COMPARISON OF GROWTH CHARACTERISTICS BETWEEN THE INDIGENOUS *OREOCHROMIS ANDERSONII* AND THE DOMESTICATED *OREOCHROMIS NILOTICUS* UNDER EXPERIMENTAL CONDITIONS

by

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Biographical background

Anthony Marc Wegener was born and raised in Katima Mulilo, Zambezi region, formerly known as Caprivi Region of Namibia. Spending most of his childhood fishing and exploring the rivers and floodplains of the Caprivi, he has gained a great deal of experience in the surrounding fish biodiversity. He has personally experienced the dramatic decline in wild fish stocks as well as the development of the Caprivi fishery and the negative impacts it has within the Caprivi. The Caprivi Region is a very special area which triggered the interests in this research project.

DEDICATION

I dedicate this thesis to my parents Douglas and Geraldine Wegener. Thank you for all the sacrifices you have made over the years, all the support you have provided and the advice you have given me. Without you, this thesis would never have been possible. I will never be able to thank you enough for all you have done for me.

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (unless to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualifications.

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ABSTRACT

The increase in the world's population and subsequent growth in demand for fisheries products is coinciding with the over-exploitation and decline of wild fish stocks. Fish however remains an important source of animal protein with more than half of the world's population depends on fish as a source of animal protein. Aquaculture has become the fastest growing animal production sector with an average increase of 8 percent per annum over the past two decades. The Caprivi region, situated in the North Eastern section of Namibia has the second highest incidence of poverty in Namibia while its wetlands contains diverse habitats and contains approximately 86 resident fish species where habitat preference, breeding strategies, migration patterns and diet can vary inter-specifically. The Caprivi's fishery plays an important role in that the majority of the population in this region depends on the fishery as a means of income, informal employment and food security. Aquaculture is promoted by the Namibian government as a supplement to the fishery in order to sustain livelihoods of the Caprivi region.

Tilapia species has developed into the second most produced freshwater fish in the world, after the common carp (*Caprinus carpio*), with the domesticated Nile tilapia (*Oreochromis niloticus*) making up more than 80 percent of tilapia production. The Caprivi region plays host to a wide variety of indigenous tilapia species, including *O. andersonii, O. macrochir, O. placidus, T. rendalli,* and *T. sparrmanii*, of which the Three Spotted tilapia (*O. andersonii*) being the more common and targeted species in terms of the local fishery.

Apart from promotion of the undomesticated indigenous *O. andersonii* for aquaculture purposes, the option remains also to introduce the domesticated and highly successful *O. niloticus*. Although beneficial in terms of aquaculture potential the introduction of *O. niloticus* though poses a significant risk of displacing various indigenous tilapia species such as *O. andersonii, O.macrochir O.placidus, T.rendalli,* and *T.sparrmanii* as well as affecting the biodiversity of the larger ecosystem.

A comparative growth trial confirmed a significantly ($P \leq 0.05$) superior growth performance of *O. niloticus* over *O. andersonii* in terms of weight and length gain, with the undomesticated *O. andersonii also* displaying significantly higher variance (CV) for these traits. The growth curve of *O.niloticus* was isometric compared to the negative allometric growth of *O.andersonii*. Significant differences ($P \leq 0.05$) for moisture and crude lipid content were noted between species, where *O.andersonii* had higher crude lipid content and *O.niloticus* had higher moisture content.

The proposed approach for developing tilapia aquaculture in the Caprivi region is to establish pilot projects to assess the economic feasibility for the production of the indigenous *O.andersonii* together with a cost-benefit analysis for the genetic improvement of the species. Furthermore to conduct a risk assessment associated with the introduction of *O.niloticus* into the Caprivi region with further decisions regarding the appropriate species to be based on the outcomes of the above assessments.

OPSOMMING

Die toename in die wêreld se bevolking en die daaropvolgende groei in die vraag vir die vissery produkte is wat saamval met die oorbenutting en agteruitgang van wilde visbronne. Fish is egter 'n goeie bron van dierlike proteïen en meer as die helfte van die wêreld se bevolking is afhanklik van vis as 'n bron van dierlike proteïen. Akwakultuur het die vinnigste groeiende diereproduksie sektor met 'n gemiddelde styging van 8% per jaar oor die afgelope twee dekades. Die Caprivi-streek, geleë in die afdeling Noord Oos van Namibië het die tweede hoogste voorkoms van armoede in Namibië terwyl die vleilande bevat diverse habitats en bevat ongeveer 86 inwoner visspesies waar habitat voorkeur, teling, migrasie patrone en dieet inter-spesifiek kan wissel . Vissery die Caprivi se is baie belangrik, want meer as die helfte van die bevolking in die streek is afhanklik van die vissery as 'n middel van inkomste, informele indiensneming en voedselsekuriteit. Die groeiende vraag na proteïen bronne kan tevrede wees deur akwakultuur van mak spesies soos O.niloticus, tans die gewildste gekweek mak tilapia spesies. Maar sodra dit ontsnap dit sal 'n negatiewe impak op die veerkragtigheid en produktiwiteit van buitelandse ekosisteem en sal die druk op en die moontlikheid van plaaslike uitwissing van verskeie vis en ander akwatiese spesies te Aan die ander kant O.andersonii is inheems aan die Caprivi, algemeen verkies deur plaaslike gemeenskappe en het potensieel goeie akwakultuur eienskappe. Afgesien van die bevordering van die produksie van die undomesticated inheemse spesie, die opsie moet ook nog 'n hoogs mak tilapia spesies vir akwakultuur doeleindes stel om te help om goedkoop goeie gehalte proteïen na omliggende gemeenskappe sowel as gemak visvang druk op wilde visbronne en te bewaar biodiversiteit. Maar die spesie hou 'n beduidende risiko van die verskuiwing verskeie inheemse tilapia spesies soos O. andersonii, O.macrochir O.placidus, T.rendalli en T.sparrmanii asook wat die biodiversiteit van die groter ekosisteem as dit ontsnap. Albei spesies ervaar lineêre groeikoerse met die mak spesies (O.niloticus) met aansienlik hoër gemiddelde daaglikse groei in terme van gewigstoename en lengte gewin, as wilde spesies (O.andersonii). O.andersonii aan die ander kant het beter koëffisiënt van variasie van die gemiddelde daaglikse groei as O.niloticus. Isometriese groei is gerapporteer deur die O.niloticus terwyl O.andersonii ervaar negatiewe allometric groei. Die toestand faktore dui beide spesies is in 'n gesonde toestand. Beduidende verskille vir voginhoud en ru lipied inhoud is opgemerk tussen spesies, waar O.andersonii het hoër ru lipied inhoud en O.niloticus het hoër voginhoud. Die stel benadering tot die ontwikkeling akwakultuur in die Caprivi is deur die ontwikkeling van loodsprojekte kweek O.andersonii en terselfdertyd bydra navorsing makmaak van die inheemse O.andersonii. Verder ondersoek die evaluering van risikobestuur op alle moontlike gevolge / risiko's wat verband hou met O.niloticus ontsnap in die omliggende rivierstelsels. Sodra die O.andersonii loodsprojekte is ten volle funksionele en al relatiewe risiko-ontledings afgehandel is, na gelang van die verskillende uitkomste kan projekte te loods op kweek O.niloticus in die

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CHAPTER 1

Introduction

The increase in the world's population and subsequent growth in demand for fisheries products is coinciding with the over-exploitation and decline of wild fish stocks. Fish remains an important source of protein with more than half of the world's population that depends on fish as a source of animal proteins (Corpei, 2001). This has stimulated the rapid development of global aquaculture, producing over 50% of world's total fish supply (SOFIA, 2010). Aquaculture has in fact become the fastest growing animal production sector in the world with an average increase of 8% per annum over the past two decades (Brugere & Ridler, 2004; SOFIA, 2010).

Farming of Tilapia has increased significantly over the past 20 years due to the broad market acceptance and environmental adaptability of the species, with current contributions from China (33%), South East Asia (32%), Latin America (14%) and Africa at 18 percent (Josupeit, 2010; Vannuccini, 1998). Tilapia production in Africa remains limited compared to the rest of the World with Egypt 's output of 380,000 tons per annum equal to 70 percent of Africa's, though less than five percent of global production (Bhujel, 2014). Aquaculture development in sub-Saharan countries were slow in comparison to global trends contributing only 30 percent towards African and 0.68 percent to global aquaculture production (SOFIA, 2014). There are 39 sub-Saharan countries participated in tilapia farming with only ten (Cote d'Ivoire, DR Congo, Ghana, Kenya, Malawi, Nigeria, Sudan, Uganda, Zambia and Zimbabwe) producing more than 500 tonnes per annum (El-Sayed, 2013). Most of the production in sub-Saharan countries is generated by small scale non-commercial tilapia farming systems (El-Sayed, 2013).

The slower than expected growth in African Aquaculture is attributed to:

- A lack of suitable resources in the form of land, water, nutrients and labour amongst rural communities with a primarily focus on subsistence aquaculture (Subasinghe *et al*, 2000).
- Economic instability associated with high population growth, migration, political instability and natural disasters (flooding, droughts) delaying economic growth and investments (Vincke, 1995).
- Limited availability technically skilled personnel (Subasinghe *et al*, 2000).
- Inadequate capacity for research, knowledge and technology transfer (Subasinghe *et al*, 2000).
- Limited supply and quality of seed stock (Subasinghe *et* al, 2000).
- Lack of good quality fish feed (Subasinghe et al, 2000).
- Inadequate transport infrastructure for the distribution of feeds, seed stock and harvests (Subasinghe *et* al, 2000).

The initial development of tilapia aquaculture was based on eight different species (Hussain, 2004) with current production dominated by the Nile Tilapia (*O. niloticus)* responsible for over 80 percent of global tilapia production. The popularity of *O. niloticus* is largely due to favourable production characteristics such as faster growth, efficient food conversion, high fecundity, good flesh quality and yield and tolerance to a wide range of environmental parameters (Kaliba *et al,* 2006). Most of the

African tilapia production also comprises of *O. niloticus*, with limited production of *O .andersonii* in Zambia and *Tilapia zilli* and *Tilapia variablis* in Tanzania (Bhujel, 2014).

The favourable traits of tilapia, *O. niloticus* in particular, have resulted in its distributed into various foreign habitats, countries across the continents of Asia, China, Europe, North and Latin America. Although some can be tolerant to the introduction of new species the majority of ecosystems remain vulnerable to alterations and changes to the dynamics of such system. The primary concerns regarding the use of non-native species in the aquaculture are:

1. The culture of a new species may lead to the establishing of feral populations which may pose risks in relation to habitat alteration, outcompeting of native species for breeding grounds and resources, resulting in changes in the food web, affecting surrounding communities, environments as well as economic activities (Hill, 2011; Canonico *et al,*2005).
2. The non-native species can be vectors for non-native pathogens which can become established in the local environment and negatively impact native fish populations (Hill, 2011).
3. Genetic alterations may occur if non-native species escape and interbreed with the native species (Hill, 2011).
4. Introduction of genetically modified organism's (GMO's) pose additional risks in relation the Trojan gene effect with GMO's gaining reproductive advantages over indigenous species or develop dominant feeding patterns that increases vulnerability of indigenous species to predation (Hill, 2011).

