FISHERIES TRAINING PROGRAMME
P.O. Box 1390, Skulagata 4
120 Reykjavik, Iceland

Final Project 2007

THE EFFECTS OF DISSOLVED OXYGEN ON FISH GROWTH IN AQUACULTURE

Yovita John Mallya
Kingolwira National Fish Farming Centre, Fisheries Division
Ministry of Natural Resources and Tourism
Tanzania.
mankay999@yahoo.com

Supervisor
Prof. Helgi Thorarensen
Holar University College
helgi@holar.is

ABSTRACT

Commercial aquaculture is growing worldwide except in Africa where production is still low. With fisheries reaching a stagnating phase, the world and more so Africa will have to look to aquaculture in the future to provide fish products that will likely be needed. In view of this, a study on water quality management was done which specifically looked at the effects of dissolved oxygen saturation on fish growth. The study was done through a review of literature and a case study using Atlantic halibut. In the case study, halibut of 20-50 g in weight were reared in replicate at 60%, 80%, 100%, 120% and 140% oxygen saturation levels in a tank recirculation system. The subsequent effect of oxygen saturation levels on growth and feed conversion ratios were taken after two weeks. The results showed that oxygen saturation level had a positive effect on the growth and feed conversion ratio when it was set at 80%-120% saturation. At 140% the growth was slightly lower and the feed conversion ratio was higher at 60% and 140% compared to the other groups. The conclusion was that oxygen saturation level has an effect on growth and feed conversion ratios of fish, and in the case of Atlantic halibut, the growth rate is higher when the oxygen level is between 80% and 120%. The feed conversion ratio for halibut was lower at 120% oxygen saturation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 State of world aquaculture

The contribution of aquaculture to global supplies of fish, crustaceans, molluscs and other aquatic animals was growing at a rate of 32.4% in 2004. Aquaculture continues to grow more rapidly than all other animal food-producing sectors. Production from aquaculture has greatly outpaced population growth, with a per capita supply from aquaculture increasing from 0.7 kg in 1970 to 7.1 kg in 2004, representing an average annual growth rate of 7.1 %. (FAO 2006a).

According to (FAO 2006a) production in capture fisheries is stagnating and aquaculture output is expanding faster than any other animal-based food sector worldwide.

Aquaculture is the fastest growing animal based food-producing sector, particularly in developing countries though it is not so fast growing in Africa as will be reviewed below. This sector alone contributes nearly a third of the world's supply of fish products. China and other Asian countries are by far the largest producers. Unlike terrestrial farming, where the bulk of the production is based on a limited number of species, aquaculture produces more than 220 species. Of these species, carps, tilapia and related fish form the largest group in terms of quantity. Other groups include aquatic plants and mollusc (FAO 2006 a).

1.2 Status of aquaculture in Africa

The Sub-Saharan Africa region continues to be a minor player in aquaculture despite its natural potential. Even aquaculture of tilapia, which is native to the continent, has not developed to a large degree. Nigeria leads in the region with the production of 44,000 tonnes of catfish, tilapia and other freshwater fishes reported. There are some isolated bright spots in the continent: black tiger shrimp (*Penaeus monodon*) in Madagascar and *Eucheuma* seaweed in The United Republic of Tanzania are thriving, and production of niche species like abalone (*Halitosis spp*.) in South Africa is increasing. In North Africa and the Near East, Egypt is by far the dominant producing country (92% of the total for the region) and, in fact, it is now the second biggest tilapia producer after China and the world's top producer of mullets (FAO 2006a).

1.3 Status of aquaculture in Tanzania

The history of fish culture in the United Republic of Tanzania is not well documented. According to Balarin (1985) in documents at fao.org/fishery/country sector/naso_tanzania, it started in 1949 with experimental work on the culture of tilapia at Korogwe (in Tanga Region) and Malya (in Mwanza Region) during which many ponds were constructed.

These ponds ended up being largely non-productive due to lack of proper management and use of incorrect technology coupled with physical problems such as drought and poor infrastructure. According to reports from FAO, 8,000 fishponds had been constructed in the United Republic of Tanzania by 1968. However, some of the ponds were too small in size (at times as small as 20 m^2) and with very low production, resulting from poor management (FAO 2006b).

Water reservoirs constructed for use in homes or for livestock, irrigation and factories or for flood-control were stocked with tilapia. This practice started in 1950 and by 1966, 50% of the reservoirs in the country had been stocked by the Fisheries Division. In 1967, the government launched a national campaign on fish farming which was unsuccessful, again due to improper management. In 1972, aquaculture was, for the first time, given some importance in the fisheries policy. After that aquaculture was included in the Fisheries Policy, although always as a low priority sector. (Tanzania Fisheries Division 2006)

Aquaculture in the United Republic of Tanzania has a vast but as yet untapped potential. The industry is dominated by freshwater fish farming in which small-scale farmers practice both extensive and semi-intensive fish farming. Small fish ponds of an average size of 10 m x 15 m (150 m^2) are integrated with other agricultural activities such as gardening and animal and bird production on small pieces of land. The United Republic of Tanzania is currently estimated to have a total of 14,100 freshwater fishponds scattered across the mainland. In addition, there is a large rainbow trout (*Oncorhynchus mykiss*) farm with an area of 25 m x 25 m situated in Arusha. (Tanzania Fisheries Division 2006)

The distribution of fish ponds in the country is determined by several factors such as availability and quality of water, suitable land for fish farming, awareness and motivation within the community on the economic potential of fish farming.

Although very profitable internationally, shrimp farming is still in the experimental phase in the United Republic of Tanzania, a number of private companies have acquired plots and permits for the culture of shrimp. Shrimp farming has the potential to be a profitable activity in the United Republic of Tanzania but there are widespread concerns about its potential environmental and socio-economic impacts based on observation of the global industry. (FAO 2006b).

In recent years, seaweed farming has become popular in some coastal areas as a means of income generation. Small-scale seaweed farms on suitably selected sites, some of which are run by groups of women and youths, are scattered along the entire coastline of the country, from Tanga in the north to Mtwara in the south, and in the islands of Mafia and Zanzibar. Seaweed cultivation has rapidly emerged as one of the major cash crops in Tanga and Zanzibar, producing enough income to cover household costs. The species farmed are *Kappaphycus cottonii* and *Eucheuma spinosum. Kappaphycus cottonii* is believed to be indigenous while *Eucheuma spinosum* and *E. striatum* were originally imported from the Philippines. There is also potential for the farming of other seaweed species such as *Glacilaria*. (FAO statistics 2006b).

The United Republic of Tanzania has good potential for the development of mariculture. In 1996 a survey was conducted along the entire coastline for the selection of a preliminary shrimp culture site, with support from the United Nations Economic Commission for Africa (UNECA).The findings indicated that the country has big potential for shrimp culture which can be developed from the northernmost region of Tanga to the southernmost region of Mtwara. The total area identified as suitable for shrimp farming was 3000 ha from which potential production was estimated at 11,350 tonnes. (FAO statistics 2006b).

Seaweed farming is so far the only form of mariculture which can be considered an established success in the United Republic of Tanzania. However, there are a total of 14,100 fish ponds scattered all over the country with differing potential from one area to another. Most farmers own small ponds of an average size of 150 m^2; covering an estimated 221.5 ha. However, there are four regions which have more than 1000 fish ponds each. These are Ruvuma (4942), Iringa (3137), Mbeya (1176) and Kilimanjaro (1660). (FAO statistics 2006b).

Use of land for fish farming is restricted to some specific areas. Where water is available its use is not a problem as it is managed by water rights stipulated under the water policy. Fish farmers use animal manure as the main source of fertilizer for their ponds. Most farmers use feeds such as domestic leftovers, maize bran, wheat bran, vegetables and wild grass. Production has been low due to small pond sizes coupled with poor management. Fish ponds are the predominant production system with only one farm using raceways for the culture of rainbow trout (*Oncorhynchus mykiss*).

Several species both indigenous and introduced are used in the Tanzania. Although there are many similarities in fish farming in both regions in Tanzania, fish farming is dominated by the tilapias and *Oreochromis niloticus* has become the predominant cultured species. Other species with potential for use in aquaculture include other fin fish and shellfish in the brackish and marine waters, such as milk fish (*Chanos chanos*) and the flathead grey mullet (*Mugil cephalus*). The fresh water areas include the northern African catfish (*Clarias gariepinus*). The cultivable shellfish include shrimp of the family *Penaeidae*, molluscs, crabs, oysters and mussels. Trials have recently been conducted for the farming of the milk fish strain (Kuyui in Swahili) in marine waters. (FAO 2006b).

