys. The two digits after the year represent the month when the survey was conducted.

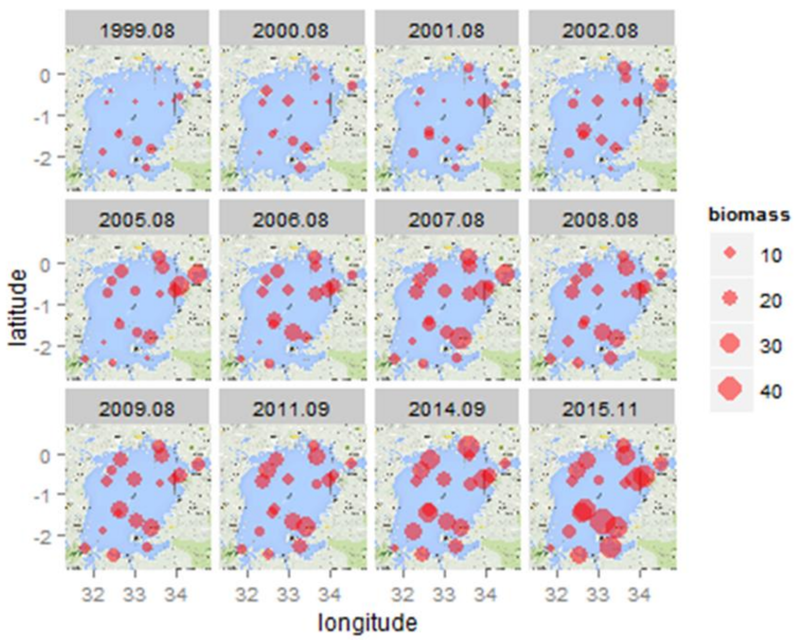

Figure 7: Distribution and abundance of dagaa (biomass in tons/km^2) in Lake Victoria from 1999 - 2015 estimated during mixing period in August, September and November through acoustic surveys. The two digits after the year represent the month when the survey was conducted.

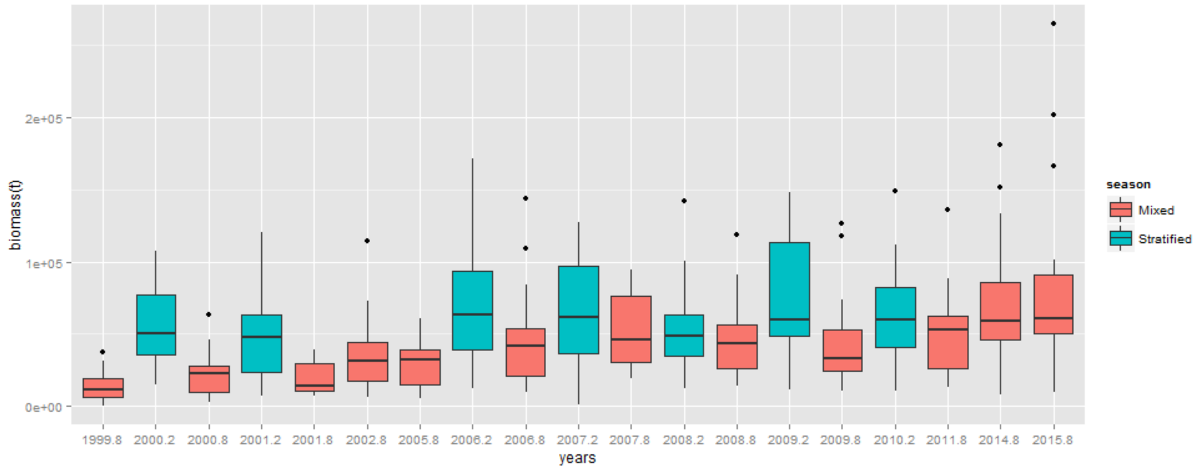

Figure 8: Mean dagaa biomass (tons) estimated during mixing and stratification periods through acoustic surveys from 1999 – 2015.

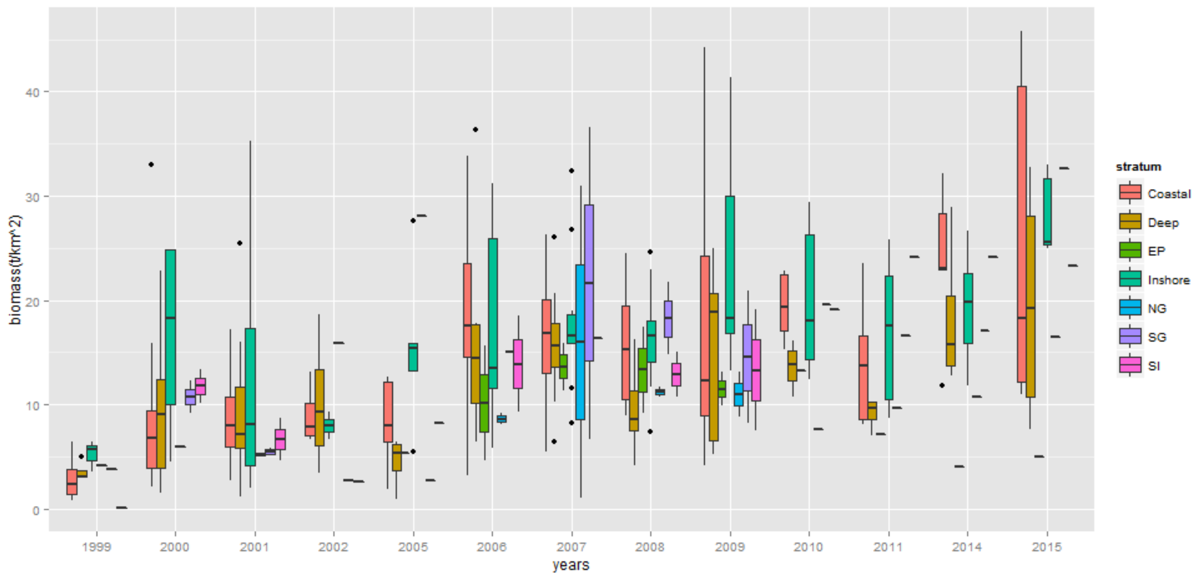

Figure 9: Biomass (tons/km^2) estimated from three gulfs (EP = Emin Pasha Gulf, NG = Nyanza gulf, SG = Speke gulf), three strata (Deep > 40m, Coastal between ≤ 20m and < 40m, Inshore < 20m) and one island (Sesse island) of Lake Victoria from 1999– 2015

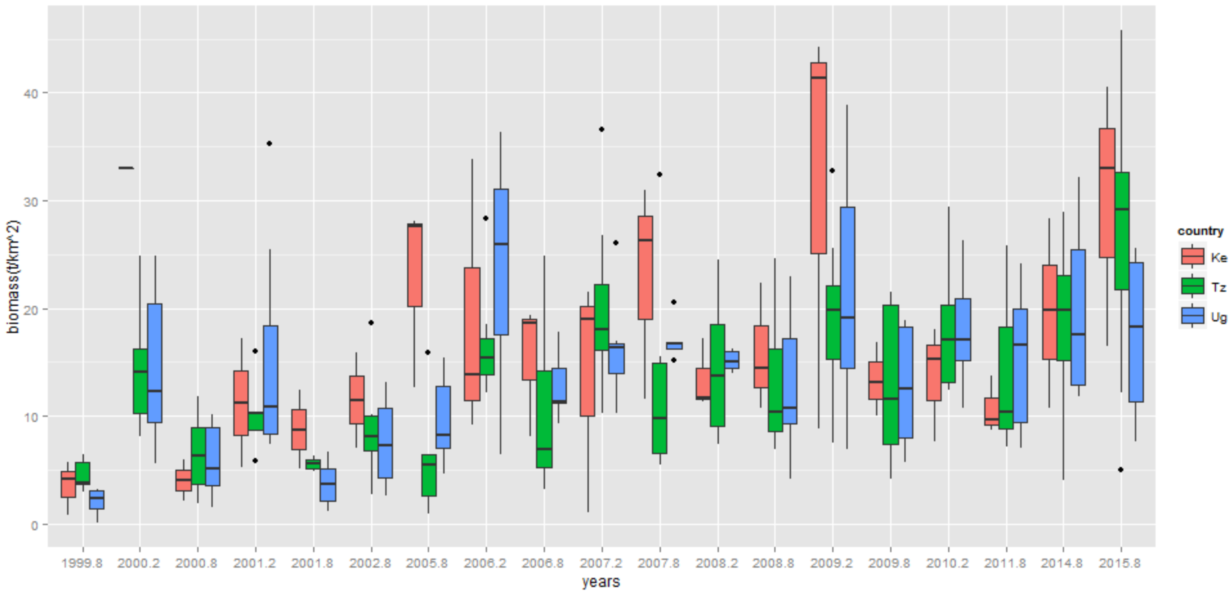

Figure 10: Biomass (t/km^2) contributed by the three riparian counties (Ke = Kenya, Tz = Tanzania, Ug = Uganda) from 1999 – 2015.

4.2 Review of monthly dagaa catch

The Kirumba international market is very important for dagaa fishery in Lake Victoria. Monthly landings recorded from 2013 to 2015 seems to follow trends, with peaks from October to February and stable catch from March to September (Figure 11).

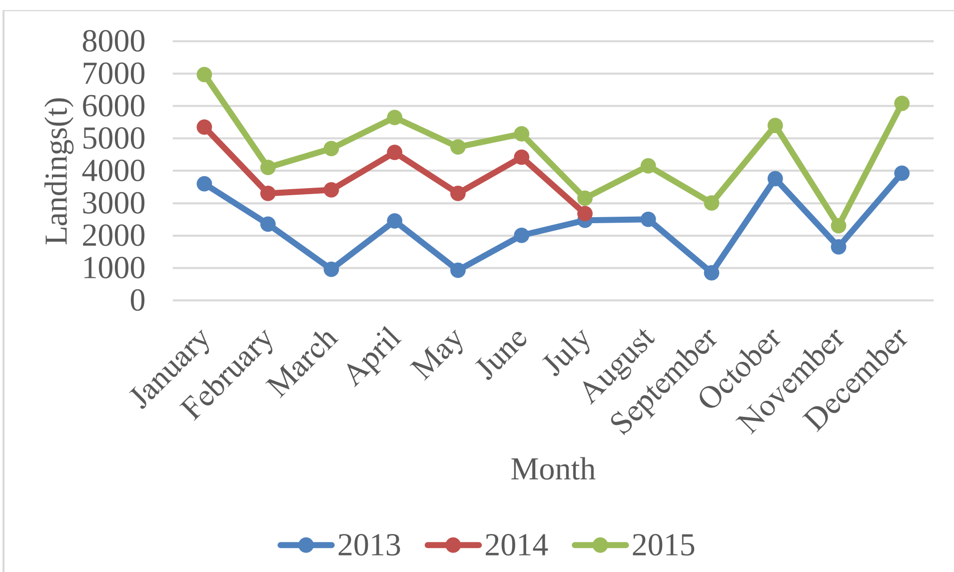

Figure 11: Monthly dagaa landings recorded from Kirumba international market in Tanzania from 2013 to 2015.

4.3 Relationship between dagaa biomass and environment

The relationships of climatic, physicochemical and biomass variables are shown in Table 6. Rainfall was positively related to abundance of dagaa in the deep strata ($R^2 = 0.44$, $P < 0.05$). Secchi depth was negatively related to the abundance in the inshore of the lake ($R^2 = -0.74$, $P < 0.05$), while water temperature was positively related to dagaa abundance in all the strata, highest correlation being at Speke gulf ($R^2 = 0.53$, $P < 0.05$). Wind stress explained the variations of dagaa abundance in the inshore ($R^2=0.49$, $P < 0.05$), Speke gulf ($R^2 = 0.32$, $P < 0.05$) and coastal ($R^2 = 0.41$, $P < 0.05$) strata. Chlorophyll a showed positive relationship in the deep ($R^2 = 0.78$, $P < 0.05$). Dissolved oxygen was positively correlated with dagaa biomass in Emin Pasha ($R^2 = 0.49$, $P < 0.05$).

