EFFECTS OF STOCKING DENSITY ON THE PRODUCTION OF NILE TILAPIA (*OREOCHROMIS NILOTICUS)* IN FLOATING NET CAGES ON THE VOLTA LAKE

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Declaration

H d cd dc d c d da cdb d d d bd d d d work that have been duly cited, this research was done by me and that no part of the work has been presented for any other degree in this University or elsewhere.

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Dedication

To my family, especially my Dad - Mr. Christian Asase who taught me positive attitudes and the importance of hard work, perseverance and sacrifice in life.

In ever loving memory of my dearly beloved

Gilbert, Gertrude and Tawiah Bansah.

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Abstract

Stocking density is an important factor affecting fish production in cages. However, information related to its impact on the growth performance of Nile tilapia *Oreochromis niloticus* fingerlings during cage culture under the ecological conditions of the Volta Lake in Ghana is limited. Hence, healthy *Oreochromis niloticus* fingerlings (2.12 ± 0.02 g) were randomly stocked in triplicate 8 m^3 cages at densities of 50 fish/m^3, 100 fish/m^3 and 150 fish/m^3 and fed a commercially extruded diet (30% Crude Protein) to evaluate their growth and economic feasibility. After 177 days of culture, differences in growth (weight gain and final weights) at these densities were significant ($p < 0.05$). Fish stocked at 50 fish /m^3 exhibited the highest average weight gain (271.98 ± 0.39 g) while fish stocked at 150 fish/ m^3 had the lowest (169.15 ± 0.49 g). There were significant effects ($p < 0.05$) of stocking density on daily weight gain, specific growth rate and survival rates. Moreover, the feed conversion ratio and protein efficiency ratio were significantly affected by stocking densities ($p < 0.05$). However, differences in daily weight gain, specific growth rates, condition factor and profit index were not significant ($p > 0.05$) between the 100 fish/m^3 and 150 fish/m^3 treatments. The production (10.697 - 22.48 kg/m^3), net yield (84.55 177.25 kg/cage) and F G 52 62 229.8) showed significant ($p < 0.05$) increase with higher stocking densities. Apart from dissolved oxygen which declined below optimal concentrations in February 2012, the levels of water quality parameters measured remained within suitable ranges for Nile tilapia growth throughout the experiment. The study demonstrated that cage farmers can utilize stocking densities of 50 fish/m^3 and 150 fish/m^3 effectively for larger size demand over a six months period and augmented production respectively.

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List of Abbreviations and Acronyms

APHA - American Public Health Association

ARDEC - Aquaculture Research and Development Center

AWWA - American Water Works sqAssociation

DOF - Directorate of Fisheries

EDTA - Ethylene diamine tetra-acetate

FAO - Food and Agriculture Organization

GDP - Gross Domestic Product

GMT - Greenwich Mean Time

ICLARM - International Centre for Living Aquatic Resources Management

MOFA - Ministry of Food and Agriculture

PVC - Polyvinyl Chloride

SME - Small and Medium Scale Enterprises

SPSS - Statistical Package for Social Sciences

UBC - University of British Colombia

UN - United Nations

WHO - World Health Organization

CHAPTER ONE

INTRODUCTION

1.1. Background information

Fish and fishery products constitute an extremely important source of protein and nutritional security for many people all over the world (FAO, 2012). Fish are low in collagen content, have a nutrient profile superior to all other sources of animal protein and its digestibility is high - as almost every nutrient is absorbed (WHO/FAO, 1999). The protein derived from fish contains all the necessary amino acids - as high as 60% on dry matter basis (Alatise *et al.*, 1 / / 5(ddcdc b c d wth.

The consumption of fish cuts across many ecological races and cultures worldwide (Alhassan *et al.*, 2012; FAO, 2012). In Africa, fish serves as food and provides nutritional security to about 200 million people (Béné and Heck, 2005). It is also the most important source of animal protein for majority of Ghanaians ranging from the rural poor to the urban rich (Aggrey-Fynn, 2001). In 2011, the average per capita fish consumption in Ghana was 23.7 kg per annum (MOFA, 2012) which was higher than both the world and Africa averages of 18.6 and 9.1 kg respectively (FAO, 2012), making Ghanaians one of the largest consumers of fish worldwide. The consumption rate is expected to increase because many Ghanaians prefer fish protein compared to other animal sources due to the relative advantages of fish pertaining to cost, nutritional value and taste.

The annual fish requirement in Ghana is estimated at 880,000 tonnes while production is 420,000 tonnes, leaving an annual deficit of 460,000 tonnes (MOFA, 2010). The nation is thus not self- b d c b V d b db d c from capture fisheries being limited, coupled with the issue of increasing population growth rate (2.3% in 2012), the demand for fish will continue to increase.

Over the years, the deficit has been made up for, through importation of mostly low quality fish. This account for about 50% of the national fish consumption yearly (Orchard and Abban, 2011). According to Onumah and Acquah (2010), the nation spends about US $125 million yearly out of her scarce foreign exchange on importation of mostly frozen fish to d d S d d d d d d F db c c security (UN, 2009).

Aquaculture was promoted by the government of Ghana to take advantage of its huge potential in the country, to progressively bridge the gap between domestic fish demand and supply (Onumah and Acquah, 2010). Its development has over the years been recognized as playing vitally important roles in meeting the growing demand for fish in Ghana.

Since 2003, aquaculture production has increased from 950 tonnes to 3,257 tonnes in 2007; 5,600 tonnes in 2008, 7,203 tonnes in 2009, 10,200 tonnes in 2010 and 19, 092.5 tonnes in 2011 (MOFA, 2012). This steady increase in production over the last decade suggests that b d d d b b a d F c b d future.

The tilapias and the clariid catfishes (*Clarias gariepinus* and *Heterobranchus* sp. respectively) have been the main focus of development efforts in aquaculture for subsistence and commercial purposes in Ghana (Agbo *et al.*, 2011). Nile tilapia, *Oreochromis niloticus*, is considered the most important tilapia species for aquaculture throughout the world, accounting for over 70% of cultured tilapia (Fitzsimmons, 2004). It is undoubtedly the species of great importance for aquaculture in Ghana (Attipoe, 2006; Ofori *et al*., 2010). It has severally been communally cultured with other species like Catfishes (*Clarias* and *Heterobranchus spp.*), Bony tongue (*Heterotis niloticus*) and Snakehead (*Chana obscura*) (Attipoe and Agyakwah, 2008).

The most common and versatile structures for culturing Nile tilapia has been earthen ponds (Bardach *et al*., 1972), but land-based aquaculture is mostly expensive and lands are limited in Ghana (Anane-Taabeah *et al*., 2011). The systems of production have moved consistently from predominantly extensive and semi-intensive culture in earthen ponds to intensive water-based culture in cages. Currently, aquaculture production with respect to culture systems in practice are about 80-85% in cages, 7.6% from pond sources and 7.2% being derived from other holding forms such as pens and reservoirs (McCarthy *et al.*, 2010; MOFA, 2012). This shows that the cage industry has a huge potential for fish production in Ghana.

The intensive cage aquaculture will continue to increase rapidly because the country offers considerable opportunity, especially in the Volta Lake (Anane-Taabeah *et al*., 2011). The government of Ghana has also in recent times concentrated efforts into promoting cage culture.

Ofori *et al.* 1/0/(d dc 0 d d bd d 76// ^{2}) has been allocated to cage aquaculture by the government. Consequently, cage culture is assuming an important option for a number of farmers and investors in the country.

The number of new small, medium and large-scale commercial entrants into the cage business has increased at a very fast rate while the older farms such as Tropo, Crystal Lake and West Africa Fish Limited have expanded their operations (TICOMFFE Project, 2011). Approximately 89% of the cage farms are presently concentrated around the Eastern and Volta regions (MOFA, 2012), specifically around the Kpeve to Kpong stretch of the Volta Lake System and Nile tilapia is the only species cultured in cages (Attipoe, 2006; Blow and Leonard, 2007; Ofori *et al.,* 2010). It has been estimated that if cage farmers in Ghana can produce tilapia yields of 50 -150 kg/m^3/9 months as done elsewhere in Africa, less than 100 hectares of fish cages can produce yields matching the current capture fisheries production (Ofori *et al.,* 2010).

This rapid growth in the cage business is affected by a number of constraints. Unavailability and high cost of quality fingerlings, lack of technical know-how with respect to culture and stocking densities, high cost of cage construction and quality feed as well as lack of access to information and support constitute major limiting factors to the development of cage aquaculture in Sub-Saharan Africa (Ridler and Hishamunda, 2001; Halwart and Moehl, 2006; Blow and Leonard, 2007; Asmah, 2008). In Ghana, lack of good quality fingerlings, feed and credit facilities have been emphasized as being critical elements in the development of the cage industry (Agbo, 2008; Amissah *et al.*, 2009).

1.2. Justification

Fingerling production and availability has remained a significant bottleneck to the continued expansion of tilapia cage culture throughout the world (Green, 2006) and Ghana due to the rapid growth in the cage business. A widely-practiced strategy in the country is the purchase of sex-reversed male fingerlings from hatcheries available - among them Tropo Farm, Crystal Lake, Jassa Farms, Fish Reit, Anson-Greenfields, Triton, and Aquaculture Research and Development Centre (Ofori *et al.*, 2009). The outputs of fingerlings from the hatcheries do not currently meet the demand of aquaculturists in the country. There is an intense pressure on the hatcheries from particularly small-scale cage operators who rely solely on them for fingerlings (Personal communication, Dr. Felix Attipoe, Officer in Charge of ARDEC, July, 2012).

Previously, cages were stocked with fingerlings weighing 10 - 30 g (Attipoe, 2006; Ofori *et al.*, 2009) but the difficulty in procuring these weights of fingerlings has now compelled farmers to stock cages with relatively smaller fingerlings (post-treated fry to 5 g) to avoid wasting time while waiting for bigger-sized fingerlings. With this shift, there has been a considerable debate with respect to the stocking densities to utilize in cages. This is because stocking densities have significant influence on the profitability of cage businesses (North *et al.*, 2006).

Stocking density has been demonstrated as a crucial variable affecting fish survival, growth performance, behaviour, health, water quality, feeding, and yield in many studies (Liu and Chang, 1992; Huang *et al.*, 2002; Rui *et al.*, 2006; Sánchez *et al.*, 2010).

Currently, most of the new small and medium-scale commercial entrants into the cage culture business in Ghana do not have adequate technical knowledge with respect to stocking density. They are observed to use a combination of intuition and experience to decide upon the most appropriate stocking density, using codes of practice and handbooks as guides.

Although Attipoe (2006) observed that fingerlings in Ghanaian cages are stocked at 60 m^3 to 150 m^3 and Ofori *et al.* (2009) stated rates of 63 to 188 fish/m^3 for fingerlings weighing 10 g to 30 g in the Volta Lake, there has been no previous attempt to systematically survey the current stocking densities practiced by the emerging small-scale cage operators on the Volta Lake. Knowledge of the current practice is therefore vital to judge the impact of imposition of any density limits on economic environmental sustainability.

Elsewhere, several studies have been undertaken to investigate the effects of stocking density on growth and survival rates (Hitzfelder *et al.*, 2006; Gibtan *et al.*,2008; Moyle *et al.*, 2009; Osofero *et al.*, 2009) welfare, condition state and physiological parameters (Araneda *et al.*, 2008; North *et al.*, 2006; Tolussi *et al.*, 2010), water quality (Suresh and Lin, 1992), and technical parameters such as yield and productivity (Hengsawat *et al.*, 1997; Rowland *et al.*, 2006). These studies yielded varied optimal densities for effective cage management in their respective regions.

It is however difficult to generalize and incorporate the findings of the various authors into F b d S adb d d d d bdc d d d fish strains and sizes for cage stocking. It is therefore beneficial to evaluate the effects of different stocking densities on the production (growth performance, survival, yield and profitability) of *Oreochromis niloticus* in the Ghanaian context and under the climatic and ecological conditions prevailing in the Volta Lake where the cage business is assuming a geometric growth.

1.3. Main objective

The primary objective of the current study was to compare the production performance of *Oreochromis niloticus* stocked at different densities in floating net cages on the Volta Lake.

1.3.1. Specific objectives

a. To conduct a survey study to collate information from small-scale cage farmers within the Asuogyaman District with respect to their current fingerlings stocking practices.

b. To compare the effects of different stocking densities on the growth performance (growth rates, condition factor and coefficient of variation) and survival of *Oreochromis niloticus* in floating net cages.

c. To determine the effects of different stocking densities on food utilization (food conversion ratio and protein efficiency ratio) of *Oreochromis niloticus* in cages.

d. To monitor the levels of some water quality parameters (temperature, dissolved oxygen, pH, ammonium, nitrite, nitrate, phosphate, total alkalinity, and total hardness) in the vicinity of the cages during the period of the study.

e. To determine the yield and profitability of the stocking densities tested in order to establish the most cost effective stocking density.

1.4. Hypotheses

a. Stocking density does not significantly affect the growth performance and survival of *Oreochromis niloticus* cultured in floating net cages.

b. There is no significant difference in the feed utilization efficiency of *Oreochromis niloticus* stocked at different densities in cages.

c. Some water quality parameters of the Volta Lake have no significant effect on the growth and survival of experimental fish.

d. There is no significant difference in the economic yield and profitability of *Oreochromis niloticus* reared at different stocking densities.

CHAPTER TWO

LITERATURE REVIEW

2.1. Global Overview of Fisheries and Aquaculture

Fish is an extremely important source of food and nutritional security, especially in the developing world. Global consumption of fish has doubled since 1973, and the developing world has been responsible for over 90% of this growth (Brummett and William, 2000; Béné *et al*. 2007). The global per capita fish consumption was estimated at 18.6 kg in 2010 (FAO, 2012).

The worldwide fisheries sector (both capture and aquaculture) supplied about 148 million tonnes of fish in 2010. Out of this, about 128 million tonnes were utilized as food for people. Preliminary data for 2011 indicate increased production of 154 million tonnes, of which 131 million tonnes were also destined as food (FAO, 2012). With sustained growth in fish production, world fish food supply has grown dramatically in the last five decades, with an average growth rate of 3.2% per year in the period between 1961 and 2009 (FAO, 2012).

The global fisheries sector also provided livelihoods and income for an estimated 54.8 million people engaged in the primary sector of fish production in 2010 (FAO, 2012). It directly employs over 36 million people worldwide, 98% of them in developing countries and indirectly supports nearly half a billion people as dependents or in ancillary occupations (Richardson *et al.*, 2011).

b d cd dc a d E N d b b c molluscs, crustaceans, and aquatic plants. Farming implies some form of intervention in the process to enhance production, such as regular stocking, feeding, protection from predators, d b H d d b a d b dc D d c 1 / / 2(The contribution of aquaculture to global fisheries has increased steadily over the years, from 20.9% in 1995 to 32.4% in 2005 and 40.3% in 2010 (FAO, 2012).

The world population is increasing as is the demand for aquatic food products. The global consumption of fish has doubled since 1973, and the developing world has been responsible for over 90% of this growth (Brummett and William, 2000; Béné *et al*. 2007). Total world fisheries in 2010 were 148 million tonnes, of which 128 million tonnes were utilized as food for people. Preliminary data for 2011 indicate increased production of 154 million tonnes, of which 131 million tonnes were also destined as food (FAO, 2012). Predictions show that capture fisheries will not meet the growing global demand for aquatic food in the future. This is because most of the main fishing areas have reached their maximum potential yield (FAO, 2012).

Aquaculture has been the world's fastest growing food sector for the past two decades and half of all fish eaten are farmed rather than caught. The global average per capita consumption of farmed fish increased from 1.1 kg in 1980 to 8.7 kg in 2010 at an average rate of 7.1% per year (FAO, 2012).

The contribution of aquaculture to world fisheries has increased steadily over the years, from 20.9% in 1995 to 32.4% in 2005 and 40.3% in 2010 and the reported grow-out in production is almost entirely destined for human consumption (FAO, 2012). The majority of aquaculture is practiced in freshwater and is mostly dominated by fin fishes. Production of freshwater fish has always been dominated by carps (71.9%, 24.2 million tonnes, in 2010) that are grown in China, India and parts of Europe. The tilapias come next to carps and have a wide distribution. Approximately 72% are raised in Asia (particularly in China and Southeast Asia), 19% in Africa, and 9% in America (FAO, 2012).

2.2. Sub-Saharan Africa Aquaculture

Fish provides protein and micro-nutrition to about 200 million people in Sub-Saharan Africa (Béné and Heck, 2005). The fishery resources are of great social and economic value to Africa but are considered by many to be largely unrecognized and not utilized to their full potential.

Aquaculture in Sub-Saharan Africa is still at its infancy stage and until now, the region continues to be a minor player providing less than 0.6% of global aquaculture, although the tilapia species most cultivated in the world originate from Africa (FAO, 2012). However, it has been advocated as an option to fulfill the increasing demand for fish products following the decline of wild capture fisheries - both marine and freshwater.

Despite challenges of ineffective institutional arrangements and its dependence on donor funds, there have been promising examples where aquaculture has demonstrated its competitiveness from Senegal, Ghana, The Gambia and Nigeria, producing fish that feeds low on the food chain in a range of well adapted environments, and providing profitable farming systems that meet the needs of user groups.

