

**ASPECTS OF THE BIOLOGY AND ECOLOGY OF NILE TILAPIA,
Oreochromis niloticus LINNE', UNDER POND CONDITIONS**

BY

MONIC NSEGA

B.SC (FA); ODST/B

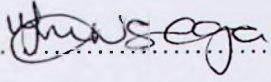


**A DISSERTATION SUBMITTED TO THE DEPARTMENT OF
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IN UGANDA**

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DECLARATION

I, Monic Nsega, declare that this dissertation is my original work and has not been submitted for a degree in any other university.

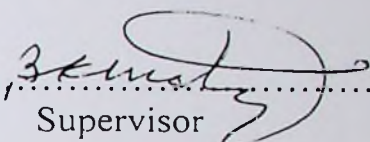
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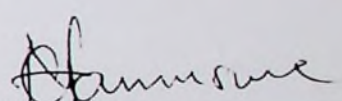
We certify that this dissertation satisfies the partial fulfillment of the requirements for the award of the degree of Master of Science (Environmental Science) of the Islamic University in Uganda.

1. Prof/Assoc. Prof/Dr. Boniface MAKANGA.....


Supervisor

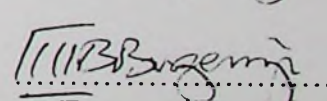
Date. th 24 Nov. 2011.

2. Prof/Assoc. Prof/Dr. Gladys Bwankye.....


Internal Examiner

Date. 24/11/2011.

3. Prof/Assoc. Prof/Dr. Frederick W.B. Bugemigye.....


External Examiner

Date. 24/11/2011.

DEDICATION

To my dear parents in recognition of their sacrifice to make me what I am.

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LIST OF ABBREVIATIONS

FAO	Food and Agricultural Organization
NaFIRRI	National Fisheries Resources Research Institute
SRAC	Southern Research Aquaculture Centre
USAID	United States Agency for International Development

ABSTRACT

Despite its introduction in the 1950s, Nile tilapia (*Oreochromis niloticus*) farming in Uganda is still mostly at subsistence level. Three private fish farms (A, B, C) stocked with mixed sex tilapia were studied between January 2009 and July 2009. Management practices differed in the three farms: Fertilization was done before stocking in Farm C but lacked in farms A and B. Rice bran and cabbage leaves were administered as supplemental feeds in Farm A; and maize bran and cabbage leaves in Farm B. The quantities of maize brain and cabbage leaves in Farm B were twice and thrice that of rice bran and cabbage leaves in Farm A respectively. Fish in Farm C depended on natural foods only. The farms were subjected to partial harvesting prior to this study. The major objectives were: to identify and quantify major natural foods within the fish ponds, determine diet, and life history traits of *O. niloticus*. Four phytoplankton taxa: Bacillariophyta, Chlorophyta, Cyanophyta and Euglenophyta were identified. Zooplankton comprised of mainly Rotifers, Copepods and Cladocerans. The dominant macro-invertebrates taxa were Gastropoda, Diptera, and Oligocheate. Farm B supported the highest densities of natural foods: 52 ± 8 cells.ml⁻¹; 1048 ± 277 organisms.l⁻¹; and 2147 ± 598 organisms.m⁻²; while Farm A had the least 5 ± 1 cells.ml⁻¹; 289 ± 53 organisms.l⁻¹ and 520 ± 111 organisms.m⁻² for phytoplankton, zooplankton and macro-invertebrates respectively. Kruskal-Wallis test detected significant differences in numerical densities of foods between farms. Chief dietary items were higher plant material, detritus, and algae. Fish from Farm B ingested more zooplankton and macro-invertebrates than that from the other farms. Supplemental feeds constituted only 3% and <1% of the fish diet from farms B and A respectively. Sex ratio (Chi-test) did not differ significantly from a 1:1 ratio. Size at first maturity was below 20g (except for males from Farm B) and the modal size class was ≤ 20 g. Males grew bigger than females, and ANCOVA test for logarithmic relationships showed significant differences both within and between farms. Fish from Farm B were heavier and grew isometrically; fish from farms A and C displayed a negative allometric growth. Excess cabbage leaves provided primarily as feed probably supplied manure that enhanced higher production of natural foods to provide a better diet which perhaps contributed to improved performance of Nile tilapia in Farm B. Farmers are encouraged to stimulate natural food production, provide supplemental feeds, farm all-male Nile tilapia, and observe management practices. Research to establish age at maturation in farmed Nile tilapia is recommended.

CHAPTER ONE

INTRODUCTION

1.0. Background to the study

Capture fisheries and aquaculture (fish farming) are key global sources of benefits that include high quality protein food, income, foreign exchange and employment for both those that are directly and indirectly involved in the fish industry. Trends in global fish production show a general decrease in capture fisheries but an increase in farmed fish production. From a production of 94.6m tonnes in 2004, world capture fisheries reduced to 94.2m tonnes in 2005, and a further reduction to 92m tonnes in 2006 (FAO, 2008). Global farmed fish production was estimated at 45.9m tonnes in 2004, 48.5m tonnes in 2005 and 51.7m tonnes in 2006 making it the fastest growing food sector in the world with an average annual growth rate estimated at 6.9% (FAO, 2008). China was the world's leading aquaculture producer with a contribution of about 67% of total (51.7m tonnes) farmed fish produced in 2006. However, despite the high potential for aquaculture in Africa, the continent still lags far behind other regions in fish farming. By 2006, Africa contributed about 1.5% of the world's total farmed fish production of which 90% was from Egypt, and about 32,300 tonnes (<1%) from Uganda (FAO, 2008).

About 86% of Uganda's fish production is from capture fisheries, with Lake Victoria as the major producer. Since 1993, Lake Victoria has experienced over-fishing in a bid to

satisfy mainly the expanding export markets. Consequently, the estimated annual fish catches from the Uganda part of the lake has been reducing (Table 1.1).

Table 1.1: Trend in estimated Annual fish Catches (tonnes) from L. Victoria, Uganda

Year	Tilapia	All fishes
2005	29,415	238,533
2006	27,061	215,943
2007	24,356	227,487
2008	19,557	173,024
2010	16,971	162,929

Source: NaFIRRI CAS surveys, 2010.

With an estimated current population of 34.5m (Population Reference Bureau, 2011), the demand for fish will increase and per capita fish consumption is likely to decline from the present 6-7 kg unless alternative supply sources are identified. It is anticipated that fish farming will address the resultant demand gap.

1.1. Nile tilapia culture systems

There are diverse systems used to rear Nile tilapia and their classification depends on the type/nature of culture systems and management intervention. Culture systems include earthen ponds, cages, concrete tanks, and raceways (flow-through system). Earthen pond is the most used culture system worldwide (de Graaf, 2004) including Uganda. Tanks and raceways mainly require intensive management and are used as alternatives to earthen

ponds in countries where water and land may be limiting. Cage culture is a form of aquaculture involving establishing enclosures (cages) in natural water bodies such as lakes and rivers.

Depending on management strategies, common fish farming systems include extensive, semi-intensive, and intensive. Extensive systems mainly depend on natural pond productivity and very limited or no technical inputs and management is involved. Extensive culture systems are characterized by either none or very low level of artificial feeding and fertilization. Usually, low investment capital is involved and production cycles may be prolonged up to 2 years. In some cases, control of stocking densities is performed. Semi-intensive systems involve a relatively higher level of intervention and higher investment capital. In Semi-intensive systems productivity is enhanced by fertilization and there may be some supplementary feeding. Fish performance and yields from semi-intensives systems are usually higher than those from extensive systems. Just like in the extensive system, Nile tilapia production under semi-intensive management is basically in earthen ponds. Intensive systems engage very high level of intervention, investment capital, and production. Fish production is based mainly on complete (balanced) formulated feeds. The most common forms of intensive culture are tank and cage culture. Compared to extensive and semi-intensive systems, intensive systems are the most productive.

Common Nile tilapia farming practices include mono-sex culture, mixed sex culture, monoculture and polyculture. Mono-sex is the rearing of either males or females separately; while in mixed sex culture both males and females are reared together. Monoculture is the farming of only one fish species while in polyculture, a predatory fish such as *Clarias gariepinus* is introduced to feed on off-springs produced and hence control overpopulation. Vincke (1987) and Dadzie (1992) regarded tilapia monoculture as the easiest and most successful system in starting rural fish farming. However, proliferation that occurs in monoculture of mixed Nile tilapia lead to low production making polyculture a better option. Proliferation is a major biological problem that can lead to stunting of fish (Popma & Masser, 1999). Nile tilapia are highly fecund and multiple spawning in ponds may result into over-population and over-crowding (Marcel, 1986). To avoid/minimize proliferation, it is advisable to harvest Nile tilapia within 5-6 months prior or soon after sexual maturity (Popma & Masser, 1999). Alternatively, farmers are often advised to stock mono-sex seed preferably males that grow faster and to a larger size (Marcel, 1986; Popma & Masser, 1999). Also, other studies show that natural foods are not effectively consumed if only one species is cultured (Dadzie, 1992; Milstein, 1992; Milstein & Svirsky, 1996).

1.2. Fish Farming in Uganda

Fish farming is reported to have started in Uganda in 1941 with the importation of carp (FAO Fact Sheets, 2006) but research experiments began in 1953 at the then Kajjansi

Experimental Fish Farm (Biribonwoha, 1976). Major fish species cultured at the time included the Nile tilapia (*Oreochromis niloticus*), cat fish (*Clarias gariepinus*) and carp (*Cyprinus carpio*). By 1970, there were over 10,000 ponds of about 0.1 ha each and production levels of about 1200 – 2300 kg ha⁻¹ yr⁻¹ (Dadzie, 1992). Since then, fish farming has been growing though not at its full potential mainly due to factors including the then abundant supplies from capture fisheries, political instability and socio-economic decline during the 1970 – 1980, and the limited fish eating habits among some social groups in the country. Although global assessment rated Uganda with Africa's fastest fish farming growth rate, the production level is still far below that from other countries such as Egypt which is the leading producer of farmed fish in Africa (FAO, 2008). In 2009 Uganda produced nearly 76,654 tonnes compared to 705,500 tonnes from Egypt (FAO-Fishstat, 2010). Nile tilapia production in 2008 was estimated at 15,000 tonnes for Uganda as opposed to 477,458 tonnes from Egypt where semi-intensive and intensive are the basic systems (FAO-Fishstat, 2010). Although farmed fish production in Uganda is projected to increase, further growth and development will be influenced by production from subsistence farmers who are currently the majority. Trends in farmed fish production from Uganda are shown in Figure 1.1.

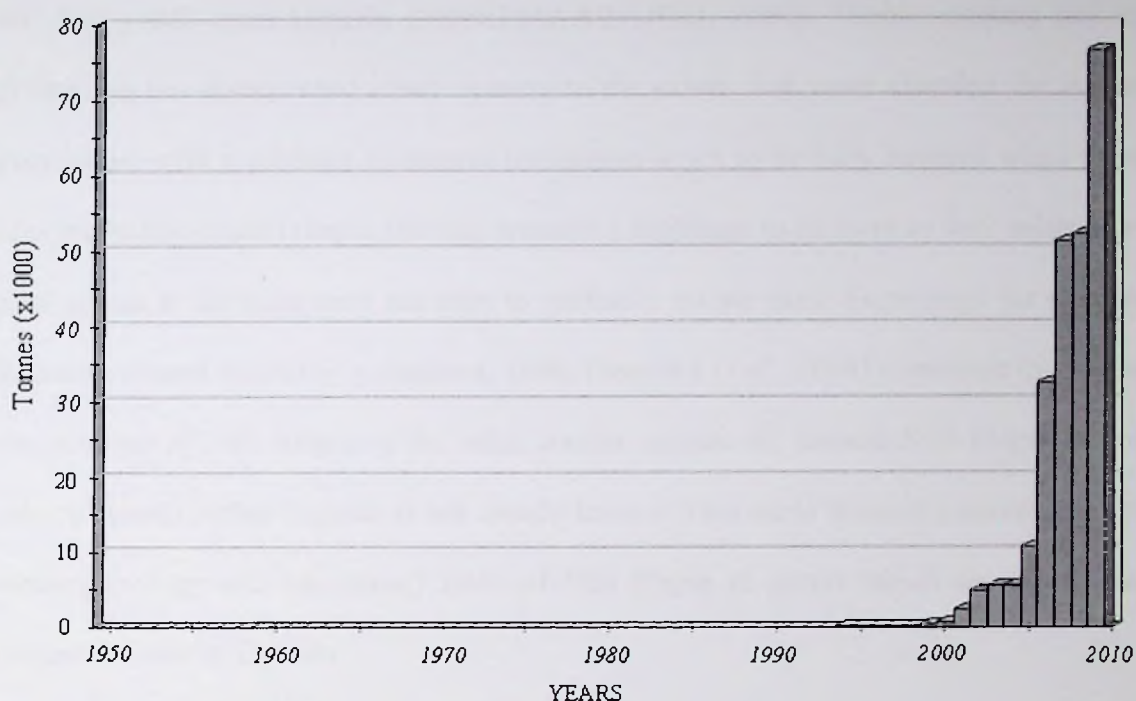


Figure 1.1: Trend in farmed fish production from Uganda. *Source: FAO-Fishstat, 2010*

Despite the recorded increase in farmed fish production over the past years (Fig. 1.1), the enterprise is still mainly at subsistence level. In Uganda, traditional earthen pond culture employing extensive system is the most common practice for Nile tilapia farming, and common practices embrace mixed sex monoculture although polyculture and mono-sex (particularly all males) are emerging. Generally, fish production from extensive mixed sex Nile tilapia culture is often low. A survey by NARO/MAAIF/DFID (2000) reported lack or limited fertilization and supplementary feeding, factors that render ponds deficient in fish foods and feeds respectively. Locally available feeds used include bran, vegetable leaves, and kitchen refuse usually of inadequate quantities and irregularly administered. Prolonged grow-out cycles and partial harvesting are additional factors contributing to

low fish yields from Uganda (NARO/MAAIF/DFID, 2000). Tilapia stunting and low production has discouraged many farmers to the extent that some abandon the venture. Polyculture with a predator to control population is yet to be fully adopted while mono-sex (preferably males) tilapia farming remains a challenge to farmers as they neither have easy access to all male seed nor able to perfectly isolate male fingerlings for stocking. Whereas several studies (e.g. Balirwa, 1998, Bwanika *et al.*, 2004) examined the biology and ecology of Nile tilapia in the wild, similar aspects for farmed Nile tilapia in pond culture system within Uganda is not clearly known. This study therefore investigated the feeding ecology and life history traits of Nile tilapia in ponds which are the primary culture systems in Uganda.

1.3. Problem Statement

The decrease in catches from capture fisheries associated with global and local demand for fish and fish products has created a fish supply gap. Fish farming is considered a potential solution. However, the enterprise is still mostly at small scale under basically extensive systems in earthen ponds where inputs and management practices are either lacking or limited. Consequently, farmed Nile tilapia often become stunted leading to low yields and negative returns. A study on the biology and ecology of farmed Nile tilapia would increase understanding of the culture requirements for improved fish production.

1.4.0. General Objective

To study the biology and ecology of Nile tilapia under culture conditions

1.4.1. Specific Objectives

1. To identify and quantify major natural foods (algae, zooplankton, macro-invertebrates) of Nile tilapia in the study fish ponds
2. To determine the diet of Nile tilapia in the study ponds
3. To determine the following life history traits:
 - i. size structure
 - ii. sex ratio
 - iii. size at first maturity
 - iv. fecundity
 - v. length-weight relationship and Condition Factor of Nile tilapia in the farms

1.5. Hypotheses

- a. There are no significant differences in Natural foods in the study farms
- b. There are no significant differences in the life history traits (sex ratio, length-weight relationship, Condition Factor) of cultured Nile tilapia in the study farms

1.6. Significance of the study

Fish is increasingly becoming scarce and expensive in the local market particularly in rural areas. Subsistence fish farming, as practiced by emerging rural fish farmers, can be a source of food security, quality protein, and income. In order to sustain and improve production in such systems there is need to understand biological and ecological factors that may be contributing to poor performance of farmed Nile tilapia.

CHAPTER TWO

LITERATURE REVIEW

2.0. Suitability of Nile tilapia as a culture species

Nile tilapia is commonly used in aquaculture because it is extremely hardy, physiologically tolerant, and characterized by a wide feeding plasticity, efficient feed conversion, faster growth and attain larger sizes in comparison to other tilapias (Marcel, 1986; Swift, 1993; El-Saidy & Gaber, 2005). The Nile tilapia is capable of utilizing food from the lowest trophic level, through the detrital food chain (Liti *et al.* 2002) thus enabling its production with none or limited external feed input. However, the physical, biological and chemical factors within an environment may often influence the growth of the Nile tilapia. For example, under poor water quality, retardation in fish growth can occur even if food/feed of high nutritional value is provided (Liti *et al.*, 2002). Swift (1993) reported tolerance for temperature range of 20 – 30°C; lethal oxygen limit of 2 - 3mg l⁻¹ and pH 5 - 11 for Nile tilapia. As a result of the wide ecological conditions under which Nile tilapia survives, it has been brought under culture conditions in many parts of the world including Uganda.

2.1. Natural food production and its importance

Natural foods include all micro-organisms and macro-organisms fed on by fish in its environment. The natural foods in a pond, for example, include plankton (phytoplankton,

periphyton, and zooplankton), bacteria, fungi, macro-invertebrates and macrophytes. Naturally occurring foods considered relatively important and available to *O. niloticus* include phytoplankton, zooplankton, and macro-invertebrates (Marriot *et al.*, 1989; Balirwa, 1992; Getabu, 1994; Balirwa, 1998; Bwanika *et al.*, 2006). In fish ponds, production of natural foods is primarily based on fertilization (Randolph, 1986), a natural pathway through which organic material enters the fish pond food web. In Uganda, higher levels of nutrients and plankton (phytoplankton and zooplankton) occurred in manured experimental ponds than in control (i.e. non-manured) ponds (Namulawa, 2002). A similar trend was observed in India by Dhawan & Kaur (2002) despite supplementary feeding in control ponds. Additional benefits of fertilization on plankton production were studied in Egypt (Abdel-Tawwab *et al.*, 2005) and Malawi (Kang'ombe *et al.*, 2006). These studies show that unlike unfertilized systems, fertilized ponds lead to higher fish growth rates and higher fish yields.

Availability of natural food provides a cheap means of fish farming (Dadzie, 1992). Natural foods are ideal because they have variable size, are high in nutritive value, cheap to produce, and have high productivity rates (Randolph, 1986). Presence of live food organisms in appropriate types and quantities influences survival and growth of fish fry and fingerlings. Under culture conditions, natural food forms a major diet for juvenile fish less than 4cm (Marcel, 1986). Natural foods are important in growth of tilapia as up to 50% of tilapia body weight is derived from natural food chain despite supplementary feeding (Swift, 1993). Schroeder (1983) and Milstein (1992) reported 60-80% tilapia

growth contribution by natural foods of autotrophic origin in a polyculture system supplied with feed pellets. Different experimental Nile tilapia culture systems supplied with feeds recorded better performance of Nile tilapia in earthen ponds, a finding attributed to additional contribution by natural food (Chakraborty *et al.*, 2011). These observations suggest that knowledge of natural foods in fish farms is important in the operations of fish farming.