Culture practices in Tanzania include ponds, small tanks and the single raceway. The average size of the ponds is 150 m^2, covering a total of 211.5 ha. The total production estimated from extrapolation of these figures is 1,522.80 tonnes. There is only one commercial fish farm that produces the rainbow trout (*Oncorhynchus mykiss*), situated in Arusha. This farm is 25 m by 25 m in size. The production from this farm was 5 tonnes in 2002, 6 tonnes in 2003 and 7 tonnes in 2004. It is expected that production will increase to 15 tonnes by 2006 and 30 tonnes by 2007.

Tilapia and catfish are usually farmed in ponds and tanks. Rainbow trout was introduced in the rivers of the northern and southern highlands in the pre-colonial period. The main purpose was to stock the rivers for fishing for sport. In seaweed farming farmers practice the fixed off-bottom method. The raft method has also been tried on an experimental basis in the Tanga region.

According to the Fisheries Division, production of fresh water fish is estimated at 1,522.80 tonnes for tilapia, valued at US$ 1,327,637.30, while the actual production of rainbow trout was 7 tonnes in 2004, worth US$ 18,308.63. The production figure for cat fish is not known. The seaweeds are mainly for export and its production is 1,500 tonnes which earns US$ 209,241 (1 US$ = 1,147 TShs i.e. Tanzanian

Shillings). Efforts are also underway for cultivation of shrimp and other marine fin fish and non finfish organisms. (FAO 2006b).

The fish produced from aquaculture is consumed locally. Only one farmer is known to export farmed fish (rainbow trout) to a neighbouring country. Seaweeds are exported when dry to Denmark and the United States of America. The seaweed exporters buy dry seaweed from farmers and pack and export the product to the importing countries. The price per kilogram varies with species and distance from Dar es Salaam and is approximately between TShs 180 and 220 per dry weight kilogram of *K. cottonni* while that of *E. spinosum* and *E. striatum* varies between TShs 80 and 100.

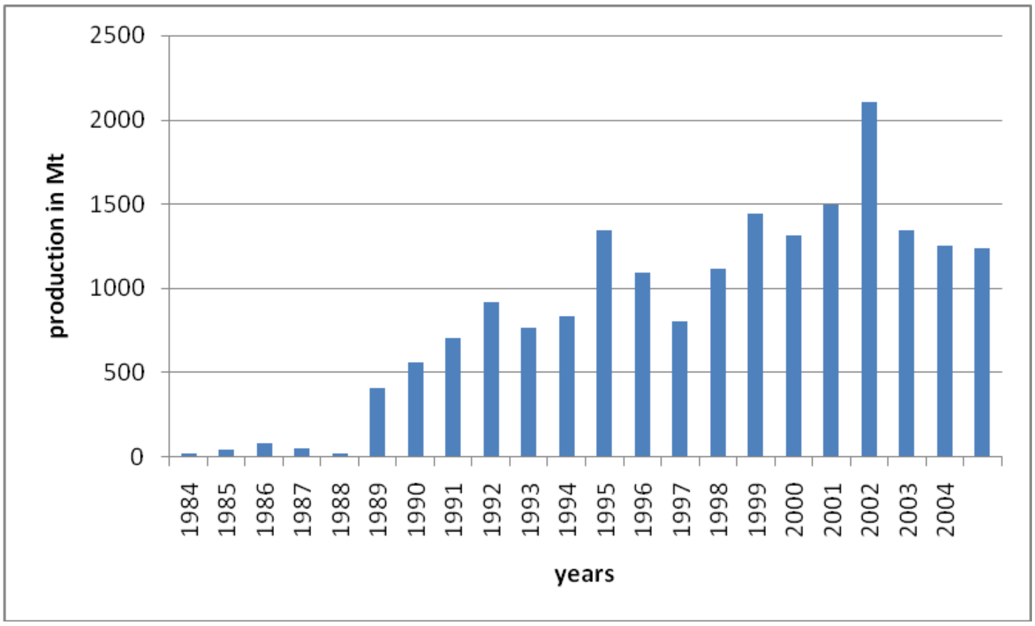


Figure 1: The graph below shows total aquaculture production in Tanzania according to FAO statistics 2006b (redrawn with data from FAO Fishery Statistics, Aquaculture Production).

The contribution of the aquaculture sector to national food security and economic development is still insignificant. Annual farmed fish production is extrapolated at 1,522.80 tonnes. This is about 0.435% of the average annual fish landings which is around 350,000 tonnes. The impact on poverty alleviation is therefore also insignificant. However, the possibility of an adverse impact on the environment is minimised since it is still at substance level. (FAO 2006b)

At present aquaculture is largely a subsistence activity practiced by poor households in the coastal and inland areas but the benefits arising from it are several: it contributes to people’s requirements for animal protein, particularly in the rural areas where there are no capture fisheries, and it provides employment opportunities and is a source of income. However, as capture fisheries are stagnating, the future for the United Republic of Tanzania lies in aquaculture and it should be commercialised in nature which calls for well researched information of better management practices of which water quality for any cultured species should be made available for success in aquaculture. Among the most important water quality parameters, oxygen plays a vital role in affecting growth of any cultured species i.e. too little or too much of it may be detrimental to the life of any cultured fish (Tanzania Fisheries Division 2006).

1.4 Motivation

Currently Tanzania has one major hatchery located within the Fisheries Division which is responsible for all the production of fry and fingerlings of tilapia to supply the farmers country-wide. However, trials are on going for the production of catfish fry and fingerlings and the Division is still registering high mortality rates of juveniles before they are supplied out to the farmers. The farmers are also facing fish stuntness in their ponds caused by poor water quality management. Water quality may be a major factor in the high mortality rates and therefore hopefully the knowledge obtained here can be used to monitor the water quality parameters to possibly solve this problem. (Tanzania Fisheries Division 2006)

1.5 Objective of the study

The main objective of the study was to gain knowledge of water quality management for commercialised aquaculture.

1.6 Goals of the study

To review the effects of oxygen on the growth and feed conversion of fish.

To measure the effects of oxygen on the growth and feed conversion of Atlantic Halibut (*Hippoglossus hippoglossus*).

1.7 Research questions

The main research questions to be answered were:

Does oxygen saturation have any effect on the growth rate of fish?
At which levels is the growth affected positively?
What is the effect of the oxygen saturation on the feed conversion ratio in fish?
At which saturation level is the feed conversion ratio best?

2 LITERATURE REVIEW

2.1 Water quality in aquaculture

Water quality is the totality of physical, biological and chemical parameters that affect the growth and welfare of cultured organisms. The success of a commercial aquaculture enterprise depends on providing the optimum environment for rapid growth at the minimum cost of resources and capital. Water quality affects the general condition of cultured organism as it determines the health and growth conditions of cultured organism. Quality of water is, therefore, an essential factor to be considered when planning for high aquaculture production.

Although the environment of aquaculture fish is a complex system, consisting of several water quality variables, only few of them play decisive role. The critical parameters are temperature, suspended solids and concentrations of dissolved oxygen, ammonia, nitrite, carbon dioxide and alkalinity. However, dissolved oxygen is the most important and critical parameter, requiring continuous monitoring in aquaculture production systems. This is due to fact that fish aerobic metabolism requires dissolved oxygen (Timmons *et al*. 2001).

2.2 Gas exchange and oxygen concentration in water

Oxygen as a gas has a low solubility in water. In addition, the amount of oxygen contained in water varies with temperature and salinity in a predictable manner. Less oxygen can be held in fully air-saturated warm sea water than fully air-saturated cold freshwater. While the oxygen content of the water sets the absolute availability of oxygen in the water, it is the oxygen partial pressure gradient that determines how rapidly oxygen can move from the water into the fish's blood to support its metabolic rate. This is because oxygen moves by diffusion across the gills of fish.

According to Fick's law of diffusion, the rate of diffusion of oxygen across the gills is determined by the gill area, the diffusion distance across the gill epithelia, the diffusion constant and the difference in partial pressure of oxygen across the gills (Crampton *et al*. 2003). Consequently, partial pressure of oxygen is the most appropriate term for expressing oxygen levels in aquaculture water. However, oxygen concentration is the more commonly used term and, for a given temperature and salinity, the partial pressure of oxygen and oxygen content in water are linearly related. Another suitable method for expressing oxygen levels in aquaculture is % air saturation (often reduced to just % saturation) which is directly proportional to the partial pressure and is reported on most oxygen probes that have built in algorithms for temperature and salinity (Bergheim *et al*. 2006). In this study % saturation was used.