Aquaculture has entered a steady phase of expansion with a three-fold increment in the past seven years in Africa and this growth has largely been achieved through the development of small and medium enterprises (SMEs) in aquaculture. The industry provides jobs, earns or saves foreign exchange and creates wealth for the investors (Brummett and Williams, 2000).

The vast majority of farmed fish in Africa is freshwater, mainly the Nile tilapia and catfish. These omnivorous fish are relatively easy to raise, and there is strong demand for them. Nigeria leads in the region, with reported production of catfish, tilapia and other freshwater species. But there are many species of greater importance such as black tiger shrimp (*Penaeus monodon*) in Madagascar, *Eucheuma* seaweed in the United Republic of Tanzania and abalone (*Haliotis* spp) in South Africa (FAO, 2006). New strains of the Nile tilapia released in Egypt, Ghana and Malawi are up to 30% faster-growing than traditional strains, and have been heralded as a leap forward for African aquaculture (Ofori *et al.*, 2010).

The principal aquaculture export products from countries in Africa are mariculture products, mainly shrimp, abalone and seaweed. Shrimp are exported frozen (Madagascar and Mozambique), seaweeds are exported dry (United Republic of Tanzania, Madagascar and Mozambique) and 80-85% of abalone produced in South Africa is exported live and the remainder is canned (FAO, 2006).

The Sub-Saharan Africa aquaculture industry has great potential to meet the increasing demand for aquatic food in most regions of the world. However, the sectors (fisheries organizations, governments and farmers) face significant challenges because fingerling availability, quality and distribution remain a serious constraint to non-commercial and commercial aquaculture enterprises. Feed availability, quality of seed, distribution of fingerlings and acceptable food conversion ratios also remain major constraints to both non-commercial and commercial producers (Halwart and Moehl, 2006; Moehl *et al*., 2006; Blow and Leonard, 2007; Asmah, 2008).

2.3. Aquaculture in Ghana

Fish contributes over 60% of the Ghanaian protein intake (Asmah, 2008). Most of the total domestic fish produced are consumed locally. Fish production contributes substantially to the national economy through employment, gross domestic product (GDP), foreign exchange earnings, food security and poverty reduction. The fishery sector contributes between 3% and 4.5% of the national Gross Domestic Product and generates US$ 80 billion through export income annually (Orchard and Abban, 2011).

F d d db b d c d d db d d d b d from subsistence to industrial. Within this range, fish stocks are mainly exploited from the marine sub-sector, and to a lesser extent, inland (freshwater) fisheries and aquaculture.

Aquaculture (fish farming) is relatively new to Ghanaians when compared to most Asian countries. Its practice is however becoming widespread in many parts of the country especially in the Ashanti, Central, Eastern, Volta and Western regions (MOFA, 2012). The contribution of aquaculture to the Ghanaian economy has not been disaggregated from the overall contribution of fisheries, so its importance is not fully recognized (Cobbina and Eiriksdottir, 2010). In recent years production from aquaculture appears to be growing at a near exponential rate. The total production has increased from 950 tonnes in 2003 to 3, 257 tonnes in 2007; 5600 tonnes in 2008, 7203 tonnes in 2009, 10200 tonnes in 2010 and 19,092 tonnes in 2011 (MOFA, 2012). It has been estimated that the production from ponds and culture-based fisheries is worth about US$ 1.5 million a year (Cobbina and Eiriksdottir, 2010).

2.3.1. Types of Production Systems

Fish farming in Ghana is comprised largely of small-scale farmers who practice on a subsistence basis using the intensive and semi-intensive systems of production in cages and earthen ponds respectively. However in recent times there are a few people who are producing on commercial basis using intensive systems. The production rate of small-scale operators alone has been estimated at 1.5 tons/ha/yr (MOFA, 2012).

According to a survey conducted by the Directorate of Fisheries in 2006, production from the few commercial operators accounted for about 75% of the total production from aquaculture. It was thus concluded that these commercial initiatives contributed to the rapid increase in production and have also provided employment (DOF, 2007).

2.3.2. Types of Fish Cultured

The predominant fish species cultured in Ghana are tilapia, catfish and *Heterotis* (Prein and Ofori, 1996). The tilapias represent about 80% of cultured fish and the remaining 20% is comprised of catfish (*Clarias gariepinus)* and *Heterobranchus* species (Cobbina and Eiriksdottir, 2010). Nile tilapia (*Oreochromis niloticus*) is the main fish species cultured either as mixed-sex or all-male in earthen ponds and is the sole tilapia species cultured in cages (Attipoe, 2006). Other species which have been introduced and grown on an experimental scale are *Oreochromis macrochir*, silver carp and tiger prawn (*Penaeus monodon*) (Cobbina and Eiriksdottir, 2010).

2.3.3. Types of Production Facilities

Aquaculture development efforts in Ghana have been almost entirely in freshwater environment and no projects have yet been developed in marine environments. Fish farming takes place in earthen ponds, pens, brush parks (*acadjas*), and cages.

Until recently the most common systems of farming has been earthen ponds, with majority of them occupying less than 0.5 ha, with a median of only 0.06 ha (Asmah, 2008). Fish production in ponds in Ghana range from about 35 kg to about 25,750 kg/ha/year (Asmah, 2008). Production cycles in ponds also range from three months to two years with an average production cycle for non-commercial farming of one year, and that for the commercial farms, about 7 months (Cobbina and Eiriksdottir, 2010).

Pens and cages are more recent additions since 2003. The main concern regarding pens is the limited suitable environment for their development. However, its usage in the country has been demonstrated in the Anglor lagoon by Anani *et al.* (2010). The use of cages is however growing in the commercial sector. Data from the Fisheries Commission for 2011 showed that, cages contributed about 80% to 85% of aquaculture production compared to 7.6% from ponds and 7.2%, from the other sources (MOFA, 2012). The cage industry is therefore expanding than ponds (Orchard and Abban, 2011).

2.4. Cage Aquaculture

Cage culture is commonly practiced worldwide in both freshwater and marine environments, including open ocean, estuaries, lakes, reservoirs, ponds, and rivers (Beveridge, 2004). It utilizes existing water resources but encloses the fish in a cage or basket which allows water to pass freely between the fish and the body of water, permitting waste removal and exchange of water (Schmittou, 2006). Cages are constructed in a variety of shapes using materials such as bamboo or wooden slats and wire, nylon and other synthetic meshes.

Cages range in size from 1 m^3 to several hundred m^3 and can be any shape, but rectangular, square or cylindrical shapes are typical (Schmittou, 2006). Small cages are more easily managed than large cages, and usually provide a higher economic return per unit volume. In Africa cage culture probably started as a convenient holding facility for a suitable quantity of caught fish alive until they were ready for sale (Beveridge, 2004).

2.4.1. Problems with cage culture

Many problems associated with cage culture are related to the high stocking densities (Beveridge, 2004). Abrasions combined with stress and high nutrient loads often result in the opportunity for diseases development and diseases spread rapidly at high densities (Masser, 2008). High densities and the associated high feeding rates can therefore exacerbate water quality problems: especially low dissolved oxygen, high ammonia, and increased turbidity.

On the other hand, feeding hierarchies, like pecking orders in poultry, are usually observed when densities are too low and lead to reduced feed consumption and slowed growth in subordinate animals (Schmittou, 2006). The potential effects of densities that are too low or too high illustrate the need for research to identify optimal densities for different species and cage types (Beveridge, 2004).

Other problems associated with cage culture include net fouling which reduces cage volume and can severely reduce water movement through the cage. Cages can also be attractive to other species in the water body as hiding places, attachment structures, and as sources of food (Schmittou, 2006). Often, wild fish are attracted to the cage at feeding times and push against the cage netting trying to get to the feed. This often intimidates the culture fish and reduces their feeding activity.

Sustainability issues surrounding cage culture are similar in many ways to those of other aquaculture production systems and include: sustainable sources of seed, diet composition, and environmental impacts (Tucker and Hargreaves, 2008). However, cage systems can be under more scrutiny as they often involve public waters and wild populations. In spite of these challenges, cage aquaculture remains an excellent culture system for many species.

2.5. Cage Culture in Ghana

Within aquaculture production systems in Ghana, there has been a move from predominantly extensive and semi-intensive systems in earthen ponds towards the use of more intensive culture system in cages where fingerlings are stocked and fed on complete diets (Attipoe, 2006). Cage culture has been developing consistently over the last decade (Anane-Taabeah *et al.*, 2011) especially in the Volta Lake. The industry is presently a major contributor to aquaculture production in the country (MOFA, 2012).

In 2007, a case study of the Ghanaian cage culture industry revealed that, there were two commercial cage-farming companies; Crystal Lake Fish Ltd. and Tropo Farms Ltd., both situated in Lake Volta (Blow and Leonard, 2007). However a high number of small-scale farmers are currently operating in the Volta Lake.

The Lake is free of pollution and the water quality is exceptionally suitable for tilapia culture. It also has consistent year round warm temperatures (Blow and Leonard, 2007). Cage culture on the Volta Lake is expected to increase rapidly as the government of Ghana b bd d d c d d d cd d d plan, 1% of the Lake surface area (8,700 km2) has been allocated to the cage industry (Ofori *et al.*, 2010).

2.5.1. Cage Types

A typical cage used in the Volta Lake is cubic shape and made of 13 to 15 mm multifilament stretched mesh net attached to a pipe frame buoyed by plastic barrels, or oil drums. The general average cage sizes reported by Ofori *et al.* (2009) are 6 m by 4 m on the sides and 2 m deep, for a volume of 48 m^3 for small scale farmers.

2.5.2. Species Cultured and Sources

The fish species cultured in cage in Ghana is *Oreochromis niltocus* (Attipoe, 2006; Ofori *et al.*, 2010). Other species such as catfish, carp, *Heterotis* etc, could also be stocked in cages (MOFA, 2012). The large commercial cage farms like Tropo and Crystal Lake produce their own fingerlings for stocking in cages.

However, the numerous small and medium-scale operators rely on fingerlings that are available from several hatcheries - among them Tropo Farm, Crystal Lake, Jassa, Fish Reit, Anson-Greenfields and from a selected line of *Oreochromis niloticus* produced at the Ghanaian Aquaculture Research and Development Centre (ARDEC) in Akosombo. The fingerlings (10 g to 30 g) are stocked at rates ranging 63-188 fish/m^3 (Ofori, *et al.*, 2009).

The Akosombo strain which was developed after several years of breeding and selection work grows about 30% faster than other farmed tilapia currently being cultured, enabling fish farmers to harvest them after six months instead of the usual eight months needed for the non-improved stocks. It also has a higher survival rate, thus it continues to attract the attention of many cage farmers. Subsequently, the current supply cannot keep up with demand by farmers and hatchery managers across the Volta Basin (Personal communication, Dr. Felix Attipoe, Officer in Charge of ARDEC).

2.5.3. Feed Supply and Nutrition

The rapid growth of any animal depends on a nutritious diet and adequate consumption. Feeds for caged tilapia must be nutritionally complete and balanced. Feeding fish in intensively managed cages can represent 50% or more of the variable costs of production (Gabriel *et al.*, 2007). Nutrients for caged tilapia may come from food sources, such as plankton, bacteria, and insects from within the cage and /or from organic matter and attached organisms.

Although Nile tilapia may obtain a few essential nutrients by filtering these foods from nutrient-rich waters, they still need a complete diet as if they were being cultured in food-free waters to ensure high yield, fast growth and good health (Schmittou, 2006).

The feeding frequency for Nile tilapia during optimum growing temperature will vary according to size or stage of the life cycle; from up to 12 times per day for newly hatched fry, 3 to 4 times a day for fingerlings, 2 to 3 times per day for grow-out production fish, and once a day for brood fish (Schmittou, 2006).

The protein requirement of tilapia decreases with age and size. Higher dietary crude protein concentrations are required for fry (30 56%) and juvenile (30 40%) tilapia but lower protein levels (28 30%) are given to larger tilapia (Winfree and Stickney, 1981; Jauncey, 1982; Siddiqui *et al*., 1988; Twibell and Brown, 1998).

Tilapia can also effectively utilize carbohydrate levels up to 30 to 40% in the diet, which is considerably more than most cultured fish (Anderson *et al*., 1984). Fiber is usually considered indigestible, as tilapia do not possess the required enzymes for fiber digestion (although some cellulase activity from microbes has been found in the gut of *O. mossambicus*) (Saha *et al*., 2006). For this reason, and to attain maximum growth, crude fiber levels in tilapia diets should probably not exceed 5% (Anderson *et al*., 1984).

2.6. Growth of Tilapia in Cages and Stocking Density

It is well known that growth is not constant and numerous environmental factors (temperature, fish size, stocking density, access to acceptable quality of food, water exchange and salinity) may influence food consumption and growth rate (Jobling, 1993).

According to Wooton (1990), one factor that complicates the study of effects of abiotic factors on growth is the effect that social interactions between fish have on their growth.

Food and space are the resources that most frequently are unequally distributed by such interactions. Although water quality and food abundance can be improved by providing aeration, and additional feeding respectively, density is the main factor that can be controlled.

The densities of cultured species stocked in cages are highly variable and little research has been done to establish optimum stocking densities for many species (Beveridge, 2004). Often, cages are discussed in terms of fish density versus cage volume. In general terms, cages can be low-density/high-volume or high-density/low-volume. High-density/low-volume cages are more common in freshwater cage culture where cages are often stocked at densities of 150 to 450 fish per cubic meter with the target harvest weight of one kilogram or less (Beveridge, 2004).

Generally as population density increases, competition for food and for living space intensifies as well. Cultures can be either density-dependent or density-independent (Huang and Chiu, 1997). If the stocking density negatively affects the growth of fish, it is considered to be density-dependent, such as reported for Chinook salmon (*Oncorhynchus tshawytscha*)

(Martin and Wertheimer, 1989), Nile tilapia (*Oreochromis niloticus*) (Tepe, 2005), and African catfish (*Clarias gariepinus*) (Haylor, 1991). In contrast, growth and survival rates have been reported to be density-independent by many authors, for example for Walleye (*Sitzostedion vitreum*) (Fox and Flowers, 1990), Golden Shiner (*Notemigonus crysoleucas*) (Tepe and Boyd, 2002), and *Oreochromis spilurus* (Cruz and Ridha, 1995).

In many cultured fish species, growth is inversely related to stocking density and this is mainly attributed to social interactions and food (Bjøernsson, 1994; Huang and Chiu, 1997). The effects of stocking density on Nile Tilapia growth as reported by Osofero et al. (2009) show that fish growth generally decreased with an increase in stocking density. This study also revealed that stocking density has an inverse relationship with the level of protein intake which affects weight and growth of *Oreochromis niloticus.*

Fish stocked at excessive densities grow less and this mostly involves the healthier and stronger fish reaching out for the distributed food faster, resulting in differential growth (Refstie, 1977). In fact, under crowded conditions at higher stocking densities, fish suffer stress as result of aggressive feeding interaction and eat less, resulting in growth retardation (Bjøernsson, 1994).

Aggressive behaviour and possibly pheromones are known or suspected density-dependent social interactions that affect caged fish. This is an observed problem with tilapia and other species at low densities (e.g., < 100 fish per m^3) but not at very high densities (e.g., > 300 fish per m^3) (Schmittou, 2006).

The full utilization of space for maximum fish production through intensive culture can improve the profitability of the fish farm. Consequently, identifying the effects and establishing optimum stocking density for a species is a critical factor not only for designing an efficient culture system (Leatherland and Cho, 1985), but also for optimum husbandry practices.

2.6.1. Effects of Stocking Density on *Oreochromis niloticus* Feed Utilization

Stocking density has a direct impact on the potential feed loss from the cage and feed access by the fish (Schmittou, 2006). As density increases, not only growth but both water quality and feed access decrease and limit production performance through its effect on water quality and feed access (Schmittou, 2006).

Feed efficiency results are most important when making an economic analysis of fish production, than they are for indicating fish growth potential. Typical FCR in *Oreochromis niloticus* cage aquaculture systems in Africa is between 1.4 and 2.5 (Beveridge, 2004; Ofori *et al.*, 2010). Guimaraes *et al*. (2008) stated that efficient utilization of diets may vary even within a single species because of the particular strain of fish used and the environmental factors.

In a study by Siddiqui *et al*. (1991), *Oreochromis niloticus* fed on a commercially prepared diet had FCR values ranging from 3.7 to 4.9. Ouattara *et al.* (2003) reported FCRs of 12.49, 13.44 and 12.65 for 50, 100 and 150 fish m ^{3} cage during a stocking density manipulation experiment for *Oreochromis niloticus.*

Papoutsoglou *et al*. (1998) and Gomes *et al.* (2006) found that the feed efficiency ameliorated in faster growing fish, while El-Sayed (2002) reported a negative correlation between growth and feed efficiency in Nile tilapia stocked at various densities. Alhassan *et al.* (2012) found that FCR was not affected with increasing stocking density as was the case of Osofero *et al*. (2009). As density increases, feed loss potential increases because of increased fish-induced water turbulence at feeding time (Schmittou, 2006). The protein and fat efficiency ratios are used as indicator of protein and fat quantity and quality in the fish diet and fish body. Hence they are used to assess protein and fat utilization and turnover, related to dietary intake and its conversion into both protein and fat gain.