4.4 Growth parameters

The growth parameters for the monthly length frequency distribution data was estimated by ELEFAN 1 routine of FiSAT II. Results of the von Bertalanffy growth curve (Figure 12), are shown in Table 7. However, short time series (4, 6 and 9 months for Nyanza, Speke and Napoleon gulfs) were used for the estimation of growth parameters, hence these findings may need to be confirmed by long time series data. Total mortality and probability of capture were estimated using the length converted catch curve (Figure 13, Table 8). The length converted curve gave the total mortality of 2.98 and 3.19 $year^{-1}$ in Speke Gulf and Napoleon Gulf respectively. Total mortality for Nyanza Gulf was not estimated because data sets did not meet the conditions for running a catch curve. Pauly's equation gave the natural mortality of 2.40, 2.65and 2.05 $year^{-1}$ in, Nyanza, Speke and Napoleon Gulfs respectively. Since dagaa is a schooling fish, a 20% natural mortality reduction (Sparre & Venema, 1992) was applied which gave new values of natural mortality of 1.92, 2.12 and 1.64 $year^{-1}$ in Nyanza, Speke and Napoleon Gulf respectively. The mean annual water temperature used was 24.6 ºC for Speke Gulf and 24.7 ºC for Nyanza and Napoleon Gulf. Growth performance index (Ø) of dagaa was highest in Nyanza Gulf, followed Speke Gulf and the lowest was at Napoleon Gulf.

Table 6: Pearson correlation coefficient (R^2) of dagaa biomass, climatic and environmental variables of the three strata (inshore (<20m), coastal (20-40m), deep (>40)) and two gulfs (Speke and Emin Pasha Gulf) of Lake Victoria, Tanzanian part. The table below shows results of the linear model, in cases where linear model did not give a better fit power (pw),, exponential (ex), and polynomial (po) models were used. The values with significant correlation ($P < 0.05$) are marked with asterisks *.

	Depth strata/gulf	**Biomass**	**Rainfall**	**Wind stress**	**Dissolved oxygen**	**Chlorophyll a**	**Temperature**
Rainfall	<20m	0.046					
	20-40m	0.229					
	>40m	0.403*					
	Speke gulf	0.121					
	Emin Pasha gulf	0.007 (pw)					
Wind stress	<20m	0.501*					
	20-40m	0.414*					
	>40m	0.267					
	Speke gulf	0.318*					
	Emin Pasha gulf	0.234 (pw)					
Dissolved oxygen	<20m	0.248 (pw)	-0.0002 (ex)	-0.038			
	20-40m	0.127 (pw)	0.032	-0.081 (pw)			
	>40m	0.091 (pw)	0.0002 (pw)	-0.074			
	Speke gulf	0.358 (pw)	0.076 (ex)	-0.107			
	Emin Pasha gulf	0.486* (pw)	0.230 (pw)	0.065			
Chlorophyll a	<20m	-0.046	0.082 (ex)	0.331	0.203 (pw)		
	20-40m	-0.006	0.002	-0.686* (pw)	0.144		
	>40m	0.777* (pw)	0.053 (ex)	-0.333	0.091 (pw)		
	Speke gulf	0.005	-0.1231 (ex)	0.267 (pw)	0.415*		
	Emin Pasha gulf	0.430 (po)	-0.373	0.426 (pw)	0.140 (pw)		
Temperature	<20m	0.106	0.250 (pw)	0.108 (pw)	0.469*	-0.197 (pw)	
	20-40m	0.327 (po)	0.208	0.034 (pw)	-0.286	-0.305	
	>40m	0.210	0.208	0.045 (pw)	0.119 (ex)	-0.403* (ex)	
	Speke gulf	0.533*	0.159	0.085 (pw)	-0.141	-0.597* (pw)	
	Emin Pasha gulf	0.213 (pw)	0.050 (pw)	0.148	0.034 (pw)	-0.545 (ex)	
Secchi depth	<20m	-0.735*	0.115 (pw)	0.078 (pw)	0.011	-0.121 (ex)	0.199
	20-40m	-0.400	-0.03	0.045 (ex)	0.335 (pw)	0.114	-0.305
	>40m	-0.108	0.036	-0.108 (ex)	0.155 (pw)	-0.002	-0.876*
	Speke gulf	0.023 (ex)	0.001 (pw)	0.025 (pw)	0.426 (ex)	0.063	-0.186 (ex)
	Emin Pasha gulf	0.174	-0.173 (ex)	-0.210	0.051	-0.205 (pw)	0.181 (pw)

Table 7: Growth parameters of dagaa determined from Lake Victoria commercial catches in Nyanza gulf, Speke gulf and Napoleon gulf.

Location	L_∞(mm)	K(year-^{1})	M(year^{-1})	F(year^{-1})	Z(year^{-1})	t_0	Ø	E
Nyanza gulf	41	0.73	1.92			-0.42	1.09	
Speke gulf	58.5	0.99	2.12	0.76	2.98	-0.59	1.5	0.26
Napoleon gulf	53.6	0.65	1.64	1.55	3.19	-0.39	1.3	0.49
Average	**51.03**	**0.79**	**1.89**	**1.16**	**3.09**	**-0.47**	**1.30**	**0.38**

Table 8: Probability of capture at which 25, 50 and 75 percent of the encountered fish were retained.

Location	L_{25}**(mm)**	L_{50}**(mm)**	L_{75}**(mm)**
Speke gulf	46.08	49.30	52.52
Napoleon gulf	22.77	24.72	26.68

4.4.1 Size and age at first maturity

Dagaa was found to mature at the small body size (Table 9). The length at first maturity(l_m) for the dagaa populations was 29.7 mm for Nyanza Gulf, 40.8 mm for Speke Gulf and 37.7 mm for Napoleon Gulf. However, the values of age at first maturity were too high than expected, hence they may need to be verified by further research. The length corresponds to the age of 1.34, 0.61 and 1.48 years for Nyanza, Speke and Napoleon Gulf respectively. The optimum length (l_{opt}) values for both the three populations was found to be smaller than the length at first maturity (l_m), which is a typical reproductive strategy of short-lived species that have high mortality rate. The estimated maximum life span for the dagaa of between 2.4 – 4.2 years from the three populations was higher than those of between 1-2 years reported by Wanink (1989), and 2.8 years reported by Froese & Pauly (2015).

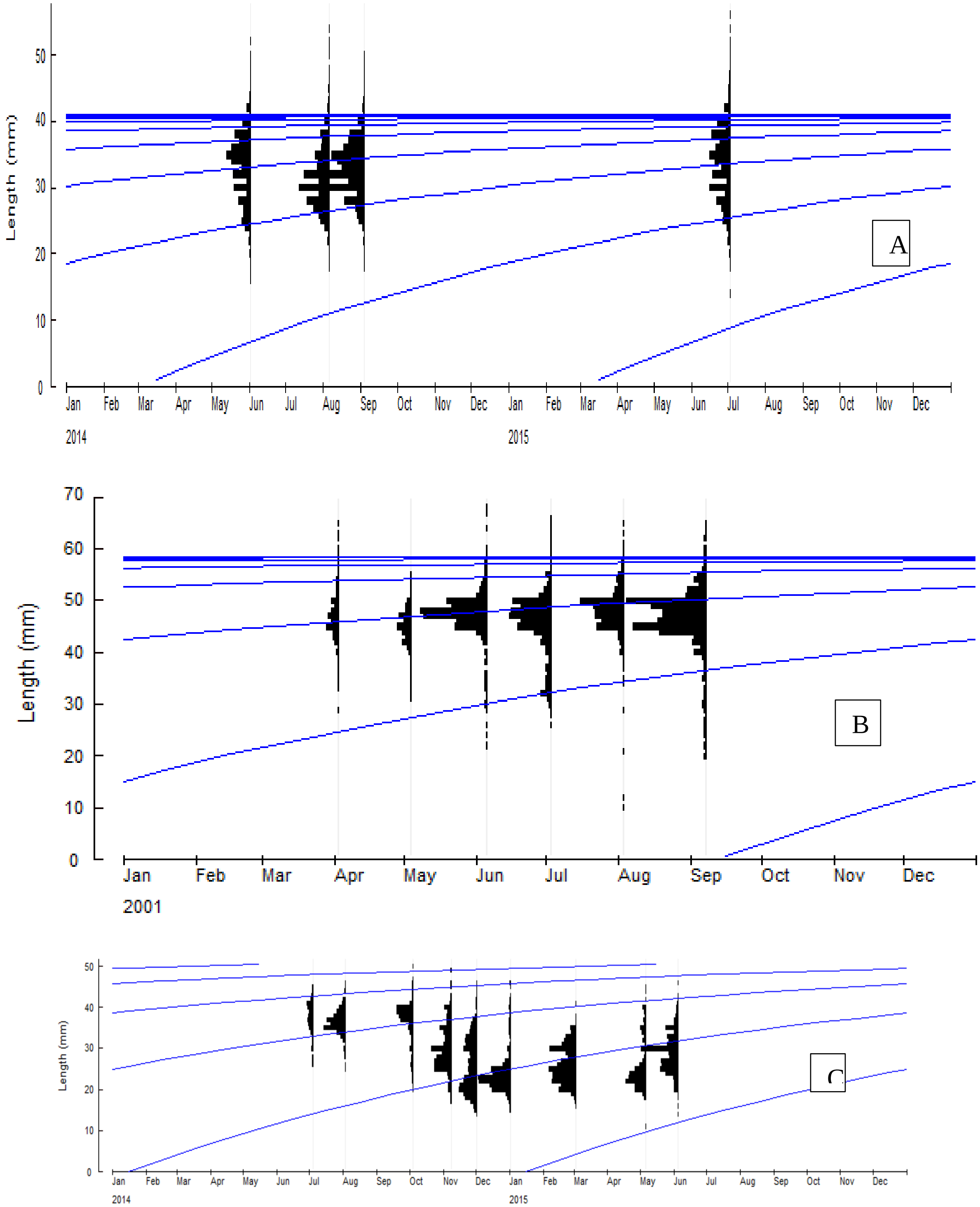

Figure 12: The von Bertalanffy growth function fitted on length frequency distribution (standard length) of dagaa from Lake Victoria commercial catches of Nyanza Gulf (A), Speke Gulf (B) and Napoleon Gulf (C).

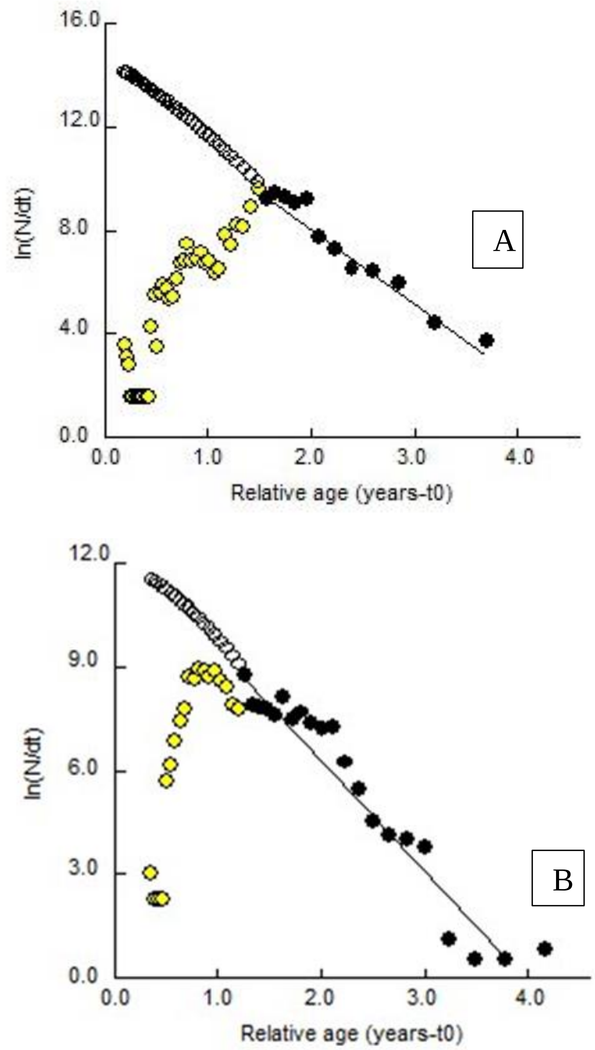

Figure 13: Catch curves used to estimate Z and probability of capture from FiSAT for dagaa populations from Speke Gulf (A) and Napoleon Gulf (B).

