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GROWTH AND PRODUCTION OF THE AFRICAN CATFISH, *Clarias gariepinus* IN INTEGRATED RICE-FISH CULTURE SYSTEMS IN NYANDO DISTRICT, KENYA

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

To my dear parents, Laban and Jane Olambla, who enduringly nurtured me in all spheres of life.

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ABBREVIATIONS AND ACRONYMS

AP - Annualized Production

APHA - American Public Health Association

DAR - Days after replacement of water

DO - Dissolved Oxygen

FAO - Food and Agriculture Organization of the United Nations

IAAS - Integrated Agriculture- Aquaculture Systems

IFAS - Integrated Fisheries Aquaculture Systems

IMTA -Integrated Multi-Trophic Aquaculture

IPUAS - Integrated peri-urban aquaculture systems

LBDA - Lake Basin Development Authority

NFY - Net Fish Yield

NTU - Nephelometric Turbidity Units

SGR - Specific Growth Rate

SRP - Soluble Reactive Phosphorus

TAN -Total Ammonia Nitrogen

UNDP - United Nations Development Programme

UNEP - United Nations Environment Programme

WHO - World Health Organization

ABSTRACT

Fish production from integrated aquaculture is very low in Africa compared to global output. In countries such as Kenya where some commercialization has been adopted, fish yields are either stagnating or declining. An innovative way aimed at improving production of the catfish could involve mixed culture of catfish and tilapia in rice. With the assumption that production of catfish is not affected by culture type, an experiment was conducted to assess growth and production of the African catfish, *Clarias gariepinus* in different culture systems where growth and production was monitored for 122 days within the Lake Victoria Basin in Kenya. The experiment was laid out in a randomized block design with three treatments and three replicates. The treatments consisted of three culture systems which included catfish-tilapia polyculture in rice as treatment 1, catfish monoculture in rice at low stocking density as treatment 2 and catfish monoculture in rice at high stocking density as treatment 3. The fish were stocked as: 4 catfish + 4 tilapia m^{-2}, 4 fish m^{-2} and 8 fish m^{-2} for treatments 1, 2 and 3 respectively. The rice variety used in the integrated culture experiment was the Basmati variety IR62032. Measurement of water quality parameters was done in the mornings only, while measurement of fish growth parameters was done monthly. The mean values of all the measured water quality parameters were calculated and reported with their standard errors. Two factor-ANOVA test was used to determine the effects of culture type on growth and production of catfish, and also to determine the effects of period and frequency of water replacement on water quality. One factor-ANOVA test was used to determine the variations in the water quality among the treatments for each DAR and between the DARs for each treatment. Production parameters (length, weight, survival, condition factors, and yield) of the fish in the treatments were compared using one factor ANOVA test. All statistical analyses were performed using MINITAB 13.0 computer software. There was a significant difference in fish weight between the three treatments ($F=11.6$; $P<0.05$) with treatment 1 registering the highest growth in terms of weight. Fish survival was significantly higher ($p< 0.05$, at 95% CI) in treatment 2 (61.3%) but insignificant between treatments 1 (46.5%) and 3 (42.2%).The general condition of the fish in the treatments was not significantly different ($p<0.05$) between the three treatments. Fish conditions deteriorated in all the treatments as the days of culture increased, the K-values eventually dropping to less than 1. Yield of fish was higher in treatment 1 (373.16 kg ha^{-1}) compared to treatments 2 (288.88 kg ha^{-1}) and 3 (236.26 kg ha^{-1}), although the values were not significantly different ($F=3.11$, $P<0.05$). Catfish production was positively affected by mixed culture of catfish and tilapia in rice-fish culture while Water quality parameters critical to survival of fish increased with increasing days of culture. Turbidity, nitrites and SRP were the major factors affecting growth and the general condition of the fish.

Key words: agro-pisciculture, rizi-pisciculture, geo-ecological zones, integrated agriculture-aquaculture, integrated fisheries aquaculture, integrated multi-trophic aquaculture.

CHAPTER ONE: INTRODUCTION

1.1 Background

In Africa, fish production from aquaculture is still at its infancy compared to global output (FAO 2004). Reliable data on production quantities and ratios of fish to rice yields are difficult to obtain as these are seldom recorded. FAO (2006 a, b) estimates total contribution to world aquaculture output by Africa at a mere 1.0% since adoption of rice-fish farming remains rather marginal (Frei and Becker 2005). Rasowo *et al.* (2008) and Radull (2007) observed that a significant increase in aquaculture production in the continent can be realized through refocusing aquaculture development strategies such as widening the range of production systems and development of innovative agronomic practices such as rizi-pisciculture as a way of reducing costs and maximizing on use of resources.

Rice-fish culture in many sub-Saharan African countries is for subsistence, undertaken by the rural peasant farmers, and contributes a negligible percentage towards the national aquaculture production. Integrated rice-fish polyculture systems are more productive than rice alone, fish alone or rice-fish monoculture systems (Yinhe, 2004). This is because in the integrated polyculture system a careful choice of the fish species ensures efficient utilization of the resources of the aquatic environment that is characteristic of rice fields (Yinhe, 2004).

The emergence and adoption of high yielding varieties of rice have created several problems to rice-fish culture. Among them is a concern about the suitability of the short stemmed varieties because of the deeper standing water required in rice-fish culture which may cause sub-optimal growth in the rice plant (Rosario, 1984). Another concern is the reduced growing period of the high yielding varieties. Many of them mature within approximately 100 days or less. With such a short culture period for fish there is a need to either stock large fingerlings with the associated risks of fish dislodging and eating the rice plants, or to harvest the fish early for further on-growing (Rasowo *et al.,* 2008) with associated higher production costs. Several rice varieties are grown in the Lake Victoria Basin and hence there is need to evaluate the most appropriate variety for rice-fish culture. However, a variety with the ability to produce a second crop (ratoon) would partially solve this problem and allow production of table size fish without necessarily resorting to out-grow ponds since it allows for production of fish for a period of approximately six months.

Many researchers in aquaculture (Omondi *et al.* 2001, Giap *et al.* 2005, Yaro *et al.* (2004), Rasowo *et al.* 2008), have often monitored the water quality parameters since they are likely to affect the growth and the general performance of cultured fish in ponds and paddies. However, water quality parameters alone cannot explain the observed variations in growth in fish from those cited by researchers in other countries with similar geo-ecological conditions. This is because some effects of chemical exposure may not be captured by the routine water quality assessments. There is a need, therefore, to employ a more inclusive approach that would not only provide the link between the routine water quality assessment procedures, but also an in-depth analysis of fish growth as influenced by other factors not captured by the water quality assessments. The condition factor or organo-somatic indices can reflect adverse effects of chemical exposure that are not monitored by routine water quality assessments. Also the two indices integrate, at organ system and organism level, the combined effects of multiple contaminants and the combined effects of contaminants and other stressors. Therefore, this study investigated the variations in condition factors among the three culture systems.

Since literature on research on integrated rice-fish polyculture system in Kenya is rare, this research design offers a promising beginning to improving the production of the catfish and thus its subsequent contributions to the fisheries in the Lake basin area which stood at a paltry 1% as at 2005 (Okumu, 2005). This would provide an alternative potential for poverty alleviation for the residents of a region which registers a development rate of less than 2% per annum (UNEP, 1995).

1.2 Problem statement and justification

Rice-catfish farming is practiced in several parts of the world (Li, 1986) including some African countries where commercialization of the practice has been done (de la Cruz *et al.*, 1992). However, yields under these systems are either stagnating or declining (Dawe, 1998). This calls for innovative culture practices that would not only increase yields of catfish, but also offer a complimentary source of income to farmers. Polyculture of catfish and tilapia in rice is one such innovation. A cost-benefit analysis carried out by LBDA/FAO/UNDP in 1999 showed a relative profitability of the catfish compared with traditional tilapia farming

The Lake Victoria basin registers a poor rate of development (less than 2% per annum), with overdependence on the capture fisheries of the adjacent Lake Victoria which has seen depletion of popular species such as the catfish (LVFO (2005). A culture system that would supplement the much needed nutritional needs of the local community and also offer additional income to the riparian families is desirable. However, no information is available on the production of the catfish in integrated agro- piscicultural systems that are seen as a possible solution to this problem.

1.3 Research questions

(i) What are the effects of culture type on growth and production of catfish?

(ii) Does the period and frequency of water replacement affect water quality?

1.4 Hypothesis

1. Growth and production of catfish does not differ with culture type.

2. Water quality does not change with period and frequency of replacement.

1.5 Objectives of the study

The main objective of this study was to asses growth and production of the African catfish, *Clarias gariepinus* in different culture systems.

The specific objectives were:

(i) To determine the effects of culture type on growth and production of catfish.

(ii) To determine the effects of period and frequency of water replacement on water quality.

CHAPTER TWO: LITERATURE REVIEW

2.1 Types of aquaculture in rice fields

Coche (1967) to classified rice-fish culture systems into four categories, based on the origin of fish and the relation of fish culture to rice crop. These included:

- Harvesting wild fish which have entered the field through water courses.
- Trapping wild fish admitted into the field with tidal water (generally brackishwater - the water flowing into the pond attract fish by rheotactic stimuli; further, often lights are used at the sluices to attract fish and prawns- phototropism and photokinesis).
- Increasing the wild crop in the field by introducing new fish directly into the field or indirectly in connected ponds, wells and other water bodies used for production of fish.
- Trapping fish as in the second category above and allowing them to grow before capture.

Of these four, the first two are captural while the third and fourth are cultural systems. Captural systems do not involve selective stocking, the fields being initially used for stocking - there is no cultural practice as artificial feeding and fertilization for fish *per se* as it involves extensive system. In the cultural system the field is deliberately stocked like a culture pond, and is often followed by artificial feeding and other culture practices-either intensive or semi-intensive (Halwart, 1994). Depending on the relationship between rice and fish crop, fish culture may be of different types: The fish and rice production can be simultaneous, when the two are grown together (contemporaneous), or "Rizi-pisciculture" and alternate (Dashu and Jianguo, 1995) when rice crop and fish crop are grown alternately in rotation. Alternate or production by rotation can be changed according to the exigencies of circumstances, and can be of different types: One rice crop and one fish crop annually, two rice crop and one fish crop in one year, and

5 harvests in two years to i.e. rice crop - fish - rice - fish - rice. Concurrent growing of fish and rice is known as rizi-pisciculture (paddy or rice-cum-fish culture) in the traditional sense. Both concurrent culture and culture in rotation have their advantages, and disadvantages, which will be discussed separately hereunder.

Yar Anjum *et al.* (2007) recognized a mixed system in which the fish stock is transferred to specially prepared ditches, channels or pools at the time of harvest, and restocking them in the rice fields for a further growing period. This system has the advantage of growing fish to larger sizes than is possible in the short duration of one crop.

The last type of classification of culture methods is based on the size of the fish harvested, which are of three types: fingerlings, table-sized fish and spawners. The mixed culture will depend on the availability of water and depth of water in the rice field. The duration of rearing is usually short, but with trenches and refuges, for fish to take shelter, longer durations of culture can be sustained. In certain cultural practices, the fish are taken and kept in holding ponds and liberated again in the rice fields thus extending the rearing period for several years. It must also be pointed out that the short time available for growing fish enables the rice fields to be used as a nursery (fry to fingerlings - perhaps also hatchling to fry) - here the paddy field would be of great help due to the paucity of space otherwise experienced for fry and fingerling production. In all systems, however, rice is the primary crop and fish culture is secondary or complementary.

Mac Kay (1995) observes that rotational schemes are twice as productive compared to concurrent rice-fish cultures (RFCs), although a considerable time is lost in growing alternative 'crops' at a time. Besides, labor costs are higher compared to concurrent systems in which the human resource-use is optimized. Since rice is planted after the fish crop in rotational schemes, productivity is higher because the fish will have improved soil fertility and also decimated populations of most of the weeds, disease vectors and pests (Frei and Becker, 2005). This is much more convenient since it is possible to determine the stocking density and the species to stock. A variety of fish species are used in RFCS. However, Frei and Becker (2005) recommend adoption of a polyculture system in which the fish species stocked will enhance efficient utilization of inputs. Edwards (1993) and Edwards *et al.* (1998) stated that this can be achieved by using species occupying different feeding niches in the aquatic trophic food web, such as *C. gariepinus* and *O. niloticus* used in this study to maximize on the utilization of resources within the aquatic environment.

The incorporation of *Oreochromis niloticus* and *Clarias gariepinus* in rice fields is a kind of Integrated Multi-Trophic Aquaculture (IMTA). The term ‘multi-trophic’ refers to the incorporation of species from different trophic or nutritional levels in the same culture system. This is one potential distinction from the age-old practice of aquatic polyculture, which could simply be the co-culture of different fish species from the same trophic level. In the latter, the different species may all share the same biological and chemical processes, with few synergistic benefits, which could potentially lead to significant shifts in the ecosystem. Some traditional polyculture systems may, in fact, incorporate a greater diversity of species, occupying several niches, as extensive cultures (low intensity, low management) within the same pond. The "Integrated" in IMTA refers to the more intensive cultivation of the different species in proximity of each other, connected by nutrient and energy transfer through water (Yar Anjum *et al.* (2007).