2.3 Oxygen uptake in and carbon dioxide release from the fish

During respiration fish, like other animals, take in oxygen and give out carbon dioxide. The process is done by using gills in almost all fish although some can also use the skin and some have lung like structures used in addition to gills. When a fish respires, a pressurised gulp of water flows from the mouth into a gill chamber on each side of the head. Gills themselves, located in gill clefts within the gill chambers, consist of fleshy, sheet like filaments transected by extensions called lamellae. As water flows across the gills, the oxygen within them diffuses into blood circulating through vessels in the filaments and lamellae. Simultaneously, carbon dioxide in the fish's bloodstream diffuses into the water and is carried out of the body (see Figure 1 below).

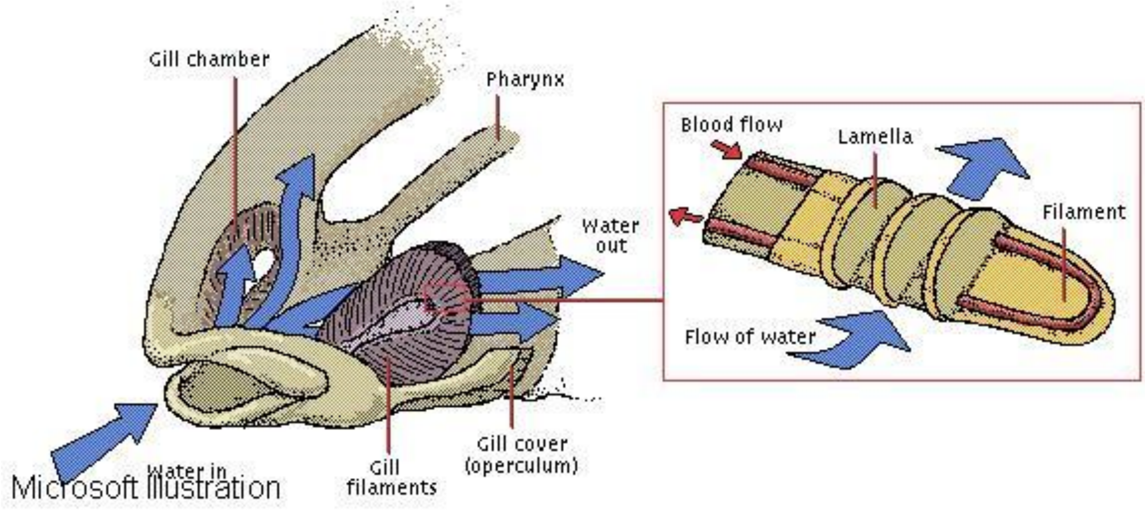


Figure 2: Diagram showing the structure for respiration (gas exchange) in fish. (Source: Microsoft Encarta.1993-2002. www.kwic.com 2008-02-08).

2.3.1 Function of fish gills

For most fish species gills work by a unidirectional flow of water over the epithelial surface of the gill, where the transfer of gases occurs (O_2 in, CO_2 out). The reason for this unidirectional flow of water is the energetic nature of the system. The energy that would be required to move water into and out of a respiratory organ would be much more than that used to move air because water holds low oxygen due to its low solubility (Groot *et al.* 1995).

The blood flowing just under the epithelial gill tissue usually moves in a counter current flow to that of the water moving over it. This allows for most of the O_2 to be taken in by the blood because the diffusion gradient is kept high by the blood picking up oxygen as it moves along, but always coming into contact with water that has a higher O_2 content. The blood receiving the O_2 continues to pick up O_2 as it moves along because fresh water is being washed over the epithelial lining of the gills (Jobling 1995). By doing so, the fish ventilate the gills while also taking in oxygen and releasing carbon dioxide (Groot *et al.* 1995).

However there are two ways fish ventilate their gills: buccal/opercula pumping (active ventilation) and ram ventilation (passive ventilation). In buccal/opercula ventilation the fish pull in water through the mouth (buccal chamber) and push it over the gills and out of the opercula chamber (where the gills are housed). At this time the pressure in the buccal chamber is kept higher than the pressure in the opercula chamber so as to allow the fresh water to be constantly flushed over the gills.

In ram ventilation, a fish swims with its mouth open, allowing water to wash over the gills. This method of ventilation is common to fast moving fish, and it enables tuna to keep enough oxygen going to the gill surface while swimming at high speed (Boyd and Tucker 1998). During this time the oxygen is absorbed into the blood while carbon dioxide diffuses out of the blood to the water.

Groot *et al.* (1995) have described the pathway taken by carbon dioxide and explain that, in the blood, CO_2 is transported in the form of bicarbonate. The bicarbonate moves from the blood by passing through the erythrocytes in which O_2 binds to Haemoglobin (Hb) at the respiratory surface, causing hydrogen ions (H^+) to be released. The increase in H^+ ions combines with HCO_3^- to form CO_2 and OH^-. Thus, more CO_2 is formed and can leave the blood across the respiratory surface. Excess H^+ binds to OH^-, forming water and allowing the pH to increase enough to promote the binding of oxygen to Hb. The release of O_2 from Hb in the tissues makes the Hb available to bind to H^+, promoting the conversion of CO_2 to HCO_3^-, which helps draw CO_2 from the tissues. Therefore, CO_2 that is being transported into and out of the red blood cells minimises changes in pH in other parts of the body because of proton binding and proton release from haemoglobin, as it is deoxygenated and oxygenated, respectively. However, carbon dioxide is rarely a problem in when dissolved oxygen concentrations are well above saturation levels. Due to these processes, oxygen level should be kept at or a little bit higher during the entire culture period.

2.4 Effects of oxygen levels on oxygen uptake by fish

It is commonly thought that if there is not enough oxygen in the water, then the fish will be seen gasping at the surface but this is a last resort means to breathe. The first indication there may be a dissolved oxygen problem in the water is when the fish become unusually lethargic and stop feeding. As oxygen levels decrease, the fish do not have enough energy to swim and feeding utilises yet more oxygen. Often it is recognised the fish have a problem at this stage but frequently some form of medication is added to the water and this can actually cause the oxygen level to drop even lower, leading to a number of mortalities. This can lead to the mistaken conclusion that the fish were suffering from some form of disease. In terms of managing any aquatic system, it is always advisable to increase the aeration when any fish start to behave abnormally, before adding any form of medication to the water. Increasing the aeration will certainly make the environment more comfortable for the fish, even if the dissolved oxygen level was already satisfactory. With respect to improving the aeration before adding medication, this will allow for any depletion of the oxygen level caused through a chemical reaction with the medication
.
The recommended minimum dissolved oxygen requirements are as follows:
Cold water fish - 6 mg per litre (70% saturation)
Tropical freshwater fish- 5 mg per litre (80% saturation)
Tropical marine fish- 5 mg per litre (75% saturation)

It is worth bearing in mind that these values are minimum requirements for healthy growth, tissue repair and reproduction (Svobodova *et al.* 1993). Most fish species will tolerate a drop below these minimum values for a short period of time, probably the cold water species are likely to tolerate a lower level than tropical fish. However, the period of time during which the oxygen level drops below the required minimum level, will cause the fish to become stressed. It is this stress which causes fish death. It may take the fish several days to recover from short term oxygen depletion but where the levels are persistently low, an assortment of stress related diseases such as fin rot and white spot may occur.

2.4.1 Fish response to hypoxia

Hypoxia or oxygen depletion is a phenomenon that occurs in aquatic environments as dissolved oxygen (DO; molecular oxygen dissolved in water) becomes reduced in concentration to a point detrimental to aquatic organisms living in the system. Dissolved oxygen is typically expressed as a percentage of the oxygen that would dissolve in the water at the prevailing temperature and salinity (both of which affect the solubility of oxygen in water). An aquatic system lacking dissolved oxygen (0% saturation) is termed anaerobic. Reducing or anoxic is a system with a low DO concentration in the range between 1 and 30%. DO saturation is called hypoxic. Most fish cannot live below 30% DO saturation. A "healthy" aquatic environment should seldom experience DO of less than 80%. In response to a low concentration of dissolved oxygen in the water, the fish can respond in two ways: the blood flow can be increased by opening up further secondary lamellae to increase the effective respiratory area (it may be difficult to increase significantly the blood flow rate through the capillaries themselves), and the concentration of red blood corpuscles can be increased to raise the oxygen carrying capacity of the blood per unit volume. The latter can be achieved by reducing the blood plasma volume (e.g. by increasing the urine flow rate) in the short term, and by releasing extra blood corpuscles from the spleen in the longer term. (Svobodova *et al.* 1993)

At the same time, the ventilation rate is increased to bring more water into contact with the gills within a unit of time. There are, however, limits to the increased flow attainable; the space between the secondary lamellae is narrow (in trout it is about 20 μm) and water will tend to be forced past the tips of the primary lamellae when the respiratory water flow is high, thus by-passing the respiratory surfaces.