Examples have been recorded where non-native species, including *O. niloticus,* escaped into the surrounding water systems resulting in the decimation and at times extinction of local indigenous species (Cook *et al*, 2008). *O. niloticus* that escaped from farming systems in Zambia and have since established feral populations in the Kafue river system where it is threatening the indigenous *O. andersonii* (Tweddle &Marshall, 2007). *O. niloticus* has also been introduced into Lake Kariba in Zimbabwe where it has established feral populations that has displaced the indigenous tilapia species *Oreochromis mortimeri* (Tweddle &Marshall, 2007; Tweddle & Wise 2007). Feral populations of *O. niloticus* have also been documented in the Limpopo River and have become a major threat to the indigenous *O. mossambicus* (Tweddle & Wise, 2007). *O. niloticus* has completely displaced *O. mossambicus* from Zhovhe Dam on the Umzingwane River after it escaped from dams further up in the catchment (B.C.W. van der Waal, pers. comm. to Tweddle & Wise, 2007). During the 1950s *O. niloticus* was introduced into Lake Victoria where it completely displaced the indigenous *Oreochromis esculentus* and *Oreochromis variabilis* (Tweddle & Wise, 2007). Further introductions have been documented in Lake Alaotra, Madagascar, where is has caused populations of various indigenous tilapia species to decline dramatically (Canonico *et al*, 2005; Tweddle Wise, 2007).

A proposed introduction of *O. niloticus* into the Caprivi region of Namibia to stimulate aquaculture production in the region should therefore be viewed with caution as it can negatively impact on the indigenous fish species in the Caprivi Region if they manage to escape into the surrounding river systems.

The Caprivi region situated on the most North eastern part of Namibia consists of several river systems and has borders with 4 countries (Angola, Botswana, Zambia and Zimbabwe). The majority of the Caprivi's population is reliant on the surrounding river systems for a main source of food, income and survival. Many communities generate an informal income from selling fish as the most consumed and preferred protein source in the region (Hay, 2011). In recent years the fish populations have been under increasing pressure due to the use of modern fishing gear, limited conservation practices and a continuously increase in market demand (Tvedten, 2002). The decreasing number and diversity of wild fish stock has raised concerns in local communities as it is the main animal protein sources in the Caprivi. Action is therefore required to preserve this unique ecosystem whilst also providing in the increasing food and protein demand of the local population. The Namibian government has subsequently launched specific initiatives, including the development of the Caprivi Inland Aquaculture Centre, to stimulate aquaculture production in the region whilst various entrepreneurs are also exploring commercial opportunities (Nashandi, 2008).

Apart from promotion of the production of undomesticated indigenous species such as the *O. andersonii*, the option remain also to introduce a highly domesticated tilapia species for aquaculture purposes, in an effort to provide an affordable protein source to surrounding communities as well as ease fishing pressures on wild fish stocks and preserve the biodiversity. The introduction of *O. niloticus* as a genetically improved aquaculture species into the Caprivi has the potential to create significant economic benefits and provide local communities with economic livelihoods and food security. However the species also poses a significant risk of displacing various indigenous tilapia species such as *O. andersonii, Oreochromis macrochir, Oreochromis placidus, Tilapia rendalli,* and *Tilapia sparrmanii* as well as affecting the biodiversity of the larger ecosystem if it escapes.

Given the need to stimulate aquaculture development in the Caprivi Region to sustain food security and to alleviate unsustainable pressure on natural fish stocks, the question is whether it should be done via the introduction of a domesticated exotic species such as *O. niloticus* or via the utilisation of an undomesticated indigenous species such as *O. andersonii*. The aim of the study is to consider both socio economic and environmental effects of the introduction of *O. niloticus* into the productive Caprivi Region's ecosystems, by means of:

- A desk based study of available literature and other sources of information regarding the Caprivi region and the two species under consideration.
- A comparative assessment of the production characteristics of the indigenous *O. andersonii* and the domesticated *O. niloticus* under controlled conditions.

CHAPTER 2

Literature review

2.1 Background to global tilapia production

Tilapias are endemic to Africa and the Middle East and have been introduced globally mainly due to aquaculture and for the purpose of aquatic weed control (Boyd, 2004; Canonico *et al*, 2005). They are a relatively deep bodied fish where herbivorous, omnivorous and carnivorous behaviour has been documented (Boyd, 2004). Tilapias fall under three taxonomic groups (genus) namely: Tilapia, Oreochromis and Sarotherdon. Species from the genus Tilapia lay their eggs on substrates, Oreochromis species are maternal brooders while Sarotherdon are both maternal and parental brooders (Teichert-Coddington *et al*, 1997). Although categorized within three taxonomic groups, all genus' are generally referred to as tilapia and will be referred to as tilapia throughout the literature review unless otherwise stated.

There are approximately 90 different tilapia species currently cultured globally (Gupta & Acosta, 2004). Although many of the tilapia species may appear similar they have in fact different characteristic in terms of morphology, biology and environmental preferences and effects. The bulk of global production is however provided via farming of the species *O. niloticus, Oreochromis aureus*, *O. mossambicus*, *O. andersonii*, *O. macrochir*, *Sarotherodon galilaeus*, *Sarotherodon melanotheron* and *Tilapia zillii* (Hussain, 2004). Of these *O. niloticus* and has developed into the predominant species contributing over 80% of global production of tilapia (Josupeit H, 2005).

Tilapia farming was initiated in Egypt approximately 4000bc (Gupta & Acosta, 2004; El-Sayed, 2006) where the first written record of tilapia culture was documented during the 1920's in Kenya (El-Sayed, 2006; Ngugi *et al*, 2007). By the 1940's tilapia were considered a potential commercial aquaculture species due to fast growth rates, easiness to breed, favourable taste, high tolerance to environmental fluctuations and hardiness (Gupta & Acosta, 2004; El-Sayed, 2006). The interest in tilapia culture has grown exponentially since the 1940's and currently has the second highest production rate of farmed freshwater fish globally which is spread over more than 140+ countries (Fitzsimmons, 2015). In 1980 the world wild capture of tilapia was estimated at 250,354 tonnes and by 2005 it had increased to 669 925 tonnes (Gupta & Acosta, 2004). In comparison the world cultured tilapia has surpassed wild harvesting increasing from 107 459 tonnes to 2 025 559 tonnes within the same period (Gupta & Acosta, 2004).

Globally, tilapias have developed into a popular aquaculture commodity with increasing imports and exports. The global production levels of tilapia for 2011 (Figure 2.1) gives an indication of the main producing countries.

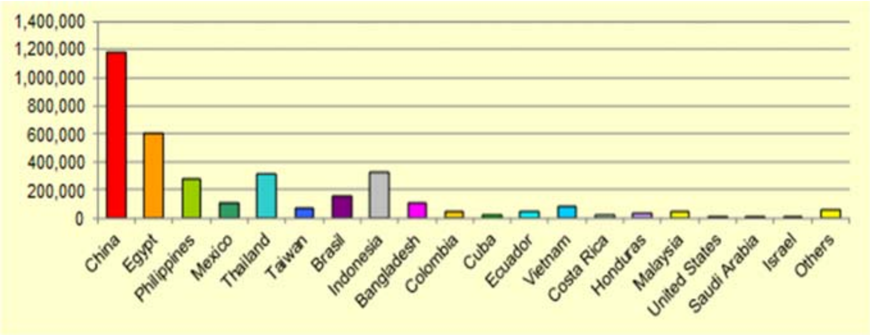

Figure 2.1 Country contributions to world tilapia production (million tonnes) in 2011 (Fitzsimmons, 2012).

During 2012 Asia dominated the tilapia market contributing 70 percent of the global production (Hongzhou, 2012) with China contributing the majority of production (2011: approximately 1.2 million tonnes) largely due to a steadily increasing domestic and international market demand (Fitzsimmons, 2012).China exports on average 67 000 tonnes (fresh tilapia and tilapia products) annually to regions/countries such as Africa, Iran and other Middle East countries, with smaller exports going to Latin American countries such as Costa Rica, Peru and Chile (Globefish, 2013). Taiwan is also a large producer and exporter of tilapia, annually producing 70 000 tonnes of which 60 percent is exported (Globefish, 2014).

Tilapia production in Egypt, Indonesia and the Philippines is largely bound for domestic markets rather than exports while a country such as Ecuador exports to the US markets (Josupeit, 2005). Europe is a popular importer of tilapia products, importing approximately 24 000 tonnes during the first three quarters of 2014 where at least 72 percent imported came from China (Globefish, 2014). Europe also imports from smaller suppliers including Viet Nam, Indonesia, Thailand, Bangladesh and Costa Rica (GL OBEFISH, 2014). Ghana has recently put a ban on the imports of tilapia products as they are aiming to create a stronger domestic production sector in Ghana (Globefish, 2014).

2.2 Inter-species comparison of O. niloticus and O. andersonii

In the context of this study two species of Tilapia are of particular concern, namely *O. niloticus* (Nile Tilapia) and *O. andersonii,* the latter which is indigenous to the Caprivi Region though undomesticated in comparison to the Nile Tilapia that is the preferred species for commercial culture due to its superior production characteristics.

2.2.1 Distribution

Both of these tilapia species are found in the tropical and subtropical regions of Africa (Figure 2.2) with *O. niloticus* widely distributed throughout all major catchments of Central and Northern Africa (Angola, Chad, Democratic Republic of Congo, Eritrea, Ethiopia, Ghana, Kenya, Nigeria and Uganda) as appose to *O. andersonii* that has a limited distribution endemic to the Zambezi, Okavango, Kunene and Kafue catchment s in Southern Africa (Angola, Botswana, Mozambique, Namibia, Zambia and Zimbabwe) (Tweddle &Marshall, 2007; Trewavas, 1983).

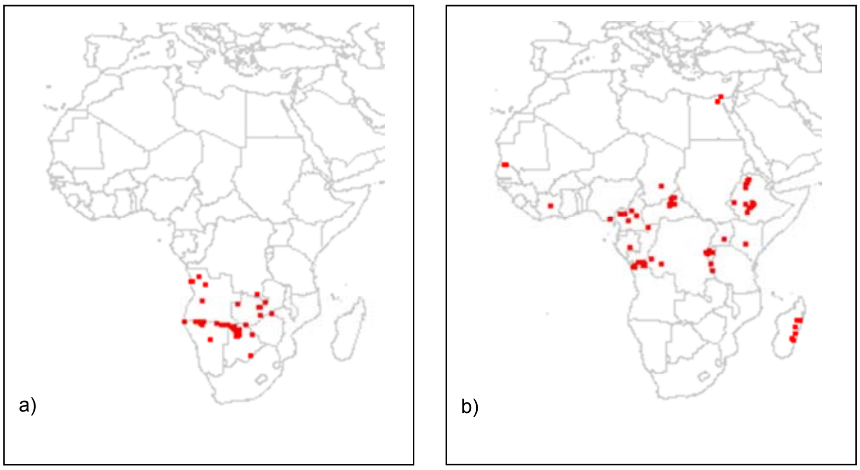

Figure 2.2 Distribution ranges of *O.andersonii* (a) and *O.niloticus* (b) throughout Africa (Trewavas, 1983).