Ideally, the biological and chemical processes in an IMTA system should balance. This is achieved through the appropriate selection and proportions of different species providing different ecosystem functions (Edwards et *al.*1998). The co-cultured species should be more than just biofilters; they should also be harvestable crops of commercial value. The best IMTA system should result in greater production for the overall system, based on mutual benefits to the co-cultured species and improved ecosystem health, even if the individual production of some of the species is lower compared to what could be reached in monoculture practices over a short term period (Yar Anjum *et al.* (2007).

2.2 Effects of integrated rice-fish culture on rice production

Many authors such as Coche, (1967), Sinhababu *et al.* (1983), Panda *et al.* (1987), de la Cruz *et al.* (1992), Mac Kay (1995), Rothius *et al.* (1999), Berg (2002), Vromant *et al.* (2002), Mohanty (2004) and Rasowo *et al.,* (2008) report of increased rice yields in integrated culture systems. Intensification has led to an improvement in rice yields in integrated systems over the years. Thus Schuster *et al.* (1955) reported an increase of 6.2% in rice production in Indonesia, 10% in Malaysia and China. In Zimbabwe, Marr (1959) reported an increase of 6%. Using an improved strain (CR 1108), Sinhababu *et al.* (1983) observed that rice growth with Indian carps in rizi-pisciculture trials showed an increase of 3.8 – 6.2%, while Yaro *et al.* (2004) reported an increase in the yield of rice by 5 to 15%. Coche (1967) summarized the factors that bring about an increase in rice production as:

- Increase in organic fertilization by fish excreta and remains of artificial feed.
- Better tillaring of the rice seedlings due to the activity of the fish.
- Reduction in the number of harmful insects, such as paddy stem borers, whose larvae are eaten by fish.

- Reduction in rat population due to increase in the water level.
- Increased mineralization of the organic matter and increased aeration of the soil resulting from the puddling of mud by benthic feeders.
- Control of algae and weeds (by phytophagonous fish) which compete with rice for light and nutrients.
- Enhanced mineralization of soils.
- Reduced volatilization of nitrogen.
- Enhanced uptake of nutrients by the rice plants in the presence of fish.

Because fish in rice fields can help eradicate pests and diseases, savings on inputs such as pesticides can be realized (Mac Kay, 1995). Yinhe (2004) reported that about 120-180 labor units per hectare can be saved with reported reduction in harmful insects and pests. de la Cruz *et al.* (1995) cite other economic benefits to include resource-use optimization, increased employment opportunities, and a spread of biological risks. Further economic benefits are realizable in cost savings with regard to land preparation, including ploughing, weeding and management of water flows.

Rothuis *et al.* (1999), Vromant *et al.* (2002), and Rasowo *et al.* (2008) also reported positive effects on individual aspects of rice growth and production, including higher number of lateral shoots (tillers) issuing from the base of stems, higher number of panicles/m ^{2}, heavier ears, lower rate of emergence of false grains and more grains per panicle. Vromant *et al.* (2002) reports that intensification of the fish culture in the rice fields results in higher growth performance due to fertilization effects. This is also attributable to higher primary productivity which increases both the food available to fish and also the amounts of dissolved oxygen in the aquatic environment (Little and Muir, 1987).

2.3 Effects of integrated rice-fish culture on fish production

Fish polyculture appears to stimulate increased yield of fish due to the complimentary utilization of different trophic niches in the rice field (Rothius *et al.,* 1998a; Frei and Becker, 2005). The model of IMTA involving the catfish and tilapia in rice provides many pathways for improved productivity of the (cat)fish. The remains of the rice plant contributes to the detritus load that forms an important diet of *O. niloticus* as the rice season progresses, and becomes especially high during the second crop of rice. This translates to higher growth and productivity in the catfish since it feeds on the juveniles of *O. niloticus* through the transfer of this biomass from the latter to its own biomass. This polyculture advantage may be somewhat attenuated when natural food is scarce and no supplementary feed is provided. This was proved by Chapman and Fernando (1994) and Vromant *et al.* (2002b) who reported interspecific competition between the different fish species in polyculture.

The increased detritus load and the shading effect of the rice foliage provides an improved environment for the growth of benthic microorganisms. Yar Anjum (2007) reported a five-fold increase in the density of detritivores in rice fields compared to fish ponds without rice. The high density of detritivores translates to high density of the food for the catfish.

Another pathway arises from the ability of rice plants to absorb and purify the water in the rice fields (Yar Anjum, 2007). This results in waters that are ever fresh, and very clear than the water in fish ponds within similar geo-ecological zones. Increased water transparency leads to increased light penetration hence higher primary productivity and the subsequent transfer of nutrient benefits to fish. By reducing soil and water pollution, there is less contamination due to self purification hence fewer fish diseases. Further to these benefits, the rice plants reduce sudden changes in temperature caused by effect of direct sunlight, adjust and stabilize water temperature and quality, and, therefore, provide an environment that is conducive for the production of natural organisms including fish, both wild and cultured. Because the fish consume plankton, and other benthic organisms, their foods not only increase in bulk, but also in diversity.

2.4 Ecological advantages of rice-fish culture

It is obvious that rice-fish culture can change the direction of energy flow in the ecosystem. In the rice-field, the stocked fish transform the stagnant energy such as that which is locked in weeds, detritus, phytoplankton, zooplankton, aquatic insects and nutrients trapped in 'sinks' into usable products (rice and fish). Various authors including Halwart (1994), Mackay (1995), Haylor and Bhutta (1997), Fernando and Halwart (2000), reported that fish in rice fields can help eradicate insects and pests thus saving on inputs such as pesticides and reducing accumulation of toxic chemicals from pesticides.

Rasowo *et al.* (2008) found a difference of up to 30% in rice yield (panicles per stool) between rice monoculture and rice-fish culture, attributing the higher yield in the latter to the presence of fish which fed on the stem borer. Yinhe (2004) reported that fish reduced populations of rice hoppers and rice leaf rollers by 2-6 times; and that the number of predators of rice pest was higher in rice-fish fields without pesticides than in fields without fish and with pesticides. This is beneficial to human health and ecological balance of the environment. Many health benefits are also derived from this ecological advantage. Yinhe (2004) found that mosquito larvae, maggots, snails, and leeches, which are immediate hosts of malaria, encephalitis, dysentery, blood fluke and filaria, reproduce rapidly in rice fields. Fish, particularly *O. niloticus* and other omnivorous species such as the catfish consume and eradicate these pathogenic parasites and thus minimize the infestation rate on human beings. This creates an improved living standard and a better level of health for the farmers.

2.5 Catfish-tilapia polyculture

Efficient utilization of pond inputs can be achieved in a polyculture with fish of different feeding niches in the trophic food web (Edwards, 1993; Edwards *et al.,* 1998). Both catfish and tilapia in a polyculture bring different benefits to the culture operations: catfish controls proliferation of tilapia offspring competing for the same resources, thus lowering farm costs for production of marketable catfish by reducing the need for formulated feed (Bruton, 1979; Machiels, 1987). It also improves soil and water aeration, thereby helping in release of nutrients trapped in the soil bottom, especially phosphorus, for increased phytoplankton productivity (FAO, 1997). Tilapias on the other hand are efficient feeders, which convert the abundant phytoplankton biomass into its own biomass, part of which is transferred to the catfish biomass through the predatory feeding of the latter on tilapia juveniles (Pillay, 1993; Stickney, 1994).

2.6 The culture species: *Clarias gariepinus*

Clarias gariepinus is a ray-finned fish (Plate 2.1) belonging to the order *Siluriformes,* and family *Clariidae*. The species is currently synonymous with *C. mossambicus, C. larezas* and *C. senegalensis* (Teugels, 1986). It is endemic to Africa and its distribution ranges from Natal and the Orange River in South Africa through Central, East and North Africa. It is particularly adapted to feeding under nocturnal and turbid water conditions (Lowe-Mc Connell, 1975;

Viveen *et al.,* 1985), relying on non-visual senses for prey detection, mainly by touch and smell. It tolerate*s* environmental extremes and withstands high density cultures (Zheng *et al.,* 1988), grows fast (Hogendoorn, 1981), has high consumer ranking (Mann, 1964; Balon, 1972; Richter, 1976; Huisman, 1985), and is an efficient food converter (Machiels, 1987; Bruton, 1979a. The fact that it also thrives on cheap feeds (Bok and Jongbloed, 1984) and is unable to spawn in captivity (Bruton, 1979a, Janssen, 1985) make it a choice candidate for this culture experiment.

2.7 The coefficient of condition of fish

The relative robustness or degree of well-being of fish is expressed by the coefficient of condition of fish also known as the condition factor, or length-weight factor, often abbreviated as Kn. Variations in a fish's coefficient of condition reflect the state of sexual maturity and degree of nourishment. Condition factors may also vary with age, and in some species, by sex (Williams, 2000).

The condition factor is an organism-level response, to factors such as nutritional status, pathogenic effect and toxic chemical exposure which cause greater-than-normal and less-than normal weights. The condition factor is used as an indicator of the well-being of individual organisms. Because it integrates many levels of sub-organismal processes (e.g. molecular, cellular, organ system e.t.c.), condition factor may signify the overall condition and nutritional status of individual fish (Adams *et al*., 1992a).

For the purpose of condition factor, weight determinations are made on live or freshly killed fish. The value varies directly with nutritional status, and inversely with disease (Schmitt and Dethloff, 2000). Greenfield *et al.* (2001) observed that body condition changes rapidly in response to environmental perturbation and is more indicative of prevailing environmental constraints to growth than measures of past growth. Condition factor is known to vary with seasons, possibly as a response to changing food resources, metabolic efficiency, or gonadal status. Doyon *et al.* (1988) and Fisher *et al.* (1996) stated that these conditions can vary from location to location within a species. A decrease in weight due to a loss of energy reserves can be compensated for by increased body water (Schmitt and Dethloff, 2000). However, they caution that condition factor and organo-somatic indices must be interpreted carefully, as possibly confounding factors need to be identified in comparison to groups of fish for contaminant exposure effects. Hence comparisons should be made only within a species or between similar species.

The use of condition factor in assessing the general well-being of fish is advantageous since it can reflect adverse effects of chemical exposure that are not monitored routinely by water quality assessments. Another advantage is that it also integrates, at organ system and organism level, the combined effects of multiple contaminants and the combined effects of contaminants and other stressors. A decrease in condition factor is considered a reflection of depletion of energy reserves (Barton *et al.*, 1987; Goede and Barton, 1990) because it is positively related to total muscle and liver energy content (Lambert and Dutil, 1997). A logical link therefore exists between this depletion of energy reserves and potential health problems for fish.

An increase in the condition factor can, however, also signal the deleterious effect of a stressor. Although the general interpretation is that a great weight relative to the length indicates a healthier condition for the fish, the presence of fewer, larger and more robust individuals (shooters) may signify an out-of-balance or abnormal condition at the population or community level (Weger and Anderson, 1978; Hehtonen and Jokikokko, 1995).

2.8 Water quality in rice-fish culture

Allen (1993) found that in rice–fish ecosystem, non biological and biological factors interact among themselves, and also influences growth and development of both fish and rice. He considers paddies are complex ecosystems with more uncontrolled interactions, both between trophic levels and between the culture systems, often affecting both physical and chemical conditions of water. The success of fish and rice culture therefore depends partly on scientific knowledge based on understanding of the rice-cum-fish management systems and water quality in the rice fields (Yaro *et al.* 2004). The different management systems must be able to improve the levels of different water quality parameters, for instance, wide spacing of rice cultivars should be adopted to maintain good oxygen content in the culture water. FAO (1997a) reports that intensification introduces into the ponds and paddies high loads of organic matter and agrochemical pollutants which lower water quality. Boyd (1990) related low water quality to periods of poor growth, disease, parasite outbreaks and fish kills. As Yar Anjum *et al.* (2007) point out, good water quality is essential, not only for growth of fish but also fish feed organisms, the many macroinvertebrates that live in the aquatic environment created by the irrigation water. Monitoring water quality is therefore an important procedure in aquaculture as a way of keeping in check the levels of the various parameters and adopting various intervention measures in situations where values are in levels that are detrimental to the production of the cultured organisms.

Temperature regimes in the paddies and ponds are influenced by the changing air temperatures (Li, 1986) which are constantly high and fluctuates due to the shallow (30-40 cm) pond depth which characterize the rice field environment. Natividad (1984) and Yaro *et al.* (2004) cite temperature range of 25-30^{0}C as ideal for the production of tilapia in the tropics. Natividad (1984) found that values outside this range impede biochemical reactions in fish, thus affecting their growth as well as quality of meat. This is because temperature has a direct effect on enzyme activity, also controls the rate of response to toxic chemicals. For instance, it increases the conversion of ionized ammonia to non-ionized form which is more toxic. Temperatures above 30^o C are known to encourage stress induced disease and mortality which in turn lowers survival.