Table 9: Size and age at first maturity (l_m = the length at first maturity, t_m=age at first maturity), t_{max} = lifespan or maximum age reached by fish in a population, t_{opt}= the length corresponding to the age group with maximum egg production) of dagaa sampled from three gulfs of Lake Victoria.

Location	l_m **(mm)**	t_m**(years)**	t_{max}**(years)**	l_{opt}**(mm)**
Nyanza gulf	29.65	1.34	3.7	27.6
Speke gulf	40.8	0.61	2.4	38.6
Napoleon gulf	37.7	1.48	4.2	35.5
Average	**36.05**	**1.14**	**3.4**	**33.9**

4.4.2 Recruitment

Monthly recruitment was estimated as a percentage using length frequency data from commercial catches. Results indicate continuous recruitment throughout the year (Figure 14). For Kenyan sector of the lake (Nyanza Gulf) the breeding peak was found in April and June. While for Tanzania (Speke Gulf) breeding peak was found in May and June. The peaks in the Ugandan sector (Napoleon Gulf) were in February and June.

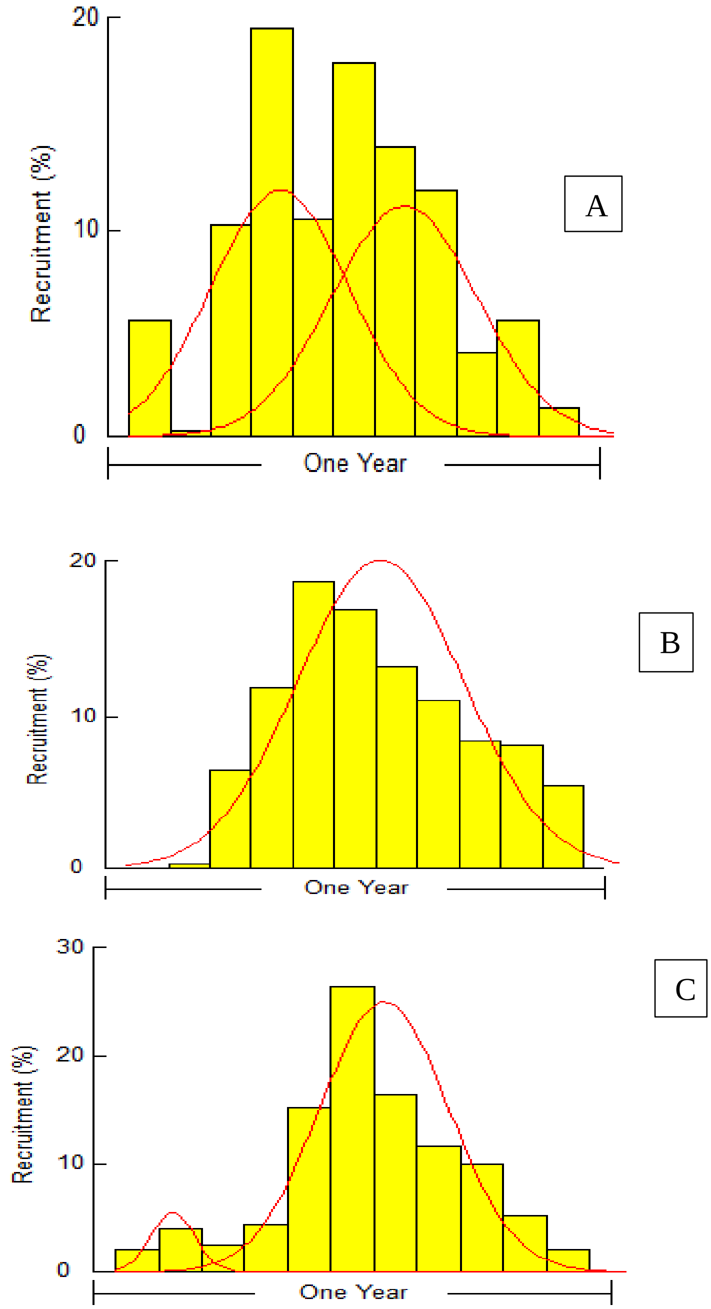

Figure 14: Recruitment pattern of dagaa from Nyanza Gulf (A), Speke Gulf (B) and Napoleon Gulf(C) of Lake Victoria.

4.4.3 Exploitation rate

The relative yield per recruit and biomass per recruit were estimated with previously estimated values of L_c/L_∞ and M/K used as input to prediction with the knife edge selection model in FiSAT II (Figure 15). The exploitation rate at different levels of yield for the three populations of dagaa were estimated. The exploitation rate which produces maximum yield E_{max} was 1.000 for Speke gulf and 0.808 for Napoleon Gulf. The exploitation rate at which the unexploited stock would have been reduced to 50% ($E_{0.5}$) was 0.465 for Speke Gulf and 0.358 for Napoleon Gulf. While the exploitation rate at which the marginal increase of the relative yield per recruit is at $E_{0.1}$ was 1.000 for Speke Gulf and 0.659 for Napoleon Gulf.

The calculated exploitation rate of 0.26 for Speke Gulf and 0.49 for Napoleon Gulf from length converted curve were lower the E_{max} values shown above, showing that the stock is not overexploited.

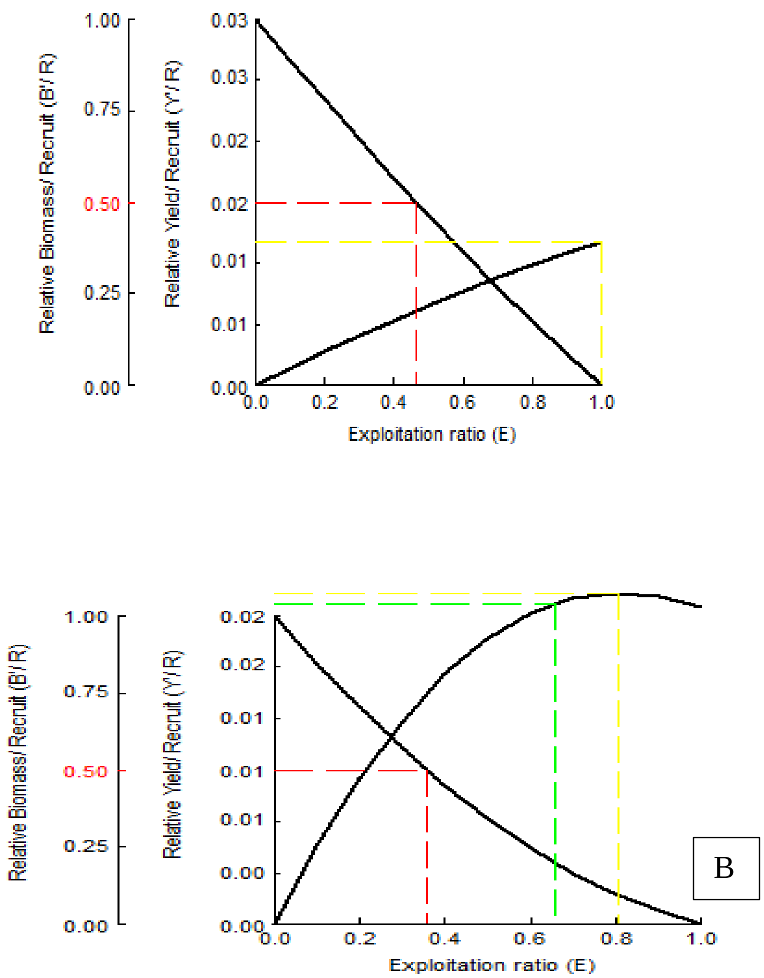

Figure 15: Relative yield per recruit and relative biomass per recruit showing differences in exploitation rate for dagaa stock in Lake Victoria (Speke Gulf (B) ($\boldsymbol{L_c/L_\infty}$= 0.840, M/K =2.14) and Napoleon Gulf (C) ($\boldsymbol{L_c/L_\infty}$= 0.461, $\boldsymbol{M/K}$= 2.527) of Lake Victoria.

5 DISCUSSION

5.1 Spatial and temporal variations of dagaa

Dagaa currently contribute about 60 % of the total fish catch in Lake Victoria (CAS, 2014). Dagaa fishery is the leading fishery on the Kenyan side of the lake, the second after Nile perch in Tanzania, and the third most important after Nile perch and Nile tilapia in Uganda (Ntara, 2015). The Kenyan part of the lake is the most intensely fished area, with fishing effort of 0.5 boats/km^2, compared to 0.08 boats/km^2 of Uganda and 0.1 boats/km^2 of Tanzania (Ojwang, 2014). Kenya has always possessed the highest concentrations of dagaa. Possibly the closure seasons that were introduced in 2001 in the Kenyan sector of the lake have been beneficial for the dagaa.

Ntara (2015) reported the peak season for trading dagaa in the Tanzanian part of Lake Victoria was during the dry seasons (from May to October), because there is enough sunshine for drying dagaa, hence resulting in quality dagaa with high price. While the low trading seasons are during the rainy season (from January to April and November to December). Data from Kirumba fish market shows that, the peak months for dagaa landings are from October to February (during rainy seasons), biomass density estimates were also higher during these seasons (Figure 8, Appendix 13). This possibly explains why fishers catch more dagaa during these periods. Unfortunately a big proportion of dagaa caught during this time gets its quality distorted because of poor processing technology causing a lot of post-harvest loss, hence sold at low price, and some end up being used as animal feed (Ntara, 2015).

The population of dagaa started to increase from 1980s after the Nile perch boom and decline of haplochromines in Lake Victoria (Wanink *et al*., 2001). This study reports the continued increasing trend of dagaa biomass over time (Figure 4 and 5). The highest biomass densities were recorded during the stratified periods (between February and March) compared to the isothermal periods (between September and November). The rains that occur during the stratified season brings nutrients in to the lake that enhance primary production, ensuring enough availability of food for dagaa during this season. In recent years wind stress has also increased in Lake Victoria and has resulted in increased mixing of the water column, increasing suitable area for fish (Appendix 11). Hence, the effect of stratification has possibly been reduced (Appendix 9 and 10). Highest biomass densities were found in shallow and inshore waters (<40m) where mixing is more pronounced, excluding the gulfs (Figure 9). The gulfs exhibit low dagaa density possibly because they are highly exploited due to their easy accessibility by most fishers. The fishery in Lake Victoria is mainly operated by sesse paddle boats and parachute that make up 75% of all vessels in the lake (Ojwang, 2014). These vessels are cheap and affordable by most fishers, but can only operate in inshore in shallow areas especially in gulfs which are sheltered from strong winds and currents.
High densities of haplochromines and the fresh water shrimps (*Caridina nilotica*) that form the main prey for Nile perch have been reported in shallow areas (Taabu-Munyaho, 2014). Thus, the higher abundance of dagaa in the shallow and inshore can also be related to the relieved predation pressure from Nile perch. Based on the recent studies on Nile perch diet conducted in the Tanzania side of Lake Victoria, dagaa is not a preferred diet for Nile perch, it constitutes only 8 % of Nile perch diet. Stomach analysis show that Nile perch diet is now dominated by the fresh water shrimp (53%) and haplochromines (33%) (TASPII, 2013). It is also important to note that, juvenile Nile perch that make up about 95% of the Nile perch population in the lake prefer fresh water shrimps

as their major diet, while adult Nile perch prefer haplochromines (LVFO, 2014; TASPII, 2013). However, according to the most recent acoustic survey findings, haplochromines have declined from 708,725 tons in 2011 to 384,552 tons in 2014, and fresh water shrimps from 196,667 tons in 2011 to 60,707 tons in 2014 (LVFO, 2014). If the observed decline of fresh water shrimps and haplochromines continues, the predation pressure of Nile perch may soon shift to dagaa, and this may affect its abundance. Fish tend to change their diet preference depending on the availability and abundance of prey. Since dagaa is abundant in the lake, there is a great possibility for Nile perch to shift its preference to dagaa. For example, Nile perch expanded its diet to fresh water shrimps in response to the decline of haplochromines (Witte *et al.*, 1992b; Sharpe *et al.*, 2012).