Presence of natural foods in adequate types and quantities can independently support fish production in fish ponds though on small scale. Other than acting as supplementary feed for tilapia, organic matter provides autotrophic and heterotrophic food webs that are keys to pond productivity (Randolph, 1986). In examining how subsistence fish farmers target productivity, it is important to know whether or not they practice fertilization.

2.2. Major factors affecting natural food production and fish performance in ponds

Fertilization enhances natural food production, fish performance and yields in ponds. Randolph (1986) listed the importance of organic fertilizers as sources of carbon and phosphorus for photosynthesis, supply of growth factors for algal growth; substrate for micro-organisms which are either directly consumed by fish, or support aquatic invertebrates which in turn are direct food items for fish. Despite extension advice, a baseline survey by NARO/MAAIF/DFID (2000) showed that at least 50% of farmers in

Uganda did not fertilize their ponds, and even those who did only applied it in preparation for stocking.

Pond productivity of natural foods and their abundance can be affected by other factors in addition to fertilization. Grazing and predation effects within food chain and food web can affect availability of natural foods hence pond productivity. An account of grazing pressure on phytoplankton community by zooplankton in ponds was given by Cottenie *et al.*, (2001). Besides, plankton species diversity and abundance were reported to display spatial and temporal variations (Abdel-Tawwab *et al.*, 2005; Davies *et al.* 2009). Seasonal variations and human activities can also influence physical-chemical variables resulting into changes in plankton abundance and diversity (Davies *et al.* 2009).

In order to realize optimum fish production, feeds should be nutritionally complete and balanced (Schmittou *et al.*, 1998). Supplemental feeds are provided to ensure good fish health (Post, 1983), promote fast growth and increase fish yield (Liti *et al.* 2002). Improved fish yields have been reported in systems with both fertilization and supplementary feeding in relation to systems with only fertilization (Abdel-Tawwab *et al.*, 2005). Single or multi-ingredients have often been used as supplemental feeds. The quality, quantity, nutrient availability to fish and effect of feed on water quality are key factors to consider when selecting feeds (Schmittou *et al.*, 1998; Liti *et al.* 2002). However, due to unavailability of quality feeds at low costs, many farmers resort to using cheap incomplete feeds such as maize bran, rice bran, vegetable leaves, and food leftovers some of which may not be easily digestible by fish. Moreover, their quantities

and feeding regimes may be reduced below recommended levels (NARO/MAAIF/DFID, 2002) causing deficiency in supplemental feeds. There is thus need to identify variations in fish growth parameters that are generally disregarded by fish farmers but may be due to lack/limited feeding and fertilization.

Controlling stocking density allows optimum utilization of pond resources to enhance proper fish growth. Stocking density can vary depending on culture system, pond productivity, management practices and target market (Marcel, 1986). A stocking density of 2 fingerlings.m² is recommended for subsistence farmers (NARO/MAAIF/DFID, 2002). Generally, in pond culture high stocking density produces smaller size fish compared to low stocking density. However, just like in intensive systems such as High Density Low Volume (HDLV) cage-culture, high stocking density in ponds can produce large-sized fish if optimum quality food is provided and water quality maintained (Schmittou *et al.* 1998). It is likely that small-scale fish farmers in Uganda produce small-sized fish due to limited knowledge of pond productivity and management including enhancement of natural food production and control of Nile tilapia proliferation respectively, factors that are not regularly reported on.

Growth performance of the Nile tilapia under culture conditions may vary depending on the system and interventions made in relation to the environmental conditions. Chakraborty *et al.*, (2011) recorded higher mean weights and faster growth rates of Nile tilapia reared in ponds compared to that from cistern, flow-through and pens. In Egypt,

Nile tilapia reared in concrete tanks with varying protein content and feeding levels attained minimum average weight of 110g after seven months (El-Saidy & Gaber, 2005). NARO/MAAIF (2002) observed better Nile tilapia performance in pond systems supplied with supplemental feeds than those without; while polyculture system using *C. gariepinus* showed improved results compared to monocultured Nile tilapia (de Graaf, 2004). The potential for males to grow faster and bigger under culture conditions was examined by de Graaf (2004) and Chakraborty *et al.* (2011). Nile tilapia weight gains noted in earlier studies are shown in Table 2.1.

Table 2.1: Performance of pond Nile tilapia with varying practices and treatment

System & Practice	wt at stocking	final wt (g)	period	source
Pond mixed sex*	-	85	5 months	Chakraborty <i>et al.</i> , 2011
Pond monosex*	-	290	5 months	Chakraborty <i>et al.</i> , 2011
Pond mixed sex**	20	192 male	7 months	de Graaf, 2004
Pond mixed sex**	20	69 female	7 months	de Graaf, 2004
Pond mixed sex***	1	94	6 months	NARO/MAAIF, 2002
Pond mixed sex****	1	55	6 months	NARO/MAAIF, 2002

* 32% crude protein feed applied; ** wheat bran feed applied

*** mixture of rice bran and sunflower oilcake feed applied

**** cow dung treatment, no supplementary feeding

Popma & Masser (1999) reported average weights of 200g in 3-4 months, 400g in 5-6 months, and 700g in 8 to 9 months for mono-sex (all males) Nile tilapia under optimum pond conditions. In Uganda, on farm trials by NARO/MAAIF (2002) achieved varying

growths of Nile tilapia in different regions an observation that was attributed to different management levels and zones. Highest weight gains were recorded in the northern region as follows: 5-55g in one month; 21-76g in 3 months; and 40-140g in 5 months (NARO/MAAIF, 2002). In extensive systems such as the ones under investigation where the fish depends mainly on natural foods, lower weights can be anticipated.

2.3. Feeding habits of Nile tilapia

Several studies (e.g. Lowe-McConnell, 1958; Marriott *et al.*, 1989; Balirwa, 1992; Getabu, 1994; Balirwa, 1998; Bwanika *et al.* 2004) elaborated feeding habits for wild Nile tilapia. Observations show that in fish ponds, *O. niloticus* can be conditioned to a variety of food items ranging from leaves (e.g. *Amaranthus*, *Ipomea*, cassava, and cabbage), peelings of potatoes, yams and cassava, maize bran, rice bran to formulated feed pellets. As in the wild, Nile tilapia is capable of utilizing pond productivity by feeding at primary (e.g. phytoplankton), secondary (e.g. invertebrates) and tertiary (e.g. detritus) levels (Marcel, 1986). In ponds, the three major food webs through which Nile tilapia may obtain its food are autotrophic, heterotrophic and direct consumption of organic matter including feeds (Boyd & Tucker, 1998). Natural foods are of paramount importance to Nile tilapia under extensive pond conditions, and also contribute to improved growth in pond systems with supplementary feeding (Schroeder, 1983; Milstein, 1992; Swift, 1993; Chakraborty *et al.*, 2011).

2.4. Life history traits

Fish growth as the increase in length and weight over time, normally occurs isometrically i.e. increase in all dimensions at the same rate to give a cubic relationship between length and weight (Ricker, 1971; LVFO, 2007). Under optimum conditions, Nile tilapia exhibits fast growth though its growth may not be uniform throughout its life span. The fish grows rapidly during its early stages with growth decreasing with increase in fish age (Swift, 1993). The decrease in growth rate with age may be due to conversion of part of the energy that would be used to build somatic cells into gonad development (Lowe-McConnell, 1958; Ricker, 1971; Swift, 1993).

Different ecological conditions give rise to different patterns of fish growth which translate into fish populations of different age and size structure. Habitat variability (e.g. habitat size, water quality), resource availability (e.g. types and abundance of food), and intensity of intra-specific (e.g. competition for food, behavioral interactions) as well as inter-specific (e.g. predation) are some of the factors reported to influence fish growth (Lowe-McConnell, 1958). In mixed tilapia pond monoculture with prolonged grow out cycles, off spring produced greatly contribute to variations in age and size structure of fish. Unlike in natural environments, aquaculture confines fish in small habitats a condition that increases fish interactions leading to accelerated reproductive growth and retarded somatic growth with the effect that fish matures at smaller sizes and age (Thomas 2006). The early maturity that results in spawning retards fish from attaining large sizes a condition known as stunting (Popma & Masser, 1999). Stunting is a major

biological constraint to development of tilapia aquaculture (Popma & Masser, 1999). However, Thomas (2006) attributes early maturation to a homeostatic response to confinement, rather than stunting. Schmittou *et al.* (1998) considered lack of quality food as a major factor. In extensive and emerging semi-intensive prolonged grow out cycles, space and food availability may impose stress to farmed fish.

Sexual maturity in tilapias is influenced by environmental conditions including size of a water body and diet (Lowe-McConnell, 1958; Popma & Masser, 1999). In natural water bodies, *O. niloticus* attained size at first maturity at varying total lengths with males maturing earlier than females (Balirwa, 1998; Bwanika *et al.*, 2007) though the reverse trend was also reported especially in small water bodies (Lowe-McConnell, 1958; Trewavas, 1983; Bwanika *et al.*, 2004). Under good pond conditions early maturity in Nile tilapia occurred within 5 to 6 months weighing 150g to 200g (Popma & Masser, 1999). A smaller size range (30-50g) for female Nile tilapia was reported by de Graaf, (2004). In experimental fish ponds at Kajjansi (Uganda), Lowe-McConnell (1958) observed live males of 18 cm in breeding condition indicating that they matured at a size below 18 cm. Poor pond conditions can lead to slow growth and stunting coupled with small sizes at first maturity and subsequent spawning at weights less than 20g (Popma & Masser, 1999). de Graaf (2004) considered a range of 30-50g for size at first maturity good enough not to affect somatic growth. For mixed sex tilapia monoculture reared in small ponds under extensive and emerging semi-intensive systems, smaller sizes at first maturity, at spawning and resultant stunting can be expected.

Exploitation (harvesting) influences growth rate and life history traits. Hutchings (2005) reported reduction in growth rate, age and length at maturity in Atlantic cod fish population over time, a phenomenon attributed to phenotypic and genetic response to over-fishing. Similar findings were observed by Edeline *et al.* (2007) in a fish population where selective harvesting of large individuals was performed. Conover & Munch (2002) observed that in captive fish, selective harvesting of large individuals from a fish population evolved smaller fish and lower yield over time, and further reported that removal of bigger fishes before they had bred resulted in selection for early breeding and dwarfing. It was therefore necessary to assess the performance of pond farmed Nile tilapia where farmers practiced partial harvesting.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study scope

Nabitambala also known as Busedde sub-county (Fig. 3.1), Jinja District, was identified as an area where fish farming was increasingly being adopted at subsistence level. This area presented an opportunity to attain information on early set-up fish farming challenges that may be discouraging farmers from engaging in fish farming for income. In an effort to sustain fish farming and also improve fish production, this study on the biology and ecology of pond Nile tilapia was carried out to generate information that could improve understanding of factors influencing its performance at subsistence level. Six private fish farms located in the sub-county were surveyed to identify fish farms that targeted Nile tilapia (*O. niloticus*) as a major enterprise (Fig. 3.1). Three of the surveyed fish farms code-named Farm A, Farm B and Farm C were observed to contain larger populations of *O. niloticus* than the other farms, and were therefore identified for the study. Sampling was done between January 2009 and July 2009. Laboratory examination of samples was carried out at NaFIRRI.

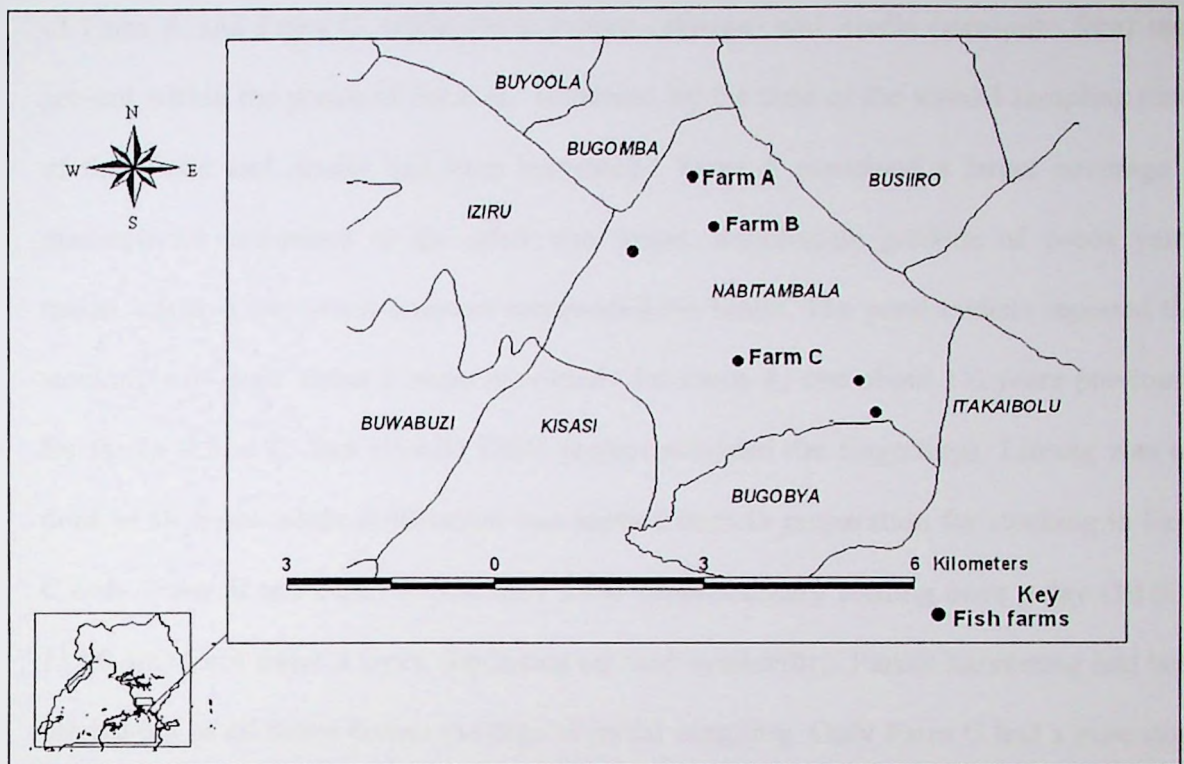


Figure 3.1: A map showing study fish farms in Nabitambala (Busedde) Sub-county, Jinja District

3.2. History and description of the study farms

The three farms are situated in Nabitambala (Busedde) sub-country, Jinja district. The description given was based on observations and information collected on management practices at each farm using a questionnaire (Appendix I) administered to farm operators. Located in wetlands, the main source of water for all the ponds was seepage from soil beneath the ponds' bottom. Protective meshes were lacking in outlets for ponds in farms B and A. The major vegetation (grass) on the dykes was *Leerseae* sp. (southern cut grass)

for Farm A and Farm C; and *Paspalum* for Farm B. *Leerseia* sp. extended into the ponds of Farm A and Farm C; while *Pistia* (water cabbage) and *Azolla* (mosquito fern) were present within the ponds of Farm B. However, by the time of the second sampling much of the *Pistia* and *Azolla* had been harvested. Farm A contained a larger coverage of macrophytes compared to the other two farms. Small-scale gardens of cocoa yams, maize, cassava and sweet potatoes surrounded the farms. The pond owners reported that stocking was done about 2 years previously for Farm A, and about 1½ years previously for farms B and C; and USAID FISH project provided the fingerlings. Liming was not done in all farms while fertilisation was applied once in preparation for stocking in Farm C only. Farm B and Farm A practiced some supplementary feeding once a day (10.00 – 11.00 am) for 4 times a week depending on feed availability. Partial harvesting had been carried out in all farms before the time of initial sampling. Only Farm C had a pure stock of *O.niloticus*; another tilapiine (*O.leucostictus*) was present in all ponds of Farm A and Farm B. Also, *O.variabilis*, haplochromines and *Aplocheilichthys* sp. were observed once in one of the three ponds of Farm A. Table 3.1 gives summarised characteristics and information on the basic management practices for the fish farms.

Table 3.1: Characteristics and description of study farms using management practices

Farm	Pond area (m ²)	Type and quantity of manure used per pond	Type of feed and quantity per pond per feeding within the sampling period	Number of partial harvestings	Stocking density (fish/m ²)
Farm A	196, 197, 230	None	100g rice bran 2 cabbage leaves	5	0
Farm B	137, 152, 154	None	200g maize bran 6 cabbage leaves	2	0
Farm C	36, 37, 90	Fresh Cow dung; 2.5 kg prior to stocking	None	3	0

3.3. Experimental design

Farm A consisted of 11 ponds; Farm B five ponds while Farm C had a total of 11 ponds. At each farm, three ponds (1, 2, 3) were selected for the study (Fig. 3.2). The choice for the selected ponds was based on pond availability in Farm C while for Farm A and B ponds of relatively similar size were selected.

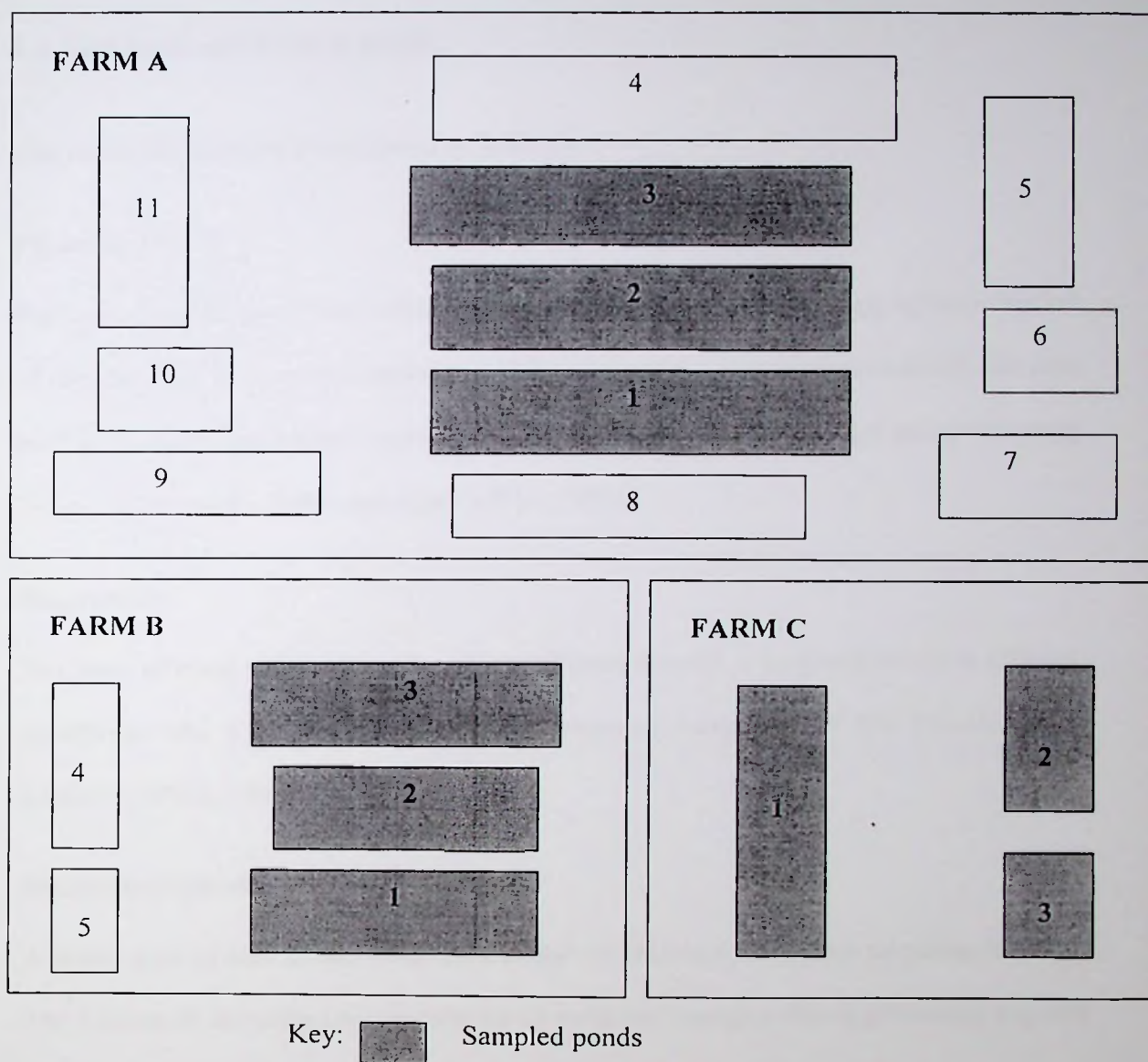


Figure 3.2. A sketch of the three study farms showing pond lay out

3.4. Fish foods and feeds in ponds

The natural foods were investigated as follows:

Phytoplankton

Ten litres of pond water was collected from the sam of capacity 5L. The water sampled was filtered thre and the concentrated sample was transferred into a 2-3 drops of Lugol's Iodine solution (APHA, 1992).