2.2.2 Environmental and biological aspects

Tilapias in general are tropical freshwater species and have a wide environmental tolerance, however, optimal conditions are species specific. Both *O. niloticus* and *O. andersonii* are benthopelagic and usually prefer depths from 0 to 6m but have been found at depths of up to 35m (Thorstad *et al,* 1995; Van Oijen, 1995). Depth preference can change with growth and development and adult tilapia usually prefer the deeper waters while juveniles reside in the shallows along the shore line. *O. andersonii* and *O. niloticus* can survive a relatively wide water temperature range; however, variation in their tolerance and optimal ranges is apparent. An optimal temperature or salinity range represents a range ideal for metabolism, breeding behaviours, feeding, growth, disease resistance and any other characteristics beneficial to survival. *O. niloticus* can survive a wider tolerance range of 8°C to 42°C and optimum temperature range of 31 to 36 °C, compared to 14°C to 33°C and 26°C to 28°C for *O. andersonii* (Philippart & Ruwet, 1982).

Although *O. andersonii* and *O. niloticus* are mainly freshwater species both can survive in brackish water systems. *O. niloticus* can withstand salinities up to 40 while *O. andersonii* can only withstand salinities up to 20 (Philippart & Ruwet, 1982; Bailey, 1994; Riede, 2004; Schofield *et al,* 2013). In environments with wide temperature and salinity fluctuations *O. niloticus* displays greater adaptability and survival compared to *O.andersonii*.

Both *O. andersonii* and *O. niloticus* are diurnal and can form large shoals which can exceed two thousand individuals. They feed on a variety of different food items consisting of aquatic plants, phytoplankton, small invertebrates, benthic fauna, periphytons, detritus and other bacterial films (FAO, 2014; Jihulya, 2014). Although both species feed on similar food items, *O. niloticus* are also known to filter feed on small particles that are suspended in the water columns. Limited information is available on filter feeding practices of *O. andersonii*, largely due to the lack of research on this understudied species (Popma and Masser, 1999).

Breeding behaviour is largely similar for the two species although some differences in breeding behaviour are apparent: In relation to breeding temperature *O. andersonii* begin breeding once water temperatures reach above 21 degrees Celsius, while *O. niloticus* only start breeding above 22 degrees Celsius (Trewavas, 1983), spawning frequency of *O. andersonii* is 1-2 times a season whilst *O. niloticus* can have multiple broods a season (Peterson *et al*, 2004; FAO, 2014).

2.3 Aquaculture potential, performance and status

2.3.1 Overview of the aquaculture potential and status of O. niloticus

Currently *O. niloticus* contributes 71 percent of the total global tilapia production (Yakubu, 2014) to the amount of 3 200 000 million tonnes (GLOBAL AQUACULTURE ADVOCATE, 2014) per annum. This species has a continuously expanding global footprint in terms of number of countries and its rapid increase in production. In addition, aquaculture activity has led to the distribution of *O. niloticus* to occur in over 100 countries worldwide (Philippart *et al*, 1982; Fitzsimmonds, 2001). The species is considered an important species in the commercial freshwater aquaculture industry and its good aquaculture characteristics (growth in captivity, easiness to breed, high fecundity and frequency of breeding and the ability to utilise low quality diets) has contributed to its success (Kour *et al,* 2014). It is also undergoing continuous genetic improvement in the form of the GIFT (section 2.3.3), Abbasa (Ibrahim *et al*, 2012) and Akosombo (Ansah *et al*, 2014) strains, to enhance its production characteristics. Supported by detailed information on nutrition, genetics, physiology, processing, etc. compared to other tilapia species.

The general attributes of *O. niloticus* in terms of production performance is summarised in Table 2.1

Trait	Range	Reference
Specific Growth Rate	0.8-1.4 %/day	Mustapha et al, 2012; Singh et al, 2012; Yakubu *et al* , 2012;
FCR	1.1-1.7:1	Bamba *et al*, 2014; Goda *et al*, 2007; Mustapha *et al*, 2012
Yield	1400-5322 kg/ha/year	Shoko *et al* 2011; Cayron- Thomas, 2010
Fecundity	260-1450 eggs/fish	Hirpo, 2013; Shalloof & Salama, 2008
Survival Rate	82-98%	Basuki and Rejeki 2015; El-Greisy & El-Gamal, 2012; Gullian-Klanian & Aramburu-Adame, 2013

Table 2.1 Summary of the production characteristics of *O. niloticus.*

2.3.2 Overview of the aquaculture potential and status of O. andersonii.

Compared to global spread of *O. niloticus, O. andersonii* has been introduced to as few as 4 African countries (Democratic Republic of Congo, Kenya, South Africa and Tanzania) (Tweddle & Marshall, 2007). *O. andersonii* is still undomesticated and apart from hybridization studies, as referred to in section 2.3.4, limited literature reference could be found in relation to genetic improvement and strain development for the species. According to Kefi (2013) *O. andersonii* is an ideal indigenous species for fish farming in Zambia, Botswana and Namibia and is well established in the local markets. The general attributes of *O. niloticus* in terms of production performance is summarised in Table 2.2.

Trait	Range	Reference
Specific Growth Rate	1.4-3%/day	Kefi *et al*, 2013; Kefi *et al*, 2012
FCR	1.78	Cayron- Thomas, 2010;
Yield	4920kg/ha/year	Cayron- Thomas, 2010;
Fecundity	634 Fry/fish	Gopalakrishnan 1988
Survival Rate	96-100%	Kefi *et al*, 2013

Table 2.2 Summary of the production characteristics of *O. andersonii.*

In a head to head comparison *O. andersonii* registered a production yield of 4.92 tons per hectare per annum compared to an average of 5.322 tons per hectare per annum for *O. niloticus* under similar pond conditions (Cayron-Thomas, 2010). Other comparative findings (Cayron-Thomas, 2010) were that *O. andersonii* produced more fry though with a lower survival rate (<54%); started breeding earlier and at lower temperatures; had a longer breeding season; was also easier to handle and less evasive than *O. niloticus*. They also reported that low water temperature (below 20°C) had a considerable negative affect on the growth of *O. niloticus*, whilst a lesser effect on *O. andersonii.*

When compared to *O. macrochir*, *T. sparrmanii, T. rendalli* (indigenous tilapia species of Caprivi Region), *O. andersonii* showed significant superiority in growth rates and maximum length (Silva, 2005). *O. andersonii* is more economically feasible and more suitable for semi intensive cultures and integrated farming systems than other indigenous species in Zambia (Cayron-Thomas, 1994). However cultures of *O. andersonii* mainly consist of small scale farms using polycultures of different tilapia species (Hecht & Moor, 2004; Cayron-Thomas, 2010). Due to the limited range expansion of *O. andersonii* and lack of published literature on *O. andersonii* no effects on biodiversity have been documented yet.

2.3.3 Genetic improvement of O niloticus, the GIFT strain

Commercial tilapia culture is largely based on the use of all-male populations, as males fish presents a superior growth rate and yield than females and display a more consistent size (Gupta & Acosta, 2004). In addition, males reach sexual maturity at a later stage than females during which less metabolic energy and reserves are directed to gonadal development and reproduction, allowing for superior growth and yield (Gupta & Acosta, 2004). A number of methods have been employed to achieve mono sex cultures of tilapia such as: manual sexing, hormonal sex reversal and hybridization' with hybridization initially considered the most popular and successful. Hicking (1960) crossed three tilapia species, *Oreochromis urolepis, Oreochromis hornorum* and *O. mossambicus,* which resulted in all male hybrids (Lazard, 1996; Shelton, 2002), whilst Shelton (2002) found that when male *O. hornorum* or *O. aureus* were crossed with either female *O. mossambicus* or *O. niloticus* the majority of the offspring were male. Mair *et al* (1997) developed a breeding program using *O. niloticus* that was able to produce sex ratios that are 95% male offspring with a 40% increase in yield (Gupta & Acosta, 2004). Male *O. niloticus* and hybrids of *O. niloticus* result in offspring with faster growth rates than species without *O. niloticus* genes (Popma & Lovshin, 1996). However, it is important to note that hybridization of *O. niloticus* with slow growing species such as *O. mossambicus* can result in an overall slower growth rate of offspring (Popma & Lovshin, 1996). Such issues become highly problematic, specifically in extensive, low input systems where management and resource supplies are minimal. Therefore the establishment of the Genetically Improved Farmed Tilapia (GIFT) program by World Fish Centre (The Food and Agriculture Organization (FAO)) in the 1970's was considered as an important development in global tilapia production.

The GIFT strain was developed through selective breeding of 8 different strains of *O. niloticus* (4 wild strains from Africa and 4 commercial strains popular in Asia) over several generations (Eknath *et al*, 1993). Subsequent comparisons by Eknath and Acosta (1998) revealed that the GIFT strain had approximately 15 percent average genetic gain per generation and an 85 percent cumulative increase in growth. This new strain was highly successful because of an increased growth rate of more than double the wild strain *O. niloticus* (Eknath, 1992; Dey, 1996) and an increased survival rate up to 50 percent (Eknath,1992). Hussain (2004) confirmed that the growth performance of the GIFT strain continuously outperformed the commonly used strains which also had a 60 percent increase in total yield compared to other strains. Overall the GIFT strain has a number of characteristics deemed appealing to aquaculture sector, including: high yield, excellent breeders, very efficient in converting organic materials to protein, very resistant to diseases, exceptionally hardy, tolerant to overcrowding and are able to grow in wide salinity ranges (Hussain, 2004). Since its initial development the GIFT strain has undergone further development where the latest variety demonstrating up to a 30 percent increase in growth compared to the original GIFT strain (Hussain, 2004), confirming the success of the GIFT strain in terms of aquaculture characteristics.

Although the GIFT strain (*O. niloticus*) has had huge success in the global aquaculture industry a number of concerns have also been raised regarding its application and distribution. The introduction of such genetically altered tilapia strains into the natural ecosystem can lead to numerous environmental repercussions such as uncontrolled hybridization with indigenous species leading to a change in stock genetic structure (Hussain, 2004; Cook *et al,* 2008). Therefore, extreme care needs to be taken when exotic domesticated species or strains, such as the *O. niloticus* GIFT strain, are introduced into new areas for aquaculture purposes. Particular attention is required in third world countries where there the unregulated releasing of invasive non-native species is more common and biodiversity and conservation management are not of high priority.

2.3.4 The use of O. niloticus in hybridization studies

A red tilapia variety was produced through interspecific crossing between *O. mossambicus* and *O. niloticus* genotypes (Josupeit, 2005). This hybrid strain has become exceptionally popular due to its reddish colour, giving it a similar appearance to high valued marine species such as the sea bream (*Chrysophrys major*) and red snapper (*Lutjanus campechanus*). Crossing of *O. niloticus* and *O. aureus* resulted in another red hybrid that is moderately saline tolerant while crossing of *O. mossambicus* and *O. hornorum* resulted in highly euryhaline red tilapia (Alceste-Oliviero, 2000). This expanded the production of red tilapia to brackish water systems.

Macaranas *et al* (1997) also reported on a series of crosses of tilapia species, including *O. mossambicus* and *O. hornorum,* where a combination with *O. niloticus* proved to be the more successful hybrid in terms of production performance because of hybrid vigour. Deines *et al* (2014) pointed out that such an approach of hybridization between exotic and indigenous species will lead to genetic erosion, impacts on biodiversity and even local extinction of indigenous species. Due to the beneficial effect of hybrid vigour, the crossing of tilapia species is still widely practiced throughout southern Africa.

The following sections will focus on the Caprivi system in Namibia as a case study contextualising the potential risks and benefits associated with the introduction of domesticated exotic species into to a biodiversity rich natural ecosystem.

