A Production Model for Commercial Integrated Aquaculture Development in KwaZulu-Natal using Family Scale Modular Units

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I, the undersigned, hereby declare that the work contained in this assignment is my own original work, and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Abstract

This paper reviews the status of world aquaculture with a primary focus on Sub-Saharan and Chinese freshwater aquaculture, and proposes a commercial integrated farming model for implementation in rural areas in KwaZulu-Natal.

The model combines the paradigms of age-old Chinese integrated pond farming principles with a commercial approach in the socio-economic context of Sub-Saharan Africa. The project's objective is to contribute to the alleviation of poverty through economic development in rural areas using environmentally and economically sustainable farming practices.

The project's medium-term goal is to achieve the critical production volume to warrant vertical integration into a hatchery, feed mill and processing facility. Integration would reduce operating costs and afford better standards of basic services. The project's long-term goal is to grow and expand the model to make a contribution to global food security through distributing a fish-based, nutritionally balanced meal to famine relieve efforts in low-income food deficiency countries (LIFDC).

The model proposes the development of individual farms each with a production capacity of 40 to 60 tons of fish per annum. The species available include tilapia, catfish, carp, mullet, bass and eels. The farms will each consist of eight grow-out fishponds totalling 4 hectares of water surface area, a basic homestead and 6 hectares for crops and livestock rearing. The farms are designed to utilize the nutrient rich effluent from the fishponds to flood-irrigate crops planted in the fields below. Through application of the principles of the integrated approach to fish-crops-livestock farming as applied by the Chinese over the last 2,000 years, the farms are designed in a way that nothing is wasted. The waste product from one system becomes input for the next system. The integrated approach is extremely cost effective and lends itself to total organic farming adhering to environmentally responsible and sustainable farming principles. Two hundred such farming units would produce a total of 8,000 to 12,000 ton per year that equates to double the current combined freshwater aquaculture production from all the SADC member countries.

Opsomming

Die werkstuk bied 'n oorsig van akwakultuur in die wêreld, met 'n primêre fokus op die stand van varswater akwakultuur in Sub-Sahara en China. 'n Ontwikkelingsmodel vir geïntegreerde kommersiële boerdery word voorgestel, in die plattelandse dele van KwaZulu-Natal word woorhou.

Die model koppel die konsepte van eeue-oue Chinese beginsels van geïntegreerde visboerdery met kommersiële winsgewendheid, binne die sosio-ekonomiese konsep van sub-Sahara Afrika. Die doel van die model is om 'n beduidende rol te speel in die verligting van armoede deur die ontwikkeling van ekonomiese aktiwiteit in plattelandse gebiede d.m.v. omgewings- en ekonomies volhoubare boerderypraktyke.

Die projek se mediumtermyndoelwit is om die kritiese produksievolume te bereik wat vertikale integrasie met 'n visbroeiery, 'n voermeule en 'n prosesseringsfasiliteit sal regverdig. Dit sal operasionele kostes verminder en beter beheer verseker oor hierdie basiese insette. Die langtermyndoelwit is om die model uit te brei ten einde 'n bydrae te maak tot globale voedselvoorsiening deur die verspreiding van 'n voedsame, gebalanseerde maaltyd met vis as basis, as hongersnoodverligting in lae inkomste lande met 'n voedseltekort.

Die model stel 'n reeks individuele plase voor, elk met 'n produksiekapasiteit van 40 tot 60 ton vis per jaar. Die beskikbare spesies sluit in tilapia, baber, harder, swartbaars en paling. Elke plaas sal bestaan uit agt uitgroeidamme van 'n halwe hektaar elk, 'n totaal van vier hektaar wateroppervlakte, 'n woonhuis en ses hektaar vir gewasse en veë. Die plase is ontwerp ten eide die voedingsryke uitvloeisel van die visdamme te gebruik vir besproeiing van die laerliggende landerye. Deur gebruik te maak van die beginsel van integrasie van 'n vis-, gewas- en vee-boerdery, aan die hand van die Chinese ontwikkelingsmodel oor die afgelope 2,000 jaar, word gepoog om niks te vermors nie. Die afvalproduk van een stelsel word 'n inset in die volgende. Hierdie benadering is uiters koste-effektief en leen homself tot organiese boerdery praktyke wat voldoen aan bewaringsbewuste en volhoubare boerderymetodes. Tweehonderd plaaseenhede sal 'n gesamentlike bydrae van 8,000 tot 12,000 ton per jaar lewer, wat gelykstaande is aan dubbeld die huidige gekombineerde varswater akwakultuurproduksie van al die SADC-ledelande.

Contents

CHAPTER 1

INTRODUCTION: THE NEED AND OPPORTUNITY FOR AQUACULTURE DEVELOPMENT IN KWAZULU-NATAL

1. Introduction

This assignment aims to add to previous work done on the subject of rural aquaculture development by suggesting a model for commercial scale integrated fish farming in KwaZulu-Natal, South Africa, using family-scale modular production units. The proposal takes a holistic approach to the aquaculture sub-sector, including the support structures that are necessary to ensure sustainable environmental and economic growth. Some historic sub-Saharan rural aquaculture development projects and recent Chinese small-scale fish farming information and trends are assessed in order to ensure realistic expectations and to avoid common pitfalls. The assignment also describes some freshwater fish farming activities in the Jiangsu Province in central China, as to provide the main focus for the farming methodology to be implemented in KwaZulu-Natal. This region of China provides an example of what could be achieved in a climate similar to regions in Southern Africa, using a relative low level of technology and input costs.

1.1 The role of Aquaculture development

1.1.1 Economic development, decentralization and poverty reduction

South Africa has an official unemployment rate of 37% (CIA, 2003) and vast areas where more than 90% of individuals earns less that R1,000 per month (Figure 1a). There is a dire need for sustainable economic development and black economic empowerment in these areas in which aquaculture development can play a major part, particularly in relation to rural areas.

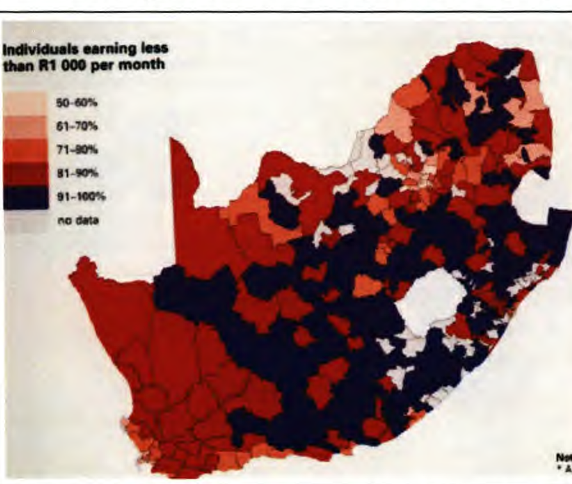


Figure 1a A map of South Africa in relation to individuals earning less than R1,000 per month (Winter, et.al., 2001).

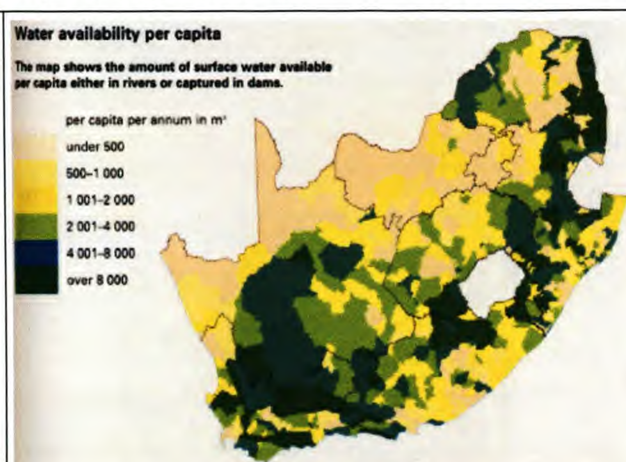


Figure 1b Water availability per capita map of South Africa (Winter et.al., 2001).

1.1.2 Water retention and conservation

South Africa has a semi-arid climate (Figure 1b) and the conservation of water is very high on the national agenda. Pond farming integrated with crop irrigation is extremely efficient in terms of consumptive utilization of water. Furthermore, pond-based aquaculture creates additional structures for water retention.

1.1.3 Food security

An estimated 800 million people in developing countries are undernourished and six million children under the age of five die of hunger every year. Almost 400 million people depend on agriculture for their livelihood in sub-Saharan Africa (FAO, 2002). The Food and Agriculture Organization of the United Nations (FAO) and World Food Program (WFP) estimates that presently as many as 15 million people in Southern Africa need emergency food assistance. The FAO describes this as the most severe human crisis in the world today. The main reasons are floods, droughts and reduced planting of maize in the area. Malawi, Zambia and Zimbabwe are the hardest hit areas, followed by southern Mozambique, Swaziland, Angola, Lesotho and Namibia. The WFP received 135 million US$ to address the issue and to set a target to supply 1,000,000 tons of food using South Africa as a base for distribution into Southern Africa. This information emphasizes the need for sustainable development and food security in the region.

In addition to this, the International Food Policy Research Institute (IFPRI) and WorldFish Center have released a report (Outlook for Fish to 2020: Meeting Global Demand), which indicates that the consumption of food fish in sub-Saharan Africa will by 2020 have increased by 72 percent over 1997 levels, from 3.7 to 6.4 million metric tons. A total of 88 percent of fish consumed in sub-Saharan Africa by 2020 will be low value food fish, of which 627,000 metric tons will have to be imported (IFPRI, 2003).

Aquaculture development in South Africa can also be export driven, targeting both first and third world markets. South East Asia (SEA) is the region with the highest population concentration in the world and has a current consumption rate of about 17.2 kg of fish/caput/annum (world avg. 15.8 kg). The population in the region is expected to reach 4.16 billion by 2020. If the current fish consumption rate is to be maintained, the region will require 70 million tons of fish by 2020, representing an increase of nearly 26 million tons from the present Asian production of 43.96 million tons. Most of SEA has limited aquaculture expansion options due to competing land use and pollution issues. In addition, capture fisheries have reached a plateau, with 13 of the 15 world oceans already overfished. This growing demand in SEA is further creating additional market opportunities (Da Silva, 2002).

1.2 Chinese aquaculture as a model for rural aquaculture development

Part of the way forward may be to again look at other parts of the world to see what kind of farming technologies can be implemented on own soil. China has overcome similar challenges and responded by becoming agriculturally self-sustainable through concerted development the last 20 years. During this time, their freshwater aquaculture production increased five-fold. China is currently the world leader in terms of aquaculture production with over 32 million tons of fish produced per year, including 76% of the world freshwater fish production.

1.2.1 South Africa's suitability for implementing Chinese aquaculture technology

The current aquaculture production in South Africa is low compared to world standards, but the rapid development in China the last 20 years sets a very encouraging benchmark for other LIFD countries. Climate and rainfall are vital parameters in assessing the suitability for pond-based aquaculture. Distinct climatic similarities exist between some regions in South Africa and the main fish-producing area of central China (figure 5). Most of the KwaZulu-Natal and Mpumalanga provinces are climatically suitable for pond-based aquaculture because of hot summers, mild winters and adequate annual rainfall (Figure 4).

Typical farming activities in KwaZulu-Natal province include commercial sugarcane farms and small plots of subsistence vegetable farming as depicted in figure 2. Figure 3 shows two different land use areas suitable for aquaculture development. The first is a typical rural area in KwaZulu-Natal with little or no agricultural or economic activity. Unemployment is high and labour is readily available in these areas. The land costs are typically also very low. The next picture is a commercial crop farm with space for aquaculture pond development. Farms like these have good basic infrastructure and the owners generally have capital to invest in developing aquaculture ponds on their land.

Figure 2a A sugarcane farm with koi ponds in KwaZulu Natal (Author)

Figure 2b An aerial view of small-scale coastal farming in KwaZulu Natal (Author)

Figure 3a An aerial view of a rural area in KwaZulu-Natal as a potential area aquaculture development (Author).

Figure 3b A vegetable farm in KwaZulu-Natal as a potential aquaculture sites (a) an aerial view of a rural area and (b) (Author).

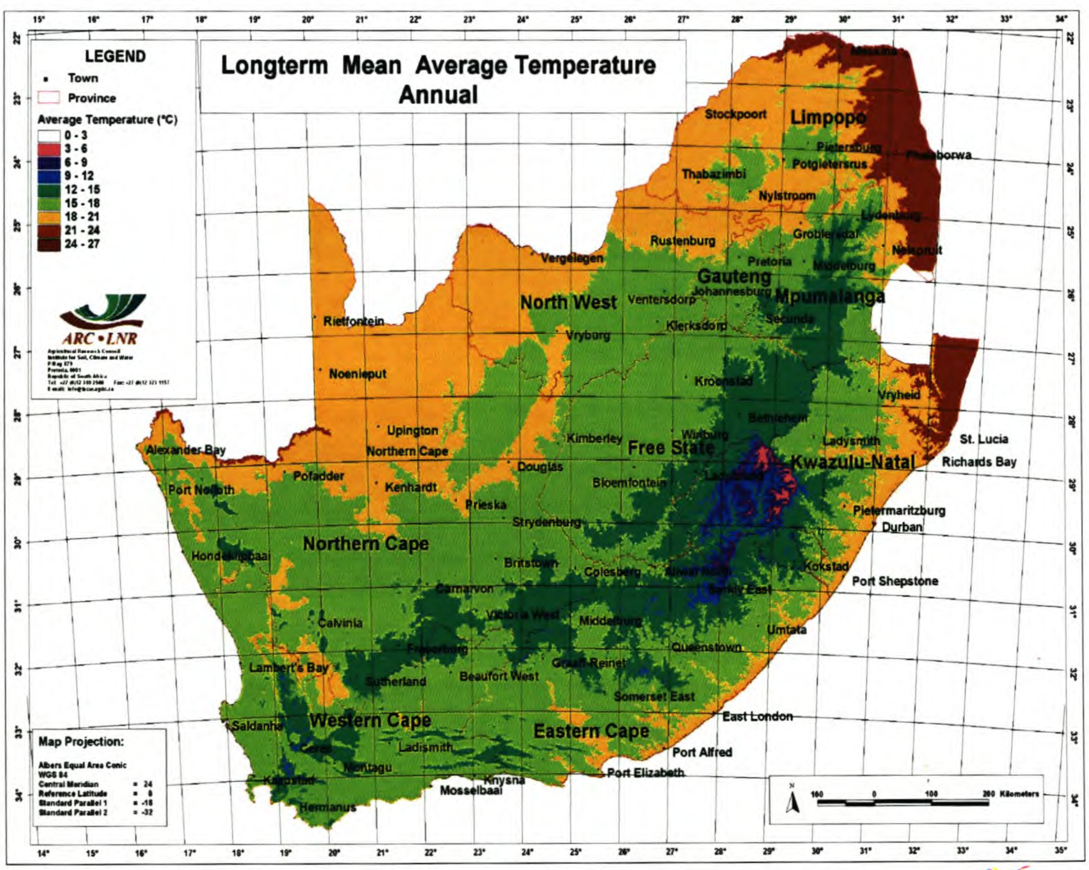


Figure 4a Long term average temperature and rainfall maps of South Africa (ARC, 2002)

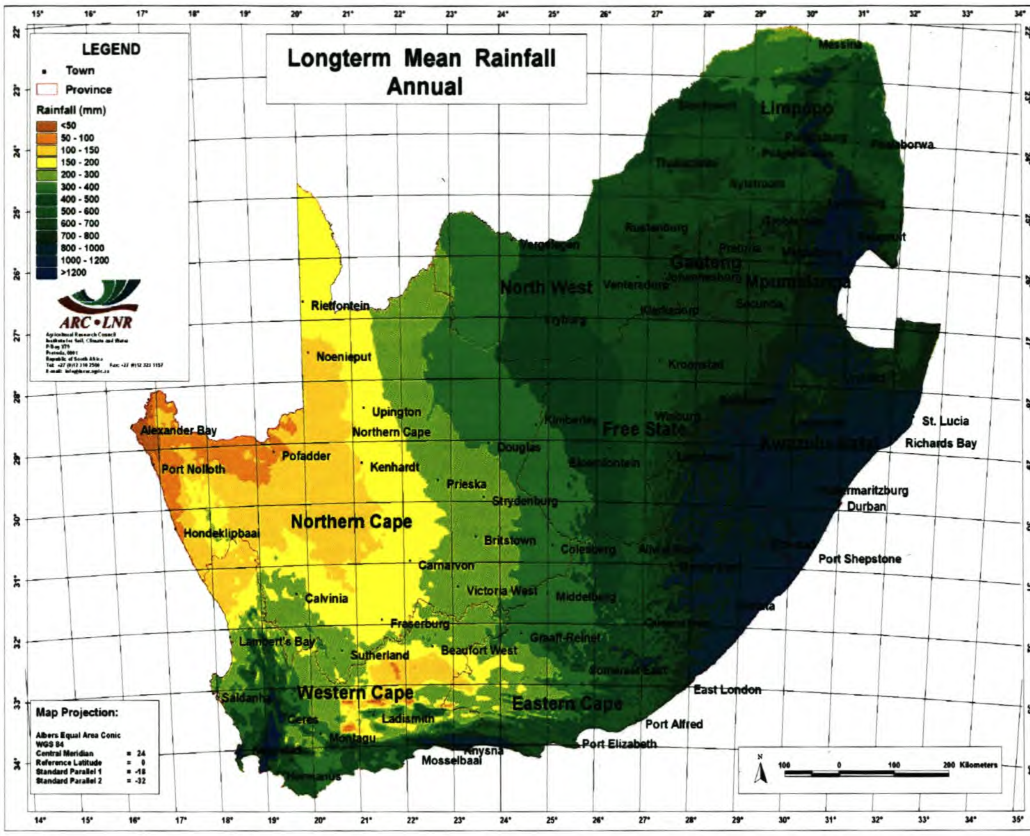


Figure 4b Long term average temperature and rainfall maps of South Africa (ARC, 2002)

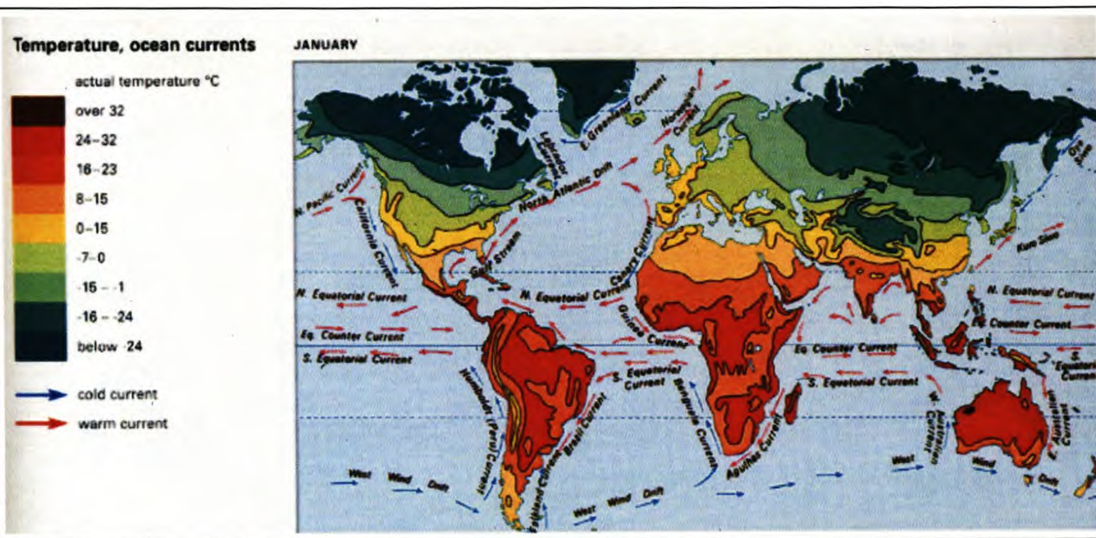


Figure 5a Comparative average global temperatures (ARC, 2002).

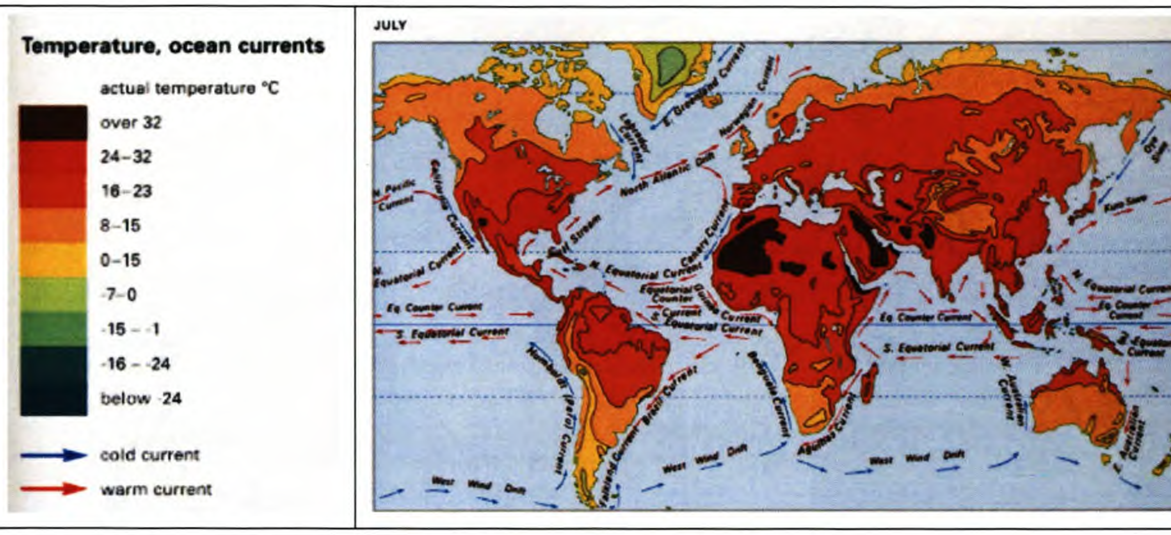


Figure 5b Comparative average global temperatures (ARC, 2002).

1.3 Conclusion

It is clear that there is a dire need to address some pressing issues in the rural KwaZulu-Natal region. These include lack of rural economic development initiatives, unemployment, food security and water conservation. Integrated pond-based aquaculture development will have a major impact on all the abovementioned challenges. The farming of pond fish is highly successful in China and the rest of South East Asia, and is a major contributor to employment, food security and the economies of that region. Large areas of rural KwaZulu-Natal have highly suitable climates for integrated pond-based aquaculture development as a sustainable, ecologically friendly agriculture sub-sector.

The following section places the proposed aquaculture development in KwaZulu-Natal in context with existing global aquaculture development, trends and history. Section C takes an in-depth look at the success of the integrated pond-based fish farming technology implemented in China. Section D proposes an implementation strategy for integrated farming principles in KwaZulu-Natal, and Sections E and F gives a detailed farm models and practical operational guidelines to achieve the necessary production levels.

CHAPTER 2

THE STATUS OF WORLD FISHERIES AND AQUACULTURE

2.1 Introduction

The contribution from capture fisheries and aquaculture is significant in terms of global food security, providing more than 15 percent of total animal protein supplies. The per capita fish supply has decreased on a global basis from 14.6 kg in 1987 to 13.1 kg in 2000, due mainly to the increase in the world population during this period against the backdrop of no increase in natural fisheries. International trade in fish products is currently at a record US$55.2 billion and has sustained growth of 4% per annum for the last decade (FAO, 2003). Net export trade from developing countries increased from US$10 billion in 1990 to US$18 billion in 2000. Furthermore, global forecasts of upper sustainable limits for capture fisheries, which have been recorded since the early 1970s, are substantiated by global fisheries statistics as recorded over recent years (FAO, 2003).