In recent years, the offshore waters (deep strata >40m) have also been found to be very important for dagaa as has also been in this study (Figure 9). Possibly this is the effect of increased wind stress (Appendix 10), that suitable habitat for dagaa may have increased in the offshore waters. High oxygen values have been reported in the offshore waters at depth ≤40m during stratified periods (Taabu-Munyaho, 2014). Furthermore, Sitoki *et al.* (2010) reported mean oxygen values of 2.55mg/l and 6.13mg/l at >40m depth during the stratified season in Lake Victoria from data collected between 2000-2001 and 2005- 2008 respectively. Moreover, the deepest areas of the lake are reported to have thick sediment deposits that during mixing periods allow release of nutrients favoring primary and secondary production (Tumwebaze, 2007; Scholz *et al.*, 1990), ensuring availability of food for fish in the offshore waters.

5.2 The association of environmental variables with dagaa biomass

Lake Victoria has a large surface area with long flushing time, allowing high nutrient and heat retention, and very little of its stored heat and nutrient is exported (Marshall, 2012). Atmospheric wet and dry deposition, runoff and river basins are the major sources of nutrient loading into the lake (Table 1). Rainfall and wind play a great role in nutrient loading and cycling in the lake. The spatial and temporal variations in the amount of rains are reported to influence a number of environmental factors that in turn determine the distribution and abundance of fish (Marshall, 1982; Mkumbo, 2002). The current study shows a positive relationship of rainfall and dagaa biomass in the offshore waters, while no relationship was found in the gulfs and shallow waters (Table 6 and Appendix 2). However, rainfall showed no relationship with oxygen, chlorophyll a, temperature and secchi depth. Studies conducted in Lake Kariba have shown a close relationship between rainfall and *Limnothrissa* catches, hence *Limnothrissa* catches were predicted based on the amount of rainfall (Marshall, 1982; Marshall, 1988; Chifamba, 2000). This is possibly due to the small size of the lake with shorter flushing time compared to that of Lake Victoria (Marshall, 2012). For such a large system with long flushing time like Lake Victoria, inter-annual variations of rainfall is unlikely to have much effect as is shown by the lack of a close relationship in other strata/gulfs with dagaa biomass and other environmental variable (Marshall, 2012).

Wind stress was positively correlated with abundance of dagaa especially in the shallow waters (Table 6 and Appendix 3). From the 1970s to the 1990s wind stress in Lake Victoria was reported to be very low which led to longer and more stable anoxic layers that covered a large portion of the lake (Kolding *et al*., 2008). However, in recent times the wind stress has shown a significant increasing trend (Appendix 11). This allows mixing of the water column, ensuring supply of nutrients and food to be well distributed throughout the water column. The force of the wind is more profound in the shallow water than in the offshore. The gulfs are normally sheltered from strong winds due to presence of hills, settlements and trees near them. This possibly could be the reason for lower relationship of dagaa biomass and wind stress in the gulfs as compared to the inshore waters. Moreover, the high concentration of dissolved oxygen could explain the abundance of dagaa in the gulfs (Table 6 and Appendix 4).

Generally, offshore waters are nutrient deficient and experience lower primary production than in the inshore waters. This study reports a positive relationship of dagaa abundance and chlorophyll a in the offshore waters (Table 6 and Appendix 5). Primary production exerted a major influence for the distribution and abundance of dagaa in the offshore waters. Our data shows that in the offshore waters, chlorophyll a concentration which is an indicator of primary production were lower compared to the inshore and gulfs (Appendix 5). Atmospheric wet and dry deposition play a great role for nutrient enrichment in the offshore waters (Table 1). Chlorophyll a was also positively correlated with wind stress and dagaa abundance in Emin Pasha Gulf, possibly due water mixing that releases nutrients from the bottom that result in increased primary production. During heavy rains, cooling of the surface waters occurs that causes mixing of the water column, releasing nutrients locked up in the bottom that enhance productivity. While unexpected negative relationship of chlorophyll a and wind stress was encountered in the rest of the strata especially the coastal waters. Wind action would be expected to trigger a release of nutrients from the bottom, resulting in increased primary production.

Lake Victoria has been experiencing an increase in temperature for several decades. From 1927 to 2009 surface water temperature has increased from 24.69^{o}C to 25.88^{o}C, while the bottom water (>50m), temperature rose from 23.32^{o}C to 24.89^{o}C (Sitoki *et al.*, 2010). Higher mean temperatures were reported by Taabu-Munyaho (2014) during stratification (25.4^{o}C and 25.6^{o}C) than during the isothermal periods (24.9 ^{o}C and 24.9 ^{o}C), while the surface mean temperatures varied between 25.5 – 26.5^{o}C and 26.3 – 26.5^{o}C in deep and coastal strata respectively. This increase in temperature has been reported to weaken the stratification of the lake, allowing more exchange of nutrients and oxygen between the surface and the bottom water. The difference between the surface and the bottom during the stratified period has also been reduced (Appendix 9 and 10). This study reports a positive relationship of temperature and dagaa biomass in Speke Gulf, but in the rest of the strata temperature showed weak relationship with dagaa (Table 6 and Appendix 6). Magadza (2011) reported a positive relationship of *Limnothrissa* catches with rise in temperature in Lake Kariba. Furthermore, temperature was negatively related with oxygen in the inshore, chlorophyll a in the offshore and gulfs (Speke and Emin Pasha).This was expected because as water temperature increases solubility of dissolved oxygen decreases. Since the rate of chemical reaction increases with increase in water temperature, dissolved oxygen that comes from the atmosphere and through photosynthesis is consumed through chemical reactions and oxidation especially through decomposition of plant biomass and other organic materials (Wetzel, 2001). Although climate change has not been proved to have direct impact on the pelagic life in Lake Victoria (Hulme *et al.*, 2003), it may have possibly contributed to the change in phytoplankton species composition, from the one dominated by diatoms to blue green algae which are inaccessible to grazers (TASP II, 2013; Kashindye *et al*., 2015). Magadza (2011) reported growth rate of green algae declined at temperatures above 25^{o}C, and a change of phytoplankton species composition from green algae to blue green algae when water temperature in Lake Kariba was approximately approaching to 28^{o}C. Moreover, climate warming has been reported to be the major driver in the decline of productivity in Lake Tanganyika, where primary production was reported to have decreased by 20% which resulted in an estimated 30% decrease of pelagic fish yield (O'Reilly *et al*., 2003). The current temperature may be favoring the growth of dagaa for now, but the predicted increase in temperature for the Lake Victoria region in the next decades as reported by the IPCC (2014) put the pelagic life in the lake at risk of the aforementioned effects happening in other African great lakes.

Visibility can be influenced by many factors such as sediments, algae and particulate organic materials. Secchi depth was negatively related with dagaa biomass in the inshore and coastal, with highest biomass recorded where secchi depth was low. In Lake Victoria, algal biomass has been reported to be the major light limiting factor especially in the shallow and gulf waters (Kolding *et al*., 2008). But chlorophyll a values of the coastal and inshore waters were between 3.8 – 7.9 µg/l and 8.2 – 17.7 µg/l respectively (Appendix 8), such values are not expected to cause light limitation as they are within the recommended ranges for tropical lake (Huszar , 2006 ; Kashindye *et al*., 2015). The high abundance of dagaa in low transparency water could be explained by favorable transparency level that allow daga to catch their prey efficiently. Moreover, transparency showed no relationship with dagaa biomass in the offshore and gulfs. This possibly because transparency was not an important factor for the distribution of dagaa in the offshore and gulfs. But this does not mean that dagaa prefer very turbid areas, vision is very important for schooling fish like dagaa.

5.3 Population dynamics

Generally, the growth parameters estimated from the von-Bertalanffy growth model were lower than most of the published values from various locations of the lake (Table 3 &7). The average values of L_∞ were lower than those reported by previous studies in Lake Victoria, reflecting a continuing trend towards smaller size. Furthermore, the average values of K which express an instantaneous growth were smaller than reported by previous studies. This also reflects that dagaa has slowed its growth. We observed a great difference in the values of K and L_∞ in the three localities (Speke, Nyanza and Napoleon gulf). This difference could possibly be explained by difference in exploitation pattern and environmental characteristics (Ojwang, 2014; Sharpe *et al.*, 2012). The three populations could have been exposed to different environmental stressors (temperature, different levels of pollutions and oxygen variations) as well as availability of food. These localities exhibit different rainfall pattern and intensity that affect the availability of food, pollution levels and climatic condition (Mkumbo, 2002). In addition, data analyses for Speke gulf were collected in 2001, hence 13 years older than data from Napoleon and Nyanza gulf. This time difference can explain the higher K and L_∞ values in Speke gulf. The level of exploitation was significantly lower in 2001. The K and L_∞ values of dagaa from this study and previous studies conducted in Lake Victoria are lower compared to other closely related short lived pelagic species from other African great lakes. Values of K of 3.05 year^{-1} for *Limnothrissa miodon* with L_∞ of 74 mm total length has been established in Lake Kariba (Marshall, 1987), and a K of 2.52 year^{-1} with L_∞ of 94 mm fork length was established for *Stolothrissa tanganicae* in Lake Tanganyika. As it has been discussed in the previous chapter of this report, fishing efforts differ in different localities in Lake Victoria. Since fish population from different locations are subjected to different stressors, they tend to respond differently, and this will ultimately affect the growth pattern of fish.
The growth performance index is used to compare the population of the same or closely related species from different localities (Pauly & Munro, 1984). The growth performance index for dagaa

differed among the three localities (Table 7). The highest growth performance index of 1.5 was exhibited in Speke gulf, while the lowest index of 1.1 was recorded in Nyanza gulf. Compared to those reported in previous publications, the growth performance was even lower (Table 3 &7). According to Pauly (1998) closely related species should have similar values of growth performance index, even if the L_∞ and K differ, but this does not apply to dagaa. Generally, dagaa exhibit a lower growth performance index compared to other species of the African great lakes. For instance, the Lake Tanganyika *Stolothrissa tanganicae* and *Limnothrissa miodon* have the growth performance index of 4.34 and 4.14 respectively (Chapman & van Nell, 1978; Moreau *et al*., 1991; Marshall, 1987). Marshall (1987) reported the growth performance index for the Lake Kariba *Limnothrissa miodon* to be 4.22. *Eugraulicypris sardella* of Lake Malawi was reported to have the growth performance index of 4.53 (Tweddle & Lewis, 1990).