2.4. The Caprivi system

The Caprivi Region is situated in north eastern Namibia and is bordered by four countries, namely Angola, Botswana, Zambia and Zimbabwe. More than half of the population in this region depends on the fishery as a means of income, informal employment and food security (FAO, 2008). Fish is considered to have a high economic value within the Caprivi region due to it being the most preferred and most consumed source of animal protein (Hay, 2011). During the annual rainy season crop production is limited due to the frequent occurrence of floods and fish therefore become an even greater importance with and increased demand amongst the local communities.

Residents of the Caprivi have to travel great distances in order to reach alternative food supplies such as retail networks, with the town of Katima Mulilo as the only urban centre in the region. Urbanisation is also increasing rapidly within the Caprivi region (Tvedten, 2002) and several informal villages have come into existence within close proximity to Katima Mulilo. The majority of the Caprivi population still live in rural villages (Tvedten, 2002) and rely on various rivers and catchments as their main source of food and water.

2.4.1 Rivers and catchments

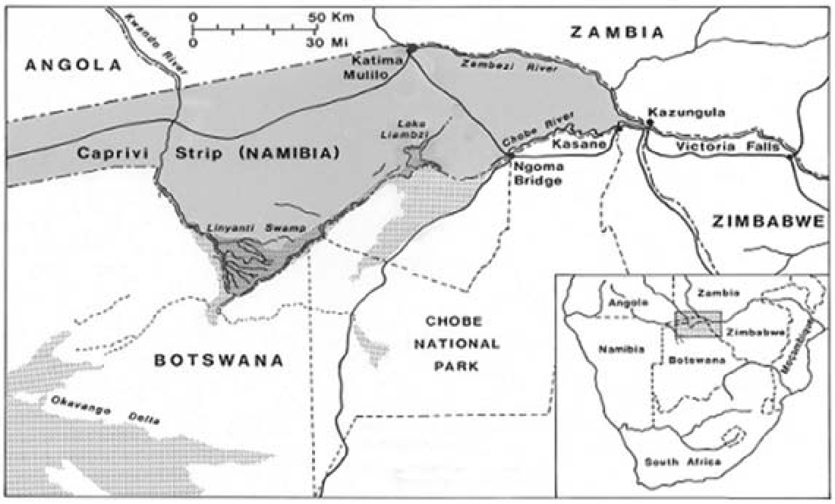

Figure 2.3 Map depicting the river systems in relation to the Caprivi region (Huchzermeyer & Van der Waal, 2012).

The Caprivi region has several river systems surrounding it, the largest being the Upper Zambezi River which is located in northern Caprivi and borders Zambia. The Linyanti River and the Kwando River are located in Southern and Western Caprivi bordering Botswana and Angola respectively while the Chobe River is in the Southern Caprivi and borders Botswana. Relatively central to the Caprivi Region is a large inland lake, called Lake Liambezi, which is fed by the surrounding rivers during rainy season (November to April) and once filled, the lake covers an area of up to 10 000 hectares (Tvedten, 2002). These river systems, including Lake Liambezi and the Okavango River (approximately 300km West of Caprivi) become interlinked during the rainy season and form the Caprivi wetlands that is important in relation to the spread and maintenance of biodiversity within this ecosystem.

2.4.2 Fish biodiversity and fishery within the Caprivi system

The Caprivi wetland contains diverse habitats and contains approximately 86 resident fish species where habitat preference, breeding strategies, migration patterns and diet can vary inter-specifically (Van der Waal, 1983). The Caprivi's fishery is a very important and unique industry which is based on selectivity of the larger species in the surrounding river systems. According to van der Waal (1983) the most popular species for commercial and subsistence fishing in the Caprivi is *Hepsetus odoe, Clarias gariepinus, Clarias ngamensis, O macrochir, O. andersonii, T. rendalli, and Hydrocynus vittatus.* Other larger tilapia species commonly found in the Caprivi wetland are*, T. sparrmanii, Sargochromis giadry, Sargochromis codringtoni, Sargochromis carlottae, Serranochromis robustus, Serranochromis macrocephalus, Serranochromis longimanus, Serranochromis thumbergi* and *Serranochromis altus*. The most popular tilapia species caught by local fishermen in the Caprivi in descending order are *O. andersonii*, *O. macrochir* and *T. rendalli* (Tvedten *et al*, 1994). These species are part of the staple diet of local communities due to its availability, low cost and high nutritional value.

2.4.3 Socio-economic considerations within the Caprivi system

According to Namibia Statistics Agency (2012) the Caprivi Region has the second highest incidence of poverty in Namibia where at least half the population live in poverty (Namibia Statistics Agency, 2012). Two thirds of all households in the Caprivi region practice some sort of subsistence agriculture. Women usually sell firewood, reeds and grass, as well as brew traditional beer in order to generate an income (Tvedten, 2002). The majority of the population grow their own crops and vegetables, which is either consumed within the house hold or sold or traded at the local market. When agro-pastoral production is low fish consumption increases and is therefore an important part of the local diet (Tvedten, 2002). At least 2 percent of the households in the Caprivi are involved in the fishing industry (Tvedten, 2002). The wealthier households are mainly involved in the commercial fishery while poorer households fish only for subsistence purposes (Tvedten, 2002). The Caprivi Fishery is therefore very important to local communities for both subsistence and income purposes (Tvedten, 2002).

The Caprivi fishery is also important in relation to the regions rapidly developing tourism industry, both in terms of food supply, eco-tourism and recreational fishing. The recreational fishery attracts anglers from all over the world to fish on the Zambezi River targeting indigenous tilapia and other predatory species such as the Tiger fish (*Hydrocynus vittatus*).The tourism sector provides an important source of income to local communities, in the form of employment and the selling curios, firewood and ornaments to tourist. The status of the fishery, also in terms of recreational fishing, is therefore inexplicitly linked to the wellbeing of the local population.

During 2010, high rainfall followed by extensive flooding provided for a significant increase in the tilapia population in Lake Liambezi resulting in the development of a flourishing fishery (Tweddle *et al,* 2011). This in turn led to an increased local trade and export of fish to Zambia and the Democratic Republic of Congo (Tweddle *et al*, 2011). As much as three tons of fish per day were exported from the region to Zambia at the time. Lake Liambezi is estimated to supply approximately 1000 tons of tilapia per year (Tweddle *et al*, 2011). The main target species of the subsistence and commercial fishery in the Caprivi is *O. andersonii* and *O. macrochir*. Together they contribute more than two thirds of the total catch from both the subsistence and commercial fisheries (van der Waal, 1980, 1990, 1991). In relation to Lake Liambezi there has also been a dramatic shift from a subsistence fishery to that of a commercial fishery. The commercial fishery also provide secondary benefits to the local communities in supporting canoe builders, net menders, fishing equipment traders, processing fish, fishmongers buying and reselling fish and transportation (Tvedten, 2002) all of which has led to economic uplift of local communities.

This phenomenon has however led to fishermen from surrounding countries illegally immigrating to the Caprivi to participate in the fishery. The illegal fishing has increased to such an extent that many of the water bodies are now invested with gill nets leading to a complete overfishing of the resource and a subsequent decrease in the daily catch of the fishermen (Peel, 2012). There is a perception among local communities that the lake system is an inexhaustible resource which will continue to produce fish many years into the future. According to Hay *et al* (2000) and Hay & van der Waal (2009) the fish stocks of the Caprivi wetland are however decreasing significantly. Improved roads and a growing demand for fish, has led to ever increasing fishing efforts along the Zambezi River (Abbott, 2001; Tvedten, 2002). Changes in the floodplain ecosystem, overexploitations of fish, the lack of management practices and the use of modernised gear have increased fishing pressures on local fish species in the Caprivi (Tvedten, 2002). Disagreements between the neighbouring countries, Botswana, Namibia and Zambia, on how to manage the fishery and the ecosystem at large, adds to the problem of overfishing as creates difficulty in controlling and management practices (Timbelake & Childes, 2004). These excessive fishing pressures can result in major changes in fish size, species composition and abundances (Turner *et al*, 1995; Tweddle, *et al*, 1995; Welcomme, 2001; Allan *et al,* 2005). In multispecies communities, such as in the Zambezi River, the larger, more popular species are targeted by fisherman. As larger tilapia species decreases in size, the fishermen decrease the net sizes thus catching smaller fish which in turn increases the number of fish species caught (Karenge & Kolding, 1995; Welcomme, 1999; Jul-Larsen *et al*, 2003; Allan *et al,* 2005). Such fishing strategies can considerably change the biotic interactions between species affecting the overall health of the ecosystem (Allan *et al*, 2005; Chapin *et al*, 2000; Hooper *et al*, 2005). Currently there have been vast amounts of complaints from local fishermen that catches have decreased over the last decade, thus emphasizing the fact that the Caprivi's fish population is under threat (Tvedten, 2002; per comm, local fisherman).

These high levels of poverty and low availability of human dietary protein emphasise the need of aquaculture development in the Caprivi region. The biodiversity risks involved in importing domesticated exotic tilapia species into the Caprivi, however requires that the aquaculture potential of all species indigenous to the Caprivi are considered in comparison to commercially available strains, such as the GIFT strain. Of the several tilapia species endemic to the Caprivi, *O. andersonii* has shown to be a potential candidate species for aquaculture production based on its biological characteristics and market preferences throughout the region.

2.4.4 Sustainability of the capture fishery within the Caprivi system

During the annual flood season (February to May) more than 35 percent of the Caprivi may be under water. According to the flood pulse concept, the majority of the productivity in a system comes from the floodplain and not from downstream transport (Junk *et at,* 1989). The seasonal flooding could therefore be considered as the main driving factor in terms of biotic diversity in the Caprivi system (Junk *et al,* 1989). According to Tockner & Stanford (2002), river-floodplain systems are one of the most diverse and biologically productive environments on earth, therefore it is vitally important to ensure that these floodplain are protected to ensure restocking of the river systems. The Caprivi is no exception and conservation and sustainable management is necessary; however the Caprivi biodiversity is currently under serious threat largely due to overfishing. Although rules and regulations including gear restrictions, mesh sizes, number and length of gillnets per fisherman and methods used to catch fish do apply to the Caprivi region (Hay *et al*, 2000; Hay & van der Waal, 2009), there is a lack of enforcement and monitoring due to various reasons such as:

1. The vast Caprivi area contains numerous backwaters, channels and inland lakes therefore patrolling the whole area at regular intervals is difficult.
2. The cost involved to patrol the river is exceptionally high, as there is approximately 150km of river to patrol and only limited funding available.
3. The development in cell phone technology and decrease in cost of use has led to greater communication between poachers resulting in only limited prosecutions. As soon as a patrol boats is spotted, poachers are contacted and all illegal nets are removed prior to the patrol boat reaching the site.
4. The distance between the Caprivi region and the freshwater fisheries head office of Namibia has led to difficulty in controlling the Caprivi fishery, monitoring law enforcement patrols, delays in administration, shortages in fishing permits as well as poor communication between head office and the Caprivi offices.
5. Closed seasons between neighbouring countries do not coincide thus when one country closes the fishing season, fishermen fish on opposite sides of the river, never easing the fishing pressures of the surround river systems.

Therefore, proper management with improved technology and intelligence needs to be developed and enforced in order to decrease fishing pressures and ensure the sustainability of the fishery (Allan *et al*, 2005).