China is still by far the largest producer of aquatic products, with reported fishery production of 41.6 million tons in 2000 (17 million tons from capture fisheries and 24.6 million tons from aquaculture), providing an estimated food supply of 25 kg per capita.

Table 1 Number of active fish farmers in the world (FAO, 2003)

	Number of fish farmers (x1,000)										
Region	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Africa	...	...	...	5	6	14	62	55	56	57	75
North & Central America	53	73	101	206	206	176	182	185	191	190	190
South America	16	15	15	20	30	43	44	42	41	42	41
Asia	3,698	3,882	4,292	4,927	5 389	6,003	6,051	6,569	6,758	6,930	7,132
Europe	11	12	13	23	26	18	23	25	25	26	27
Oceania	neg.	neg.	neg.	neg.	1	1	4	5	5	5	5
World	**3,778**	**3,983**	**4,423**	**5,182**	**5,657**	**6,254**	**6,366**	**6,880**	**7,075**	**7,249**	**7,470**

Employment in Aquaculture is increasing on average by about seven percent per annum. Most of the growth of employment in fish farming and other culture practices have occurred in Asia, particularly in China, where the reported number of people engaging in cultivation of aquatic life has doubled in the past decade. Greater economic opportunities derive from the commercial aquaculture production sector; for instance, in 1999 the average annual income of Japanese households engaged in aquaculture was nearly twice as much as that of households engaged in coastal fishing. In Japan the households that engaged in aquaculture derived on average 64 percent of their income from aquaculture-related activities, whilst fishing-related activities accounted for an average 38 percent of the income of fishing households.

2.2 Marine fisheries status

The total production of marine capture fisheries reached 86.0 million tons in 2000. It provided about 17% of animal protein for human consumption and came close to the projected maximum sustainable catch of 90 - 100 million tons. Of the 15 global oceans, 13 are over-fished (FAO, 2003). Only about 25% of the major marine fish stocks are under-exploited or moderately exploited. Stocks or species groups in this category represent the main source for the potential expansion of total marine catches. Approximately 47 percent of the main stocks or species groups are fully exploited and are therefore producing catches that have reached, or are very close to reaching their maximum sustainable limits. Thus, nearly half of world marine stocks offer no reasonable expectations for further expansion. Another 18 percent of stocks or species groups are reported as overexploited. Prospects for expansion or increased production from these stocks are negligible. Furthermore, there is an increasing likelihood that stocks will decline further and catches will decrease, unless remedial management action is taken to reduce over-fishing conditions. The remaining ten percent of stocks have become significantly depleted, or are recovering from depletion, and are far less productive than they used to be.

2.3 World aquaculture status

Aquaculture is growing more rapidly than any other animal food producing sectors. Worldwide, the sector has increased at an average compounded rate of 9.2 percent per year since 1970, compared with only 1.4 percent for capture fisheries and 2.8 percent for terrestrial farmed meat production systems. Aquaculture's contribution to global supplies of fish, crustaceans and molluscs continues to grow, increasing from 3.9 % of total production by weight in 1970 to 27.3% in 2000 with a total aquaculture production of 45.7 million tons worth US$56.5 billion. More than half of the total world aquaculture production in 2000 was finfish. In addition, the growth of the major species groups continues to be rapid.

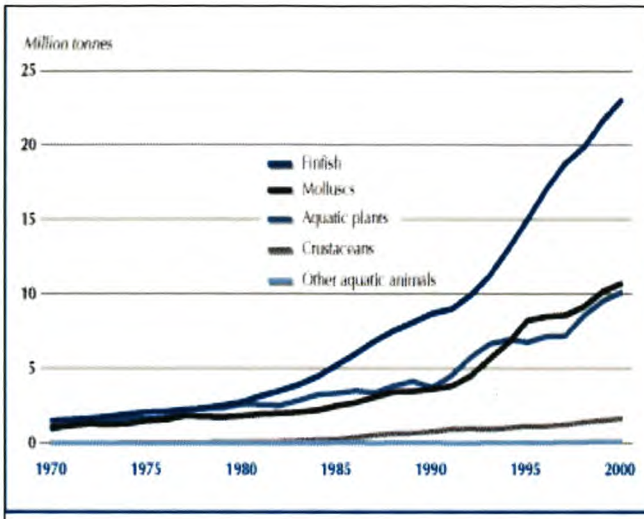


Figure 2.1 Trend of world aquaculture production by major species groups (FAO, 2002b)

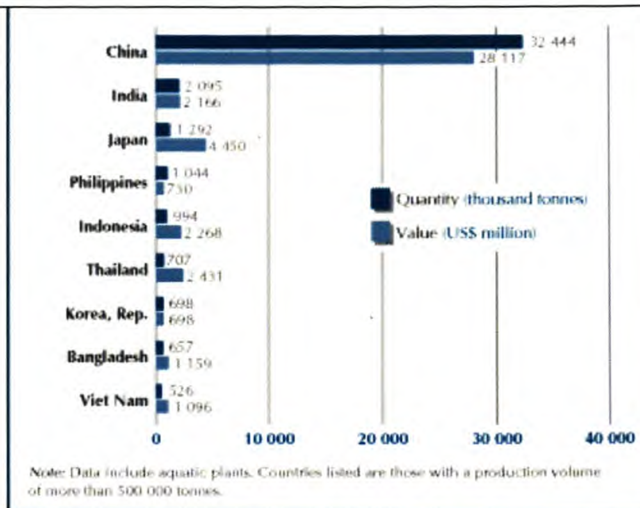


Figure 2.2 Aquaculture production: major producer countries in 2000 (FAO, 2003)

In 2000, more than 210 different aquatic animal and plant species were farmed. The species farmed comprised of mostly omnivorous/herbivorous fish or filter-feeding species in developing countries compared to 73.7% carnivorous fish in developed countries. Production growth among low-income food deficient countries (LIFDC), excluding China, has been slower than among non-LIFDC. Aquaculture production within developed countries has been growing at an average rate of 3.7 % per year since 1970. The world aquaculture sector outside China produced about 11 million tons of farmed aquatic products for human consumption in 2000, compared to about 52 million tons from capture fisheries.

The potential of aquaculture to enhance local food security, alleviate poverty and improve rural livelihoods has been well recognized over the last three decades. The Bangkok Declaration and Strategy (NACA & FAO, 2000) emphasizes the need for the aquaculture sector to continue development towards its full potential.

2.4 African Aquaculture

It is imperative to look at the history of aquaculture development in Africa to identify the pitfalls and areas of success. Unfortunately, small-scale aquaculture development in Africa does not have a very good track record. Since 1972, about 130 aquaculture projects have been funded in Africa. Ten years later, the total "on-going" grants and loans amounted to 100 million US dollars.

Despite these efforts, Africa's contribution to global production remained insignificant at approximately 11,800 metric tons in 1985, 0.1% of world production (Huisman, 1986).

The investment in the continent played a big part in the eightfold increase in production from 1985 to 1995 and a four-fold increase in the contribution that Africa has made to worldwide production. These figures indicate that there has been some progress. Nevertheless, the progress is far from satisfactory and falls short of expectations, especially considering the massive amount of aid that has been poured into the development of aquaculture in the continent. Currently, aquaculture in Africa produces about 1.2% (0.43 million MT) of world aquaculture production (Brink, 2003). Production is growing rapidly, increasing by 36% in weight and 62% in value from 1997 to 2000 (Brink, 2001).

Table 2.2 Major contributors to African aquaculture per country (Brink, 2003)

Egypt	83.2%
Nigeria	6.3%
Madagascar	3.2%
South-Africa	1.6%
Ghana	1.3%
Tunisia	1.2%

2.5 Small-scale aquaculture in sub-Saharan Africa

Large areas of Southern Africa are considered to be highly suitable for aquaculture production of warm-water fish. The total production of finfish from sub-Saharan Africa was estimated to be a disappointing 29,500 metric tons in 1995. Hecht and De Moor (2001) see the disappointing performance of sub-Saharan Africa in terms of aquaculture production against the background of continued poverty of the region, as well as environmental degradation and soil erosion. Destructive farming systems in Africa cause 70t/ha/year soil erosion. Deforestation claims 100,000 ha, or 1% of African forest area every year. Desertification has taken place on over 80% of African rain-fed lands and 30% of irrigated lands have turned saline in sub-Saharan Africa (Lightfoot *et al* 1996). All these factors contribute to a complicated agricultural environment in which to promote new farming concepts like aquaculture.

Huisman (1986) contributes the emphasis on the culture of cichlids as one of the factors that constrains aquaculture in Africa. The trend in the rest of the world is based principally on cyprinids, accounting for over 60% of production. Overpopulation of ponds with small-sized fish is one of the inherent problems with traditional tilapia (cichlid) farming.

Other major technological constraints to aquaculture development in sub-Saharan Africa are:

- Inadequate supply of fish feed ingredients
- Prohibitive transport costs
- Lack of juveniles for stocking ponds
- Political instability
- Lack of farmer training

2.6 Aquaculture development projects in sub-Saharan Africa

An initial high interest in the innovation of farming fish dwindled rapidly during the 1960s as expectations were not met and many enterprises were abandoned. Poor infrastructure and lack of production inputs were cited as initial problem areas. In 1975, a FAO report on sub-Saharan African aquaculture development stated that "*Failures of some of the ill-conceived programmes during the early part of the century have continued to remain a major constraint in convincing the farmers and investors of the economic viability of aquaculture. Insufficient appreciation of the basic requirements of an effective aquaculture development programme and consequent inadequacy of governmental support activities, have handicapped the orderly and rapid development of the industry.*"

Thirteen years later, the 1988 FAO Expert Consultation on Planning for Aquaculture Development (ADCP/REP/89/33) concluded that output from sub-Saharan Africa was still very low. Most production was attributed to small-scale, semi-intensive farming of tilapia, with few large-scale commercial ventures able to demonstrate long-term economic viability. Ineffective or nonexistent policies combined with inadequate infrastructure, poor extension support and unavailability of inputs (including seed, feed and credit) were cited as major problem areas.

Five years later, the FAO, assisted by other collaborators, assembled a series of aquaculture reviews from countries responsible for 90 percent of the region's aquaculture production (Coche *et al.*, 1994). These reviews identified the major constraints on the continental level as:

- No reliable production statistics
- Credit availability limited for small-scale farmers
- Very low technical level of fish farmers
- Unavailability of local feed ingredients

- Lack of well-trained senior personnel
- Prohibitive transport costs
- Lack of juvenile fish for pond re-stocking

African fish farmers achieved relatively low productivity with mean yields of approximately 500 kg/ha/yr. Commercial tilapia farms in the same areas reported 20 to 30 times better production with pond yields of 10 to 15 mt/ha/yr, while Clarias yields can exceed 20 mt/ha/yr. Optimal use of resources (water and land, labour and climate) by small-scale farmers has frequently been curtailed by poor infrastructure and lack of production inputs. In the light of these accumulated challenges, the approach that aquaculture should be promoted and developed as an enterprise and not as a means to simply enhance nutrition started to accrue wide spread support.

Machena & Moehl (2001) have identified the main challenges as:

- The shrinking role of governments as countries are faced with varying degrees of socio-economic volatility combined with low levels of industrialization
- Dependence on the export of primary goods
- On-going structural economic adjustment programmes
- Inadequate or nonexistent development policies

They conclude that expansion of aquaculture required several enabling factors, including:

- A positive perception of aquaculture
- Sound policies at the national level
- Strong public institutions
- Availability of nutrient inputs
- Conducive investment policies to attract increased private-sector participation
- Access to credit for commercial-scale enterprises

The recommendations for the way forward in sub-Saharan African aquaculture development cover three main approaches:

- To promote a greater involvement of interest groups, including the private sector, to replace the shrinking role of the public sector
- To better understand the socio-economic and socio-cultural constraints affecting the adoption of fish farming
- To increase sub-regional and regional networking

Hecht and de Moor (2001) attribute the failure of historical aquaculture development projects in rural sub-Saharan Africa to a number of factors. The first is the absence of a cultural tradition of fish farming in sub-Saharan Africa. The second is the inability of aquaculture development agencies to address the real and not the perceived needs of rural African people. Most aquaculture developing agencies have a poor awareness and knowledge of the African situation, aspirations and needs of small-scale farmers.

The philosophy of aquaculture development agencies is primarily based on creating basic food security and gender affirmation, focusing on the needs of the poorest of the poor. This philosophy for promoting fish farming appears to be based on northern Hemisphere perceptions with regards to the needs of rural African people, instead of the aspirations of the farmers themselves. Development agencies must realise that the aspirations of rural African people in the late 20th century are similar to those in the northern hemisphere, i.e. acquisition of knowledge, generation of income and accumulation of wealth with which to educate children, improve quality of life and to have purchasing power.

Furthermore, developing agencies should take the farmer's skill level and the community's resources in consideration before implementing pure integrated farming projects. While the basic idea of enhancing pond productivity by way of animal manure is a good one, farmers do not have the resources to acquire the necessary livestock with which to implement this option. Development projects should be based on the farmers and their needs. Good examples of what kind of research needs to be undertaken include the ICLARM and MAGFAD projects in Malawi. Hecht & de Moor reiterate that the growth potential of aquaculture in Africa is enormous, but that it is important to remember that aquaculture is an economic activity no matter how small the scale of the enterprise. Aquaculture must be promoted and developed as an enterprise and not as a means to simply enhance nutrition.

During the 1980's, it was hoped that aquaculture would play an important role in reducing poverty and for this reason, the primary emphasis of many development programmes has been on food security rather than cash income. However, considering the fact that intensive aquaculture is actually a capital intensive activity, which does not require a large amount of labour, many experts are now suggesting that a greater degree of commercialisation is the most logical way in which aquaculture should develop in the future.

2.7 Historic low production and profitability of small scale fish farms in Africa

Fish farming seems like a lot of hard work that requires a great investment compared to other economic activities available to small farmers, like raising other livestock (including chickens, goats and cattle) or crops (maize and vegetables). Investing in farming technology that is foreign to farmers and usually not very well understood represents a major investment risk.

Hecht and de Moor (2001) state that the economic value and viability of smallholder fish farming operations in Africa are assessed according to both cash income and food security. This is in stark contrast to the normal profit and loss scenario applied to the evaluation of commercial fish farms.

A portion of the fish produced is often bartered or used for household consumption, reducing the cash income for the farmer. Social and cultural pressures may also force the farmer to sell to his own community, often at reduced prices compared to what he could get if the fish was sold to neighbouring communities or at the open markets in the cities. The value of the fish consumed by the farmer should be determined according to the market price and not the cost of production for the farmer.

The availability of fish from the farmer's pond in times when other food products are scarce or unavailable in the region adds value to the operation in terms of insurance against starvation. The portion of small-scale African fish farmer's crops sold on local markets varies extensively. The most important of the factors influencing the percentage sold are the farmer's yield, market demand and price.

Input costs vary according to the level of intensification the farmer applies. Most of the farmers feed low value food by-products, manure and kitchen trash to the fish. Another important factor influencing the cost of production is the value of the farmer's labour. The market value of unskilled labour in areas where chances of finding a wage-earning job are very low is very low, in monetary terms. In previous studies on labour costs on such farms, labour costs were evaluated in terms of man-hours spent on different farming activities. The production/labour ratio from fish farming in Indonesia was found to be poor (1.39 kg/day worked) in comparison to some other forms of farming for high protein products, such as duck-eggs (5.2kg/day) and free-range chickens (5.1 kg/day) (Christensen, 1995). However, the production/labour ratio for integrated farming (i.e. 10.6 - 14.3 kg/day) is much more favourable than that calculated for fish farming alone

2.8 Southern African Development Community (SADC)

Aquaculture development was formally included as part of the goals of the Southern African Development Community (SADC) when it was established at the Summit of Heads of Government in Windhoek, Namibia, in August 1992. The SADC created a formal platform for aquaculture development strategies and funding coordination. Its member countries are Angola, Botswana, The Democratic Republic of the Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe.

The objectives of the SADC are to:

- Achieve development and economic growth, alleviate poverty, enhance the standard and quality of life of the peoples of southern Africa and support the socially disadvantaged through regional integration
- Evolve common political values, systems and institutions
- Promote and defend peace and security
- Promote self-sustaining development on the basis of collective self-reliance and the interdependence of member states
- Achieve synergy among national and regional strategies and programmes
- Promote and maximize productive employment and utilization of the resources of the region
- Achieve sustainable utilization of natural resources and effective protection of the environment
- Strengthen and consolidate the long-standing historical, social and cultural affinities and links among the peoples of the region

The SADC launched a new Food, Agriculture and Natural Resources Directorate (FANR) in 2001, which deals with eight sub-sectors, including Marine Fisheries and Resources. One of the SADC's most important recent achievements in the field of marine and inland fisheries and aquaculture is the Protocol on Fisheries, which was adopted during the Summit of Heads of State and Government in August 2001. The Protocol is inspired by the FAO Code of Conduct for Responsible Fisheries and aims to promote the responsible use of living aquatic resources in the SADC region. Funding of more than US$60 million for current SADC marine fisheries projects over the next five years has been committed. A summary of the SADC fisheries and aquaculture production can be found in table 2.3.

Table 2.3 SADC fisheries and aquaculture production, food balance and trade (FAO, 2003)

Aquaculture production	1988	1992	1996	2000
Inland production (`000 tons)	3	7	7	8
Percentage of world total	0.0	0.1	0.0	0.0
Marine production (`000 tons)	1	3	2	3
Percentage of world total	0.0	0.0	0.0	0.0
Fisheries production				
Inland production (`000 tons)	679	632	583	631
Percentage of world total	11.0	10.2	7.8	7.2
Marine production (`000 tons)	1 556	1 205	947	1 289
Percentage of world total	1.9	1.5	1.1	1.5
Fisheries and aquaculture production				
Combined total (`000 tons)	2 239	1 846	1 540	1 930
Percentage of world total	2.2	1.8	1.3	1.5
Food balance				
Total food supply (`000 tons)	1 525	1 327	1 244	...
Per capita supply (kg)	10.3	8.0	6.7	...
Fish as share of animal protein (%)	22.6	18.3	17.3	...
Trade in fishery commodities				
Total imports (US$ millions)	224	231	286	195
Percentage of world total	0.6	0.5	0.5	0.3
Total exports (US$ millions)	200	299	602	892
Percentage of world total	0.6	0.7	1.1	1.6

Note: ... = data not available.

2.8 Description of the South African aquaculture sector

Freshwater Aquaculture is still a developing industry in South Africa with no large-scale farms in production at present. The total freshwater food fish production for 2001 was about 2,670 tons with a value of 11 million US$. Of this, rainbow trout (*Oncorhynchus mykiss*) made the most significant commercial contribution with an annual production of 1,750 tons.

Table 2.4 South African freshwater aquaculture production statistics for 1998, 2000 and 2003 (Brink, 2003).

Species: Freshwater	Common name	1998 (Metric tons)	2000 (Metric tons)	2003 (Metric tons)	Production Value (Rmillion)
Aponegeton distachyos	Water hawthorne	120	150	170	0.28
Carrasius auratus	Goldfish	465 000*	805 000*	930 000*	3.319
Cherax tenuimanus	Crawfish	4	8	13	0.699
Clarias gariepinus	African catfish	40	65	240	3.202
Cyprynis carpio	Carp	45	55	80	1.106
Koi carp (C. carpio)	Koi carp	128 000*	375 000*	110 000*	1.563
Micropterus salmoides	Bass	5	8	8	0.072
Mugulidae	Mullet	12	15	17	0.231
Onchorhynchus mykiss	Rainbow trout	1 650	1830	1750	44.011
Oreochromis mossambicus	Tilapia	45	130	210	3.098
Oreochromis spp.	Tilapia spp.	25	45	52	0.739
Ornamental fish spp	Ornamental	5	7	7	0.52
Penaes indicus	Shrimp	85	120	130	11.83
Total		2 036	2 433	2 670	70.673

* unit = number of fish

A total of six intensive catfish farms have been built during the last two years, which have the potential of producing 50 to 200 tons/annum each. There are also pilot projects under way to produce *O. mossambicus* in KwaZulu-Natal. Hopefully these ventures will be successful and add a bit of depth to the local freshwater aquaculture industry.

There is a growing local market for farm-raised fish in South Africa. It is, however, very difficult to compete with products from the well-developed capture fisheries industry, supplying large quantities of seafood at low prices. Diversification within the aquaculture industry and targeting high value species can help struggling small farmers. South Africa has a good disease control status with regards to aquaculture, and there are opportunities for koi and trout eyed ova exports.

Some of the challenges faced by producers include annual and seasonal variations in production, competition from imported products and increases in production costs. There has been some renewed interest in commercial tilapia production. Limited local market demand has shifted the focus to export to the USA, Europe and South America. The restrictions on culture species call for the domestication of *O. mossambicus* and the selection and development of strains that exhibit desirable traits, including fast growth and low temperature tolerance.

Factors that are stimulating aquaculture development in S.A. include:

- Access to good natural resources at relative low land prices
- Developed fisheries & agricultural infrastructure
- Access to technologies and international partnerships & collaboration
- Good fiscal policies, banks, communications infrastructure and government

South Africa lacks a co-ordinated marketing structure for freshwater fish, with the exception of the trout producers. The most noticeable is the ornamental fish industry that suffers from disorderly marketing structures, in spite of efforts during the last 10 years to stimulate communication between producers and wholesalers to co-ordinate production and marketing. The local industry is under severe pressure from imports and has to date not been able to work together to meet export market demand. The catfish and carp production boomed in the 80's and 90's failed similarly due mainly to a lack of co-ordinated and planned marketing.

There is limited access to development capital. Furthermore, funding for aquaculture ventures are difficult to come by. One of the major reasons for this is the limited and often negative tract record of aquaculture in South Africa. The lack of profitable ventures in the country places aquaculture in a very high-risk bracket with financial institutions compared to other agri-businesses. Ithala, the Landbank, Kula, etc. are vital investment partners for any Black Economic Empowerment (BEE) venture. Linkage to governmental incentive-based projects may also be considered in order to assist in carrying onerous development risks, which the private sector is reluctant to bear. Other funding sources include, but are not limited to:

- Private investors
- LRAD program
- Black Economic Empowerment (BEE) and Sustainable Development Programs
- Banking institutions
- Department of Trade and Investment
- Small Business Development Centre

- Municipalities
- Para state companies: ESCOM, Umgeni Water, SASOL
- Corporate Investors – Irvine & Johnston, Richards Bay Minerals
- Venture capital groups

International agencies could also provide links to funding opportunities, including the:

- World Bank
- Food and Agriculture Organisation of the United Nations (FAO)
- World Food Program (WFP)
- Network of Aquaculture Centres in Asia-Pacific (NACA)
- International Centre for Living Aquatic Resources Management (ICLARM)
- USAID

The South African aqua feed industry produces mainly trout feeds, though some producers are currently diversifying into other feeds, including catfish and tilapia feeds. Production was estimated at 2,800 tons worth R9 million in 2001. Feeds that are available differ greatly in price and quality. Lower quality feeds can be bought retail for about R2.50/kg while higher quality feeds may cost R7.00 to R10.00/kg delivered. The industry faces some challenges, including pressure to utilise less fishmeal and more non-food grade local resources, and improving feed formulations to minimise waste and environmental impacts.

South Africa has a number of government fish hatcheries including Marble Hall, Clanwilliam, Nagle Dam, Makathini flats, Jonkershoek and Gariep hatchery. The major functions of government hatcheries should be to serve as demonstration and research units, technology transfer centres, nodes from which extension services are coordinated and training centres for fish farmers and extension officers. The hatcheries should also provide low cost fingerlings to farmers. A number of private entrepreneurs have started to produce fingerlings for the developing industry with mixed success.