These reactions are quite adequate to compensate for the normal fluctuations of energy demands of the fish and of dissolved oxygen concentrations in the water. One of the consequences, however, of an increased ventilation rate is that there will be an increase in the amount of toxic substances in the water reaching the gill surface where they can be absorbed (Boyd and Tucker 1998).

However, oxygen deficiency causes asphyxiation and fish will die, depending on the oxygen requirements of the species and to a lesser extent on their rate of adaptation. Fish exposed to oxygen deficient water do not take food, collect near the water surface, gasp for air (cyprinids), gather at the inflow to ponds where the oxygen levels are higher, become torpid, fail to react to irritation, lose their ability to escape capture and ultimately die. The major pathological-anatomic changes include a very pale skin colour, congestion of the cyanotic blood in the gills, adherence of the gill lamellae, and small haemorrhages in the front of the ocular cavity and in the skin of the gill covers. In the majority of predatory fish the mouth gapes spasmodically and the operculum over the gills remains loosely open. (Svobodova *et al.* 1993)

More than that, fish reduce food intake, leading to a reduction in growth. Reproduction is inhibited, and both fertilisation success and larval survival are compromised. Energy utilisation is decreased, associated with a shift from aerobic to anaerobic metabolism. To reduce energy expenditure under this situation, fish move to water at lower temperature, and reduce activity, reproduction, feeding, and protein synthesis. Transcription is reduced, mediated by increased levels of hypoxia-inducing factor 1 (HIF-1), which also up-regulates genes involved in erythropoiesis, capillary growth and glucose transport. All these responses are directed at maintaining cellular oxygen homeostasis and reducing energy expenditure, thereby augmenting survival of the animal during hypoxia. In general, the actions of toxicants are exacerbated during hypoxia, through a variety of mechanisms. Some species are much more tolerant of hypoxia than others, leading to differential survival during extended periods of hypoxia (Poon *et al.* 2002). To avoid this, aquaculture systems have to be supplied with enough oxygen saturation. However, too much oxygen is also harmful to fish.

2.4.2 Fish response to hyperoxia

Hyperoxia is the state of water when it holds a very high amount of oxygen. At this state, water is described as having a dissolved oxygen saturation of greater than 100%. This percent can be 140-300%.

At this water condition, oxygen molecules will begin to move around within the water column looking for a little elbowroom. If there is non available, it will return to the atmosphere or attach to the organisms around (Florida Lake Watch 2004).

If fish are exposed (at a lower atmospheric pressure) to such water, their blood equilibrates with the excess pressure in the water. Bubbles form in the blood and these can block the capillaries; in sub-acute cases the dorsal and caudal fin can be affected, and bubbles may be visible between the fin rays. The epidermal tissue distal to the occlusions then becomes necrotic and cases are known where the dorsal fins of trout have become completely eroded. In severe cases, death occurs rapidly as a result of blockage of the major arteries, and large bubbles are clearly seen between the rays of all the fins. The remedy is either to remove the fish to normally equilibrated water or to provide vigorous aeration to strip out the excess gas (Svobodova *et al.* 1993). In some species such as salmons and fast swimming fishes, the swim bladder acts like an oxygen store, to be used during the hypoxia. When the gads level in the blood is high gases will diffuse from the blood to the bladder. When the water is supersaturated (hyperoxia) the bladder becomes over-inflated and this leads to buoyancy problems especially in small fishes (Groot *et al.* 1995).

2.5 Effects of oxygen level on growth and food conversion ratios of fish

Successful fish production depends on good oxygen management. Oxygen is essential to the survival (respiration) of fish, to sustain healthy fish and bacteria which decompose the waste produced by the fish, and to meet the biological oxygen demand (BOD) within culture system. Dissolved oxygen levels can affect fish respiration, as well as ammonia and nitrite toxicity. When the oxygen level is maintained near saturation or even at slightly super saturation at all times it will increase growth rates, reduce the food conversion ratio and increase overall fish production.

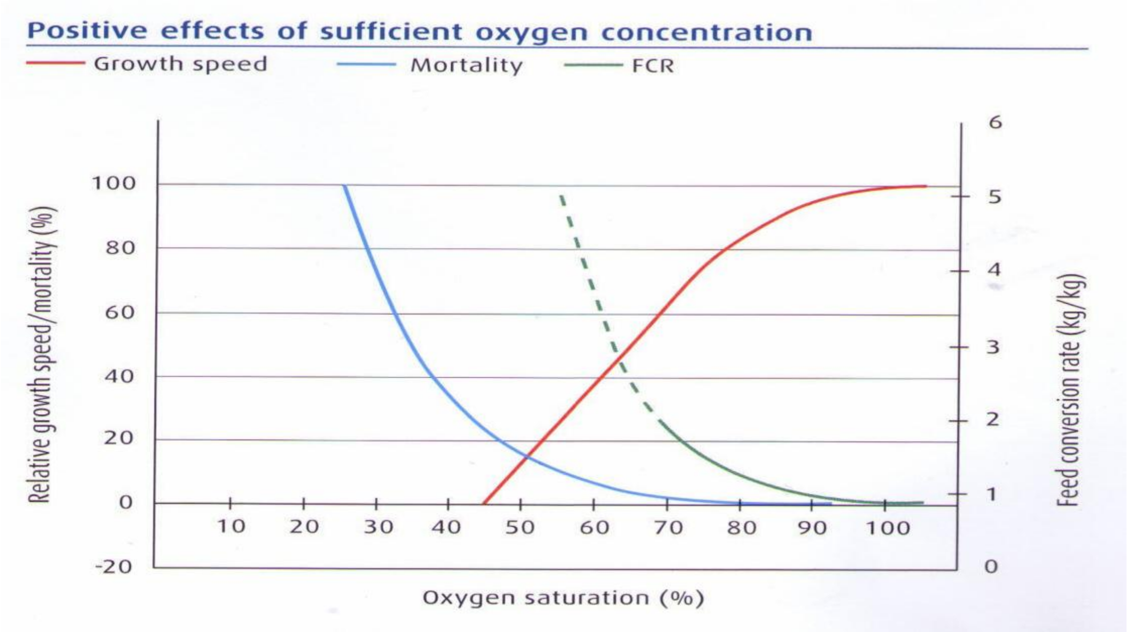


Figure 3: The effect of oxygen level on growth and food conversion ratios. (Linde-gas 2007).

2.5.1 Effect of oxygen on fish growth

Oxygen is important in respiration and metabolism processes in any animal. In fish, the metabolic rate is highly affected by the concentration of oxygen in the rearing environment. As the dissolved oxygen concentration decreases, respiration and feeding activities also decrease. As a result, the growth rate is reduced and the possibility of a disease attack is increased. However, fish is not able to assimilate the food consumed when DO is low (Tom 1998).

Overall health and physiological conditions are best if the dissolved oxygen is kept closer to saturation. When the levels are lower than those mentioned above, the growth of the fish can be highly affected by an increase in stress, tissue hypoxia, and a decrease in swimming activities and reduction in immunity to diseases.

However, there is a need to maintain the level of dissolved oxygen at the saturation level which will not affect its physiological or metabolic activities, so as to have high production in any culture system (Wedemeyer 1996). More than that, one has to keep in mind that the oxygen level requirement depends on the species, but also on fish size and activity of the fish.

According to Tom (1998) oxygen requirements per unit weight of fish significantly decline with increasing individual weight. In carp this reduction may be expressed by the following ratios: yearling = 1, two-year-old carp = 0.5–0.7, marketable carp = 0.3–0.4. Significant differences in oxygen demand are also found for different species. Using a coefficient of 1 to express the oxygen requirement of common carp, the comparative values for some other species are as follows: trout 2.83, peled 2.20, pike perch 1.76, roach 1.51, sturgeon 1.50, perch 1.46, bream 1.41, pike 1.10, eel 0.83, and tench 0.83.