Fishing is a traditional part of live in the Caprivi and other Southern Africa regions with many fishermen believe that it is their ancestral right to have full access to the fishing resources irrespective of season or method used. This has led to many commercial fishermen using illegal fishing methods and activities such as fishing out of season, in order to sustain or increase their catches. In addition, local fisherman in the Caprivi also have the perception that external aid will always provide help if fish stocks are low, thus giving them right to catch as much fish as they want (per comm, local fisherman).

2.4.5 Possible contribution of aquaculture/Tilapia culture

Local communities in the Caprivi region rely for food mainly on subsistence farming of crop and livestock as well as harvesting of fish from the surrounding river systems (Tvedten, 2002). As the human population in the Caprivi increases together with fluctuating seasonal rainfall and flooding, food shortages amongst the surrounding communities are becoming more prevalent (Barnes, 2013). Inhabitants often have to abandon their villages along the river during the flood season resulting in loss of agricultural land and crops that increases food shortages during the flooding season. Due to the vast size of the floodplains the difficulty in catching fish also increases due to the decrease in ratio of fish per volume of water (Linhoss *et al,* 2012). This situation necessitates the government of Namibia to provide communities with flood relief (maize meal) and the establishment of refugee camps during flood season, until flood waters have dropped and villagers are again accessible.

Aquaculture are subsequently promoted by the Namibian government (Ministry of fisheries and marine resources, Namibia, 2010) as an alternative food supply to local communities in the Caprivi, reducing dependence on external aid, whilst ensuring sustainability of the regional fishery and biodiversity. Aquaculture production is dependent on various factors such as the availability and quality of water supply, with water temperature in particular affecting growth and productivity. The Caprivi Region, bordering the Zambezi River has access to various permanent supplies of good quality water to support aquaculture development on a large scale. The high demand and establish market for fish in the Caprivi suggests that the development of tilapia aquaculture would be both profitable and beneficial (food supply and employment opportunities) to the local communities and surrounding markets.

A pertinent question is whether to achieve this by means the introduction of a domesticated exotic species with good productivity such as *O. niloticus*, or via the use of undomesticated indigenous species with lower productivity, such as *O. andersonii*. In relation to aquaculture, productivity in terms of growth, survival, feed conversion, yield and cost of production remains pertinent. In the wider context, however, biodiversity and environmental sustainability remains a key consideration. Although poverty and the lack of food security may seem to weight in heavily on the argument, the introduction of exotic species may have negative impacts on the surrounding biodiversity as well as communities within the Caprivi.

Literature suggests that both *O. andersonii* and *O. niloticus* are good aquaculture species with indications that domesticated strains of *O. niloticus* has an advantage in terms of significantly superior growth rates and shorter time to reach harvestable sizes (Macaranas *et al*, 1997; Silva, 2005; Kefi, 2013). Various reports, however, points towards high biodiversity risks associated with the culturing of invasive species such as *O. niloticus* (Kour *et al,* 2014), whilst the costs associated with the genetic development of an undomesticated indigenous species such as *O. andersonii* on a regional scale, could be prohibitive.

2.4.6 Potential impacts of invasive species: O. niloticus

Gozlan (2008) stated that introducing a highly competitive alien species will negatively impact on the resilience and productivity of an ecosystem and will increase the pressures on and the possibility of local extinction of various fish and other aquatic species (Martin *et al*, 2010). Non-native species is known to affect habitat structures, food webs and the community composition of surrounding ecosystems, however, determining what such impacts may be is difficult due to the complexity of the ecosystem (Cook et al, 2008). The response of natural communities to the introduction of invasive species is very complex and can either be positive/negative or negligible, depending on the species, location, age or the type of habitat considered (Neira *et al,* 2005; Gribben & Wright, 2006). In the case of *O. niloticus* previous studies have reported negative impacts on *O. andersonii*, *O. placidus*, *T. rendalli*, *T. sparrmanii* and *O. macrochir* when in the same habitat (Van der Waal, 1983; Tweddle & Marshall, 2007). This increases the degree of risks involved as all of these species is indigenous to the Caprivi wetland, pointing towards potentially negative impact *O. niloticus* within the ecosystem. The potential impact of *O. niloticus* on the Caprivi ecosystem therefore needs to be assessed prior to extending it to aquaculture practices through precautionary principles and approaches. The precautionary approach aims to minimize the probability of bad events taking place within acceptable limits. This approach is used when the degree of uncertainty and the possible costs are significant when full reversibility of the effects caused by associated risks is not guaranteed but at least partial reversibility is achieved. Requires maintenance of a resilient and flexible fishery and addresses issues important to management of the fishery including resource sustainability, overfishing, protection of endangered and non-targeted species, environmental management of aquaculture, developing new fisheries and maintain ecosystem productivity (FAO, 1996). While the precautionary principle aims to avoid permanent damage and high costs to resources. It is used in instances with high levels of uncertainty complete or even partial reversibility is highly doubtful (FAO, 1996).

One such introduction and farming event which is well documented is the introduction of *O. niloticus* into Zambia. The Zambian Department of Fisheries in partnership with Peace Corps Rural Aquaculture Promotion Projects imported *O. niloticus* into Zambia to solve the issues of poor performance species within Zambia (Thomas, 2007). Initial studies indicated that *O. niloticus* was successful as the yields were increased specifically in systems where pond management was improved (Thomas, 2007). However the resilient and high production nature of *O. niloticus* corresponded with a decreased biodiversity with the resident ecosystem related to an increase in disease exposure and susceptibility and genetic erosion amongst endemic tilapia species (Mahmud ul Ameen, 2000). The Zambian Department of Fisheries discontinued the use of *O. niloticus* by small scale farmers throughout Zambia (Simataa & Musuka, 2013).

Tilapias are capable of causing eutrophication of surrounding water bodies through increasing the amount of nutrients within the system as a consequence of their feeding habit of disturbing bottom sediment and detritus, resulting stimulating the development of fast growing algae (Figueredo & Giani, 2005). There are reports on *O. niloticus* stimulating the development of algae biomass and the state of eutrophication by increasing the Phosphorous and Nitrogen recycling in the river systems (Figueredo & Giani, 2005). In addition, invasive species can influence and change the phytoplankton species abundances thereby changing the community structures (Tatrai *et al,* 1990; Ramcharan *et al,* 1996). *O. niloticus* being a filter feeder are able to influence the size structures of algal populations through selective capture of zooplankton or size selections ingestion of particular algae species (Lazzaro, 1987; Northcote *et al*, 1990; Ramcharan *et al,* 1996; Komarkova, 1998; Turker, *et al*, 2003). A further example is that of *T. rendalli* that was accidently introduced into a power plant reservoir in North Carolina where it reduced all the macrophytes through grazing which resulted in a decline in native fish species (Cook *et al,* 2008). This may have an effect on other tilapia species in the same river system that feed on specific phytoplankton as well as other aquatic organisms that rely on specific types of phytoplankton.

Apart from habitat disruption and competition the introduction of exotic species pose further risks to local ecosystems through the introduction and release of non-native organisms, parasites and pathogens. Aquaculture often entails the cultivated species needs to be farmed at high densities to be economically viable (Cook *et al,* 2008), whilst providing ideal conditions for pests, parasites and diseases to thrive (Minchin & Rosenthal, 2002). The trematode, *Gyrodactylus salaris,* for example was introduced into Norway via the introduction of Atlantic salmon, *Salmo salar* from Swedish hatcheries and resulted in increased salmon mortalities. The introduction of a rotund nematode worm (*Anguillicoloides crassus*) that is easily dispersed by copepods, fish and insects had a significant adverse effect on the European eel population (Cook *et al,* 2008).

The aquaculture industry remains highly dependent on ongoing genetic improvement of aquaculture species (Cross, 2000). In natural environments genetic variation manifest on the level of within and between families, where in relation to aquaculture genetic variation of a species depends largely on the organisational level among populations (Youngson *et al,* 2001). Genetic complexes then develop within these cultured populations as aquaculture species are often bred for specific traits which increases the complexity (Cook *et al,* 2008). When individuals from cultured populations escape back into the wild and breed with natural populations, such introgression could result in hybridisation and reduced fitness in relation to specific traits (Mooney & Cleland, 2001; Skaala *et al,* 2006; Cook *et al*, 2008). The highly domesticated *O. niloticus* can potentially hybridize with indigenous Tilapia species in the Caprivi therefore negatively affecting the surrounding biodiversity.

According Mooney and Cleland (2001), even small populations of invasive species has the potential to threaten indigenous species. Interspecies hybrids can result in unbalanced sex ratios such as when *Tilapia tholloni* hybridize with *O. mossambicus* where all the offspring would be female (Agnese *et al*, 1998). On the other hand hybridization between *O. spirulus* and *O. leucostictus* resulted in a majority male offspring (Agnese *et al,* 1998). The possibility and effect of hybridization between *O. niloticus* and *O. andersonii* and other tilapia species native to the Caprivi region has not been fully assessed and so caution is required in this regard.

Although there is no record of alien fish species in the Caprivi wetlands (Timberlake & Childes, 2004) there is a risk that *O. niloticus* may reach the Caprivi system from surrounding countries (Zambia, Zimbabwe) and regions where it has been introduced for aquaculture purposes. Angola also has good potential for freshwater aquaculture further up in the Zambezi/ Okavango catchment where donor funded aquaculture projects is expected to develop in the wake of recent political stability and economic development (Timberlake & Childes, 2004). Past introductions *O. niloticus* into Zambia is expected to reach the surrounding river systems including the Caprivi.

It is therefore recommended that an indigenous species rather be used to promote aquaculture in the Caprivi system in order to preserve the aquatic biodiversity, although such an alternative species must be able to compete with exotic domesticated species in terms of production traits in order to ensure economic viability.

2.5 Rational and objective of the study

The indigenous *O. andersonii* is a very important protein source for local communities in the Caprivi region. Overexploitation of fishery by local fisherman is putting the ecosystem and communities at risk, hence the need to introduce aquaculture production to supplement the supply of fish into the local and regional market. This poses the question whether the undomesticated indigenous *O. andersonii* or the domesticated exotic *O. niloticus* should be used for the establishment of aquaculture in the Caprivi region. *O. niloticus* has been very successful elsewhere in Africa, Asia, China and South America although it has demonstrated invasive capacity that could negatively impact biodiversity and the functioning of the Caprivi system. On the other hand, genetic development of *O. andersonii* will require a significant effort in terms of time and costs to ensure that it is competitive with *O. niloticus* from an aquaculture perspective.

The objectives of this study are:

- Compare the growth and production characteristics of the indigenous *O. andersonii* with that of domesticated strains of *O. niloticus.*
- Assess the potential risks and benefits involved with the introduction of *O. niloticus* into the Caprivi region for aquaculture purposes.
- Provide recommendations regarding the use of indigenous versus domesticated strains/species of tilapia in relation to aquaculture development in Southern Africa.

CHAPTER 3

Materials and methods

3.1 Experimental facilities

The experiment was conducted at Welgevallen Experimental Farm, Stellenbosch University, South Africa. The facility consists of a greenhouse with controlled atmospheric temperature (set at 31 ºC), containing a recirculation system consisting of twelve 120 litre glass tanks draining into a central 500 litre biofilter (Figure 3.1) maintaining the water quality. Each glass tanks were continuously aerated to maintain dissolved oxygen levels at saturation throughout the experimental period, with average water temperature ranging between 24.7 to 26.7 degrees centigrade.