Zooplankton

Ten litres of pond water was collected and filtered t transferred into a 10 ml plastic vial and preserve solution (APHA, 1992).

Macro-invertebrates

A ponar grab of area 245cm^2 was used to collect se The volume of the sediment was reduced by washing a macro-fauna sieve of $250\mu\text{m}$, and preserved in following standard methods. A square net sampler macro-invertebrates associated with macrophytes.

Supplemental feeds

Information on feeds supplied to fish by farmers (supplemental feeds) was obtained by interviewing farm operators (Appendix I). Responses on the types of feed, quantities and frequency of feeding formed part of the description of the farms give in Table 3.1.

3.5. Fish sampling

Fish sampling was done thrice during the months of January, April, and July 2009 at each farm between 11.00 a.m – 12.30 pm. A 1" mesh seine net 34m (length) x 3m (width) was used to harvest fish. At least 30 *O. niloticus* were randomly selected from the seined fish samples in each pond. Identification of *O. niloticus* was based on description by Greenwood (1966). Biometric data i.e. total length (cm), weight (g), sex, gonad state, and stomach fullness for each specimen was recorded in a data sheet (Appendix II). The state of maturity for gonads was determined according to classification by Ricker (1971) (Table 3.2).

Table 3.2: Scale (Ricker, 1971) used in the classification of maturity stages

Gonad stages	Description
I & II	Immature: Gonads very small, sexual products undeveloped. Stage II relatively bigger than stage I. Male gonads thin and elongate (ribbon-like); female gonads flat shaped and stout, eggs invisible to the naked eye.
III	Mature: Gonads bigger than those in stages I & II. Eggs distinguishable to the naked eye as scattered dots; testes change from transparent to a pale rose colour. <i>(This study regarded stage III immature (Njiru et. al., 2006).</i>
IV	Mature: Sexual products ripe but not extruded when light pressure is applied on the belly; orange-reddish eggs clearly visible to the naked eye; left over eggs appear to be disintegrating within the ovary for females undergone earlier spawning. Male gonads attain a cream colour with distinct blood vessels.
V	Mature: Sex products ripe and extruded on application of light pressure on the belly; Yellow to orange round eggs; testes appear whitish with milt
VI	Mature: This is the spawning (ripe-running) stage when sexual products (eggs and milt) can be extruded involuntarily even with very slight pressure on the belly
VII	Mature (Spent condition): Sexual products have been discharged; female gonads appear deflated sacs and may contain a few left over eggs; tests have some residual milt

Female gonads (stages V and VI) were extracted and preserved with 70% ethanol. The gonads were later analysed in the laboratory for fecundity. Female fish were examined for mouth brooding condition i.e. eggs in buccal cavities. Eggs found in the mouth were counted and recorded in a biometric sheet (Appendix II).

Fish stomach fullness was determined by pressing the content away from the anterior of the stomach (pyloric sphincter), and was recorded as either full (F), three quarter full (T), half full (H), quarter full (Q), or Empty (E) following procedure in Hynes (1950). The stomachs with food were preserved in 5% formaldehyde solution for laboratory analysis of the stomach content.

3.6. Physical parameters

In-situ measurements of physical parameters (temperature, °C; pH, and dissolved oxygen, mg l^{-1}) were recorded between 9.00 am – 10.30 am using probes (WTW LF 330 and WTW OXI 320). Total depth (m) of pond water was taken by vertically lowering a meter rule (fixed on a board) to touch the bottom of the pond. The mark showing the end of the wetted part of the meter rule was recorded as the total depth. Transparency (secchi depth) was determined using a black-white secchi disc of 25cm diameter. The mid-point mark at which the disc disappeared and re-appeared (Wetzel, 1983) was taken as the secchi depth.

3.7. Laboratory procedures

Standard procedures for analysis of algae elaborated in APHA (1992) were followed. In the laboratory algae samples were left to sediment for at least one week. One ml of the bottom sample was collected using a dropper, emptied into a Sedgewick rafter graduated into 1000 small squares and left to settle for two hours. Examination was done using an inverted microscope (Magnification x400) to identify and count individual cells. Numerical abundance (numbers per ml) of identified genera was determined from the random counts from 10 small squares as follows:

$$\text{Numerical Abundance} = \frac{C_s \times V_c}{V_s \times V_i}$$

where, C_s = cell count in the 10 squares; V_c = volume (ml) of concentrated sample

V_s = volume (ml) of water in the 10 small squares of the sedgewick chamber;

V_i = Initial volume (ml) of sample;

Zooplankton samples were re-filtered, sub-divided into 2 equal parts and one portion placed into 2.5ml sedimentation chamber and left to settle for at least one hour. An inverted microscope (Magnification X400) was used to identify and count zooplankton genera. Zooplankton was identified using appropriate taxonomic keys for Copepoda, Cladocera and Rotifera (Pennak, 1978; Fernando, 2002). Species identified were enumerated and densities determined to give numbers per litre (no. l^{-1}). Macro-benthos/macro-invertebrates were sorted from the washed sediment material. The sorted organisms were examined by both eye and microscope (Magnification x45). Identification was based on illustrations by Pennak (1978).

Stomach contents were emptied in clean petri-dishes. Distilled water (5 – 10 ml) was added and the contents mixed by shaking. Large food items visible to the naked eye were sorted and identified. The remaining content was examined using a binocular microscope (Magnification x45) and compound microscope (Magnification x400). Identification of food organisms was supported by identification checklists (Pennak 1978; Mosille, 1984; Fernando, 2002; John *et. al.*, 2002). Frequency of occurrence and relative importance (Hynes, 1950) for the different food items were calculated.

The female gonads were soaked in water overnight to clean off the ethanol. The gonads were mopped dry with blotting paper, weighed and teased to separate the eggs. All the eggs in the two sub-gonads were counted to give total counts. Regression analysis was used to determine Fecundity-length and Fecundity-weight relationships.

3.8. Biometric data deduction

Biometric data was used in determining the size structure, sex ratio, size at first maturity, fecundity indices (Fecundity-length relationship, Fecundity-weight relationship), length-weight relationship, and condition factor. Since in fish farming weight is preferred to length of fish, size structure was composed by grouping fish in weight classes of 20g. The number of fish in each group was counted and a histogram constructed. In determining sex ratio, fish whose gonads were too small to be identified as either female or male were not considered. The proportion of males to females was recorded as sex ratio. The length-weight relationship was determined using regression to generate a

straight line. Fulton's Condition Factor (K) was determined from the formula: $100W/L^3$ where W = individual weight of fish, L = corresponding total length of fish (Ricker, 1971). The length at which 50% of individuals' gonad developments were mature using maturity state IV was noted as the size at first maturity (Njiru *et al.*, 2006). A regression analysis was carried out for proportions of mature fish against the total. SOLVER TOOL was used to fit sigmoid curves through a data set ranging from zero maturity to 100% maturity. The value at the point where the curve crosses the y-axis at 0.5 maturity scale was recorded as size at first maturity. Using length-weight relationship $W = aL^b$ Where W = weight (g); L = Length (cm); a = constant, and b is the exponent., the size at first maturity in grams was determined.

3.9. Data analysis

Data on the natural foods (i.e. abundance of the different natural food categories) from each pond were captured in Excel spread sheets and analysed using SPSS statistical packages. Significant differences in natural foods among fish farms were tested using Kruskal-Wallis test. One-way ANOVA was used to detect significant differences among weight of fish from the farms, fecundity and Fulton's Condition Factor. Chi-square test was used to detect significant differences in the sex ratios of fish and ANCOVA tested for significance differences in length-weight relationships using log transformed data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Results

4.1.1. Pond physical parameters

Farm A had the largest ponds (196, 197, 230)m², followed by Farm B (137, 152, 154)m², while Farm C had the smallest (36,37,90)m². The mean physical parameters (dissolved oxygen, pH, temperature) were within tolerance ranges (Table 4.1).

Table 4.1: Mean physical parameters of ponds in the study farms

	TD (m)	SD (m)	pH (m)	DO (mg l ⁻¹)	T (°C)
Farm A	0.59 ± 0.11	0.42 ± 0.07	7.24 ± 0.25	4.77 ± 0.52	24.8 ± 0.5
Farm B	0.40 ± 0.06	0.16 ± 0.04	7.49 ± 0.92	5.49 ± 0.40	25.0 ± 0.8
Farm C	0.39 ± 0.06	0.33 ± 0.08	6.45 ± 0.58	4.32 ± 0.89	24.0 ± 0.8

TD = Total depth; SD = Sechhi depth; DO = Dissolved oxygen; T = Temperature

4.1.2. Natural foods in ponds

Phytoplankton

Four phytoplankton taxa namely Euglenophyta (flagellates), Chlorophyta (green algae), Bacillariophyta (diatoms), and Cyanophyta (blue-green algae) were observed (Fig. 4.1). Blue-green dominated in farms B and A while in Farm C green algae gave the highest count. The highest density (± SE) was recorded at Farm B (52.3 ± 8.4), followed by Farm

C (29.7 ± 4.6), and Farm A had the least (4.5 ± 0.5). Chlorophyta had 13 genera; Cyanophyta 6; Bacillariophyta 5; and Euglenophyta 3 (Appendix III). There were low algal cell counts with most genera registering less than one cell per ml (Appendix III). The genera that gave counts of at least one cell.ml⁻¹ were *Cyclotella*, *Nitzschia*, *Scenedesmus*, *Closterium*, *Aphanocapsa*, *Microcystis*, *Merismopedia*, *Euglena* and *Trachelomonas* for Farm B; and *Coelastrum*, *Scenedesmus* and *Euglena* for Farm C. In Farm A, no single algal genus added up to 1 cell.ml⁻¹. Kruskal-Wallis Test showed highly significant ($p < 0.001$) differences in phytoplankton groups between the study farms (Appendix IV). Figure 4.2 shows some of the genera observed.

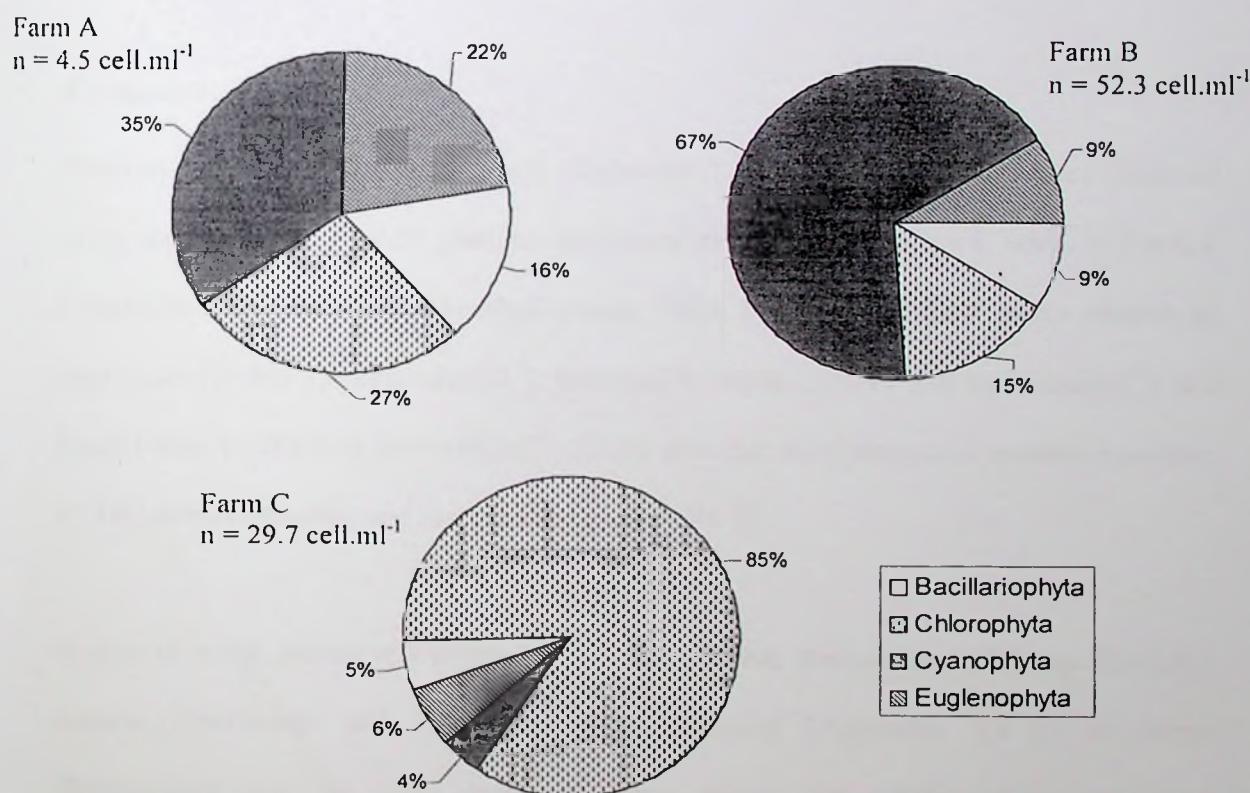


Figure 4.1: Percentages of mean algal taxa from the three study farms

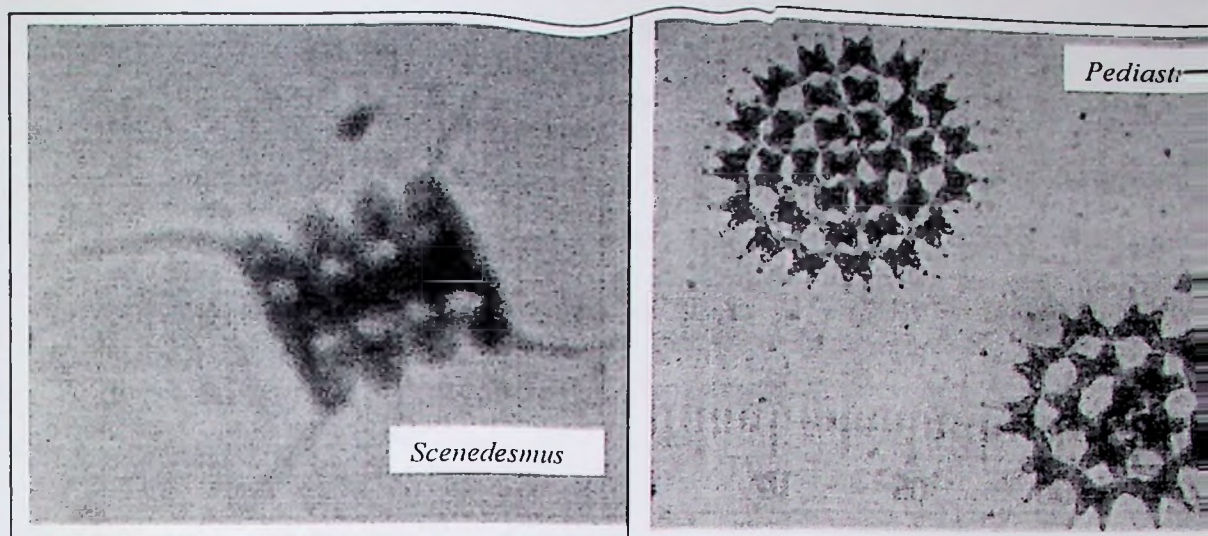


Figure 4.2: Some genera of phytoplankton found in pond water samples

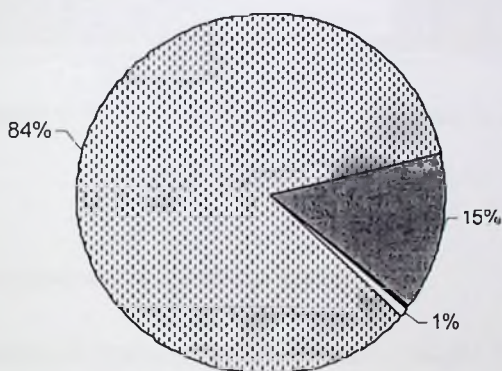
Zooplankton

Three major zooplankton taxa namely Cladocera, Copepoda, and Rotifera were observed in the study farms (Fig. 4.3). Rotifera dominated in Farm B and Farm C while in Farm A Copepoda dominated. Just like algal counts, Farm B had the highest mean number of organisms (1048 ± 277 individuals.l⁻¹); followed by Farm C (549 ± 189 individuals.l⁻¹); lastly Farm A (289 ± 53 individuals.l⁻¹). Other taxa that were present in smaller quantities (< 1%) were Ostracoda and insect larvae (Appendix V).

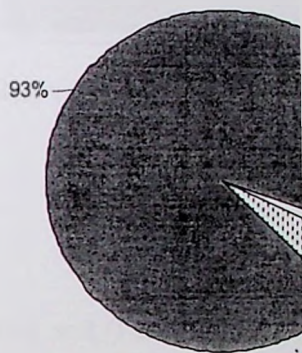
A total of seven genera of Rotifera namely *Asplanchna*, *Branchionus*, *Filinia*, *Keratella*, *Lecane*, *Syncheata*, and *Trichocerca* were recorded (Appendix V). In all farms, *Branchionus* was the most dominant genus among the rotifers. Cladocera were represented by *Moina* except at Farm C where *Chydorus* also occurred, though in small

numbers. All adult Copepods were Cyclopoids but the nauplii (young s the highest percentage in all the farms. The insect larvae from Farm A a Ephemeroptera while those from Farm C were Diptera. Overall zooplankl so low that no single genus numerical count added up to one organism p V). Kruskal-Wallis Test showed highly significant ($p < 0.001$) difference groups between the study farms (Appendix VI). Some of the zooplankt shown in Fig. 4.4.