Several studies have investigated the relationship between oxygen saturation and fish food intake. Randolph and Clemens (1976) found that feeding patterns of channel catfish varied with temperature and oxygen availability. When the oxygen content drops below 59% fish starts to lose its appetite. Rainbow trout (*Oncorhynchus mykiss*) reduced its appetite when oxygen saturation fell below approximately 60% (Jobling 1995). Similar results have been obtained from European sea bass (*Dicentrarchus labrax, L*) (Thetmeyer *et al*. 1999) blue tilapia (*Oreochromis aureus*) (Papoutsoglou and Tziha 1996) channel catfish (*Ictalurus punctatus*) (Buentello *et al*. 2000), juvenile turbot (Pichavant *et al.* 2001) and common carp (*Cyprinus carpio. L*), showed reduced growth when exposed to low oxygen levels.

2.5.2 Effect of oxygen on the food conversion ratio in fish

Tolerance for low oxygen may relate in part to the metabolic rate of a fish (Verheyen and Decleir 1994). Fishes will regulate their metabolic rate over a range of dissolved oxygen concentrations; however, at some point, a further reduction in oxygen tension will produce a shift from a metabolic rate that is independent of oxygen concentration to one that is dependent on oxygen level. The point is referred to as the critical oxygen tension (Ultsch *et al*. 1978).

Decreased oxygen availability is also considered a major factor in determining food intake. Low dissolved oxygen is a type of stress frequently found in fish farms characterised by high fish densities and polluted fresh or marine waters. The food conversion ratio (FCR) is the amount of fish food consumed to generate a given weight gain. It is the ratio between the weights gained in a given period to the total feed intake by the fish in the same period. It is the inverse of the feed intake. The food conversion ratio is improved (lowered) at higher growth rates (Markore and Rorvik 2001, Crampton *et al*. 2003, Norgarden *et al*. 2003).

The average FCR from several recent studies of fish growth is 0.97. In most cases, the FCR appears to be slightly lower for tank studies (mean: 0.93) than for net-pen studies (mean: 1.02). The industrial average FCR values in Scotland and Chile were 1.28 and 1.26 respectively (Neuman *et al*. 2004). The best FCR in Scotland was 0.99 while Chile’s best came in at 1.1. Kreiberg and Brenton-Davie (1998) report an FCR of 0.99 for Atlantic salmon in a Sea Systems floating bag. An experiment done on tilapia (*Oreochromis niloticus*) showed that FCR was inversely proportional to the dissolved oxygen level (1.45 at higher dissolved oxygen level and 6.75 at lower dissolved oxygen level) (Tsadik and Kutty 1987).

Bromage *et al*. (2000) showed that halibut are capable of achieving a 1:1 food conversion ratio (FCR).

2.5.2.1 Tilapia (Oreochromis niloticus)

It is well known that tilapia can tolerate hypoxic and even anoxic conditions for short periods and are thus better suited than other species to hypereutectic conditions that may exist in static water aquaculture systems (Chorn *et al.* 2006). It is also known that fish found both in the tropics and temperate waters have incipient limiting oxygen levels which may occur as in hypoxia. Incipient limiting levels generally average at 73 mmHg (2.29 g/l at 28°C for warm water fish and 90 mmg/l at 6.17 mg/l for cold water fish such as the salmonids)

In reference to *Oreochromis niloticus,* studies have shown that the incipient oxygen requirements are between 1.39 mg/l -2,92mg/l.

Studies done by Tsadik and Kutty (1987) on the influence of ambient oxygen on feeding and growth in *O. niloticus* showed that experiments under the various oxygen regimes varied as shown in Figures 3 and 4 below.

The increase in mean weight of individual fish during the course of the growth tests for the high, medium and low levels of DO is shown in Figure 3. The fastest rate of growth was at high DO and the slowest growth in the low DO.

Figure 4 shows the changes in mean weight of fish under the two tests at high DO and the two tests at fluctuating DO. It is obvious that the difference in the conditions of the two tests at high DO (demand feeder and manual feeding) or at low DO (fish fed with demand feeder and no supplementary feed) has not made any serious difference in the growth within the sets, but the difference in growth of high DO tests and fluctuating DO tests were marked.

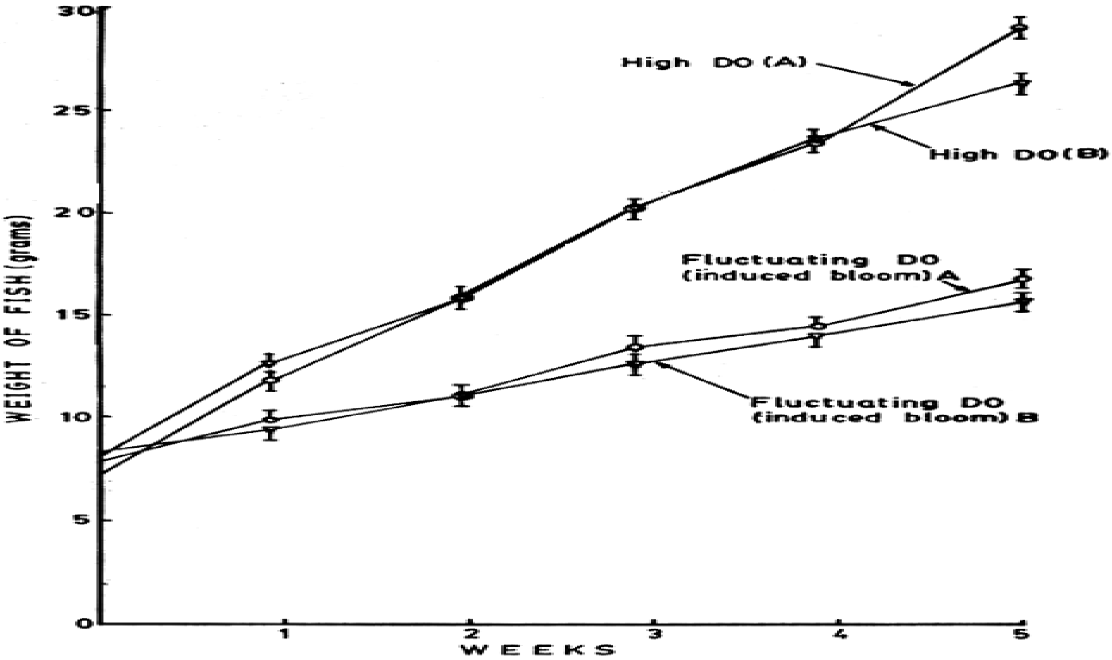


Figure 4: Weight increase of *O. niloticus* grown under high ambient oxygen (near air saturation) and under simulated conditions of diel flux in oxygen. Data from 2 separate sets of experiments (A and B) are indicated. Curves drawn through mean values (± SD; n = 8) indicated (see test). (Source: Tsadik and Kutty 1987)

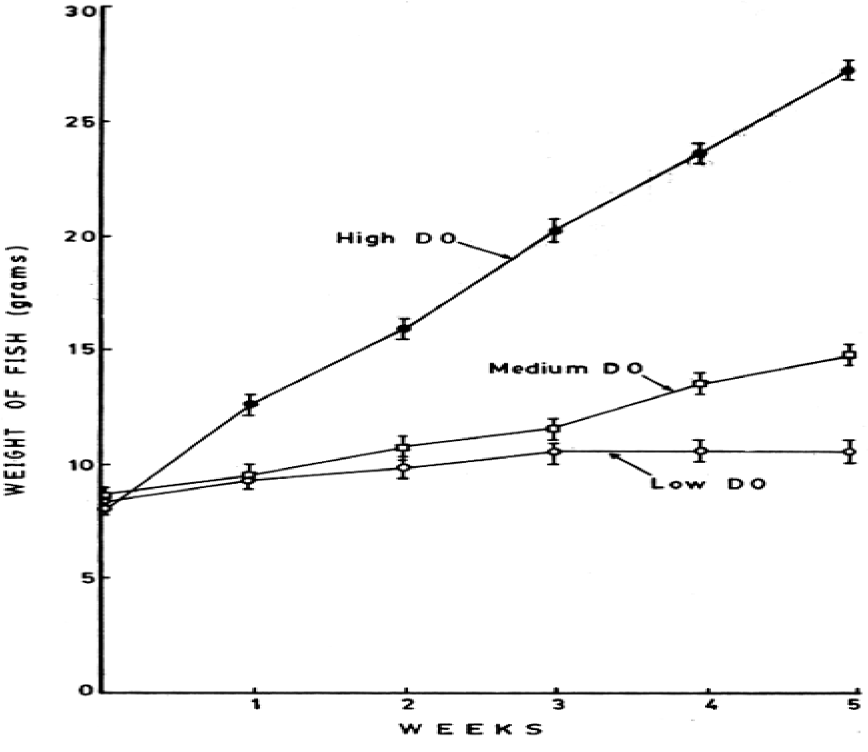


Figure 5: Increase in weight of *O. niloticus* grown under high (near air saturation), medium and low ambient oxygen. Mean values (± SD; n = 8) are indicated (Source: Tsadik and Kutty 1987).