3.2 Experimental material

Two tilapia species were employed in the study: *Oreochromis niloticus* and *Oreochromis andersonii*. About 500 O. *niloticus* (GIFT strain) were obtained as juveniles (average weight = 1.33g) from Nam Sai Farms Co Ltd, Ban-Sang, Prachinburi, Thailand. About 50 *O. andersonii* juveniles (average weight = 1.45g) were randomly collected as wild stock from various locations along the Zambezi River near Katima Mulilo, Namibia (17° 33' 18.42" S, 24° 30' 10.79"E; 17° 33' 29.78"S, 24° 30' 31.69"E; 17° 32' 26.70"S, E24° 31' 25.37"E). A total of 20 fish per species were randomly selected as broodstock and conditioned for synchronized breeding. The high initial import quantity was necessary to ensure that sufficient numbers survived the long distance transportation for use in the experiment. The remainder of the fish were ethically euthanized due to the requirements of the import permits. Broodstock of each species were kept in separate tanks where a ratio of 1 male to 3 females was maintained. Following mass spawning, progeny groups were raised to the age of 30 days, weighing approximately 1.5 grams per individual.

3.3 Experimental layout

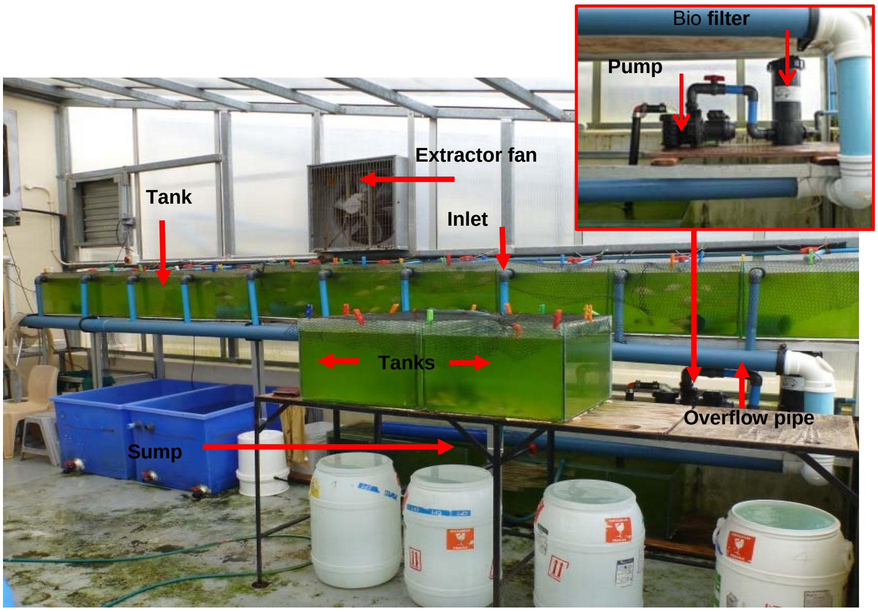

Plate 3.1 Experimental layout of the recirculation system used at Welgevallen experimental farm

The experimental layout was a random block design, consisting out a total of 12 tanks with six replicates per species and a total of 55 mixed sex fingerlings randomly allocated per replicate.

3.4 Experimental management

The stocking density of 55 fish per 120 litre tank was calculated using final fish weight estimations. The predicted average weight of 50 grams per fish at the end of the 120 day trial period was based on the expected average daily weight gain (0.5 g/day) of the GIFT strain of *O. niloticus*, preventing any over stocking toward the end of the trial period. An average mortality rate of 10 percent was incorporated into the calculation to ensure that there was a sufficient samples size (n ≥ 16) at the end of the trial.

3.4.1 Experimental maintenance

All fish were fed a formulated diet (Aqua plus Fish Diets 40% crude protein) to saturation once a day. Water parameters in the form of water temperature, dissolved oxygen and pH were measured twice daily, once in the morning at approximately 8:00 and once in the afternoon at approximately 16:00. Monitoring and maintenance of the sump, tanks and bio filter was done on a daily basis to maintain good quality water, sufficient water flow and aeration. In addition, a 50 percent water change per volume was conducted every 14 days.

3.4.2 Sampling and measurements

The experiment extended over a period of 144 days, incorporating a total of nine sampling sessions at 14 day intervals. At each interval, all available fish per repeat were sampled. Fish were anesthetized using clove oil, where after live weight of individual fish were recorded using a calibrated electronic scale measuring up to two decimals of a gram. Both standard and total length measurements were recorded on a measuring board to the nearest millimeter (Plate 3.2a and b).

Plate 3.2 Recording of the standard and total length on a measuring board (top right), and live weight of individual fish on an electronic balance (top left).

The following non-destructive sampling protocol was applied at each sampling interval:

1. Each tank (replicate) was drained and all fish were removed and place in a net suspended in an aerated 20 liter water drum, each drum labeled with the corresponding replicate number.
2. Approximately 3-4 drops of clove oil was then added to a liter of water and mixed into the drum to anesthetize the fish thereby preventing handling stress levels and injury (Plate 3.3).
3. On completion of sample measurements the fish was returned to a randomly chosen tank to eliminate possible tank effects, until the particular replicate was reinstated.

Plate 3.3 Showing tilapia juveniles (left) before and (right) after anesthesia with clove oil.

3.5 Proximate composition

The proximate composition of both species was determined in terms of the average moisture (%), crude protein (%), crude lipid (%) and ash (%) content based on duplicate analyses per sample. Calculations were conducted according to method described by the Association of Official Analytical Chemists Standard Techniques (AOAC, 1997).

3.5.1 Sample preparation

All the replicates per species were pooled at the end of the trial period, after which 18 fish per species were randomly selected for analysis. After the scales and the viscera were removed, the sampled fish were pooled into groups of six and homogenized to comprise one sample. Grouping of the fish was necessary to obtain sufficient sample mass to chemically analysis. A total of three homogenized samples (n = 6) per species were analyzed for proximate composition.

3.5.2 Moisture content

The moisture content (%) of the two species was determined by drying the samples at 100°C for 24 hours as according to the official method (934.041) of the Association of Official Analytical Chemistry (AOAC International, 2002).

3.5.3 Crude protein content

The crude protein of the two species was determined using the Dumas combustion method (992.15) specified by the Association of Official Analytical Chemistry (AOAC International, 2002). The Nitrogen content was calculated using the LECO® FP – 528 Nitrogen & Protein Analyzer (LECO ® Corporation, St. Joseph, USA) which was multiplied with a conversion factor of 6.25 to determine the crude protein (%).

3.5.4 Crude lipid content

The total lipid content (%) of both *O. andersonii* and *O. niloticus* was determined using a chloroform/methanol extraction method (1:2 chloroform/methanol) as according to Lee *et al* (1996).

3.5.3 Ash content

The ash content (%) of both *O. andersonii* and *O. niloticus* samples was determined using the official AOAC method (942.05) by placing samples in a furnace oven at 500°C for 6 hours (AOAC International, 2002).

3.6 Data analysis

The data was statistically analyzed using Statistical Analysis System Enterprise Guide 9.1 (SAS Institute Inc. 2012) and the significance level was set at 0.05. General linear models (GLM) and one-way analysis of variance (ANOVA) was used to statistically analyze the data. Outliers and data-entry errors were determined prior to analysis and were corrected and/or removed. For all linear modelling purposes the data were tested for normality (Shapiro-Wilk test) and homoscedasticity (Bartlett's and Levene's test) (Shapiro & Wilk, 1965; Levene, 1960). Where data did not meet the appropriate assumptions for each test, non-parametric tests (Kruskal –Wallis) were used.

3.6.1 Average daily weight (ADWG) and length gain (ADLG)

ADWG and ADLG were estimated for each replicate per species (6 replicates per species) as the linear regression coefficients for each measurement type on age, as shown by the equation:

$$y_{ijk} = \mu + \beta(\alpha_{ijk}) + \varepsilon_{ijk}$$

- y_{ijk} is the jth observation of the ith tank for the kth species,
- μ is the common mean,
- β (α_{ijk}) is the regression of trait of interest of the j^{th} observation of the i^{th} tank for the k^{th} species on age at measurement, and
- ε_{ijk} is the random error of the j^{th} observation of the i^{th} tank for the k^{th} species.

3.6.2 Comparison of growth rates (standard length, total length and weight) between species

Differences in average daily growth rate (standard length, total length and weight) between species were assessed by means of a one-way analysis of variance as shown by the equation:

$$y_{ik} = \mu + \sigma_k + \varepsilon_{ik}$$

- y_{ik} is the regression coefficients that were previously estimated for the i^{th} observation (tank) of the k^{th} species,
- μ is the common mean,
- σ is the main effect of the k^{th} species,
- ε_{ik} is the random error of the i^{th} observation for the k^{th} species.

3.6.3 Length to weight ratios, conditioning factor (K), tail to body ratio and mortalities

Linear regressions were determined using standard length and weight relationships for each replicate (6 per species) over the duration of the trials. The intercept 'a' values from the linear regressions were used to calculate the slope 'b' per fish per replicate per species at the end of the trial period using the equation below:

$$W=aL^b \text{ (Pauly, 1983)}$$

- W is fish weight (g),
- L is fish standard length (cm),
- a is rate of change of weight with length (intercept).
- b is weight at unit length (slope)

Calculation of intercept ‘a’ and slope ‘b’ values where the data (weight and standard length) was log-transformed:

Log W= log a + b log L (Mortuza and Al-Misned, 2013)

Condition factor (K) as calculated per fish at the end of the trial period (Gomiero & Braga, 2005):

$$K=100W/L^{b}$$

- K is condition factor,
- W is fish weight (g),
- L is fish standard length (cm),
- b is the slope obtained from the previous calculation

The total mortalities per species were calculated using the following formulae:

$$n = a - b$$

- n is total mortalities per species,
- a is total no. of samples at the start of the trial period
- b is total no. of samples at the end of the trial period

The total mortalities per species was analysed for significance by means of a Kruskal-Wallis test.

CHAPTER 4

Results

The ADWG and ADLG were calculated and the average for each species was determined (Table 4.1). Table 4.1 suggests both species experienced an increase in weight and length throughout the trial period. *O. niloticus* experienced more than double the average daily growth rates in terms of weight, standard length (SL) and tail length (TL) gain compared to *O. andersonii* (Table 4.1).

Table 4.1 Summary of One-Way ANOVA results where six variables were tested between the two tilapia species (*O. andersonii* and *O. niloticus*) over the entire trial period of144 days. (± s.e. refers to standard error)

Traits	*O. andersonii* Mean (± s.e)	*O. niloticus* Mean (± s.e)	P	r^2
ADWG (grams/day)	0.11^a (<.00)	0.25^b (<.00)	<0.001	0.988
ADLG (Standard Length gain, mm/day)	0.04^a (<.00)	0.06^b (<.00)	<0.001	0.989
ADLG (Total Length gain, mm/day)	0.04^a (<.00)	0.07^b (<.00)	<0.001	0.989
Length to weight ratio	2.11^a (0.19)	2.98^b (0.05)	<0.01	0.665
Condition Factor (K)	2.16^a (0.16)	2.92^b (0.21)	<0.05	0.457
Mortalities	3.50 (2.16)	10.00 (6.3)	NS	N/A*

^{a,b} Means in rows with different superscripts are statistically different (P<0.05); * Kruskal Wallis rank sum test; NS represents Non Significant differences; N/A represents Not applicable

ADWG and ADLG were significantly different between *O. andersonii* and *O. niloticus.* These results suggest *O. niloticus* has a higher ADWG and ADLG than *O. andersonii* (Table 4.1). Highly significant differences of mean length to weight ratios between *O. andersonii* and *O. niloticus* ($p < 0.01$) was however apparent (Table 4.1). *O. niloticus* experienced growth very close to isometric growth (b=2.98), while *O.andersonii* experienced negative allometric growth (2.11) during the trial period (Table 4.1). The condition factor (K) was significantly different ($p<0.05$) between species where *O. niloticus* had higher condition factor than *O. andersonii*. The condition factor is an important trait because it is a measure of the overall well-being of the species throughout the trial period.