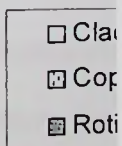
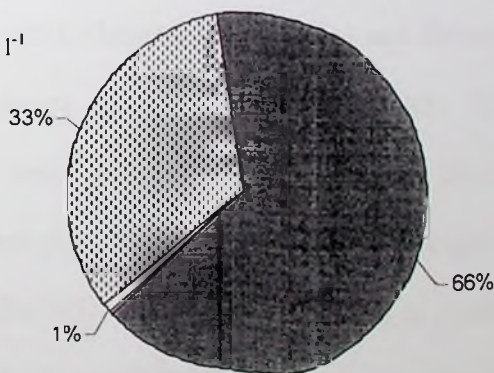
Farm A. $n = 289 \text{ ind. l}^{-1}$



Farm B. $n = 1048 \text{ ind. l}^{-1}$



Farm C.
 $n = 549 \text{ ind. l}^{-1}$



Note: ind. = individual

Figure 3.3: Percentages of mean zooplankton counts from the study farms

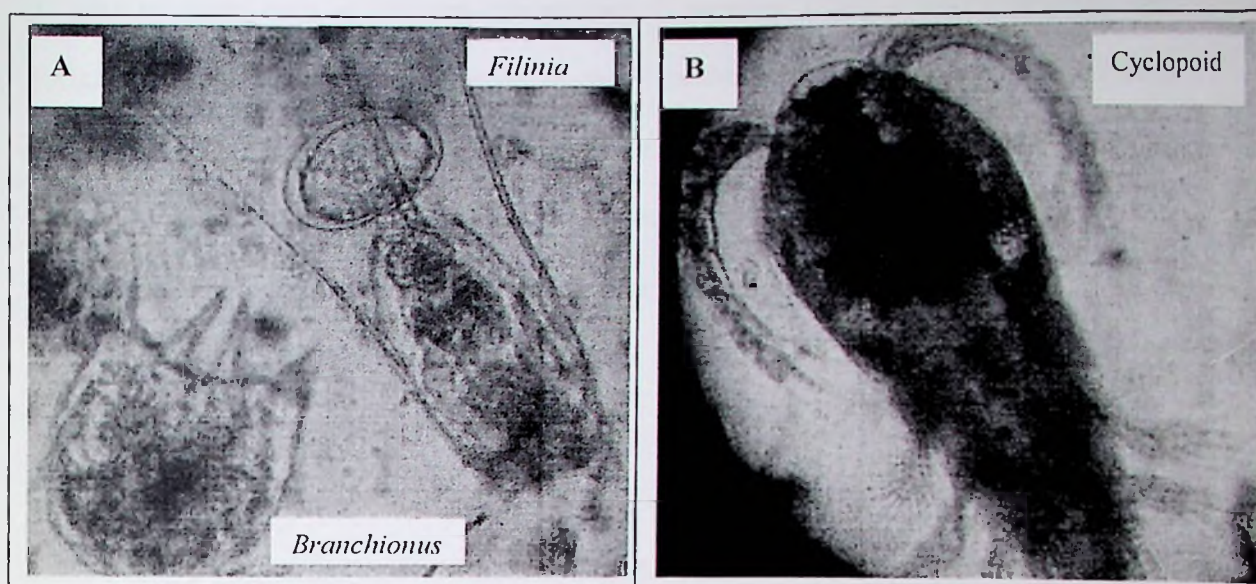


Figure 4.4: Some zooplankton observed in samples: (A - rotifers, B – copepod)

Macro-invertebrates in sediment

Sediment types in the study farms ranged from clay soil (Farm B); a mixture of sand and clay (Farm A), to sandy soil (Farm C). Nine macro-invertebrate orders namely Gastropoda (water snails), Odonata (dragon flies and damselflies), Diptera (true flies), Hemiptera (water bugs), Ephemeroptera (mayflies), Coleoptera (water beetles), Lepidoptera (aquatic caterpillars), Hirudinea (leeches), and Oligochaete (aquatic earth worms) were recorded (Fig. 4.5a). Farm C supported eight orders, Farm A (six), and Farm B four (Appendix VII). Oligochaete dominated in Farm B, Gastropoda in Farm C, and Diptera in Farm A. The overall density of organisms from the study farms followed a similar trend to that of plankton i.e. Farm B had the highest ($21423 \pm 594 \text{ organisms.m}^{-2}$) while Farm A had the least ($412 \pm 70 \text{ organisms. m}^{-2}$).

A total of eight taxa of Diptera comprising 2 families (CERATOPOGONIDAE and TABANIDAE), 5 genera, in addition to other unidentified chironomids were recorded (Appendix VII). The dominant genera of Chironomids at each farm were *Chironomus*, *Tarnytarsus*, and *Tanypus* at farms B, C and A respectively. In all farms, Gastropodes were represented by *Melanoides* spp although *Lymnaea* spp also occurred in Farm C. Overall, three families of Hemiptera (CORIXIDAE, MACROVELLIIDAE, MESOVELLIIDAE), two families of Odonata (COENOGRIONIDAE, LIBELLUDAE), and one family of Lepidoptera (PYRALIDIDAE), Oligochaete (NAIDIDAE), and Coleoptera (ELMIDAE) each were identified. *Caenis* was the only Ephemeroptera genus recorded (Appendix VII). Kruskal-Wallis Test showed significant differences ($p < 0.05$) in some macro-invertebrates groups (Gastropoda, Diptera, Oligochaete, Odonata) between the study farms (Appendix VIII).

Macro-invertebrates associated with macrophytes

Seven macro-invertebrate orders were identified (Fig. 4.5b). The overall density of macro-invertebrates was directly related to the vegetation cover that extended into the ponds. Farm A and Farm C that had more vegetation supported higher densities compared to Farm B. Odonata dominated in Farm A while Gastropoda gave the highest count in Farm C and Farm B. A general comparison of macro-invertebrate in sediment and that associated with macrophytes gave higher densities and orders for the former than the latter. However, many of the macro-invertebrate orders associated with macrophytes had a higher diversity (Appendix IX) than their counterparts in the sediment (Appendix VIII). Figure 4.6 shows some of the organisms observed.

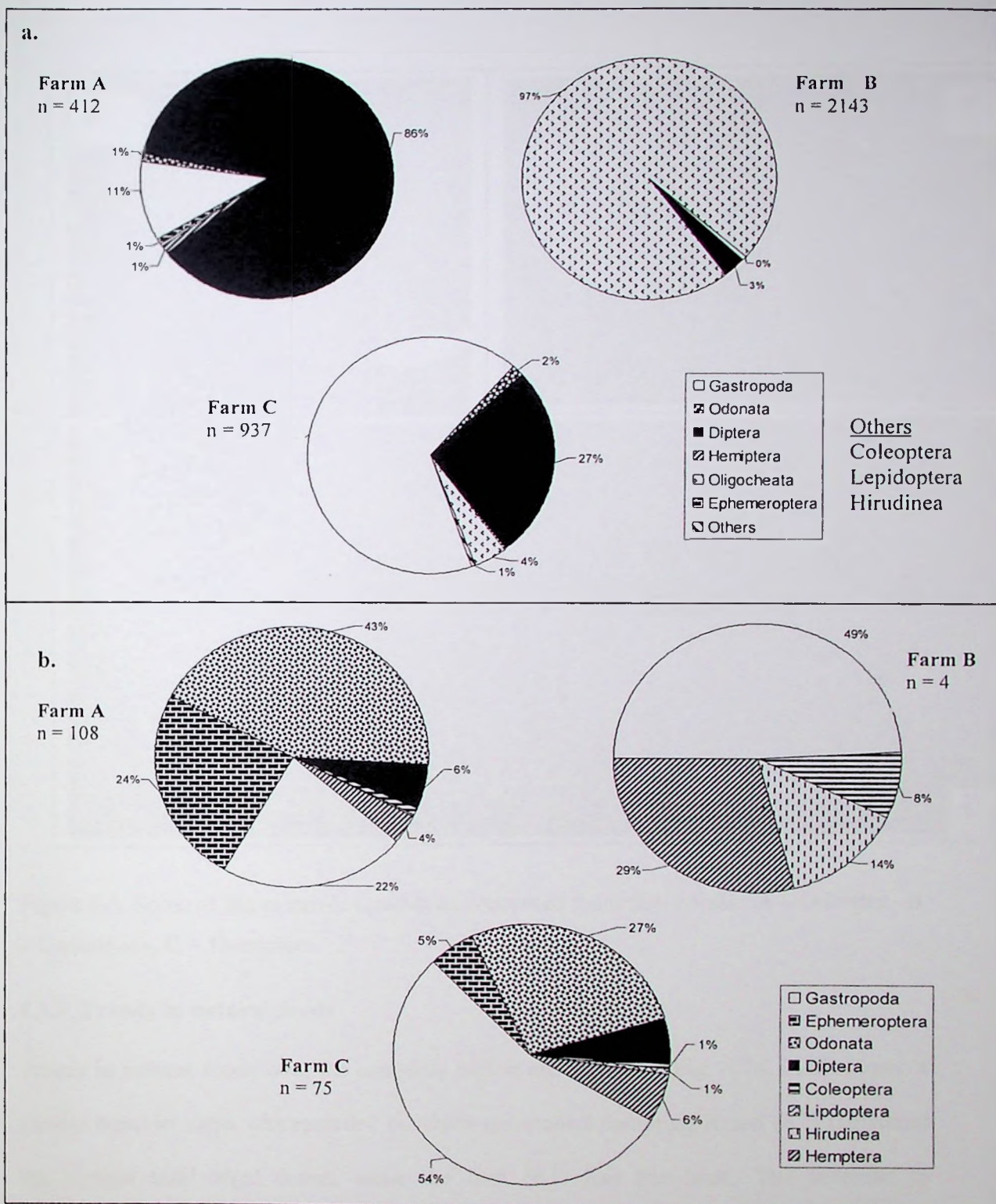


Figure 4.5: Percentage of mean macro-invertebrates: a) in sediment (b) associated with macrophytes in the study farms

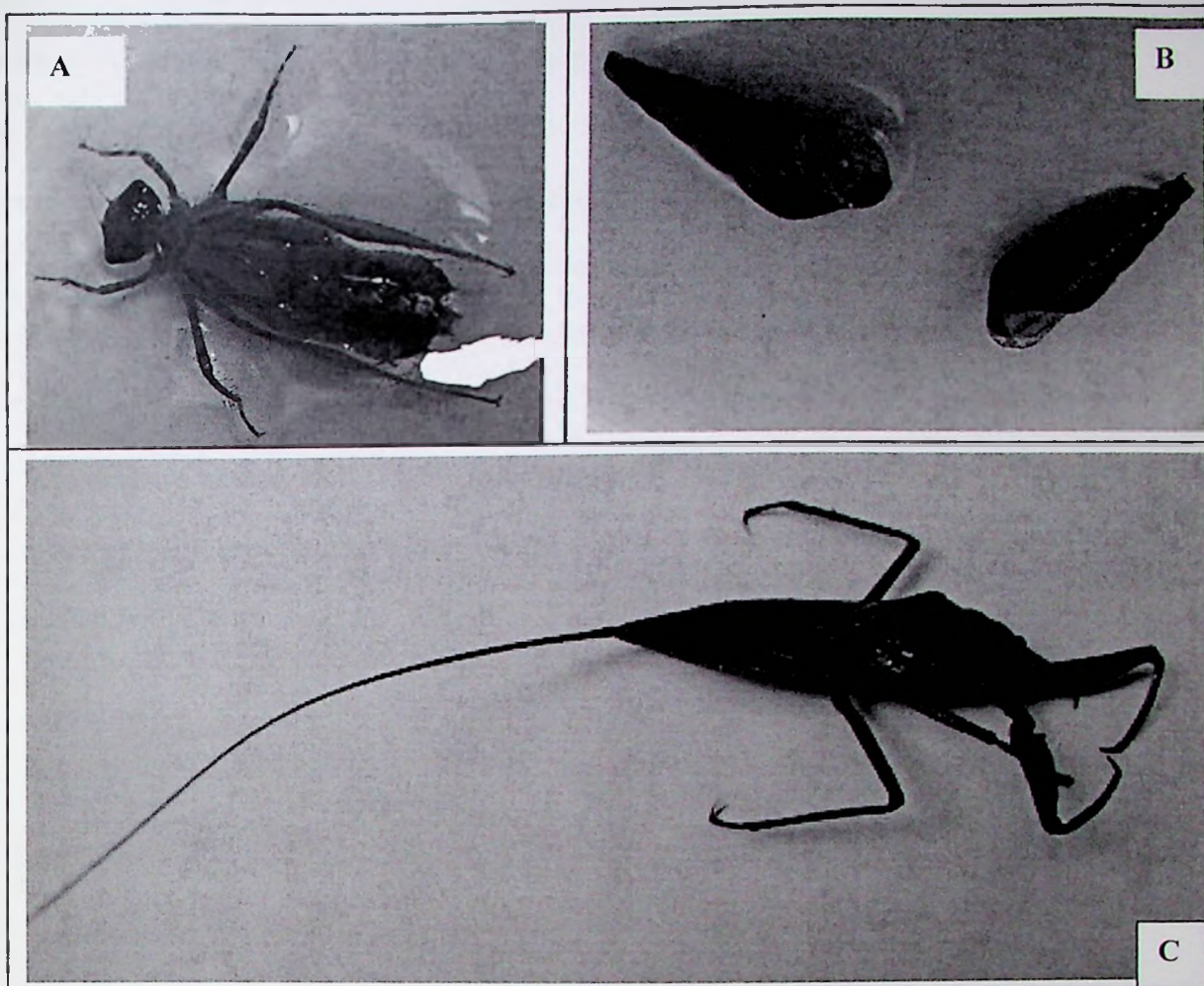


Figure 4.6: Some of the macro-invertebrates recovered from fish ponds: A – Odonata, B - Gastropods, C - Hemiptera

4.1.3. Trends in natural foods

Trends in natural foods over the sampling period are shown in Fig. 4.7a. In all farms, a similar trend in algae was recorded in which the second sampling round (R2) registered the highest total algal count, while the first (R1) had the least. The increase in phytoplankton from the first to the second sampling round was highest in Farm B where it increased by a factor of 4. Changes in zooplankton density showed different trends in

the study farms. In Farm B, increases in zooplankton density were recorded throughout the sampling rounds. In Farm A, a decrease in zooplankton density occurred from the first to the second sampling round, but a slight increase was noted in round 3. In Farm C, the increase in zooplankton recorded in the second sampling was followed by a decrease. While Farm A and Farm C registered decrease in macro-invertebrates in the third sampling, a drastic increase was recorded in Farm B. Overall, Farm B had the highest mean number of natural food (Fig. 4.7b). Among the plankton, phytoplankton dominated in all farms while macro-invertebrates from sediment registered higher counts than that associated with plants.

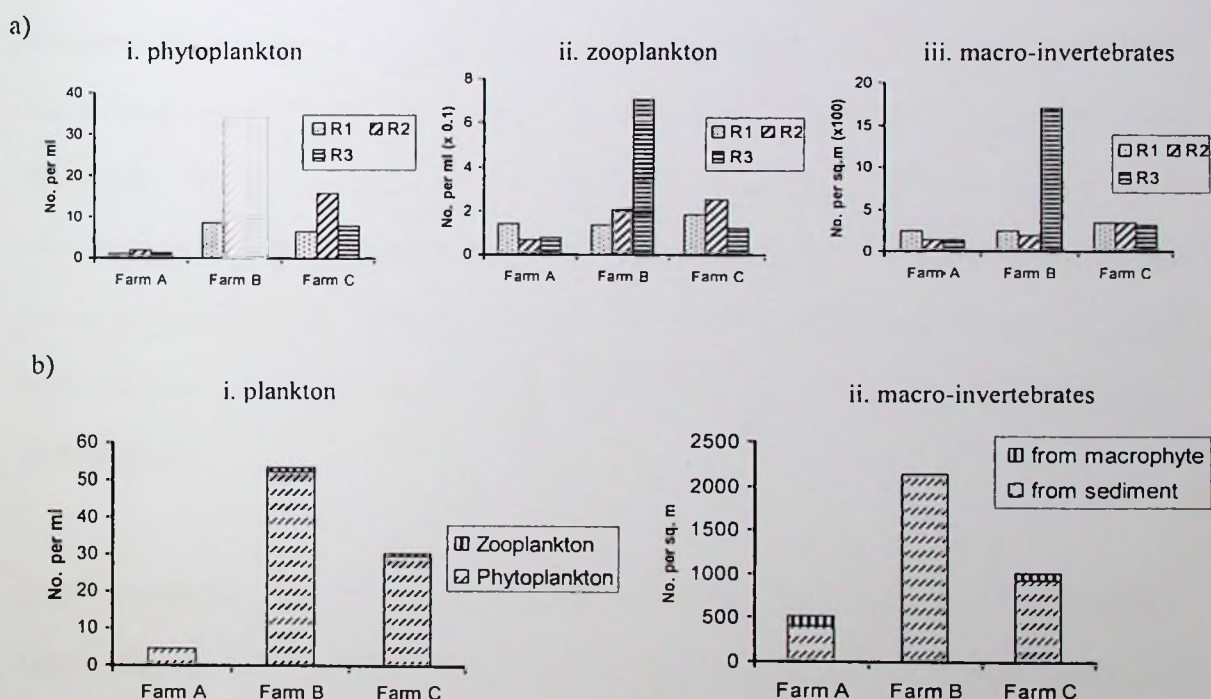


Figure 4.7: Trends in natural food (a): i) phytoplankton (ii) zooplankton (iii) macro-invertebrates (R1 – January, R2 – April, R3 – July); and (b) total natural foods: i) plankton (ii) macro-invertebrates from the study farms

4.1.4. Diet and feeding of *O. niloticus*

A total of 960 farmed *O. niloticus* were examined for stomach fullness. The proportion of empty stomachs (i.e. fish that had not fed at the time of sampling) varied between farms. The highest percentage (23.5%) of fish that had not fed was from Farm A, followed by 12.9% (Farm C), and least (6.7%) from Farm B.

Out of the stomachs with food, gut contents were analysed for 181 from Farm A, 205 from Farm B, and 184 from Farm C so as to identify items ingested by fish. The three main food items were higher plant material, detritus, and algae (Fig. 4.8). The most important food (having high relative importance) in stomachs from each farm were higher plant material (47% in Farm A; 29% in Farm B) and Algae (40%) in Farm C. The higher plant material ingested was from either of two sources or both i.e (i) that which was supplied as supplemental feed e.g cabbages, and (ii) aquatic macrophytes within the ponds e.g. *Pistia*, *Azolla*, *Learsea*. The food (e.g. higher plant material, detritus, algae) of high relative importance also scored highly (>80%) in frequency of occurrence (Appendix X).