Low dissolved oxygen (DO) is usually the first water quality constraint to fish growth in intensively managed ponds (Natividad 1984). Commonly cultured species of tilapia and the catfish usually survive routine dawn DO concentrations of less than 0.5 mg/l, levels considerably below the tolerance levels for other cultured fish species (Popma and Lovshin, 1995). Survival in water with low DO is due, in part, to their ability to extract DO from the film of water at the water-air interface when DO is below 0.1 mg/l. For this reason, heavy growth of floating plants likely reduces their survival in ponds due to low DO (Mukherjee, 1995). Levels of DO in the paddy waters depend on rice spacing, and on the rice seeding rate (Vromant *et al.*, 2001; Mustow, 2002). Mukherjee (1995) found that promoting a growing biomass of phytoplankton generates more oxygen, and helps maintain relatively high DO levels. Generally, there is an increase of 1.5–8.2 mg/l (average 5.1 mg/l) in dissolved oxygen in rice fields with fish. Furthermore the fish tend to raise the dissolved oxygen content level because they stir up the water and increase the contact between water and air. The activities of the fish can also make the distribution of oxygen more uniform (Popma and Lovshin, 1995). Because they move the soil, the fish also improve the oxygen supply to the soil, a factor which favors the breakdown of organic matter and reduced material in the soil (Wurtz and Durborow, 1992). This is why many rice–fish fields that are not exposed to the sun and are not weeded still yield 10% more than fields in which fish are not reared (Yinhe, 2004). Fishes possessing air breathing apparatus, such as the catfish, survive well in the rice fields due to their hardiness and ability to survive at extremely low DO levels (Coche, 1967).

Boyd (1992) reported that photosynthetic activity of phytoplankton during the day reduces carbon dioxide levels in water thus increasing pH. At night, however, pH drops as more carbon dioxide is released from respiratory activities and none gets consumed as photosynthesis ceases. Both Natividad (1984) and Lichkoppler (1977) report diurnal pH range of 6.5 – 9.0 as ideal for optimum production of fish in the tropics (Figure 2.1). Natividad (1984) reported reduced fish appetite and a limited growth of phytoplankton as the negative effect of lower pH values. At values below 5.5, Yaro *et al.* (2004) reported prohibition of recycling of nutrients in the ponds. Haroon (1998) found that pH values >8.5 encourages nitrogen loss through ammonia volatilization, a process primarily controlled by photosynthetic aquatic biomass.

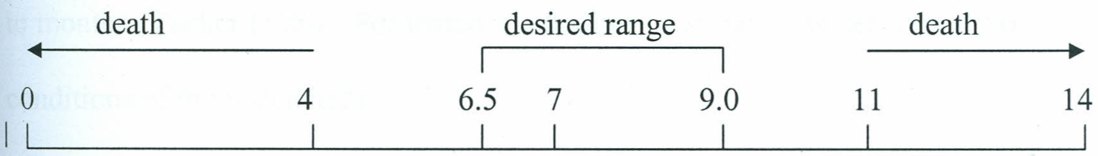

Figure 2.1 pH scales showing recommended range for fish culture in the tropics (Lichkoppler, 1977).

Ammonia toxicity is closely correlated with pH and to a lesser extent, with water temperature and DO (Popma and Lovshin, 1995). At high pH, a greater percentage of total ammonia converts to the toxic un-ionized form. At pH 7, less than 1 % of the total ammonia is in the toxic un-ionized form; at pH 8 about 5-9 % is un-ionized; at pH 9, 30 % and at pH 10, 80-90 % (Tucker (1984). Consequently, ammonia toxicity is more problematic in poorly buffered ponds (with alkalinity below 30 mg/l $CaCO_3$) which frequently experience afternoon pH levels of 9 or even 10, and also at higher temperatures (Tucker (1984). The ranges, in percent, for un-ionized ammonia given above reflect conditions at 24 - 32 ^{o}C. Toxicity of Ammonia also increases at low DO although this is largely balanced in fish ponds by decreased toxicity produced by an increasing concentration of carbon IV oxide gas which lowers pH (Lichkoppler, 1977).

Water quality in fish ponds is also affected by the interactions of several other chemical components (Tucker, 1984). Alkalinity, pH, carbon dioxide (CO_2) and hardness are interrelated. Tucker (1984) has given factors for the relationship between alkalinity, pH and CO_2 (Table 2.1). The concentration of carbon dioxide in water can have profound effects on pond productivity, the level of stress and fish health, oxygen availability and toxicity of ammonia as well as that of certain metals (Lichkoppler, 1977). Most features of water quality are dynamic, changing daily (e.g. CO_2 and pH) while others remain relatively stable but can change over time, usually weeks to months (Tucker (1984). For instance, alkalinity and hardness depend on pH or geo-ecological conditions of the watershed).

Alkalinity is the measure of the acid combining capacity of the water; or it may be regarded as the buffering ability (Wurtz and Durborow, 1992). It measures the amounts of carbonates and bicarbonates in the water. Alkalinity is measured by the amount of acid (H^+) water can absorb before achieving a designated pH. Total alkalinity is expressed as mg/l or ppm CaCO3. Although a range of 75-200 mg/l is recommended for fish culture, a total alkalinity of 20 mg/l or more is desirable for good pond productivity (Wurtz and Durborow, 1992).

Agrochemicals used in aqua-farms have a direct effect on water quality (Omondi *et al.*, 2001). Fertilizers are applied as one of the management strategies in rice-fish fields. This is done principally to promote growth and production of both rice and fish (Yinhe, 2004). It is also used to enhance natural food production and thus indirectly provide protein to compliment energy-rich cereal brans used as feed (Omondi *et al.*, 2001). However, indiscriminate fertilizer treatments might positively or negatively affect the ecosystem quality to the benefit or detriment of live aquatic organisms, including fish.

Insecticide use can be a major constraint to integrated rice-fish culture systems (Del Mel and Pathiratne, 2005). In rice fields, organophosphate and carbamate insecticides are widely used in rice fields to control insect pests (Del Mel and Pathiratne, 2005). These insecticides however act as neurotoxicants by affecting synaptic transmission in cholinergic parts of the nervous system in fishes. To limit cost implications and health hazards and enable fish culture as an additional crop in rice-fields, Haylor (1997) advises, pesticides should be applied only when pest population levels economically justifies the control action.

Table 2.1 Factors for calculating CO_2 concentrations in water with known pH, temperature and alkalinity measurements. For practical purposes, CO_2 concentrations are negligible above pH value of 8.4. The number (factor) which corresponds to the measured pH and water temperature is multiplied by the measured alkalinity value (mg/l) $CaCO_3$). The product of these numbers estimates the CO_2 concentrations (mg/l).

	Temperatures						
pH	5	10	15	20	25	30	35
6.0	2.915	2.539	2.315	2.112	1.970	1.882	1.839
6.2	1.839	1.602	1.460	1.333	1.244	1.187	1.160
6.4	1.160	1.010	0.921	0.841	0.784	0.749	0.732
6.6	0.732	0.637	0.582	0.531	0.495	0.473	0.462
6.8	0.462	0.402	0.367	0.335	0.313	0.298	0.291
7.0	0.291	0.254	0.232	0.211	0.197	0.188	0.184
7.2	0.184	0.160	0.146	0.133	0.124	0.119	0.116
7.4	0.116	0.101	0.092	0.084	0.078	0.075	0.073
7.6	0.073	0.064	0.058	0.053	0.050	0.047	0.046
7.8	0.046	0.040	0.037	0.034	0.031	0.030	0.030
8.0	0.029	0.025	0.023	0.021	0.020	0.019	0.018
8.2	0.018	0.016	0.015	0.013	0.012	0.012	0.011
8.4	0.012	0.010	0.009	0.008	0.008	0.008	0.007

Source: Tucker (1984)

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of study site

A six month study on the effects of integrated rice-tilapia culture system on productivity of the African catfish (*Clarias gariepinus*) was carried out between November 2007 and May 2008 at the Ahero National Irrigation Board field research station within the Ahero Irrigation scheme. The scheme is located in the East Kano plains of Nyando District, Nyanza Province, Kenya (Figure 3.1). The station lies within $0^{0}08'$ latitude South and $34^{0}56'$ longitude east, 5 km to the N-E from Ahero town. The mean annual rainfall ranges between 450 and 600 mm, the pattern being bimodal with first season between March-May while the secondary peak is in September-November. Mean annual temperature range is 15 - 30 ^{0}C. It has a total area of 1538 ha, out of which about 880 ha are under irrigated rice cultivation.

The irrigation water is pumped from a station located on the Nyando River at the foot of Nandi hills, approximately 5 km from the research station. Commercial rice cultivation is the main farming activity in the scheme that supports some 527 settler families, and a much larger riparian population. The area is prone to seasonal flooding that makes it near impossible to practice other cropping systems. Majority of the people depend on fishing from the adjacent Lake Victoria. This area was chosen for this study because of its commercial rice cultivation system that could allow for integration with semi-intensive fish culture and thus greatly reduce dependence on the capture fisheries from Lake Victoria.

3.2 Research design

The research was done on a 2-acre plot subdivided into nine separate paddy fields, each measuring 20 x 20 m (Figure 3.2). This randomized block design allowed blocking along two axes and also for the control of environmental variables along two gradients rather than one.

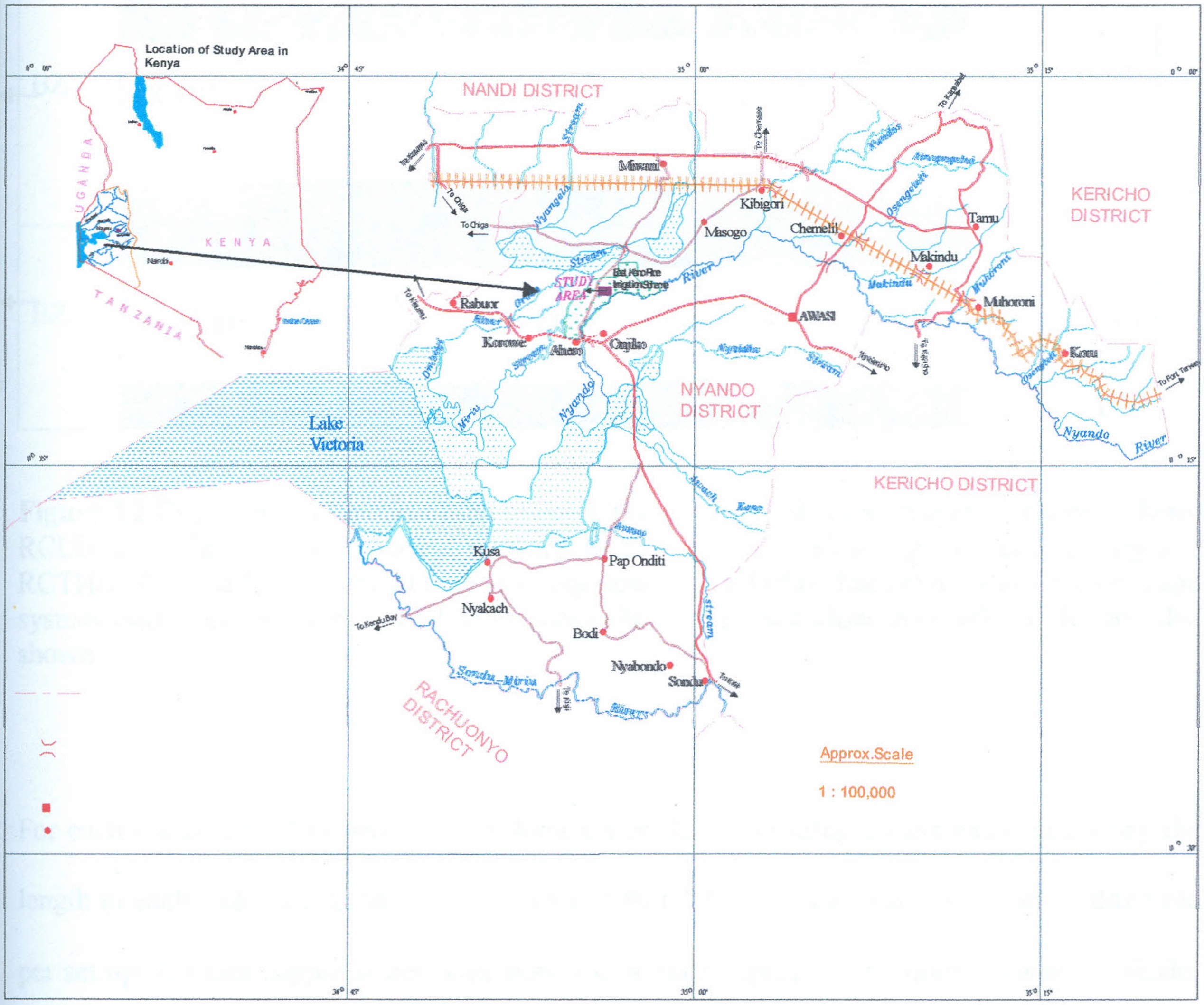

Figure 3.1 Map showing the location of the study site in Kenya at the East Kano irrigation scheme, Ahero. Source: Survey of Kenya series Y503, sheet SA-37-5, Edition 5-SA. Adjacent water sources are shown to indicate the vast water resources of this region.