2.6.2. Effects of Stocking Density on Condition Factor of *Oreochromis niloticus*

Weight d d d dc d b b d -ad d d db d d ad c C 1 / / 0(c negative effect of an increased stocking density of cod *Gadusmorhus* on the condition index and postulated decreased food intake associated with increased stress as the cause.

Interestingly, the same authors observed a significant increase in the condition index in some of their experiments with cod but attributed this result to the fact that they might have started with post-spawning fish (Lambert and Dutil, 2001).

Jørgensen *et al*. (1993) found that the condition of Arctic charr reared for 9 weeks at high stocking densities improved with time, while the condition of the same fish stocked at low densities for the same time did not.

In both of the cited experiments, the condition index changed in parallel with growth. Condition factor helps in determining the degree of feeding activity of a species. It is therefore indicative of judicious use of its food for somatic growth. However, condition factor is not always indicative of the direction of growth. For instance, when condition factor was back calculated from data given by Papoutsoglou *et al*. (1998) for European sea bass, there was no increase in the condition of the fish during the growth period or differences among treatments, although all fish had grown during the experiment and those at high densities had grown more than those at low densities.

2.6.3. Effects of Stocking Density on Size Variation

Jobling and Baardvik (1994) stated that coefficient of variation values above 10% are indicative of non-homogeneity within a group of fish. In aquaculture, as in any kind of animal husbandry, it is desirable to have a homogeneous animal size since that would facilitate feeding, harvesting, marketing and processing. Inappropriate size variation may also have consequences for scientific advice about optimal stocking density, mortality and yield.

Fre´chette *et al*. (2005) recommended that size variability of experimental and commercial groups during the start of the experiment be similar. Yousif (2002) realized a significantly different final body sizes of fish although initial size was homogeneous. Alhassan *et al*. (2012) reported that stocking density had an effect on the final size among individuals of initially uniform size and attributed the cause to social interactions through competition for food and/or space which negatively affected the fish growth (Aksungur *et al*., 2007).

2.6.4. Effects of Stocking Density on *Oreochromis niloticus* Survival Rate

F d d b d c b d b 3 (d d fish are stocked and proper management are provided. However, mortality from 6% to 8% is common for tilapia within a week after stocking (Schmittou, 2006).

Several stocking density experiment using *Oreochromis niloticus* have relayed varied conclusions regarding the effects of stocking levels and survival rates. Gibtan *et al.* (*2008*), after 150 days of culturing *Oreochromis niloticus* at varying densities (50, 100, 150 and 200 fish/m^3) reported that survival rates were not affected by stocking density. Alhassan *et al.* (2012) also agreed the insignificant impacts of stocking density on survival. However, Osofero *et al.* (2009) found out an inverse relationship between survival rate and stocking density in a similar study.

In spite of the discordant results, the best density in most stocking density studies is defined as that which will produce a survival greater than 95% (Schmittou, 2006). Gibtan *et al.* (2008) reported survival rates of 94, 95, 95.33 and 97% for 50,100,150 and 200fish/m^3 respectively. Ouattara *et al*. (2003) also found 98%, 96% and 100% survival rates for the same species stocked at 50, 100 and 150 fish/m^3 respectively. A similar case was reported by Balcázar *et al.* (2006) stating 96.5, 94.3, and 98.5% survival rates for 200, 300 and 400 fish/m^3 respectively.

Typical survival rate in small-scale tilapia cage culture is in the range of 70 80% (Mikolasek *et al*. 1997; De La Cruz-Del Mundo, 1997). Mean survival rates of 70% and 75% were reported by Liti *et al*. (2005) and Abou *et al.* (2007) for *Oreochromis niloticus* reared in cages. Survival as low as 60% has also been associated with stocking densities in excess of 70 fish per m^2 (Yi *et al.,* 1996). During a comparison trial on all male and mixed sex *Orechromis niloticus* on the Volta Lake, Ofori *et al.* (2010) encountered serious mortalities resulting in an overall survival, averaging 29 ± 28.4% in all the cages but the cause was attributed to handling and transport.

2.6.5. Effects of Stocking Density on Yield and Profitability of Caged Tilapia

The main aim of aquaculture is to maximize production efficiency. The costs associated with cage construction and mooring vary greatly depending upon materials and sizes used. As with many types of construction, the cost per unit volume generally decreases as size increases.Cage netting or mesh can be relatively inexpensive if plastic or fiber netting is used. In general, cage farms are less expensive to build and operate compared to other systems (Beveridge, 2004).

Feed costs are usually the highest variable cost averaging around 50 to 60% of total costs (Beveridge, 2004). This implies that the profitability of intensive cage aquaculture is closely related to cost of feed protein (Hoffman *et al*., 1997). The second highest variable cost is usually seed or fingerling costs and can range from 10 to 40% of variable cost (Beveridge, 2004).

Watanabe *et al.* (1990) reported a positive relationship between stocking density and yield for Nile tilapia. Strong trends for total production increment with increasing stocking density have also been reported by Cruz and Ridha (1991), Alemu (2003) and Gibtan *et al*. (2008) for *Oreochromis niloticus*. Osofero *et al. (*2009) also agreed that that fish production increased as the stocking density increased with significant differences in the profit index for fish reared at 50, 100 and 150/m^3 treatments. These observations were due to the fact that highest stocking densities led to the highest biomass gain.

2.7. Importance of Water Quality in Cage Tilapia Culture

Fish are totally dependent upon water to breathe, feed and grow, excrete wastes, maintain a salt balance, and reproduce. Aquacultural ecosystems, including those involving cage fish culture, are composed of physical, chemical and biological factors that interact individually and collectively to influence culture performance (Schmittou, 2006). Although all of the impacting variables are important, only those that normally cause fish stress or otherwise limit performance in some way are of concern to the practical aquaculturist. The key water quality variables related to tilapia culture in cages are temperature, dissolved oxygen (DO) and hydrogen-ion concentration (pH). However, other parameters such as ammonia, nitrates, phosphates, alkalinity and hardness also have significant impacts within aquacultural ecosystems (Abolude, 2007).

2.7.1. Temperature

Temperature is among the most important environmental variables and a major metabolic modifier in fishes because fish assume approximately the same temperature as their surroundings.

It affects their activity, behavior, feeding, growth, survival, reproduction (Dupree and Hunner, 1994) and efficiency of food conversion (Martinez-Placious *et al*., 1993).

Temperature impacts cage tilapia culture in two major ways: firstly the temperature of the water where the fish are located and secondly, the temperature stratification of the water column in which the cages are located (Schmittou, 2006). Ideally, water temperature surrounding tilapia in production should be about 26°C to 28°C and within optimum range of about 23°C to 30°C. However, *Oreochromis niloticus* shows optimum food consumption and growth at temperatures ranging between 31-36 ^{o}C (Mires, 1995). Stress-induced disease and mortality are problematic when temperatures exceed 37°C or 38°C. At the other extreme, handling at lower temperatures can also result in stress-induced trauma, and in mortality at temperatures lower than 17°C or 18°C (Schmittou, 2006).

2.7.2. Dissolved oxygen

Dissolved oxygen is the most important and critical parameter, requiring continuous monitoring in tilapia cage systems. Oxygen naturally enters and dissolves into the water primarily through direct diffusion at the air-water interface and oxygen-releasing photosynthesis. Diffusion is relatively insignificant unless there is considerable wind action.

Low dissolved oxygen levels are critical to caged tilapia and are responsible for more fish kills, either directly or indirectly, than all other problems combined (Schmittou, 2006). This is because fish aerobic metabolism requires dissolved oxygen (Timmons *et al*., 2001).

Fish are not the only consumers of oxygen in cages but bacteria, phytoplankton, and zooplankton in the water also consume large quantities as well.

Low dissolved oxygen is associated with increased ammonia, increase in free carbon dioxide, decreased pH, increased nitrite, increased fish metabolism, increased water temperature, abundant gill parasites and numerous other factors, which when combined can significantly reduce fish production performances (Schmittou, 2006). Tilapia are highly tolerant of low DO concentration, even down to 0.1 mg/l (Magid and Babiker, 1975) depending on the stocking density. Optimum growth for *Oreochromis niloticus* is obtained at dissolved oxygen concentrations greater than 3 mg/l (Ross, 2000).

2.7.3. Hydrogen Ion Concentration (pH)

The effect of pH on the chemical, biological and physical properties of water systems makes its study very crucial to the lives of the organisms in the medium. Therefore, regular monitoring of pH is an essential part of the operation of intensive freshwater-fish culture systems such as cages. Caged tilapia seem to grow best in water that is near neutral or slightly alkaline. Lethal limit for high pH is 11 12, and *Oreochromis niloticus* can tolerate low pH to approximately 5 however best growth rates are achieved between 7 to 9 (Ross, 2000).

2.7.4. Ammonia

Ammonia is the principal nitrogenous product of fish metabolism. It originates from the deamination of amino acids and if present at high concentrations, it will slow growth rates and might increase mortality (El-Sherif *et al*., 2008). Ammonia toxicity in caged tilapia culture is closely correlated with pH and to a lesser extent, water temperature and dissolved oxygen concentration. Low dissolved oxygen increases ammonia toxicity, however this is largely balanced by decreased toxicity produced by increasing carbon dioxide concentration, which lowers pH (Schmittou, 2006).

Mass mortality of caged *Oreochromis niloticus* occurs with a couple of days of their sudden transfer to water with un-ionized ammonia concentrations greater than 2 mg/l, but optimum concentrations are estimated to be below 0.05 mg/l (El-Sherif *et al*., 2008). The level of nitrite (NO_2) tolerated is approximately 2.1 mg/l however, approximately 50% tilapia acclimated to sublethal levels will survive 3 or 4 days at un-ionized ammonia concentrations as high as 3 mg/l. The first mortalities from prolonged exposure begin at 0.2 mg/l and at concentrations as low as 0.08 mg/l, un-ionized ammonia begins to depress the appetite of tilapia (Schmittou, 2006).

2.8. Major Constraints in the Ghanaian Cage Industry

The Ghanaian cage industry is faced with a number of constraints. Lack of good quality fingerlings during times of stocking, lack of quality feeds as well as lack of financial resources through credit facilities have been noted as critical constraints in the development of the cage industry in Ghana (Agbo, 2008; Amissah *et al.*, 2009).

From a study conducted by Anane-Taabeah *et al.* (2011) to identify constraints and opportunities in cage aquaculture in Ghana, lack of funds and financial resources which d d a c ddc c b vernment extension services were the main constraints. Other constraints identified in the cage development included lack of organized markets, inadequate technical staff, poor governance, low research input, damage to cage nets by the local fishers and mixing of the lake (Asmah, 2008).

With regards to diseases, apart from external bacterial infections (*Columnaris*) and fish lice (*Argulus*) that were reported, no serious disease problems have been encountered in Ghana (Blow and Leonard, 2007).

Unavailability of quality fingerlings, lack of technical know-how with respect to culture and stocking densities, high cost of cage construction and quality feed as well as lack of access to information and support constitute major constraints to the development of cage aquaculture in Sub-Saharan Africa (Ridler and Hishamunda, 2001; Halwart and Moehl, 2006; Blow and Leonard, 2007; Asmah, 2008).

In spite of these constraints, the use of small floating net cages to culture tilapias in West Africa has been successfully demonstrated by Ofori *et al.* (2010) and recommended for fishers and investors.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study area

A preliminary survey was conducted in thirty-two small-scale cage farms (annual production between 10 to 50 tonnes) sited on the Volta Lake within in the Asuogyaman District of Eastern Region, Ghana, to capture data on stocking density practices. The farm sizes ranged from two to twenty-five floating cages. Consideration of this area was based on the numerous small-scale cage farms dotted below the Akosombo dam (Stratum II) of Volta Lake within the District (MOFA, 2012).

The experimental study was conducted at the Aquaculture Research and Development Center (ARDEC) of the Water Research Institute at Akosombo, Ghana, between December, 2012 and June, 2013. The site (N 06^0 16.996, E 000^0 03.562) was located downstream of the Volta Lake (Figure 1).The site, 20.6 m from shore was well suited for cage culture of tilapia due to reasons such as a more stable water quality, high flow rate of the water in the cages (0.1 ms^{-1}) and greater depth (10.5 m) between the cage floor and the bottom of the water (Tamot *et al.*, 2008).

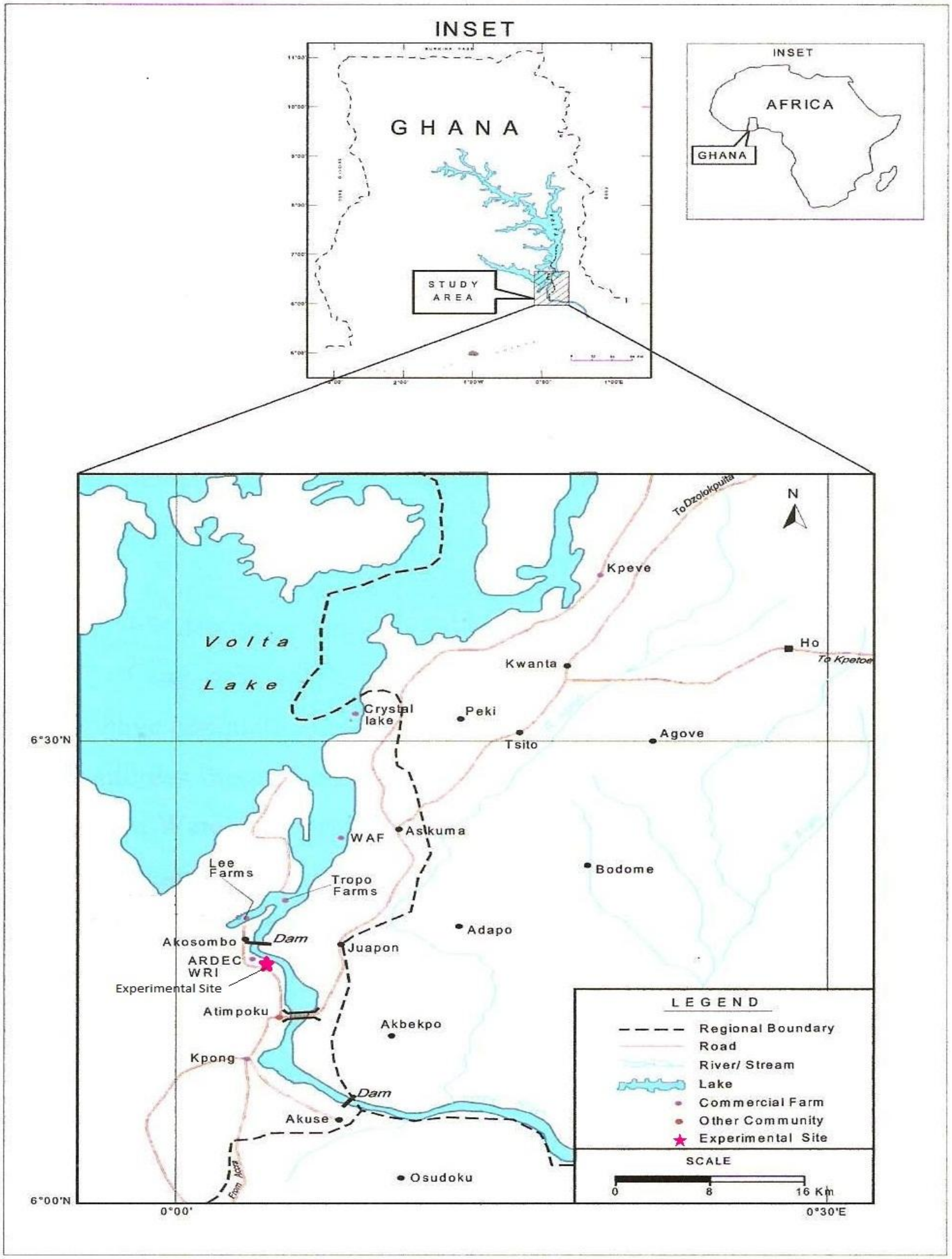

Figure 2: Map of Ghana showing the study area and site of experiment.

3.2. Preliminary survey

On-farm visits and interviews were conducted using structured interview guides (Appendex A) to solicit relevant data from small-scale cage farmers (respondents) on demographics, source and sizes of fish at stocking, stocking rates and problems limiting their operations. Survey and on-farm visits were conducted from August to November, 2012. A purposive sampling approach was used where only operational small-scale cage farms were targeted based on a list of farms provided by the Asuogyaman District Fisheries officer (Appendix B). In all, thirty two farmers were interviewed based on the availability of cage operators, their preparedness to voluntarily answer questions and ability to provide exact answers.

3.3. Installation of experimental cage units

Nine cage compartments, each of size 8 m^3 were constructed for this study. Each of the three density treatments had three replicate cages. The cages were constructed using galvanized pipes welded into a cage frame and floated on the Volta Lake by empty rubber drums (Plate 1). Cage nets (15 mm square) were securely fixed to the cage platform using nylon twines. The cages were anchored with $0.3m^3$ concrete blocks to prevent them from drifting by currents from their original positions. A free board (above water space) of 0.2 m was maintained in each of the cages throughout the duration of the experiment.