A number of fish processing plants exist in South Africa as a result of its well-developed marine capture fisheries sector. To meet regulations and quality control to export markets, processing plants should hold a Hazard Analysis Critical Control Point (HACCP) certification.

Aquaculture research is currently performed in an *ad hoc* manner in South Africa without a national strategy to identify critical areas and to guide institutions. There is a need for a co-operative research centre, where research and development can be aligned and co-ordinated between the different academic and research institutions. There is also a need for a South African aquaculture forum, which will create a platform from where technology transfer, funding and marketing could be co-ordinated.

Aquaculture training is specialised and currently limited to Universities, focusing on postgraduate level and not necessarily on entrepreneurial application. There is currently very little outcome- based education and an absence of skills training with commercial application in the industry (Brink, 2001).

There is a need in South Africa for a workable aquaculture policy with one department responsible for the processing of aquaculture applications. Currently, responsibility for aquaculture policies and legislation seems to fall somewhere between a number of governmental departments, including the Department of Water Affairs and Forestry, Department of Agriculture, Department of Environmental Affairs and Tourism and the Department of Trade and Industry. Aquaculture is a form of agriculture and involves the use of water bodies or fresh and marine water to produce food. The National Department of Agriculture (NDA) therefore needs to regulate certain activities relating to health and production. According to the directorates, the main NDA responsibilities lie in policy formulation, legislation, regulations and coordinating regional, interdepartmental (Department of Environmental Affairs and Tourism [DEAT], Department of Water affairs and Forestry [DWAF]) and inter-provincial actions and involvement (Swart, 2001). The NDA is currently still in the process of developing an aquaculture policy and strategy, trailing behind neighbouring countries like Mozambique, Zimbabwe, Malawi and Namibia, which have their policies in place. Policy formulations should involve provincial departments, aquaculture working groups and the private sector. The NDA can play a major role in an aquaculture industry boost similar to what is currently happening in Australia, New Zealand, Canada, Ireland, Vietnam, Chile and the USA.

Provincial conservation authorities are often breeding and stocking exotic rainbow trout in National Parks for fly-fishing revenues, but are reluctant to issue permits for aquaculture ventures, especially for applications including exotic species like *O. niloticus*. It is even harder to understand the reluctance to issue permits for the farming of *O. mossambicus*, an indigenous fish species on the grounds that it originates from a different catchment area in the same province, when game is sold and moved all over South Africa from the Umfolozi game auction and indigenous plants are distributed from KwaZulu-Natal Nature Conservation Services (KZNNCS) nurseries all over the province. The Nairobi declaration on the conservation of aquatic biodiversity and the use of genetically improved and alien species for aquaculture in Africa gives good practical guidelines to adhere to in formulating policies (UNEP, 2002). It is very important for the conservation authorities to assess their role and support to aquaculture development, as pressure mounts on government to develop sustainable agriculture projects. Regulatory obstacles currently hinder the development of the aquaculture sub-sector and deter critically needed investment in the industry, handicapping efforts to address serious food security and economic issues in rural areas in the province.

CHAPTER 3
CHINESE AQUACULTURE
A MODEL FOR FISH FARMING AND DEVELOPMENT

3.1 Why focus on China?

The challenge is to develop aquaculture in Southern Africa to contribute to food security, employment, economic growth and foreign exchange revenue. The question beckons as to what developmental model provides a realistic framework for aquaculture development in SA? China provides food for a third of the world's population on 7% of the world's arable land, including 71% of the world aquaculture production (FAO, 2002). China is therefore quite accurately referred to as "the home of aquaculture". But are we able to apply the Chinese production methods to aquaculture development in Southern Africa? Although the climatic conditions in areas of KwaZulu-Natal and Mpumalanga is similar to that of certain areas in China and suitable for pond-based farming, one should take a more holistic look into the Chinese aquaculture sector to assess the potential for successful implementation in South Africa.

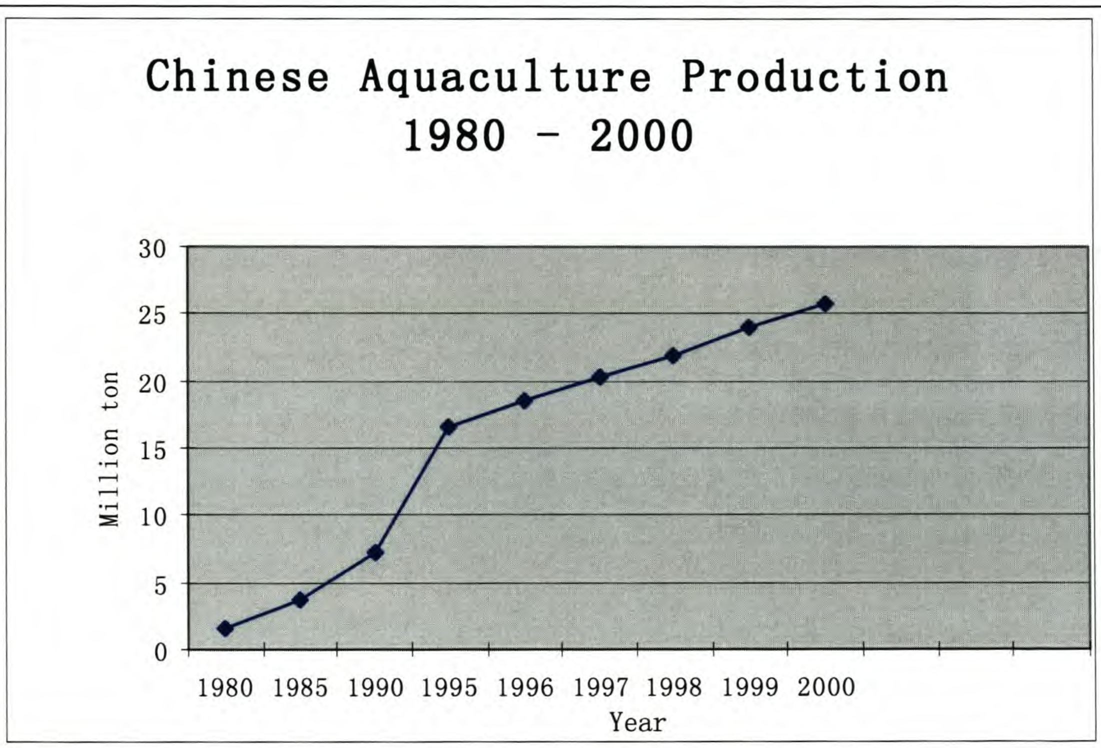


Figure 3.1 Chinese aquaculture production 1980 – 2000

China has a 3,000 year old history of aquaculture, though production has increased fivefold over the last 20 years. The growth of inland water aquaculture production has been particularly strong in China, where it averaged 11.5 percent increase per year between 1970 and 2000, compared with 7.0 percent per year in the rest of the world over the same period. China's aquaculture production presently stands at 32.4 million tons per year, of which 13 million tons are freshwater fish, which amounts to 76% of world freshwater aquaculture production. The total value of Chinese fisheries products in 2000 was 35 billion US$. Export of these products represents an important source of foreign currency and that reached US$ 3.83 billion in 2000.

3.2 Impact of China's fisheries sector

The increase in aquatic production has led to an improvement in the nutritional condition of the people of China. Fisheries currently provide about 30 - 40% of people's animal food consumption in China. The per capita consumption of aquatic products has increased from less than 10 kg per person per year 20 years ago to current levels of more than 30 kg per year.

The growing fisheries sector also creates job opportunities and income. Employment in the Chinese fisheries sector amounted to approximately 13 million in 2000. The income level of people living in rural areas has improved, as fish farming proved more profitable than traditional crop farming. Per capita income of people involved in fisheries was, on average, US$1,000/year in 2000, twice the average income of people engaged in agriculture.

3.3 Reasons for the high aquaculture production in China

3.3.1 Government support

The increase in aquaculture production was the result of a government-driven initiative to expand the pond area for aquaculture, to focus research on increasing production and to distribute the available information and technology to farmers through government-funded extension networks. Currently, there are over 3,000 extension stations across China with over 15,000 extension staff. The focus on human resource development is further emphasized by 30 universities that offer specialized education in aquaculture. Most research and development is done at a series of 220 fisheries research institutions that employs over 10,000 qualified staff members. There has been a substantial increase in aquaculture production as a direct result of technological improvements that include:

- Breeding technology: resulting in an adequate supply of high quality seed for farmers.
- Feed development: formulated diets are used instead of raw feedstuffs resulted in much higher production. The development of cheaper feeds with less fishmeal and fish oil, together with the use of the protein sparing effect of other sources of energy has been a main focus.

- Disease control: the focus has shifted from treating just the symptoms to a wider ecological approach, treating the environment and causes, not just fish. With stricter control and diagnosis of medication used on consumer products, new emphasis is given to developing alternative treatments using traditional Chinese medicines, e.g. herbs.
- Culture systems and models: polyculture with high value aquatic products is the main focus of this research.
- Development of culture species: research in this area includes the development of faster growing and higher quality animals through both selection and molecular genetic modification.

The Chinese government's open door policy also created an environment to facilitate massive growth in aquaculture production. Changes that took place include allowing the farmers to farm any species they wanted. This laid the foundations for the degree of competitiveness China has obtained in world trade of aquatic species today, after being accepted into the World Trade Organisation in 2002. Farming exotic species has some ecological and bio-security impacts, that has to be evaluated against the US$3.83 billion earned in foreign currency in 2000. This open legislative approach to species selection has been adopted worldwide by most of the major aquaculture producing countries, giving them a competitive edge compared to countries that remain crippled by strict governmental controls. This is a vital area of concern in the South African context and is further discussed in the South African aquaculture status section in Chapter 2.

Other significant changes include the shift to a free market system based on supply and demand instead of government-controlled pricing systems. With the restructuring of China from a socialist to a free market economy, the production sector was liberated and income became dependent on production achieved. This in turn created incentives for farmers to focus on refining their own individual pond farming practices to increase yield and production.

3.3.2 Expansion of fish culture area

Expansion in culture area is one of the most important factors for constant fast growth in freshwater aquaculture. It is also a very good indicator of freshwater aquaculture development in a country. Figure 3.2 shows a typical sight travelling through Central China - networks of fishponds lines the countryside as far as the eye can see.

The area under freshwater aquaculture in China increased by 65% during the period from 1983 to 1998, with the area of fishponds increasing by 116% during same period as depicted in figure 3.3.

Figure 3.2 A network of fishponds in Central China

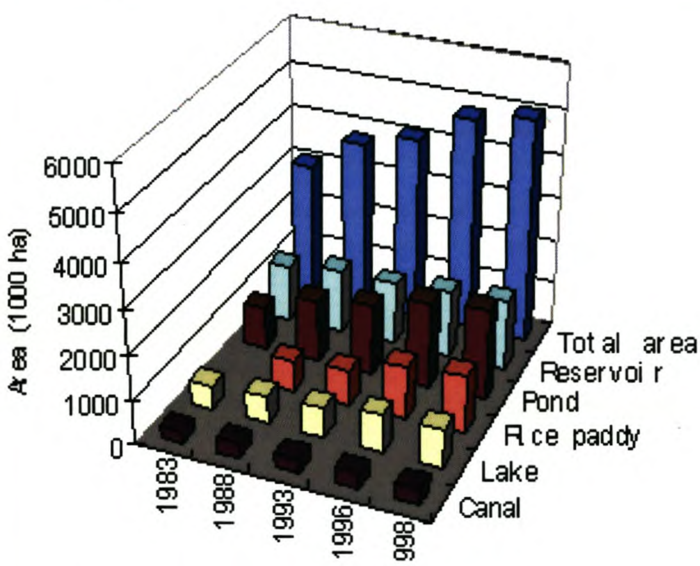


Figure 3.3 Expansion of fish culture area in China from 1983 to 1998.

3.4 Main aquatic animal species cultured in China

The main aquaculture species cultured in China can be divided into finfish, crustaceans, turtles and freshwater pearls, with a summary of the most important species presented in Figure 3.4a to Figure 3.4r.

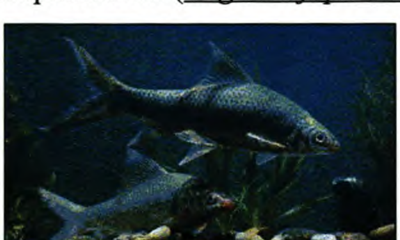

Figure 3.4 a. Silver carp (*Hypophthalmichthys molitrix*) b. Bighead carp (*Aristichthys nobilis*)


c. Grass carp (*Ctenopharyngodon idellus*) d. Black carp (*Mylopharyngodon piceus*)


e. Common carp (*Cyprinus carpio*) f. Crucian carp (*Carasius auratus*)


g. Bluntnose black bream/Wuchang fish (*Megalobrama amblycephala*) h. Tilapia (*Oreochromis nilotica*, *O. aurea*)


i. .Japanese eel (*Anguilla japonica*) j. Mandarin fish (*Siniperca chuatsi*)




k. Mud carp (*Cirrhina molitorella*) l. Chinese river catfish

m. Prawn *(Macrobrachium nipponesis, n. M. rosenbergii, o. Penaeus vannamei)*

p. Mitten handed crab (Eriocheir sinensis) q. Soft-shelled turtle (Trionyx sinensis)
r. Freshwater pearl clam (Hyriopsis cumingii)

3.5 The Jiangsu Province as an example of what can be achieved

3.5.1 Climate and production

Jiangsu Province is a coastal province located in central China with a population of 75 million people and covers an area of 102,600 km^2, slightly smaller than KwaZulu-Natal. The climate is similar to that of KwaZulu-Natal with reference to hot, humid subtropical summers and cool, temperate winters. Winter temperatures range from 0-15°C. The inland aquaculture production for the province in 2000 was 1,88 million metric tons, with a value of US$2.46 billion. To put this in perspective, Jiangsu province produces 50 times more freshwater fish than the total aquaculture (marine and freshwater) production from the African continent, see figure 3.4. This is enough fish to supply 62.5 million people with 50% of their annual nutritional requirements from animal protein.

The province's topography mainly consists of flat floodplains with clay-loam soils. Water is supplied through an extensive network of manmade channels fed from major rivers. There are severe water quality problems as a result of industrial and agricultural pollution. Fish farming support structures are well developed in the region and farmers have easy access to seed/fingerlings, extension stations, fisheries universities, and training centres.

3.5.2 Species used in Jiangsu Province

Pond based aquaculture in the Jiangsu Province is still dominated by the production of polyculture carps, with a gradual market driven shift to high value species. A breakdown of the species groups cultured in Jiangsu can be found in tables 3.1 and 3.2. This serves as a good indication what is produced in a mature balanced aquaculture sector in an area with a similar climate as KwaZulu-Natal.

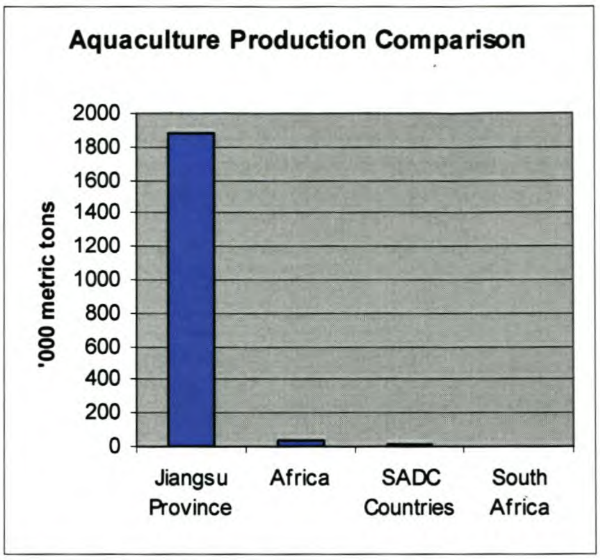


Figure 3.4 Comparisons of aquaculture production (Author)

Table 3.1 Species groups cultured in Jiangsu Province (China Fish. Stat. Yearbook, 2000)

Description	Weight Produced	Value	Average Value/kg
Polyculture carps	1,501,000 tons	1,400 million US$	0.93 US$
High value species	210,000 tons	1,000 million US$	4.76 US$
Monoculture	200,000 tons	800 million US$	4.00 US$

Table 3.2 Major farmed freshwater species and value in Jiangsu Province (China Fisheries Statistic Yearbook, 2000)

Species	Annual Production	Value in US$/kg
Black Carp	48,413 mt	2.00
Grass Carp	320,752 mt	0.90
Silver Carp		0.50
Bighead Carp		0.80
Common Carp	115,842 mt	1.50
Crucian Carp	302,228 mt	1.50
Chinese Bream	159,502 mt	1.10
Tilapia	5,573 mt	1.50
Mandarin Fish	4,251 mt	5.00

Eel	4,398 mt	7.00
Freshwater Shrimp	19,403 mt	3.50
River Crab	11,997 mt	18.00
Soft-shelled Turtle	8,608 mt	10.00
Other Spp	226,942 mt	

3.5.3 Aquaculture systems used

The province has a total of 604,000 ha lakes (including dams) and 203,000 ha rivers. The water surface area includes an amazing 280,000 ha of aquaculture ponds with an average production of 4.4 tons/hectare. Pond fish culture (polyculture based integrated fish farming) is traditionally the most important production system. The rest of the inland aquaculture crops are produced in a variety of systems including extensive culture in lakes and reservoirs, fish culture in rice paddies, cage and pen fish culture in inland water bodies, and indoor highly intensive culture systems.

Table 3.3 Production from different freshwater aquaculture systems used in Jiangsu province (China Fisheries Statistic Yearbook, 2000).

Environment:	Pond	Lake	Reservoir	River	Rice paddy	Other
Metric tons:	1,232,962	154,348	21,519	198,542	178,401	96,585

In China, all natural resources (water, land etc.) belong to the public domain. In most cases fishponds are contracted to farmers (individual families) or groups of people (large scale corporate farms). The payment for the use of pond and land differs substantially, depending on area and operators. If the operators are native (local) residents, payments are normally very small, but pond rental can reach US$ 900-1,500/ha for foreign parties from outside the municipal district.

3.5.4 Marketing and distribution channels

Traditionally, most fish are sold live to consumers. As a result of this, there are highly developed live haul networks in place to get the product from the farms to the distribution points. Most commonly, fish are transported in special live haul boats fitted with aerators and big hull-mounted tanks. These boats take fish to special distribution docks where the product is weighed and loaded into special live haul trucks. The trucks in turn transport these fish to markets where it is sold to restaurants, traders and the public. A portion of the fish are iced down and packed in small packing warehouses situated at the dockside. These are shipped to more distant destinations and markets.

Figure 3.5a, b, c, d Livehaul boats delivering fish to the market in Jiangsu Province, China (Author, 2003)

To quantify a yearly return for fish farmers is by nature difficult since it is highly dependant on productivity, species used and local markets at that time. An average family of two people working as a team on a farm with 4 hectares (60 mu) of ponds, using low input (manure, grass and supplementary low quality pelleted feeds) polyculture methods, produced 40 to 50 tons of major carps per year. The annual average net income per farm in 2002 was between US$8,000 to US$12,000 dependent on management level, costs of input and price of the fish.

3.5.5 Case study: Wujin City, Jiangsu Province, Central China

Wujin City has a population of 1.17 million people and generated US$103 million in 2001 from aquaculture. The total fish production in the area was 50,000 tons with an average yield of 10 tons/hectare. This supplied per capita 42.7kg fish per person in the municipal area.

Table 3.4 Water surface area under aquaculture in Wujin City, 2001					
Species:	Fish	Freshwater shrimp	Freshwater crab	Freshwater pearls	Total
Area:	4,933 ha	2,333 ha	2,333 ha	3.333 ha	13,000 ha

3.6 Some trends in the Chinese Freshwater Fisheries sector

Fish farming activities have been reduced in an around the bigger cities since the 80's due mainly to two reasons:

- The booming industrial sector provided job opportunities that required less effort at better pay compared to fish farming.
- New roads, buildings and houses were built on areas previously used for fish farming.

Small-scale family-managed farms remain stable, but increased expectations from especially young farmers have resulted in them leaving fish farming and taking better-paid factory jobs in the cities. This urbanization is accompanied by the usual socio-economic problems. The Chinese government is trying to promote economic activity in rural areas to assist decentralization.

The species that are produced has also changed. Most consumers could only afford the cheaper, lower quality fish like carps in the past. As a result of the economic development in China since the 80's, the disposable income of the average consumer grew to the extent that consumers can afford better quality fish. The growing market demand for the higher value species resulted in the farmers producing more of the higher value species. This has mainly been as a result of a change in the economic objectives of the farmers. Farmers were historically part of a controlled economy, and therefore focused merely on production. With the new free market economic dispensation in China and recent admittance to the World Trade Organization, the focus has become market-oriented and on maximizing economic benefit.

Legislative authorities have embraced a shift towards more environmentally sustainable development to curb the environmental pollution problems China faces problems related to both industrial and agricultural effluents. China is also currently embarking on a "zero growth" policy in marine capture fisheries to assist in the protection of natural fish resources.

There has also been a marked increase in diversification of species for freshwater aquaculture. In the 1970's, about ten species of fish (mainly carps) were cultured. Several other species like eel, tilapia and rainbow trout were cultured only in some parts of the country in limited quantities. Currently, more than 40 species of aquatic animals including finfish, crustaceans, molluscs and reptiles are cultured in different systems. The diversification was mainly market driven and included the introduction of new exotic and indigenous species. The reasons for the diversification of cultured species in China since 1980's include:

- Consumer demands for new and better quality species.
- Declining economic return from traditional species, forcing fish farmers to seek new species that can achieve better economic return.
- China's open-door policy provides the possibility of exchanging cultured species with other countries.

There are distinct regional preferences for different major carp species in China. Common carp is preferred in northern China, Grass carp and Wuchang fish (Chinese bream) in central China and Mud carp and tilapia in southern China. Filter feeding species normally demand lower prices than other species.

3.7 Conclusion

After taking a holistic view at the Chinese freshwater aquaculture sector, is clear that the technology and farming practises used to produce the fish in China are not major obstacles and can and has been replicated on South African soil. The areas under discussion in KwaZulu-Natal are also climatically suitable for pond-based integrated fish farming. There are however some distinct differences that has to be noted between South Africa and China and the impact of these on the development of this type of aquaculture development has to be carefully assessed. Differences include:

- Relative pond area available for aquaculture production – South Africa has very little pond area devoted to producing fish. China experienced a huge government driven initiative to expand aquaculture area the last 20 years, and aquaculture production increased fivefold as a direct result. Without ponds there are nowhere to culture the fish in, it's as simple as that.
- The Chinese government's open approach on the farming of all aquaculture species in order to be competitive in the multi billion dollar global seafood market. In stark contrast is the South African conservation authorities' approach to aquaculture. South Africa has some of the most stringent restrictions on species available for aquaculture in the world. This is hard to understand, especially seen against the dire need for economic

development in impoverished rural areas and the desperate lack of food security in the Southern Africa region.

- China's well-developed support structures and established marketing and distribution channels makes farming fish a relative uncomplicated task. In South Africa, this will develop like in the other agricultural sub-sectors as the result of aquaculture farming activity, not the other way around.

CHAPTER 4

PROPOSED STRATEGY FOR THE IMPLEMENTATION OF INTEGRATED AQUACULTURE DEVELOPMENT IN KWAZULU-NATAL

4.1 Introduction

The proof of the economic viability and sustainability of aquaculture, as for any other farming sector, lies in the existence of established commercial farms. This is a major concern when looking at the South African aquaculture sector. There are relative few commercial aquaculture farms when seen in the context of the great potential for aquaculture development that currently exists in South Africa. These stimulating factors include sufficient scientific capacity, research facilities, pilot projects, adequate natural resources, land and climate, low labour and operating costs, high unemployment and a need for better food security. With the exception a number of trout farms and the handful of ornamental fish producers, no profitable freshwater fish farming sector managed to establish it self in recent times. Carp and catfish initiatives in the 1980's failed mainly due to a lack of cohesion amongst producers, marketing and product development.