Algae constituted four major groups namely Euglenophyta (flagellates), Chlorophyta (green algae), Bacillariophyta (Diatoms), and Cyanophyta (blue-greens). Chlorophyta (17.6%) was the most important algal taxa in fish stomachs from Farm C, while Euglenophyta (10.9%) dominated in fish stomachs from Farm B. Overall, the most important algal genera were *Phacus*, *Trachomonas*, *Euglena* (Euglenophyta);

Scenedesmus, *Coelastrum*, *Pediastrum*, *Closterium* (Chlorophyta); *Surirella*, *Navicula*, *Nitzchia* (Bacillariophyta); and *Merismopedia*, *Oscillatoria*, and *Aphanocapsa* (Cyanophyta). Other food items for fish were macro-invertebrates (insects, molluscs, Oligochaete, leech) and zooplankton (Rotifera, Cladocera, copepods). Unique food items with low percentages included supplemental bran in farms B and A, and fish in fish stomachs from farm A only. Figure 4.9 shows some of the food items ingested by fish.

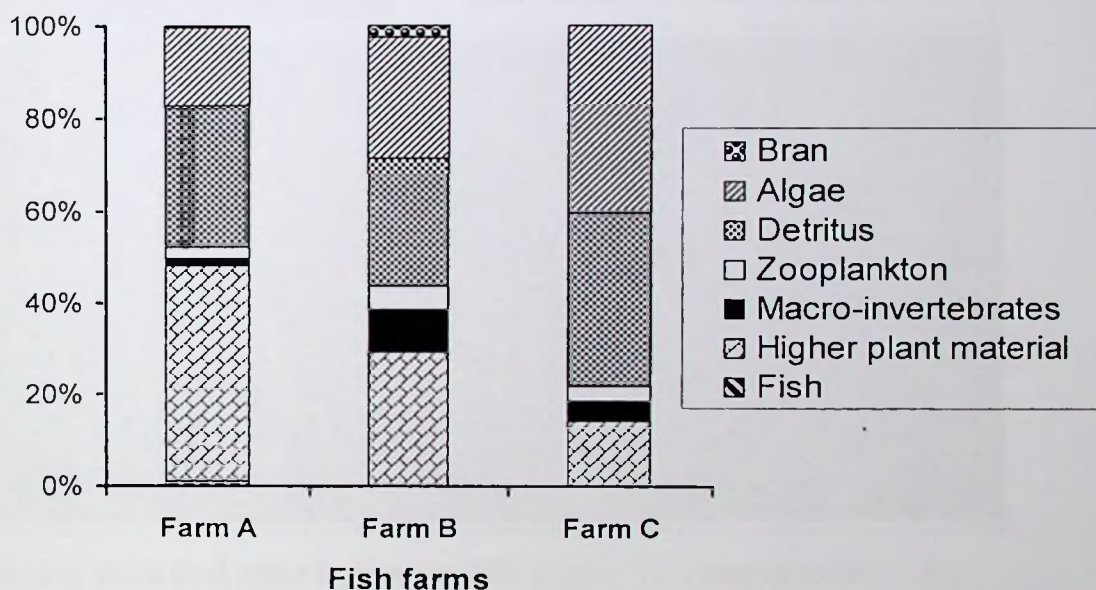


Figure 4.8: Percentages of the different food groups in fish stomachs

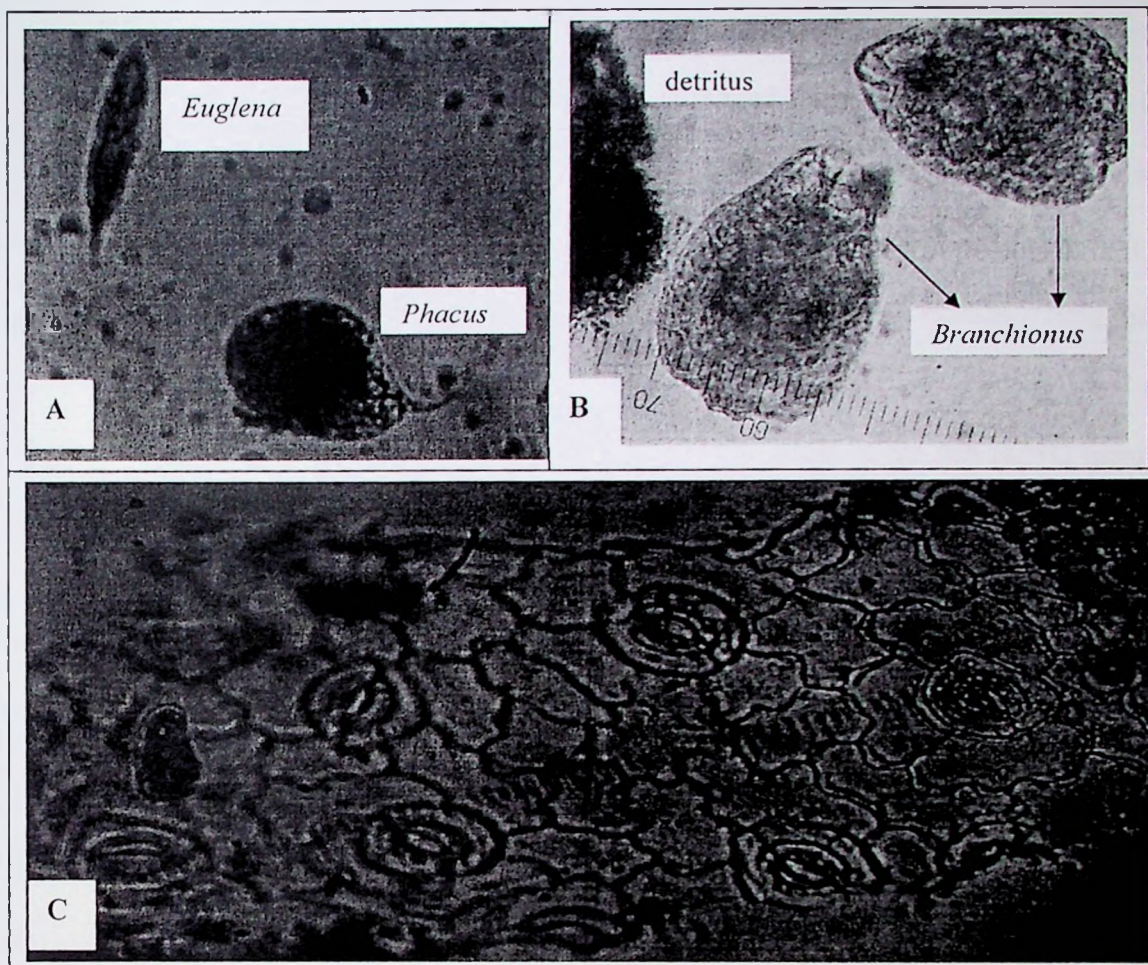


Figure 4.9: Some food items ingested by Nile tilapia: A – phytoplankton; B – zooplankton and detritus; C – higher plant material

4.1.5. Size structure of *O. niloticus* from the study farms

Size structure shows that in each of the farms the modal class was $\leq 20\text{g}$ indicating a general poor performance (Fig. 4.10). Considering individual farms, the weight ($\text{g} \pm \text{SE}$) and Total length ($\text{cm} \pm \text{SE}$) of fish from Farm A ranged from 3 - 128 g (5.9 - 20.1 cm)

with mean values of (13.4 ± 0.8) g and TL (9.2 ± 0.1) cm. Majority of the fish (83%) constituted ≤ 20 g size class; about 17% were in size classes 20 - 100g; and <1% had individual weight >100g. Fish from Farm B ranged from 4 - 283g (6.4 - 27.0 cm) with mean values of (77.7 ± 3.4) g and TL (15.3 ± 0.3) cm. In Farm B, the smallest size class (≤ 20 g) contained most of the fish (23%), and grouping of size classes above 20g gave the following distribution: 48% in classes >20g but ≤ 100 g, 25% in classes >100g but ≤ 200 g, and 4% in class >200g. In Farm C fish ranged from 3 - 87g (5.8 - 18.3 cm) and recorded mean weight of 14.5 ± 0.6 g and TL (8.6 ± 0.1) cm. Most of the fish (80%) from Farm C was in size class ≤ 20 g and the rest in size classes 20 - 100 g.

In all farms, males attained bigger mean weights: 15.8 ± 1.1 g, 104.6 ± 5.0 g, (17.6 ± 0.9) g compared to females (10.9 ± 1) g, (46.2 ± 2.9) g, (10.9 ± 0.5) g in farms A, B, and C respectively. Analysis of size structure by sex indicated that in all farms small size classes were dominated by females (Fig. 4.10).

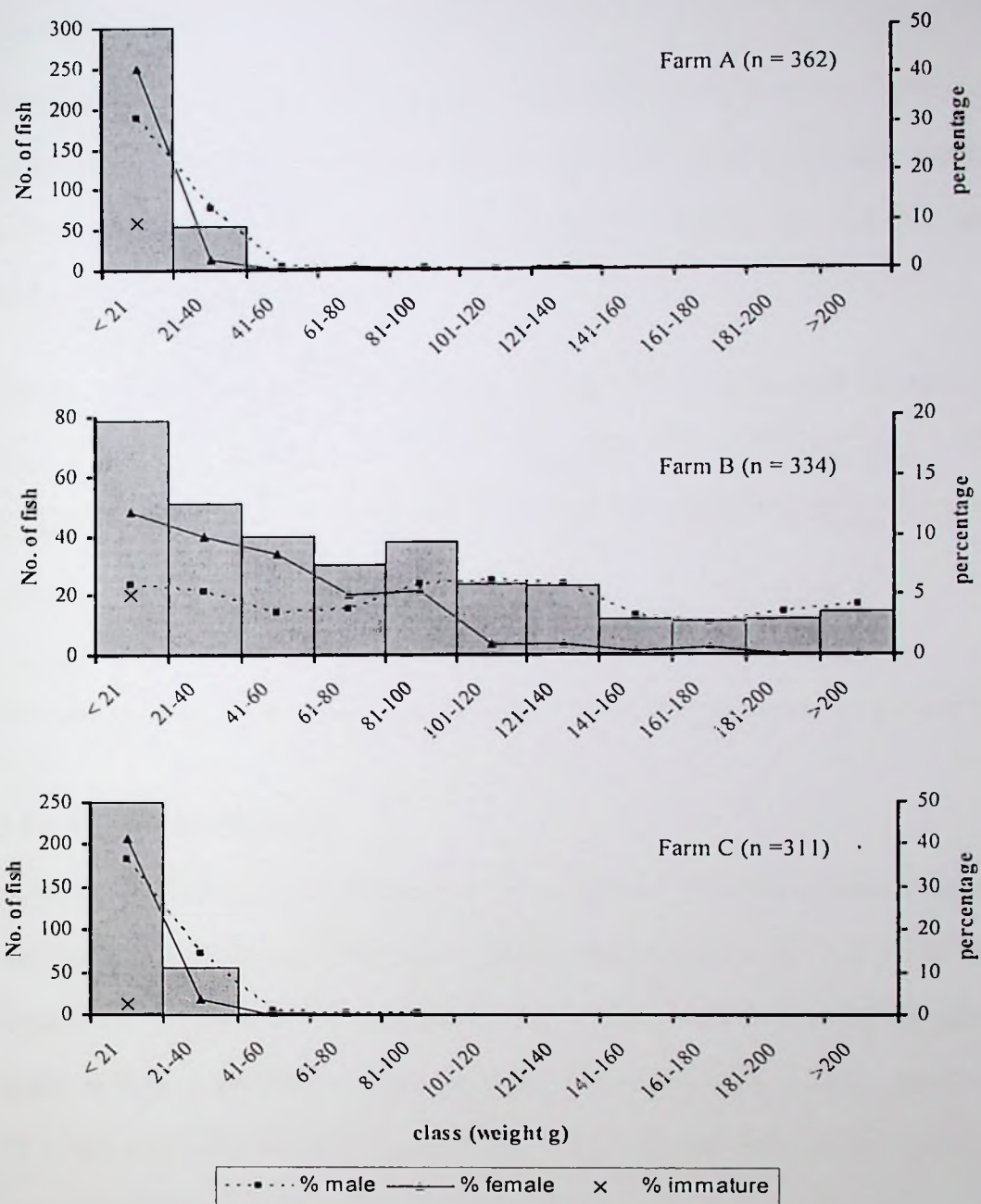


Figure 4.10: Size structure and percentage of male, female, and immature Nile tilapia

4.1.6. Sex ratio

The total counts for males and females from each farm are shown in Table 4.2. In all farms, the males were more than the females. However, sex ratios of males: females were close to 1:1. Chi-square test showed no significant difference ($p > 0.05$) in sex ratios between the farms (Appendix XII).

Table 4.2: Number of males, females, and sex ratio of *O. niloticus* from the farms

Farm	Males	Females	Sex ratio	n
Farm A	164	162	1:0.99	326
Farm B	170	145	1:0.85	315
Farm C	162	141	1:0.87	303

4.1.7. Gonad Development

A total of 944 *O. niloticus* from the three study farms were examined to determine sex and gonad development. The gonad stages were grouped into two major maturity categories: immature (I - III) and mature (IV - VII) (Fig.4.11). More than half of the males in Farm A and Farm C were immature. Among the mature males, spawning stage (V - VI) dominated in Farm A and Farm C. Farm B had more mature males (mostly spawning) than immature males (Appendix XIII).

Examination of female gonads showed that in all farms there were more mature females (dominated by spawning stage) than immature. A comparison of males and females in

each farm gave more mature females than males in Farm A and Farm C, but almost equal percentage of immature males and females in Farm B.

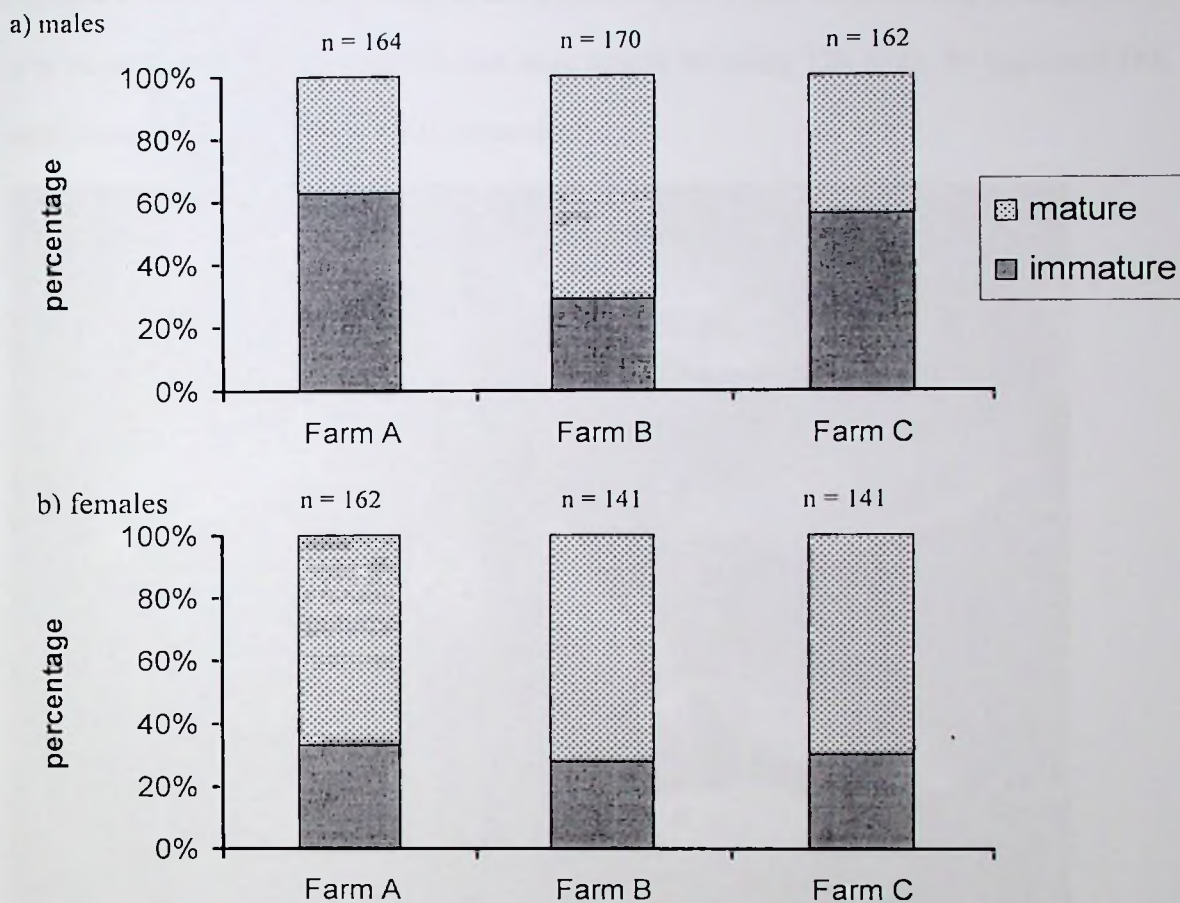


Figure 4.11: Relative percentages of immature and mature Nile tilapia: (a) males (b) females (immature = gonad stages I – III, mature = stages IV – VII)

In females, fish that had undergone earlier spawning (recycling denoted as state 4R) were observed. One female (79 g) was observed from Farm B. Five recycling females were recorded at Farm A and Farm C each with sizes ranging from (6 – 20)g and (8 – 9)g

respectively. A female (43 g) that had discharged eggs (stage VII) with 44 eggs in its buccal cavity (mouth brooding) was noticed in Farm B. Three brooding females observed in Farm C depicted varying weights and gonad stages. These weighed 10g in stage IV; 7 g in stage V and 18 g in stage VI, that were mouth brooding 136 eggs, 48 eggs, and 148 newly hatched fish fry (Fig. 4.12) respectively.



Figure 4.12: A sample of Nile tilapia showing a mouth brooding fish and fish fry

4.1.8. Size at first maturity

Regression was used to calculate size at first maturity (Appendix XIV). The size at first maturity in *O. niloticus* varied between farms (Fig. 4.13). In male fish the size at first

maturity was highest (15.6 cm) in fish from Farm B, followed by 10.8 cm (Farm A) and 10.6 cm (Farm C). Female fish depicted a similar trend with sizes at first maturity recorded as 10.8 cm, 7.3 cm and 6.4 cm for Farm B, Farm A, and Farm C respectively. In all the study farms, the size at first maturity (weight g) was below 20 g except that for male fish from Farm B (Table 4.3). A comparison of size at first maturity by sex showed that males attained maturity at a larger size than females.