Plate 1: Cage platform constructed from galvanized pipe frames and buoyed by plastic barrels at the experimental site. (Photo by Author)

3.4. Fish stocking, mortality and replacements

Prior to stocking, the same cohort of *Oreochromis niloticus* (Akosombo strain) were withheld feed for 24 hours and then bar-graded to group them into uniform sizes. A total of 7,200 individuals were counted from the graded cohort and samples were taken to measure their initial weight (g) and standard length (cm).

Fingerlings with mean weight of 2.12 ± 0.01 g (mean ± SE) were then randomly assigned to treatments in cages at stocking density of 50 fish/m^3, 100 fish/m^3, and 150 fish/m^3 with three replicates for each density treatment. The reason for the choice of fingerling size and densities was because most of the cage farmers utilize these sizes and densities on the Volta Lake.

Extreme care was taken during transport and handling to avoid heavy mortality. However, deaths that occurred in the first week of the experiment due to handling, and those observed during a time of Lake overturn (in February) were recorded and replaced with spare similar sized fingerlings. Consequently, daily mortality were recorded but not replaced and were noted for the purpose of calculating fish feeding rate.

3.5. Feeding

Fish were fed a commercially available extruded feed (Raanan), containing 30% crude protein (Plate 2; Appendix C). The choice of feed (Raanan) was due to its preference by most cage farmers in Ghana and availability throughout the year. Fish were fed five times (08:00 hours, 10:00 hours, 12:00 hours, 14:00 hours and 16:00 hours GMT) daily with 0.5 mm-diameter pellet feed at 12% body weight during the first two months of culture. Thereafter, the feeding rates and frequencies declined as the fish grew following the method of Nandlal and Pickering (2004) (Appendix D). Formulated feeding was however, suspended when caged fish became torpid and failed to react to feeding in mid February and early March 2013 due to overturn of the Volta Lake.

Plate 2: Nile tilapia in cages being fed by hand broadcasting. (Photo by Author)

3.6. Fish sampling and final harvest

Fish were sampled bi-weekly (between 07:00 and 10:00 hours GMT) during when the weights (Ohaus portable digital scale (model DIGI DS 671); ± 0.1 g), standard length (measuring board; ± 1.0 mm) and the number of fish were assessed for each treatment. Fifty live fish were randomly scooped out of each cage unit for their measurements and immediately returned to their respective cages. The cage nets were inspected and cleaned during each sampling.

After 24 weeks of the culture, all the experimental cages were emptied and fish in each cage counted and weighed in kilograms to determine final average weights and survival rates.

3.7. Water Quality Determination

Physico-chemical parameters of water in the vicinity of the cages were monitored prior to stocking and bi-weekly thereafter to ensure that they were within the recommended limits for fish growth and also to detect possible influences of the environmental and/or limnological variables on the growth dynamics of the fish. Temperature was monitored daily around 09:00 hours and 13:00 hours GMT.

Dissolved oxygen, total hardness, total alkalinity, ammonium-nitrogen, nitrate-nitrogen and nitrite-nitrogen of the water were determined bi-weekly. Water samples for laboratory analysis were collected from the top of the water column at 20 cm below the surface. Samples of water were collected in 1 litre bottles that were rinsed with portions of the Lake water and kept in an ice-chest during transportation to the laboratory. All water quality measurements and sample collection were made between 08:00 and 09:00 hours GMT and analyzed using standard methods (APHA/AWWA, 1998) as follows:

3.7.1. Temperature and pH

Temperature and pH were measured *in-situ* with a HACH EC 20 pH/ISE meter. The meter probe was immersed into the Lake water to a depth of 20 cm (Plate 2). The temperature and pH values were read and recorded in degrees Celsius (^{o}C) to one decimal place and pH units to two decimal places respectively.

Plate 3: *In-situ* measurement of water temperature and pH. (Photo by Author)

3.7.2. Dissolved Oxygen (DO)

The DO was determined by Winkler Method. Samples of the water were carefully collected into DO bottles to exclude air and bubbling. The bottles were filled till they overflowed. Two (2) ml each of Manganous Sulphate ($MnSO_4$) and Alkali-iodide azide solutions were added. The bottles were then closed with stoppers and inverted several times to mix. It was then allowed to precipitate leaving clear supernatants at the top.

Two (2) ml of concentrated Sulphuric acid (H_2SO_4) was then added, and shaken until the precipitates completely dissolved. Hundred (100) ml of the solution was measured into a conical flask and titrated with 0.0125M sodium thiosulphate ($Na_2S_2O_3$) solution to get a pale straw colour. Ten drops of 2% aqueous starch indicator solution was added to get blue-black colour. The titration was continued till the point (end point) when the blue-black colour first disappeared.

Calculations: Dissolved Oxygen, mg DO/l = (A x M x 8000) / V

Where A = ml of titrant, M = Molarity of $Na_2S_2O_3$ and V = volume of sample used.

3.7.3. Total hardness (as $CaCO_3$)

The Ethylene diaminetetra acetic acid (EDTA) Titrimetric Method was used in determining the total hardness. To a 50 ml of the sample measured into a conical flask, 1ml of buffer solution was added to produce a pH of 10.0 ± 0.1. An appreciable quantity (0.1- 0.2g) of Eriochrome Black T indicator crystals were added and mixed constantly. The solution was then titrated against standard 0.01M EDTA until the colour changed from purple to bright blue.

Calculation: Total Hardness = (A x B x 1000) / V

Where A = ml EDTA titrated, B = mg of $CaCO_3$ equivalent to 1.00ml EDTA titrant and V = volume of sample used.

3.7.4. Ammonium-Nitrogen (NH_4 –N)

Ammonium-Nitrogen was determined using the Direct Nesslerization Method. Twenty five (25) ml of sample was measured into a conical flask and a drop (0.05 ml) of ethylenediaminetetra acetic acid (EDTA) reagent was added and mixed thoroughly.

One (1 ml) of Nessler d d d ccdc dc d c d dc stand for 10 minutes for yellow colour development. A 25 ml deionized water zero blank and a standard solution of 1.00 mgNH_4 N/l were also treated the same way. The zero blank and standard solutions were used to standardize a HACH DR/2000 Direct Reading Spectrophotometer at wavelength of 425 nm using a 2.5 cm light-path glass cell. The ammonium concentration in the sample was then measured and the result expressed in mg NH_4-N/l to two decimal places.

3.7.5. Nitrite-Nitrogen (NO_2 –N)

Diazotization Method was used in the determination of nitrite-nitrogen. Twenty (20) ml of each sample of water was measured into a conical flask and 1 ml of 0.3 M sodium hydroxide (NaOH) solution was added and mixed gently. One ml colouring reagent was added to the sample and mixed gently. The solution was allowed to stand for 15 minutes for pink colour development. A 20 ml deionised water zero blank and standard of 0.250 mg/l NO_2 N were treated the same way and used to standardize the HACH DR/2000 Direct Reading Spectrophotometer at a wavelength of 507 nm using a 2.5 cm light path cell. The nitrite concentration in the sample was read and the result expressed in mg NO_2 N/l to three decimal places.

3.7.6. Nitrate- Nitrogen (NO_3 –N)

Nitrate was determined using the Hydrazine Reduction Method. Twenty (20) ml of sample was measured into a test tube and 1ml of 0.3 M NaOH solution was added and mixed gently. One (1) ml reducing mixture was then added. The mixture was then heated for 10 minutes at 60 ^{o}C and cooled to room temperature. One (1) ml of colouring reagent was added, mixed gently and 15 minutes reaction period was allowed for pink colour development.

A 20 ml deionised water zero blank and a standard of 0.25 mgNO_3 N/l were treated the same way and used to standardize the HACH DR/2000 Direct Reading Spectrophotometer at a wavelength of 507 nm using a 2.5 cm light path cell. The nitrate concentration in the sample was measured and the result expressed in mg NO_3-N/l to two decimal places.

3.7.7. Phosphate-Phosphorus (PO_4 –P)

Phosphate was determined by Stannous Chloride Method. Twenty five (25) ml of water sample free from colour and turbidity was measured and 0.05 ml (1 drop) phenolphthalein indicator added and mixed. One (1) ml molybdate reagent was added and mixed followed by three drops of stannous chloride reagent. The solution was mixed and allowed to stand for 10 minutes for blue colour development indicating the presence of phosphate-phosphorus. A 25 ml deionised water zero blank and standard of 0.50 mg/l PO_4 P were treated the same way and used to standardize the HACH DR/2000 Direct Reading Spectrophotometer at a wavelength of 890 nm using a 2.5 cm light path cell. Phosphate concentration in the sample was measured and the result expressed in mgPO_4 P/l to two decimal places.

3.8. Economic Analysis

A simple economic analysis was developed to estimate the profitability and return on investment (ROI) as comparative indicators. The cost of feed, fingerlings, cage units and total revenue generated from harvest were estimated. The value of fish was based on price of Nile tilapia at ARDEC (GH 4 4. 1// c FG 5 4. 14/ (

The cost of feed was based on the market price of Raanan commercial feed (FG 34.00/20kg) at the start d d d d b FG 0 6 d S d feed used during each experimental period was determined by using the feeding adjustments recorded during each sampling period. The total cost of production was determined by the summation of the cost of fingerlings, feed, and cage amortized over 4 years.

3.9. Fish Growth and yield analyses

The specific growth rate, condition factor, coefficient of variation in weight, net yield and survival rates were calculated for the determination of growth.

3.9.1. Specific growth rate, SGR

The specific growth rate for each treatment group was calculated as:

$$SGR = SGR = 100 \times [(\log_e Wf \quad \log_e Wi)]\ t^{-1}$$

Where, $\log_e$ is natural log, Wf is the final mean wet weight (g), Wi is the initial mean wet weight and t is the time in days (Ricker, 1975).

3.9.2. Mean daily weight gain

This was calculated as (Wf – Wi) t^{-1} where Wf is the final mean weight at harvest (g), Wi is the initial mean weight at stocking and t is the time in days.

3.9.3. Condition Factor, K

The condition factor K was calculated as: $K = BW / SL^3$, (Tesch, 1971).

Where, BW is body weight of fish (g) and SL is the standard length of fish (cm).

3.9.4. Coefficient of variation in weight, CV

$CV = [(SD/Wn)] \times 100\%$.

Where, Wn is the mean fish weight and SD is the standard deviation of the Nile tilapia weight.

3.9.5. Food conversion ratio, FCR

FCR = dry weight of feed fed (g) / wet weight gain (g) (Castell and Tiews, 1980).

3.9.6. Protein efficiency ratio, PER

PER = Fish weigh gain / Protein intake

Where, Protein intake = (% protein in feed x total diet consumed) /100.

3.9.7. Net Yield and Survival rate, SR

The net yield was estimated as the biomass harvested minus the biomass stocked (Mohammed *et al.*, 2006). The survival rate = 100 (Number of fish that survived) / (total number of fish stocked)

3.9.8. Economic analysis

The Benefit-cost ratio, BCR was calculated as, BCR = net benefit / total expenditure. Profit index, PI PI = (Value of fish/kg) / (Total cost of production). Production (Kg/m^3) Production (Kg/m^3) = (Total weight of fish harvest (Kg)) / (volume of cage).

3.9.9. Data analyses

Data gathered from the questionnaire were coded serially in IBM SPSS version 20.0 and responses were analyzed based on their values as demographic information, stocking density practices and constraints.

Data gathered on both fish morphometry and water quality were assembled in Microsoft Excel 2007 and systematically transferred into IBM SPSS version 20.0 where statistical analyses were performed. Data were reported as mean ± standard, and those expressed as percentages were arcsine-transformed prior to analysis.

There were initial explorations of data for normality using the Shapiro Wilk d In order to determine differences in density treatments, a one-way ANOVA was conducted on data. This was done after data passed the normality test. Tukey G d R b C d d bd test (Tukey) was conducted where statistically significant differences ($P \leq 0.05$) were detected among the density treatments.

CHAPTER FOUR

RESULTS

4.1. Studies from Survey

4.1.1. Demographics

A total of 32 small-scale cage farms on the Volta Lake were visited. Out of this number, 75% were concentrated at Akwamufie, Atimpoku, Senchi and Old Akrade. All the respondents were males assuming roles of either care-takers/managers (53%) or feeders (47%). The experience levels of respondents in cage aquaculture are shown in Figure 2. A total of 66% of the respondents had between 1 and 4 years experience in cage culture. With respect to technical training in cage aquaculture, 75% of them did not have any training. However, the greatest percentage of respondents (84.4%) had formal education and Junior High Schools were the highest levels attended by the majority (Figure 3). Only 5 (16%) of the respondents were illiterates. The average age of the small-scale farms was 4 years.

4.1.2. Cage descriptions

A high percentage of cages (88%) in the farms visited were square in shape ranging in volume between 50 and 125 m^3. Only one of the farmers utilized circular cages. The cage platforms were constructed from either galvanized pipes (69%) or wooden frames (28%) that were floated by empty plastic barrels and metallic drums respectively. The cage nettings were mostly made from nylon multi-filament stretched nets with mesh sizes ranging from 13 mm to 15 mm.

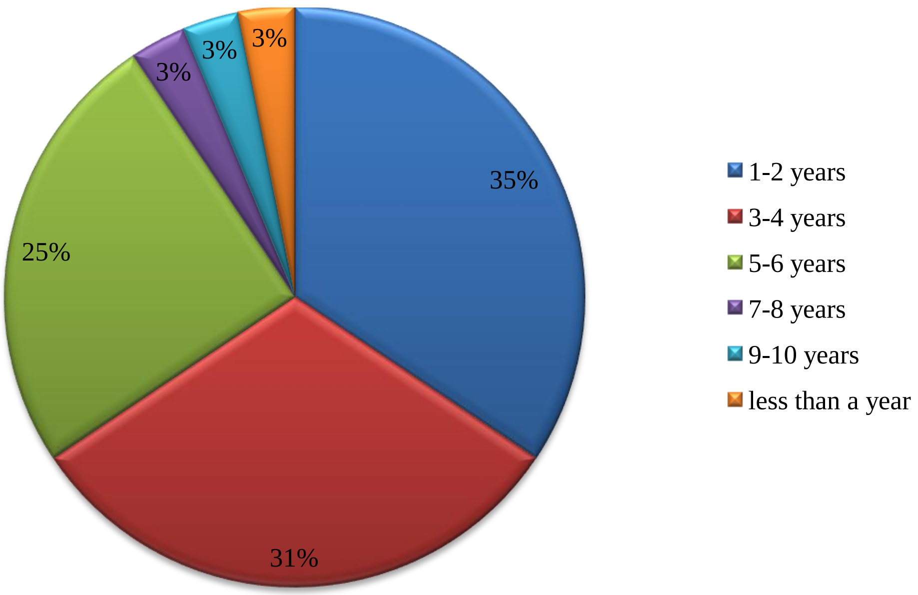

Figure 2: Small- b d d d d d d bd b d b d d U d (August to November, 2012).

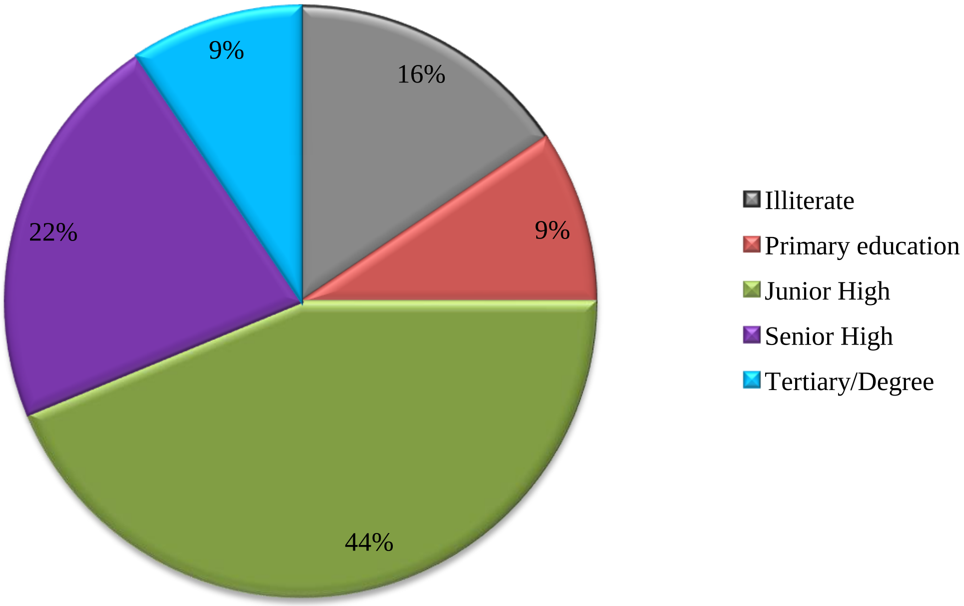

Figure 3: Education levels of small-scale cage operators on the Volta Lake (August to November, 2012).

4.1.3. Cultured fish species and fingerling sources

All the cage farms cultured only Nile tilapia (*Oreochromis niloticus*). Most of the farmers (78%) stocked their cages with sex reversed (all-male) fingerlings while 22% used mixed-sex populations. As shown in Figure 4, a relatively high percentage (41%) of the respondents procured the Nile tilapia fingerlings particularly the Akosombo strains from the Water Research Institute-Aquaculture Research and Development Center (ARDEC) in Akosombo. An appreciable percentage of the respondents (47%) admitted that it was usually difficult to acquire fingerlings during times of cage stocking.