2.5.2.2 Cat fish culture (*Clarias gariepinus)* water quality requirements

More than 100 species of the genus *Clarias* have been described all over the world. In Tanzania the family Clariidae has only one native species the African catfish *Clarias gariepinus* (Burchell 1822) (Synonyms: *Clarias lazera* and *Clarias mossambicus*) have recently been introduced in this country.

Table 1: Water quality requirements of African catfish

	Eggs, larvae early fry	Advanced fry (Tolerance)	Fingerlings/adults
O_2	80–100% saturation	3–5 ppm	>3 ppm
Temperature	opt. 30°C	opt. 30°C	opt. 26–28°C
NH_3-N		0.1 ppm (1.0 ppm)	
NO_2-N		0.5 ppm	
NO_3-N		100 ppm	
Ph		6–9	
CO_2-C		6 ppm (10–15 ppm)	
Salinity		10 ppt. (15–16 ppt)	

(Source FAO repository paper 2006b).

2.5.2.3 Oxygen deficiency

African catfish has lung like structures that enable them to breathe air. This made it possible to survive very low oxygen levels in the pond. However, when African catfish is under mixed or polyculture, oxygen level is important for the species mixed with in the pond.

3 MATERIALS AND METHODS

3.1 Study area

The study was conducted at Verid the Holar University College research centre in Saudarkrokur in January and February 2008

3.2 Experimental fish

Juvenile halibut was obtained from Frisky hatchery in Akureyri Iceland. The fish were transported from Akureyri to Verid in a tank while oxygen saturation was maintained at 400% and temperature at 5ºC. The fish were then acclimatised for two weeks under 99.5-106% oxygen saturation, and 18pp salinity and 8.5-10ºC temperature.

At the start of the third week the fish were starved for two days before they were individually measured to obtain the initial weight. During the measurement, the fish were anasethised using Tricaine methane sulfonate (TMS) used in the ratio of 40-50 mg per litre of water. 150 fish were individually tagged intraperitoneally with Trovan Passive Transponder tags. In total, 300 fish were individually tagged. The fish were then distributed into 12 tanks (Figure 2) each with 25 tagged and 25 not tagged fish.

3.3 Experimental design

The fish were exposed to five different levels of oxygen saturation. The target saturation value in each group was 60%, 80%, 100%, 120% and 140%.

The system consists of 12 culture tanks, three reservoir tanks, three aerators which are combined with low head oxygenator (LHO) and three pumps (Figure 6).

The fish were reared in 7 m^3 fibre glass tanks. Water was delivered to the tank through PVC pipe and water flow can be adjusted by the valve (See Appendix 1). The water level in the tanks was adjusted by varying the height of external stand pipes. The culture tank has a central drainage system at the bottom through which water flows out to the reservoir tank. The water flows from the central drainage passes through the wire mesh where the remaining feed pellets were collected, and then the water goes through the PVC pipe back to the reservoir tank.

The reservoir tanks are about 460 litres and are made of high density polyethylene (HDPE). From the reservoir tank, water from the culture tank mixes with the fresh water from the inlet and is then pumped to the aerator which is combined with a low-head oxygenator (LHO). A pinnacle 75 pump with 0.55 kWh is plumbed one to each reservoir tank. The pump delivers the water to the aerator from the reservoir tank (Figure 6). The aerator and low head oxygenator (LHO) is a single unit. The aerator adds oxygen to the water and removes carbon dioxide while the LHO adds more oxygen to the water inside the aerator. A fan draws air through the aerator counter current to the direction of the water flow in the proportions of 1 volume water to 10 volumes air. Then the water flows through the LHO column where oxygen gas elevates the oxygen saturation of the water. The system can elevate the oxygen saturation to over 120% air saturation.

3.3.1 Oxygen levels in the system

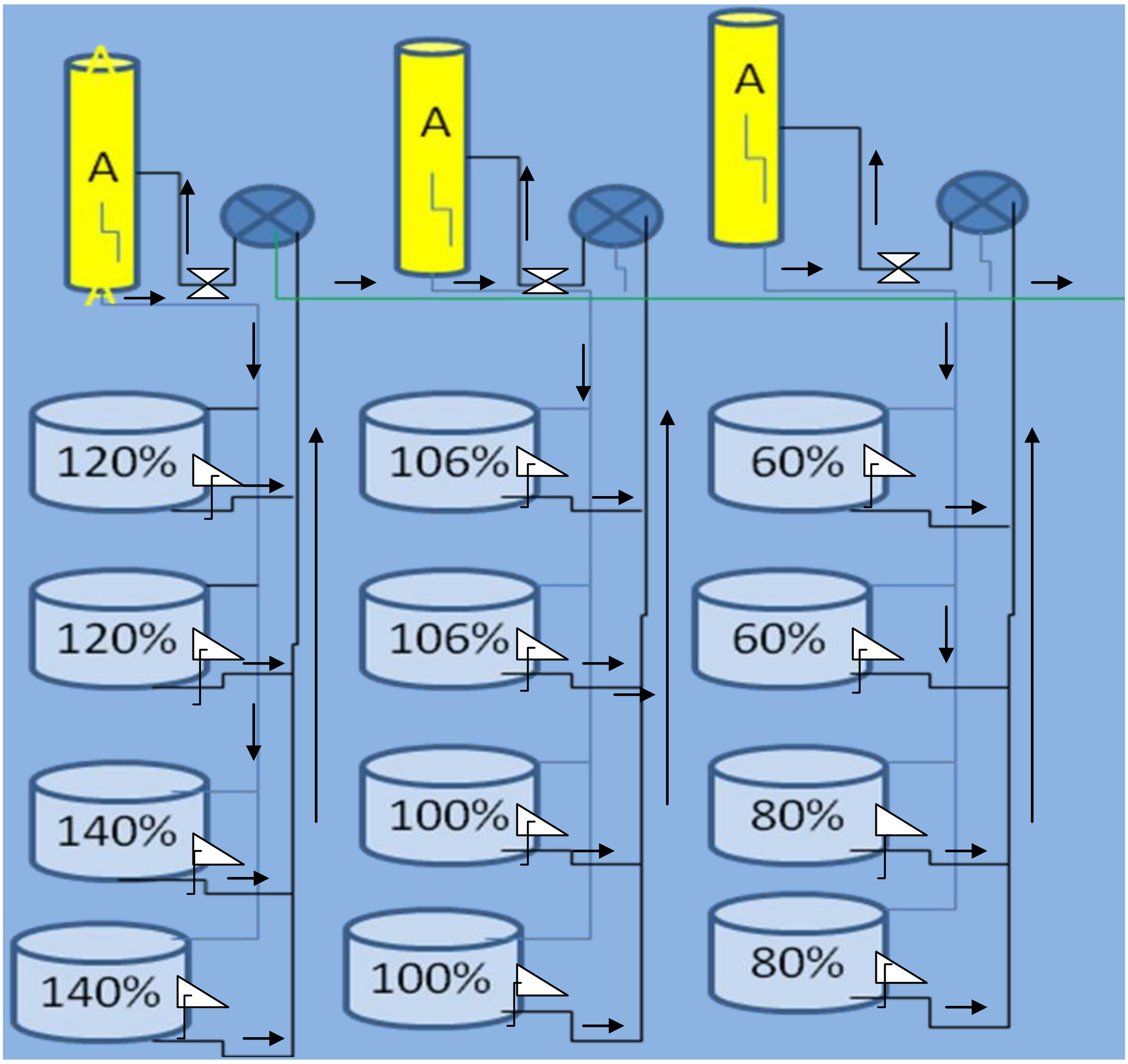
In total there were 12 tanks in the system used. The target oxygen saturation was 60%, 80%, 100%, 120% and 140% (Figure 6). The oxygen saturation in the tanks was regulated as follows.

The system consisted of three tank rows, each with four fish tanks (Figure 6). The first row had 60% and 80% oxygen saturation. The saturation levels were obtained by injecting nitrogen gas to the LHO which supplies water to the four tanks to reduce the saturation from 100% to 60% saturation. The nitrogen gas was added from a gas tank through a hose connected to the LHO. The amount of the gas injected was regulated from the nitrogen gas tank. However, in addition to the nitrogen gas, oxygen gas was added directly to two of the fish tanks in the row to raise the saturation level to 80%.