Fish often reproduce when they have reached about half of the maximum size they are likely to reach (Froese & Pauly, 2015). The mean length and age of fish at which fish of a given population become sexually mature for the first time are important parameters used to monitor whether enough juveniles in an exploited stock mature and spawn (Froese *et al*., 2000). Dagaa now mature at a very small size compared to the previous results reported by other studies in Lake Victoria (Table 9). For instance, Wandera & Wanink, 1992 found that female dagaa matured at 43-44mm and male at 40-41mm. The decrease in the length at first maturity can be associated with higher fishing efforts, as it has been previously explained that the gulfs are the highly exploited areas in the lake. This study further reports the L_m for both the three populations of dagaa were smaller than the L_{opt}. This is in agreement with Froese (2000) who reported that in small fishes the L_{opt} may be smaller than or equal to L_m, whereas in larger fish the L_{opt} is usually larger than the L_m. Beverton (1992) pointed out that, starting maturity at maximum biomass ($Lm \approx Lopt$) would maximize egg production at first spawning, this being an important factor in the reproductive strategy of short lived species with high mortality rate (Froese *et al.*, 2000).

The maximum length (L_{max}) for dagaa was 70 mm SL in Speke Gulf, 56 mm SL in Nyanza Gulf and 50mm SL in Napoleon Gulf. The mean length was 41mm SL in Speke Gulf, 32 mm SL in Nyanza Gulf and 28.4 mm SL in Napoleon Gulf. The L_{max} and mean length for Speke gulf was higher than the rest mainly due to the aforementioned reasons associated with time difference and exploitation rate. The smaller values of L_{max} in Nyanza and Napoleon gulf indicates that, the present commercial catch could be operating on smaller sized dagaa. The findings of this study concur with the current outcry from most dagaa fishers around the lake, that the current recommended legal mesh size of 8-10 mm is too large to catch dagaa (LVFO, 2014). This has triggered the illegal use of mosquito nets and other undersized mesh size for dagaa fishery. The most recent frame survey reported that, the recommended mesh size makes up only 15% of all gears used in the dagaa fishery lake wide (LVFO, 2014). The use of mosquito nets and other illegal nets for dagaa fishery has been common in many parts of the lake (Ojwang, 2014), this if continued can endanger the sustainability of the stock.

The natural and total mortalities estimated in this study were quite high, and were in agreement with those reported by several authors in Lake Victoria (Table 3 & 7). High mortality rate is normal for small short lived pelagic fish like dagaa. Total mortality for the Lake Victoria dagaa is lower compared to other closely related short lived species from other African lakes. Chapman & van Nell (1978) gave a total mortality of 5.2 for *Stolothrissa tanganicae* from Lake Tanganyika.

Eugraulicypris sardella of Lake Malawi was reported to have the total mortality of 12.3, and *Limnothrissa miodon* of Lake Kariba had the total mortality of 8.6 (Marshall, 1987). Fishing mortality was between 0.76 – 1.55 $year^{-1}$ that lie within the values reported by Manyala & Ojuok, 2007, and many other authors in Lake Victoria (Table 3).

Most short-lived species have a maximum life span of 2-3 years. Wanink (1989) reported the life span of dagaa to be between 1-2 years. This study reports the maximum life span of between 2.4-4.2 years. However, this may not reflect the reality since data used for the estimation was collected for less than a year. In addition, the current study converted length of fish to age through length converted curve in FiSAT II, the best approach of using otolith aging technique to estimate the growth and age of dagaa has been recommended in Njiru (1995).

Recruitment is one of the major events in the history of any exploited fish stock as it reflects the size, time and number of new generations added into the fishery. This study found that, dagaa breeds almost throughout the year but with one or two peaks. The peaks in Nyanza gulf was found in April and June, in Speke gulf only one major peak between May and June, and in Napoleon gulf one major peak was found in June and a minor peak in February. These findings partly are in agreement with Njiru (1995) who found dagaa breeding throughout the year in Nyanza gulf, but with two recruitment peaks, one from April to June and other from October to December. Wandera & Wanink (1995) found dagaa has a single recruitment peak and breeds throughout the year, with peaks in October and November in Ugandan waters, and February and March in the Tanzanian waters of Lake Victoria. Okedi (1973) reported the breeding peaks for dagaa to be in June, July and August. However, factors that trigger the variations in reproductive cycle of dagaa is not well understood, but it has been related to biological strategy for the species to cope with the fluctuating environment. Dagaa undergoes high reproductive efforts when the environment is favourable (enough oxygen and availability of food), so that juveniles coincide with favourable condition for their survival (Sharpeet *et al.*, 2012).

The relative biomass per recruit (B'/R) plotted along with the relative yield per recruit (Y/R) has the reference point $E_{0.5}$, that refers to the value under which the stock has been reduced by 50% of its unexploited biomass (Figure 15). The plots computed from FiSAT II show that the fishery is not over exploited. The theoretical $E_{0.5}$ that maximizes surplus production using relative biomass per recruit was 0.465 for Speke Gulf, and 0.358 for Napoleon Gulf. The calculated exploitation rate was 0.26 for Speke Gulf and 0.49 for Napoleon Gulf. The exploitation rate were below the maximum acceptable limit (E_{max}) and biological optimum ($E_{0.1}$). A slightly higher effort below $E_{0.5}$ could be applied to catch dagaa in all the gulfs before it dies by other causes. Since the populations of short lived species are generally unstable, the effort applied to the fishery is recommended to be below $E_{0.5}$ for all the gulfs so as to avoid the risk of recruitment overfishing. However, interpretation of results from the knife edge method should be used with precaution. The danger of using E_{max} estimated from the knife edge model for management could reduce the parent stock to the level that can harm the fishery. Other shortcomings of the knife edge model is that, it is limited to the assumption of steady state which does not apply to most short live species as they tend to fluctuate a lot. Moreover, the model assumes that fish at first length of capture (L_c) are suddenly exposed to fishing mortality which does not apply in a real-life situation, it over estimates the number of old fish and underestimates the young fish retained by the fishing gear (Njiru, 1995). The method can at best give an indication of the level of exploitation (Mkumbo, 2002).

6 CONCLUSIONS AND RECOMMENDATIONS

The highest concentration of dagaa were found in the inshore in shallow waters ≤40m, outside the gulfs. In addition, the offshore waters are increasingly becoming important for dagaa probably due to increase of wind stress. Wind stress has significantly increased in Lake Victoria and was found to be the major driver that influenced the distribution of dagaa. However, this study found limited relationship between other climatic and environmental factors with dagaa abundance, possibly due to the short time series of data used in a large lake with long flushing time. Thus, interpretation of such results should be done with precaution as some of the relationship may occur by chance. Biological communities and their reactions to climatic factors are very complex and sometimes the reaction to the biological communities may be indirect (Marshall, 2012). Further research should be done to understand how climate change could possibly be affecting recruitment pattern of dagaa in Lake Victoria. We recommend establishing a long and regular time series of environmental, climatic, biological and catch data for better and more reliable comparison.

The estimated growth parameters (K, L_∞) showed a continued trend towards a smaller size. Large differences in the values of K and L_∞ were also observed in the different gulfs. Based on the yield per recruit plots, dagaa is not overexploited. A slightly higher effort could be applied to increase the catch before dagaa die by other causes. This effort should be moved to the offshore areas, where dagaa abundance is increasing, instead of the gulfs where it is declining. However, before increasing effort in the offshore waters we recommend conducting lake wide surveys to understand the current biology, population dynamics and reproductive cycle of dagaa which is not well studied in the lake. Effort should be reduced in the gulfs and shallow areas where dagaa breeds to avoid recruitment overfishing. The observed rapid changes in life history of dagaa in the gulfs of Lake Victoria can be the sign of multiple stressors such as high fishing effort, predation and environmental changes. Hence, we recommend enforcement of the current legal mesh size to protect juvenile dagaa in the gulf and near shore shallow areas. Moreover, further research should be done to understand other possible causes of mortalities such predation by other fish, birds, and the quantity of dagaa biomass lost to detritus.

Higher biomass densities of dagaa were found during the rainy season, which also coincided with the highest landings recorded at Kirumba market during the same season. Although these months (October – February) are peak for dagaa catch, the landed dagaa face the problem of poor quality because of the heavy rains that occur during this time. This study recommends improving the processing technology for dagaa so as to increase value of dagaa and prevent post-harvest losses. Increasing the quality of dagaa will contribute to reduction of poverty in the region through increased price of the product that will also attract international markets. In addition, since landing records from Kirumba market have shown a notable trend for the dagaa catch in Lake Victoria (Figure 11), we recommend establishing fisheries statistics offices and improving data handling in other important markets and landing sites lake wide so that the information can be used for the assessment of the stock.