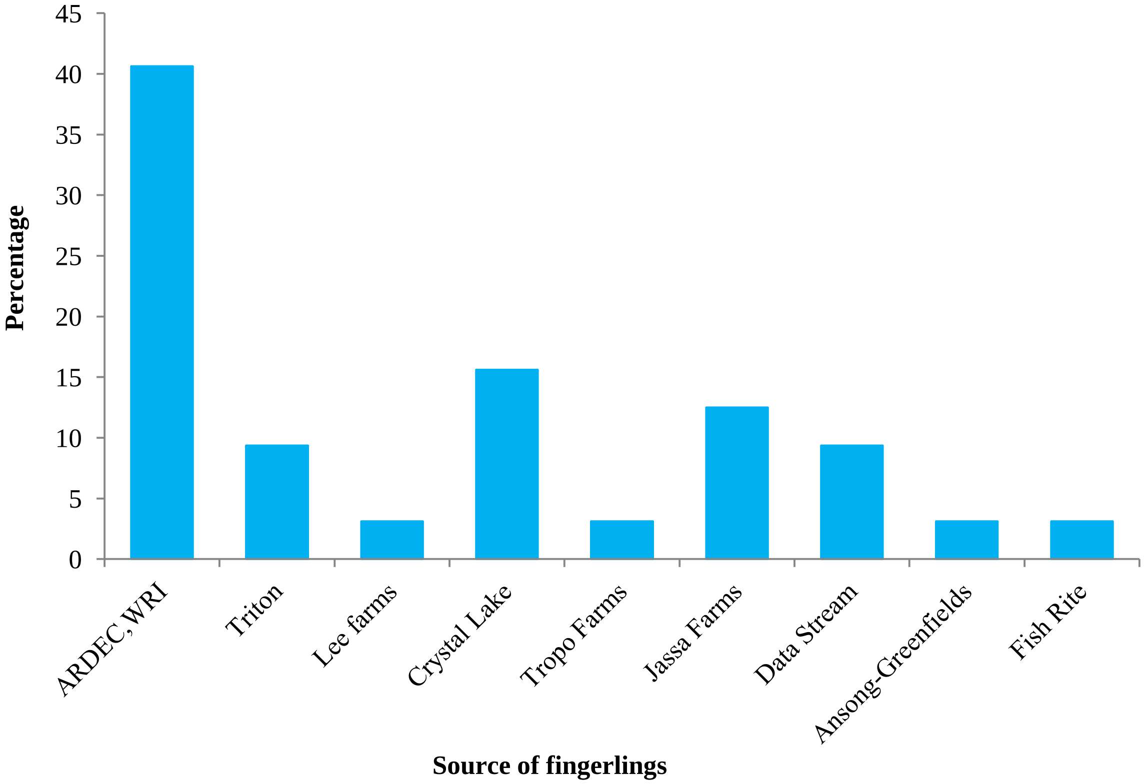

Figure 4: Sources of Nile tilapia fingerlings for small-scale cage farms in the Volta Lake (August to November, 2012).

4.1.4. Sizes of fingerlings and densities at stocking

The small-scale farms stocked Nile tilapia fingerlings ranging from mostly 2 g to 4 g (56%) and 5 g to 8 g (16%). A small percentage (9.4%) of the respondents stocked post treated fry as well (Figure 5).

The stocking densities practiced were mostly from 100 fish/m^{3}to 150 fish/m^3 (31%), and 50 fish/m^3 to 80 fish/m^3 (22%). Some farms (13%) used stocking rates above 200 fish/m^3 while a few others (6%) practiced rates below 50 fish/m^3 (Figure 6).

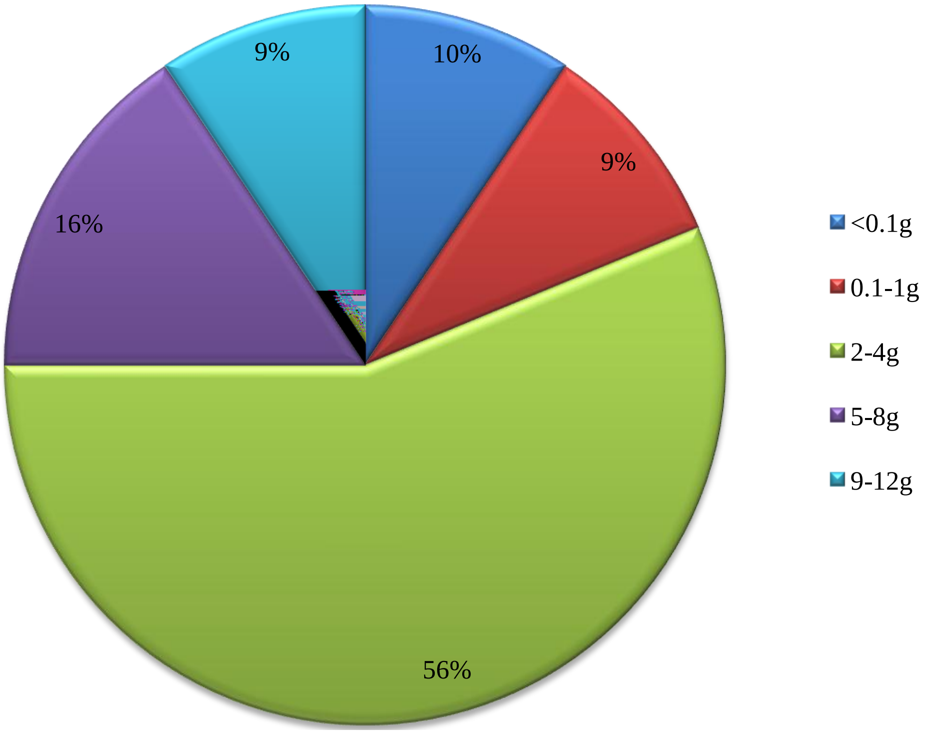

Figure 5: Sizes of Nile tilapia fingerlings stocked in floating net cages on the Volta Lake (August to November, 2012).

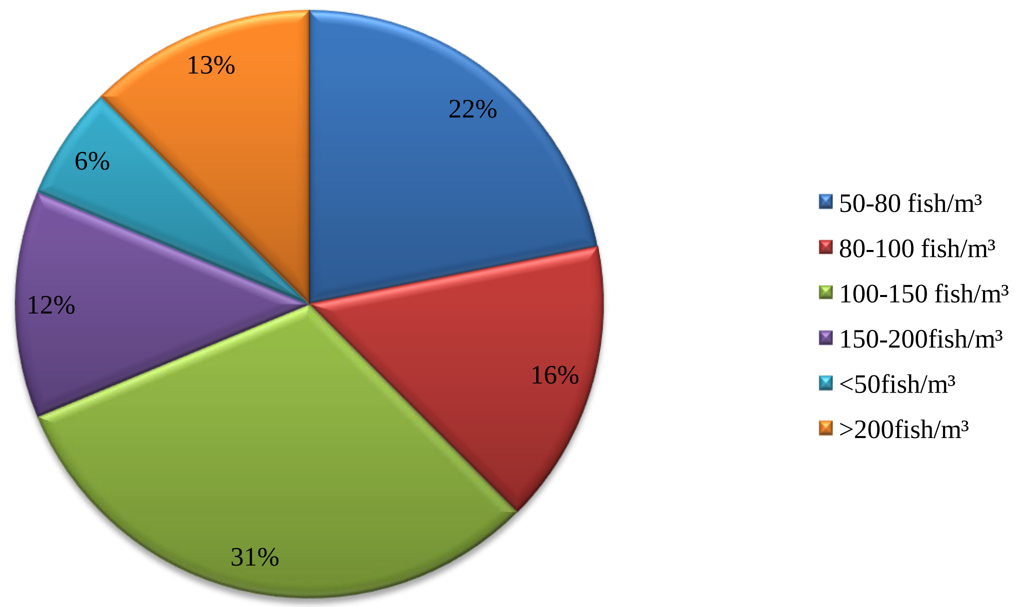

Figure 6: Fingerlings stocking densities used by small-scale cage operators on the Volta Lake (August to November, 2012).

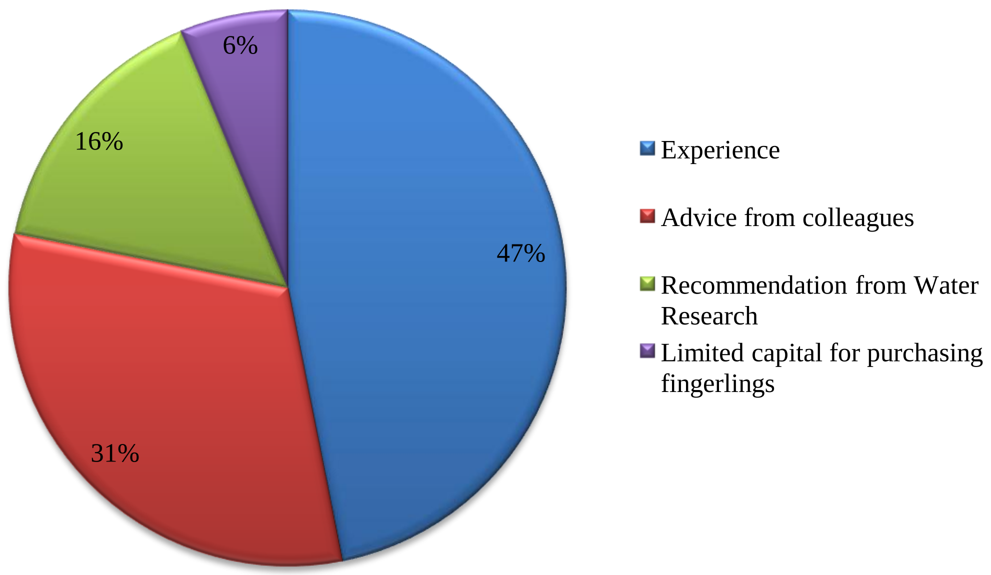

Figure 7: Farmers reasons for stocking tilapia fingerlings at different rates on the Volta Lake (August to November, 2012).

Most of the respondents (47%) used their own experiences to determine fish stocking rates while others (31%) received advice from colleague farmers. Only 16% of the farms received advice on stocking rates from the Water Research Institute (Figure 7).

Six commercial types of feed were found to be fed to Nile tilapia in cages within the Asuogyaman District (Figure 8). Exactly 50% of respondents used Raanan feed while 19% and 16% used Skreting and Nicolluzzi Rancoes respectively.

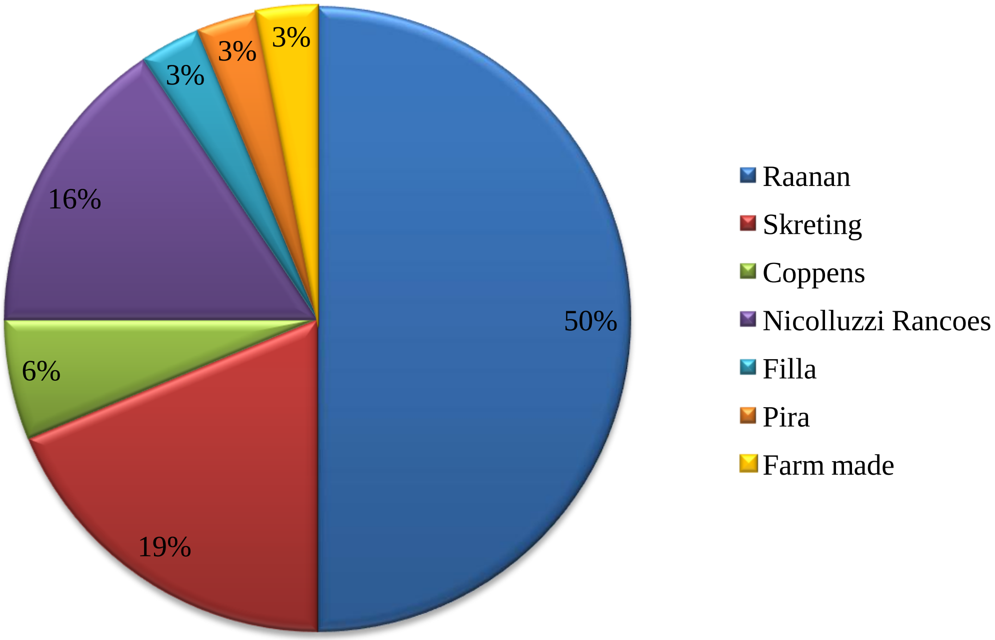

Figure 8: Types of Nile tilapia feeds used by small-scale cage farmers on the Volta Lake (August to November, 2012).

4.1.5. Problems faced by small-scale cage farmers

The problems that small-scale cage operators faced, as prioritized by the respondents were as follows: Difficulty in procuring larger fingerlings (above 10 g) during times of stocking (47%), high cost of quality feeds (22%), lack of skilled personnel with adequate technical knowledge (13%) and high cost of overall operation (9.4%) especially in cage construction. Other technical issues identified were fish poaching, sudden fish mortality during Lake overturn, damage to cage nets by local fishers and a few occurrences of fish fungal infections (3%).

4.2. Experimental Study

4.2.1 Fish growth parameters

Results of growth performance of *Oreochromis niloticus* at three stocking densities is presented in Table 1 and the growth patterns are shown in Figure 9. The mean final weight of fish increased to 274.10 ± 0.69 g, 180.12 ± 0.64 g and 171.13 ± 0.33 g in treatment densities of 50 fish/m^3, 100 fish/m^3, and 150 fish/m^3 respectively from the initial mean weights of 2.12 ± 0.03 g for all treatments.

There were significant differences ($p < 0.05$) in the growth parameters evaluated. The highest daily weight gain (1.537 ± 0.002 g) and specific growth rate (2.75 ± 0.007%) were observed in fish stocked at 50 fish/m^3. The mean daily growth rates for fish in the 100 fish/m^3 and 150 fish/m^3 were statistically similar ($p > 0.05$). Although they were not significantly different from each other, the specific growth rate in the fish stocked at 100 fish/m^3 (2.51 ± 0.002%) was higher than fish in 150 fish/m^3 (2.43 ± 0.004%).

Mortality was generally low in all treatments with survival ranging from 77.8 ± 2.03% for stocking densities of 50 fish/m^3 to 91.7 ± 1.2% for stocking densities of 150 fish/m^3.

Table 1: Growth and survival (mean ± standard error) of *Oreochromis niloticus* stocked at three densities in cages for 177 days.

Parameters	**Treatments**		
	50 fish/m^3	100 fish/m^3	150 fish/m^3
Initial Mean Weight (g)	2.13 ± 0.14^a	2.09 ± 0.06^a	2.15 ± 0.22^a
Final Mean Weight (g)	274.10 ± 0.69^a	180.12 ± 0.64^b	171.13 ± 0.33^c
Mean Gain in Weight (g)	271.98 ± 0.39^a	177.99 ± 0.72^b	169.15 ± 0.49^c
Mean Daily Weight Gain (g)	1.537 ± 0.002^a	1.006 ± 0.004^b	0.954 ± 0.003^b
Specific Growth Rate (%/day)	2.75 ± 0.07^a	2.51 ± 0.02^b	2.43 ± 0.04$^{c, b}$
Initial Mean Standard Length (cm)	3.97 ± 0.14^a	3.98 ± 0.01^a	4.09 ± 0.14^a
Final Mean Standard Length (cm)	17.30 ± 0.02^a	16.69 ± 0.03^b	16.39 ± 0.01^c
Mean Gain in Standard Length (cm)	13.32 ± 0.11^a	12.71 ± 0.02^b	12.30 ± 0.12^c
Survival rate (%)	77.81 ± 2.03 ^{a}	91.34 ± 0.81^b	91.72 ± 1.20^b

$^{a,\ b}$ Treatment means within the same row with different superscript letters are significantly different ($P < 0.05$)

From the growth curves (Figure 9), fish in all the treatments showed similar trend in growth with slight variation in weight gains during the initial weeks (up to 10th week) of culture. From the 11th week onwards, the fish stocked at 50 fish/m^3 began to show significant differences in growth from the other treatments. Only a slight variation was shown in the growth pattern of fish in the 100 fish/m^3 and 150 fish/m^3 treatments.