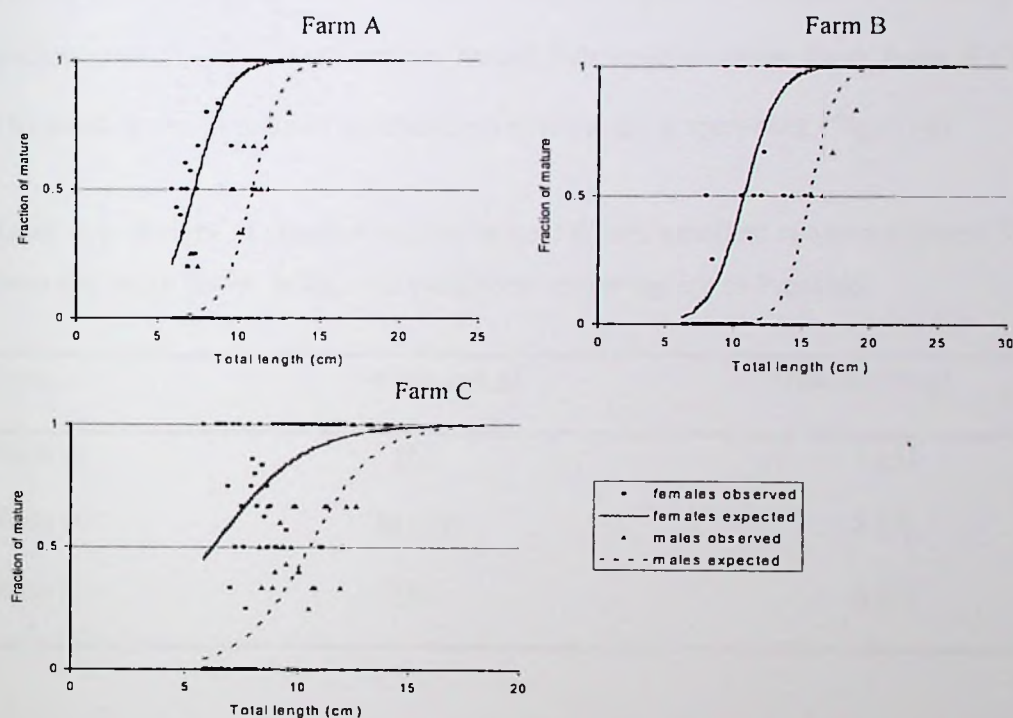


Figure 4.13: Length (TL cm) at first maturity of *O. niloticus* from the study farms

Table 4.3: Size at first maturity (weight g) for Nile tilapia from the study farms

Farm	Male (weight g)	Females (weight g)
Farm A	19	6
Farm B	59	19
Farm C	16	4

The minimum mature male was from farm A while the highest figures for minimum mature male and minimum mature female fish were recorded from Farm B (Table 4.4).

The small sizes at maturity resulted into small sizes at spawning (Fig.4.14).

Table 4.4: Weight of smallest mature (stage IV) and smallest spawning (stage VI) fish from the study farms. Minimum weights at spawning are in brackets

Farm	Male (wt g)	Females (wt g)
Farm A	5 (6)	3 (4)
Farm B	44 (64)	8 (9)
Farm C	8 (9)	3 (5)

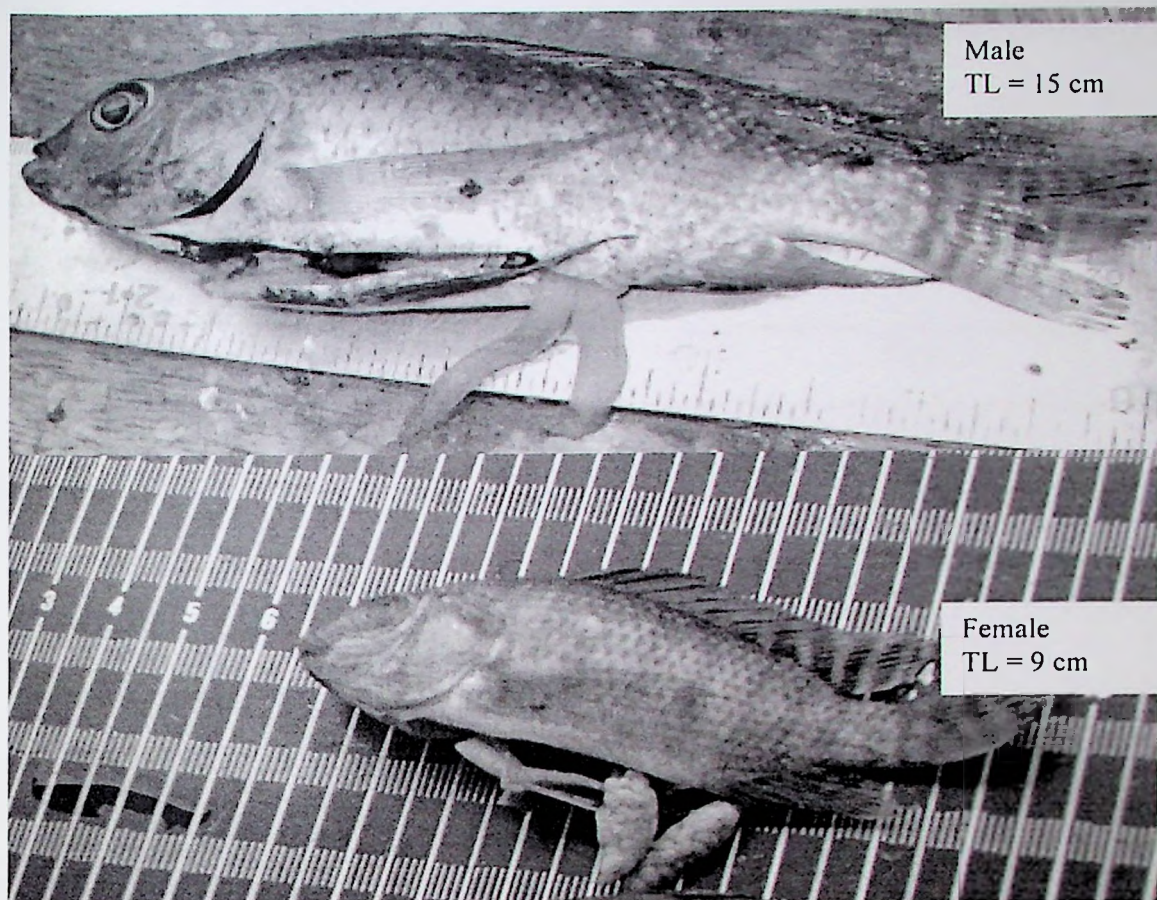


Fig. 4.14: Spawning (gonad stage VI) male and female *O. niloticus*

4.1.9. Fecundity

Thirty seven (37) ripe (gonad stages V and VI) female *O. niloticus*, size range (4 - 114)g, from Farm A; 44 ripe females (9 - 175)g from Farm B; and 31 ripe females (5 - 22)g from Farm C were examined for fecundity. Fish with highest absolute fecundity (i.e. total egg counts in each fish) came from Farm B while the fish with lowest came from Farm A. Similarly, mean absolute fecundity was highest in fish from Farm B, followed by

Farm C (Table 4.5). One way ANOVA showed significant differences ($p < 0.001$) in mean absolute fecundity between farms except for Farm A and Farm C (Appendix XV).

Table 4.5: Mean absolute fecundity, relative fecundity, mean total length and weight of examined female *O. niloticus*

Parameter	Farm A	Farm B	Farm C
Mean absolute fecundity	78.9 ± 12.2	302.9 ± 25.7	95.7 ± 7.2
Fecundity. cm^{-1}	7.9 ± 0.6	18.5 ± 1.2	10.9 ± 0.6
Fecundity. g^{-1}	5.9 ± 0.2	4.9 ± 1.2	9.3 ± 0.5
Mean fish total length	9.0 ± 0.4	15.5 ± 0.4	8.6 ± 0.2
Mean fish weight	14.7 ± 3.3	64.6 ± 5.5	10.5 ± 0.8
n	37	44	31

4.1.10. Length-Weight Relationships

Fish grew according to the equation, $W = aL^b$ (W = weight (g) of individual fish; a = constant which is the intercept; L = total length (cm) of fish; and b = slope of a straight line graph represented by the respective equations (Fig. 4.15). Fish from Farm B depicted isometric growth ($b = 3$) while that from farms A and C gave negative allometric growth ($b < 3$). Farm B had the strongest R^2 values followed by Farm A (Fig. 4.15). ANCOVA test for logarithmic relationships between males and females both within and between farms showed highly significant differences ($P < 0.001$) in intercepts (Appendix XVI).

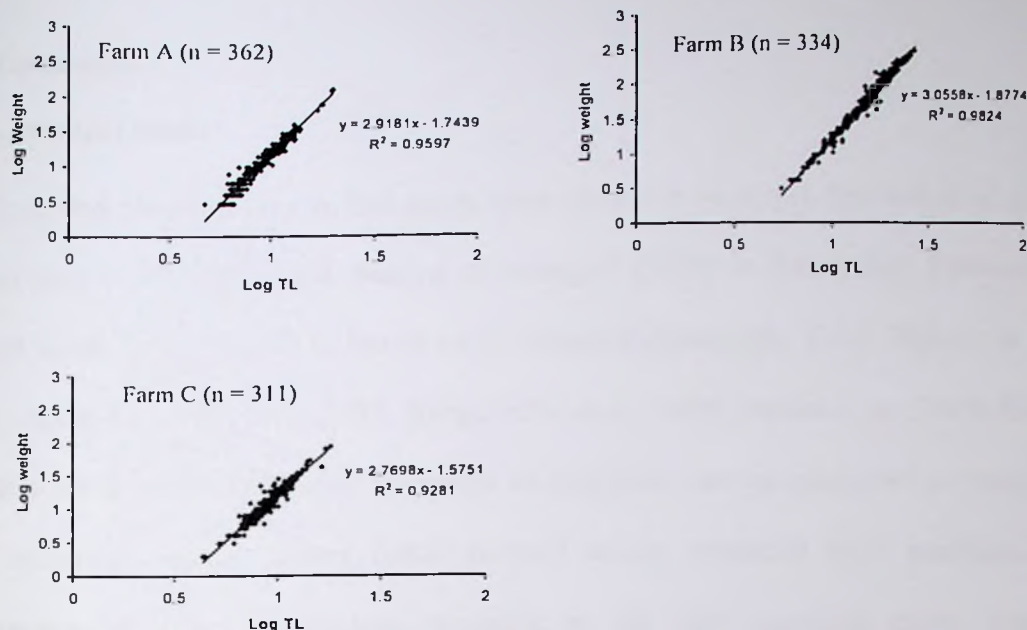


Figure 4.15: Length-Weight relationships of *O. niloticus* from the study farms

4.1.11. Fulton's Condition Factor

Fulton's Condition Factor (K) for fish was 1.53 ± 0.27 (Farm A), 1.55 ± 0.23 (Farm B) and 1.63 ± 0.30 (Farm C). Slight variations occurred in condition for males and females at each farm (Table 4.6). One way ANOVA detected a significantly ($p < 0.05$) higher Condition Factor for fish from Farm C than that for Farm A and Farm B (Appendix VII).

Table 4.6: Fulton's Condition Factor (mean $\pm$ SD) of *O. niloticus* from the study farms

Farm	Males	Females	Overall	n
Farm A	1.51 ± 0.24	1.56 ± 0.28	1.53 ± 0.27	361
Farm B	1.56 ± 0.22	1.55 ± 0.25	1.55 ± 0.23	334
Farm C	1.62 ± 0.27	1.63 ± 0.31	1.63 ± 0.30	311

4.2. Discussion

4.2.1. Natural foods

The recorded plankton taxa in this study were observed by Abdel-Tawwab *et al.* (2005), Kango'mbe *et al.* (2006) and Ssanyu & Schagerl (2010) in fish ponds. Production of natural foods in fish ponds is based on fertilization (Randolph, 1986; Dhawan & Kaur, 2002; Abdel-Tawwab *et al.*, 2005; Kango'mbe *et al.*, 2006; Davies *et al.*, 2009). In Farm B, the cabbage leaves provided primarily as fish feed was not consumed to completion thus releasing organic matter (after rotting) which enhanced algal production and subsequent secondary production recorded in the third sampling round. Enriched sediment with organic matter is known to provide a favorable environment for proliferation of Euglenophyta, Oligochaetes, and rotifers particularly the omnivorous *Brachionus* and *Filinia* (Marcel, 1986; Pennak, 1978) as observed in Farm B. The initial fertilization applied in Farm C was possibly responsible for the observed quantity and diversity of natural foods. However, the single fertilization done in Farm C and the quantity of cabbage leaves provided in Farm A were perhaps inadequate and this probably accounts for the lower natural foods than in Farm B. In comparison to earlier studies where fertilization was performed (e.g. Dhawan & Kaur, 2002; Abdel-Tawwab *et al.*, 2005; Kango'mbe *et al.*, 2006) and water bodies prone to nutrient enrichment due to anthropogenic activities in the surrounding (e.g. Davies *et al.*, 2009; Kemigabo & Adamek, 2010), this study recorded lower plankton counts implying that the study farms contained less nutrients for natural food development.

Apart from fertilization, spatial variation is known to influence plankton diversity and abundances (Davis *et al.*, 2009). In India, Dhawan & Kaur (2002) recorded higher phytoplankton abundance from un-manured ponds than in the present study, as well as higher zooplankton abundance than that from farms A and C. Differences in phytoplankton abundances and species composition can occur even in ponds within the same locality (Boyd, 1979 as reported by Kwei, 1986) indicating that variations among distant farms, as was the case in this study, is a very likely scenario.

The effect of grazing on pond plankton abundance was demonstrated by Cottenie, *et al.*, (2001). In Lake Victoria, Mwebaza-Ndawula (1998) attributed changes in zooplankton species composition and abundance to predation by fish and other zooplanktivores such as *Chaoborus*. However, the low zooplankton:phytoplankton ratio observed in this study perhaps had minimal grazing effects on the abundance of natural foods. From the diet results, it is evident that fish exerted grazing/predatory impacts on the natural foods particularly phytoplankton. Presence of rotifers in prodigious quantities could be attributed to their short regeneration period of 2–3 weeks (Marcel, 1986) despite predation on them by fish and potential predatory species such as *Asplanchna*, *Synchaeta*, *Trichocerca* (Pennak, 1978) and *Chaoborus* (Mwebaza-Ndawula, 1998). Dominance of Cyclopoids in Farm A could be due to reduced predation by fish as shown by the low percentage frequency of occurrence in diet, an observation that could be related to copepods' efficiency to escape fish attacks (Cottenie, *et al.*, 2001).

There was a direct relationship between numerical densities of macro-invertebrates associated with macrophytes and macrophytes coverage, reflecting the role of macrophytes as habitat for macro-invertebrates (Cottenie, *et al.*, 2001). Presence of larger coverage of macrophytes in Farm A possibly offered an extended habitat so as to support a wider variety of organisms.

4.2.2. Diet and feeding

Stomach fullness and diet composition varied among farms. Generally percentage stomach fullness were high (>75%) an observation possibly due to day time (11.00 am – 12.30 pm) sampling a period when Nile tilapia exhibit peak feeding (Balirwa, 1998). Food availability influenced percentage stomach fullness and feeding pattern. Farm B that supported the highest densities of natural foods registered the lowest percentage (6.7%) of empty stomachs. Like in the wild, *O. niloticus* under study was omnivorous and fed on diverse food items to reflect flexibility and un-specialized feeding (Lowe-McConnel, 1958; Balirwa, 1998). Diet results show that natural foods formed the biggest percentage, implying that much of the tilapia body weight was derived from natural food (Schroeder, 1983; Milstein, 1992; Swift, 1993) which probably also consisted of food from heterotrophic origin as well as directly consumed organic matter (Boyd & Tucker, 1998). Cannibalism noted in Farm A probably signals limited food availability. It is therefore important to ensure food availability through fertilization.

Besides food availability (Lowe-McConnel, 1958), the growth of Nile tilapia is more influenced by food quality in particular its digestibility and utilization for growth (Balirwa, 1998; Schmittou *et al.*, 2002). Bowen (1982) reported that the assimilation efficiency in Nile tilapia that fed on natural foods was high for blue-green algae and diatoms but low for green algae and macrophytes. Similarly, Popma & Masser, (1999) reported poor digestibility of Chlorophyta (green algae) by Nile tilapia. It is therefore likely that despite their high relative importance in diet, Chlorophyta (17%) in Farm C and higher plant material (47%) in Farm A were not of much nutritive value to fish. Conversely, fish from Farm B contained a diet richer in food of animal origin (15%) comprising of rotifers important for juvenile fish (Marcel, 1986; Mwebaza-Ndawula, 1998) as well as the macro-invertebrates that have a higher nutritive value (Balirwa, 1998; Bwanika *et al.*, 2006).

Supplementary feeding is important in fish farming for fast growth and increased fish yield (Liti *et al.* 2002; Schmittou *et al.*, 2002; Abdel-Tawwab *et al.*, 2005). From the types and quantities of supplemental feeds provided, coupled by irregularities in feeding, it was clear that feeds were administered with limited consideration for quality and quantity which are key factors in selecting the most suitable feed (Schmittou *et al.*, 1998; Liti *et al.*, 2002; El-Saidy, *et al.*, 2005). Rather the choice of feed was influenced by availability and cost. The farmers could not afford formulated feeds and so they resorted to on-farm feeds (rice and maize bran) that do not supply all the nutritional requirements for optimum fish growth (Schmittou *et al.*, 1998). Mlay *et al.* (2005) reported crude

protein content for maize bran of 10.9% while that for rice bran (2002), levels below the minimum of 20% for fast fish growth. Also, the cabbage leaves provided as feed was perhaps not assimilated by Nile tilapia (Bowen, 1982). The low quality, quantity and frequency of feeding perhaps explains, in part, the lower recorded average specific growth rate in the present study compared to earlier studies (e.g de Graaf, 2004; Chakraborty *et al.*, 2011) where supplementary feeding was provided. The supplementary feeding in Farm B was of relatively higher quantity and quality than in Farm A, which perhaps contributed to the difference in fish performance. It is evident that pond inputs (feeds, fertilisers) are important for improving fish production, which was probably limiting in the present study. Sustainable production of Nile tilapia, which formed the principle sources of protein was uncertain owing to the lack of fertilization, particularly in farms C and A respectively.

4.2.3. Life history traits

The observed traits could be partly attributed to management practices. The information provided by the fish farmers and results of this study suggest that poor husbandry practices were applied in all the study farms. The presence of *Oreochromis variabilis*, haplochromine) whose seed were probably present in the water when stocking with Nile tilapia. Such species could probably compete with Nile tilapia for resources (space and food).

Results of sex ratio indicated a mixed Nile tilapia culture which is known to allow proliferation (Popma & Masser, 1999; de Graaf, 2004) and this possibly contributed to the observed size structure. Possible remedies that include polyculture with a predator e.g. *C.gariepinus*, mono-sex culture, implementation of a single harvesting cycle prior or soon after sexual maturity so as to control proliferation (Marcel, 1986; Popma & Masser, 1999) were not applied. In the absence of polyculture, mono-sex culture of male Nile tilapia that attain larger sizes under culture conditions (Marcel, 1986; Popma & Masser, 1999; de Graaf, 2004; Chakraborty *et. al.*, 2011), also observed in this study, would have been a better option. Unfortunately, adoption of mono-sex culture remains a challenge to subsistence fish farmers perhaps due to lack/limited understanding of the advantages of mono-sex culture, inability to perfectly isolate male fingerlings for stocking, and lack of easy access to all male seed.