The oxygen saturation in the fish tanks in the second row was set at 100-106% saturation by injecting oxygen into the LHO.

In the third row, the oxygen saturation of water from the LHO was increased to 120% through injection of oxygen. Furthermore, oxygen gas was added directly to two tanks to raise the saturation level to 140%.

The oxygen gas was added through a hose from the oxygen tanks, the tail of the hose was connected to the gas tank while the head was connected to the rectangular wood diffuser. The piece of wood was used to make very small fine air bubbles of oxygen gas. The small air bubbles are known to increase oxygen transfer by increasing the surface area for oxygen diffusion. Oxygen saturation was measured using (YSI 550) probe while salinity was measured using PAL made in Japan pocket refract meter.



Legend:

A= Aerator and Low-head oxygenator

⊗ = Reservoir tanks

= Outlets

=Inlets

=Water pump

=Pellet collector plate

→ =Direction of water.

Figure 6: The arrangement of the tank system used in the experiment, showing the oxygen saturation levels, inlet and outlet pipes, water pumps, food collector plates and aerators.

3.4 Sampling and measurements

The body mass and growth performance were measured every two weeks, while oxygen saturation, temperature and salinity were recorded daily.

3.4.1 Specific growth rate

Weight measurements were taken every two weeks to obtain the specific growth rate (SGR). Prior to measuring the fish were starved for two days. Both the individual tagged and untagged fish were weighed. Both the initial weight and final weight of the fish were used to calculate the growth performance in terms of SGR.

The SGR of individually tagged fish was calculated as follows:

$\%SGR = [(\ln w_2 - \ln w_1) / (t_2 - t_1)] * 100$

Where w_1 and w_2 are the initial and final weights of the fish at times t_1 and t_2 respectively.

3.4.2 Feeding and the collection of leftover feed

The fish were fed manually commercial (Laxa Feed Mill, Akureyri) feed pellets (2.5 mm) four times each day. Following feeding the remaining pellets were collected from a feed trap on the outflow from each tank and counted. The average weight of a sample of 100 fresh pellets was 0.0148 g and based on that it was possible to calculate the original weight of the remaining pellets (Fr) before they were soaked in water.

3.4.3 Feed conversion ratio (FCR)

The total amount of feed consumed (CT) was calculated as:

CT = Amount of feed fed – (number of uneaten pellets x mean weight of pellet)

Feed conversion rate (FCR) indicates how much feed is required for each unit gain in weight.

FCR = CT / increase in body mass during the same time

4 RESULTS

4.1 Growth

There was no significant difference in growth rate of the Atlantic halibut reared at different oxygen saturation levels (Figure 7) during the first period (SGR1). However, there was a significant difference ($p<0.02$) in the growth rate of the fish during the second period (SGR2). Then the SGR of fish reared at 100% saturation was significantly higher than that of fish reared at either 60% or 140% saturation.

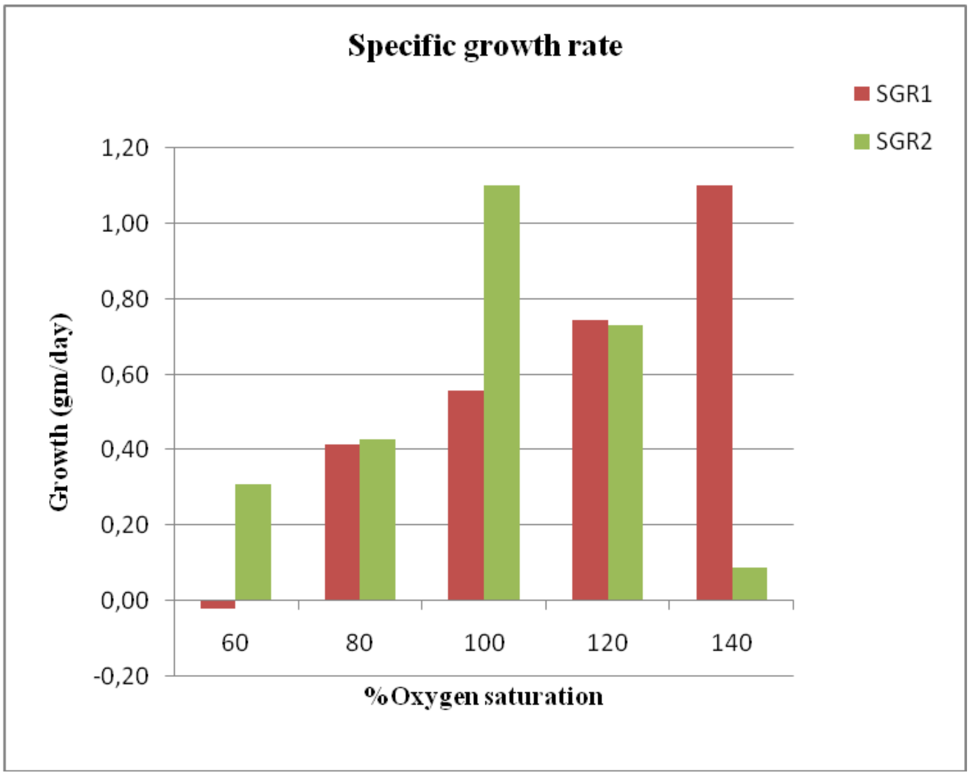


Figure 7: The graph showing the specific growth rate (SGR) of Atlantic halibut reared at different oxygen saturation levels.

4.2 Feed conversion ratio (FCR)

There was no significant difference in FCR of fish reared at different oxygen saturation levels (Figure 8). However, the FCR was lowest at 100% and 120% saturation.

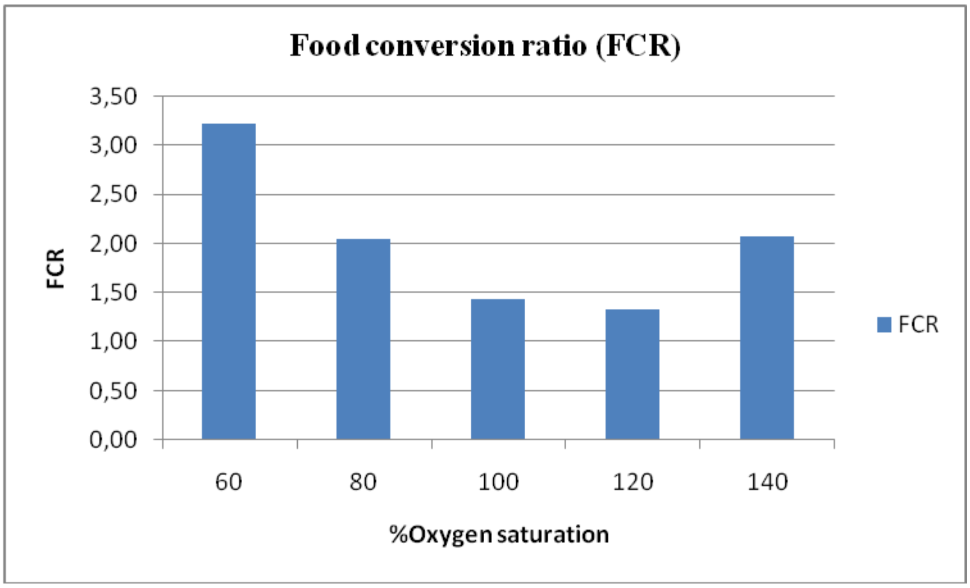


Figure 8: The feed conversion ratios (FCR) of Atlantic halibut reared at different oxygen saturation levels.

5 DISCUSSION

The results of the experiment under different oxygen levels clearly showed that growth is affected by the level of oxygen saturation. During the second period the SGR was highest at 100% saturation. The best FCR was obtained in the groups with the highest growth rate although there was no significant difference in FCR of fish reared at different oxygen saturation levels. The growth of other species of fish is also affected by oxygen saturation such as tilapia (Tsadik and Kutty 1987) and Atlantic salmon (Crampton *et al*. 2003, Seymour *et al.* 1992, Forsberg and Bergheim 1996). The growth of Atlantic halibut and Atlantic salmon increases with increasing saturation up to 100% saturation. However, these species appear to be more sensitive to oxygen saturation than tilapia.

6 CONCLUSIONS

The results suggest that oxygen saturation levels affect both growth performance and feed conversion ratios of Atlantic halibut. The maximum growth rate and lowest feed conversion ratio in Atlantic halibut can be attended at higher oxygen saturation levels between 90% and 120%. However, more research is needed in order to know at which saturation point the growth is maximised.