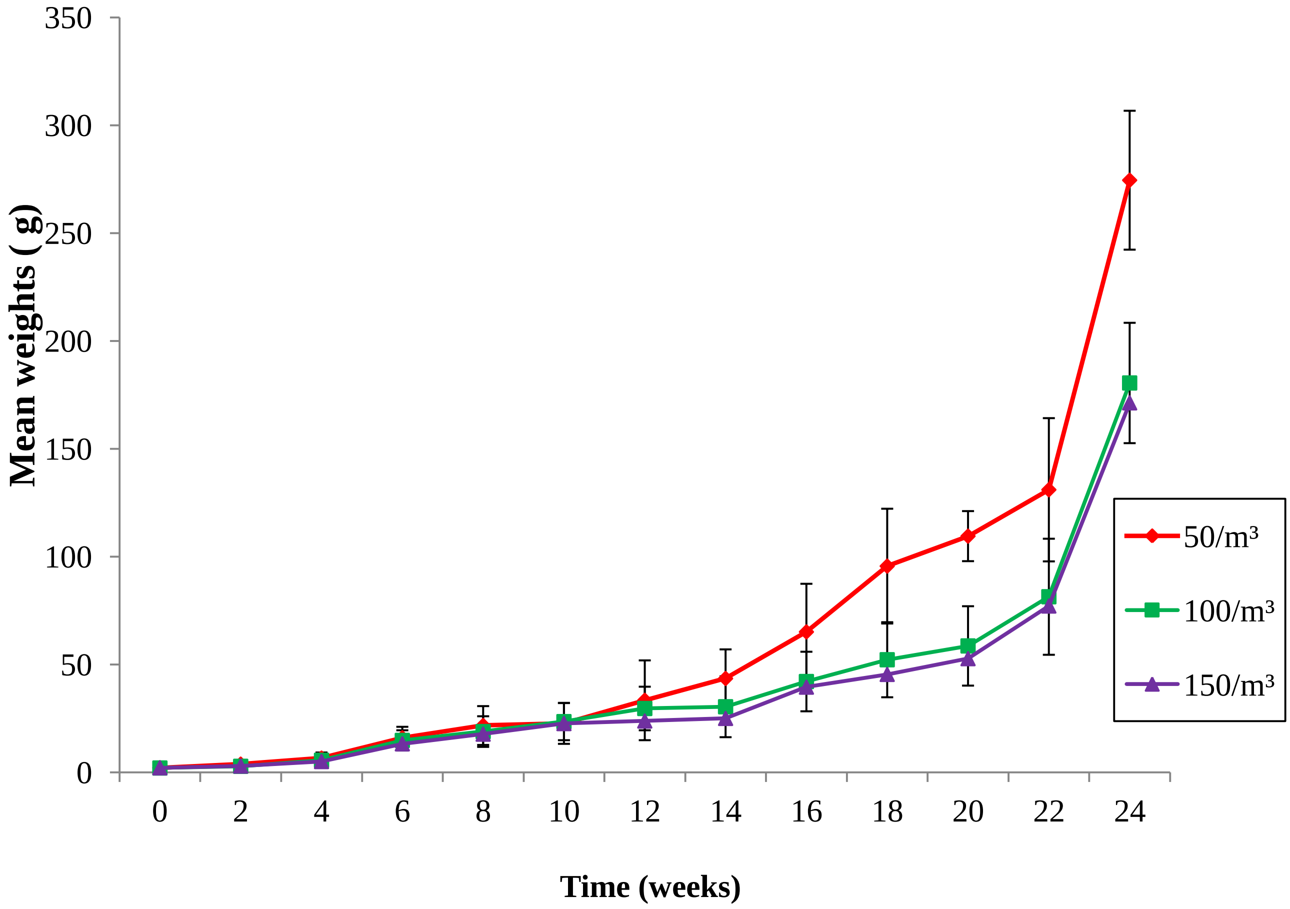

Figure 9: Growth performance of *Oreochromis niloticus* stocked in cages at three stocking densities for 177 days.

4.2.2. Fish Condition Factor (K)

The condition factors, in cultured fish were significantly affected ($p < 0.05$) by stocking densities. The treatment with 50 fish/m^3 had the best mean condition factor (3.90 ± 0.15) while the treatments with 100 fish/m^3 and 150 fish/m^3 showed similar ($p > 0.05$) mean condition factors of 3.71 ± 0.13 and 3.70 ± 0.13 respectively (Figure 10).

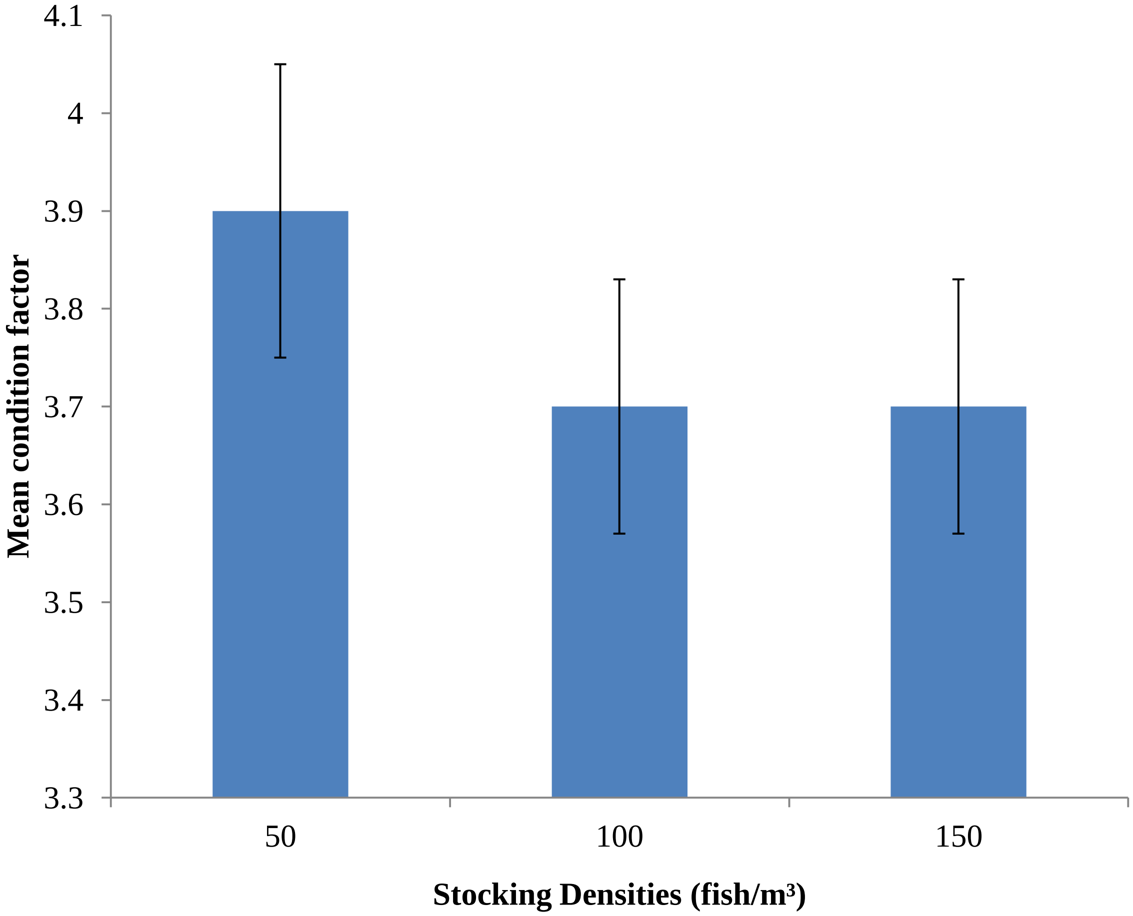

Figure 10: Mean condition factors of *Oreochromis niloticus* stocked in cages at three densities for 177 days.

4.2.3. Coefficient of variation (CV) in fish weight

The mean variations in the weights of sampled fish for the three stocking densities is shown in Figure 11. There were regular fluctuations in the mean coefficient of variations throughout the period of growth with no defined trend for each treatment. The overall mean values showed a significantly higher variation ($p < 0.05$) for fish in the 150 fish/m^3 treatment (39.7 ± 2.1%) while similar variations were observed among fish in the 50 fish/m^3 (36.9 ± 1.6%) and 100 fish/m^3 (37.0 ± 1.2%) treatments.

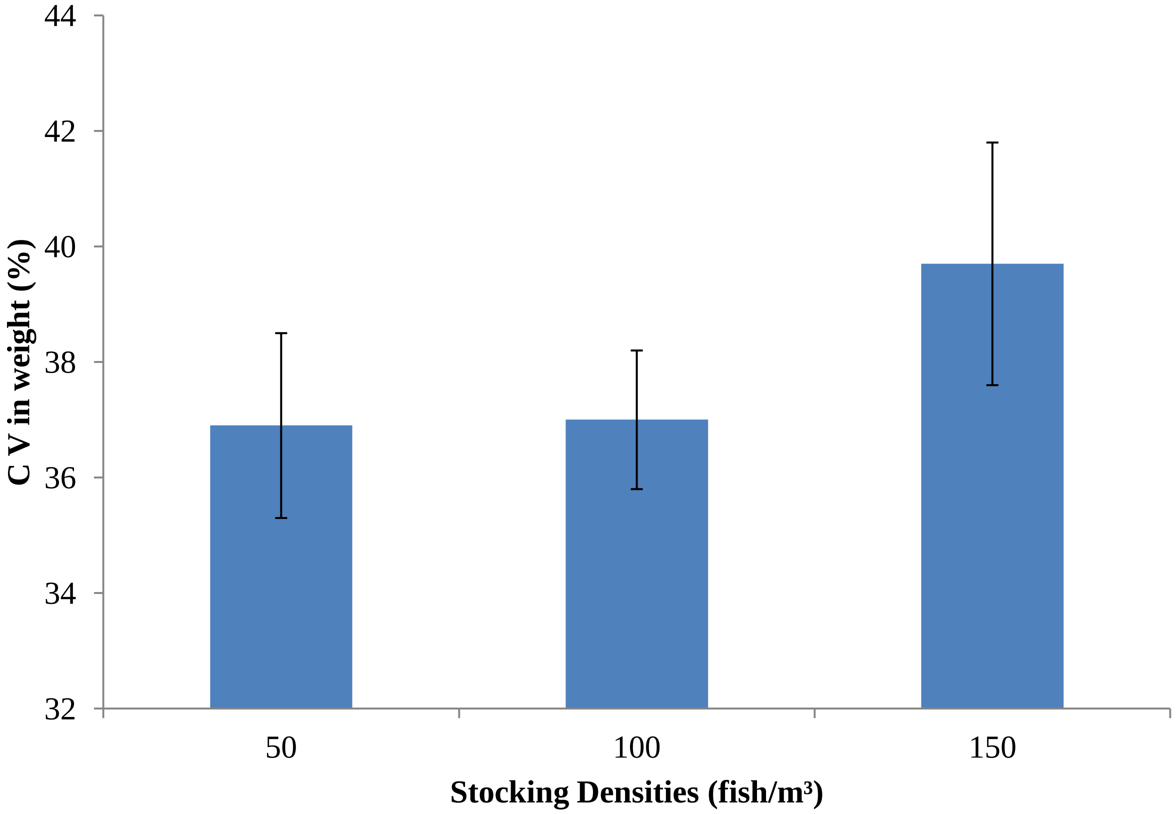

Figure 11: Mean variations in the body weights *Oreochromis niloticus* cultured in cages at three densities for 177 days.

4.2.4. Feed use efficiency by fish

Analysis of food conversion ratio (FCR), which expresses the ability of fish to effectively convert feed into body flesh, were statistically similar ($p > 0.05$) and better in fish stocked at 50 fish/m^3 (2.51 ± 0.01) and 100 fish/m^3 (2.50 ± 0.01) than the 150 fish/m^3 fish (2.70 ± 0.01). Similar results were shown by fish in the protein efficiency ratios for the three stocking densities (Table 2).

Table 2: Feed conversion and protein efficiency ratios (mean ± standard error) of *Oreochromis niloticus* stocked in cages at three densities for 177 days.

Parameters	Treatments		
	50 fish/m^3	100 fish/m^3	150 fish/m^3
Feed Conversion Ratio	2.51 ± 0.01^a	2.50 ± 0.01^a	2.70 ± 0.03^b
Protein Efficiency Ratio	1.330 ± 0.005^a	1.335 ± 0.004^a	1.219 ± 0.002^b

$^{a,\ b}$ Treatment means within the same row with different superscript letters are significantly different ($P < 0.05$)

4.2.5. Water quality parameters

The levels of key water quality parameters monitored throughout the study are shown in Figure 12 and a summary of their mean values and range are presented in Table 3. From Figure 12, it was observed that DO levels reduced drastically between the 8th and 12th weeks of culture. The lowest DO level (1.2 mg/l) was measured in the 10th week of growth when there was an overturn of the Volta Lake leading to some fish deaths (Figure 13) that were counted and replaced.

Table 3: Water quality parameters for *Oreochromis niloticus* cultured in cages on the Volta Lake for 177 days.

Parameter	**Mean ± SE**	**Range**
Temperature (°C)	28.42 ± 0.01	26.5 - 28.8
pH	-	6.52 - 6.89
Dissolved oxygen (mg/l)	3.71 ± 0.05	1.2 - 5.2
Total alkalinity (as $CaCO_3$) (mg/l	28.50 ± 0.04	27.9 - 691573

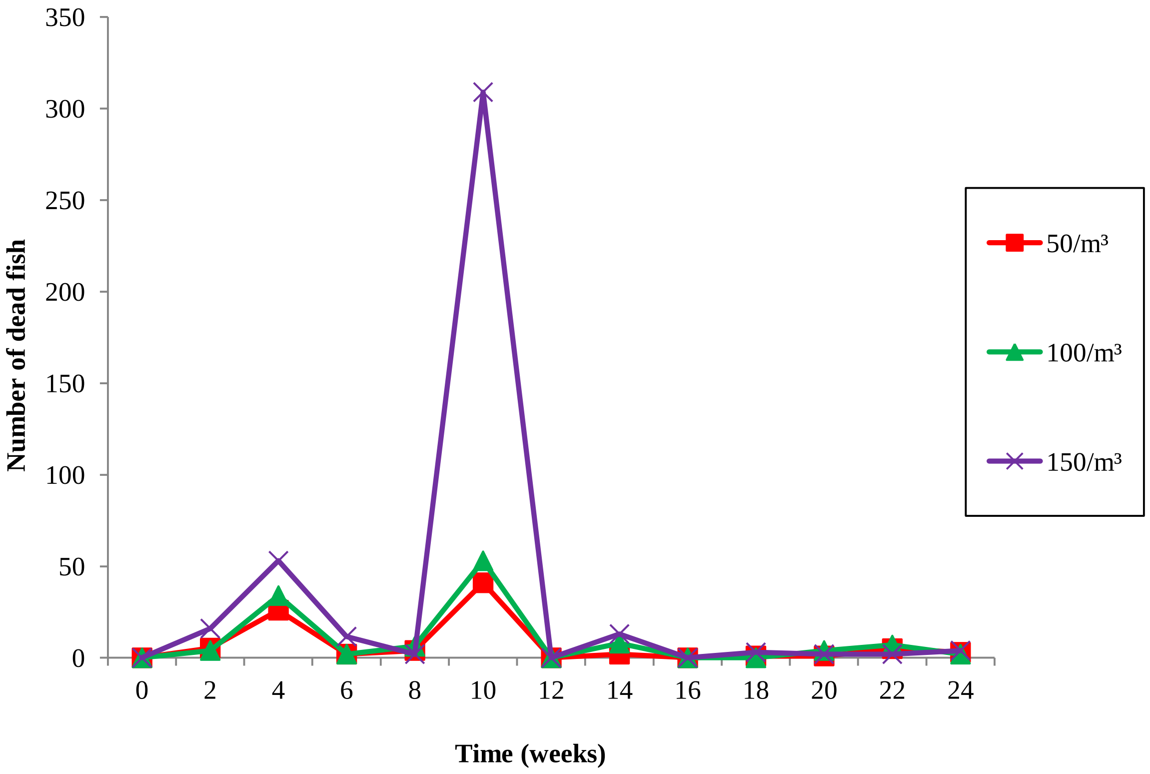

Figure 13: Trend in mortalities of caged *Oreochromis niloticus* under three stocking densities.

4.2.6. Yield Characteristics

Results of the yield obtained from growing *Oreochromis niloticus* at three stocking densities are shown in Table 4. Biomass harvested was highest (179.8 ± 12.1 kg) for fish stocked at 150 fish/m^3 followed by fish in the 100 fish/m^3 treatment (132 ± 10.1 kg) and the lowest biomass (85.4 ± 8.7 kg), was obtained in the 50 fish/m^3 treatment. The net yields were significantly affected by stocking densities with weights ranging from 84.55 ± 8.73 kg for stocking densities of 50 fish/m^3 to177.25 ±12.13kg for stocking densities of 150 fish/m^3.

Table 4: Biomass and yield of *Oreochromis niloticus* stocked at three densities in cages for 177 days.

Yield characteristics	**Treatments**		
	50 fish/m^3	100 fish/m^3	150 fish/m^3
Biomass stocked (kg/)	0.848 ± 0.034^a	1.696 ± 0.051^b	2.544 ± 0.033^c
Biomass harvested (kg/cage)	85.4 ± 8.7^a	132 ± 10.1^b	179.8 ± 12.1^c
Production (kg/m^3)	10.69 ± 2.11^a	16.50 ± 1.95^b	22.48 ± 3.10^c
Survival rate (%)	77.81 ± 2.03^a	91.34 ± 0.81^b	91.72 ± 1.20^b
Net Yield (kg/cage)	84.55 ± 8.73^a	130.30 ± 10.15^b	177.25 ± 12.13^c

[a, b] Treatment means within the same row with different superscript letters are significantly different ($P < 0.05$)

4.2.7 Economic profitability

Table 5 shows the cost and profits in using the three stocking densities for cage culture of Nile tilapia. Feed was the major cost in all the treatments, averaging 54% of the total variable costs. The total feed fed to fish for all treatments were highest (251.5 kg) in fish stocked at 150 fish/m^3 and lowest (150.5 kg) in fish stocked at 50 fish/m^3.