Annual reports on rural African aquaculture development provide little inspiring news.

Figure 4.1 a, b Abandoned fishponds in Nigeria (WAS magazine, 2003)

Scientists, volunteers and NGO's often report on disappointing results whilst most of the projects and facilities falls into disrepair on completion of the initial phase of development and assistance (Figure 4.1 a, b). This raises concerns about the approach to promote sustainable aquaculture development in Southern Africa by initiating fish farming at grassroots level. Reports on these projects often contain issues of distrust and unrealized expectations from the recipient communities

The current economic and socio-political environment in South Africa is conducive to large-scale commercial aquaculture development. The construction of proper facilities and the establishment of successful commercial ventures is a requirement to convince government, decision-makers, funding agencies, existing commercial farmers, landowners, rural communities and export businesses of the viability of aquaculture on a commercial scale in South Africa.

Figure 4.2 Examples of commercial fish farms in Australia, USA, Mexico, and Brazil.

The concept as proposed for the development of integrated aquaculture in KwaZulu Natal is the development of a profitable commercial scale modular unit that can be duplicated, thereby contributing to economic growth, employment, and food security in the region. Care should be taken in the development and sustainable implementation of the plan to also account for current trends in aquaculture such as the need to reduce the use of fishmeal in fish feeds and the emphasis on organic farming practices. The farming systems should also incorporate Best Management Practices for aquaculture and agriculture in order to ensure that consumers demands in terms of environmentally standards and ecological sensitivity are being met, whilst price incentives through products labelling can be obtained.

A wide variety of unique problems and pitfalls that challenge development of small-scale aquaculture in rural areas of developing countries exist. These challenges have been thoroughly documented and provide a most valuable base on which to develop a sustainable model.

4.2 Proposed business structure

The proposed business unit, hereafter referred to as a cooperative, should provide for vertical integration and must be managed from a central administrative address. Fish production takes place on a series of farming units. Each unit comprises out off eight ponds with a total water surface area of four hectares. Fingerlings are produced by a hatchery controlled by the Co-op and distributed with live-haul trucks to the farmers. The Co-op should also provide a central processing facility for the fish and harvesting capacity to harvest and transport the product from the farms to the processing plant. The Co-op should provide both managerial, administrative, training and extension services, including the sourcing of supplies, financial management, marketing and distribution, public relations, human resources and operational management.

A laboratory with a capacity to provide fish diseases diagnostics and water quality analysis should form part of the operations and will be placed at the central hatchery facility. This should enable the qualified hatchery manager then also assists with disease diagnoses and water quality analysis, to be followed with managerial recommendations and the supply medication and recommendation to the farmers. Farmers should also be able to collect feed and other supplies, like fertiliser and salt, from a central depot. A well-equipped mechanical workshop and a multi purpose hall should be available at the depot for farmers meetings, training session, etc. Assistance should also be provided in terms of agronomy and crop production, i.e. a nursery, supplies like seed and fertilizers and packing shed to support crop production activities on the flood-irrigated land below the fishponds.

There are two options in which to structure the relationship between the producers and the Co-op. The first is that the Co-op owns all land, ponds, infrastructure, equipment and crops and that the farmers are merely employees of the company. They are provided with fingerlings, feed and other supplies to raise the fish until they reach market size. Extension officers monitor production parameters, including growth and feed rates, water quality and fish health. When the crops are ready they harvested and transports to the processing plant under supervision of the Co-op. The Co-op is responsible for everything from supplies to harvesting and processing. Farmers receive performance incentives based on the crop of fish produced and feed conversion ratios, which may differ between individual units. The farmers, support personnel and managements should also share in a portion of the Co-op's profit on a performance incentive basis at the end of the financial year.

The second option can be based on the farmers leasing or buying a 4ha production unit to act as satellite farmers for the Co-op. Fingerlings, feed and supplies can be bought through a credit system. To qualify for the credit-based system, the farmer has to become members of the Co-op and act in adherence of its constitution. All fish must be supplied to the processing plant when they are ready for harvest. All costs associated with supplies and services are then recovered from the value of the fish harvested and the farmer is paid out the balance in the form of a first and then final settlement.

If the farmer opts to pay cash for fingerlings and supplies and hence has no debt obligations to the Co-op, he will be allowed to sell his fish to an alternative market or use it for own consumption. The farmers are obliged to enter into an extension service contract with the Co-op. These services will include the monitoring of water quality, assistance with feed management and fish health. As the farmer gains sufficient experience, he may wean himself from the support services in order to reduce his overhead costs. Pond and equipment maintenance are regulated by the Co-op on a predetermined schedule, whether the farmer does it himself or outsource it to the Co-op. A similar arrangement should be structured in relation to the harvesting of the fish.

The Co-op should offer training options to its employees, its members as well as to prospective members as well as to participate on research and development issues in collaboration with universities, technical colleges, government departments and other commercial farmers.

An agricultural co-operative provides a suitable entity to accommodate the proposed business structure, i.e. an independent board, a constitution, centralised administration and services with membership in a sustainable though non-profitable business environment.

4.2.1 Amount of grow out farms

The availability and costs of capital to start the project will to a large extent determine the initial size and expansion of operations. An initial pilot scale phase is suggested where one to five of the 4ha farms are to be built. The production and economic performance of these units will pivotal to attract additional investment to accomplish the project's medium and long-term goals.

The project's medium-term goal is to achieve the critical production volume to warrant vertical integration into a hatchery, a feed mill and processing facility. Twenty-five farms should produce between 1,000 and 1,500 tons of fish per year. If harvesting is staggered throughout the year, a relatively small processing unit with a staff of three to five is capable of handling a quantity of 20 to 30 tons of fish per week. The 25 farms together will require 1.2 million to 1.8 million fingerlings per year, taking into account a mortality factor of 20%. A hatchery with 2 hectares of fingerling ponds should be able to supply 1,5 to 2 million fingerlings per year. The project's annual feed requirements will depend largely on the feeding regime the farmers implement. It could range from 500 tons of formulated feed when it is fed as supplement to other low value feed inputs like grass and vegetable matter, to 3,000 tons if fish are raised exclusively on formulated feed. These volumes of feed equates to anything from 10 to 60 tons per week. A feed mill will be developed as an alternative to buy in feed when it becomes financially viable according to the economy of scale.

The project's long-term goal is to grow and expand the model to make a real contribution to global food security through distributing a fish-based nutritionally balanced meal to famine relieve efforts in low income food deficiency countries (LIFDC). When a total of 120 of the farms are fully operational, the project will produce between 3,600 and 7,200 tons of fish per annum. These expectations is not merely based on an extrapolation of data, but have been realized in various instances such as in the case of Scotland fish farm in Mississippi, USA, which produces over 8,000 tons of catfish per year and Rainforest Aquaculture in Canas, Costa Rica that produces and processes 13,000 tons of tilapia per year.

4.3 A Case study: Indonesia

This example of a shrimp farm in Lampung Province, Indonesia, is an example of a large-scale community based co-operative that is sustainable because of reliable production and economic viability. The company, Charoen Pokphand Group, incorporate 3,500 former tree cutters and their families into the operation to become gainfully employed shrimp farmers. In addition to this, 2,700 men and women are currently employed by the project as support staff (Global Aquaculture Advocate, April 2003). The company's responsibilities are to:

Figure 4.3 A Large-scale shrimp farming community in South Sumatra (Global Aquaculture Advocate)

- Construct the ponds
- Breed the fry/post larvae
- Manufacture the feed
- Process and cold store the product
- Develop supporting infrastructure and services

- Implement continuous and intensive training courses for farmers

The farmers' responsibilities are to:

- Purchase the fry and feed
- Grow out the product to market size
- Sell their harvests to the company
- Full time monitor their production ponds

The farmers purchase their ponds with an accompanied three-room house through a credit arrangement secured by the company. Payments are made at harvest time, twice a year. The farmers' net income is about R22 000 per year from a 0.5 hectare pond, plus they have the opportunity of being land and homeowners for the first time in their lives. This project has become a showcase of progressive community and sustainable aquaculture development through the combination of modern management practises and dedication of the farm owners/operators.

4.4 Functions of the farming co-operative:

4.4.1 Networking, marketing and distribution

An essential component in building up this new industry is to promote synergy and co-operation between producers. Co-operation between producers is one of the main reasons for the success of small-scale aquaculture in South East Asia whilst the lack thereof has been identified as one of the most important reasons why the South African catfish industry collapsed in the early nineties. The establishment of individual production units in the absence of co-operative structures should therefore be avoided and a holistic developmental strategy should be implemented. Some important aspects to consider include:

- The implementation of best management practices to ensure that good product quality and food safety standards are maintained.
- The provision of accessible information to farmers
- Arrangements for transporting of harvested fish to processing plant and/or markets.
- A generic marketing campaign and alignment of the production goals to ensure consistency of supply.

4.4.2 Extension work and farmer training

Primary training of farmers can be done in co-operation with training institutions, government departments and existing commercial farmers. The training programme should include aspects related to skills development, production technology and business management.

An important aspect to ensure commercial success in new aquaculture ventures is to include the input and mentorship from existing commercial farmers and aquaculturists, in particular relation to practical aspects of fish farming. The need to develop capacity for an intuitive, internalised decision process based upon experience of previous situations, or "gut feel" is of utmost importance to prospective fish farmers (Chaston, 1988). The advance nature of intensive aquaculture demands total commitment from farmers, whilst ongoing technical support specifically during the first and second crop stages is required to achieve success.

The identification of the right candidates as operators of the production units is a further prerequisite to ensure success of the farming units. These individuals must have the correct personal/entrepreneurial profile and be committed, diligent, hard working and observant. These attributes in effect outweigh any previous knowledge or training in the field. The principles of managing a grow-out pond can be taught within weeks and more advanced problems can be diagnosed and treated with the help of the extension staff. It remains, however, the responsibility of the farmer to oversee the fish farming operations from the day the fish are stocked to the day they are harvested and to identify water quality and disease related problem as soon as possible.

4.4.3 Marketing and product development

Limited success has been achieved with the marketing of freshwater fish in South Africa, with the exception of trout. Most people associate freshwater fish caught in South African dams and reservoirs to exhibits a "muddy taste". Freshwater fish are not presented in any of the major supermarkets and retail outlets in SA. Although tilapia is showing promise to be readily accepted by consumers as a fresh fish product, the marketing of carp and catfish products to levels capable of supporting the envisaged production volumes are considered challenging and even risky. Freshwater fish produced in earthen ponds is often prone to have an inferior taste to marine fish caused by the presence of mono cellular algae, especially blue-green algae (Cyanobacteria) that are prevalent in earthen ponds. This issue need to be addresses as only a small portion could be sold live into Asian niche-markets, while most of the harvest will have to be processed.

There are a number of issues that must be considered when marketing the product. The first is to determine what price can be realistically achieved for each level of processing, i.e. product type, and what quantities can be absorbed by the different market sectors. A co-operative approach to processing and marketing in partnership with established major seafood processors like Irvine & Johnston or Sea Harvest could be considered in the initial stages of the venture. The initial capital investment would be far less, and smaller margins could be offset by the opportunity to focus on production. It may be a better opportunity to invest in a processing plant when the farms are up and running and a steady/sufficient supply of fish can be guaranteed. Following this approach there will either be a reliance on the established processors for market development and branding, or the product will be absorbed with low value marine fish and cut-offs to produce reformed products like fish cakes and fish fingers. Although this might offer a relatively easy outlet for the product compared to marketing directly, the product will compete with low value marine fish and by-catches from trawlers, and subsequently the price obtained might be relatively low. To ensure economic viability and make full use the competitive advantage of producing fish under a controlled and organic environment, the product should eventually be branded and marketed as such.

4.4.3.1 Markets

The markets for aquaculture products are often lucrative and can be very profitable, especially if products are presented, priced and placed correctly. Some general guidelines for the pricing product in South Africa are as follows:

- Gate sales - live or whole on ice @ R8.00 to R15.00/kg
- Fresh delivered - Fish mongers, restaurants, markets @ R15.00 to R30.00/kg (whole on ice)
- Domestic markets - Supermarkets @ R15.00 to R30.00/kg (gutted & scaled)
- Export markets - Western Europe, Asia, USA, Central Africa @ R30.00 to R50.00/kg (fillets)

Export markets offer an attractive option for larger producers or farmer co-operations. Aquaculture development in Southern Africa can be export driven in particular by targeting the expanding Asian market for aquatic produce. Asia has the highest population concentration in the world and currently consumes the highest quantities of fish per capita. The population in the region is expected to reach 4.16 billion in 2020. If the current fish consumption rate is to be maintained, the region will require 70 million tons of fish per year in 2020, an increase of nearly 26 million tons from the present Asian production of 43.96 million tons (Da Sylva, 2002). This growing deficit is creating opportunities for exports into the region.

Although there seems to be an apparent demand for catfish fillets in Europe, there are unique costs involved in exporting fish. Frozen African catfish fillets currently sell for an average of US$6.50/kg in Europe. With the current Rand/Dollar exchange rate (1US$=6ZAR, March 2005) a local producer can expect between R11.00 and R19.00/kg live weight based on a 30% dress out ratio. Major costs that accompany exporting fish are freight and bank charges, agents and handling fees and export/import permits. There are also a number of accreditations that abattoirs must have before it can export fish. These include the USA's Food and Drug Administration (FDA) approval, Hazard Analysis Critical Control Point (HACCP) accreditation, ISO 9002 and the South African Borough of Standards' (SABS) Good Manufacturing Practices (GMP).

Asian countries compete heavily in the US market for frozen Tilapia. The fresh fish market is mainly supplied from Caribbean and Central American countries, like Costa Rica, Honduras, Equator, Mexico and Brazil. The wholesale price for fresh tilapia fillets in Miami (ex-Brazil) is around \$3.50/lbs (Feb 2005). More than 200,000 tons of catfish is consumed annually in the USA, Europe and South East Asia. Cheap imports from especially Vietnam has had a negative effect on market prices which is forcing increasing numbers of US catfish farmers and shrimp fishermen out of business. Although the export market is often the most rewarding in terms of quantities and margins, it requires expensive production systems and processing plants that have to comply with stringent international quality standards. The processing specifications will depend on the market requirements, such as:

- Level of value added, for example filleting, smoking, fishcakes, packaging, etc.
- Abattoir for local markets
- Abattoir for export markets

Figure 4.4 Examples of the presentation and marketing of tilapia products in developed countries, often as an alternative to sea bream and snapper

4.4.3.2 Product quality & Marketing campaigns

The produce from the Co-op must be of a high quality in order to create the premium image needed to obtain higher financial margins. A high quality image would increase the profitability of the individual farms without any additional production input. The image of a professional high quality product becomes very important when distributing to up-market food stores like Woolworths or supplying chefs in the hotel and restaurant trade. It is also advantages when tendering for grants to supply famine relief efforts.

To be above reproach the product should be produced in terms of organic and environmentally sustainable practices. A specific effort should also be made to move away from utilizing fishmeal as an animal protein source in the feeds. Alternative animal protein sources, such as chicken meal, could be used (Joubert, 1998), and feeds should include more plant protein sources, such as Soya bean meal. The processed product should also contain only approved natural preservatives and no Genetically Modified Organisms (GMO's) or mono-Sodium Glutamate (MSG). The health attributes of fish including its high poly-unsaturated fatty acids (PUFA's) and essential fatty acid content, easy digestibility and immune stimulation capabilities should be emphasized. An endorsement by the Heart Foundation would go a long way to establish the product as a healthy food. In recent years, consumers have been exposed to a number of food scares with regards to red meat including Bovine Spongiform Encephalopathy (BSE), dioxin residues and Foot and Mouth Disease. The use of growth hormones and antibiotics in the red meat and poultry sectors could further swing the scale to fish as the light tasting, healthy alternative.

A strong marketing campaign highlighting the health benefits and other advantages eating fish should include scientific research done on brain development and improved immunity, compared to other meat types. Fish is already known to be a light tasting, healthy alternative to red meats, and this should be emphasized in marketing campaign. The fact that the farm-raised products will contains no growth hormones or antibiotics could make a big impact on discerning buyers or decision-makers for big purchasers. Target markets for the cheaper baseline product includes hospitals, schools, prisons, hostels, mines, street vendors, retirement homes, food-aid programs. More expensive products from the higher quality species and value-added products should be marketed to restaurants and retail stores.

A proposed flagship product could be a nutritionally balanced meal in the form of a fish cake, canned product or a ready meal. It can be developed in cooperation with the CSRI and culinary departments of Universities and Technicons, to be sold as a balanced meal and distributed in hunger relief programs. Vitamins and minerals can be added to supplement specific deficiencies in the target communities. The product can be produced in several different flavourings to render it more palatable.

The most common value added processing of fish includes: smoking, salting, marinating, drying and canning. The instant ready meals market is rapidly expanding and offers good opportunities to fish processors. Fish can also be processed and reformed into various marketable products, including: fish cakes, fish patties, fish fingers, fish cubes, fish chips, fillet shape, fish balls, fish soup, fish mince, processed block that can be sliced like ham, sandwich spread, fish sausages, dried & powdered, etc.

4.5 Research and development

Once the core business components have been established, various potential spin-off business opportunities do exist. These include the production of carcass-meal from the fish-waste from processing. This meal has a high protein and calcium content and is suitable for inclusion into poultry and pig diets. It is among the safest animal proteins ingredient to include into the diets of farm animals, as none of the dangerous diseases like Foot and Mouth and BSE are transferable between fish and traditional farm animals. The second usable by-product from the system is the nutrient-rich effluent obtained through the daily drainage of the fishponds. The effluent contains high concentrations of nitrogen and phosphate and can be converted into a high value organic fertilizer. The run-off water from the ponds can also easily be linked to a hydroponics system, as most of the nutrients required by the plants are already present in the enriched water. Other by-products include process skins and chemical extracts.

Figure 4.6 a, b, c Hydroponic and planted lettuce fed with aquaculture wastewater and compost fertiliser prepared from fishpond effluent.

4.6 Biological and genetic quality of farmed fish

One of the principles of successful fish farming is to have access to good quality seed material as it has a large influence on production performance, i.e. growth rate, feed conversion, survival, etc. In China the government taken over the responsibility of supply of good quality seed and breeding material to the farmers after it was identified that the quality of seed and breeding material was as one of the main causes of lower yields and diseases in the local industry. Signs of deteriation in the quality of fish include:

- Early maturation
- Low survival from fry to fingerling stages
- Poor growth rate
- Poor disease resistance
- Poor fertility
- Low yield
- Poor meat quality
- Higher fat content

The main reasons for deteriation in the quality of fish are:

- Changes of living habitat and environment
- Lack of exercise and competition in the pond culture environment
- Fish are fed unbalanced feed nutrients
- Inadequate genetic management of broodstock, e.g. inbreeding

The prevention of inbreeding amongst broodstock is of extreme importance to avoid genetic degradation and farmers should replenish broodstock from credible sources on regular intervals. A hatchery manager needs to adhere to sound genetic management practices in terms of population size and mating systems. Sources of new bloodstock are:

- Other credible fish farmers
- Wild fish from rivers or dams
- Imported fish from credible foreign sources

There is, however, a substantial risk of introduction of disease when acquiring fish from other sources. Fish must therefore be properly quarantined and exposed to prophylactic treatment before being introduced to the farm.

The improvement of the genetic quality of farmed fish should focus economic important traits, such as:

- Improved growth rate
- Body shape, yield and improved dress-out percentage
- Reduction of cannibalism
- Disease resistance
- Improved feed conversion ratio
- Ease of harvesting – less jumping and crowding stress
- Temperature tolerance

Hybridization between compatible species is widely used to produce hybrids with beneficial characteristics of both parental species. Hybridisation can also produce monosex progeny, for example *O. niloticus* male x *T. aureus* female = 100% male hybrids. It is important to note that the parental generation must be of pure strains. Monosex populations play a major role in commercial aquaculture, most notably in tilapia farming. The male tilapia grows faster than the female and in the presence of females, directs a lot of energy towards reproduction from a very early age. This results in stunted growth and a population explosion in uncontrolled culture environments. Hybridisation, is one way to achieve an all-male progeny groups. The most widely used method is hormonal sex reversal. Triploid (3n) fish can exhibit sterility and faster growth. Grass carp for example is widely used for controlling aquatic macrophytes in developed countries and is mostly sold as certified triploids to ensure effective population control.

4.7 Conclusion

The proposed implementation strategy for integrated aquaculture development in KwaZulu Natal is to focus on developing profitable commercial farms, based on Chinese integrated farming practises instead of small subsistence farming units. The farms will be modular units consolidated under a Co-op. Each farm consists of 8 ponds with a total water surface of 4 hectares, producing 40 to 60 tons of fish per year. The Co-op will facilitate sourcing supplies, providing technical and logistical support and marketing the product. The initial phase will establish a couple of individual farms to produce a crop or two to prove the production technology. The second phase will be the expansion to 25 farming units to warrant full vertical integration, and the end vision is to expand the Co-op to 120 farms to reach production capacity of up to 7,200 tons/year. This will have a substantial impact on providing food security, creating jobs and developing the industry as a whole in not only KwaZulu-Natal, but also the whole Southern Africa.

CHAPTER 5
PROPOSED FARMING MODEL FOR DEVELOPMENT OF INTEGRATED AQUACULTURE SYSTEMS IN KWAZULU NATAL

The proposed farming model differs from existing rural small-scale fish farm development in a number of ways. It proposes a semi-intensive commercial operation as oppose to a low input extensive production system. The planned farms are 15 hectares each, consisting out of 8 ponds of 0.5ha each, a basic family home and services, and 10 hectares of land below the ponds suitable for crops and/or livestock rearing. Storage is required on site for feed and equipment.

5.1 Farm site

5.1.1 Water supply

The water supply or source at the potential site is one of the most important factors to take into consideration. Fresh water should be added to the pond at regular intervals to adjust water depth, control water quality and replenish the dissolved oxygen supply. The water must be of sufficient quality to sustain the particular species of fish. Water parameters outside optimum levels for the species will result in reduced growth and disease resistance, causing lower production and profitability. Water quality parameters for production of the main aquaculture species considered for the farms can be found in table 6.9 in the following chapter. A thorough water quality analysis should be done on the potential water source before any development does take place. A good standard test to assess the quality of the available water is the test for domestic consumption and livestock watering (table 5.1). This will also guide the developer when planning the water supply to the abattoir, ice machine, staff facilities and any other application that requires potable water.

The water supply must provide enough water on a year round basis to fill four hectares of ponds which takes approximately 110,000 cubic meters of water. Water loss in a system that size due to evaporation ranges between 135 to 250 cubic meters per day, depending on ambient temperature, wind and humidity while peculation or leaching rate is largely dependant on the soil type.

Table 5.1 Recommended water quality tests for domestic consumption and livestock watering (Umgeni Water, 2001)	
Water Usage	Determinants Recommended
Domestic consumption SABS 241 of 1999	Aluminium, antimony, arsenic, cadmium, calcium, chloride, chromium, cobalt, coliforms, coliphages, colour, conductivity, copper, Cryptosporidium, cyanide (free), cyanide (total), faecal coliforms, fluoride, Giardia, iron, lead, magnesium, manganese, mercury, nickel, nitrogen – ammonia, nitrogen - nitrate, nitrogen - nitrite, odour, pH, phenols, potassium, selenium, sodium, soluble organic carbon, sulphate, total dissolved solids, total hardness, total plate count, total trihalomethanes, turbidity and zinc.
Livestock watering Department of Water Affairs and Forestry Guidelines 1993	Algae, aluminium, arsenic, boron, cadmium, calcium, chloride, chromium, cobalt, conductivity, copper, fluoride, iron, lead, manganese, magnesium, mercury, molybdenum, nickel, nitrogen - nitrate, nitrogen - nitrite, organochlorine pesticides, pathogens, selenium, sodium, sulphate, total dissolved solids, vanadium and zinc.