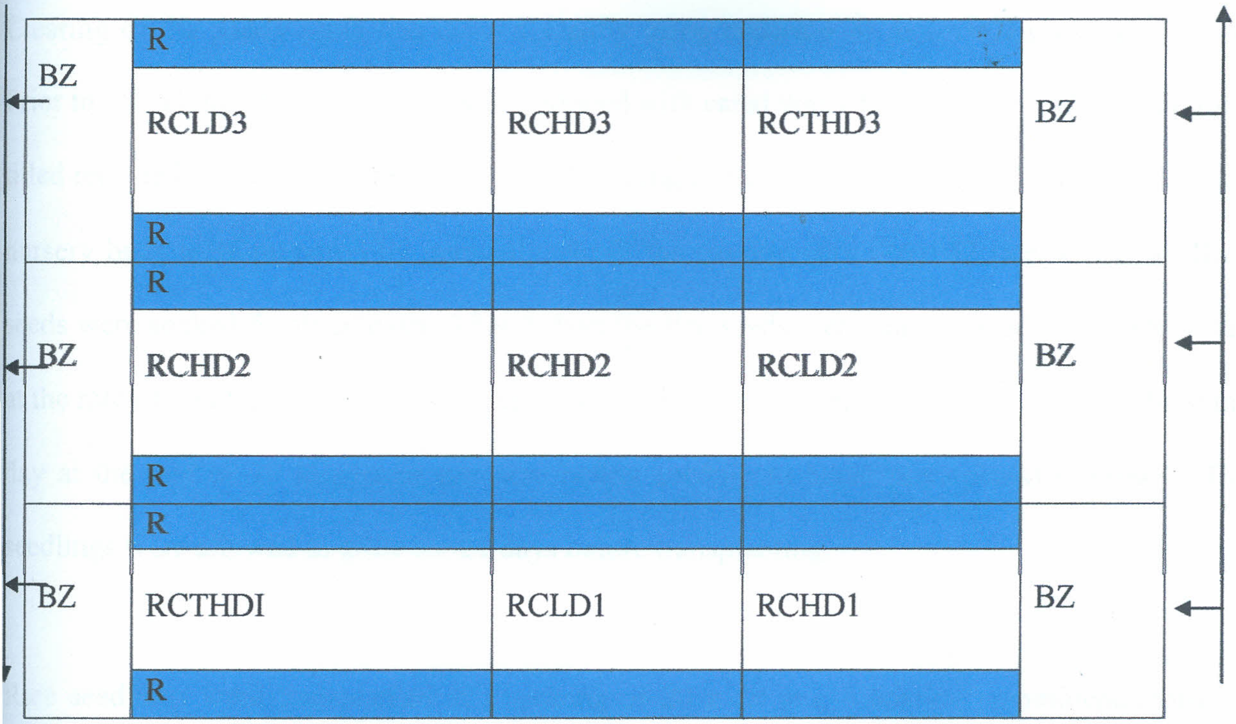

Figure 3.2 Experimental layouts of the research plots at the East Kano irrigation scheme, Ahero. RCLD: Rice-Catfish at low stocking density, RCHD: Rice-Catfish at high stocking density and RCTHD: Rice-Catfish-Tilapia at high stocking density (RCTHD). The arrows show the drainage system (water in take and exit). Buffer zones (B.Z) with rice alone and refugia (R) are also shown.

For each paddy, two-2 m wide x 20 m long x 1 m deep fish refugia were excavated along the length in each paddy field, giving a total area of 80 m^2 fish pond area and a 320 m^2 paddy field per set up. A water supply system comprising of a main supply and a drainage canal, 2x feeder canals and 2 x drainage canals served the experimental system. At both the inlet and outlet of each paddy, screens of mesh size 1-inch were fitted to limit ingression of bioaggressors and loss of stocked fingerlings.

3.3 General management

Clearing of the paddy plots was done manually using cutlasses to remove bushes and grasses. Prior to ploughing, the rice paddies were flooded with canal water for 3 days to soak the soil then illed repeatedly until the soil was puddled. Leveling of the soil was then done 3 days after. Rice nursery beds were prepared by manually. In all the experiments IR62032 rice was used. Rice seeds were soaked for three days. After 3 days the rice seeds were hand-seeded on the same day at the rate of 150 kg ha^{-1} . Basal application of Ammonium Sulphate fertilizer was done the same day at the rate of 18 kilograms per acre before seeding to boost phytoplankton growth. The seedlings were allowed to grow for 21 days before transplanting.

Rice seedlings were transplanted at a spacing of 20 x 20 cm, following recommendations by Yaro *et al.* (2004). Rice seedlings were planted at 4 seedlings per hill due to the low tillaring ability of the variety, following the recommendations of Giap *et al.* (2005) to boost phytoplankton growth.

Water in the paddies was replaced 10 days after the first application of fertilizer (and ransplanting) to remove excess fertilizer. The paddies were then flooded at all times until the first harvesting of rice. Before tillaring, the water level was kept at a minimum of 5 cm. This was done to promote good tillaring of rice. Thereafter, the water level was kept at 30-50 cm until the ice harvesting (Yaro *et al.*, 2004). This was done to reduce weed development during the production period. Weeding was manually done, every month. However, on the dykes, grasses were repeatedly trimmed or cut as need arose. Three-metre borders around the experimental plot were kept free from weeds and bushes to ward off snakes, frogs and rodents. The whole experimental plot was fenced using a 1-inch wire mesh to ward off predators, including among others, monitor lizards, frogs, snakes and humans.

3.4 Water quality assessment

3.4.1 Physical parameters

a) Temperature, dissolved oxygen, conductivity and pH

Measurements of temperature, dissolved oxygen, conductivity and pH, were taken monthly *in situ* using a hand held YSI sample analyzer; model YSI 3500i in the mornings only, between 8.30 – 10.00 am. The portable analyzer was lowered to uniform depth of 20 cm below the water surface in the refugia.

b) Water turbidity

The relative refugia turbidity was gauged from *in situ* measurements using a turbidimeter, model HACH 2100P-470 from Jenway. Measurements were taken in Nephelometric Turbidity Units (NTU).

3.4.2 Determination of chemical parameters

a) Total alkalinity

Alkalinity was determined on 100 ml-volumes of water samples using methods adapted from Boyd and Tucker (1992). The water sample was titrated against a 0.02 N Sulphuric acid to get an estimate of the acid-neutralizing capacity of the refugia waters, using methyl orange indicator. This method is based on the principle that hydroxyl ions present in the water react with additions of a standard acid. The alkalinity relationship was calculated using the Wetzel and Likens (1979) formula described by Boyd and Tucker (1992):

$$\text{Total alkalinity (Mg/l)} = \frac{\text{Volume of } H_2SO4 \text{ X Normality of acid X 50,000}}{\text{Volume of the water sample (mls)}}$$

b) Total ammonia nitrogen

The concentration of total ammonia nitrogen (TAN) was determined according to Phenol-hypochlorite method described by Boyd and Tucker (1992). The complexation of phenol and hypochlorite in an alkaline solution to form phenylquinone-monoimine, and its subsequent reaction with ammonia in water, forming a green blue color at pH of about 12.6 in the presence of a Sodium Nitroprusside catalyst, forms the basis of this method. The green colour is due to indophenol and its intensity is proportional to TAN concentration. Preparation of the reagents was done using de-ionized water as outlined below:

- Phenol solution, 2.5 g of NaOH + 10 g phenol dissolved in 100 mls of water, 0.5% Na-Nitroprusside, 0.5 g Sodium Nitroprusside will be dissolved in 100 mls of water.
- Alkaline citrate, prepared by dissolving 200 g Tri-sodium citrate + 10 g NaOH in 1000 mls of water.
- Oxidizing solution was prepared by mixing 100 mls of alkaline citrate + 25 mls of Na – hypochlorite.

Total ammonia nitrogen was determined on 20 ml-volume pre-filtered water sample, in a 50-ml Erlenmeyer flasks. This was done as follows: addition of 1 ml phenol followed by 1 ml 0.5% Na-Nitroprusside, followed by 2.5 mls of the oxidizing solution. Standard solutions of 0.00, 0.50, 1.00, 1.50 and 2.00 mg/l as TAN was prepared with NH_4Cl salt and de-ionized water from a stock solution of 1000 mg/l TAN concentration. All the standards and samples were then after covered with Para film and placed in the dark for one hour for colour to develop. Absorbance was then measured at 640 nm on a spectrophotometer. A calibration curve drawn from the reading of the prepared standards was then used to back-calculate the concentration of TAN in the refugia water.

c) Nitrites

Determination of nitrites was done according to methods described by APHA (1998) and Mackereth *et al.* (1989). 0.5 mls of diazotizing reagent was added to 25 mls of filtered water sample in a 100-ml, beaker stirred and allowed to stand for two minutes for complete reaction. Thereafter, 0.5 ml coupling reagent was added and then stirred. This was left to stand for 10 minutes to form azo-compound. Absorbance was then measured at 543 nm after setting spectrophotometer reading to zero using reagent blank.

d) Soluble reactive phosphorus

One drop of Phenolphthalein indicator was added to 25 ml water samples in 125-ml Erlenmeyer flasks. Drops of 5 N H_2SO_4 were added to samples where red colour developed until the red colour disappeared. 4 mls of combined reagent was added and stirred. The set up was left to stand for 30 minutes to allow for colour development. Absorbance was then measured at 880 nm using distilled water reagent blank to zero spectrophotometer.

All the measurements of water quality parameters were done monthly. For each month, measurements were done on a specific day after the water was replaced. Thus for the first month he measurements were taken on the first day after the water was replaced, for the second month, wo days after replacement of water and so on. This was designed to help determine the effect of accumulation of nutrients as water takes more days in the paddies before being replaced.

3.5 Fish growth and well-being

The refugia were stocked with fish (Table 3.1) two weeks after transplanting rice. The three weeks-old fingerlings in each case were measured for both total length, TL (to the nearest mm) and weight (to the nearest g) before stocking. Thus Catfish fingerlings of average weight and ength of 16.6 g and 9.5 cm respectively were stocked. The length and weight increase in the *Clarias gariepinus* was studied for 122 days, the measurements being taken monthly.

During this period, lengths and weights of 36 fish, each for treatments 1 and 2 and 42 for treatment 3 from each paddy were recorded separately at the time of stocking and repeated once every month, the last of such measurements being taken at harvest, 122 days after stocking (DAS). Measurement of fish weight was done using a Mettler's balance with a sensitivity of 0.1 mg, while a diel calipers was used for measurement of length after sorting according to species. The data were pooled to obtain treatment averages. The total length and body weight were recorded immediately after collection to provide an indication of the general condition at harvest.

Data of weight was used to calculate the specific per cent growth rate (SGR) using Brett and Groves (1967) formula:

$$SGR = \frac{(\ln W_2 - \ln W_1) \text{ X } 100}{(t_2 - t_1)}$$

Where: - t_1 and t_2 are the start and end period of culture respectively in days,

-W_1 and W_2 (g $fish^{-1}$) are the mean initial and final weight for the same period, and

-$\ln W_1$ and $\ln W_2$ are natural logarithms of weights at stocking and harvest respectively.

Table 3.1 Treatments and stocking densities applied to different study plots. The abbreviations RCTHD, RCLD and RCHD imply rice-catfish-tilapia at high stocking density, rice-catfish at low stocking density and rice-catfish at high stocking density respectively. All other treatments were as for general rice cultivation.

	T_1		T_2		T_3	
Species	**catfish**	**tilapia**	**catfish**	**tilapia**	**catfish**	**tilapia**
Density (fish m^{-2})	4	4	4	-	8	-
No. of fish per refuge	320		160		320	
Mean initial wt. (g $fish^{-1}$)	16.6 ± 0.2		16.0 ± 0.1		16.2 ± 0.4	
Mean initial length (mm $fish^{-1}$)	9.1 ± 0.1		9.3 ± 0.5		9.2 ± 0.2	

Weight and length gains (%) were calculated according to the formula:

$$\text{Weight/length gain} = \frac{\text{final weight- stocking weight X 100}}{\text{stocking weight (g)/length (cm)}}$$

Survival, or per cent recovery rate was calculated as the percentage of the number of fish harvested to the number stocked (Rothius *et al.* 1998):

$$\text{Survival} = \frac{\text{Nt X 100}}{\text{No}}$$

Where,

Nt = total number of fish harvested (recovered),

No = total number of fish stocked.

Growth rates and survival indices for catfish were compared among the three treatments. Length and weight data were used to compute values of the condition factor of the fish at harvest. The data used were those taken at harvest when the fish were still alive. Relative condition factor (K) was calculated according to Schmitt and Dethloff (2000) formula:

$$K = \frac{W \times 10^5}{L^3}$$

Where,

W = weight in grams

L = length in millimeters

and 10^5 is a factor to bring the value of K to near unity.