Mortalities between species were notably different with *O. andersonii* (n=19) and *O. niloticus* (n=60), however these differences were not significant ($p>0.05$, Table 4.1).

Table 4.2 Summary of One-Way ANOVA results where proximate composition was tested between the two tilapia species (*O. andersonii* and *O. niloticus*). (± s.e refers to standard error)

Proximate components	***O. andersonni*** **Mean (± s.e)**	***O. niloticus*** **Mean (± s.e)**	**P**	r^2
Moisture (%)	71.95^a (0.19)	73.76^b (0.5)	<0.05	0.740
Crude protein (%)	13.45 (0.96)	14.33 (0.96)	NS	0.094
Crude Lipid (%)	5.15^a (0.11)	4.5^b (0.05)	<0.01	0.869
Ash (%)	4.87 (0.14)	4.03 (0.46)	NS	0.430

[a,b] Means in rows with different superscripts are different (P<0.05). NS represents Non Significant differences

Proximate analysis (moisture, crude protein, crude lipid and ash) was done and results statistically analyzed to determine if any significant differences (in terms of meat quality) between the selected species were apparent (Table 4.2). Significant and highly significant differences in moisture ($p<0.05$) and crude lipid ($p<0.01$) content between the species was observed. *O. niloticus* had significantly higher moisture content while *O. andersonii* had highly significantly higher crude lipid content (Table 4.2). There was no significant differences noted in crude protein ($p>0.05$) and ash ($p>0.05$) content between the selected species (Table 4.2).

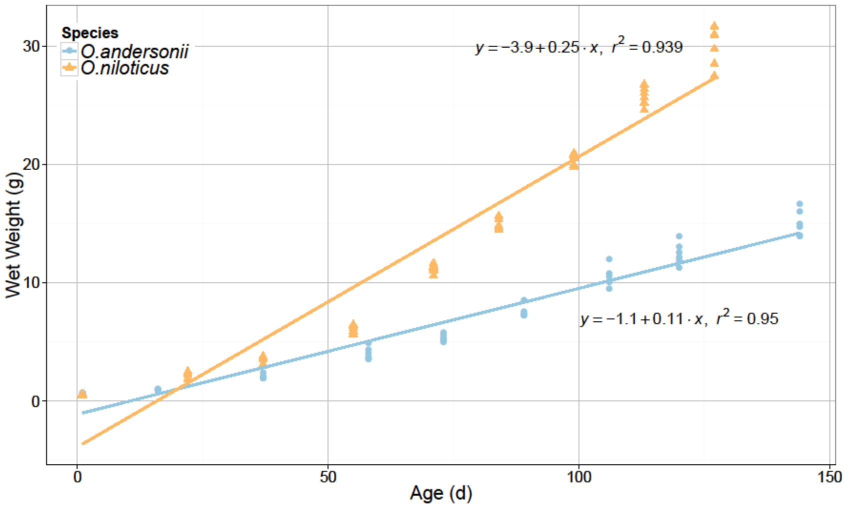

Figure 4.1 Linear regressions of live weight over time of *O. andersonii* and *O. niloticus*. The fitted points are means of each replicate. The solid lines indicate overall species growth rates and intercepts regression as well as coefficients of determination (r^2). (d) refers to days.

High r^2 (*O. andersonii* (0.95) and *O. niloticus* (0.939)) values suggest ADWG for either species was linear throughout the duration of the trial period (Figure 4.1). *O. niloticus* experienced the higher ADWG between the two species (Figure 4.1).

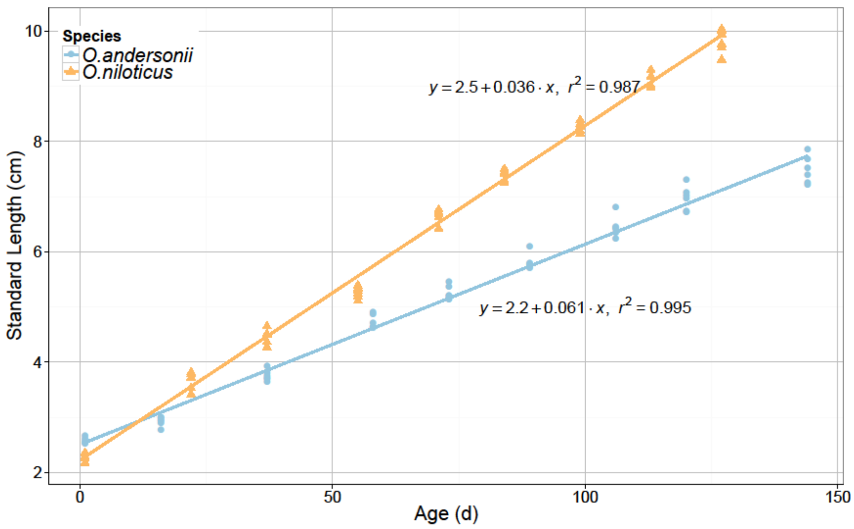

Figure 4.2 Linear regressions of standard length over time of *O. andersonii* and *O. niloticus*. The solid lines indicate overall species growth rates and intercepts regression as well as coefficients of determination (r^2). (d) refers to days.

Linear equations in figure 4.2 suggest high r^2 values for both species (*O. andersonii* (0.987) and *O. niloticus* (0.995)). This suggests ADLG (SL) was linear throughout the duration of the trial period and *O.niloticus* had the superior ADLG (SL) between the two species (Figure 4.2).

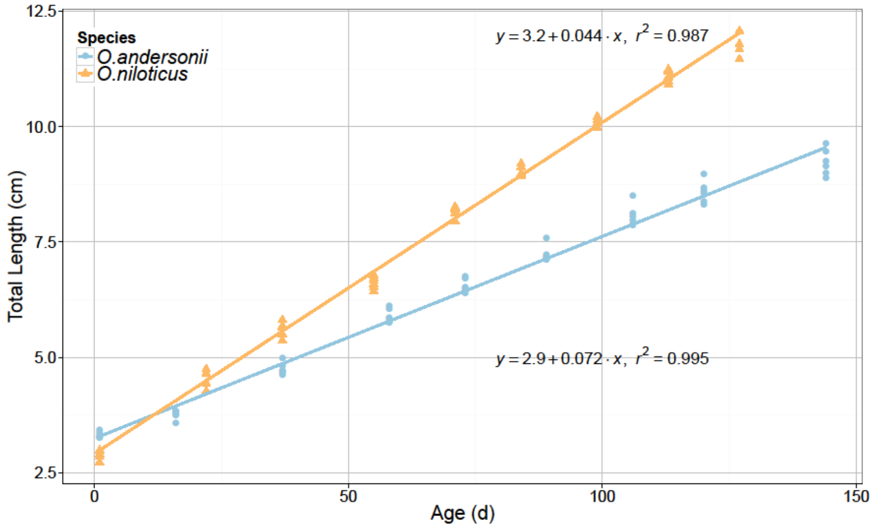

Figure 4.3 The linear regressions of total length over time of *O. andersonii* and *O. niloticus*. The solid lines indicate overall species growth rates and intercepts regression as well as coefficients of determination (r^2). (d) refers to days.

These linear equations resulted in high R-squared (*O. andersonii* (0.987) and *O. niloticus* (0.995)) values suggesting ADLG for both species was linear throughout the duration of the trial period (Figure 4.3). *O. niloticus* also experienced the superior ADLG compared to *O. andersonii* (Figure 4.3).

***4.1** Observations noted during the trial period*

Deformities (gills and mouth) among *O. andersonii* were noticed only during the fourth sampling session (58 days old). Deformities among *O. niloticus* were first noted during the second sampling session (22 days old). Damaged eyes among the *O. niloticus* replicates were first observed during the third sample session (37 days old).

O. andersonii samples were noticeably fat during the fourth sampling session (58 days old), eggs were first noticed at the fifth sampling session (73 days old) while *O. andersonii* in all replicates displayed signs of breeding (fingerlings and several females securing eggs in mouths) by the sixth sampling session . *O. niloticus* displayed no signs of breeding except for a few samples which displayed breeding colors near the end of the trial period. However, eggs were first noticed after the trial period when randomly selected *O. niloticus* samples were dissected for proximate analysis.

All *O. niloticus* replicates displayed signs of higher aggressiveness (attempts to jump out during feeding, feeding aggressively and harder to catch during sampling sessions) throughout the duration of the trial period.

CHAPTER 5

Discussion

The background to the study remains the overexploitation of fisheries in the Caprivi region of Namibia and the need for intervention to ensure sustainable livelihoods. The development of aquaculture is proposed as an alternative to historical reliance of fisheries resources. Tilapia, in particular *O. andersonii*, is an obvious candidate for aquaculture development based on environmental conditions, consumption patterns, established markets and the species being native to the region. The distribution of genetically improved strains of the exotic *O. niloticus* are approaching shared catchments and markets near to the Caprivi raises the question whether aquaculture development should be based on the use of genetically improved exotic species, as appose to undomesticated native species. The purpose of the trial is to compare the production characteristics of *O. andersonii* and *O. niloticus* with the study exploring the broader ecological impacts and social benefits.

5.1 Comparison of growth

The average daily growth rate (ADGR) relates fish weight with age and may either be described as linear, exponential or more complex models such as the Gompertz or von Bertalanffy models (Santos *et al*, 2013). Growth rates are not constant and change throughout the life span of fish (Santos *et al*, 2013). Faster growth rates results in shorter culture periods which increases the production yield and maximizes profits (Kefi *et al*, 2013). Growth rates also enable farmers to project fish growth over a specific period as well as assisting in calculating optimal feed rations for extended periods of time (Soderberg, 2006).

According to Santos *et al* (2013) domesticated fish species generally outperform undomesticated species independent of the environmental conditions experienced. Such assumptions are in line with the results of the current study where the domesticated *O. niloticus* had a superior ADWG of 0.25 grams per day and ADLG of 0.06 millimeters per day compared to the 0.11 grams per day and ADLG of 0.04 millimeters per day of the undomesticated *O. andersonii*. Due to the extensive selection strategies incorporated into the breeding of the GIFT strain of *O. niloticus* compared to wild variants such as *O. andersonii*, it was somehow expected that *O. niloticus* (GIFT strain) would experience faster growth. However the extent of the differences between the two species was not expected where in this case *O. niloticus* had more than double the ADWG and ADLG of *O. andersonii.* According to Ng & Hanim (2007) the GIFT strain is also displaying superior feed conversion efficiency compared to other tilapia strains, including the Red tilapia strain, further suggesting enhanced benefits. These results not only provide further evidence that the genetic improvement of tilapia species through selection can considerably increase growth rates of such strains, but also that this approach should be considered in relation to improvement of the indigenous *O. andersonii* in the Caprivi.