It is advisable to get historic data on the water availability on the site in years of drought. There are a wide variety of water sources for earthen ponds. Some farmers in areas with heavy annual rainfall depend solely on rain to fill their ponds. Some ponds are gravity fed from a river or a weir in a river.

Figure 5.1a, b Example of water supply systems in Kwazulu Natal: a dam overflow near Richards Bay, a supply canal for a prawn farm at Mtunzini (Author).

An impoundment or dam can be a very good and stable supply of water (figure 5.1). If the farm is situated below the dam wall, water can be fed by gravity from the dam, or a canal can supply the farm. A good option is to build the ponds on land that is part of an existing canal-fed irrigation scheme like the one depicted in figure 5.2.

Figure 5.2 Example of water supply systems in Brazil and in central China (Author)

Aquaculture ponds are often situated on flat lying areas where water must be pumped in and out of the ponds that will have a significant effect on production costs. Water can also be pumped from a river, dam or underground wells straight into the ponds or into a storage reservoir. When surface or underground water is pumped under high pressure, care should be taken to avoid super-saturated of atmospheric or underground gasses that may cause the occurrence of gas bubble disease.

5.1.2 Temperature

Fish are cold blooded animals and water temperature therefore plays a vital role in their metabolism. The ambient temperature profile of the potential site is therefore of extreme importance, as it would greatly affect the water temperature in ponds and the metabolic efficiency of the fish. Different species of fish have different optimal temperatures in which they grow the fastest and have the highest resistance against diseases. Both the summer and winter water temperatures should be monitored in existing ponds in the area to assess the suitability to the target species. The main species under consideration has a optimal temperatures range of between 25°C and 32°C. Catfish needs a minimal spawning temperature of 21°C with optimum hatching at 27°C. The best growth is obtained at 28 - 32°C, while feeding and growth stops at a temperature of 15°C and below. Common carp spawns at 16 - 26°C with optimum hatching of larvae at 17 - 22°C. Tilapia (*O. mossambicus*) also has an optimum between 24 - 35°C, Breeding stops below 22°C, with growth declining sharply below reaching sub-lethal levels at 12°C (Avault, 1998).

5.1.3 Soil type

When evaluating a site to develop earthen ponds, a core sample of the soil type up to a depth of 3 meters is recommended. The best soil to build earthen ponds in is loamy soil. Sandy soils do not form a good impervious bottom and water seepage occurs. If the soil has too high clay content, its low permeability causes it to seal well, but the fine particles are suspended easily, causing high turbidity or muddy water. This will influence sunlight penetration and subsequently the natural productivity of the pond. Excessive turbidity can also irritate the gill filaments of some species, especially in the early life stages. The bottom layer of silt also becomes too thick and the clay absorbs a lot of nutritive minerals and salts rendering it unavailable to plankton (NACA, 1989).

A good rule of thumb to test the soil's suitability for pond construction is to take handful of soil, moisten it and roll into a tube of about 10cm in length. If you can bring the two ends together without breaking, the soil should have a high enough clay content to hold water.

Figure 5.3 Installation of a HDPE liner in earthen ponds (AquaticEco catalogue 2003)

If the soil is unsuitable for a pond bottom, suitable earth can be trucked in and used to line the pond bottom. Another option is to mix in artificial clay called bentonite, which will bind with your existing soil to create an impermeable layer. The third option is to line the ponds with a HDPE liner as depicted in figure 5.3. These are costly and restrict the natural productivity of a pond due to the absence of an earth-based silt layer on the bottom, but are pretty much the only option when construction ponds in sandy soils.

Some farmers use chicken manure to help seal a new pond. When the pond is filled, the manure is slowly mixed into the water at the inlet so that it spreads evenly over the pond bottom and forms an organic layer that helps with the sealing process

5.1.4 Distance from markets and services providers

The distance from the market influences the costs of getting supplies to the site and shipping the product out. It could become a significant component of the operational costs given the quantities of fish that are going to be produced. A location closer to markets also provides an alternative to supply fresh and live fish to the markets. Another important factor to keep in mind is the distance from major suppliers and services providers. The cost of supplies increases substantially when the product has to be transported over a long distances. Other important service providers include reliable electricity supply, communications services and road networks.

5.1.5 Local communities

Information on local community structures must be considered before deciding on a site to build the farms. Care should be taken when there is a history of unrest, crime and political violence. The underlying factors and issues are normally not easily resolved and safety considerations must be adhered to. If a good standard of living cannot be offered on site, the business will find it difficult to attract the best people for the available positions (Avault, 1998). The business should provide for good public relations and human resources capacity to ensure a good relationship with the surrounding community. Job creation in the local community should be high on the agenda and personal relationships with local tribal Nkosis (Headmen) should help a lot towards curbing theft and ensuring safety for personnel. Sensitivity towards tribal customs and a strong participatory approach should be followed to ensure support from the local community leaders.

5.1.6 Environmental impact

A fish farm, like any other farming activity, has the potential of impacting negatively the surrounding environment. Environmentally sustainable farming practices are becoming a global norm while stricter control over issuing of permits and monitoring farming practices has become the order of the day. The main concerns regarding environmental impacts are:

- Effluent discharge

  Nutrient rich effluents can pollute natural water bodies. The discharge of organic nitrogen in the form of nitrates, phosphates, chemicals and heavy metals can lead to a habitat change to aquatic fauna and flora and even eutrophication.
- Bio-security

  Escape of farmed animals into natural water bodies is a valid concern. They may compete with the naturally occurring fish for food sources, spread diseases or cause distortions in the genetic diversity.

To counter these concerns, all water drained from the pond must be used to irrigate the crop fields ensuring that the nutrients are utilised by the terrestrial plants and that there is no passage for escaped fish into a natural water body.

5.2 Site plan and components

5.2.1 Pond design and layout

Ponds should be rectangular in shape with flat even bottoms to simplify rearing management and netting operations. Pond dykes should be built wide enough that a vehicle can drive on it. Each farm will consist of eight ponds with a measurement of 50 meters wide by 100 meters long. These ponds should be built adjacent to each other, sharing their long dykes. The ponds should be 2.5 meters deep at the shallow end and 3 meters deep at the deep end. A 30cm diameter PVC drainpipe should be installed in the pond at the deepest end, allowing the farmer to adjust the water level in his ponds.

The initial pond construction is one of the major expenses in building each farm. The construction of the ponds should be outsourced to a construction company that has previous experience in building ponds. The Co-op can over time integrate the pond building as part of its operations and invest in heavy earthmoving equipment and operators when the project grows to the number of farms where such an investment can be warranted.

Pond fish farmers all over the world suffer heavy losses to birds preying on their fish. One of the cheapest and most effective ways to protect the ponds of that size against bird predation is to cover it with monofilament netting. Stretching fishing lines over the pond every 30cm both lengthwise and width wise does a good job to keep most birds out. White ribbons of plastic can be tied to the line ever so often to act as a warning indicator to the birds to avoid them tangling themselves up in the line. The netting must be suspended high enough over the pond to allow easy access for feeding, harvesting and pond management. Cables should span the width of the pond every 20 meters to help support the netting and keep it from excessive sagging. The cables can be stretched between CCA treated poles or concrete pillars made by pouring concrete into a pre-planted PVC pipe with rebar in the centre.

5.2.2 Equipment

Each farm will have various movable assets that is essential to proper management and maintenance of the farm. Each pond needs aerators to improve the dissolved oxygen concentration in the pond, increasing the pond's carrying capacity and subsequently the total yield per hectare. Pond aeration devices, from surface aerators to synergistic airlifts, put atmospheric oxygen into the water between the rates of 0.6 – 6.0 kg per kilowatt-hour. Fountains are at the very low end of the oxygen transfer rate, as they expend much more energy putting water in the air than air in the water. Synergistic airlifts are at the other end of the spectrum because they expend very little energy in circulating huge quantities of water. In this case the oxygen transfer takes place via diffusion from the atmosphere at the surface of the pond.

Airlift synergistic diffusers are used in deeper lakes and can have an efficiency of up to 4.5kg of dissolved oxygen transfer per horsepower. Floating diffusers are used in shallow ponds where efficiency averages about 0.9kg of dissolved oxygen transfer per horsepower. Paddlewheels and aspirating aerators are the most extensively used aerators in larger aquaculture ponds and work on the principle of moving water. It can create zones of high dissolved oxygen where fish can concentrate in an emergency situation. Although not as efficient, it is much better than aerators that mix the water column in a low oxygen situation.

Each pond should be equipped with two paddlewheel aerators (figure 5.4) of 1 horsepower each. These should be turned on when the dissolved oxygen concentration drops below 5ppm, which normally happens in the early morning hours as a result of the photosynthetic cycle of the phytoplankton present in the pond. Hot, windless days are also dangerous as the amount of dissolved oxygen decreases as water temperature increases. Wind and accompanying wave action greatly increases the rate of oxygen transfer via diffusion between the atmosphere and the water surface. For this reason, the pond dykes should not be planted with trees or have any structures that would shield it from the wind. Another very important piece of equipment to have available is a backup air blower powered by a petrol engine (figure 5.4), which can be mounted on a wheelbarrow and easily pushed to where it is needed.

Each farmer should have a handheld dissolved oxygen meter (figure 5.5) to measure dissolved oxygen concentrations in his ponds. This is, together with the different nitrogen levels (especially ammonia), the most important parameter to check. To measure basic water quality parameters, each farmer should have simple a water quality testing kit (figure 5.5) and be trained how to use them and interpret the results.

Figure 5.4 Paddlewheel aerator in action and backup blower

Each farmer will have a small rowing boat or canoe to distribute feed and do other management tasks. There is some equipment that is only used a couple of times a year. In this case it is not viable for each farm to own the equipment, and it makes more sense that farmers share between them. Mobile diesel-powered backup generator should be available all year around and on short notice to power the aerators in case of electricity blackouts. This could either be the property of the Co-op or of a reliable supplier in the area. Emergency hook-ups for the generators should be centrally located and easily accessible in adverse weather. This is a very essential part of the operational planning and should not be left until it becomes necessary. An alternative to backup generators for the paddlewheels is PTO driven aerators. These can be connected to tractors and lowered into ponds for emergency aeration.

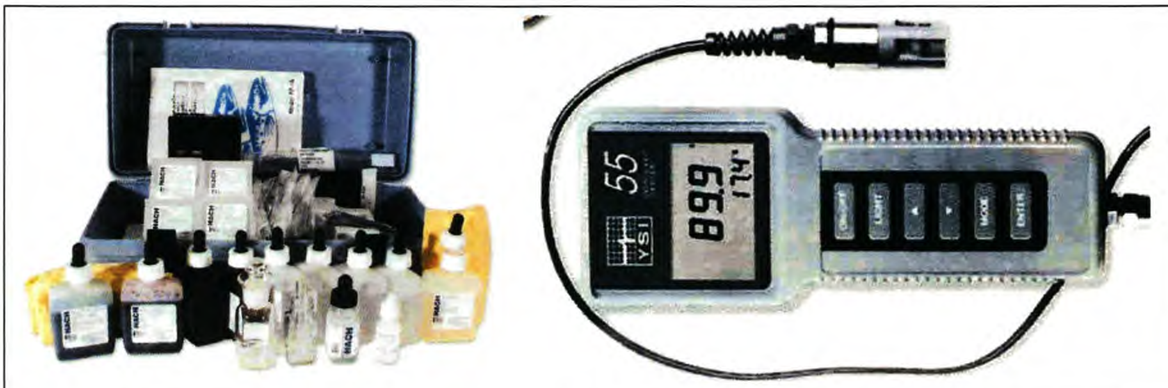


Figure 5.5 A basic water quality test kit designed for freshwater aquaculture by HACH, and handheld dissolved oxygen meter by YSI

The ponds will require regular maintenance and even reconstruction after 8 to 10 years as a result of erosion. At such a time, all the water is drained out and the silt needs to be removed to make it possible for the heavy machinery to work in the pond. A floating 8hp 3" dredging pump is another vital piece of equipment that can be shared by the farms for this purpose. The dredge pump is the only cost-effective way to remove silt from ponds when the silt layer needs to be reduced or removed.

5.3 Species available for aquaculture

There is a wide variety of fish, livestock and crop species that can be produced on the individual farms. The choice and combination of these three farming facets will depend on how management and ownership of the farms are structured. Crops may be assigned to farmers to fit into the co-operative's holistic production schedule if the co-operative owns all the farms with the farmers as employees. On the other hand, farmers as owners may have the choice of species depending on their available capital, experience and chosen exposure pertaining to marketing or production risks. Farming models can range from high value capital-intensive species like Koi-carps, exotic birds, and organic herbs to relative low value low risk species like catfish, goats and maize and cabbage.

Most exotic species available to fish farmers in other major aquaculture producing countries are not available to South African fish farmers. The South African Department of Environment Affairs and Tourism strictly controls or bans the use of non-indigenous aquatic species for commercial production. These species are considered an ecological threat by conservation agencies because they may compete with and displace, prey on, or interbreed with indigenous species. In addition, there is a chance of transferring foreign parasites and diseases to local species. Many of these banned species play pivotal roles in polyculture systems in other parts of the world. The Nile tilapia (*Oreochromis niloticus*), Chinese major carps and freshwater prawn (*Macrobrachium rosenbergii*) are examples of species that are of huge economic importance in worldwide aquaculture, but are banned in South Africa, which forces aquaculturists to look at local species alternatives.

The most promising warm water species available are African catfish, Mozambique tilapia and common carp. All three species are cultured successfully in other parts of the world. A lot of data is available on culturing methods. There are other marginal species that can be produced in polyculture with the three main species. This can be done to improve pond yield by utilizing ecological feeding niches complimentary to the main culture species. Table 5.2 lists some local alternatives to the traditionally used species in China. Efforts to develop special markets for some of these species should be pursued to increase the financial return on the crop. The species with high value marketing potential include Largemouth bass, Butter catfish and the Longfin eel.

Table 5.2 Chinese aquaculture species with potential South African counterparts

Chinese species	South African alternatives
Herbivorous:	
Grass carp	Red breasted Tilapia (*Tilapia rendalli*)
Blunt snout bream	

Filter feeders (Phyto&Zooplankton):	
Silver carp	Mullets (*Mugil cephalus)*
Bighead carp	Mozambique tilapia (O. *mossambicus)*
	Threespot barb *Barbus trimaculatus*
Omnivorous:	
Common carp *Cyprinus carpio*	Common carp (*Cyprinus carpio)*
Crucian carp	Catfish (*Clarias gariepinu)s*
	Eels (*Anguilla mossambica)*
	Silver catfish (*Schilbe intermedius)*
	Vundu (*Heterobranchus longifilis)*
Carnivorous:	
Snakehead	Largemouth bass (*Micropterus salmoides)*
Mandarin fish	

5.3.1 Major aquaculture species

5.3.1.1 Tilapia


Figure 5.5 Mozambique tilapia (Jensen, J)

The Mozambique tilapia (*Oreochromis mossambicus*) is native to KwaZulu Natal and thrives in ponds and rivers throughout the province. The species has been introduced to tropical and warm-temperate areas throughout the world. It is a hardy fish that tolerates a wide range of temperatures (15°C – 40°C), crowding and low water quality. It feeds mainly on diatoms and detritus and readily takes pelleted formulated feeds. Although its growth rate is lower than other cultured tilapia species, it has a better tolerance to colder water and high salinity. The fish matures very fast and starts breeding at a small size of about 40g, which leads to energy being directed into reproduction rather than growth, overcrowding and eventual stunting at below market size. To address the problem it is suggested to stock ponds with monosex populations of tilapia, which can be done through a number of ways. Hand sexing each fish individually is one labour-intensive way. Changing the phenotype of the fry through feeding or emersion in androgens like 17-α-methyl testosterone is done during the window period where fry are still totipotent. Genotypic female fry can change into phenotypic males after exposure to the androgens. This method is most widely used in commercial tilapia aquaculture to achieve all-male populations.

Another method that is used to achieve all-male population in *O. mossambicus* culture is to sex-reverse male tilapia into female tilapia with estrogens and spawn these fish with normal males. The resulting F1 generation will have 25% female fish with XX genotype, 50% male fish with XY genotype and 25% males with YY genotype. The YY fish are referred to as "super males". These fish will produce a 100% all male F2 generation when spawned with a female fish.

5.3.1.2 Catfish

The African Sharptooth catfish (*Clarias gariepinus*) is a remarkably hardy species that can tolerate adverse water conditions and is completely omnivorous. It grows well in crowded aquaculture conditions and is widely cultured throughout Africa and in intensive recirculation aquaculture systems in Europe. The fresh meat is of good quality and it lends itself well to curing, smoking and other forms of processing.

Catfish farming took off in South Africa in the eighties with annual local production peaking at 1,150 tons of catfish in 1991. The sudden rise of fishmeal prices in the late eighties had a direct impact on feed costs. The product was never developed or marketed properly, and farmers weren't getting high enough prices for the fish locally to make it profitable and most of the operations stopped producing catfish in the early nineties.

Figure 5.5 African sharptooth catfish (Lovshin,)L

Prinsloo & Theron (1998) attribute the collapse of the industry to marketing problems, high production costs and farmer incompetence. Many producers produced catfish without having identified a market and ended up with fish that they could not sell. Some producers sought markets overseas but these markets required high volumes, more than what was being produced by all the catfish producers in South Africa at the time. Linked to the marketing problem were high production costs (mainly high feed costs) that resulted in a product that was too expensive for the local market where it had to compete against other fish and meat types such as marine fish and chicken. Many potential producers were under the wrongful impression that there is a direct correlation between other livestock production and aquaculture, e.g. that a pig farmer will automatically be able to transfer his piggery management skills to an aquaculture venture, while indeed two unique sets of management skills are required.

The farming of catfish in Africa is still a marginal activity (4,500 tons in 1993) due to local market forces, inadequate regional infrastructures, production costs, the socio-economics of fish farming and the underlying philosophy upon which aquaculture development in Africa is still largely based. However, the future potential for the farming of Clarias gariepinus in Africa is huge (Hecht & Wilson, 1997).

5.3.1.3 Common Carp

Common carps *(Cyprinus carpio)* originate from central Asia and Europe. It has been cultured for centuries as a food fish in these areas and all over the world during the last century. It spawns easily, tolerates a wide temperature range and can be cultured on low cost feed ingredients. Common carp has relative low quality reddish meat with a lot of small bones. There is, however, a niche market for the fresh product and it is highly esteemed by some South African communities, especially over religious holidays. There is also, like with many other freshwater species, a lucrative live fish market in selling to the Asian communities.

Figure 5.6 Common carp varieties (Lovshin, L)

5.3.2 Secondary aquaculture species:

5.3.2.1 Other tilapias

The Redbreast tilapia *(Tilapia rendalli)* feeds mainly on macrophytes (water plants) and algae. Although it grows slower than *O. mossambicus*, it's feeding habits makes it a valuable herbivorous species to be included as a local polyculture candidate.

Figure 5.7 Redbreast tilapia (Seegers, L)

5.3.2.2 Mullet

Mullet species are extensively utilized as foodfish all over the world. Its meat is high in essential fatty acids. Although mullets are not commercially cultured in South Africa, the species has been included for its potential as filter-feeding polyculture species. There are 16 species of mullet that can be found in freshwater systems in South African. Most of them feed on microalgae, filamentous algae, forams, diatoms, terrestrial plant material, aquatic insects, and detritus associated with sand and mud. The Flathead mullet, *Mugil cephalus*, has the most potential as aquaculture species and feeds on zooplankton, benthic organisms and detritus. Adult fish tend to feed mainly on algae while inhabiting fresh waters.

Figure 5.7 Flathead mullet (Lovshin, L)

5.3.2.3 Silver catfish/Butter barbel

Although there is still a lot of work to be done in researching optimum production methods for the Silver catfish (*Schilbe intermedius*), it is included in this section for its high quality flesh. Production limitations include relative slow growth, cannibalism, and difficulty in handling and grading because of its habit of locking the pectoral fins perpendicular to the body (Polling, 1999). The Silver catfish or Butter barbel is one of the best tasting freshwater fish in South Africa. The species has great potential to be marketed fresh as a high value product. Rearing could be done in cages, monoculture or polyculture with other species.

Figure 5.8 Silver catfish/Butter barbel (De Vos, L)

5.3.2.4 Largemouth Bass

The largemouth bass (*Micropterus salmoides*) is a good eating fish with high quality meat that can be sold fresh. It is produced in large scale in the USA for consumption and sport fishing. The fry are weaned onto formulated feed from live feed in small tanks or cages and raised subsequently exclusively on pelleted feed in floating cages or raceways.

Figure 5.9 Largemouth bass (Jensen, J)

5.3.2.5 Vundu

The Vundu (*Heterobranchus longifilis*) in the largest freshwater species in Southern Africa, and can attain about 55kg (Skelton, 1993). Although the fish does not naturally occur in Kwazulu Natal, it can be hybridised with African catfish to produce a faster growing hybrid species.

Figure 5.10 Vundu (Helias, J)

5.3.2.6 Threespot Barb

The Threespot barb (*Barbus trimaculatus*) is a hardy species that can tolerate a wide water temperature range (16 °C to 32 °C) and adverse water quality conditions. It spawns very easily and grows to about 15 cm in a year. In an experimental trial done at the Aquaculture Research Unit of the University of the North, fish were stocked and grown through the winter in small ponds with fresh chicken manure as only feed input. Although the fish were exposed to great water temperature fluctuations and extremely poor water quality, they grew well with a good survival. The fish can be dried or processed like small sardines and kapenta, used as live feed to largemouth bass or sold as live bait.

Figure 5.11 Threespot barb (Gratwicke, B)

5.3.2.7 Eels

There are a number of high value niche markets with the Asian communities in bigger cities for live eels and a lucrative export market to Japan if quantities and quality requirements can be met. The barrier to sustainable large-scale eel farming in South Africa is attaining permits for glass eel recruitment from South African estuaries. The Longfin eel (*Anguilla mossambica*) shows a lot of promise as aquaculture candidate species. Eels take formulated paste feed readily and can be cultured at high densities due to good tolerance to adverse water quality conditions.

Figure 5.10 A Longfin eel (Skelton, 1993)

5.3.2.8 Ornamental fish

Koi-carp (*C. carpio*) and Goldfish (*Carasius auratus*) can be successfully raised in earthen ponds. It takes a bit more experience and careful management to raise these fish, as they are more susceptible to diseases and predation. Harvesting, purging, packing and transporting of the fish is very different from food fish operations. There are unique risks and marketing challenges involved when producing ornamental fish, and thus, inexperienced farmers should rather start with easier food fish. The potential for higher economic returns does, however, exist. Furthermore, farmers can look at diversifying operations to increase farm viability down the line.

Figure 5.12 Goldfish market in China (Author)

5.3.2.9 Freshwater prawns

The giant freshwater prawn (*Macrobrachium rosenbergii)* is cultured extensively all over the world where the climate permits. It feeds on detritus and is a good polyculture candidate as it lives on the bottom of the pond, occupying a normally vacant spatial niche. There is a strict social hierarchy that is formed around the alpha males, but removal of these individuals and/or the addition of structures in the pond relieve a lot of the negative impact of this phenomena on growth. The prawn's meat is of very good quality and can be sold into existing seafood markets. A special permit will have to be acquired to culture this species in South Africa.