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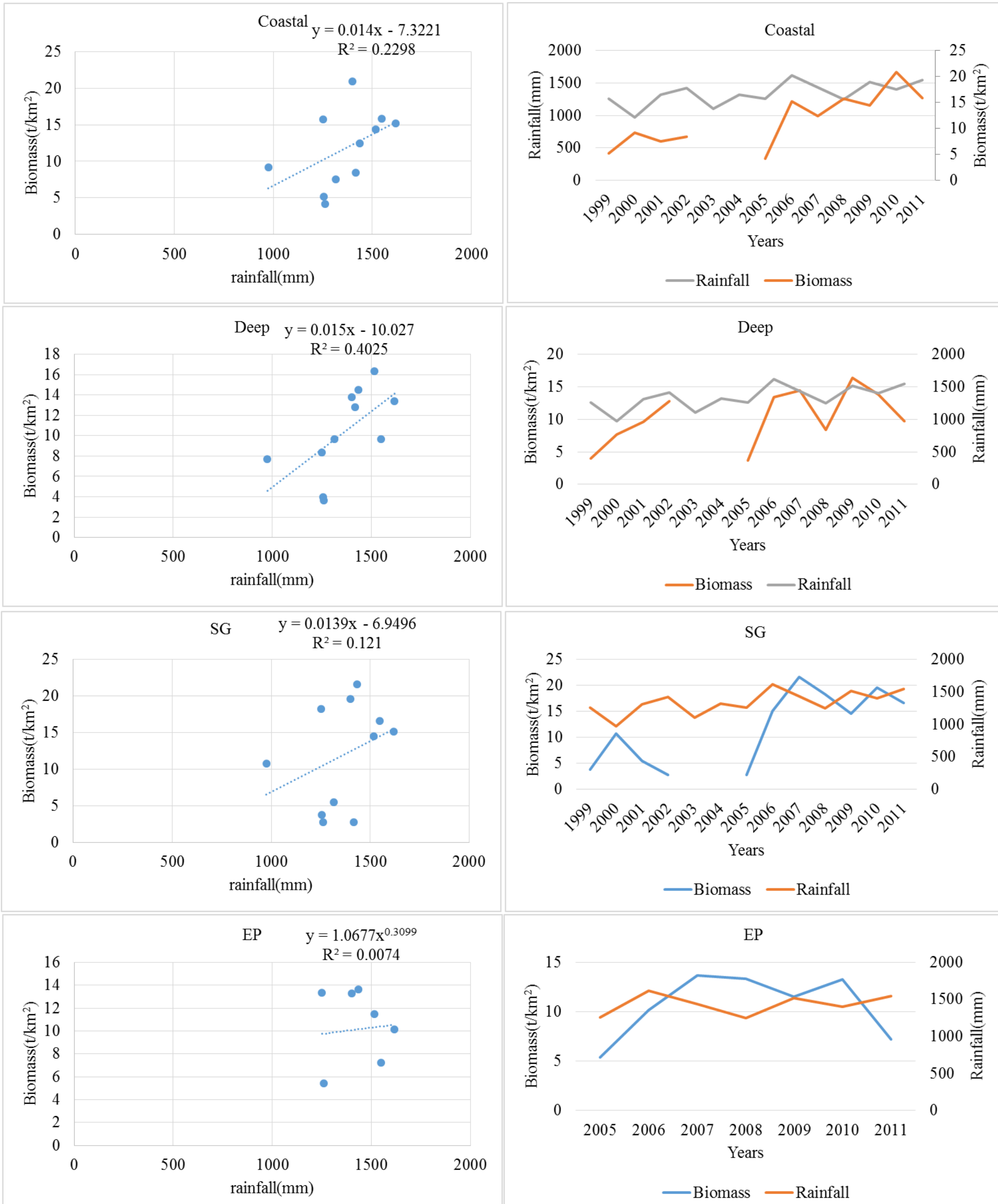
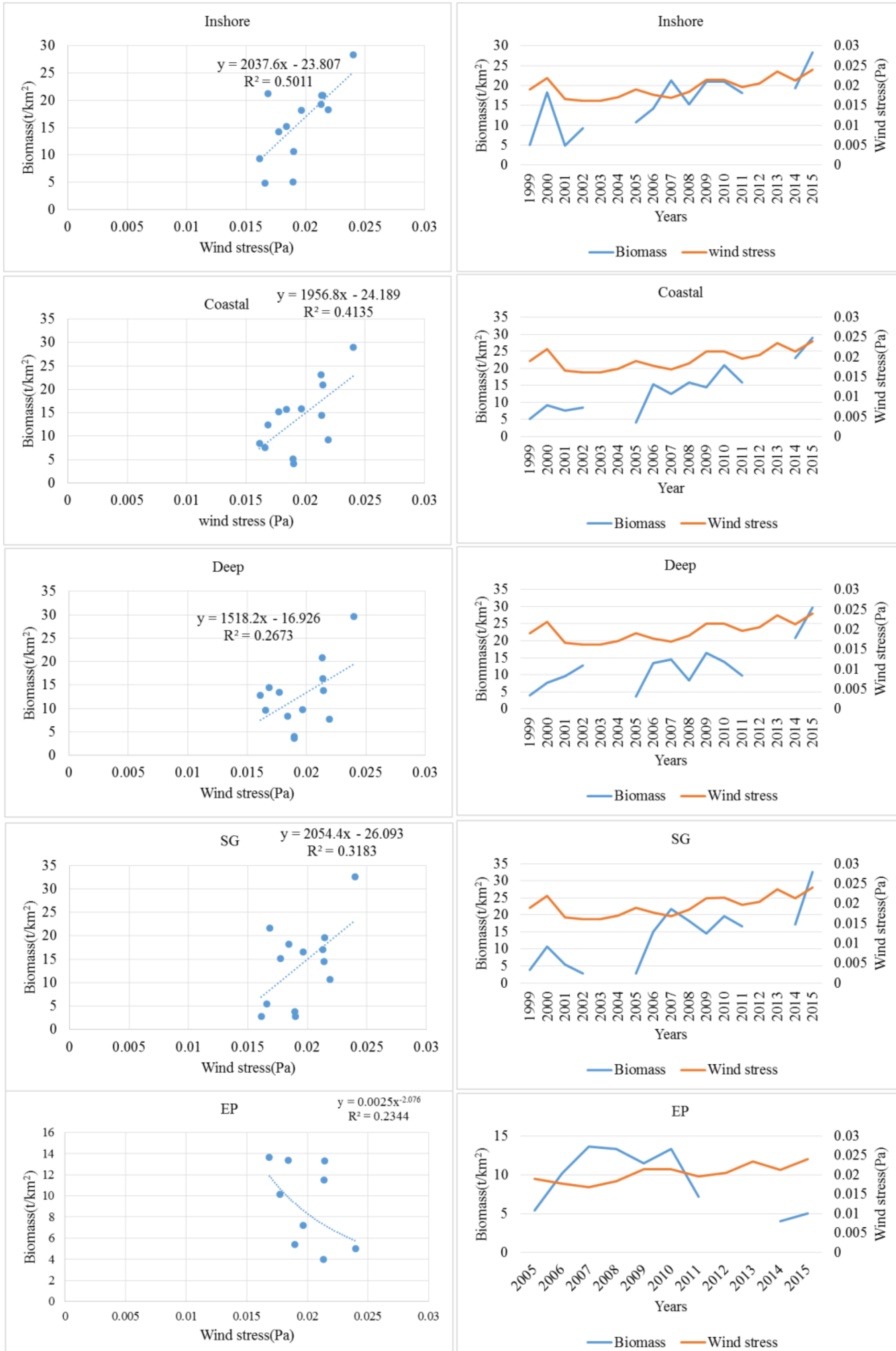
APPENDICES

Appendix 1: Mean biomass (t) and density (t/km2) of dagaa in Lake Victoria estimated through acoustic surveys from 1999 – 2015. The two digits after the year represent the month when the survey was conducted.

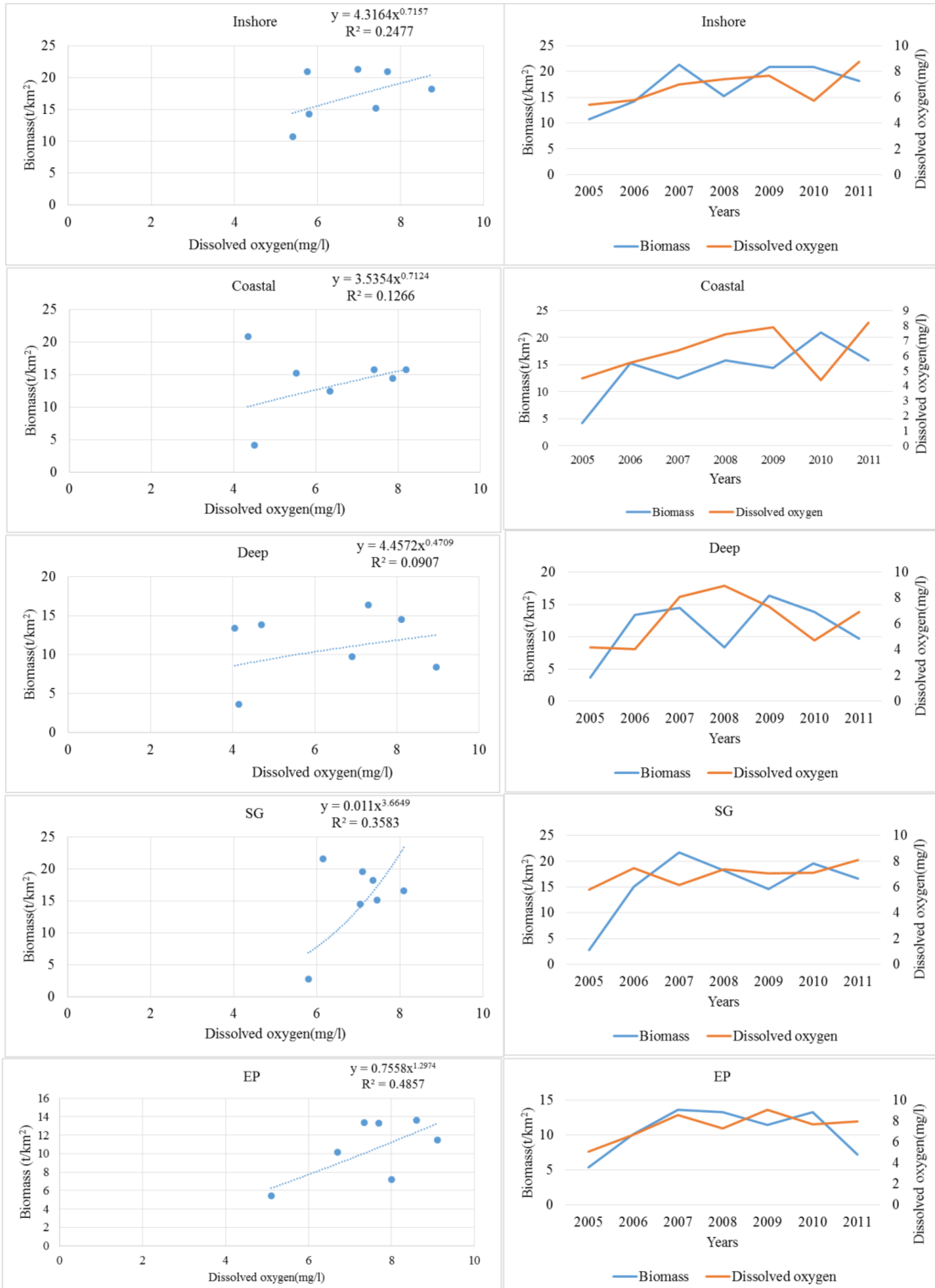
Year& Month	Biomass(t)	Density(t/km^2)
1999.08	212,460.2	3.5
2000.02	773,595.3	15.9
2000.08	320,370.5	5.9
2001.02	735,635.3	12.9
2001.08	274,684.4	5.3
2002.08	513,661.0	8.8
2005.08	518,272.9	10.1
2006.02	1,259,268.1	19.8
2006.08	791,376.4	12.3
2007.02	1,168,536.8	17.7
2007.08	950,431.8	16.0
2008.02	961,861.4	14.6
2008.08	832,997.9	13.5
2009.02	1,340,829.6	22.4
2009.08	860,045.6	12.9
2010.03	1,157,067.2	17.3
2011.09	905,549.3	13.9
2014.09	1,288,815.0	19.1
2015.11	1,530,481.0	23.6



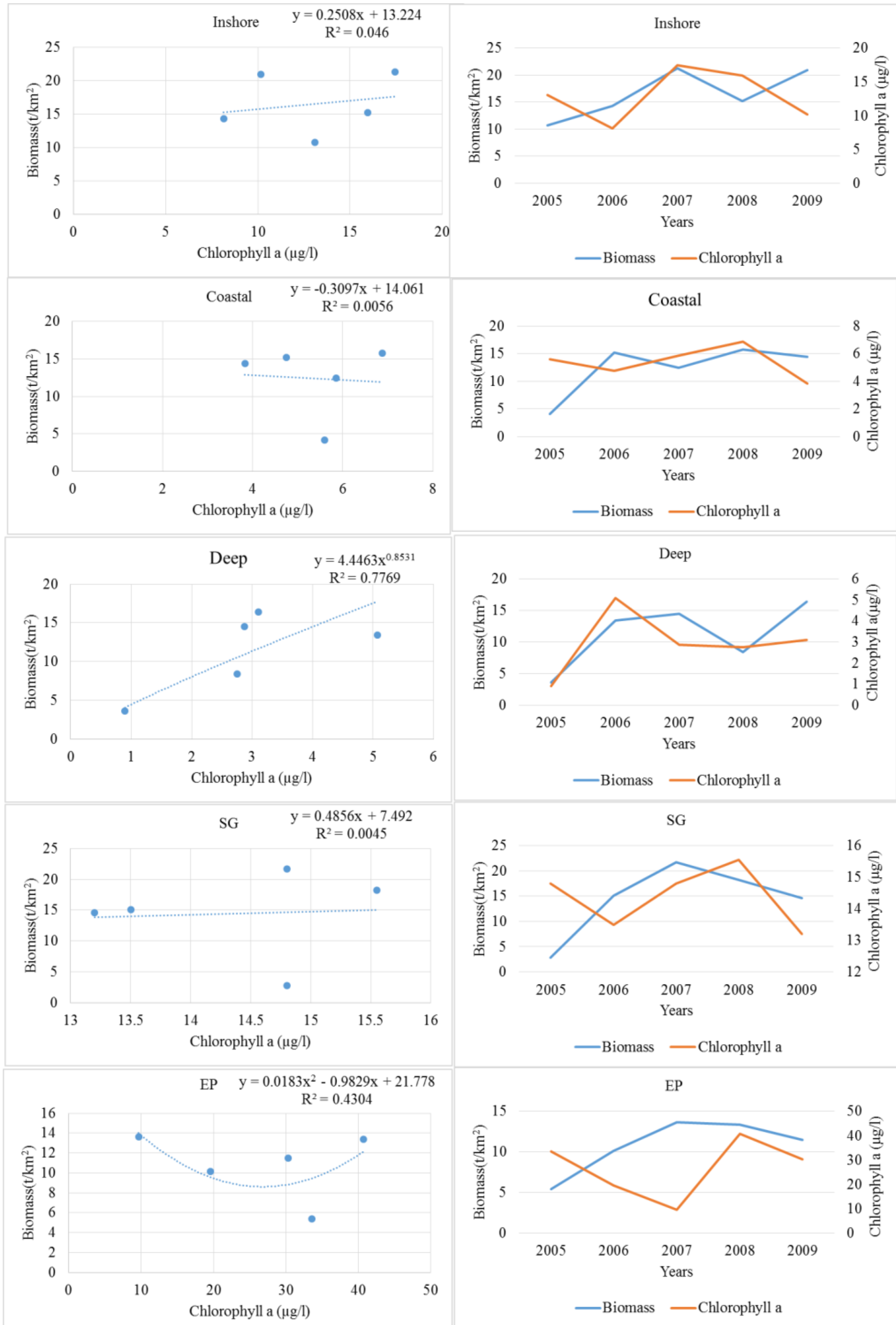
Appendix 2 : Relationship of rainfall and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.