Males from each farm were significantly heavier than females, and the fact that a greater percentage of males were immature perhaps shows their potential to grow bigger. Heavier weights in males could be partly attributed to their faster growth rate under culture conditions (de Graaf, 2004; Chakraborty *et. al.*, 2011) which probably also accounts for the observed sex ratio, and larger sizes at first maturity compared to females. Growth superiority in male tilapia over females was as well reported in Lakes Nabugabo and Wamala (Bwanika *et. al.*, 2007). The larger sizes in farmed male Nile tilapia could also be ascribed to a reproductive strategy; engagement of males in building nests and guarding spawning sites possibly offered a reproductive advantage to large males

(Bwanika *et al.* 2007). Nevertheless, promotion of mixed tilapia culture may not be logical since off-springs produced compete for space and food to result into stunting of fish (Popma & Masser, 1999). However, fish population within the study farms was probably not the only factor determining fish performance. Basing on observations of quantity of fish trapped in the seine net during harvesting, Farm B supported the highest population but gave the best performance. It is therefore likely that food availability and quality played a key role.

Female Nile tilapia attained smaller sizes, an observation that was possibly due to a slower growth rate compared to males (Marcel, 1986; de Graaf, 2004; Bwanika *et al.* 2006; Chakraborty *et al.*, 2011) and this perhaps partly contributed to early maturation and subsequent spawning at small sizes leading to reduction in somatic growth but higher reproductive development (Ricker, 1971; Swift, 1993). The nature of reproduction in females probably also partly influenced their small sizes. Females mouth-brood eggs and newly hatched fry in their mouths (also evident in this study) during which periods they do not feed (Lowe-McConnel, 1958; Trewavas, 1983; Marcel, 1986; Nandlal & Pickering, 2004).

In comparison to earlier studies (e.g. Gwahaba, 1973; Balirwa, 1998; Njiru *et al.*, 2006) for wild Nile tilapia, the sizes of fish and sizes at first maturity in this study were smaller. Stress arising from confinement (Lowe-McConnel, 1958) perhaps partly accounts for the smaller sizes in farmed fish. In small water bodies, female Nile tilapia tend to mature at

smaller sizes than males (Lowe- McConnell, 1958; Trewavas, 1983; Bwanika *et. al.*, 2004), as observed in the present study. It is likely that early maturation that occurs in Nile tilapia due to a homeostatic response to confinement (Thomas, 2006) could be stronger in females. Except for males from Farm B, the size at first maturity for fish was below 20g. de Graaf (2004) reported no effect on somatic growth in Nile tilapia with size at first maturity in the range of 30-50g, while Popma & Masser (1999) considered Nile tilapia spawners below 20g stunted. This study observed spawning in some females, particularly from farms C and A, at weights below 20g pointing to possibilities of stunting. In addition, presence of fewer size classes beyond size at first maturity in females (Gwahaba, 1973), and a higher relative fecundity compared to 3 eggs.g⁻¹ for wild *O. niloticus* (Balirwa, 1998) further depicts increased investment in gonad development but reduced somatic growth, giving more likely indicators of stunting..

Length-weight relationships show that fish from Farm B assumed an isometric growth (Njiru *et. al.*, 2006) while those from farms A and C exhibited an allometric growth. Njiru *et. al.*, (2006) attributed higher gradient to fatter mature fish. Observations in this study can be ascribed to a better diet for fish from Farm B in comparison to a less nutritive diet (Balirwa, 1998; Bwanika *et. al.*, 2006) for fish in farms A and C. Diet in Farm B possibly contributed to the larger size at first maturity which perhaps influenced somatic growth and in turn length-weight relationship. Fulton's Condition Factor in this study was lower than that for *O. niloticus* from lakes Victoria, Kyoga and Albert (Balirwa, 1998); lakes Turkana and George (Lowe-McConnel, 1958) probably due to

environmental stress in farmed fish. The seemingly better Fulton's Condition Factor for fish from Farm C could be associated with increased investment in reproductive organs that possibly compromised somatic growth (Ricker, 1971; Swift, 1993). In females, increased investment was reflected in relative fecundity per gram which was highest in Farm C. It seems Condition Factor may not be a reliable parameter for assessing performance of stunted farmed *O. niloticus*.

Effects of selective harvesting on growth rates and life history traits in farmed Nile tilapia were observed by Conover & Munch (2002), and also reported in various studies (e.g. Gwahaba, 1973; Hutchings, 2005; Edeline *et. al.*, 2007) in wild fish populations. The farms under study prolonged production cycles up to 2 years but practiced selective harvesting which perhaps partly contributed to reduction in growth rate, decreased size at first maturity and small sizes (Gwahaba, 1973; Hutchings, 2005; Edeline *et. al.*, 2007).

The water quality values (temperature, pH, dissolved oxygen) were within the tolerance range (Swift, 1993) and this probably had minimal effects, if any, on the development of natural foods and growth performance of Nile tilapia. However, optimum pond productivity is based on proper management of water quality (Swift, 1993; Liti *et al.*, 2002) including phytoplankton (Kwei, 1986). Continuous application of excess cabbage leaves as feed could lead to over-fertilisation that can cause undesirable effects. Therefore it is vital to follow proper procedures for pond fertilization.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

This study assessed the performance of pond Nile tilapia in three subsistence code-named Farm A, Farm B and Farm C. Considering that low fish yields characterize subsistence fish farming, this study on the biology and ecology generated more understanding of the factors that influence its performance and production. Interactions with the fish farmers and personal observations on management practices (e.g. liming, fertilization, supplementary feeding, proliferation, single harvesting cycle) were either lacking or inadequate (To achieve study objectives were: to identify and quantify major natural foods (algae and macro-invertebrates) in the study ponds; to determine the diet of Nile tilapia; to determine life history traits (size structure, sex ratio, size at first maturity, length-weight relationship and Condition Factor of pond Nile tilapia.

Results of Natural foods indicated that Farm B that applied 24 cabbage leaves (which could not be consumed to completion and ended up rotting to release over a week's period contained the highest density: i. e. $52.4 \text{ cells.ml}^{-1}$ (plankton) and $2147 \text{ organisms.m}^{-2}$ (macro-invertebrates) compared to $30.2 \text{ cells.ml}^{-1}$ (plankton) and $1017 \text{ organisms.m}^{-2}$ (macro-invertebrates) from Farm C that had initial fertilization but no stocking but no cabbage leaves used as feed, and $4.8 \text{ cells.ml}^{-1}$ (plankton) and $1017 \text{ organisms.m}^{-2}$ (macro-invertebrates).

organisms.m⁻² (macro-invertebrates) from Farm A that applied 8 cabbage leaves per pond over a week's period. These results imply that regular fertilization is important in natural food development.

Fish diet comprised of three major items: higher plant material (47%, 29%, 14%); detritus (31%, 28%, 38%), and algae (17%, 26%, 40%) for fish from farms A, B, and C respectively. Food of animal origin (mainly zooplankton and macro-invertebrates) known to be more nutritive than that of plant origin comprised 15% (Farm B), 8% (Farm C) and 6% (Farm A). Availability of zooplankton (in particular rotifers), and macro-invertebrates (specifically oligochaetes) in large numbers in Farm B probably influenced their contribution to fish diet. Since secondary production is driven by primary production, it is necessary to enhance development of natural foods through proper fertilization practice.

Results of life history traits showed poor performance of Nile tilapia in all the study farms. The culture of mixed sex Nile tilapia promoted early maturation with sizes at first maturity below 20g except for males from Farm B (matured at 59 g). Majority of fish were in size class ≤ 20 g. Overall, males attained bigger mean weights: 15.8 ± 1.1 g, 104.6 ± 5.0 g, 17.6 ± 0.9 g compared to females 10.9 ± 1 g, 46.2 ± 2.9 g, 10.9 ± 0.5 g in farms A, B, and C respectively. Fish from Farm B depicted isometric growth while that from farms A and C gave negative allometric growth. However, fish from Farm C recorded a higher condition (1.63 ± 0.30) than that from Farm B (1.55 ± 0.23) and Farm A (1.53 ± 0.27), a scenario attributed to increased investment in gonad development that compromised

somatic growth in terms of length for fish from Farm C. A comparatively better performance of fish from Farm B was probably due to a more nutritive omnivorous diet.

5.2. Conclusions

Based on findings from this study, the following conclusions are made:

1. Farm B had the highest density of natural foods, followed by Farm C while farm A had the least. The highest increase in phytoplankton density occurred in Farm B following application of cabbage leaves as feed but was not consumed to completion by fish.
2. Nile tilapia from the study farms depicted an omnivorous feeding habit. Unlike the other two farms, the diet of fish from Farm B contained a higher percentage of zooplankton and macro-invertebrates important for improved fish performance. Where supplementary feeding was practiced, its contribution was small and fish depended mostly on natural food.
3. All the study farms contained mixed sex Nile tilapia that depicted early maturity and poor performance with size structure comprising mostly of small fish (modal class <20g) and poor condition (<2.0). Farm B gave a relatively better performance.
4. In all farms, males matured at larger sizes and also grew bigger compared to females.

5. Management practices in the study farms were inadequate and did not fully address aspects such as liming, fertilization, adequate supplementary feeding, and complete harvesting.

5.3. Recommendations

1. There is need to stimulate primary production through proper fertilization practice so as to avail adequate quantities of natural foods including zooplankton and macro-invertebrates important in fish diet

2. Although supplementary feeding is encouraged, farmers are advised to seek technical assistance about recommended quantities and frequency of feeding depending on availability of feeds

3. A follow up study to establish age at first maturity for farmed Nile tilapia could add to improved understanding of its culture requirements

4. Farmers are encouraged to stock all male Nile tilapia that grow bigger

5. Farmers are advised to follow proper management practices

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APPENDICES

Appendix I: Questionnaire used to collect information on pond management practices

Part A. (Questions asked during first sampling at each farm)

1. Name of Farm Owner (s)
2. Month and year when farm was started.....
3. Fish species farmed
4. Source of seed
- 5a. Date of stocking
- b. Number of stocked fish per pond
6. Was liming done before stocking?
- 7a. Was fertilization done: (i) before stocking?
- (ii) after stocking?
- b. If yes: (i) which fertilizer
- (ii) quantity
- (iii) frequency
- 8a. Have you ever harvested some of the farmed fish
- b. If yes: (i) how many times
- (ii) during which month(s)
- 9a. Are supplemental feeds applied
- b. If yes: (i) which feed (s)
- (ii) quantity
- (iii) time of feeding
- (iii) frequency of feeding

Part B (Questions asked during subsequent sampling)

10. Are there any changes in: (i) type of feed provided
 (ii) quantity (iii) time of feeding
 (iv) frequency of feeding

Appendix II: Biometric Data Sheet

Fish Farm

Sheet 50. ---

Pond

Date

[illegible]

Appendix III: Mean numbers of algal cells per ml $\pm$ SE from the three study farms

(cell.ml ⁻¹ $\pm$ SE) $\times 10^{-1}$			
Algae	Farm A	Farm B	Farm C
<u>Bacillariophyta</u>	7.1 $\pm$ 1.0	47.4 $\pm$ 10.9	15.4 $\pm$ 1.6
<i>Cyclotella</i>	1.4 $\pm$ 0.4	17.0 $\pm$ 4.2	1.6 $\pm$ 0.4
<i>Melosira</i>	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1
<i>Navicula</i>	0.7 $\pm$ 0.2	0.8 $\pm$ 0.3	3.1 $\pm$ 0.5
<i>Nitzhia</i>	3.9 $\pm$ 0.6	26.6 $\pm$ 6.9	7.1 $\pm$ 1.4
<i>Surirella</i>	1.0 $\pm$ 0.2	2.9 $\pm$ 0.6	3.5 $\pm$ 0.6
<u>Chlorophyta</u>	11.5 $\pm$ 2.2	80.1 $\pm$ 25.1	250.5 $\pm$ 43.5
<i>Ankistrodesmus</i>	0.1 $\pm$ 0.1	1.2 $\pm$ 1.0	0.1 $\pm$ 0.1
<i>Closterium</i>	0.4 $\pm$ 0.2	35.4 $\pm$ 22.2	0.5 $\pm$ 0.2
<i>Coelastrum</i>	3.4 $\pm$ 1.1	1.9 $\pm$ 0.8	225.6 $\pm$ 43.3
<i>Cosmarium</i>	0.4 $\pm$ 0.1	0.2 $\pm$ 0.2	0.3 $\pm$ 0.1
<i>Crucigenia</i>	0.3 $\pm$ 0.1	1.3 $\pm$ 0.6	0.0 $\pm$ 0.0
<i>Kirchneriella</i>	0.2 $\pm$ 0.1	0.0 $\pm$ 0.0	1.9 $\pm$ 0.7
<i>Monoraphidium</i>	0.5 $\pm$ 0.2	6.7 $\pm$ 2.3	0.1 $\pm$ 0.1
<i>Oocystis</i>	0.2 $\pm$ 0.1	0.2 $\pm$ 0.2	0.7 $\pm$ 0.4
<i>Pediastrum</i>	0.3 $\pm$ 0.1	1.5 $\pm$ 0.6	6.2 $\pm$ 1.9
<i>Scenedesmus</i>	3.4 $\pm$ 0.9	27.1 $\pm$ 7.2	11.5 $\pm$ 3.2
<i>Spirogyra</i>	0.2 $\pm$ 0.2	0.1 $\pm$ 0.1	1.2 $\pm$ 0.5
<i>Straurastrum</i>	0.0 $\pm$ 0.0	0.5 $\pm$ 0.2	2.3 $\pm$ 0.8
<i>Tetraedron</i>	2.1 $\pm$ 0.5	4.1 $\pm$ 2.1	0.2 $\pm$ 0.1
<u>Cyanophyta</u>	16.3 $\pm$ 2.3	350.1 $\pm$ 68.2	13.3 $\pm$ 1.8
<i>Anabaena</i>	1.2 $\pm$ 0.4	0.9 $\pm$ 0.4	0.2 $\pm$ 0.1
<i>Aphanocapsa</i>	0.2 $\pm$ 0.1	283.1 $\pm$ 65.8	0.0 $\pm$ 0.0
<i>Merismopedia</i>	2.8 $\pm$ 1.1	10.4 $\pm$ 2.7	5.4 $\pm$ 1.4
<i>Microcystis</i>	9.8 $\pm$ 1.6	47.5 $\pm$ 9.3	5.9 $\pm$ 0.9
<i>Oscillatoria</i>	1.3 $\pm$ 0.5	3.4 $\pm$ 1.1	0.4 $\pm$ 0.1
<i>Planktolyngbya</i>	1.0 $\pm$ 0.4	4.7 $\pm$ 0.9	1.4 $\pm$ 0.3
<u>Euglenophyta</u>	10.3 $\pm$ 0.9	45.4 $\pm$ 8.6	18.0 $\pm$ 3.2
<i>Euglena</i>	4.4 $\pm$ 0.5	16.0 $\pm$ 3.8	11.6 $\pm$ 2.5
<i>Phacus</i>	0.8 $\pm$ 0.3	3.8 $\pm$ 1.1	2.3 $\pm$ 0.8
<i>Tracholomonas</i>	5.1 $\pm$ 0.6	25.7 $\pm$ 5.1	4.2 $\pm$ 0.6
Total mean count	45.2 $\pm$ 5.2	523.1 $\pm$ 84.2	297.3 $\pm$ 45.8
Number of taxa	26	26	25

Appendix IV: Kruskal-Wallis test for significance in algae between fish farms
(site codes 1 = Farm A, 2 = Farm B, 3 = Farm C).

Ranks

	site code	N	Mean Rank
Chlorophyta	1	27	20.13
	2	27	42.72
	3	27	60.15
	Total	81	
Bacillariophyta	1	27	24.56
	2	27	50.91
	3	27	47.54
	Total	81	
Euglenophyta	1	27	29.04
	2	27	54.31
	3	27	39.65
	Total	81	
Cyanophyta	1	27	33.48
	2	27	60.78
	3	27	28.74
	Total	81	

Test Statistics^{a, b}

	Chlorophyta	Bacillario phyta	Euglenophyta	Cyanophyta
Chi-Square	39.306	20.106	15.753	29.193
df	2	2	2	2
Asymp. Sig.	.000	.000	.000	.000

- a. Kruskal Wallis Test
- b. Grouping Variable: site code

Appendix V: Density (mean no. l⁻¹ ± SE) of zooplankton from the study farms.

Taxa	Farm A	Farm B	Farm C
Cladocera	2.3 ± 0.4	17.1 ± 3.6	4.1 ± 1.5
<i>Chydrous</i>	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.3
<i>Moina</i>	2.3 ± 0.4	17.1 ± 3.6	3.4 ± 1.6
Copepods	243.7 ± 52.0	55.7 ± 13.2	180.9 ± 63.7
Cyclopoid	44.5 ± 10.4	18.1 ± 4.8	19.3 ± 4.7
Naupulii	199.2 ± 41.9	37.6 ± 9.1	161.6 ± 60.4
rotifers	42.6 ± 6.8	974.3 ± 274.3	363.2 ± 128.2
<i>Asplanchna</i>	0.0 ± 0.0	1.7 ± 0.6	0.0 ± 0.0
<i>Branchionus</i>	40.6 ± 6.5	956.7 ± 272.5	354.5 ± 125.9
<i>Filinia</i>	1.3 ± 0.2	4.3 ± 0.8	2.5 ± 1.1
<i>Keratella</i>	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.3
<i>Lecane</i>	0.3 ± 0.01	0.3 ± 0.2	0.6 ± 0.2
<i>Syncheata</i>	1.7 ± 0.3	8.9 ± 2.1	2.6 ± 0.7
<i>Trichocerca</i>	0.3 ± 0.1	2.5 ± 0.6	2.4 ± 1.2
Ostracods	0.1 ± 0.04	0.0 ± 0.0	0.5 ± 0.2
Insect Larvae	0.6 ± 0.3	0.6 ± 0.2	0.7 ± 0.2
Total mean counts	289.3 ± 52.8	1047.8 ± 276.7	549.3 ± 188.6
No. of taxa	10	10	12

Appendix VI: Kruskal-Wallis test for significance in zooplankton between fish farms
(Farm codes 1 = Farm A, 2 = Farm B, 3 = Farm C)

Ranks

	Farm Code	N	Mean Rank
Cladocera	1	27	33.56
	2	27	56.46
	3	27	32.98
	Total	81	
COPEPODA	1	27	51.69
	2	27	27.02
	3	27	44.30
	Total	81	
ROTIFERA	1	27	23.74
	2	27	59.07
	3	27	40.19
	Total	81	

Test Statistics^{a,b}

	Cladocera	COPEPODA	ROTIFERA
Chi-Square	17.708	15.637	30.499
df	2	2	2
Asymp. Sig.	.000	.000	.000

a. Kruskal Wallis Test

b. Grouping Variable: Farm Code

Appendix VII: Density (mean no. m⁻² ± SE) of macro-invertebrates in sediment from the study farms.