Domesticated strains of *O. niloticus* are displaying low gene-environment interactions and as a consequence are expected to performing well across different sets of environmental conditions (Macaranas *et al*, 1997). However, Santos *et al* (2013) suggested due to the ectothermic characteristics of tilapia species, tilapia species may not necessarily perform equally well at different temperature regimes. The superior growth results of the GIFT strain of *O. niloticus* obtained under controlled and optimal experimental conditions may not necessarily be replicated under natural environmental conditions, such as the Caprivi region that fall outside its native range. This possibility needs to be considered when comparing the aquaculture potential of these two species in relation to the Caprivi region.

The early onset of reproduction of *O. andersonii* recorded at around 9 weeks of age in the current study is a common characteristic associated with undomesticated tilapia species; whilst the lack spawning behavior observed in *O. niloticus* is consistent with results reported by Yakubu *et al* (2012) with minimal spawning activity over a culture period of 24 weeks. It is proposed that wild variants such as *O. andersonii* is directing metabolic energy primarily towards reproduction while domesticated strains, such as the GIFT strain, spent energy primarily on growth which is a likely factor in variation in growth performance (Githukia *et al*, 2015). Although Mair & Little (1991) suggested that the sexual maturity of *O. niloticus* may occur as from 20 grams, *O. niloticus* above this threshold were not observed to spawn during the trial period of ±18 weeks. Reasons for this delayed breeding behavior may be due to the lower than optimal water temperatures experienced during the trial period and/or high stocking densities which can disrupt breeding behavior (DeLong *et al*, 2009). However both species were stocked at equivalent stocking densities during this trail and is therefore not suggested to have disrupted the breeding behavior of *O. andersonii*.

O. niloticus strains (including the GIFT strain) have been described to have growth rates far exceeding the 0.25 grams/day reported in the current study, with values as high as 6.89 grams/day have been reported (Rakocy, 1989; Muir *et al*, 2000; Santos *et al*, 2013). The lower than expected growth performance of *O. niloticus* could be an indication of exposure to sub-optimal rearing conditions during this trial, in relation to the temperature, water quality and feeding regime. Fish growth is a complex process that is influenced by various environmental factors (Martinez *et al*, 1996), each of which require optimization in order to achieve optimum growth performances, essential for maximizing production (Azaza *et al*, 2008). Water temperature is considered to be one of the most influential environmental factor on fish growth (El Sayed & Kawanna, 2008; Azaza *et al*, 2010) and can additionally affect physiology, reproduction and metabolism (Santos *et al*, 2013). Increasing rearing temperatures to 30 degrees Celsius have been found to increase weight gain in the GIFT strain (Santos *et al*, 2013) and digestion, feed consumption and FCR in other *O. niloticus* strains and tilapia species (Popma and Lovshin, 1995; Azaza *et al*, 2008). Therefore, temperature is suggested to be a confounding factor in the suboptimal growth rate observed in *O. niloticus* where rearing temperatures were ±26 degrees Celsius during the trial period. It is important to note that mean annual temperatures in the Caprivi (±21ºC) is lower than the mean temperatures reported in this study which will negatively affect the growth of *O. niloticus* and suggests that *O. andersonii* may have a temperature advantage over *O. niloticus* in the Caprivi Region

5.2 Comparison of length to weight ratios

The length to weight relationship is commonly used to determine condition factors which indicate a fish's overall well-being within their habitat (Machado *et al*, 2005). The data used to describe the relationship between length and weight enables one to predict the weight from a given length or vice versa (LeCren, 1951; Pauly, 1993). The length to weight relationship can also be used to indicate fatness, health status and gonadal development of individual fish by measuring variations from expected fish populations, as well as compare biotic and abiotic effects on the well-being of fish populations (Cone, 1989).

Length to weight relationships identifies whether that fish experiences either negative allometric growth ('b' < 3), isometric growth ('b'=3) or positive allometric growth ('b'>3) (Bagenal & Tesch, 1978). Negative allometric growth suggests slower growth as length gain is superior to weight gain, isometric growth suggests weight gain and length gain are equally proportional and positive allometric growth suggest faster growth as weight gain is superior to length gain (Veeramani *et al*, 2010; Safran, 1992). According to Froese (2006) finfish should experience a 'b-value' between 2.5 and 3.5 while Bagenal & Tesch (1978) suggests finfish experience 'b-values' between 2 and 4. Mortuza & Al-Misned (2013) reported mixed sex *O. niloticus* to have a 'b-value' of 3.01 which is consistent with the results of the current study. *O. niloticus* experienced growth very close to isometric growth at b = 2.98 ± 0.05, while *O. andersonii* experienced negative allometric growth at b = 2.11 ± 0.19. However, it is important to note that the significantly higher 'b-value' of *O. niloticus* may also be attributed to the general morphology as *O. niloticus* is more rotund than the slender *O. andersonii* (Boyd, 2004).The results from the length to weight relationships shows *O. niloticus* to display a more favourable body type.

5.3 Comparison of condition factors

Both the condition factor and length to weight relationships may be affected by ecological factors (e.g. temperature, food quantity and quality), spawning conditions, seasons and habitat and physiological factors (e.g. stress, sex, age, gonad maturity, stomach fullness and health) (Sparre, 1992; Khallaf et al., 2003). Although the scope of this study did not take these ecological and physiological factors into account, the length to weight relationship and condition factor was calculated to determine and compare the well-being between species under the controlled environment. The low length to weight ratios reported for *O. andersonii* may be attributed to preferable water temperature and early gonadal development. According to Mortuza & Al-Misned, (2013) higher condition factors (>1.00) suggest that fish are in a healthy condition. The condition factors reported for *O. andersonii* (K= 2.16 ± 0.16) and *O. niloticus* (K= 2.92 ± 0.21) suggest that both species were in very healthy condition where the condition factor for *O. niloticus* is consistent with that observed by Mortuza & Al-Misned (2013).

5.4 Comparison of proximate analysis

Fish meat is an valuable food source which is considered high in protein and essential minerals and low in fat yet containing essential polyunsaturated fatty acids such as omega 3 (Kefi *et al*, 2013; Young, 2015). The chemical composition of fish can vary significantly between species (Adeniyi *et al*, 2015) with nutritional information being of growing importance to consumers. In the current study no difference in protein and ash was observed; although this indicates comparable quality of both species, differences in individual mineral and amino acid complex may exist which were not examined in the current study. The average ash content of both *O. andersonii* (4.87%) and *O. niloticus* (4.03%) were within previously detected ranges in tilapia species (*O. mossambicus* and *O. niloticus*: 3.85 - 7.97%) reported by Adefemi (2011) and Oladipo and Bankole (2013). Such inter-study variability in ash content may be due to several different attributes such as species, age, sexual cycle, feed quality, stage of maturity and environmental parameters (Alemu *et al*, 2013; Khitouni *et al*, 2014). The average crude protein of *O. andersonii* (13.45 %) and *O. niloticus* (14.33 %) were within previous described ranges (13.10% - 18.80%) for different tilapia species such as *O. aureus, O niloticus* and *Tilapia zilli* (El-Hawarry, 2012; Olagunju *et al*, 2012; Job *et al,* 2015).

The results from this experiment revealed that *O. niloticus* has significantly higher moisture content than *O. andersonii* which is consistent with Mphande & Chama (2015). O. *niloticus* had a significantly lower crude lipid content than *O. andersonii* which is contradictory to the findings of Mphande & Chama (2015). According to Osibona *et al* (2009) lower crude lipid contents may be a result of expenditure of lipid reserves during spawning. In this trial however, *O. andersonii* displayed a significantly higher crude lipid content together with early reproduction, compared to *O. niloticus* that displayed no reproduction together with a lower crude lipid content. The higher crude lipid content observed in *O. andersonii* may be attributed to wild species reportedly retaining genes associated with an increased crude lipid content coinciding with decreasing water temperatures, increasing survival over extended periods of cold water temperatures (Mphande & Chama, 2015).

5.5 Other observations

O. niloticus experienced a higher number of mortalities (n=60) than *O. andersonii* (n=19); however the majority of the *O. niloticus* mortalities (n=41) occurred on a single day which was concurrent with a sudden change in water parameters. Over a relatively short period (±24 hours) water temperatures increased from 21.3 to 28.2 degrees Celsius and dissolved oxygen levels decreased from 74 to 46 percent. This observation could suggest that *O. andersonii* may be more tolerable to fluctuations in water parameters although such reasoning needs further experimental and statistical analysis.

Deformities and damage may negatively impact species marketability due to negative attributes such as, aesthetic, textural and odour changes (Amany, 2010) each of which may be due to genetic, environmental, pathogenic and/or nutritional factors (Noga, 1996; Easa, 1997). However, very few deformities were noted during this experiment such that any effects are suggested to have insignificant effects on consumer choice and marketability. The damaged eyes noted in one of the *O. niloticus* replicates indicate possible signs of aggression within the species. However the overall limited incidences reported suggests that these injuries may be a result of accidental injuries (attempts to jump out during feeding sessions and feeding more aggressively) whilst no genetic deformities were detected.

5.6 General conclusions and recommendations

The objectives of this study were:

- to compare the growth and production characteristics of the indigenous *O. andersonii* with that of domesticated strains of *O. niloticus*;
- to assess the potential risks and benefits involved with the introduction of *O. niloticus* into the Caprivi region for aquaculture purposes; and
- to provide recommendations regarding the use of indigenous versus domesticated strains/species of tilapia in relation to aquaculture development.

The experimental results conclude that the domesticated *O. niloticus* outperformed the indigenous wild *O. andersonii* by significant margins in relation to ADWG and ADLG, making it the preferred species from a production perspective. The growth performance of *O. niloticus* under the below optimal average water temperature conditions of the Caprivi should however be taken into account and preferably be assessed to substantiate the above. The other production characteristics considered provide no further advantages, accept for the more favorable body type of *O. niloticus*.

An ecologically sustainable approach to the development of tilapia aquaculture in Caprivi needs to take into consideration both potential economic and socio-economic benefits and environmental and socio-economic impacts when considering the preferred species for aquaculture purposes. Literature provides convincing evidence of environmental risk in relation to the invasive behavior, disruption of genetic and biodiversity in ecosystems where *O. niloticus* were introduced. Benefits in relation to the superior production characteristics of *O. niloticus* seems attractive from an economic perspective. The irreversible nature of the environmental impacts, against the lack of quantified benefits leaves little choice as to apply the precautionary principle in relation to the introduction of *O. niloticus* into the Caprivi region.

The recommended approach with regard to the development of tilapia aquaculture in the Caprivi region is:

- To conduct a detailed risk assessment specific to the Caprivi region to determine the biological and ecological impacts of the introduction of *O. niloticus*.
- To conduct a detailed cost benefit analysis to establish a genetic improvement program for *O. andersonii* in the Caprivi region.

Further recommendations include:

- Fisheries management practices need to be effectively enforced to ensure the maintenance of resilient and genetically diverse natural population of indigenous species in the Caprivi region.
- Effective farm management practice to be implemented to limit the effect of farmed populations on natural populations in terms of fish health, genetic diversity and habitat conservation.

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