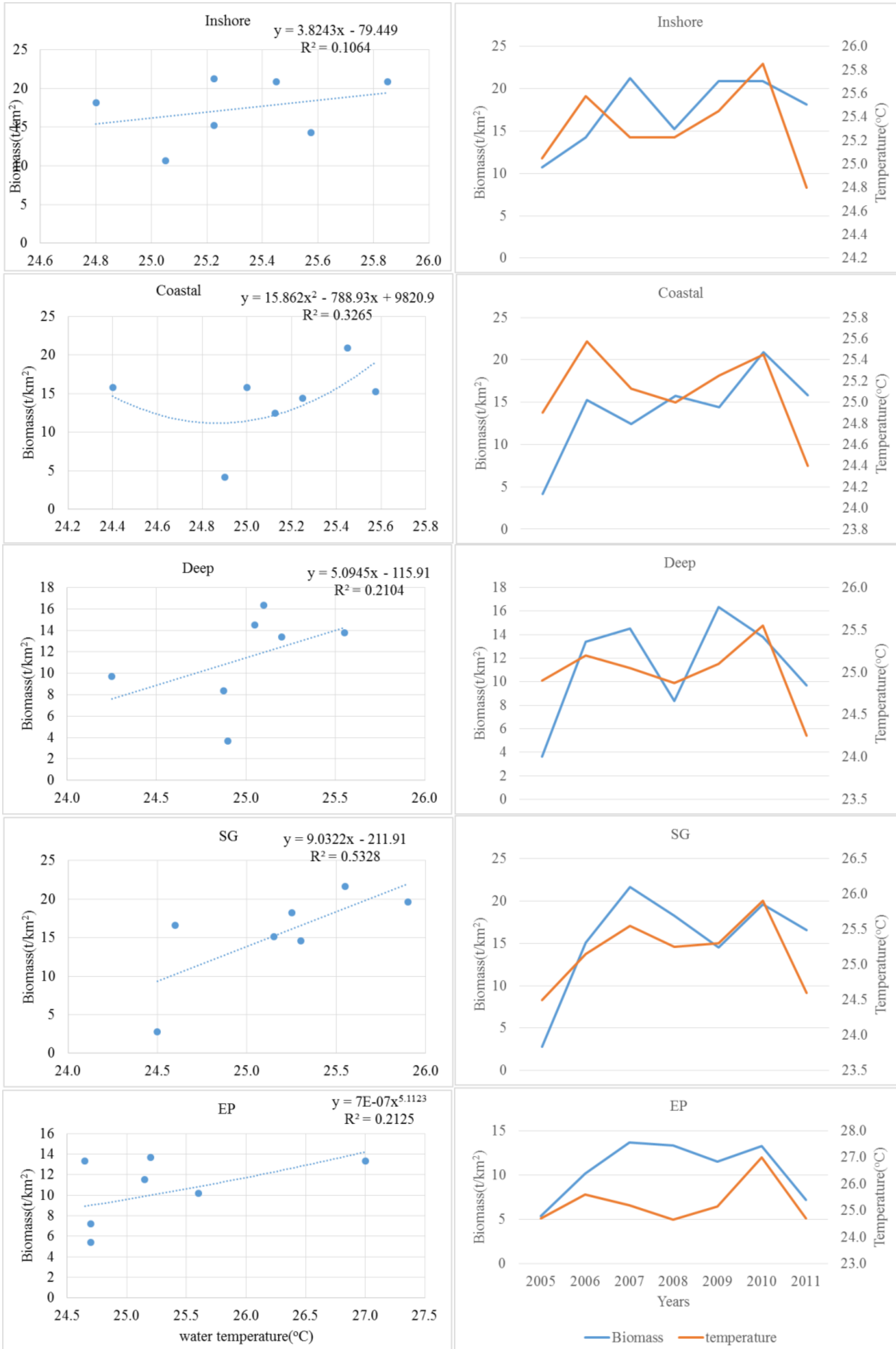
Appendix 3: Relationship of wind stress and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.



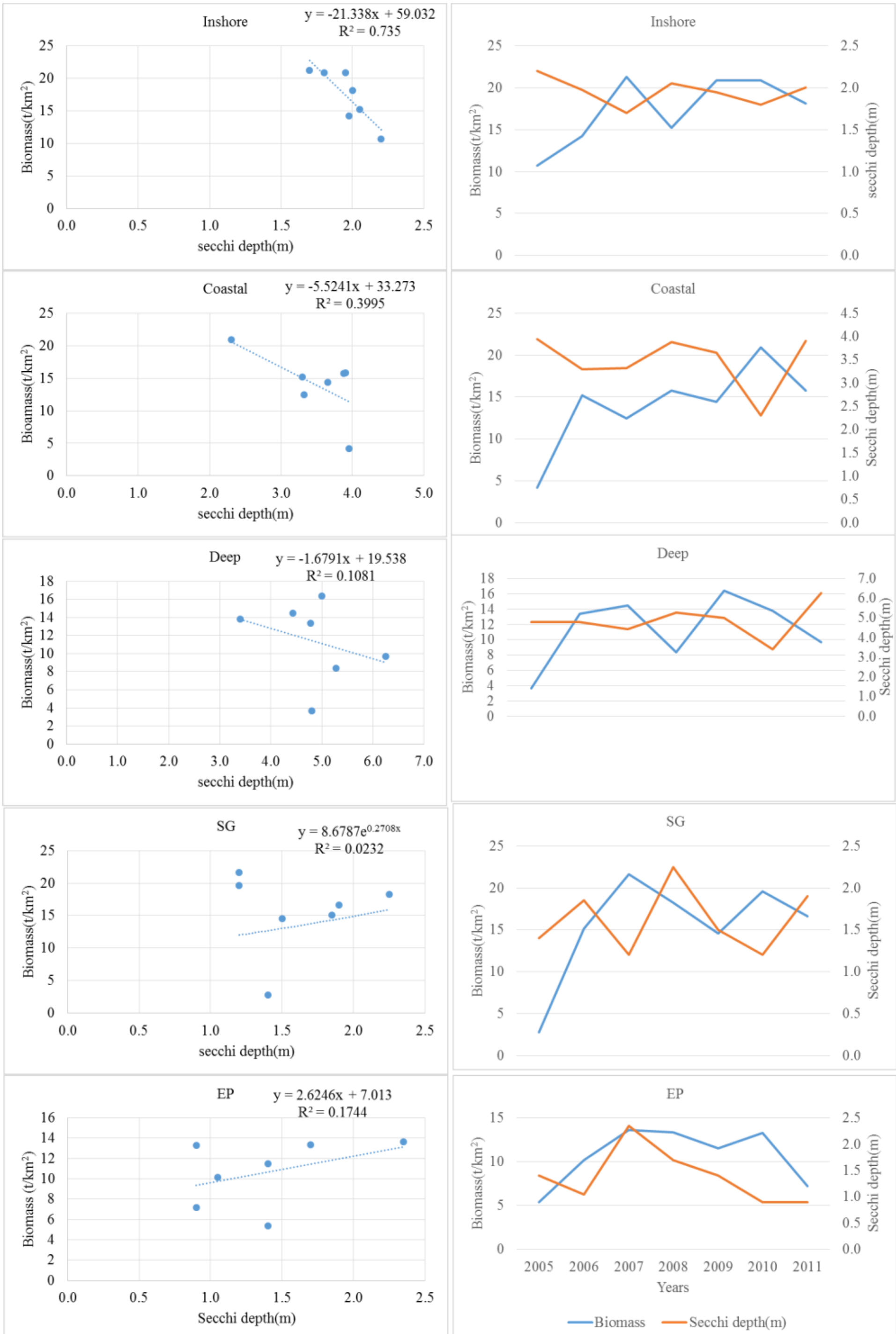
Appendix 4: Relationship dissolved oxygen and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.



Appendix 5: Relationship of wind Chlorophyll a and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.



Appendix 6: Relationship of temperature and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.

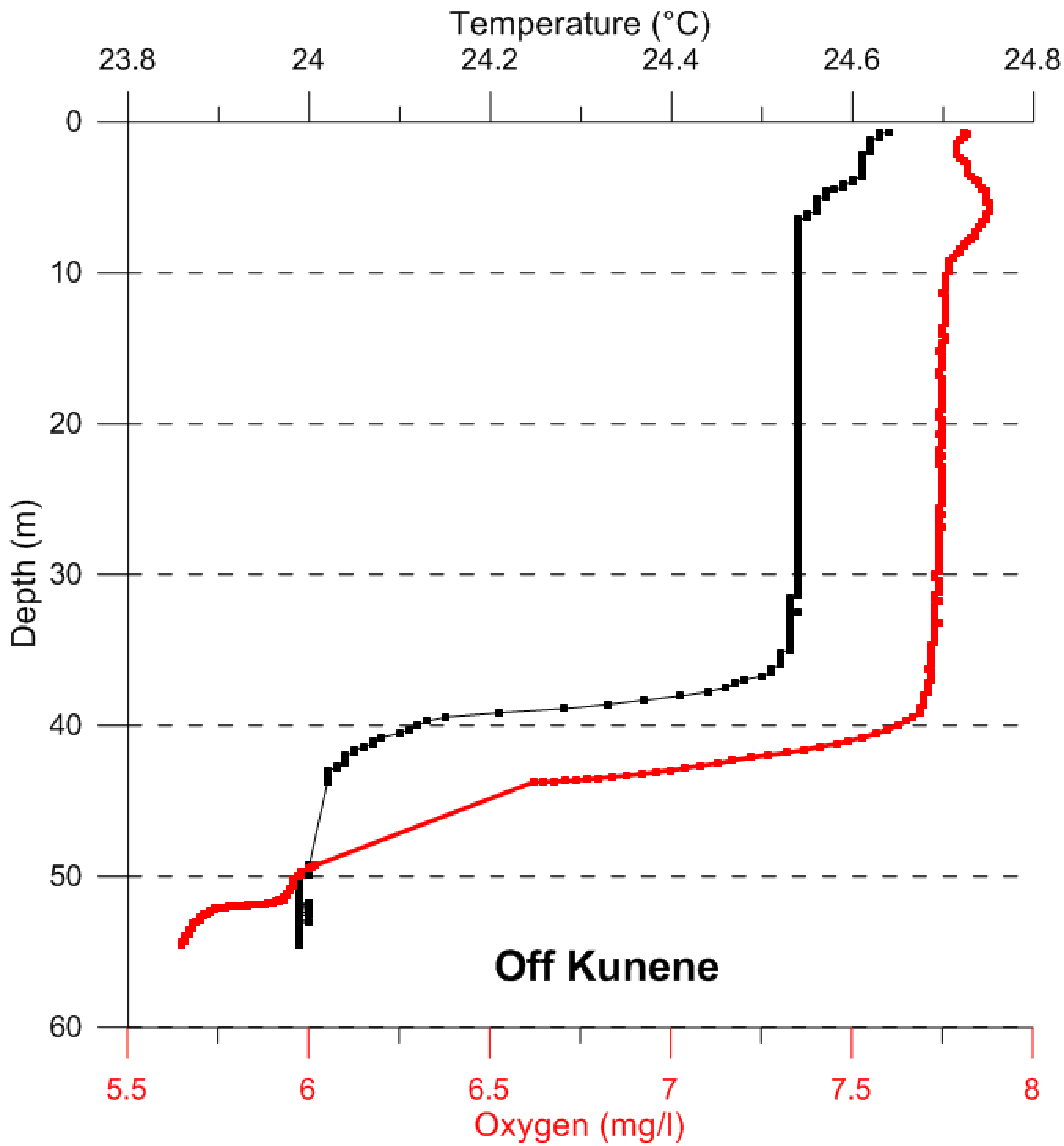


Appendix 7: Relationship of secchi depth and dagaa biomass in Lake Victoria, Tanzanian sector of the lake.