Comparatively, the estimated return on investment (ROI) ranged from 76.8% to 88.5% following the order: 50 fish/m^3 > 100 fish/m^3 > 150 fish/m^3. Profit index was significantly higher ($p< 0.05$) for fish stocked at 150 fish/m^3 (1.30 ± 0.01) than the 50 fish/m^3 and 100 fish/m^3 treatments that recorded similar indices of 1.13 ± 0.01 and 1.17 ± 0.02 respectively.

Table 5: Comparison of the cost-benefit analysis of *Oreohromis niloticus* cultured at three stocking densities in cages for 177 days.

Economic Parameters	**Treatments**		
	50 fish/m^3	100 fish/m^3	150 fish/m^3
U d b FG (	555.1	726	988.9
Feed input (kg)	150.5	196.3	251.5
B ddc. FG (	1.7	1.7	1.7
Cost of feed used (GH)	255.85	333.71	427.55
B d FG (	48	96	144
B b d FG (*	187.5	187.5	187.5
S B O c b FG (	491.35	617.2	759.1
F FG (	63.75	108.8	229.8
Profit Index	1.13	1.17	1.30
Return on Investment (%)	88.5	85	76.8

* Cage amortized over four years.

CHAPTER FIVE

DISCUSSION

5.1. Preliminary Studies via Survey

The present survey has provided information about the range of particularly stocking densities and fingerling sizes utilized by small-scale farmers within the Asuogyaman district. V d d dc d d b d d d d F d promoting it, coupled with the high performance of Akosombo strain of Nile tilapia, the cage industry is keen to further develop especially along the Kpeve to Akuse stretch of the Volta Lake.

Cages used by the small-scale operators in the district were mostly built from galvanized pipes that were floated by rubber drums and tied to nylon multifilament stretched nets. The cage materials, sizes and installation procedures were similar to those reported by Ofori *et al.* (2009) for West Africa. Categorically, all the cage farms visited cultured only *Oreochromis niloticus* in their floating cages. This confirms the report by Attipoe (2006), Blow and Leonard (2007) and Ofori *et al.* (2010) that, Nile tilapia (*Oreochromis niloticus*) is the only species cultured in cages Ghanaian cages. Sex-reversed (all-male) fingerlings (Akosombo strain) purchased from Aquaculture Research and Development Center, Jassa Farms, Data R d d d b d d d d d d b dc d b d S d proximity of these hatcheries to the farm sites on the Volta Lake encouraged farmers to procure fingerlings from them, thus reducing risks of heavy mortality associated with distant transport of fingerlings (Ofori *et al.*, 2009).

It was shown from the present study that, the small-scale cage operators stocked fingerlings with weights ranging from 2 g to 4 g in their cages. For a successful cage culture, fingerlings weighing at least 15 g is the recommended weights for farmers to maximize their growing season, and hence increase returns (Beveridge, 2004). The current average weights of fingerlings for cage stocking (2 g - 4 g) in the district showed a significant decline from the 10 g - 30 g reported for small holder farms in West Africa (Ofori *et al.*, 2009). It also deviated drastically from the recommended weight (15 g) for cage stocking in general (Beveridge, 2004).

The main reason was attributed to difficulty in procuring d 04 (fingerlings at times of cage stocking. Hence the cage farmers purchased and stocked these smaller fingerlings available in order to avoid wasting time while waiting for bigger sizes. This observation corroborates with Halwart and Moehl (2006) who identified lack of fingerlings for cage stocking to be a major constraint for cage culturists in Africa.

Fingerlings availability has remained a significant bottleneck to aquaculture throughout the world (Green, 2006) but the prevalence of some hatcheries in Ghana and the development of Akosombo strain of Nile tilapia seeks to address the issue locally (Anane-Taabeah *et al.*, 2011). However, outputs of fingerlings from these sources do not meet the current demand of the numerous small-scale farms emerging on the Volta Lake. Hence this study identified and documented the unavailability of fingerling sizes, appropriate for stocking in cages as a key constraint to small-scale cage farmers in Ghana.

The study also showed that, most of the farmers stocked their cages with fish at densities ranging from 50 to 200 fish per cubic meter. With the prevailing stocking of smaller fingerlings (2 g to 4 g) in cages, the stocking densities were expected to be higher because smaller fingerlings are generally stocked at higher rates (> 350 fish/m^3) (Schmittou, 2006). Nevertheless, farmers still practiced the rates reported by Attipoe (2006) and Ofori *et al.* (2009) (50 to 150 and 63 to 188 fish per cubic meter respectively) for 10 g to 30 g fingerlings on the Volta Lake.

The reasons for utilizing these densities were mostly attributed to d experience and advice from colleague cage operators. This agrees with Chakraborty and Banerjee (2010) who reported a similar case in India where most of the cage farmers are thought to use a combination of intuition and experience to decide upon the most appropriate stocking density, using codes of practice and handbooks as guides.

The fact that most of the small-scale farmers, particularly new entrants, had inadequate technical knowledge on optimal stocking densities suggests that training on these subjects is required to assist them in understanding the scientific concept and principles of stocking densities for sustainable cage farming. It also implies that strengthening of technical assistance and extension strategies that prioritize new commercial entrants would be beneficial. Strong linkages between government extension workers and the small-scale fish farmers through regular farm visits and consultation have been suggested from this study to be of substantial contribution to boost the cage aquaculture industry in Ghana.

The survey also identified high cost of feed and lack of start-up capital to be serious limitations in small-scale cage businesses. Indeed feeding fish in intensively managed cages can represent over 50% of the variable costs of production (Diana, 2004). The farmers utilized commercial diets due to their high quality and availability in the Ghanaian market. However, they complained that the feeds were relatively expensive to purchase compared to farm made feeds.

Fish poaching and damage to cage nets by local fishers around the cage farms were also reported to be challenges that small-cage operators faced within the district. Hence the employment of security persons could remedy these challenges. This suggestion agrees with Beveridge (2004) who opined that security is an element that all cage farmers must consider and plan for all contingencies.

5.2. Effect of Stocking Density on Growth Performance of fish

In the current study, the performance of cultured *Oreochromis niloticus* in terms of daily growth rates, specific growth rates, final length and weight gains were affected by the stocking densities tested. Adopting the growth curves (figure 9) alone, the trend was that biweekly weights did not diverge among density treatments until the mid-stages (12th week onwards) of culture when the effects commenced. This could be that, the inhibitory effects of different stocking densities emerged as fish reached an average weight of 25 g and not below. It can thus be suggested that densities higher than 150 fish per cubic meter appear feasible during the first three months of culturing 2 g Nile tilapia fingerlings in floating cages on the Volta Lake without any significant effects on growth.

Growth was shown to reduce during the 8th to 11th weeks of culture. This could be due to the evidence of stress (feeding cessation) observed while DO levels in the Lake reduced (1.2 mg/l) below optimal levels (> 3.0 mg/l) especially in the 10th week. The low DO recorded was attributed to natural upwelling of the Lake and not fish stocking densities because the incidence was reported to occur along a wider stretch of the Volta Lake system. Fish in cages became torpid and failed to react to feeding during the period of upwelling.

This could be explained by Schmi 1//5(d d ddc is the second limiting factor to cage fish production and gives way to the first limiting factor, water quality, usually in the form of low dissolved oxygen. Coche (1982) recommended 3.0 mg/l as the minimum DO level, below which adverse effects appear for cage culture of tilapia in freshwater. Hence this might have led to a reduction in fish growth and some observed mortality (Figure 13).

In addition, Green and Duke III (2006) reported that for any given culture management strategy, fish will grow at a maximum rate until food or some other environmental factor becomes limiting, causing growth to deviate (critical standing crop) from its maximum rate to a decreasing rate. Thus, slower growth observed during the weeks of low oxygen and feed cessation might be that, the critical standing crop had been exceeded and natural cage periphyton was insufficient to maintain rapid tilapia growth for all the treatments.

Nevertheless, rapid growth resumed after the DO increased beyond 3 mg/l in the 12th and subsequent weeks of culture resulting in active reception of formulated feeds by caged fish. This observation agrees with Green and Duke III (2006) who stated that if the limiting growth limiting factor is removed, fish once again can grow at a maximum rate.

The sharp increment in average weight of fish in the 24th week of experiment (Figure 9) might perhaps be due to the usage of all fish for the calculations. Although some fish specimen (50) from each cage were sampled for determination of weights throughout the study, final weights for the last week (week 24) was rather calculated from total cage population (harvest) and not samples. Ideally, higher number of specimen is required during sampling but in dealing with live fish, that could increase mortalities. This showed that the number of fish sampled bi-weekly were not statistically representative of the entire c b a d A d 0883(d d d b standardized methods for fish sampling in aquaculture experiments for monitoring growth of fish. Hence a more appropriate sampling numbers and strategies are needed for sampling live fish from cage populations.

In addition to the aforementioned, the sharp growth might be attributed to highest DO (5.2 mg/l) observed in the final week of culture, thus ensuring the fastest fish growth rates. This accords with studies done by Tsadik and Kutty (1987) on the influence of ambient oxygen on feeding and growth in *Oreochromis niloticus.* Their studies showed that, the highest growth rate was at high DO and the lowest growth rate was in the low DO concentration.

Generally, *Oreochromis niloticus* fingerlings stocked at 50 fish/m^3 treatment significantly showed higher individual weight gain, length gain, daily growth rates and specific growth rates while those stocked at 100 fish/m^3 and 150 fish/m^3 were statistically similar (Table 1). The study therefore showed an inverse relationship between stocking density and growth. The lower growth performance of Nile tilapia stocked at stocking densities of 100 fish/m^3 and 150 fish/m^3, relative to the 50 fish/m^3 could have been caused by increased stress (Ouattara *et al*., 2003), voluntary appetite suppression, more expenditure of energy because of intense antagonistic behavioural interaction and competition for food and living space (Diana *et al.*, 2004). Possibly, pheromones influences, which are suspected density-dependent social interaction in cages also influenced the growth and general performance of fish stocked at 100 fish/m^3 and 150 fish/m^3.

Gibtan *et al.* (2008) conducted a similar study in Lake Kuriftu, Ethiopia, using 45.8g *Oreochromis niloticus* and found a significantly higher average daily weight gain (1.15 g/fish/day) for those stocked at 50 fish/m^3 compared with 100 and 150 fish/m^3. Diana *et al.* (2004) also reported that sex-reversed Nile tilapia stocked in ponds at a low density of 3 fish m ^{2} had higher growth than at a higher density of 6 and 9 fish m ^{2}. The range in daily weight gain of all the fish in this study was similar to the 0.82 1.15 g fish ^{1} day ^{1} reported by Gibtan *et al.* (2008).

Additional evidence on growth difference at different stocking density can be obtained from results of specific growth rates. In the present study, it ranged from 2.43 2.73 %/day. These rates were higher than 1.14 - 1.55 %/day reported by Osofero *et al.* (2009) who initiated with 29.5 g Nile tilapia at the same stocking densities as applied in this study.

This could be due to differences in water quality dynamics and culture systems. Their study was conducted in a reservoir using bamboo cages while the present study was conducted on the Volta Lake and in floating net cages where water exchange in the cages is relatively high.

5.3. Effect of Stocking Density on Condition Factor

The fish from this study, although stocked initially at different densities exhibited no significant ($p > 0.05$) differences in their physiological well-being (K). However, the overall averages over the entire culture period showed a significantly ($p < 0.05$) higher value (3.9) for the low density (50 fish/m^3) than the high densities (100 fish/m^3 and 150 fish/m^3) which were statistically similar (both recorded 3.7).

The better condition factor observed in the 50 fish/m^3 could be that, fish in that treatment judiciously utilized their food for somatic growth as it was evident in their greatest weight gain. Anani *et al.* (2010) stated that feeding and food availability influence the condition of fish because food reserves accumulated through feeding increase the fish condition. Hence the best condition in this treatment might have as well contributed to the significant improvement observed in the average daily weight gain and specific growth rates in the 50 fish/m^3.

The fact that there were no incidences of diseases in all the experimental fish confirms the report by Schmittou (2006) that healthy tilapia crowded at densities of 400 to 700 fish/m^3 in cages are unlikely to become diseased.

Consequently, crowding of Nile tilapia (150 fish/m^3) in the cages did not in itself increase the incidence, spread, and severity of diseases as is sometimes assumed. However, skin abrasions were observed in a few number of fish especially at 150 fish/m^3 treatment and this conforms closely to Ma d 1 / / 7) report that abrasions combined with stress often result at high densities.

5.4. Effect of Stocking Density on Coefficient of Variation (CV)

A major drawback for producing marketable *Oreochromis niloticus* in freshwater cage culture is differential growth. Fish marketability is always better when uniformly sized fish are harvested. This is because live market vendors generally have strict size tolerances for fish they will accept or purchase from producers.

This study showed average coefficient of variation in the range between 36.9% and 39.7%. The variations could be attributed to differential growth among individual fish. This agrees with Green and Duke III (2006) who observed that when similar fish sizes are cultured together, there will always be a percentage, albeit small, of the fish population that will grow more slowly during every phase of culture.

According to Jobling and Baardvik (1994), coefficient of variation values above 10% are indicative of non-homogeneity within a group of fish. Thus, it can be stated that the experimental fish in this study were not uniform in all the treatments.

However, the tested stocking densities in this study significantly ($p < 0.05$) affected the weight variations of fish. Fish stocked at 150 fish/m^3 exhibited a significantly higher CV (39.7%) than the other two treatments which had almost the same CV values of 37%. This corroborates the findings of Alhassan *et al*. (2012) that stocking density has an effect on the average weights among individuals of initially uniform weight. Nevertheless, the findings disagree with that of Watanabe *et al.* (1990) who found that, higher stocking densities within the range of 150 and 300 fish/m^3 lowered growth variation of Florida red tilapia in marine cages.

The observation in the present study could be attributed to some fish in the 150 fish/m^3 cages trying to establish feeding hierarchies (like pecking others in poultry) of dominant and subdominant individuals of which the latter were chronically stressed and could not efficiently utilize feed and/or space. Schmittou (2006) confirmed this by reporting that, feeding hierarchies were usually observed when densities are around 150 to 200 fish/m^3 leading to reduced feed consumption and slowed growth in subordinate animals.

The present study suggests that stocking fish at densities of 50 fish/m^3 and 100 fish/m^3 are advantageous not only for increasing weight gain, but also for minimizing growth variation. In order to ensure consistent, uniformly sized product for market, it is suggested that small-scale farmers adopt some grading method before transporting fish to market. Moreover, as live fish vendors easily detect size variations, fish destined for market could be sorted to even market weight.

5.5. Effect of Stocking Density on Feed Utilization

Feed utilization (food conversion ratio and protein efficiency ratio) in this study was significantly affected by stocking density as was the case of Gibtan *et al.* (2008) and Osofero *et al*. (2009) although differences in 50 fish/m^3 and 100 fish/m^3 treatments were similar. Feed conversion ratios (FCR) observed in this study ranged between 2.50 to 2.57 and it showed significant increment with higher stocking densities.

The average FCR of 2.57 for all fish in this experiment was not significantly at variance with the typical FCR values (1.4 to 2.5) for *Oreochomis niloticus* cage systems in Africa (Beveridge 2004; Ofori *et al.,* 2010). Feed conversion ratios obtained in the 50 and 100 fish/m^3 (both 2.5 ± 0.01) were better than values obtained in the 150 fish/m^3 treatment (2.7 ± 0.03). The relatively better FCRs obtained for 50 and 100 fish/m^3 treatments (Table 2) suggests more efficient food utilization through the extraction of nutrients from the feed and converting it into flesh.

On the other hand, poor utilization of feed in the 150 fish/m^3 treatment could be attributed to fish expending more energy on aggressive feeding than converting into flesh. Feed wastage might also be a contributing factor to the poor performance at high densities because as density increases, feed loss potential increases due to increased fish-induced water turbulence at feeding time (Schmittou, 2006).

5.6. Effect of Stocking Density on Survival

From the present study, mean survival rate in the three treatments (86.3%) was higher than the typical survival rate in small-scale tilapia cage culture which is in the range of 70 80% (Mikolosek *et al*.1997; De La Cruz-Del Mundo, 1997). The relatively high survival rate recorded in all the treatments could be attributed partially to favourable levels of physico-chemical parameters of the Lake (El-Sherif *et al.*, 2008) and adequacy of food supplied throughout the period of culture.

In spite of this, rates greater than 90% has been associated with stocking densities in excess of 100 fish per m^2 (Ouattara *et al*., 2003; Balcázar *et al.*, 2006; Gibtan, 2008; Osofero *et al*., 2009). The inability of fish in the present study to attain such rates could be attributed to deaths that occurred during in the 4th week of culture (Figure 13) due to effects of harmattan that started in the culture area in January and the few deaths that were observed a day or two after sampling.

The results of this study (77.8, 91.3 and 91.7% survival rates for 50 fish/m^3 , 100 fish/m^3, and 150 fish/m^3 respectively) showed that, survival rates increased with high stocking density although the latter two were statistically similar ($p < 0.05$). This trend compares well with those of Ouattara *et al.* (2003), who found 98%, 96% and 100% survival rates for 50 fish/m^3, 100 fish/m^3 and 150 fish m ^{3} treatments. Gibtan *et al.* (2008) also found 94%, 95%, and 95.33% survival rates for Nile tilapia stocked at the same densities. However, these and several similar works did not find significant differences among the tested densities.