Figure 5.13 Freshwater prawns (Author)

5.3.2.10 Freshwater crayfish

Individual farmers have acquired permits for the culture of Australian freshwater crayfish in South Africa. *Cherax tenuimanus* (marron), *C. destructor* (yabbie) and *C. quadricarinatus* (redclaw) are the three species most widely cultured. Niche markets for fresh specimens exist especially in the seafood and restaurant trade.

Figure 5.14 Freshwater crayfish (Author)

5.4 Integrating crops and livestock

The farms are to be designed to allow farmers and their families to utilise the synergies associated with integrating farming practises. The secondary crops and livestock farmed on the 5-hectare land situated in an area below the ponds can supplement the farmer's income and subsistence needs. Crops can also be planted under contract to a feed mill to produce ingredients for the manufacturing of fish feed. Nutrient rich water and sludge from the ponds can be used to water and fertilise crops. Because the land is situated below the ponds, no pumping should be necessary. Water can simply be siphoned from the pond with inexpensive PVC irrigation piping. The crops or some of their by-products can be fed to the pond fish as supplementary to the formulated pelleted feed.

The type of crops planted should be determined by the site's climate, soil type, farmer competency and labour availability, initial capital investment and market demand. Examples of crops available are garden vegetables, maize, grain, herbs, fruit, cut flowers, citrus, nuts, soybeans and sunflowers. Livestock can be kept and fed on the crops or by-products. Livestock suitable for integration includes chickens, goats, cattle, pigs, rabbits and ducks.

There are also some alternative high value niche-market products that can also be considered for including:

- Ornamental waterfowl
- Ornamental birds including parrots and ringnecks
- Game birds for wing-shooting, restaurants and fly-tying feathers
- Crocodiles (*Crocodylus niloticus*)
- Snails for niche restaurants
- Frogs (*Rana catesbeiana*) and *(Xenopus lavea)* for niche restaurants
- Mushrooms
- Earthworms and compost
- Bee keeping for honey production
- Duckweed aquaculture *(Lemnea spp.)*
- Ornamental aquarium and pond plants
- Crabs
- Ostriches
- Spirulina raceways

5.5 Conclusion

Proven Chinese pond design and production technologies provide the foundation for the proposed farming model. The identification of suitable farm sites remains one of the most important steps in the implementation of the project. Water supply, climate and soil type are absolutely critical parameters and cannot be compromised on. The development of integrated aquaculture systems in KwaZulu-Natal will use local aquatic species as alternative to the species used in China, adhering to safe and sustainable environmental practices. Tilapia, catfish and carps will be the major species propagated, making up the bulk of the production volume. Other species in the production model include high value species and minor species that can be grown in polyculture with the major species to occupy the underutilized space and feeding levels in the ponds.

CHAPTER 6

PRACTICAL OPERATIONAL GUIDELINES

6. Farm operations

This chapter is devoted to the practical managerial operations of a pond-based fish farm to be used as a guide to new fish farmers. To successful production of a crop of fish is dependant on the correct and detailed implementation of various principles and guidelines. It is difficult to obtain appropriate practical guidelines for fish farmers. The production strategy on the farms would involve stocking fingerlings into suitably prepared production ponds and growing them out until a harvestable size is reached. Feeding rates, water quality monitoring and disease control are some key management issues that need to be adhered to in order to grow a successful crop of fish.

The Chinese pond fish farmers adhere to seven key principles in relation pond fish farming:

- Water: Water quality and productivity of ponds.
- Seed: It is important to start with good quality fry or fingerlings. Genetic degradation, stress, physical damage and disease are some of the aspects that farmers should pay attention to when receiving fish from a hatchery.
- Feed: Fish should be fed enough to maintain fast growth while not compromising the pond's water quality. The farmer's feed management normally has the greatest impact on profit margins. Feed formulations should be as low in costs as possible without compromising growth rate or causing water quality deterioration. The Chinese farmers also believe in conditioning or 'training' their fish by feeding them at the same time and place every day with the same amount of feed. Gross feeding rates are adjusted according to the growth of the fish.
- Density: Stocking densities should be optimal for the pond used. Aeration, water quality and feed used play a part in determining how many fish can be stocked.
- Polyculture: The stocking of different fish species together in a pond is referred to as polyculture. This is done to create a production synergy by utilizing the different feeding and spatial niches available in a pond.
- Rotation farming: Fingerlings are stocked with older fish to fully utilize the available production space and capacity of a pond. As fish are harvested from the pond, new fish are stocked in their place.

- Disease prevention and management. Diseases can threaten a whole crop or reduce growth and survival rate to the extent that expected production targets are not met and profit margins do not materialize. It is therefore imperative that farmers identify when the fish are stressed, weak or unhappy and determine the cause. The sooner diseases are diagnosed the more effective treatments are in controlling the pathogens causing the disease.

6.1 Pond clearing

The operations begin with pond preparation for the fingerlings. Pond clearing is the first step in pond preparation. Surplus silt on the pond bottom consumes oxygen and is therefore removed, leaving behind a layer silt of 5cm to 15cm. The next step is disinfecting the silt with Quick lime or hydrated lime (CaO) as depicted in figure 6.1. Suggested dosages are listed in table 6.1. This kills pathogens and improves water quality by increasing the alkalinity of the pond silt. There is also a fertility regulation action when absorbed nutrients (NH_4^+ and K^+) are released from the silt by replacing them with Ca_2^+. The nutrients are subsequently made available for assimilation by plankton when the pond is filled and maturated.

Table 6.1 Effective dosages for pond clearing with Quick or hydrated lime (CaO).

Water depth	5cm to 10cm	30cm	100cm
Dosage	900 to 1125 kg/ha	1125 kg/ha	1800 to 2250 kg/ha

The next step is to fertilize the pond to improve its natural productivity, similar to a crop farmer fertilizing his fields. Microorganisms including bacteria, phytoplankton and zooplankton assimilate the nutrients from the fertilizers and play an important part in the pond's food cycle. The organisms are food for newly stocked fish fry and fingerlings and greatly improve the fish's survival and growth.

Fertilizers are initially applied as a base fertilization and can thereafter be applied regularly to maintain the fertility of the pond. Fresh manure, fermented manure, green manure and compost are examples of organic fertilizers that can be used. Chicken manure is an especially productive organic fertilizer and should be applied at a rate of 500 to 750kg/ha/week. Care should be taken when sourcing chicken manure that it is obtained from chickens that are not receiving any antibiotic or growth hormone treatments.

Inorganic fertilizers like 16-20-0 (N-P-K) can be used in combination with organic manures to improve algal growth in particular and should be applied at 25 to 50kg/ha/week. Inorganic fertilizers sink to the bottom of the pond and are absorbed rapidly by the silt. It is therefore necessary to either dissolve such fertilizers in water before application or to apply it onto a submerged platform to keep it off the bottom.

Figure 6.1 Pond treatment with hydrated lime.

6.2 Transportation of fish

Fish can be transported in a variety of containers and tanks. The most important parameters to keep at acceptable levels are dissolved oxygen concentration, ammonia and water temperature. Transport tanks are normally aerated with small atmospheric blowers or pure oxygen systems. Tanks should be slightly ventilated to allow for the air-stripped carbon dioxide to escape. Fish are purged by not feeding them for a set period before the haul. This reduces ammonia excretion and thus the impact on the tank water quality during the haul. Depending on how long they are going to spend in the tanks, fish are purged for three to seven days. Most live-haul tanks are insulated to prevent tank water from heating up or cooling down too much during the haul. Salt is added to the tank-water at a concentration of five to10ppt, depending on the species. This helps to calm the fish down and reduces osmotic pressure on the fish. Acriflavin or Methylene blue is sometimes added in the water as a prophylactic against bacterial and fungal infections. Another important way to reduce stress and physical damage to especially small fish is to never net them out of the water. Fish should be loaded in buckets of water to support their fragile bodies, and

Figure 6.2 Stocking fingerlings from a livehaul truck into a raceway (Author)

off-loaded via a smooth pipe straight into the pond as demonstrated in figure 6.2. Commercial fish haulers in the USA use a number of smaller tanks on a big flatbed truck, rather than one big tank. This way the risk is spread and there is more flexibility to haul different species and size classes or to deliver accurate portions of the fish to different ponds or farms. A fair sized live-hauling truck could have 20 tanks of 500 litres each with the capacity to haul 1.5 to 2 tons of tilapia or up to 3 tons of catfish.

6.3 Stocking of fingerlings into grow-out ponds

The ponds should be stocked to allow for a 20% mortality factor from fingerling to harvest size fish, which would be the expected rate of attrition. Fish mortalities occur mainly as a result of poor water quality or excessive predation from birds in particular. Fish should be grown for at least a year before the first harvest. In this period, tilapia can achieve 600g to 800g and catfish and carp 1kg to 1.5kg.

6.3.1 Stocking rates

Chinese fish farms are recording net yields of up to 18,200 kg/ha/year (total yield at harvest 27,500 kg/ha) using polyculture stocking patterns with herbivorous, omnivorous and filter feeding fish. Herbivorous fish should account for more than 50% (60 to 78%) of the total weight and plankton feeders less than 15%. The balance should be made up of omnivorous fish. The optimum stocking weight for this type of polyculture with low cost feed input is 2,400 to 2,550/ha, with an average net production of 12,630 kg/ha. Under Chinese market conditions and with prevailing production costs, a farmer can expect a gross profit in the range 30 to 40% on his crop of fish.

6.3.2 Case Study: Comparing stocking patterns and economic benefits

The municipalities of Wuxi and Suzhou are located in a traditional fish culture area in central China. The farmers are practicing low input polyculture fish farming and the average production between the 7,000 hectares of ponds in the area is 7,500 kg/ha. Yang and Liu (1994) studied three farms in Wuxi and Suzhou located in the Taihu Lake basin in central China. The Zhangzhuang Aquafarm in Wuxian county, Suzhou, has 81 fishponds with a water area of 38.3 ha. The Helei Aquafarm in Wuxi has 32 ponds with a surface area of 69.6 ha and the Helei Fisheries village has 27 ponds covering an area of 15.9 ha. The stocking patterns, management and economics benefits were investigated and analyzed. Yang and Liu concluded that the main methods to raise the economic benefits obtained from the pond fish culture techniques used by these farmers are:

- Using proper stocking patterns. Herbivorous fish should account for 60 – 78% of the total stocking weight, with filter feeders less than 15%
- Stocking at optimum weight. If the stocking weight ranges from 2,400 – 2,550 kg/ha the net production reached 12,630 kg/ha/year.
- Peak profit is reached at a yield of 12,630 kg/ha/year.
- Operating costs must be kept below 64% of crop value to obtain optimum profit margins.

Based on the above information, the relationship between per-unit stocking weight and net production can be expressed by the following binary quadric regression equations unique to each farm.

Zhangzhuang Aquafarm: $y = -395.57 + 7.95x - 1.05 \times 10^{-3}x^2$ $(P<0.01)$

Both Helei Aquafarms: $y = -6623.74 + 5.33x - 2.86 \times 10^{-4}x^2$ $(P<0.1)$

Where y is the net production (kg/ha) and x is the stocking weight (kg/ha).

Table 6.2 Stocking and harvesting of surveyed fishponds (Yang and Liu, 1994)

Zhangzhuang:	Herbivorous	Filter feeders	Omnivorous	Totals
No. 10 Stocking weight (kg/ha)	2094	133	727	2954
(0.5 ha) Net production (kg/ha)	5528	2117	9544	17189
No. 14 Stocking weight (kg/ha)	1181	307	52 + 599	1518
(0.5 ha) Net production (kg/ha)	3935	2682	2122 + 2622	11362
No. 15 Stocking weight (kg/ha)	1189	307	52 + 600	2147
(0.5 ha) Net production (kg/ha)	3384	3249	1964 + 2512	11109
No. 39 Stocking weight (kg/ha)	1068	121	152 + 380	1721
(0.4 ha) Net production (kg/ha)	3858	2039	2830 + 1478	10205
No. 33 Stocking weight (kg/ha)	1451	119	59 + 382	2011
(0.5 ha) Net production (kg/ha)	4814	2270	1688 + 1706	10478
No. 24 Stocking weight (kg/ha)	729	118	272+ 672	1791
(0.5 ha) Net production (kg/ha)	2795	2429	5423+ 2035	12682
Helei Aquafarm:				
No. 16 Stocking weight (kg/ha)	1792	1472	876 + 188	4328
(2.2 ha) Net production (kg/ha)	1807	4394	6184 + 145	12530
No. 19 Stocking weight (kg/ha)	2065	1307	1110 + 751	5233
(2.2 ha) Net production (kg/ha)	3612	3150	5961 + 567	13291

No. 13 Stocking weight (kg/ha) (2.2 ha) Net production (kg/ha)	1879 2617	1475 3348	733 + 294 3394 + 434	4381 9793
No. 25 Stocking weight (kg/ha) (2.2 ha) Net production (kg/ha)	2166 3936	1265 4291	874 + 578 3639 + 521	4883 12387
Helei Fisheries Village:				
No. 1 Stocking weight (kg/ha) (0.6 ha) Net production (kg/ha)	3062 4494	2331 3339	917 + 1145 7617 + 1683	7455 17133
No. 2 Stocking weight (kg/ha) (0.6 ha) Net production (kg/ha)	2255 3745	1699 4649	821 + 766 4747 + 1301	5541 14442

6.4 Feeds and Feeding

Feeds are normally the largest variable cost item in production of intensively cultured fish and can make up as much as 70% of operating costs. It is therefore one of the main factors influencing the viability and commercial success of the venture. The cost of feed is closely related to the cost of feed protein, the major components of all fish feeds. Traditionally, fishmeal was used as the protein source, but rising costs necessitates a search for cheaper protein alternatives.

Although some low input Chinese production systems rely solely on manure or grass input to produce fish, the proposed farming system would utilize a balanced formulated pelleted feed as main dietary input for the fish. Fresh or fermented manure and other shredded feedstuffs can be fed supplementary to the formulated feed to increase pond productivity or decrease feeding expenses. Examples of feed stuffs that can be minced, shredded or even pelleted as supplementary feed:

- Soybean
- Maize
- Grain
- Rice bran
- Sunflower seeds
- Vegetables
- Abattoir waste
- Culled chickens/day old chicks
- Restaurant/household food stuffs

When looking at foodstuffs or by-products as potential feed for fish, one should bear the following aspects in mind:

- Palatability or taste to the fish, does the fish eat or reject the feed
- The nutritional value to the fish
- Protein: % Protein in product, % Protein available to the fish, Amino acid profile of the protein available to the fish
- Energy levels: Lipids and carbohydrates
- % Edible parts: The rest is excreted and accumulates as sediment on the pond bottom. Excessive sediment is detrimental to fish production in the pond.

6.4.1 Formulated feeds

In pond culture, one can use feed of a lower quality than in a recirculation system. The earth ponds act as a natural biological buffer, breaking down uneaten feed, fish waste and other organic matter. Detritivorous fish can utilize this directly. It also acts as organic fertilizer in the pond and results in phytoplankton and subsequent zooplankton blooms that can be utilized by filter feeding fish.

Feed formulations should be guided by the nutrient requirements of the different species of fish. Omnivorous fish need a much lower percentage protein in the feed and can utilise carbohydrates as an energy source much better than piscivorous or carnivorous fish. Fish like largemouth bass need a greater percentage of protein and lipids included in the feed to achieve optimum growth and health.

The Spesfeed program is one of the purpose made software program packages for animal feed formulations available. Table 6.3 gives an example of a balanced feed formulated for C. *gariepinus* using the Spesfeed program.

Table 6.3 Formulated feed for *C. gariepinus* (Joubert, 1998)

Feed ingredients	Percentage weight
Animal protein source (fishmeal/chicken)	29.00%
Sunflower oil cake	12.30%
Soy oil cake	10.10%
Prime gluten	8.00%

Cooked Maize	33.80%
Mono-Ca PO_4	4.40%
Limestone	1.40%
Vitamins (Mineral/vitamin premix)	0.55%
Minerals	0.45%

The price of fishmeal is increasing and therefore influencing the cost of feeds. The reasons for this are mainly due to two factors: global decline in marine fish landings (Ratafia, 1985) and competition with other well-established farming practises for fishmeal (Hoffman *et al*., 1997). In addition to this, natural resources of fishmeal are under threat of over-exploitation. It is therefore beneficial to look at using fish feed that is formulated on the basis of plant proteins such as soymeal or alternative animal proteins such as bloodmeal, feathermeal or chicken meal. There is some high quality fish feeds available in South Africa, which could be used for feeding fish produced in intensive production systems for high niche markets.

6.4.2 Case study: Experimental catfish feed

An experimental feed for catfish was manufactured using low cost equipment at a s cost was R1154.00/ton (excluding equipment depreciation, labour and electricity costs) using the Spesfeed formula of Table 6.3. This low cost was accomplished by replacing the expensive fishmeal component with chicken meal. Fresh day-old chicken mortalities were collected from chicken hatcheries, minced up through 10mm holes and dried. The dried matter was then hammer-milled through 2mm holes to end up with a chicken meal.

After the dry ingredients were thoroughly mixed, 0.160 litre of water per kg dry feed was added to bind the mixture. The paste was passed through a commercial mincer with 2mm die holes and the spaghetti-shaped strings were dried and broken up into feed pellets. The feed was analysed for chemical proximate composition and amino acid composition and the results are listed in table 6.4 and table 6.5. The feed was fed to catfish in a growth trial and performed similar to feeds with fishmeal as animal protein source. Rainbow Chickens are one of the main chicken producers in South Africa, with many production farms in KwaZulu-Natal.

Table 6.4 Proximate analysis of the experimental feed	
Proximate analysis	Percentage
Protein	32.12
Lipid	11.05
Fibre	4.63
Ash	8.65
Dry matter	89.3

One of their five chicken hatcheries situated throughout South Africa is the Palala hatchery near Krugersdorp. This hatchery records an average loss of 100,000 chicks per week out of a total number of 900,000. This converts to approximately 6 tons of chickens available per week, from which approximately 20 tons of fish feed can be manufactured when using the formulation of the experimental diet. Currently a waste removal company collects and disposes of the dead chickens at great cost to the hatchery. The hatchery has indicated its willingness to provide these chickens to any party that would agree to a service contract free of charge (Kotze, 1998).

Table 6.5 Amino acid analysis of the experimental feed	
Amino-acids	Grams per 100 grams of feed
Aspartic acid	2.76
Glutamic acid	5.46
Serine	2.32
Glycine	1.94
Histidine	0.85
Arginine	2.20
Threonine	1.57
Alanine	2.08
Proline	2.25
Tyrosine	1.29
Valine	1.61
Methionine	0.81
Isoleucine	1.37
Leucine	3.10
Phenylalanine	1.79

6.4.3 Manufacturing plant

It is imperative to set up a low cost feed manufacturing plant for large-scale pond culture ventures and other extensive aquaculture applications. The lower cost feed will bring production costs down, enabling farmers to sell their products at a lower price and compete in domestic markets, or increase their profit margins.

Figure 6.3 A small feed pelleting machine

The small pelleting machine in figure 6.3 can make up to 5 tons of un-extruded feed per day. The ingredients are simply mixed and pushed under high pressure through a grid and then cut into pellets by a rotating blade. This is one of the cheapest ways of making fish feed, but the feed is of much lower quality than proper extruded feed. While the company can start with equipment such as this and purchase high quality feeds from existing manufacturers, a proper feed mill will have to be set up to reduce operating costs.

6.4.4 Amount of feed needed

The amount of formulated pelleted feed needed can be roughly estimated at between 60 and 100 ton of feed per farm per year in the proposed model. This figure is highly dependant on the feed quality, stocking densities and crop management. A good rule of thumb for calculating feeding quantities for warmwater finfish production is 1 to 3% of the biomass per day. This applies to fish past the fingerling stage and when formulated feed is the only feed input. See hatchery section in this paper for feeding guidelines with younger fish.

6.5 Water quality management

6.5.1 Dissolved oxygen (DO)

Dissolved oxygen is one of the most important variables in intensive aquaculture. During any fish's aerobic metabolism, oxygen is the final electron acceptor in the electron transport system. Prolonged exposure to low concentrations of dissolved oxygen (DO) is harmful to fish and causes changes in behaviour, blood chemistry, survival, growth rate and food intake. Hypoxia may result in necrosis, haemorrhage, hyperplasmia, hypertrophy and hyper anaemia in gills, liver, kidneys and spleen (Plumb *et al*, 1973). Fish are also more susceptible to bacterial infections during low DO conditions.

Table 6.6 Oxygen saturation levels (mg/l) for freshwater at different temperatures and elevations (Avault, 1998)

Temperature	Sea level	305m elevation
5°C	12.8 mg/l	12.3 mg/l
10°C	11.3 mg/l	10.9 mg/l
15°C	10.1 mg/l	9.7 mg/l
20°C	9.1 mg/l	8.9 mg/l
25°C	8.3 mg/l	8.1 mg/l
30°C	7.6 mg/l	-

The amount of DO water is capable of holding at saturation is heavily dependant on the temperature of the water as seen in table 6.6. As temperature increases, oxygen at saturation decreases. Warmwater species also become more active as temperature increases and their oxygen demand increases while the water capacity to hold dissolved oxygen decreases. For these reasons it is important to monitor a pond's DO levels and add additional aeration when levels drop below 5ppm. Hot, windless mornings are one of the most dangerous times concerning low DO levels because the fish are active and thus using a lot of oxygen through respiration; the pond just went through the night with the phytoplankton using oxygen and producing CO_2 instead of photosynthesising, and the lack of wind means less surface diffusion of atmospheric oxygen.

In intensive pond culture of warmwater fish, DO concentrations should be above 5mg/l for at least 16 hours of any 24 hour period and never drop below 3mg/l (McKee and Wolf, 1963). Values above 6mg/l are regarded as optimum. Super saturation of water occurs when the DO levels are higher than saturation levels for that specific temperature, salinity and atmospheric pressure. Super saturation of water with atmospheric air is dangerous and can cause gas bubble disease that are associated with the formation of small air bubbles within the capillaries that blocks blood flow and can cause ruptures and haemorrhaging. Super saturation of water using pure oxygen does not cause the disease and the fish, when using this method of aeration, can tolerate concentrations up to 150% of saturation.

In order to maintain high enough fish densities that are required to meet the production targets, additional aeration in the form of paddlewheel aerators will have to be used. In a pond without aeration, the main sources of dissolved oxygen are derived from the photosynthetic activity of the phyto-plankton and the diffusing of atmospheric oxygen through the water surface. Fish production in Chinese ponds delivers on average less than 1,500kg per hectare without aeration whilst 12,000kg to 15,000kg per hectare can be obtained with aeration.

6.5.2 Ammonia

Total ammonia, ammonia-N or total ammonia nitrogen (TAN) is the sum of ionised ammonia (NH_4^+) and un-ionised ammonia (NH_3). The toxic effect of ammonia on fish is highly dependent on the pH and water temperature. Table 6.7 shows to what degree the acutely toxic un-ionised fraction (NH_3) increases with an increase in pH and temperature. Ammonia toxicity increases with low DO levels, but decreases with an increase in free CO_2 levels.

According to Boyd (1982), ammonia damages gills, reduces the oxygen transport ability of the blood and the oxygen consumption rate of the tissues. Sub lethal concentrations of ammonia may cause histological changes in the blood, thyroid tissue and kidneys and increase susceptibility of fish to diseases. Osmoregulation, membrane stability and growth are also affected. Toxic concentrations of NH_3 vary between species and the LC50 value ranged from 0.5ppm to 3.8ppm. In the source water total ammonia should not exceed 0.2ppm, and NH_3 should not exceed 0.02ppm (Avault, 1998).