The method of length is indicated as K-SL, K-FL or K-TL,

where:

SL = standard length

FL = fork length

TL = total length

For the purpose of this research, TL was used as the basis for determination of the fish condition. Net fish yield (NFY) in kg ha^{-1} was calculated according the method adopted by Omondi *et al,* (2001):

$$\text{Net fish yield (NFY)} = \frac{\text{Net fish weight gain}}{\text{Surface area of refuge (ha)}}$$

where,

Net fish weight gain = total weight at harvest - total weight at stocking.

Annual production (AP) in kg $ha^{-1}yr^{-1}$ was calculated according to Omondi *et al.* (2001):

$$\text{Annual production (AP)} = \frac{\text{NFY X } 365}{D_C}$$

where Dc = days of entire culture period.

Coefficient of variation (CV) of both final weight and length was calculated by dividing the standard error of final weight/length by mean of final weight/length and multiplying by 100 (Giap *et al.*, 2005).

3.6 Statistical analysis

The mean values of all the measured water quality parameters were calculated and reported with their standard errors. Two factor ANOVA was used to determine the effect of culture type on water quality, growth and production of the catfish and the general condition of fish while one factor ANOVA was used to asses the variations in the water quality between the treatments for each DAR and between the DARs for each treatment. Production parameters (length, weight, survival, condition factors, and yield) of the fish in the different treatments were compared using the same test. Simple linear correlation tests were done to determine the relationship between water quality and fish condition. All statistical analyses were performed using MINITAB 13.0 computer software.

CHAPTER FOUR: RESULTS

4.1 EFFECTS OF CULTURE TYPE ON GROWTH AND PRODUCTION OF CATFISH

4.1.1 Fish growth

The mean weights and lengths of the fish at harvest are shown in tables 4.1(a) and 4.1(b) respectively. The mean fish weight was significantly higher in treatment 1 (F = 11.6, d.f. =2, P< 0.05) compared to 2 and 3, but insignificant between treatments 2 and 3. Mean fish length was significantly higher in treatment 1 (F = 11.6, d.f. =2, P< 0.05), but insignificant between treatments 2 and3 (Table 4.2).

Table 4.1 (a) Mean harvest weights of fish (g) in the different treatments.

Treatment	N	Mean	S.E.M.	Min	Max
1	36	197.23	9.55	100.20	300.8
2	36	150.27	9.64	48.70	294.8
3	42	136.36	8.49	60.60	350.0

Table 4.1 (b) Mean lengths of fish (cm) in the different treatments.

Treatment	N	Mean	S.E.M.	Min	Max
1	36	29.8	0.7	20.3	37.2
2	36	29.4	0.8	18.1	41.0
3	42	26.4	0.7	17.8	33.3

Table 4.2 Variations of mean fish weights and lengths among the three culture types. The means re values for three replicates. SEM= standard error of the mean. Means denoted by different etters in respective production parameters are significantly different at F values shown.

arameters	**Treatment**	**Mean**	**SEM**
Veights	1	197.23a	17.31
	2	150.27b	17.81
	3	136.36b	15.04
value	**11.6**		
value	**0.0**		
ength	1	29.789a	1.04
	2	29.428a	11.30
	3	26.383b	1.30
value	**7.16**		
value	**0.001**		

.1.2 Fish yield

ean fish yields were 373.16, 288.88 and 236.26 kgha^{-1}yr^{-1} for treatments 1, 2 and 3 espectively. The yield for treatment 1 with mixed culture of catfish and tilapia in rice was 23 per ent higher than treatment 2 and 37 per cent higher than treatment 3.

.1.3 Fish survival

ercentage fish survival was significantly higher (F = 36.20, d.f. =2, P < 0.05) in treatment 2 han in high density monoculture (treatment 3) of *Clarias gariepinus* (Table 4.12).

able 4.3 Fish survival (%) in the three culture systems. The values are totals for three eplicates for each treatment.

reatment	total no. stocked	total no. harvested	survival (%)
1	1920	889	46.3
2	960	588	61.3
3	1920	808	42.1

4.1.4 Monthly variations in fish condition among the culture types

Fish condition varied significantly among the months for each of the treatments (F=26.33. d.f. = 4, P<0.05), (F=66.17, d.f. = 4, P<0.05) and (F=18.85, d.f. = 4, P< 0.05) for treatments 1, 2 and 3 respectively. In rice-catfish-tilapia culture, fish condition showed a sharp decline in the first month of study (29%) before dropping further steadily in the subsequent months. Mean fish condition at harvest stood at 2.06 at stocking but had dropped to a low of 0.84 at harvest (Table 4.4). In rice-catfish monoculture at low stocking density, the fish conditions deteriorated within the months from 2.30 at stocking to 0.61 at harvest. This was also the case in fish condition between the months in the rice-catfish at high stocking density, with mean fish condition dropping from 2.21 at stocking to 0.92 at harvest.

Table 4.4 Mean fish conditions in the three culture types over the five month study period.

	Day of culture				
	0	30	60	90	120
Culture type					
1	2.06	1.46	1.22	0.99	0.84
2	2.30	1.10	0.84	0.73	0.61
3	2.21	0.90	0.83	0.97	0.92
F	0.82	13.18	3.26	2.10	2.51
P	N.S.	0.00	0.04	N.S.	N.S.

The mean fish conditions among the treatments varied significantly in the second and third months (F=13.18, d.f.=2 P<0.05 and F=3.26, d.f=2, P<0.05 respectively). The general trend showed declining fish conditions (Table 4.13). A two factor ANOVA test established that there was a significant interaction effect (F = 8.00, D.F. =8, $P<0.05$) between treatment and time in months

The elements of production for the catfish in the three treatments are summarized in table 4.5.

Table 4.5 Growth performance of *Clarias gariepinus*: a summary. SGR=specific growth rate; CV= coefficient of variation. CV of final weight length = standard deviation of final weight/length/mean of final weight x 100. Values are means ± SE of three replicates. Mean values in the same row having different superscripts are significantly different ($p<0.05$).

HARVEST			
Mean final body wt. (g fish^{-1})	156.9 ± 9.09	150.3 ± 6.4	136.1 ± 11.2*
Total wt. gain (g fish^{-1})	140.3 ± 12.1*	134.3 ± 9.2	119.5 ± 13.7
C V final body weight (g)	52.8*	37.9	40.1
S.G.R. (% day^{-1})	1.8	1.8	1.7
Weight gain (%)	842.5	839.4	737.6*
Mean final length (mm fish^{-1})	27.9 ± 12.5	29.4 ± 8.9	26.6 ± 7.3
C V of final length (mm)	21.5	16.3	16.5
Gross yield (kg ha^{-1} yr^{-1})	373.16	288.88	236.26
SURVIVAL RATE (%)			
Mean	46.5	61.3 *	42.2
Range	41.7 - 50.4	60.0 - 62.7	40.0 - 43.6

4.2 EFFECT OF TIME AND CULTURE TYPES ON PHYSICO-CHEMICAL PARAMETERS OF WATER

a) Water temperature

The mean water temperatures ranged between 23.2 °C to 25.6°C during the study period (Table 4.6). Treatment 3 (mean 25.06 °C) had a higher temperature than treatment 1 (mean 24.45 °C) nd treatment T_2 (mean 24.43 °C). Water temperature showed a general decline as water stayed n the paddies longer before replacement. The lowest and highest recorded temperature values in he refugia were for treatment 3, the values being 23.2°C and 26.1°C respectively. Mean emperatures did not vary significantly between the treatments (F=0.01, d.f. =2 $P>0.05$), while here was a significant difference in the mean temperature values between the days after eplacement of the water (F=6.7, d.f. =4, $P<0.05$). One way anova tests for each DAR and reatment showed no significant variation in the values between the treatment for each DAR and etween DAR for each treatment (Table 4.6)

able 4.6 Mean temperature values (°C) measured at different days after first replacement DAR) of water in the paddies and refugia. The values are means ± SE of three replicates. The F nd P values for one way anova tests are also shown. T_1=rice/catfish/tilapia at high stocking ensity, T_2=rice/catfish at low stocking density and T_3= rice/catfish at high stocking density.

Treatment	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
T_1	25.2±0.6	25.1±0.4	24.4±0.5	24.3±0.2	23.2±0.9	2.1	ns
T_2	25.4±0.6	25.1±0.6	24.0±0.7	24.4±0.5	23.3±0.6	0.5	ns
T_3	25.6±0.5	24.8±2.5	24.7±0.5	23.7±0.4	23.2±0.8	2.2	ns
F	0.30	0.10	0.43	1.10	0.01	-	-
P	N.S.	N.S	N.S	N.S	N.S	-	-

) Water turbidity

ean turbidity ranged from 11.9 to 62.6 Nephelometric Turbidity Units (NTUs). The higher urbidity values measured were for days immediately following heavy rains which washed the oils from adjacent bunds into the experimental plots. There was however a general increase in ater transparency as the water took more time to settle in the refugia (Table 4.7). Water in the refugia where the azolla weed covered the water surface became more transparent after a shorter period of time than water in open refugia. Mean turbidity did not vary significantly between the treatments (F=0.06, d.f. =2, P>0.05) and the days after replacement of the water (F=1.52, d.f. =4, P>0.05). One way anova test for each DAR and treatment showed no significant variation in the values between the treatments for each DAR and between DAR for each treatment.

Table 4.7 Mean turbidity values (NTU). The values given are means± SE of three replicates.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	58.9±40.2	55.5±35.5	53.6±33.1	26.7±5.3	14.0±0.5	2.1	N.S
T_2	60.6± 32.8	56.0±31.5	54.7±34.9	27.4±5.1	11.9±4.2	0.5	N.S
T_3	62.6±33.6	59.1±35.3	57.7±34.1	26.5±7.7	22.7±3.4	2.2	N.S
F	0.01	0.00	10.36	0.58	2.25	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

c) Water pH

The mean water pH in the refugia ranged from 7.5 to 8.3. Generally, the mean pH values tend to reduce as the water takes more time in the refugia (Table 4.9). Mean pH did not vary significantly between the treatments (F=0.57, d.f. =2, P>0.05), indicating that culture type has no effect on pH changes. The period after water replacement had a significant effect on pH (F=13.33, d.f. =4, P<0.05). There was similarly a significant interaction between culture type and time taken before replacement of water (F=8.02). However, one way anova tests for each DAR and treatment showed no significant variation in the values between the treatments for each DAR and between DAR for each treatment (Table 4.8).

Table 4.8 Mean pH. The values are means ± SE of three replicates.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	8.3±0.5	8.2±0.1	7.9±0.2	7.6±0.2	7.5±0.2	2.1	N.S
T_2	8.3±0.3	7.9±0.9	8.0±0.1	7.8±0.3	7.8±0.2	0.5	N.S
T_3	8.3±0.3	8.2±0.9	7.9±0.1	7.8±0.3	7.7±0.2	2.2	N.S
F	0.00	2.46	0.11	2.89	0.31	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

d) Water alkalinity

The mean values for water alkalinity in the refugia ranged from 121.0 to 179.0 mg/l CaCO$_3$. The values showed a general decline as the water stayed in the refugia longer. Mean alkalinity was significantly different between the days after replacement of the water (F=11.63, d.f. =2, P<0.05), while there was no significant difference between treatments (F=0.88, d.f. =4, P>0.05). nteraction between the culture types and treatments was significant. One way anova tests for each DAR and treatment showed no significant variation in the values between the treatments for each DAR and between DAR for each treatment (Table 4.9).

Table 4.9 Mean alkalinity (mg/l $CaCO_3$). The values given are means ± SE of three replicates. Values with different letters in the same row are significantly different.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	169.0±9.3	159.0±8.2	156.7±11.6	138.0±14.2	130.0±4.6	2.5	N.S
T_2	179.0±8.2a	176.7±15.5a	158.7±9.8a	146.0±3.5a	121.0±2.7b	0.5	N.S
T_3	178.0±7.2	162.0±16.7	160.0±14.5	136.7±10.5	150.7±26.1	0.9	N.S
F	2.01	0.39	0.04	0.24	0.98	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

e) Dissolved oxygen

Mean values of dissolved oxygen in the refugia ranged between 5.4 to 7.4 mg/l. There was a general decrease in the amount of dissolved oxygen with increasing number of days taken before water replacement (Table 4.10). Mean values of dissolved oxygen did not vary significantly between the treatments (F=4.15, d.f. =2, P>0.05), but significantly higher in the first month after replacement of the water (F=14.8, d.f. =4, P<0.05). It was established that the interaction between culture type and time taken before replacement of water was significant (F=7.99). One way anova tests for each DAR and treatment did not show any significant variation in the values between the treatments for each DAR and between DAR for each treatment (Table 4.10).