Taxa	Farm A	Farm B	Farm C
Gastropoda	43.6 ± 15.3	9.3 ± 4.1	627.1 ± 145.7
<i>Lymnaea</i>	0.0 ± 0.0	0.0 ± 0.0	3.1 ± 2.2
<i>Melanoides</i>	43.6 ± 15.3	9.3 ± 4.1	624.0 ± 145.4
Ephemeroptera	3.1 ± 3.1	0.0 ± 0.0	0.0 ± 0.0
<i>Caenis</i>	3.1 ± 3.1	0.0 ± 0.0	0.0 ± 0.0
Odonata	4.7 ± 2.6	0.0 ± 0.0	15.6 ± 5.1
Coenagrionidae	4.7 ± 2.6	0.0 ± 0.0	1.6 ± 1.6
Libellulidae	0.0 ± 0.0	0.0 ± 0.0	14.0 ± 5.0
Diptera	353.3 ± 66.2	70.0 ± 20.6	249.0 ± 86.0
Ceratopogonidae	7.8 ± 5.5	21.8 ± 10.4	1.6 ± 1.6
<i>Chaoborus</i>	43.6 ± 15.9	0.0 ± 0.0	0.0 ± 0.0
<i>Chironomus</i>	68.5 ± 19.0	29.6 ± 11.2	20.2 ± 8.5
<i>Clinotanypus</i>	6.2 ± 2.9	0.0 ± 0.0	10.9 ± 3.6
<i>Tanypus</i>	84.0 ± 20.1	1.6 ± 1.6	0.0 ± 0.0
<i>Tarnytarsus</i>	0.0 ± 0.0	0.0 ± 0.0	87.1 ± 67.2
Tabanidae	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Other Chironomids	143.2 ± 36.4	17.1 ± 9.8	127.6 ± 56.0
Hemiptera	3.3 ± 2.2	0.0 ± 0.0	1.6 ± 1.6
Corixidae	1.6 ± 1.6	0.0 ± 0.0	0.0 ± 0.0
Macroveliidae	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Mesoveliidae	1.6 ± 1.6	0.0 ± 0.0	0.0 ± 0.0
Coleoptera	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Elmidae	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Lepidoptera	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Pyrilididae	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.6
Hirudinea	0.0 ± 0.0	3.1 ± 2.2	1.6 ± 1.6
Oligochaete	1.6 ± 1.6	2060.4 ± 586.4	38.9 ± 10.0
Naididae	1.6 ± 1.6	2060.4 ± 586.4	38.9 ± 10.0
Total	412.4 ± 69.7	2142.9 ± 594.2	936.8 ± 151.2
No. of taxa	12	7	15

Appendix VIII: Kruskal-Wallis test for significance in macro-invertebrates between fish farms (Farm codes 1 = Farm A, 2 = Farm B, 3 = Farm C).

Ranks

	Farm code	N	Mean Rank
Gastropoda	1	27	36.61
	2	27	30.30
	3	27	56.09
	Total	81	
ODONATA	1	27	40.07
	2	27	35.50
	3	27	47.43
	Total	81	
DIPTERA	1	27	53.22
	2	27	29.09
	3	27	40.69
	Total	81	
Hemiptera	1	27	42.50
	2	27	39.50
	3	27	41.00
	Total	81	
Coleoptera	1	27	40.50
	2	27	40.50
	3	27	42.00
	Total	81	
Lepidoptera	1	27	40.50
	2	27	40.50
	3	27	42.00
	Total	81	
Hirudinea	1	27	39.50
	2	27	42.50
	3	27	41.00
	Total	81	
Oligoch.	1	27	21.89
	2	27	66.67
	3	27	34.44
	Total	81	

Test Statistics^{a, b}

	Gastropoda	ODONATA	DIPTERA	Hemiptera	Coleoptera	Lepidoptera	Hirudinea	Oligoch
Chi-Square	22.673	9.986	14.931	2.051	2.000	2.000	2.051	59.861
df	2	2	2	2	2	2	2	2
Asymp. Sig.	.000	.007	.001	.359	.368	.365	.359	.000

a. Kruskal Wallis Test

b. Grouping Variable: Farm code

Appendix IX: Density (mean no. m⁻² ± SE) of macro-invertebrates associated with macrophytes from the study farms

Taxa	Farm A	Farm B	Farm C
Gastropoda	23.9 ± 12.5	1.8 ± 1.8	40.6 ± 23.6
<i>Biomphalaria</i>	17.1 ± 12.3	1.6 ± 1.6	0.0 ± 0.0
<i>Bulinus</i>	1.4 ± 0.9	0.0 ± 0.0	0.0 ± 0.0
<i>Lymnaea</i>	2.2 ± 2.2	0.3 ± 0.3	3.2 ± 1.7
<i>Melanoides</i>	2.2 ± 1.0	0.0 ± 0.0	37.3 ± 22.4
<i>Pila ovata</i>	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
<i>Gyraulus</i>	0.8 ± 0.8	0.0 ± 0.0	0.0 ± 0.0
Ephemeroptera	26.2 ± 8.0	0.0 ± 0.0	4.1 ± 1.9
Caenidae	14.1 ± 5.3	0.0 ± 0.0	0.0 ± 0.0
Baetidae	12.2 ± 3.9	0.0 ± 0.0	4.1 ± 1.9
Odonata	46.3 ± 18.7	0.0 ± 0.0	20.3 ± 9.2
Libellulidae	3.2 ± 1.3	0.0 ± 0.0	4.6 ± 2.4
Protoneuridae	43.0 ± 18.3	0.0 ± 0.0	15.7 ± 7.0
Diptera	6.1 ± 2.9	0.0 ± 0.0	4.3 ± 3.5
Chironomidae	5.1 ± 2.8	0.0 ± 0.0	2.7 ± 2.2
Chaoboridae	0.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Culicidae	0.5 ± 0.5	0.0 ± 0.0	1.6 ± 1.6
Hemiptera	4.1 ± 0.6	1.1 ± 0.3	4.5 ± 0.5
Naucoridea	0.3 ± 0.3	0.3 ± 0.3	0.8 ± 0.6
Corixidae	0.5 ± 0.5	0.3 ± 0.3	0.3 ± 0.3
Gerridae	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Notonectidae	1.6 ± 0.6	0.0 ± 0.0	0.0 ± 0.0
Nepidae	1.4 ± 0.6	0.5 ± 0.5	3.5 ± 1.9
Coleoptera	0.8 ± 0.6	0.3 ± 0.3	0.5 ± 0.4
Haliplidae	0.8 ± 0.6	0.0 ± 0.0	0.0 ± 0.0
Hydrophilidae	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0
Elmidae	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Gyrinidae	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Lepidoptera	0.3 ± 0.3	0.0 ± 0.0	0.5 ± 0.5
Pyalididae	0.3 ± 0.3	0.0 ± 0.0	0.5 ± 0.5
Hirudinea	0.0 ± 0.0	0.5 ± 0.5	0.0 ± 0.0
Total	107.5 ± 41.2	3.7 ± 3.7	74.9 ± 34.8
No. of taxa	20	7	13

Appendix X: Percentages and Frequency of Occurrence of the fish food items

Food items	% Relative Importance			% Frequency of occurrence		
	Farm A	Farm B	Farm C	Farm A	Farm B	Farm C
Higher Plant material	47.1	29.1	13.9	92.8	82.9	79.9
Detritus	30.6	27.6	38.1	86.2	95.6	96.7
Bacillariophyta	4.1	4.2	9.6			
<i>Cyclotella</i>	0.1	0.2	0.1	4.4	11.7	4.9
<i>Cymbella</i>	0.1	0.1	< 0.1	3.9	5.9	1.6
<i>Melosira</i>	0.1	0.2	0.5	3.3	12.2	10.3
<i>Navicula</i>	1.4	0.7	4.3	37.6	34.6	77.7
<i>Nitzschia</i>	0.6	1.2	0.4	17.1	39.5	13.0
<i>Rhopalodia</i>	0.0	< 0.1	0.1	0.0	2.0	1.1
<i>Surirella</i>	1.8	1.7	4.2	40.9	51.2	57.6
Chlorophyta	3.0	7.5	17.6			
<i>Ankistrodesmus</i>	0.1	0.3	< 0.1	3.9	10.7	0.5
<i>Closterium</i>	0.1	2.6	0.3	3.3	28.8	6.5
<i>Coelastrum</i>	0.1	0.1	7.8	3.3	2.0	46.2
<i>Cosmarium</i>	< 0.1	0.0	0.5	1.7	0.0	8.2
<i>Crucigenia</i>	< 0.1	0.2	< 0.1	1.7	6.3	0.5
<i>Euastrum</i>	0.0	0.0	< 0.1	0.0	0.0	1.1
<i>Kirchneriella</i>	< 0.1	0.0	< 0.1	1.7	0.0	0.5
<i>Monoraphidium</i>	< 0.1	0.2	< 0.1	0.6	12.7	1.1
<i>Pediastrum</i>	0.8	0.5	2.5	21.0	10.7	35.9
<i>Scenedesmus</i>	1.1	2.9	5.5	27.1	62.4	61.4
<i>Spirogyra</i>	0.5	0.2	0.4	9.9	3.9	8.2
<i>Straurastrum</i>	0.1	0.1	0.4	2.2	3.4	11.4
<i>Tetraedron</i>	0.1	0.4	0.1	8.3	14.6	3.3
Cyanophyta	0.9	3.2	1.1			
<i>Anabaena</i>	0.1	0.1	0.1	5.0	12.2	3.8
<i>Aphanocapsa</i>	0.0	1.2	0.0	0.0	14.1	0.0
<i>Merismopedia</i>	0.1	1.2	0.4	6.1	15.1	10.9
<i>Microcystis</i>	0.0	0.2	0.3	0.0	4.9	4.3
<i>Oscillatoria</i>	0.7	0.4	0.2	17.7	16.1	9.3
<i>Planktolyngbya</i>	< 0.1	0.1	0.1	1.1	11.7	6.5
Euglenophyta	9.0	10.9	11.8			
<i>Euglena</i>	3.9	2.1	3.7	51.4	37.1	40.8
<i>Phacus</i>	3.1	1.5	6.7	48.6	29.8	76.1
<i>Trachlemonas</i>	2.0	7.3	1.4	31.5	60.5	16.3
Macro-invertebrates	1.5	9.6	4.7			
Chironomids	0.0	0.2	0.3	0.0	3.4	4.7
Odonata	0.0	0.0	0.2	0.0	0.0	0.5
Insect Remains	1.2	0.8	3.1	8.3	23.4	18.5
Oligochaete	0.2	5.2	0.0	1.7	23.4	0.0
Leech	0.0	< 0.1	0.0	0.0	1.0	0.0
Molluscs	0.1	0.0	1.1	2.2	0.0	16.8
Fish	1.2	0.0	0.0	1.1	0.0	0.0
Zooplankton	2.5	5.3	3.1			
Cladocera	0.2	0.3	< 0.1	2.2	6.3	1.1
Copepods	0.1	0.3	0.1	0.6	4.9	1.1
Rotifers	2.2	4.4	3.0	29.3	51.7	42.9
Bran	0.2	2.6	0.0	8.3	35.1	0.0
Number of stomachs	181	205	184	181	205	184

Appendix XI: One Way ANOVA for test for significance in mean fish weight between the study farms.

ANOVA

WT

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	856104.7	2	428052.359	321.819	.000
Within Groups	1251626	941	1330.102		
Total	2107731	943			

Multiple Comparisons

Dependent Variable: WT

	(I) Farm Code	(J) Farm Code	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1	2	-64.38*	2.881	.000	-71.15	-57.62
		3	-1.09	2.910	.926	-7.92	5.74
	2	1	64.38*	2.881	.000	57.62	71.15
		3	63.29*	2.935	.000	55.40	70.18
	3	1	1.09	2.910	.926	-5.74	7.92
		2	-63.29*	2.935	.000	-70.18	-56.40
LSD	1	2	-64.38*	2.881	.000	-70.04	-58.73
		3	-1.09	2.910	.708	-6.80	4.62
	2	1	64.38*	2.881	.000	58.73	70.04
		3	63.29*	2.935	.000	57.53	69.05
	3	1	1.09	2.910	.708	-4.62	6.80
		2	-63.29*	2.935	.000	-69.05	-57.53

*. The mean difference is significant at the .05 level.

Appendix XII: Chi-square test for significance in sex ratios between fish farms
 (site codes 1 = Farm A, 2 = Farm B, 3 = Farm C; sex codes 1 = males,
 2 = females)

site code * SEX_CODE Crosstabulation

Count		SEX_CODE		Total
		1	2	
site	1	164	162	326
code	2	170	145	315
	3	162	141	303
Total		496	448	944

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.014 ^a	2	.602
Likelihood Ratio	1.013	2	.602
Linear-by-Linear Association	.648	1	.421
N of Valid Cases	944		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 143.80.

Appendix XIII: Percentages of Gonad Stages in Males and Females

Farm/sex	Gonad states							n
	I	II	III	IV	V	VI	VII	
Farm A (M)	32.3	18.9	11.6	11.0	13.4	12.8	0.0	164
Farm A (F)	1.2	4.3	27.8	32.7	13.6	20.4	0.0	162
Farm B (M)	10.6	3.5	14.7	20.6	20.0	30.6	0.0	170
Farm B (F)	5.5	9.0	13.1	33.8	19.3	18.6	0.7	145
Farm C (M)	19.1	10.5	25.9	20.1	11.7	12.3	0.0	162
Farm C (F)	3.5	9.2	17.7	32.6	18.4	18.4	0.0	141

M = males, F = females

Appendix XIV: Part of Regression values used to plot size at first maturity for *O.niloticus* from Farm A

TL (cm)	females observed	females expected	males observed	males expected
5.9	0.5	0.21024119		0.004188157
6		0.226733432	0	0.004680312
6.1	0	0.24411195	0	0.005229998
6.2	0.428571429	0.262386366	0	0.005843863
6.3	0	0.281511104	0	0.006529306
6.4	0.4	0.30145996	0	0.007294557
6.5	0.5	0.322188616	0	0.008148762
6.6	0.333333333	0.343641418	0	0.009102079
6.7	0.6	0.365751857	0	0.010165781
6.8	0.5	0.388442988	0	0.011352366
6.9	0.2	0.411628237	0.2	0.01267568
7	0.571428571	0.435212531	0.25	0.014151041
7.1	0.25	0.459093726	0.25	0.015795376
7.2	1	0.483164304	0	0.017627365
7.3	0.25	0.507313261	0	0.019667587
7.4	0.5	0.531428139	0	0.021938674
7.5	0.666666667	0.555397115	0.2	0.024465468
7.6	0	0.579111059		0.027275169
7.7	0	0.602465493		0.030397492
7.8	1	0.62536237	0	0.033864799
7.9	0	0.647711608	0	0.037712224
8	0.8	0.669432352	0	0.041977767
8.1		0.6904539	0	0.046702362
8.2		0.710716318	0	0.051929884
8.3	1	0.730170726	0	0.057707118
8.4	1	0.748779276	0	0.064083628
8.5	1	0.766514868		0.0711111557
8.6	1	0.783360629		0.078845294
8.7	0.833333333	0.799309203		0.087341029
8.8	1	0.814361909	0	0.09665614
8.9		0.828527798	0	0.106848418
9	1	0.841822665	0	0.117975098
9.1	1	0.854268042	0	0.13009169
9.2	1	0.865890214	0	0.143250603
9.3	0	0.876719272	1	0.157499566
9.4		0.886788235	0	0.172879859
9.5	0.666666667	0.896132246	0.5	0.189424394
9.6	1	0.904787846	0.5	0.20715569
9.7	1	0.912792342	0.5	0.226083809
9.8	1	0.920183264	0	0.246204354
9.9	1	0.926997896	0	0.267496626
10	1	0.933272895	0.333333333	0.289922066
10.1	1	0.939043985	0	0.313423107
10.2	1	0.944345711	0.333333333	0.337922564
10.3	1	0.949211252	0.666666667	0.363323665

Appendix XV: One way ANOVA for test for significance in fecundity from the study farms (site code 1 = Farm A, 2 = Farm B, C = Farm C)

ANOVA

NO._EGGS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1255427	2	627713.618	45.854	.000
Within Groups	1492132	109	13689.287		
Total	2747560	111			

Multiple Comparisons

Dependent Variable: NO._EGGS

	(I) site code	(J) site code	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1	2	-224.01*	26.098	.000	-286.03	-162.00
		3	-16.76	28.488	.827	-84.45	50.93
	2	1	224.01*	26.098	.000	162.00	286.03
		3	207.25*	27.436	.000	142.06	272.45
	3	1	16.76	28.488	.827	-50.93	84.45
		2	-207.25*	27.436	.000	-272.45	-142.06
LSD	1	2	-224.01*	26.098	.000	-275.74	-172.29
		3	-16.76	28.488	.558	-73.22	39.70
	2	1	224.01*	26.098	.000	172.29	275.74
		3	207.25*	27.436	.000	152.88	261.63
	3	1	16.76	28.488	.558	-39.70	73.22
		2	-207.25*	27.436	.000	-261.63	-152.88

*. The mean difference is significant at the .05 level.

Appendix XVI: ANCOVA test for significance in logarithmic relationships for fish weight between fish farms (Farm codes 1 = Farm A, 2 = Farm B, 3 = Farm C)

Between-Subjects Factors

	N
SEX_CODE 1	496
2	448

Tests of Between-Subjects Effects

Dependent Variable: LOG_WT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	208.683 ^a	2	104.342	20997.549	.000
Intercept	65.382	1	65.382	13157.328	.000
SEX_CODE	2.510E-04	1	2.510E-04	.051	.822
LOG_TL	194.392	1	194.392	39119.051	.000
Error	4.676	941	4.969E-03		
Total	1720.053	944			
Corrected Total	213.360	943			

a. R Squared = .978 (Adjusted R Squared = .978)

Appendix XVII: One way ANOVA test for significance in Condition Factor (K) between fish farms (Farm codes 1 = Farm A, 2 = Farm B, 3 = Farm C)

ANOVA

K

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.905	2	.952	13.680	.000
Within Groups	69.757	1002	.070		
Total	71.662	1004			

Multiple Comparisons

Dependent Variable: K

	(I) Farm Code	(J) Farm Code	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1	2	-.0257	.02005	.406	-.0728	.0214
		3	-.1036*	.02040	.000	-.1515	-.0557
	2	1	.0257	.02005	.406	-.0214	.0728
		3	-.0779*	.02082	.001	-.1268	-.0290
	3	1	.1036*	.02040	.000	.0557	.1515
		2	.0779*	.02082	.001	.0290	.1268
LSD	1	2	-.0257	.02005	.200	-.0650	.0136
		3	-.1036*	.02040	.000	-.1436	-.0636
	2	1	.0257	.02005	.200	-.0136	.0650
		3	-.0779*	.02082	.000	-.1188	-.0370
	3	1	.1036*	.02040	.000	.0636	.1436
		2	.0779*	.02082	.000	.0370	.1188

*. The mean difference is significant at the .05 level.