Regarding future experimental work the results of this trial should be reconfirmed and given more time so that more observations can be made. The actual oxygen saturation point at which Atlantic halibut has maximum growth should be identified, hence more experimentation is needed.

ACKNOWLEDGEMENTS

I would like to express my gratitude to all the people who were involved and have made the culmination of this project possible, for their kind help.

To my supervisor, Prof. Helgi Thorarensen from Holar University College for his valuable guidance and advice. I would also like to thank the technical staff at Saudarkrokur, Holar University College for giving me the opportunity to use their installations and equipments, also for their assistance during the experimental period. I am also grateful to Arnthor Gustavsson and Ingolfur Arnarson from Holar University for their help in the experimental design and weighing the fish which I could not have managed alone.

I am indebted to Dr. Tumi Tomasson, Director of the UNU-FTP and Mr. Thor Asgeirsson, Deputy Director and Sigridur Kr. Ingvarsdottir for their valuable assistance, care and guidance before and during the project.

I would also like to thank my UNU fellows in the aquaculture speciality whose encouragement enabled me to do the work even when I felt like giving up.

I would like to thank my Director Mr. Geoffrey Nanyaro at the Tanzanian Fisheries Division for having given me leave which made it possible to accomplish this study.

Last, but not least, to my family, for their great concern and love all the time that I spent here in Iceland. Special thanks are given to my lovely husband for his love, encouragement and concern during the time I was away from home.

LIST OF REFERENCES

Balarin, J.D., 1985. National reviews for aquaculture development in Africa. 10. Uganda. FAO Fish.Circ., (770.10):109p.

Bergheim A. Martin G. Anders N., Per M., Holland, Per Krogedal and Viv Crampton. 2005. *A newly developed oxygen injection system for cage farms.* Aquacultural Engineering 34(2006) 40-46

Bjornsson B. and Tryggvadottir SV. 1996. Effects of size on optimal temperature for growth and growth efficiency of immature Atlantic halibut (Hippoglossus hippoglossus L.). *Aquaculture* 142: 33-42.

Boyd C.E. and Tucker C.S., 1998. *Pond Aquaculture Water Quality Management*, Kluwer Academic Publishers, Boston, MA (1998) 700 pp .

Bromage, N., Mazorra, C., Bruce, M., Brown, N. and Shields, R., 2000. Halibut culture. In: Stickney, R.R., Editor, , 2000. *Encyclopedia of Aquaculture*, Wiley, New York, pp. 425–432.

Buentello, J.A., Gatlin III, D.M., Neill, W.H., 2000. Effects of water temperature and dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish (Ictalurus punctatus). Aquaculture 182, 339–352.

Chorn E. Lim *et al* . 2006. Feeding Practices. The Hawthorn Press. 547-559.

Crampton V., A. Bergheim, M. Gausen, A. Næss, and P. M. Hølland *(2003) Effect of low Oxygen on fish performance. (www.ewos.com*).

FAO 2006a. State of world fisheries and Aquaculture. FAO report 2006

FAO 2006b. *Aquaculture Production in Tanzania* FAO Fishery Statistics, Aquaculture production 2006)

Fisheries Division Tanzania 2007.*Status of Aquaculture in Tanzania.*

Florida Lake watch 2004.The beginners guide for water management oxygen and temperature. Department of Fisheries and Aquatic Sciences Institute of Food and Agricultural sciences. University of Florida, Fist edition.

Forsberg O.I. and Bergheim A. 1996. The impact of constant and fluctuating oxygen concentrations and two water consumption rates on post-smolt Atlantic salmon production parameters, *Aquacult. Eng.* **15** (1996), pp. 327–347.

Groot .C. Margolis L., and W.C. Clarke 1995. *Physiology, Ecology of pacific salmon*. Department of Fisheries and oceans, Biological sciences Branch Pacific biological station Nanaimo, British Columbia, Canada.

Groot C., Margolis L., and Clarke.1995. *Physiological Ecology of Pacific Salmon* Department of Fisheries and oceans, Biological sciences Branch Pacific biological station Nanaimo, British Columbia, Canada.

Jobling M. 1995. *Environmental biology of fishes*. Chapman and Hall Fish and fisheries series 16.

Kreiberg, H., Brenton-Davie, V., 1998. Seawater growth of Atlantic salmon in SEA System^{sTM} floating bag. *Aquaculture* Update 81: 1-2.

Linde – gas 2007. http://www.lindegas.com [Dec 2006]

Microsoft Encarta.1993-2002. www.kwic.com *Respiration in fishes.* Microsoft incarta.copyright 1993-2002 Microsoft Corporation.

Morkore, T. and Rorvik, K.-A., 2001. Seasonal variations in growth, feed utilisation and product quality of farmed Atlantic salmon (Salmo salar L.) transferred to sea water as 0+ smolts or 1+ smolts. *Aquaculture*, 199, 145–158

Moyle B. P and Cech J.J.Jr 2000. *Fishes an introduction to Ichthyology Fourth edition* .Upper Saddle River NJ 07458.

Neuman, J., Weir, M., Beattie, C., 2004. Skretting in the UK and Chile: *An opportunity for comparison.* Skretting Outlook 21: 8-11

Nordgarden, U., Oppedal, F., Taranger, G.L., Hemre, G.-I and Hansen, T. 2003. Seasonally changing metabolism in Atlantic salmon (Salmo salar L.). *Aquac. Nutr*. 9: 287-289.

Papoutsoglou S.E. and Tziha G. 1996. Blue tilapia (*Oreochromis aureus*) growth rate in relation to dissolved oxygen concentration under recirculated water conditions. Aquacultural Engineering 15: 181-192.

Poon W.L, C.Y. Hung and D.J. Randall 2002. *The effect of aquatic hypoxia on fish*. Department of Biology and Chemistry, City University of Hong Kong, Kowloon, Hong Kong, SAR, China. EPA/600/R-02/097.

Pichavant, K., Person-Le-Ruyet, J., Le Bayou, N., Severe, A., Le Roux, A., and Bcouf, G. 2001. Comparative effects of long-term hypoxia on growth, feeding and oxygen consumption in juvenile turbot and European sea bass. J. Fish Biol. 59: 875-883. doi:10. 1111/j.1095-8649.2001.tb00158.x

Randolph, K.N., and H.P. Clemens. 1976. Some factors influencing the feeding behaviour of channel catfish in culture ponds. Transactions of American Fisheries Society 105: 718724.

Seymour *et al.*, 1992. E.A. Seymour, O.I. Forsberg and J.P. Aabel, The effect of arious stocking densities, low water use and two oxygen levels on production parameters of adult Atlantic salmon (*Salmo salar* L.) in land-based tanks. Report from Rogaland Research, RF-193/92 (1992), p. 36.

Svobodova Z., Richard L., Jana M., and Blanka V. 1993 *Water quality and fish health* EIFAC Technical paper 54

Tanzania Fisheries Division aquaculture section 2006. *Aquaculture in Tanzania* Ministry of Natural resources and Tourism Fisheries Division.

Timmons M.B., James M.E., Fred W.W., Sreven T.S. and Brian J. V. *Recirculating Aquaculture Systems.* NRAC publication No.01-002.

Thetmeyer, H., Waller, U.,Black, K.D., Inselmann, S., Rosenthal, H., 1999. Growth of European sea bass (Dicentrarchus labrax L.) under hypoxic and oscillating oxygen conditions. *Aquaculture*, 174, 355-367.

Tom L.1998, *Nutritional and feeding of fish*. Kluwer Academic Publishers. Second edition.

Tsadik Gagma M.N. Kutty 1987. *Influence of ambient oxygen on feeding and growth of tilapia*, Oreochromis *niloticus* ARAC/87/WP/10.United Nation Development Programme. Food and Agriculture Organization of the United Nations, Nigerian institute for oceanography and marine research project RAF/87/009.

Ultsch, G.R. H. Boschung and M.J.Ross 1978. Metabolism, critical oxygen tension, and habitat selection in darters (Etheostoma). Ecology 59:99-107.

Verheyen E.R. Bluse and W. Decleir 1994. Metabolic rate, hypoxia tolereance and aquatic surface respiration of some lacustrine and riverine African cichlid fishes (Pisces: Cichlidae). Comp. Biochem. Physiol. 107A:403-411.

Wedemeyer, G.A 1996. Interactions with Water Quality Conditions in Physiology of Fish in Intensive Culture Systems. Chapman and Hall, New York, New York 1996.