Table 4.10 Mean DO in the refugia water (mg/l). There was no significant difference in the values between the treatments and the days after replacement of water. The values given are means ± SE of three replicates.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	6.4±0.9	5.9±0.6	5.9±0.8	5.8±0.6	5.6±0.3	0.2	N.S.
T_2	7.1±0.8	6.4±0.4	6.1±0.2	5.7±0.2	5.4±0.4	2.9	N.S.
T_3	7.4±0.6	6.3±0.7	6.1±0.5	6.0±0.8	5.9±0.1	1.1	N.S.
F	0.0	0.1	0.8	0.7	0.55	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

f) Total ammonium nitrogen

The mean values of ammonium nitrogen ranged between 0.23 and 0.75 mg/l. There was a general increase in the amount of ammonium nitrogen as water stayed in the paddies longer. Mean values of ammonium nitrogen varied significantly between the treatments (F=23.9 d.f. =2, P<0.05) and the days after replacement of the water (F=36.0, d.f. =4, P<0.05). There were no ignificant variations in the values between the treatments for each DAR and between DAR for ach treatment (Table 4.11).

g) Soluble reactive phosphorus (SRP)

The mean values of SRP ranged between 11.6 and 21.8 mg/l. Overall; there was an increase in he values of SRP as water took more time in the experimental plots before replacement. Mean

Table 4.11 Mean Ammonium Nitrogen (mg/l).The values given are means ± SE of three replicates. F and P values are also shown.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
T_1	0.23±0.03	0.30±0.03	0.46±0.02	0.47±0.18	0.49±0.01	0.66	N.S.
T_2	0.30±0.01	0.39±0.16	0.48±0.02	0.50±0.07	0.64±0.01	0.27	N.S.
T_3	0.35±0.01	0.50±0.02	0.58±0.02	0.57±0.01	0.75±0.01	0.87	N.S.
F	0.27	0.12	1.0	0.13	3.55	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

values of SRP did not vary significantly between the treatments (F=0.11, d.f. =4, P>0.05), but were significantly different between the days after replacement of the water (F=8.65, d.f. =4, P<0.05). One way anova tests for each DAR and treatment showed no significant difference in the values between the treatments for each DAR. However, there was a significant difference (F=4.6, d.f.=4, P=0.02) between the DARs for treatment 2 (Table 4.12).

Table 4.12 Mean soluble reactive phosphorus (mg/l). The values given are means ± SE of three replicates.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	11.6±2.5	15.3±0.1	16.2±2.6	20.1±5.0	21.8±3.6	1.58	N.S
T_2	15.5±0.5	14.2±2.2	16.9±1.3	17.4±2.2	21.6±1.1.	0.23	N.S
T_3	15.2±1.9	15.6±1.4	16.4±1.5	16.7±0.4	19.4±2.7	0.92	N.S.
F	2.32	0.20	0.16	2.25	0.31	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

h) Nitrite nitrogen

The mean values of nitrite nitrogen in the refugia water ranged between 11.6 and 24.3 mg/l. There was a general increase in the concentration of nitrates in the water in the refugia as water took longer before replacement (Table 4.13). Mean values of nitrites did not vary significantly between the days after replacement of the water (F=2.73, d.f. =2, P>0.05) , but were significant between the treatments (F=4.94, d.f. =4, P<0.05).The interaction between the months and culture type was also significant (F=8.0). One way anova tests for each DAR and treatment showed no significant variation in the values between the treatments for each DAR and between DAR for each treatment (Table 4.13).

Table 4.13 Mean concentration of nitrites (mg/l). The values given are means ± SE of three replicates.

	Days after replacement of water (DAR)						
	0	30	60	90	120	F	P
Treatment							
T_1	11.6±2.5	16.2±2.3	17.0±0.9	20.2±5.1	21.8±0.6	1.58	N.S.
T_2	19.5±3.1	20.3±2.2	22.7±0.5	22.2±4.1	24.3±2.2	0.23	N.S
T_3	20.1±3.6	20.8±2.6	20.7±3.0	27.9±4.9	19.4±0.5	0.92	N.S.
F	2.32	0.20	0.16	2.25	0.31	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

) Conductivity

Mean values for water conductivity in the refugia ranged from 280.33 to 327.33 during the study period. Comparison of treatments for each replacement session showed no significant difference (F=2.23, d.f. =2, P>0.05), indicating that treatment variation had no effect on conductivity.

However, there was a significant variation in conductivity between the replacement sessions (F=9.02,d.f. =4, P<0.05). One way anova tests for each DAR and treatment showed no significant variation in the values between the culture ponds for each DAR and between DAR for each treatment (Table 4.14).

Table 4.14 Mean values of water conductivity (Ohm s^{-1}). The values given are means ± SE of three replicates.

	Days after replacement of water (DAR)						
Treatment	0	30	60	90	120	min	max
T_1	327.3±25.1	326.3±13.3	315.7±15.6	303.7±45.5	290.3±37.5	233	432
T_2	312.7±12.4	303.7±29.1	317.7±20.0	291.0±31.8	300.3±43.6	250	454
T_3	318.3 ±9.7	306.0±20.8	320.3±24.1	288.3±34.8	280.3±60.0	220	440
F	0.56	0.24	0.17	0.00	0.19	-	-
P	N.S	N.S	N.S	N.S	N.S	-	-

CHAPTER FIVE: DISCUSSION

5.1 Effects of culture type on growth and production of the catfish

Growth expressed in terms of weight and length both showed significant differences between the treatments. Treatment 1 with mixed culture of the catfish and tilapia in rice had the highest production compared to the other treatments (Table 4.9 a, b). This could be attributable to the polyculture advantage, in which case the fish species in treatment 1 benefit from their ability to exploit different feeding niches thus resulting into efficient utilization of the rich nutritional resources provided by the culture environment (Yar Anjum, 2007). The fish benefit from consumption of natural fish food (plankton), insects, insect larvae, rice pollen, and periphyton growing on the rice plants. The fish, through their excrement also act as source of minerals used in the photosynthetic production of a rich plankton biomass; and as sources of organic substrates and minerals for heterotrophic microorganisms and zooplankton (Coche, 1967). It is worth noting that the increased density of fish food promotes growth where two fishes, occupying different feeding niches are cultured together in the rice fields as evidenced by the results of this experiment.

The results of this study showed significant difference in the fish survival in the three culture experiments. Survival was highest in treatment 1 with mixed culture of the catfish and tilapia, and lowest in monoculture at high density (treatment 3). This could be due to monoculture disadvantage which limits the ecological opportunities available to the fish, notably in nutrient acquisition from within the rich aquatic environment provided by the rice plants. On the contrary, fish in the mixed culture enjoyed the polyculture advantage, where the exploitation of different feeding and habitat niches by the two species provides greater opportunities for better survival (Fernando and Halwart, 2000; Halwart, 1994 and Vromant *et al.*, 2002b).

Apart from the monoculture disadvantage, higher stocking density also appears to be a deterrent factor to survival in the *Clarias gariepinus*. This is probably due to intraspecific competition since the most aggressive individuals out-compete the less aggressive ones, leading to abnormally high differences in growth and size (Vromant, 2002b). The fish which were bigger in size (shooters) could have predated on smaller individuals which are 10% or less of their weight (Pillay, 1993), a factor that could have contributed to the general reduction in survival. Individuals that are out-competed become weak due to low food intake and stress induced susceptibility to predators and diseases. This has a direct effect of lowering the number of fish surviving in the refugia.

This study established that the mean catfish yield in treatment 1 was 16 per cent higher than in treatment 2 and 30 per cent higher compared to treatment 3. In rice-tilapia-catfish polyculture, efficient utilization of pond inputs by both species and the subsequent transfer of energy and nutrients from the tilapia to the catfish through predatory feeding contribute to better growth in the catfish in treatment 1 than in the other treatments where this polyculture advantage is lacking.

These yields compare favorably with those reported by other researches in various countries (Table 5.1), although most of the fish were below the marketable weight (300 g) for the catfish. These results reinforce the observations by Schroeder (1980) that integrated polyculture of fish with different nutritional preferences promotes and subsequently leads to increased yields of fish. This is partly attributable to the complimentary roles that the two fish species play, especially the different feeding niches that the two species occupy: the catfish is omnivorous, feeding on tilapia offspring that would otherwise offer competition for the same resources in the rice fields. The catfish also improves soil and water aeration as it disturbs the bottom thereby increasing the rate of decomposition hence releasing more nutrients for use within the paddies. Further, the movement of the catfish helps release nutrients trapped in the soil bottom, especially phosphorus. This leads to increased phytoplankton productivity which translates into higher aquatic vegetative biomass.

Table 5.1 Comparative fish production in integrated systems as reported by various authors.

* Value given in kg ha^{-1} yr^{-1}

Country	Type of study	Fish yield (kg/ha)	Fish species	References
Vietnam	Field experiment	291-474	*C. carpio* *B. giononotus* *O. niloticus*	Rothius *et al.*, 1998a Vromant *et al.*, 2002a
Vietnam	Socio-economic	326-459	*C. carpio* *B. giononotus* *O. niloticus*	Berg, 2002
Bangladesh	Field experiment	226-271	*B. giononotus* *O. niloticus*	Haroon and Pitman, 1997
Cameroon	Field Experiment	343.4	*C. gariepinus*	
Nigeria	Field experiment	343-602	*O. niloticus*	Yaro *et al.* 2004
Kenya	Field experiment	3111-3762*	*C. gariepinus*	Rasowo *et al.*, 2008
India	Field experiment	906-1282	*C. catla* *C. mrigala* *L. rohita* *C. carpio*	Mohanty *et al.*, 2004
China	Review	225-2250	*C. carpio* *B. giononotus* *O. niloticus*	Li., 1986
Present study (Kenya)	Field experiment	236.26-373.16	*C. gariepinus*	-

which is transferred to the tilapia biomass through herbivorous feeding. Later, as the catfish feeds on tilapia juveniles, part of this biomass are transferred to it thus the witnessed difference in growth between the culture experiments.

5.2 Effects of water quality on fish condition

The results of this study reveal the presence of a few, large and more robust individuals called shooters. Although the presence of shooters is normally taken to be an indicator of healthier condition of the individual fish, Weger & Anderson, 1978; and Hehtonen & Jokikokko (1995) stated that this may signify an out-of-balance or abnormal condition at the population or community level.

The relative condition factor (Kn) is an expression used to asses the condition and well being of fish, and Kn values of 1 or more is indicative of the well being of fish. The present study, all the mean Kn values were below 1 in all the treatments after the second month, falling further to 0.84, 0.61 and 0.92 for treatments 1, 2 and three respectively at harvest from 2.06, 2.30 and 2.21 at stocking. It is evident that a factor(s) that affected the condition of the fish was common to all the treatments. These observations are indicative of distressed growth in the catfish, since there was no significant difference (F=2.51, d.f. =2, P>0.05) in the condition factor among the three treatments at harvest.

Although earlier studies by Iwama *et al.* (2000), Schmitt and Dethloff (2000), and Williams (2000) on fish growth revealed sub-optimal growth of fish, they did not provide the evidence of any causative factor. In the present study, the sub-optimal growth of fish in the three treatments, while partly attributable to nutritional inadequacy, due to absence of supplementary feeding, can also be attributed to the prevailing physico-chemical factors. Of particular concern are the high measurements of turbidity, total ammonia nitrogen, nitrites and soluble reactive phosphorus which are several folds higher than the recommended ranges for catfish growth. The high levels of these physico-chemical parameters could directly or indirectly interfere with fish physiology and affect their growth.

High turbidity is a problem in many different types of water but turbidity caused by clay tends to occur mostly in soft, poorly buffered soils (Hargreaves, 1999) which are typical of the study area. It reduces photosynthetic zone resulting in night time decline of DO (Zweig, 1989) and higher pH (Boyd, 1979). It also reduces the blood pH and causes alkalosis, damages skin, gills, and eyes, and also increases mucus production. It would be desirable to extend the time it takes between water replacements in such soils to reduce the negative effects of high turbidity that is caused by clay.

High ammonia levels affect oxygen consumption in fish (Tilak *et al.*, 2005). Besides, high concentrations of ammonia in water interfere with oxygen transport from gills to blood (Smart, 1978; Lewis & Morris, 1986, Datta and Morris, 2005) and damage gills, while sub-optimal levels of un-ionized ammonia (0.1 - 0.42 mg/l) are known to cause significant variation in condition factor (Datta and Morris, 2005). It is possible that the values recorded for this study (0.2 – 0.6 mg/l), which extend beyond the above range, could have contributed to the lower condition factors of the fish in the three treatments.

Phosphate is a nutrient which causes a rich phytoplankton crop (Moss, 1993). However, an optimum concentration range of 0.1-0.2 mg/l is ideal for both phytoplankton and fish growth

(Sreenivasan, 1965). In the present study, phosphate levels were several folds higher than the recommended value and could have contributed to the low conditions of fish.

Nitrite could be hazardous to fish if its concentration exceeds the permissible range with 0.1mg/l considered optimum for fish culture in the tropics (Hart and Reynolds, 2002). The high measurements of nitrites could have been responsible for the algal blooms and dense mats of Azolla spp. weed that covered the water surface. Oxygen uptake in fish is affected by high nitrite levels (Tilak *et al.*, 2005) which interferes with its transport from gills to blood (Smart, 1978; Lewis & Morris, 1986, Datta *et al.*, 2005), and damages gills. Since the values recorded for this study extend beyond the above range, the lower condition factors of the fish could partly be attributable to the prevailing levels of nitrite nitrogen which exhibits a strong negative correlation with fish condition.