6.5.3 pH values

The pH value of water is defined as the negative logarithm of the hydrogen ion concentration on a scale of 0 – 14. Most natural waters have pH values between 6.5 and 9, with optimum fish cultivation levels of between 7 and 8. Low production occurs outside these parameters with the acid death point at 4 and the alkaline death point at 11 (Avault, 1998).

The lethal pH levels are influenced by variables such as free carbon dioxide, total hardness, sodium concentration and chloride concentration (Alabaster & Lloyd, 1980). Acid effluents may release CO_2 from bicarbonate in the water either to be directly toxic or cause the pH levels of 5-6 to become lethal. At low pH levels, the toxicity of most metals increases. Low pH values disrupt the gill epithelium, cause fish to excrete mucus on the gills, reduce their osmoregulation ability and lower the blood pH (acidosis). Exposure to high pH levels may destroy gill and skin epithelia and damage eye lens and cornea.

Table 6.7 Percentage un-ionised ammonia in aqueous solution at different pH values and temperatures (Boyd, 1990).

	16°C	18°C	20°C	22°C	24°C	26°C	28°C	30°C	32°C
7.0	0.30	0.34	0.4	0.46	0.52	0.60	0.70	0.81	0.95
7.2	0.47	0.54	0.63	0.72	0.82	0.95	1.10	1.27	1.50
7.4	0.74	0.86	0.99	1.14	1.30	1.50	1.73	2.00	2.36
7.6	1.17	1.35	1.56	1.79	2.05	2.35	2.72	3.13	3.69
7.8	1.84	2.12	2.45	2.80	3.21	3.68	4.24	4.88	5.72
8.0	2.88	3.32	3.83	4.37	4.99	5.71	6.55	7.52	8.77
8.2	4.49	5.16	5.94	6.76	7.68	8.75	10.00	11.41	13.22
8.4	6.93	7.94	9.09	10.30	11.65	13.20	14.98	16.96	19.46
8.6	10.56	12.03	13.68	15.40	17.28	19.42	21.83	24.45	27.68
8.8	15.76	17.82	20.08	22.38	24.88	27.64	30.68	33.90	37.76
9.0	22.87	25.57	28.47	31.37	34.42	37.71	41.23	44.84	49.02
9.2	31.97	35.25	38.69	42.01	45.41	48.96	52.65	56.30	60.38
9.4	42.68	46.32	50.00	53.45	56.86	60.33	63.79	67.12	70.72
9.6	54.14	57.77	61.31	64.54	67.63	70.67	73.63	76.39	79.29
9.8	65.17	68.43	71.53	74.25	76.81	79.25	81.57	83.68	85.85
10.0	74.78	77.46	79.92	82.05	84.00	85.82	87.52	89.05	90.58
10.2	82.45	84.48	86.32	87.87	89.27	90.56	91.75	92.80	93.84

6.5.4 Total hardness

Total hardness is defined as the concentrations of the divalent metal ions in water. Water is referred to as "soft" (0-75mg/l), "moderately hard" (75-150mg/l), "hard" (150-300mg/l) and "very hard" (>300mg/l). The anions of alkalinity and the cat ions of hardness are both derived from dissolved carbonate minerals and are therefore usually related. The calcium and magnesium concentrations required for fish are both present if total hardness exceeds 20mg/l (Boyd, 1982).

Total hardness plays a role in osmoregulation and the intake and toxicity of certain metals. Gill permeability decreases with an increase in water hardness, while the major cation (Ca^{+}) also causes the outside of the gill to become more positively charged, thus increasing the ability to repel positive ions (Heath, 1987).

6.5.5 Alkalinity

Alkalinity refers to the total concentration of bases in the water and is expressed as mg/l $CaCO_3$. The predominant bases in most water bodies are carbonates (CO_3^{--}) and/or bicarbonates (HCO_3^-). They are the main supply of carbon for photosynthesis and also act as the main buffering system to reduce pH fluctuations. Alkalinity is normally positively correlated with fish production, unless there is a shortage of carbon dioxide at high levels of alkalinity. Very high alkalinity may cause calcium carbonate precipitation and forming of calcareous formations on crustaceans. Optimum levels of alkalinity in fishponds are between 20mg/l ($CaCO_3$) and 175mg/l ($CaCO_3$). Alkalinity levels outside these parameters generally result in lower production potential.

6.5.6 Free carbon dioxide

CO_2 is produced through respiration by fish, plankton and aerobic bacteria. CO_2 diffuses from the fish's bloodstream through the gills into the water. Although free CO_2 itself is normally not toxic to fish, high concentrations of CO_2 in the water make it more difficult for CO_2 to diffuse out of the fish. It begins to accumulate internally and lower the blood pH. High concentrations of CO_2 in the blood also affect the ability of haemoglobin to bind with oxygen, thus raising the minimum tolerable DO levels for the fish. Levels below 20mg/l are normally tolerated without any detrimental effects. If acclimatized, fish can be grown in intensive systems with levels as high as 60mg/l if high DO levels are maintained.

6.5.7 Nitrite

Nitrite is present in water as the ion NO_2^- or free acid HNO_2. Both forms are toxic to fish, influencing oxygen transport and causing gill damage. Nitrite is formed as an intermediate product during nitrification of ammonia and during anaerobic bacterial reduction of nitrate. When there is an imbalance in the nitrification process, such as a die-off, in *Nitrobacter* colonies or a depletion of oxygen, nitrite can accumulate in the system or pond.

Nitrite reacts with haemoglobin in the fish's blood to form metahaemoglobin, reducing the oxygen carrying capacity of the blood. Blood with a high concentration metahaemoglobin turns brown and therefore, nitrite poisoning is often referred to as "blown blood disease". The toxicity of nitrite is reduced with an increase in calcium (hardness) and chloride concentrations (Boyd, 1982).

6.5.8 Sulphide

Sulphides are formed during anaerobic degradation of organic matter in sediments and are normally present in groundwater from swampy or coastal areas. Un-ionised hydrogen sulphide (H_2S) is very toxic to fish and affects reproduction, respiration and growth. The toxicity of hydrogen sulphite decreases with an increase in pH. Boyd (1982) suggested that detectable levels of H_2S (rotten egg smell) should be considered harmful to fish production. H_2S can be air stripped through a de-gassing tower or vigorous aeration.

6.5.9 Suspended solids & Turbidity

Suspended solids include organic material and organisms like phyto- and zooplankton and bacteria and inorganic material from soil like sand, silt and clay. Suspended solids affect light penetration and temperature and can cause direct physical irritation or damage to fish gills. The primary production cycle of a pond is highly dependant on light penetration for the growth of phytoplankton and subsequent oxygen production through photosynthesis. At least 10% of available sunlight should reach the bottom for effective photosynthetic production according to Avault (1998). Table 6.8 gives guidelines on how to interpret Secchi disc readings, one the most commonly used tools in pond turbidity determination.

Table 6.8 Secchi disc readings as a tool to determine pond turbidity (Avault, 1998)

Secchi disc visibility	Comments
Less than 20cm	Pond too turbid. If pond is turbid with phytoplankton, there will be problems with low D O concentrations. When turbidity is from suspended soil particles, productivity will be low
20 to 30cm	Turbidity becoming excessive
30 – 45cm	If turbidity is from phytoplankton, pond is in good condition
45 – 60cm	Phytoplankton becoming scarce
More than 60cm	Water is too clear. Inadequate productivity and danger of aquatic weed problem

6.5.10 Settled solids

Settled solids form a layer on the pond bottom, sometimes referred to as silt, sludge or pond mud. This layer plays a very important role as seed-bank for proper plankton development. It contains the bacteria and plankton cysts necessary for a healthy plankton bloom after the pond is fertilized and filled.

The pond silt can, however, also create problems in fish production if not managed right. The depth of the silt layer should be between 5cm and 15cm. Excessive silt makes harvesting fish difficult. The seine net can get stuck in the silt, especially when using a fine mesh size for smaller fish of fingerlings. The survival of fish harvested from a pond with excessive silt is also lower as a result of damage to the gill filaments and suffocation in the silt collected in the net during harvesting. Fish also tend to bury themselves in the silt layer if it is too deep, in an effort to escape when being harvested. A heavily silted pond also makes it difficult with regards to walking and working conditions.

An important factor to consider when managing the pond bottom in pond fish culture is the biological activities that take place in it and how it influences the quality, especially the dissolved oxygen concentration in the rest of the pond water. The silt forms an organic layer on the bottom that can create an oxygen deficit. This happens when aerobic bacteria decomposing the organic material use up the available oxygen in the bottom layer of the water. The process of decomposition stops when the oxygen runs out and will carry on when oxygen becomes available. An oxygen deficit at the bottom is especially dangerous when a pond turnover occurs.

A pond turnover occurs when the bottom water suddenly gets turned over to the surface of the pond. The following conditions can cause a pond turnover to occur:

- Water becomes denser as it cools down. When the surface layer's temperature drops below the bottom layer's temperature, it will sink to the bottom of the pond, displacing the bottom layer. This can happen during a heavy rainstorm or a sharp drop in ambient temperature.
- Strong winds can also cause pond turnover. The wind creates a surface current to one side of the pond and the bottom water gets drawn up from the opposite side.
- Most aerators create currents that mix the bottom and top water, causing pond turnover.
  Another danger is that during anoxic conditions, anaerobic microbial activities may produce toxic substances like nitrite during nitrification and anaerobic fermentation.

Table 6.9 consolidates the most important water quality parameters for the major warmwater aquaculture species considered for this project. This serves as a valuable guide to assist farmers in water source evaluation and during production.

Table 6.9 Water quality parameters in mg/l (ppm) for the major species considered for the project

Parameter	Optimum	Critical
Temperature	25°C - 30°C	<16°C, >34°C
Dissolved Oxygen	5 – 10mg/l	<2mg/l, >20mg/l
PH	6.5 – 9	<5, >10
Ammonia (un-ionised, NH_3)	< 0.025mg/l	>0.3mg/l
Hardness	20 – 300mg/l	
Alkalinity	20 – 170mg/l	
Carbon Dioxide	2 – 5mg/l	>60mg/l
Chlorine	< 0.003mg/l	>0.05mg/l
Nitrite	< 0.15mg/l	>5mg/l
Sulphide (H_2S)	< 0.002mg/l	>0.012mg/l
Suspended solids	25 – 80mg/l	>1,000mg/l

6.5.11 Managing off-flavour in freshwater pond fish

Freshwater fish often have an inferior taste compared to marine fish. The off flavours are mainly caused by certain organisms in ponds that are ingested and even absorbed across the culture species' gill membrane, giving the fish a muddy or musty taste. Actinomycete bacteria such as *Streptomyces tendae* and blue-green algae such as *Oscillatoria tenuis, Symploca muscorum* and *Anabaena* sp. produce metabolites called geosmin (1, 10-trans-dimethyl-trans-9-decalol) and MIB (2-methylisoborneol) that causes the off-flavour (Lorio *et al*, 1992).

Off-flavour can be detected by cooking a fish without seasoning in a microwave oven for 15 minutes and comparing it to a fish of the same species that comes from a clean pond. A rating between 0 and 7 is given to quantify the quality of the fish regarding off-flavour, where 0 is excellent and 7 is extremely poor/repulsive. A procedure of purging fish for a period of 2 to 3 days before harvesting in clean water is used to remove any off-flavour.

6.6 Harvesting

The only practical way to harvest large production ponds is to use a seine-net the fish and concentrate them near the bank or pond levee (figure 6.4). From there the fish can be moved with a crane-mounted basket net or fish-pump (figure 6.4) into the harvest truck or containers. The target amount of fish for the harvest will determine how much of the pond is harvested. The mesh-size of the seine-net can also be used as a tool to grade unwanted smaller fish from the harvested crop. It is important not to overload the basket net during harvesting of the fish is order affect the quality of the. Too many fish on top of each other will bruise each other and cause haemorrhaging as they are lifted out of the water.

Figure 6.4 Fish being harvested using a fish pump seine-nets

The method of harvesting the fish directly influences the quality of the final product. Ponds should be harvested in a manner that inflicts the minimum stress and physical damage to the fish. When fish are stressed, adrenalin is injected into the bloodstream and fish swim around frantically trying to escape the danger. This activity can deplete the available oxygen in the blood and fish will switch to anaerobic metabolism to power their muscles. One of the by-products of anaerobic metabolism is acetic acid, which starts accumulating in the muscle tissue. If the fish is killed with a high concentration of acetic acid in the muscle tissue, it will influence the muscle tissue's ability to hold water, causing the meat to be dryer and of tougher texture. During times of stress, more CO_2 is excreted in the blood, causing the pH to drop and reducing the ability of haemoglobin to bind with oxygen. When fish are crowded for too long periods of time in the seine net, ammonia levels rise and DO levels drop, causing fish to stress even more. It is therefore of critical importance to get fish out of the water and into a container filled with ice sludge as soon as possible during harvest.

In the USA most harvested catfish are transported in livehaul trucks to the processing plants. This method places the fish under even more stress after harvesting, reducing the meat quality. If species are harvested that are more oxygen sensitive, they could die in the livehaul tanks and rapidly degrade in the livehaul environment. The main reason the catfish farmers opt for this harvesting method, is to keep their operational costs as low as possible, even if it results in a lesser quality product. Channel catfish is considered a low value fish in the USA and farmers are currently getting less than US$0.75/lbs pond side. Most catfish farmers in the Mississippi delta consider the additional cost and effort of icing down the fish during harvest to achieve a higher quality product superfluous.

Figure 6.5 Harvesting shrimp from a pond into ice totes using a net attached to a backhoe.

Using the method of chill-killing fish on-site during harvesting negates these factors and also reduces the transport weight. Chill-killing fish in ice sludge directly after harvesting is a very good method to kill fish in a humane way inflicting the minimum of stress on them and start preserving the product on the way to the processing plant. A practical way is to use 1,000-litre insulated fish totes pre-filled with about 200kg ice flakes each as depicted in figure 6.6. The totes are filled with water to the 500-litre mark and left to cool down to form ice sludge. Five hundred kilograms of live fish can be dumped into each of these totes and the truck can head back to the processing facility. The fish are chill-killed and cooled down, ready to be processed within an hour of being placed into the ice sludge. Harvested fish weights can be calculated very accurately by noting the volume of water displaced in harvesting totes when fish are added to the ice-sludge.

Figure 6.6 Fish are crowded towards the pond levee using a seine net.

6.7 Processing

Fish can be processed into a wide range of products. The prevailing market will dictate where the best profit margins are to be made and in what quantities. When adding value to harvested fish, the amount of labour and percentage yield in the final product must be taken into consideration when pricing structures and profit margins are determined.

Figure 6.7 Processed tilapia yielding 32% fillets (Author)

Fresh fish can be processed as whole on ice, dressed, filleted (skin on), filleted (skin off) as in figure 6.8a or as fish mince. The product can be further processed into a product called surumi, which is flavoured, coloured and reformed into for example crabsticks. A drawback of fresh fish is its relatively short shelf life. Fish can be frozen (Figure 6.8b, c), cured by pickling or smoking, or canned to extend the shelf life. Fish can be stored for extended periods when deep-frozen. The shelf life of freshwater fish at storage temperatures of minus 18°C is about 12 months and at minus 25°C up to 18 months.

Figure 6.8 a, b, c Tilapia as fresh fillets, fresh eviscerated, and frozen whole fish

The design and management of the processing plant will depend on the market requirements, such as the level of value added, for example filleting, smoking, fishcakes, packaging, etc. It also depends to a great extend on whether products are processed for the local market or for the export market. It is a good idea to have the plant HACCP approved to have the flexibility to export product.

Figure 6.9a, b Workers cleaning and packing farm-raised fish

After harvesting, the fish are chill-killed and arrive at the plant as such. The fish is then size-sorted and either packed fresh on ice or washed for further processing. This would mostly include evisceration and filleting (Figure 6.9a, b). Further value adding like curing, smoking, mincing, forming etc can be done after the initial processing steps. The product is packed according to customer specifications and shipped.

6.7.1 Case studies

The HD Hill Catfish Farm in South Africa employed five unskilled and untrained workers from the local township to process catfish in a test trial (Figure 6.10a, b). The fish were averaging about 1kg in weight. The workers managed to behead and eviscerate about 100 fish/hour. The dress-out percentages from 50 of these catfish are listed in Table 6.10. The Tight Lines Fishery in Margate, South Africa, filleted and packed catfish in 5kg wholesale boxes at 15 fish/hour/person during a test trial. According to management at the plant, the workers could push productivity up to 30 fish/hour/person as they get used to the new species. The processing charge at the time was estimated at about R3/kg to fillet and pack the catfish (2002). This price is heavily dependant on shipment volume. At the Blue Heron Aquafarm in Florida, USA, 3 people size sort and pack Striped Bass fresh on ice at 600 to 700kg fish/hour. Figure 6.8 shows a processed 1kg tilapia with the fillet yield, off cuts and waste. The average skinless fillet yield for 1 kg tilapia at the Blue Heron farm is 32%.

Table 6.10 Dress out percentage of 50 catfish processed at the HD Hill Plant (2002)

Live weight	50.573 kg	100%
Dressed	38.34 kg	75.90%
Heads	7.63 kg	15.10%
Blood	0.252 kg	0.50%
Guts	4.29 kg	8.50%

Figure 6.10a, b Beheaded and eviscerated catfish ready for shipment (Author)

6.7.2 Processing waste

Processing waste includes water, viscera, heads, bones, scales and fins. These waste products can be utilized as ingredients in frozen or fresh pets mince, canned pet food, fishmeal or direct feed in crocodile, prawn or crab culture. If the waste products are going to be utilized, it might be a good idea to link up with other abattoirs and trawlers for waste and trash fish to increase the volume to make the effort economically viable.

6.8 Disease Prevention, Identification and Control

The most common cause for the failure of aquaculture ventures is non-realization of production targets. The main contributor to this is fish mortalities as fish are very susceptible to diseases and water quality.

Fish are exposed to a wide range of parasites and pathogens under natural conditions. These include bacteria, protozoa, flukes, viruses, fungi and nematodes. The immune system of the fish helps to protect it from these organisms and the diseases they cause. When fish are stressed, their immune system is impaired making them more susceptible to the pathogens. Stress can be as a result of environmental conditions, overcrowding, handling, water quality or the presence of pathogens. If a farmer takes care of the environment the fish lives in, the chances of the fish getting diseased are greatly reduced.

Fish normally have a physical response to stress and diseases that the farmer can pick up when he observes the fish during general management, e.g. feeding, grading, etc. A common observation is when fish concentrates at the inflow, around the aerators or at the surface of the pond du to a lack of oxygen. If the dissolved oxygen concentration of the pond is normal (above 5ppm) the fish may have trouble absorbing oxygen through the gills. The gill lamellae could be compromised as a result of parasitic or bacterial infection. Furthermore, high concentrations of CO_2 or nitrite can affect the uptake of O_2 by the blood. The cause should be identified as soon as possible because fish can suffer huge mortalities over a short time as a result of suffocation.

Other abnormal symptoms and behaviour are listless slow swimming near the surface, low appetite and slow feeding, and abnormally high excretion of mucus or slime on the body. The farmer should react immediately to any of these signs by performing a water quality analysis screening for critical parameters. If the water quality is normal, a couple of live fish showing these symptoms should be taken out and examined for the presence of pathogens. Wet mounts of skin scrapes, gill and fin clippings should be viewed under a microscope as fast as possible after the fish has been removed from the pond. The fish should be kept alive in a bucket, as most parasites will leave the fish as soon as it dies. Most parasites can readily be identified from a fresh wet mount under 100x to 400x magnification. Some bacterial infections need Gram staining or growing on selective agar mediums to be identified.

There are a couple of basic things every farmer should do to reduce the risk of diseases. Firstly, one should make sure that good quality seed stock (fry or fingerlings) are acquired. A supply of strong, healthy fingerlings of good genetic quality helps improve growth rate and survival.

Nutrition and feeds also play a major part in producing healthy fish with strong immune systems. Fish should get their essential minerals, vitamins, fatty acids and amino acids from the feed. It is important to provide a high enough protein concentration and energy source for the different species.

Water quality is one of the major factors that a farmer can control. High ammonia and low dissolved oxygen concentrations are vital stress-inducing parameters that can change rapidly in a heavily stocked pond. A sudden change in temperature will also affect fish. Most warm water fish are more susceptible to infections at lower water temperatures as their metabolism and subsequently their immune response slows down. Bad managerial practices such as over or under feeding, crowding and handling fish unnecessary, overstocking ponds, a lack of monitoring water quality parameters and health status are also contributing to fish disease outbreaks.

6.8.1 Treatments

Most chemicals used to treat fish are expensive, can cause water quality deterioration and also causes stress to the fish themselves. Inadequate treatment of fish will also not accomplish the required results, while over-treatment or treating weak fish may result in killing the fish. It is therefore wise to approach disease treatment in a cautious manner.

The first thing a farmer should do when confronted with stressed fish, bad water quality or sick fish is to stop feeding. Water replacement is sometimes a good way to calm fish down, improve water quality and reduce pathogen loads in the water. It is especially effective when there is a heavy concentration of detrimental bacteria like *Aeromonas* or *Flexibacter* in the water.

Fish can be treated with a variety of chemicals to kill or reduce external pathogens. This can be done by treating the whole pond by means of a prolonged bath method, or treating and flushing the pond by means of a short bath method, or harvesting the fish and dipping them into the concentrated treatment solution before returning them into the pond. There are some obvious logistical problems with administering the last two treatments in large ponds. Fish can also be fed medicated feed. Approved additives for consumption fish like oxytetracycline or Romet can be added to feed and fed to fish to help fight the infections systemically.

Some chemicals frequently used by fish farmers include:

- Trichlorophon
- Copper Sulphate
- Potassium Permanganate
- Formalin
- Lime
- Salt

6.9 Yields, financial forecasts and production targets

Yields from the proposed 4 ha farm model should range from 8,000 kg/hectare to 15,000 kg/hectare, depending on the survival of the crop and management experience of the individual farmers. This will supply 30 to 60 tons of fish per 4 ha farm per annum. The production figures can be achieved with the suggested model of production methodology:

- Supplemented aeration with two paddlewheel aerators per pond.

- Water exchange to maintain water quality and counter evaporation.
- Use of relatively low cost formulated pelleted feed, with supplementary feeding of agricultural by-products.

This model and parameters are based on real data from active commercial fish farms in Asia and the USA. It offers a semi-intensive approach with good yields following relative low input costs and production risks. Any of these parameters can be improved to increase yield up to 25 tons/hectare, but profitability and risk must be determined by trial before the benefits or disadvantages can be properly assessed.

If a conservative gate price of R10/kg is assumed, the farm turnover will be between R320,000/year at a production of 8 tons/hectare and R600,000/year at a production of 15 tons/hectare. Based on a provisional financial analysis, breakeven point for the farm should be at about R410,000. This analysis is based on the assumptions/parameters used in the table below, including a monthly salary of R5,000 for the farmer. At R10/kg gate-sale price, the farmer should aim to produce at least 10 tons per hectare, a very achievable target using the production methods described in this document.

Table 6.11 Estimated operational expenses

Description	Annual expenses
Feed @ R2.00/kg and 2,5:1 FCR	R200,000
Fingerlings @ R1 each and 80% survival	R 50,000
Electricity	R 15,000
Canal water costs, medication, etc	R 6,000
Equipment maintenance	R 2,500
Farmer's salary @ R5,000/month	R 60,000
Interest on loan 12% on R400,000	R 48,000
Annual capital expenses	R 27,100
Total annual expenses	R408,600

Table 6.12 Capital expenses

Description	Total cost	Depreciation	Annual expense
Land	R 80,000	20 years	R 4,000
Ponds	R 50,000	10 years	R 5,000
House	R 30,000	20 years	R 1,500
Aerators	R 80,000	5 years	R16,000
Storage container	R 2,500	5 years	R 500
Nets etc	R 500	5 years	R 100
Total	R243,000		R27,100

6.9.1 Hatchery for Fingerling Production

The availability of fingerlings for farmers to purchase and grow to marketable fish is one of the historic bottlenecks in aquaculture ventures in developing countries (Hecht, 2000; Machena & Moehl, 2001). The spawning of fish and the rearing of larvae, fry and fingerlings to a size ready for stocking into grow-out ponds is a rather complex and technically advance component of the production process. To achieve this on a reliable and consistent manner is an even more challenging task that requires highly skilled labour, experienced management and sufficient infrastructure. In order to operate the farms successfully, a dedicated fingerling-producing hatchery should be built and commissioned to supply farmers with small fish to stock into their grow-out ponds.