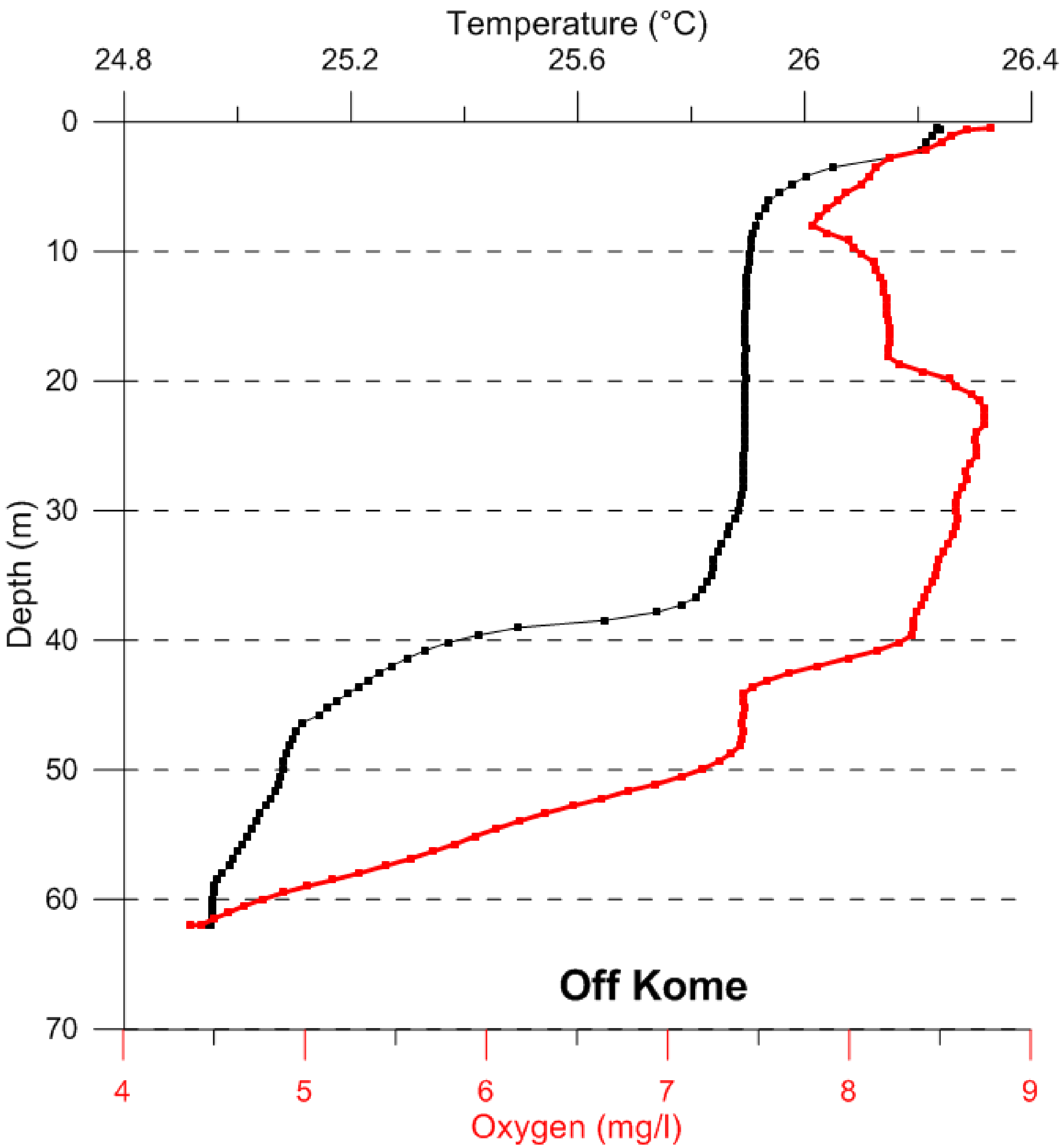
Appendix 8: Mean dissolved oxygen, chlorophyll a, temperature, secchi depth in Lake Victoria. Data was adapted and modified from Hydro acoustic and Regional Stock assessment report of 2014.

Dissolved Oxygen(mg/l)	Year	Coastal	Deep	EP	Inshore	SG
	2000	6.2	5.5		7.5	6.8
	2001	7.6	6.8		8.3	8.4
	2002	7.8	7.3		8.8	8.2
	2003					
	2004					
	2005	4.5	4.2	5.1	5.4	5.8
	2006	5.5	4.1	6.7	5.8	7.5
	2007	6.4	8.1	8.6	7.0	6.2
	2008	7.4	9.0	7.4	7.4	7.4
	2009	7.9	7.3	9.1	7.7	7.1
	2010	4.4	4.7	7.7	5.8	7.1
	2011	8.2	6.9	8.0	8.8	8.1
	2012					
	2013					
	2014	6.3	6.7	7.8	7.5	6.9
Chlorophyll a(µg/l)	2000	4.4	3.5		11.5	16.2
	2001	7.9	9.6		14.8	18.7
	2002	7.9	8.6		16.5	20.0
	2003					
	2004					
	2005	5.6	0.9	33.6	13.1	14.8
	2006	4.8	5.1	19.6	8.2	13.5
	2007	5.9	2.9	9.7	17.5	14.8
	2008	6.9	2.8	40.7	16.0	15.6
	2009	3.8	3.1	30.3	10.2	13.2
Temperature(°C)	2000	24.4	24.3		24.4	24.2
	2001	24.4	24.3		24.5	24.2
	2002	24.4	24.3		24.5	24.1
	2003					
	2004					
	2005	24.9	24.9	24.7	25.1	24.5
	2006	25.6	25.2	25.6	25.6	25.2
	2007	25.1	25.1	25.2	25.2	25.6
	2008	25.0	24.9	24.7	25.2	25.3
	2009	25.3	25.1	25.2	25.5	25.3
	2010	25.5	25.6	27.0	25.9	25.9
	2011	24.4	24.3	24.7	24.8	24.6

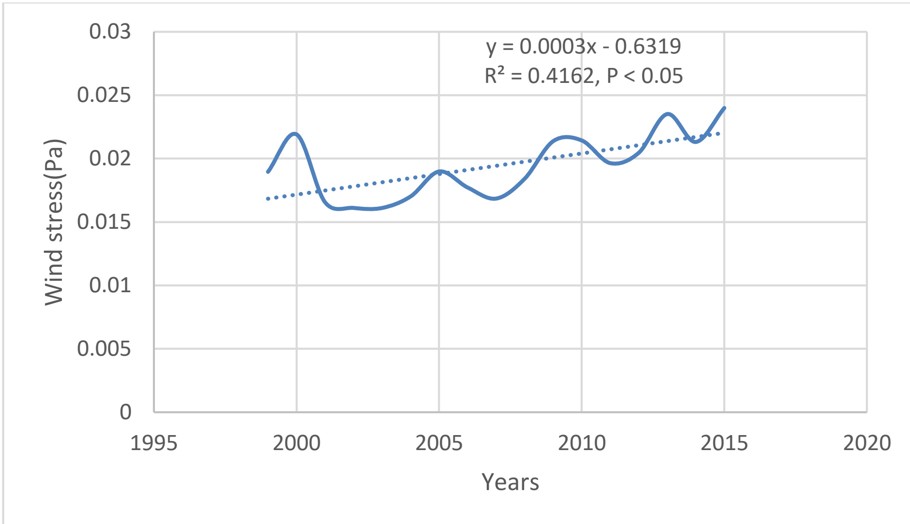
	2014	24.8	24.5	25.1	25.3	25.0
Secchi depth(m)	2005	4.0	4.8	1.4	2.2	1.4
	2006	3.3	4.8	1.1	2.0	1.9
	2007	3.3	4.4	2.4	1.7	1.2
	2008	3.9	5.3	1.7	2.1	2.3
	2009	3.7	5.0	1.4	2.0	1.5
	2010	2.3	3.4	0.9	1.8	1.2
	2011	3.9	6.3	0.9	2.0	1.9
	2012					
	2014	3.5	4.2	1.4	2.1	2.1



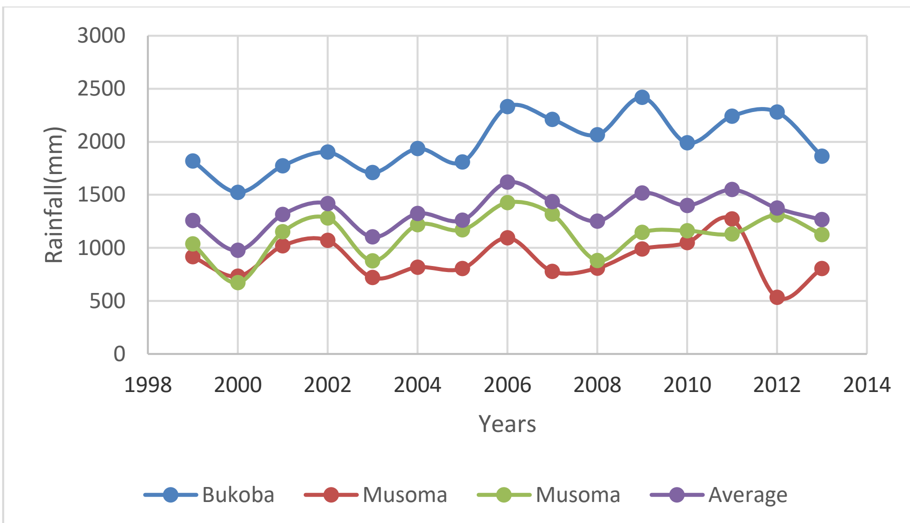
Appendix 9: Oxygen and temperature profiles recorded during the mixing season at one of the offshore sampling station (Off Kunene) in Lake Victoria 2014



Appendix 10: Oxygen and temperature profiles recorded during the stratified season at one of the offshore sampling station (Off Kunene) in Lake Victoria 2008



Appendix 11: Trends of wind stress in the Tanzanian side of Lake Victoria



Appendix 12: Total rainfall as recorded from three regions bordering Lake Victoria, Tanzanian side. Total rainfalls from the three regions are averaged to represent the whole Tanzanian part of the lake

Appendix 13: Schematic presentation of the dagaa fishery in the Tanzanian side of Lake Victoria

<table>
<tr><td colspan="2">Low trading season</td><td colspan="3">?</td><td colspan="4">High trading season</td><td colspan="3">Low trading season</td></tr>
<tr><td colspan="2">High catch</td><td colspan="3">Moderate catch</td><td colspan="4">Moderate catch</td><td colspan="3">High catch</td></tr>
<tr><td colspan="5">Biomass high</td><td colspan="4">Biomass low</td><td colspan="3">Biomass high</td></tr>
<tr><td>Partial mixing</td><td colspan="2">Strong stratification</td><td colspan="2">Partial mixing</td><td colspan="4">Complete mixing</td><td colspan="3">Partial mixing</td></tr>
<tr><td colspan="5">Long rain season</td><td colspan="4">Dry season</td><td colspan="3">Short rain season</td></tr>
<tr><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>