The combined effect of all these physico-chemical factors outside the recommended levels might induce stress response as suggested by Iwama *et al.* (2000). It is an established fact that stress adversely affects growth of animals. Hence sub-optimal growth of the catfish as indicated by the lower Kn values can be attributed to the prevailing physico-chemical conditions in the paddies, in addition to nutrient inadequacy. This is because stocking density difference does not seem to affect productivity so much as to cause a remarkable difference in fish yields among the different culture systems. This finding agrees with the observation by Areerat (1987) that high stocking density does not negatively affect productivity of the catfish, especially when supplementary feeds are provided. He did not find any evidence that production in the catfish declines even at extremely high stocking densities of 100 fish m^{-2}, with standing crops in pond culture reaching as high as 100 t ha^{-1} in intensive cultures with trashfish, chicken offal or pelleted feed, which generally cause poor water quality and heavy phytoplankton biomass throughout the grow-out period.

However, the problem of poor water quality can be solved by changing the pond water at between 120-150 days as recommended by Areerat (1987). It is however possible that this practice of changing the pond water at some stage in the production cycle may pose a serious challenge in agronomic practices where the rice crop is involved since the unbalanced nitrogen-phosphorus ratio (high nitrogen content) characteristic of this type of culture can cause fruiting failure in the rice. The current production model eliminates this requirement since in the paddies, water flow through the system is very regular, and hence the water carries away any waste or excessive nutrient that would otherwise accumulate in the paddies.

5.3 Effects of culture type on water quality parameters

The temperature range (23.5 - 26.1 °C) recorded in this study fall either below or closer to the lower limits of the optimal range (25 - 30 °C) cited by Natividad (1984) as being suitable for the production of tilapia and catfish in the tropics. Water temperatures for the three treatments showed a decline as the weather conditions changed from dry, with open skies to wet rainy seasons between March and May. This could be explained by the fact that as the rice plants grew, the added foliage covered the water surface, shielding it from direct heat of the sun. This supports the findings of Yinhe (2004) who observed a similar trend in temperature values.

Rice fields are known to experience sudden fluctuations in temperature, which is attributable to the shallow paddy waters (Coche, 1967). However, as the rice plants grow and their increased foliage increasingly covers the water surface, the phenomenon of sudden change in temperature is minimized and the temperatures also reduce (Yinhe, 2004). This is because the rice plants usually adjust and stabilize the water temperature and quality, and, therefore, provides an environment that is conducive to the reproduction of natural organisms. This is evident from the trends seen in temperature values over the culture period where values drop progressively from the start to the end of the culture period in all the three treatments.

The lower temperature values recorded in this study (as low as 21 °C) in some stations could also be due to the dense mats of the azolla weed which covered the water surface in those paddies, and also due to the fact that temperature measurements were taken in the mornings only. It is natural that the afternoon temperatures would have been higher. That values were not significantly different between the treatments is a confirmation that culture type does not influence water temperature.

In fish culture, low turbidity levels (20 - 30 NTU) are desirable (Zweig, 1989) since higher level turbidity affects the photosynthetic process of the phytoplankton and therefore the potential yield of the ponds (Sukumaran & Das, 2005). The high turbidity of the water in the refugia is attributable to the hydrogeology of the study area. As the rains fall, the heavy run-off with silt laden surface water carry with it large amounts of suspended substances which eventually find their way into the river that is the source of irrigation water. The high water turbidity (above 50 NTUs after DAR 3) measured in some paddies can also be attributable to the high activity of the catfish in the refugia owing to their feeding habit of scouring the bottom material.

However, as the production period increases, the increasing foliage density of the rice plant, together with the dense mats of azolla weed filtered the suspended substances from the water thus making the water increasingly transparent. Some of these values are obviously way above the recommended range for production of fish in the tropics. However, since the catfish have high tolerance levels to turbid waters; these values could not have had a major impact on the production of the catfish. Further, the insignificant difference in the values between the treatments shows that water turbidity is not affected by culture type.

The mean pH values (range of 7.3-9.3) are much within the range (6.5-9.0) recommended by Natividad (1984) and Lichkoppler (1997) where the fish thrive well and grow quickly. The values for this study are therefore classified as alkaline since the values are generally greater than 6.5 (Orendt, 1999), but not to the extent of causing fish death. The alkaline nature of the paddies may be due to the hydro geological characteristics of the research area, probably due to basic metal oxides forming the basements of rocks of the study area (Saggerson, 1962) which form alkaline solutions. The values also conform to those of most world water bodies which have a mean annual range of 6.4 and 8.4 and a median value of 7.6 (UNEP, 1995; UNEP/WHO, 1987).

Of concern however is the fact that a few paddies (3) had values more than 8.5, the value beyond which nitrogen loss through ammonia volatization is common (Haroon, 1998). Even if this were the case, ammonia loss may not have had a profound effect on the dynamics under investigation n the catfish since its (ammonia) concentration was not significantly different between the culture experiments. It is confirmed by the results of this experiment that culture type does not affect pH in fish refugia.

The range of values (Table 4.5) obtained for water alkalinity during this study (150.67-157.47 mg/l $CaCO_3$) fit perfectly within the range (100-400 mg/l $CaCO_3$) cited by Schroeder (1980) as being optimal for fish culture in the tropics. It is therefore inconceivable that water alkalinity could have been a limiting factor to the growth of the fish in the experiment. The results confirm, too, that culture type has no effect on water alkalinity.

Yinhe (2004) reported that DO levels of less than 4 mg/l characterized rice fields in the mornings. However, the values recorded for DO in this study (range 4.8-8.4mg/l) are within the normal optimum range for the culture of fish in the tropics (Natividad, 1984). Much as there was no significant difference in the values of DO among the culture experiments, treatment 3 had generally higher DO values than the other two. Since treatment 3 had the same number of fish (8 fish m^{-2}) as treatment 1, this difference could be as a result of the high density of the catfish in treatment 3 which was double that of treatment 1. Due to its vigorous movements in the shallow water, it breaks the surface membrane formed by aquatic microorganisms covering the soil. This increases the dissolved oxygen level in the soil, and subsequently in the water, and, elevates its oxidation and reduction potential during the grow-out period. These changes improve the oxygen content and effectively increase the utilization rate of soil nutrients for improved productivity of both rice and fish.

Generally the DO was higher for the measurements taken soon after replacement of water and decreased as the water stayed longer in the paddies. The higher values following replacement are due to the effects of mixing as water enters the paddies. The subsequent lower values are due to depletion as a result of use by aquatic biota, including the Azolla weed (at night) which formed dense mats in most of the paddies. It was also possible that the subsequent low water mixing in the periods after replacement of water contributed to reducing levels of dissolved oxygen. The aquatic vegetation cover reduces the water surface area in contact with air, thus reducing water aeration. Further, as the rice plants grow and increase the detritus load in terms of fallen and/or dead plant parts, the biochemical oxygen demand increases and cause a reduction in dissolved oxygen as decomposition by microorganisms consumes oxygen.

The level of TAN recorded for this study (0.23 – 0.8 mg/l) is much higher than the value of 0.02-0.2 mg/l reported by Alabaster & Lloyd (1980) and Joseph *et al.* (1993) as being conducive for fish growth. This is because high levels of ammonia in water blocks oxygen transfer from gills to the blood (Smart, 1978). Un-ionized ammonia is also known to start depressing fish appetite at concentrations as low as 0.08 mg/l (Popma & Lovshin, 1995).

Phosphorus is a nutrient which promotes a rich phytoplankton crop (Moss, 1993). An optimum level of 0.1-0.2 mg/l (Sreenivasan, 1965) is needed for growth of plankton. The range of values for SRP (10.3-27.6 mg/l) recorded for this study was therefore several folds higher than this range. This could be explained by the feeding behavior of the catfish. Being a bottom feeder, the catfish disturbs the bottom material, releasing the nutrients (especially phosphorus) which are often locked up in these ‘sinks’. Another possible source of phosphorus could be the catfish excrement with an average catfish releasing about 2 g of excrement every day (Morris and Mischke, 2009).

Nitrites can be hazardous to fish if levels exceed the recommended range (Train & Russell, 1979) with 0.1 mg/l considered optimum for fish culture in the tropics (Hart & Reynolds, 2002). For instance, high levels of nitrites are known to reduce oxygen uptake by the fish (Tilak *et al*, 2005). The concentration of nitrites in the present study the (range 15.9 - 27.8 mg/l) was several folds higher than the recommended range. These high values could be due to insufficient water circulation during certain periods in the experiment.

Very often, limnologists have used electrical conductivity to estimate the degree of water mineralization. The amount of dissolved ionizable salts in fresh water is chiefly related to their potential productivity (Coche, 1967). The insignificant difference in conductivity among the treatments shows that culture type has no influence on water mineralization.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Arising from the findings of this study on the effects of integrated rice-tilapia culture system on the productivity of the African catfish, *Clarias gariepinus* in Nyando district of the Lake Victoria basin the following conclusions can be made:

- Catfish production is positively affected by mixed culture of catfish and tilapia in rice-fish culture. On this basis, the null hypothesis that growth and production of catfish does not differ with culture type is rejected.
- Water quality parameters critical to survival of fish increases with increasing days of culture. The null hypothesis that water quality does not change with period and frequency of replacement is rejected.

6.2 RECOMMENDATIONS

From the results and conclusions above, the following recommendations are made:

- Mixed culture of catfish and tilapia in rice should be encouraged as a way of increasing yields of catfish in integrated aquaculture systems.
- Regular flushing of pond water should be encouraged to reduce chances of accumulation of nutrients arising from fish excrement which enrich the culture environment.
- The production period should be extended, or larger sized fingerlings should be stocked in order for the fish to reach this marketable weight.
- Further research should be carried out to investigate the same production model with supplementary feeding.
- A comprehensive economic analysis (cost-benefit study) should be carried out to determine the economic returns for this production model.

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APPENDICES

Appendix 1: Measured catfish morphometric parameters over the 122-days study period.

a) Treatment 1 (rice-catfish-tilapia polyculture at high stocking rate)

Stocking		Month 1		Month 2		Month 3		Harvest	
L	W	L	W	L	W	L	W	L	W
9.2	20.4	17.9	90.7	26.2	200.0	30.0	251.9	35.0	300.6
8.8	16.9	16.2	81.6	24.3	121.2	31.4	166.7	37.2	197.2
9.7	15.4	18.1	81.9	23.4	161.3	26.6	194.3	28.1	201.3
9.9	16.5	19.2	77.8	24.8	122.2	26.9	161.8	30.3	188.0
9.0	17.1	18.4	100.3	20.8	179.8	30.0	222.2	34.9	241.2
9.7	17.3	17.8	89.4	18.9	191.3	19.3	200.7	20.0	221.0
9.6	19.0	19.1	91.2	24.3	201.7	27.7	277.8	31.3	292.2
9.9	14.5	20.3	88.6	25.3	120.9	30.6	171.2	34.1	199.3
10.1	17.1	21.1	101.1	24.8	172.3	29.7	213.2	32.3	255.0
8.7	16.4	19.1	92.3	23.8	144.3	26.3	194.8	29.8	213.0
9.9	17.1	18.7	91.8	25.4	151.2	28.1	188.9	30.6	222.7
8.1	16.1	16.7	77.1	24.2	94.9	27.9	99.1	33.4	102.0
8.6	17.1	14.9	76.3	19.2	88.2	23.1	94.3	26.1	102.8
8.2	15.9	17.1	81.4	24.3	100.2	26.7	121.7	28.0	138.2
11.0	16.9	19.2	82.2	22.3	102.7	25.3	201.9	29.2	236.6
9.0	15.9	17.9	77.3	21.9	111.3	24.1	148.1	29.0	166.3
8.8	16.3	18.8	69.3	21.4	99.7	26.3	130.7	28.5	252.2
9.1	16.1	16.8	72.2	23.2	94.9	26.1	119.6	29.1	150.4
9.9	18.1	14.9	81.1	17.2	164.8	19.9	207.1	20.4	261.3
9.6	17.2	16.9	66.1	20.3	194.3	24.3	211.3	27.8	245.7
9.5	16.3	15.9	104.7	19.1	121.1	22.1	139.2	24.3	151.1
9.9	19.1	19.9	91.7	21.2	201.3	24.1	266.8	26.0	300.8
9.3	17.8	13.9	89.1	18.4	108.7	21.3	111.4	24.1	161.0
9.4	14.9	19.8	88.8	21.8	111.3	25.1	122.9	27.4	150.6
9.9	14.6	16.7	99.8	24.7	141.9	30.8	207.3	36.0	269.9
11.4	13.4	18.4	79.1	21.1	99.9	23.9	107.4	26.7	122.0
9.1	14.8	19.9	77.3	23.0	108.4	26.6	144.5	34.1	171.8
9.9	15.9	18.1	66.3	22.7	101.1	28.4	166.6	33.1	188.1
9.0	16.4	18.2	81.7	21.1	144.9	24.9	191.7	29.6	211.3
8.4	17.1	16.8	88.1	25.3	101.4	31.1	148.6	34.2	199.1
8.9	16.5	17.9	61.8	25.1	84.3	29.3	92.1	32.0	100.2
9.8	17.4	18.8	72.3	22.1	81.1	25.5	93.9	29.4	101.0
9.7	17.5	18.2	78.1	23.9	192.2	24.4	211.1	27.3	255.1
7.8	16.7	16.1	71.1	22.7	136.3	27.1	247.6	28.2	200.2
11.2	16.9	20.4	77.3	26.2	144.7	30.7	212.9	34.6	254.1
9.8	16.2	20.2	70.4	24.1	99.4	28.8	147.1	30.0	177.2