The significantly lower number of survivors in the 50 fish/m^3 treatment of the current study could be attributed to fish jumping out of the cages and escaping into the Lake. This assumption was because, the number of dead fish found in the 50 fish/m^3 cages throughout the culture period was far different from the number of survivors counted at harvest, a situation that was not observed in the other treatments. In addition, regular inspection of the cage nets revealed no holes where fish could have escaped. Morever, some aggressive fish jumped out of the cages in the later weeks of sampling and at harvest when fish had grown bigger and became difficult to fully control during scooping.

This suggests the need for stricter guidelines and training for small-scale farmers pertaining to fish collection from cages. It also suggests the importance of protective/double netting both on top and around cages to capture fish that could not jump farther from cage vicinity.

5.7. Water Quality in the Vicinity of Cages

Average maximum and minimum temperature, pH, total alkalinity, total hardness, ammonium, nitrite, nitrate and phosphates during the study (Table 3) remained within the limits for good tilapia culture (Boyd, 1990) and were suitable for cage cultured *Oreochromis niloticus* (Schmittou, 2006). The afore-listed parameters therefore did not present any significant effects on fish growth or the points monitored in the lake.

Nevertheless, morning (08:00 09:00) DO reduced drastically (minimum; 1.2 mg/l) due to Lake overturn especially in the 10th week (February) of culture resulting in fish stress and some abnormal mortality (Figures 12 and 13) due to asphyxiation.

The fact that fish stocked at 150 fish/m^3 recorded the highest mortality (Figure 13) during the overturn period showed that, the 50 and 100 fish/m^3 stocking densities are more tolerant of hypoxia than the 150 fish/m^3. It could therefore be deduced from the present study that crowding Nile tilapia at 150 fish/m^3 might be a very risky management technique for cage farmers on the Volta Lake where the incidence of Lake overturn could be difficult to predict.

5.8. Economic Production of Fish Reared at Different Densities

The main aim of any aquaculture business is to reduce production cost and maximize profit. An economic analysis, in addition to general feasibility analysis, is therefore required to decide whether a farmer should adopt a new production strategy.

In the present study, feeds were the largest variable cost with an average of 54% in all treatments. This confirms that the profitability in intensive cage culture is closely related to cost of feed (Hoffman *et al*., 1997).

The highest stocking density (150 fish/m^3) led to the highest cage biomass (179.8 kg) and FG 118 7(S d c c b b d d increasing stocking density. This is similar to the findings of Watanabe *et al.* (1990) who reported a positive relationship between stocking density and production yield for Nile tilapia. Studies by Cruz and Ridha (1991), Alemu (2003) and Gibtan *et al*. (2008) for *Oreochromis niloticus* cultured at different stocking rates similarly revealed the same trend. These observations were due to the fact that highest stocking densities led to the highest biomass gain.

The stocking densities employed produced an average production of 16.6 kg/m^3 over 24 weeks (within the range of 10.69 to 22.48 kg/m^3/6 months) compared with yields between 50 and 150 kg/m^3 over nine months produced elsewhere in Africa (Ofori, *et al.,* 2010). Profit indices for the 50 and 150 fish/m^3 treatments were statistically similar. This is in contrast with the report of Osofero *et al. (*2009) who found significant differences ($p < 0.05$) in the profit index for fish reared at 50 fish/m^3, 100 fish/m^3 and 150 fish/m^3 treatments.

This study has therefore shown that, the potential of cage aquaculture for higher yields in Ghana exists such that, production from less than 100 ha of fish cages could just about match the current capture fishery output of about 90, 000 tonnes (MOFA, 2012).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Tilapia cage culture is a promising industry, particularly for small-scale farmers in Ghana. It has huge potential to make significant contribution to the national fish production. Sustainability of the current boom in the cage industry in Ghana partly rests on a well-planned management strategy pertaining to stocking densities.

The present investigation has identified the range of *Oreochromis niloticus* weights (2g to 5g) and densities (50 fish/m^3 to 200 fish/m^3) used by small-scale farmers for stocking in cage on the Volta Lake. The study has also shown that the scope of knowledge obtained about b cd d d d d d d d bd d through interactions with colleagues. It was also revealed that lack of larger fingerlings for initial stocking in grow-out cages is a major challenge to the local small-scale cage industry.

In this study, the effects of stocking density were significant on the growth and profitability of Nile tilapia in terms of daily weight gain, specific growth rates, food utilization, condition factor and yield. Adopting growth performance alone, the resultant trend was that as stocking density increased, the indicators-daily growth rate, specific growth rates and final weight gain decreased significantly. Hence growth performance attributed to the stocking densities showed superiority in the order 50 fish/m^3 > 100 fish/m^3 > 150 fish/m^3.

In terms of survival, significant differences were found in the tested stocking densities. However fish mortalities were not influenced by higher densities (100 fish/m^3 and 150 fish/m^3) as is sometimes assumed. Indeed some deaths occurred during times of Lake upwelling (February) and mostly a day or two after sampling but these were solely natural phenomenon and fish stress due to handling respectively.

Besides February when oxygen concentration significantly dropped below recommended levels, all the water quality parameters monitored were within optimum ranges and therefore did not affect the growth of *Oreochromis niloticus* at the tested densities. Moreover, there was no observed impact of the experiment on Lake water in the site.

The viability and sustainability of aquaculture in Ghana will to a large extent depend on the level of profits that will accrue to stakeholders in the sector. Best achievement in net yield and profitability was shown in fish stocked at 150 fish/m^3. The study however showed that, if a fish weight of >250 g fish ^{1} is desired as the table size, the 50 fish/m^3 would be the most cost effective stocking density because of higher growth rates over a short period of time at lower production costs.

6.2. Recommendations

The following recommendations were distilled based on the major findings from the study:

a. Training on cage culture practices especially stocking densities, is required to equip small-scale farmers with sufficient scientific knowledge on this subject. Strengthening of technical assistance and extension services to the operators through regular farm visits and consultation could be of major help. Extension workers should also be encouraged to be more active and respond to the needs of the farmers.

b. Farmers could use any of the stocking densities studied but their choice must be guided not only by the cost of production but the awareness that, the most economical stocking density is not necessarily that which results in the highest growth rate, but that which results in the highest yield per unit area.

c. Research should be problem solving and focused on the needs at the farm level. The farmers should participate in developing research plans and short term studies should provide immediate practical application of results to address significant issues.

d. Research should be designed to thoroughly access the effects of densities between 150 and 300 on fish growth in intensive cage culture in Ghana.

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APPENDICES

Appendix A. Interview guide used during farm visits to cage farmers on the Volta Lake in the Asuogyaman District.

DEPARTMENT OF MARINE AND FISHERIES SCIENCE

UNIVERSITY OF GHANA, LEGON.

PLEASE NOTE ALL THE INFORMATION PROVIDED WILL BE TREATED AS STRICTLY CONFIDENTIAL

GENERAL

P d dB cd M d E
C d

M d d cd

Role of respondent

cc d E Sd

Name of town/Village

EXPERIENCE

How many years experience do you have in cage culture?...

Did you have any prior knowledge or experience before you started operation?
d M H d c c b d
them?..

....

G d d cdc b db d> d M H d d
it?

Do you obtain any technical aid or advice from any government institution eg. Fisheries
C QCDB> d M

When did you start this cage culture operation?..................

TECHNICAL

How many cages do you have? ....cages

R d b d d B b B a b

What is the size of the cage? Length................... Breadth................. Depth...................

d b d d d d> d M H d d db

What is the cage made of?

a. platform .... b. float ....

b b d. net ....

e. others (specify) ....

V dc bdad dd d b b d c da d d >

What is the mesh size of the cage net?

G b db d d > .

What fish species do you culture in the cages?

0
l

Where do you get your fish fry/fingerlings?

Why do you prefer the above source/s?

What are the purchased size of the fingerlings?

H d dad b >
Why?...............................

G c d d b dc>

What are the present prices of the fingerlings?

Size (g)	Price (cedis)

H dd c b d bd d c b dc d> d M

If yes, elaborate

Do you have any plans to secure the supply of the fingerlings (Eg. nursing of fries)?
d M H d d d
db

G d d a dd a d S d > d M

a C d b d > d M c. Diseases? d M c E c
d M e. Others (specify)?

N d a d b d d b d a d b> a b c

What are the precautionary measures taken to reduce or alleviate it? ....

In your opinion, what are the factors that contribute to high survival rate? ....

What do you know to be the factors that affect the growth rate of fish? ....

V d d c d d d d d bdc>

What measures are taken to prevent disease a d >

What is the stocking density by cages species and size?

Size of fish	Size of cage/ mesh size	Stocking density

How do you arrive at such a stocking density?

What recommended densities do you know?

C d db d b d> d M d db

G d d d d dc d d d > d M

if yes, name

How long is the culture period? ....

What is the price and preferred marketing size range of the fish

Sizes	Price

d d d d d d d d a c > d M
G d c d >C V d L
N d db (

V d d ddc dc>

How do you obtain the feed?
....

What is the crude protein content of the feed?

What is the frequency of feeding per day

How is the feed administered to the fish in cages?
....

What is the amount of feed used in relation to cage size? percent body weight?.....................

What is the price of the feed? ....

C d b d d b d ddc > d M G d d >
V d d ddc dc>

What records do you keep?

a. fish fingerling (purchased) record?
b. fish stock in cages record?
c. input/output of stock?
d. sales and purchases?
e. equipment records?
f. expenses records?
g. others (specify)?

Did you have any of these management problems or difficulties in fish cage culture since operation commenced and how did you prevent or overcome them? (Please elaborate)

a. Lack of skilled
   d
b. Lack of
   dc d
c. Loss/damage of cage and
   d d

d. Poaching of

e. Lack of
d
f. High cost of
d
g. High cost of overall
d
h. Low survival
d
i. Others (specify)?

C d d a d d > d M

What management measures do you adopt to ensure that the fishes are in the best of
b c

I guarantee your privacy. The information in this questionnaire, and in particular your personal details, will not be used for commercial ends nor will they be given to a third party**.**

Thank you very much.

Appendix B: List of fish farms and their locations provided by the Asuogyaman District Fisheries Officer (July, 2012)

Name of Farm	**Location**
Dieu D'Abord	Abotia
Aqua Consult Farms	Abotia
Tilafish Ltd.	Adjena Akadan
Lee's Farm	Adjena Donor
Sun Woo Culturing System	Adjena Dornor
F. A. F. F (NGO)	Adome
From Grace to Glory	Adome
Natgold Fish Farm	Adome
Adomi Biakoye Farm	Adome
Opoku's Fish Farm	Adome
Paradise Ventures	Adome
Christian Martey farm	Adome
Jerry farm	Akuse
Nii & Francis Fish Farm	Akwamufie
Volta Rapid Tilapia Ltd	Akwamufie
Cee & Max Farms	Akwamufie
His Grace Farms	Akwamufie
Danas Fish Farm	Akwamufie
Rehoboth Goshen	Apaatifi
Asafo Farms	Asafo Akwamu

List of fish farms (continued)

Name of Farm	Location
Daniel Clinton Farm	Asafo Akwamu
Julius Fish Farm	Asafo Akwamu
West Africa Fish Ltd.	Asikuma
Big Bite Fish Farm	Atimpoku
Gabriel Fish Farm	Atimpoku
Issah Yirenkyi Fish Farm	Atimpoku
K.C.Y.O. niloticus	Atimpoku
Osu Fish Farm & Works	Atimpoku
Safohene Fish Ltd	Atimpoku
Shehu Fish Farm	Atimpoku
Siphons Farm	Atimpoku
Dey Farms	Atimpoku
Kobby Farms	Atimpoku
Desmond's Fish Farm	Atimpoku
Nana Obiri II Fish Farm	Atimpoku
Letitia otubea's Fish Farm	Atimpoku
Maximum Victory Farms	Atortorsi
Crystal Lake Fish Ltd	Dodi-Asantekrom
Triton Aquaculture Africa Ltd.	Dodi-Asantekrom
Nahim Farms	Dodi-Asantekrom
Kingsmat Dan Co. Ltd	Gyakiti

List of fish farms (continued)

Name of Farm	**Location**
Kingsley Fish Farm	Kojopo
FreshLake Farms Ltd	Kudikope-Awurahi
Oceaba Farms	Labolabo
Tropo Farms	Mpakadan & Asutuare
New Powmu Fish Farmers Association	New Powmu
First Fresh Water	Old Akrade
Godson Fish Farm	Old Akrade
Jassa Farms	Old Akrade
Data stream Farms	Old Akrade
Panuel Farms	Old Akrade
Mahara Fish Farms	Old Akrade
Reeba Farms	Old Dodi Asantekrom
U.S. Micro-Finance Farms Co.	Sedom
Amebor Farms and Works	Senchi
Ayensu Farms	Senchi
C & J	Senchi
Ansong's Farm	Senchi
S/Hoint Ltd.	Senchi
Chally Tilapia Farms	Senchi
Appiah Farm	Small London

List of fish farms (continued)

Name of Farm	**Location**
Dawufre Fish Farm	Small London
Elorm Fish Farm	Small London
Blue Leaf Farm	South Senchi
Dakey Farm	South Senchi
Gadason Fish Farm	South Senchi
Lan's & M Fish Farm	South Senchi
South Senchi Fish Farmers Assoc.	South Senchi

Appendix C: Proximate composition of the Raanan commercial floating feed utilized

Content	Composition (%)
Protein	30
Fat	5.0
Fiber	5.0
Ash	8.0
Phosphorus	1.4
Moisture	9.5

Source: Raanan Fish Feed West Africa Ltd (2012)

Appendix D: Ration of feed administered to fish during the experimental period

Fish Body weight (g)	**Feeding rate (%) body weight**
2-5	12-10
5-20	10-7
21-50	7-4
51-100	4-3.5
101-250	3.5-1.5

After Nandlal and Pickering, 2004

Appendix E: Average body weights of fish attained by fish stocked at three stocking densities throughout the study

Weeks	**50 fish/m³**	**100 fish/m³**	**150 fish/m³**
stocking	2.2	2.1	2.2
2	3.9	2.9	3
4	6.7	5.7	5.1
6	16.1	14.9	13.3
8	21.8	19	17.8
10	22.8	23.6	22.7
12	33.5	29.7	23.9
14	43.6	30.5	25.1
16	65.2	42.2	39.6
18	95.7	52.3	45.5
20	109.6	58.7	52.8
22	131.1	81.5	77.2
24	274.1	180.1	171.1

Appendix F: Average variation in weights (CV) of fish stocked at three stocking densities throughout the study

Weeks	50 fish/m³	100 fish/m³	150 fish/m³
stocking	3.4	3.5	3.4
2	3.5	3.2	3.3
4	3.3	3.8	3.8
6	4.0	4.0	3.7
8	4.0	4.2	4.1
10	3.6	3.5	3.7
12	3.5	3.5	3.6
14	3.5	3.4	3.6
16	3.9	4.0	3.8
18	3.9	3.8	3.9
20	5.0	3.9	3.7
22	4.0	3.3	3.6
24	3.4	4.0	3.1

Appendix G: Average condition factors of fish stocked at three stocking densities throughout the study

Weeks	50 fish/m³	100 fish/m³	150 fish/m³
stocking	3.4	3.5	3.4
2	3.5	3.2	3.3
4	3.3	3.8	3.8
6	4.0	4.0	3.7
8	4.0	4.2	4.1
10	3.6	3.5	3.7
12	3.5	3.5	3.6
14	3.5	3.4	3.6
16	3.9	4.0	3.8
18	3.9	3.8	3.9
20	5.0	3.9	3.7
22	4.0	3.3	3.6
24	3.4	4.0	3.1

Appendix H: Lake water parameters measured at experimental site of Nile tilapia culture

Weeks	**Temperature (°C)**	**pH**	**Total Alkalinity (mg/l)**	**Total Hardness (mg/l)**	**DO (mg/l)**
stocking	28	6.8	27.9	25	3.9
2	27.1	6.71	28.7	24	3.5
4	26.5	6.54	28.6	23	2.9
6	26.7	6.52	28.5	24	2.6
8	27.5	6.74	28.5	24	2.9
10	27	6.67	29	23	1.2
12	28.3	6.89	28.5	25	3.75
14	28.8	6.83	28	23	3.7
16	28	6.37	28.5	23	2.65
18	28.3	6.61	28.5	24	2.9
20	28.6	6.65	27.5	29	4.2
22	28.5	6.74	28.5	28	3.6
24	28.7	6.61	29.5	31	5.2

Appendix I: Some nutrient levels (mg/l) of Lake water taken from experimental site of Nile tilapia culture

Weeks	Concentration (mg/l)			
	NH4-N	**Nitrite (NO2-N)**	**NO3-N**	**PO4-P**
stocking	0.02	0.002	0.03	0.01
2	0.04	0.004	0.03	0.03
4	0.03	0.003	0.04	0.02
6	0.03	0.003	0.09	0.01
8	0.04	0.004	0.07	0.01
10	0.06	0.007	0.03	0.04
12	0.06	0.002	0.05	0.09
14	0.01	0.001	0.03	0.08
16	0.08	0.006	0.04	0.11
18	0.06	0.012	0.02	0.07
20	0.03	0.004	0.03	0.05
22	0.02	0.003	0.05	0.04
24	0.06	0.005	0.04	0.08