b) Rice-catfish monoculture at low stocking rate

7.9	17.1	16.1	68.1	30.7	140.0	36.7	183.2	41.0	206.3
8.4	16.7	17.2	61.8	23.4	164.7	27.3	250.7	30.4	294.8
9.8	17.2	18.4	62.4	21.8	144.3	26.6	217.6	30.0	248.0
11.2	18.1	21.8	61.8	24.7	122.9	25.9	139.8	30.1	191.5
10.1	16.9	20.4	53.1	26.4	153.4	30.1	194.3	34.3	204.2
9.1	16.7	17.4	50.4	26.8	149.7	28.2	177.7	31.1	209.1
6.9	17.1	14.0	66.8	20.1	120.1	24.3	166.8	27.8	181.0
9.5	17.9	20.2	59.0	26.1	122.9	28.1	149.3	30.0	197.0
8.8	16.8	18.1	71.8	25.9	142.1	29.9	180.4	36.1	201.0
7.8	14.2	16.8	49.4	24.7	99.3	30.1	104.3	33.6	122.9
8.7	16.1	17.1	60.8	21.9	89.1	27.8	119.6	30.3	156.1
9.9	15.9	22.3	52.2	24.6	121.7	25.9	166.3	33.2	189.0
11.2	18.2	18.1	70.1	23.1	140.4	26.6	181.7	27.6	201.0
11.0	18.0	22.3	73.1	27.1	84.5	28.0	91.4	35.0	98.7
9.7	16.6	19.4	69.8	24.3	111.2	26.2	139.3	30.2	151.3
8.1	14.8	17.1	70.5	21.9	99.9	24.7	104.9	28.5	133.7
9.1	18.1	18.2	52.5	25.4	82.7	29.1	100.7	32.2	119.7
9.9	17.4	19.1	64.0	24.9	100.4	29.6	121.7	30.8	139.8
7.9	16.8	17.9	86.1	22.8	119.4	26.4	151.6	33.4	177.9
8.1	19.1	18.4	49.1	24.6	140.8	29.0	177.1	30.6	199.6
9.6	14.1	19.4	79.2	22.8	106.6	27.2	133.8	29.4	141.2
10.3	16.6	22.1	76.7	26.6	94.8	29.0	111.0	31.1	116.0
9.7	17.1	19.9	73.3	27.4	101.7	30.7	161.8	34.8	189.2
8.9	17.4	17.9	55.8	24.9	79.7	29.2	104.9	32.0	131.0
9.2	18.1	16.2	74.4	22.6	104.3	26.9	149.3	29.9	192.0
10.1	19.0	22.8	84.5	26.1	144.5	29.3	187.8	31.1	201.2
9.7	16.1	15.7	42.8	19.1	55.6	20.0	64.3	24.4	67.3
9.8	15.8	17.1	47.2	21.8	49.8	28.8	78.9	29.1	94.1
8.8	13.6	16.6	40.3	18.4	60.6	19.1	69.4	20.6	71.8
9.4	14.1	17.1	52.1	18.1	64.7	19.9	79.8	21.3	80.7
6.9	16.8	14.7	53.4	17.4	71.8	19.7	94.7	22.0	108.1
8.4	17.1	14.1	59.5	20.3	81.0	24.8	94.7	27.1	101.3
8.2	12.8	14.9	55.5	16.8	66.7	20.1	74.7	21.3	90.0

c) Rice-catfish monoculture at high stocking rate

8.8	16.1	18.1	40.2	22.3	80.7	26.3	101.4	32.0	121.2
7.9	19.2	17.1	44.8	20.4	90.1	22.8	122.4	26.1	141.9
9.1	18.4	19.2	47.2	23.8	88.7	29.2	109.1	33.3	134.6
9.5	18.1	18.1	41.9	24.9	104.8	27.6	133.1	31.6	155.2
11.1	16.7	20.3	43.9	22.1	88.7	23.1	102.7	24.6	119.0
10.2	16.8	19.4	40.8	23.1	91.4	24.9	122.8	26.3	133.4
9.9	16.9	21.2	44.2	22.3	89.2	22.9	114.9	23.6	129.3
7.1	16.6	15.6	40.6	20.9	77.4	27.4	99.4	31.1	120.1
8.9	16.3	17.0	53.6	24.6	101.9	28.2	166.1	30.6	180.3
8.6	19.1	17.4	47.2	20.4	76.9	25.5	94.7	28.9	114.6
9.4	17.8	18.9	46.5	25.7	88.1	29.3	104.6	32.2	135.7

9.9	16.9	18.1	44.8	27.4	89.8	29.3	113.7	33.1	134.6
10.4	11.8	20.3	58.4	22.2	99.7	26.7	147.5	29.3	161.3
9.4	16.1	19.2	40.6	24.7	84.3	28.8	94.9	30.1	108.7
11.2	17.8	17.1	38.7	22.8	51.7	25.4	61.9	27.4	66.8
11.4	16.8	21.5	44.1	25.7	94.3	28.1	130.2	30.4	144.8
8.4	18.1	18.6	37.2	19.4	69.3	21.2	79.1	22.3	98.1
8.9	19.3	17.2	34.6	24.1	58.1	26.3	81.8	29.1	99.0
9.9	16.4	18.8	33.7	24.9	44.7	29.7	54.7	32.1	69.9
8.8	17.1	16.6	35.7	20.1	60.7	21.7	71.9	23.9	88.8
7.6	18.8	17.1	37.8	20.9	49.2	22.1	61.8	23.6	74.7
9.7	16.6	16.9	36.7	18.8	77.2	25.4	82.3	28.8	89.3
9.4	19.0	14.6	39.4	20.4	66.1	23.3	88.1	25.1	99.6
11.2	21.3	19.9	42.3	24.5	88.7	28.1	93.6	31.1	101.6
9.4	14.9	20.1	31.8	22.0	68.1	26.1	79.1	28.3	97.1
7.9	17.9	17.8	36.6	20.9	77.9	24.2	94.5	26.4	101.0
8.9	16.8	16.9	38.1	21.4	71.8	25.0	80.4	26.1	87.0
9.4	19.8	15.4	41.7	22.3	74.7	25.7	89.9	28.7	99.7
8.8	11.8	14.4	80.4	16.9	201.8	19.0	334.7	20.1	350.0
9.1	14.9	17.1	30.9	18.7	79.7	21.3	170.3	23.3	188.1
9.5	16.1	16.1	54.1	17.7	101.1	18.9	166.7	21.1	199.6
9.9	16.4	17.8	34.6	21.9	66.3	23.7	86.9	25.2	94.8
9.5	16.8	14.7	43.1	16.6	90.8	18.1	101.7	19.9	144.3
9.1	16.6	16.9	84.6	17.0	171.8	17.4	211.8	17.8	241.3
7.4	14.8	17.1	79.1	20.7	104.9	24.8	144.3	26.8	177.9
8.1	12.7	14.9	52.1	17.3	151.7	18.1	166.4	19.1	187.5
9.8	16.1	19.7	60.8	21.5	169.1	25.5	194.6	27.1	211.5
10.1	14.1	18.1	56.7	21.3	99.4	21.9	101.7	22.4	127.8
11.2	18.1	20.1	37.8	21.1	88.7	23.1	122.2	23.9	134.1
8.9	16.7	14.4	53.9	20.9	144.3	23.3	177.3	24.1	190.9
9.5	19.1	19.5	34.6	26.1	49.8	27.8	59.9	28.2	60.6
9.9	17.1	16.9	79.1	19.1	169.4	20.9	200.0	23.0	212.3

APPENDIX 2 Measured water quality parameters

	Treatment	Replicate	Days after replacement of water				
			0	30	60	90	120
Temperature	T_1	R_1	25.7	24.0	24.6	23.9	24.8
		R_2	24.4	25.6	25.2	24.5	21.9
		R_3	25.2	26.0	23.5	24.6	22.8
	T_2	R_1	26.5	24.1	24.0	23.6	24.5
		R_2	24.5	24.9	25.1	25.3	22.3
		R_3	25.1	26.2	22.8	24.4	23.3
	T_3	R_1	26.1	25.9	25.7	23.0	24.7
		R_2	24.7	24.7	24.5	24.3	21.8
		R_3	26.1	25.5	23.9	23.8	23.0
Dissolved oxygen	T_1	R_1	8.2	5.6	4.8	4.8	5.8
		R_2	5.2	5.2	7.4	6.8	5.0
		R_3	5.8	7.0	5.6	5.8	5.6
	T_2	R_1	5.8	7.0	6.0	5.8	5.4
		R_2	7.2	6.4	5.8	5.8	5.0
		R_3	7.1	6.4	6.1	5.6	5.4
	T_3	R_1	6.4	7.4	5.8	6.6	6.0
		R_2	8.4	5.0	7.0	7.0	5.8
		R_3	7.4	6.6	5.4	4.4	6.0
pH	T_1	R_1	7.9	8.3	8.4	7.5	7.3
		R_2	9.3	8.0	7.6	7.4	8.0
		R_3	7.7	8.3	7.8	8.1	7.4
	T_2	R_1	7.9	8.0	8.0	7.3	8.1
		R_2	7.8	8.0	8.4	8.1	7.8
		R_3	9.1	7.8	7.5	8.0	7.6
	T_3	R_1	8.0	8.2	7.7	7.8	8.1
		R_2	8.1	8.1	8.1	7.9	7.7
		R_3	8.8	8.4	8.0	7.8	7.4

Alkalinity	T_1	R_1	168	162	134	166	130
		R_2	186	172	164	128	122
		R_3	154	144	172	120	138
	T_2	R_1	164	196	142	152	122
		R_2	182	188	176	140	125
		R_3	192	146	158	146	116
	T_3	R_1	164	130	158	116	198
		R_2	182	170	186	150	146
		R_3	188	186	136	144	108
Ammonium nitrogen	T_1	R_1	0.18	0.29	0.90	0.42	0.29
		R_2	0.22	0.30	0.21	0.81	0.47
		R_3	0.29	0.39	0.28	0.17	0.69
	T_2	R_1	0.13	0.70	0.50	0.39	0.44
		R_2	0.29	0.16	0.50	0.50	0.67
		R_3	0.49	0.31	0.16	0.62	0.80
	T_3	R_1	0.11	0.88	0.55	0.35	0.49
		R_2	0.43	0.16	0.99	0.67	0.82
		R_3	0.52	0.45	0.15	0.71	0.95
Nitrites	T_1	R_1	16.5	13.3	18.8	23.1	15.2
		R_2	9.9	21.4	16.3	27.1	22.7
		R_3	8.5	14.0	16.0	10.3	27.6
	T_2	R_1	13.4	22.2	23.3	29.2	20.2
		R_2	21.9	23.0	21.8	15.0	24.8
		R_3	23.3	15.9	23.1	22.5	27.9
	T_3	R_1	24.6	25.9	14.6	21.7	22.5
		R_2	13.0	18.2	23.3	37.5	29.1
		R_3	22.6	18.2	24.1	24.6	22.5

Soluble Reactive phosphorus	T_1	R_1	16.5	14.6	13.3	23.1	15.2
		R_2	9.9	16.3	21.4	27.1	22.7
		R_3	8.5	15.1	14.0	10.3	27.6
	T_2	R_1	14.5	15.2	18.7	13.2	19.6
		R_2	16.0	10.0	14.4	18.4	21.9
		R_3	15.9	17.5	17.6	20.7	23.0
	T_3	R_1	18.1	17.5	13.5	17.4	14.0
		R_2	15.7	13.0	17.4	16.6	22.6
		R_3	11.7	16.4	18.2	16.2	21.7
Turbidity	T_1	R_1	138.9	20.6	19.0	37.0	13.8
		R_2	25.7	19.5	119.8	24.2	13.2
		R_3	12.1	126.4	21.9	24.2	14.9
	T_2	R_1	17.0	118.1	20.1	36.0	13.3
		R_2	124.8	34.8	19.6	27.9	16.0
		R_3	40.1	15.2	124.4	18.2	16.3
	T_3	R_1	129.5	28.7	19.5	42.0	19.9
		R_2	35.7	19.2	125.7	18.8	29.4
		R_3	22.7	129.4	27.8	18.8	18.8