Figure 6.12 Catfish fingerlings produced in KwaZulu-Natal and tilapia fry being transferred into fingerling hapas (Author)

6.9.2 Broodstock

Broodstock needs to be maintained at the hatchery in specialized broodstock holding ponds. Males and females should be held in separate ponds to prevent natural spawning. Controlled spawning can be induced by a number of methods including hormone injections, presence of opposite sex fish, presence of spawning media and manipulation of water level or quality. After spawning, fish should receive prophylactic treatment for external injuries and should be released into a post-spawning pond where they can recover, recondition and overwinter for the next season. Tilapia breeders can be stocked at a 2:1 female to male ratio and spawned in hapas as shown in figure 6.13. Fertilized eggs can be washed from the females' mouths or newly hatched fry can be harvested from the hapas. The eggs and fry should be transferred to indoor systems for hatching and sex-reversal treatment.

Figure 6.13 Tilapia fry are raised in hapas

Broodstock should be conditioned for spawning by getting a premium high protein diet. Broodstock health and nutrition plays a vital role in egg and sperm quality, survival and growth in the larval phase. Similarly important is broodstock genetics, and good records should be kept to keep tract of the relation between parental lines used and quality seed produced.

6.9.3 Hatchery size and production capacity

The hatchery's design and capacity will be determined by the fingerling demand for the different species. Each farm will need approximately 50,000 to 75,000 fingerlings each year to produce 40 tons of fish per year on the 4 hectares. For 20 farms to produce 800 – 1200 tons of fish, they will need 1 million – 1.5 million fingerlings. The hatchery will then have to produce 6 million to 9 million fingerlings for 120 farms.

Figure 6.14 Fish laboratory Aquaculture Research Unit, UNIN

Existing operating large-scale hatcheries provide valuable information on how to calculate the area of ponds needed to achieve specific production capacity. The Changsu City Fish Farm in central China produces 0.25 billion fry and 15 million fingerlings per year. The farm was established in 1956 as the seed supplier for Changsu City. The hatchery belongs to the municipality, but is under family based management contracts. The hatchery has 15 breeder ponds covering an area of 3.2 hectares. Fish are spawned in 5 spawning tanks with a total volume of $400m^3$. The eggs are hatched in 16 incubators or circulators with a total volume of $160m^3$. Fingerlings are produced in 50 fingerling ponds covering 8 hectares. Water for the incubators and spawning tanks are pumped from 2 reservoirs of 120 m^3. The whole hatchery's water supply is derived from 6 pumps using 36Kw/hour electricity in total. The hatchery also has a 75Kw backup diesel generator.

The hatchery should have a hatchery building for induced spawning, egg hatching, treatments and fish sorting. The building should also house a fully equipped laboratory. Figure 6.14 shows one of the well-equipped fish research laboratories at the Aquaculture Research Unit at the University of the North, South Africa. Some basic laboratory equipment needed include:

- Stereo dissecting microscope
- Light microscope with digital camera
- Chemicals
- Dissecting kits
- Micro-scale
- Water testing kits
- Fridge & freezer

The proposed hatchery will therefore need six hectares of outside ponds to produce enough fingerlings. The pond area should be divided into:

- Three hectares of broodstock holding and conditioning ponds, made up of 18 ponds with dimensions of 50m x 30m. These will include separate ponds for males and females with back-up ponds in case of stock loss, and post-spawning ponds for recovery and over wintering. Four of these ponds will be fitted with hapas for tilapia production.
- One and a half hectares of fry ponds, made up of 22 ponds with dimensions of 20m x 33m.
- Three hectares of fingerling ponds, made up of 24 ponds with dimensions of 25m x 50m.

Figure 6.15a, b Indoor tilapia hatchery with technician monitoring hatching eggs

6.9.4 From eggs to fingerlings

After spawning, larvae are stocked into specially prepared fry ponds at 150/ m^2 to 450/ m^2, depending on the species. Figure 6.15 shows a commercial scale indoor tilapia hatchery. Three weeks later they are harvested at about 3cm length, sorted and stocked into fingerling ponds at 50/ m^2. They grow into stocking size fingerlings within 4 to 7 weeks, depending on the species, available feed and water temperature. Figure 6.12 shows 7 week old catfish fingerlings ready for stocking and 3 week old tilapia fry being transferred into hapas. The average survival rate from larvae to fingerling in a well-managed fry and fingerling ponds is about 50%. Fry ponds are normally 600m^2 (about 20m x 30m) and fingerling ponds 1350m^2 (30m x 45m). Both type ponds are 1.5 to 2.5 meters deep.

6.9.5 Nursery pond preparation

The clearing and preparation of the fingerling ponds is the same as for the fry ponds, and start with drying and repairing the pond. Remove excess silt and leave 10 – 15 cm of silt on pond bottom. The silt contains nutrients, bacteria and plankton cysts and is very important to provide a starting stock for plankton production as well as to ensure good pond fertility. The bottom can be tilled with spades or rakes and exposed to the air and sunlight for oxidation of organic substances trapped in the silt. Level the bottom and remove any weeds, stones or other obstacles that may make netting and managing the pond difficult. Damage on the dykes is normally as a result of erosion and must be repaired during this time. The water inlets and outlets can be repaired as necessary. Care must be taken to ensure the integrity of the sock filter covering the inlet pipe.

This stops the introduction of unwanted animals and predators into the pond. All the hatchery ponds must be properly predator proofed against birds, platannas (African clawed frog – *Xenopus lavea*), otters and wild fish. Supply water should be filtered through a fine mesh sock to prevent unwanted organisms or eggs to enter the ponds.

The next step, often referred to as clearing, is to apply chemicals to disinfect the pond. This is a very important step to remove any unwanted animals and predator, and to make sure that the normal plankton cycle evolves naturally after fertilization. Quicklime (CaO) must be dissolved in shallow pits dug in the pond silt and spread over the surface of the pond bottom. The pond bottom can be covered with 5 – 10 cm of water to act as catalyst for the quicklime to be effective. The lime is added at a dosage of 900 – 1125 kg/ha. When quicklime is applied to a pond with a water depth of 1m, the dosage must be doubled. Bleaching powder (Chlorine) can be used as an alternative chemical to quicklime for effective pond clearing. It is done the same way, but with a dosage of 75 – 150 kg/ha. Fill the ponds up to 70 – 80cm after two hours.

6.9.6 Fertilization, plankton growth and feeding

Zooplankton species are the main source of food for the newly stocked fry. The availability of a large quantity of the right type of zooplankton at the right time in the culture period is an important factor influencing success or failure of the fingerling crop. Regular access to feed is of paramount importance to a successful culture unit, particularly with regard to small fish because of their high metabolic rate. After 2 days of starvation, the growth rate may be reduced by 50% and the survival rate by 30%. Farmers have practiced the process of fertilizing the pond after pond clearing to initialise the complex interrelated development of the different microorganisms with great success for some time in China. The feeding sequence in which most fry utilises plankton is first rotifera (and copepoda nauplii if available), then cladocera, and then copepoda and other feeds. The natural sequence of plankton development after a pond has been cleared is similar so that the peak biomass of organisms appear in a matching sequence to the diet requirements of the developing fry.

After clearing and before stocking the pond with fry, base manure should be applied to the pond to propagate a plankton community of rotifer, nauplii, micro zooplankton, etc. The application time and quantity of base manure applied depend on the type of manure and size of the pond. After stocking, additional manure should be applied regularly to stabilize the fertility of the pond.

The pond can be fertilized with inorganic fertilizer or organic fertilizer to start the development of the microorganisms. Animal manure can be applied as a sole fertilizer at 4.5 to 6 tons/ha, evenly spread or in the corners of the pond. If green manure only is used, it is applied at 6 to 7.5 tons/ha. A combination of animal manure and green manure can be used very successfully. Fermented pig manure can be applied at 3,750 to 4,000 kg/hectare together with some green manure at 3,000 kg/hectare as organic fertilizers in the nursery pond. The green manure must be bundled and sunk in the corners of the pond. The piles of green manure should be turned once every 2 days to assist the spreading of the decomposing particles from the pile. Care should be taken as the green manure consumes a lot of oxygen during the second and third day of decomposition.

The most important factor for fry production is to have good plankton. Zooplankton proliferates quickly after manure application as seen in table 6.13. Peak populations occur in the following order: protozoa, rotifers and nauplii, micro-cladocera and the copepods. The fertilization should be planned and timed so the fish can be stocked at the beginning of the peak biomass of the rotifera-bloom. Generally, rotifera reach this peak 5 to 10 days after fertilization in cleared ponds at a temperature of 20 to 25°C. It is very important to have adequate rotifera cysts in the pond silt as this forms the base of the population. Pond stocking should be timed to ensure a sufficient supply of palatable, natural food at each growing stage of fry.

The appropriate density of rotifera after stocking is of vital importance, especially the first 3 to 5 days after stocking. Generally, the minimum rotifera density should be 5,000 to 10,000/liter of pond water, with a minimum biomass of 20mg/liter. This should be maintained for 3 to 5 days. Refer to Appendix A for quantitative determination of zooplankton.

Table 6.13 Plankton densities before and after fertilization in a 660m^2 nursery pond.

	Cladocera	Copepoda	Rotifera	Nauplii
Before fertilization	0.4/liter	0.3/liter	566/liter	4.16/liter
Two weeks after fertilization	17/liter	155.4/liter	2988/liter	204/liter

Soybean milk is added to the ponds to feed the fish directly and to act as a supplementary fertilizer to enhance plankton growth. The soybeans are first soaked in water for 7 to 8 hours at 25°C. The soybeans are then ground into milk adding 15 to 20 litres of water to every kg of soybeans. The milk must be applied immediately because it starts to precipitate and clot after 1 hour. The solids that were separated from the milk in the grinding process can be fed to common carps of over 1.5cm.

Soybeans can be fed this way at 45 to 60kg/ha daily for the first 5 days, 2 to 3 times per day. This rate must be gradually increased to 75 to 90 kg/ha daily. The quantity of large zooplankton will be almost depleted 10 days after stocking. Some fine-pelleted feed or crumbles need to be fed apart from the milk from this period onwards. For some species, the feed must be applied as an even sprinkle. For others the feed should be dropped in small piles all along the dyke, 50 cm into the pond. Herbivorous fish will require *Wolffia* and/or duckweed (Lemnea) after the fish reach 2cm. This is fed *ad lib*. A handy rule of thumb is that 8kg soybeans can produce 10 000 summer fingerlings.

6.9.7 Stocking of larvae into nursery pond

The growth and survival of the fry are closely linked to the stocking density, because stocking density has a direct effect on food supply, water space, and water quality. Stocking density can be optimised with skilful farming and careful management. The larvae of different species are normally stocked in a monoculture to eliminate the competition between species as they utilize the same feeds during the fry-rearing period. The differences between species are also still very difficult to distinguish during the larval phase.

Optimum stocking densities are 120 to 180 larvae per m^2 for fish to reach the target size of 3cm in 20 days. The variables when calculating the optimum stocking densities include rearing time, expected final size, feed supply and fertilizer, and the management experience available. Common carp can be stocked at a maximum density of 300 to 450 larvae per m^2.

Special caution must be taken when stocking fish of such a small size bearing in mind that they are still very weak and susceptible to environmental stressors. The water temperature should be above 15°C for carp species, above 18°C for largemouth bass and above 20°C for tilapia and catfish to avoid temperature induced mass mortalities. Temperature shock is another important factor to keep in mind when stocking fish. If the difference between the water in which the fish are transported and the pond water is more than 5°C, the fish need to be acclimatized by floating the transportation bag in the pond without opening it, or slowly mixing pond water with transportation water when fish are transported in a container or tank. This also helps fish adjust to physio-chemical parameters of the new water. A rule of thumb is to replace 50% of the water in 40 minutes.

Harmful organisms must be eliminated before stocking of fish. Netting is necessary when the interval between pond clearing and stocking is long. It is also important to make sure the toxicity of pond clearing chemicals vanished by submersing some fry for 2 – 3 hours in the pond and observing them for any negative effects.

6.9.8 Nursery pond management

The nursery ponds are carefully managed to maintain the fine balance between ensuring good water quality for fish growth and maintaining the optimum levels of food organisms to feed the fish. Pond filling and water exchange is done while keeping this principle in mind. Filling the pond with water weekly is important to achieve the maximum growth and survival of the fry. During stocking, the optimum water depth should be 50 cm. The pond level is gradually raised from 60 to 70 cm to 1.5 meter by filling it with fresh water to dilute the nutrients. The first filling is done 5 to 7 days after stocking, then once every 3 to 5 days, increasing the water level by 20 cm at a time. It is imperative to screen the water flowing in to prevent harmful and unwanted organisms to enter the pond.

Water is only exchanged when the farmer is confronted with very bad water quality that endangers the survival of his fish or suppresses the development of food organisms. It is important to prevent fish from escaping by screening the pump or drainage pipe.

The daily inspection of the fishponds serves as the reference base for making management decisions on feeding and water quality management for the pond. It normally consists of two inspections, one in the morning and one in the afternoon. Water quality and growth of the fish are observed. The behaviour of the fish can also provide critical information about the status of the pond concerning water quality, dissolved oxygen and feed availability.

The fish will surface at periods of low dissolved oxygen level, and lasting periods of surfacing will indicate a dangerously low dissolved oxygen level in the pond. The fish will hang at the surface, gasping for air. Reducing fertilization and feeding, adding fresh water or applying emergency aeration can raise the dissolved oxygen level. Fry swimming in schools parallel to the dyke in search for food is called 'Horse running.' This behaviour indicates that there is insufficient food available for the fry and they are thus spending a lot of energy in the search for food. Feeding and fertilizing rates can be adjusted to remedy the problem.

Harmful organisms, like insects, snakes and frogs must also be removed during these inspections. Frog eggs should be removed before they sink and hatch, as the tadpoles will compete for food and oxygen with the fry.

6.9.9 Conditioning and harvesting of fry

When the fry are reared into summer fingerlings, they must be transferred into fingerling ponds for further rearing. Before this, the fish should be conditioned so that they are strong enough to tolerate the transferring operation. The fry should be about 25 to 30 mm in length after the nursing period. They have small tender bodies with high water content. Since fry are not used to stress, they will excrete a lot of waste and mucus during the post capture period. The waste and mucus would foul the water and reduce the quality fast if they were packed and transported straight after capture, which would ultimately result in a lower survival rate. To counter this phenomenon, the fry can be trained or conditioned to reduce the effect of harvest-induced stress. In principle, holding the fry under stressed conditions by crowding them, while maintaining a good water quality, will increase the tolerance of the fish against stress. When the fish are eventually transported, they excrete less mucus and waste and the survival rate is therefore much higher. The water content of the fish is also reduced and their bodies become stronger and tougher.

The fish are netted slowly and carefully, and then transferred into a 2m x 3m cage or hapa. It is important to let the fish swim into the cage, as the fish are still too small to lift them out of the water using a scoop net. The cage is pushed around slowly in the pond for an hour to supply fresh water continuously. The fish are then released into the pond again. The principle of this conditioning is to crowd the fish while maintaining good water quality.

The second conditioning is done the same way, but the cage is left in one place. The fish are left in there for 3 – 4 hours and then released back into the pond. The principle is to crowd them and so introduce additional stress of reduced water quality.

If the fish are earmarked for long distance travel and have to be strong enough to survive for extended periods of time in the transportation bags, they are conditioned a third time. The fish are netted and transferred into the cage like the first two times and left overnight in the cage. It is important to observe them throughout the period and to select a fine day with good weather conditions. The fish should be transferred into the cage at 9 or 10 in the morning, when oxygen levels have risen from the night before. It is also important to make sure that no mud is transferred with the fish, as this will add to the oxygen consumption in the cage and can also damage the sensitive gill filaments of the fish.

The first conditioning is done 3 to 4 days before transportation and the following conditionings every day thereafter until final harvest.

6.9.10 Counting and measuring the harvested fry

The fry can be counted when they are in the cage by crowding them in a portion of the net and scooping a small container full of fish. The fish per scoop are counted and multiplied with the number of scoops to remove all the fish from the cage, to calculate the total quantity of harvested fish. Some of the summer fingerlings must be kept during the counting process to calculate the average size and weight of the crop.

6.9.11 Grading

Some species, like catfish and bass, need to be graded on a weekly basis during the fry and fingerling-rearing phase to reduce cannibalism and promote uniform growth. This is done by concentrating the fish in an area of the pond with a very fine seine net, scooping them with buckets and carefully pouring them through floating graders. The fish that are small enough pass through the graders back into the pond, while bigger fish and 'shooters' are left behind. These larger fish can be placed in floating hapas and combined with similar sized fingerlings.

As an experiment a 20m x 33m nursery pond was prepared as suggested above and 100,000 carp larvae were stocked into the pond. They were grown out for 18 days, harvested and counted before being transferred to fingerling ponds. Water temperature at fertilization was 20ºC, at stocking 23ºC and at harvesting 26ºC. The harvested fry had an average length of 3.425 mm and average weight of 0.565 gram. The total survival rate from larvae to fry was 66%.

6.9.12 High value species as secondary hatchery crop

The hatchery capacity can also be used to produce high value aquatic species after the fingerling production requirements for the season have been met. This will ensure that full use are made of the available infrastructure and staff capacity. Ornamental species like goldfish, koi and livebearers like swordtails, mollies and platies are good candidates for production in the off-season. Other high value species can be spawned for farmers that want to grow them parallel to their normal fish crops. These include freshwater prawns and crayfish, turtles and frogs. The hatcheries live-haul truck can also be used to bring in glass eels for growing out in the farms.

6.10 Conclusion

South Africa is in need of economic development and employment in rural areas. Sustainable commercial fish farming can provide opportunities for black economic empowerment and help alleviate the pressing food security challenges in Southern Africa. The Kwazulu-Natal region in

South Africa with its adequate rainfall, available land, sub-tropical climate and human resources provides a suitable opportunity for the development of a commercial fish-farming sector.

The proposed project differs from other aquaculture development projects in a number of ways. The average fishponds in Africa range from 0.01 to 0.03 hectares in size and 1m to 1.5m in depth in comparison to this project that is based on Chinese farming principles, for fish production ponds of0.5 to 1 hectare in size and 2.5m to 3m deep is recommended. Instead on relying on animal manure and farm by-products as sole source of feed, this proposal is based on the use of a balanced, formulated pelleted feed as an additional input.

The project will have to be implemented on a large enough scale in order to be profitable, and should integrate the different components from hatchery, grow-out, processing and marketing. Successful marketing and product development will play a very important role in the success of the project. The establishment of realistic expectations amongst the participating farmers, investors and supporting institutions will also play an important part in the successful implementation of the proposed project.

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Appendix A: Quantitative determination of zooplankton in nursery ponds

Counting of large zooplankton (*Cladocera* and *Copepoda)*

Large zooplankton refers to Cladocera and Copepoda. After the plankton died in the 4% formalin fixating solution it sinks to the bottom of the glass bottle and can be observed as a thin layer of sediment. The total number of large zooplankton in the water sample must be counted. To reduce the amount of counts per sample, the water volume is reduced by carefully removing the top layer of plankton-free water with a dropper, until only about 10ml is left. Care must be taken not to disturb and re-suspend the sediment.

The sample is counted using a counting chamber with a volume of 1ml. Place the counting chamber under a microscope and covers it partially with a cover glass. Use a quantitative dropper to remove approximately 1ml at a time from the sediment left in the bottle and place it in the counting chamber. Slide the cover glass over the counting chamber and count the large zooplankton present under a microscope at low to medium power. Care must be taken to count the plankton in the fields systematically by moving the platform, starting at one corner of the slide and not overlapping fields. The quantities of Cladocera and Copepods must be noted on the data capture sheets. This quantity is the total large zooplankton per 10 litres of nursery pond water. Total large zooplankton population densities for the pond can be calculated from this data.

Sampling of water:

Collect 10 litres of water sample from selected sampling points (5 points) around the pond. Filter the entire water sample through plankton netting (size 25). Transfer the filtrate of the water sample to a sampling bottle of 50-100 ml volume. Wash the plankton with a little water to rinse off all plankton and collect this washing water in a bottle. Fix the water sample with formalin at the concentration of 4 %.

Counting:

Fill the zooplankton counting chamber with the water sample. Count the number of *Cladocera* and *Copepoda* in the whole chamber under microscope with magnifying power of 10, and record the numbers separately. Wash away the counted sample and fill the chamber with new sample, then repeat the counting step. Repeat until the entire sample in the bottle is used up.

Note: During the counting, no water sample should be wasted.

Calculation:

Add the numbers of *Cladocera* and *Copepoda* of each counting together respectively, then divide the results by 10, this is the number of *Cladocera* and *Copepoda* in one litre of water respectively.

Counting of small zooplankton (rotifera and nauplii of *Copepoda)*

The water sample for the quantitative analysis of the small zooplankton (Rotifera and Copepoda nauplii) present in the fry-nursing pond is fixed with 4% formalin and poured into a glass funnel with a drainage valve at the bottom. The clear top layer of the water is carefully siphoned out using a length of flexible tubing until the water level is below the holding ring. Care must be taken not to disturb and re-suspend the settled plankton. The content is then drained into a measuring cylinder via the bottom valve. The glass funnel is washed and the water is collected again in the measuring cylinder. The condensed sample in the measuring cylinder must then be made up to a fixed volume (30ml or 40ml or 50ml) with distilled water. The content is mixed thoroughly to achieve a homogenous solution. Exactly 1 ml of this solution is inserted into the above-mentioned counting chamber. The small zooplankton is counted in the same way as the large zooplankton and noted in the appropriate data capture sheets. But the whole sample is not counted, only 2 – 3 ml of the solution is counted and that should be representative of the whole sample if the differences between counts are less that 15%. The fixed volume is important to note, as the average count will be multiplied with that volume to calculate the total densities of the small zooplankton present in 10 litres of water in the nursery pond.

Water sampling:

Decide the number and position of sampling points according to the size of water body (5 points in fish pond). Collect 1 litre of water sample at each point with water sampler, and then mix all the water samples thoroughly. Take 1 litre mixed water sample and fix it with formalin at the concentration of 4 %.

Precipitation:

Transfer the fixed sample to a 1-liter separating funnel and let it precipitate/settle for 12-24 hrs. Siphon off the supernatant liquid carefully without disturbing the sediment. Transfer the sediment to a graduated bottle or cylinder and wash the funnel with little water and collect the water into the bottle. Fix the volume of the sediment to exactly 30 or 50 ml through adding distilled water slowly.

Counting:

Take exactly 1 ml condensed sample with a quantitative dropper (shake the bottle before taking sample to homogenize the solution) and fill the zooplankton counting chamber carefully and cover the chamber with cover glass. Counting all the rotifer and nauplii of *Copepoda* in the chamber carefully and record it respectively. Wash away the counted sample, then repeat first 2 steps once. The difference between the counting should be less than 15 %, other wise it should be repeated.

<u>Calculations</u>:

Get the average (n) of the results from the 2 countings. Calculate the density of (N) of rotifer and nauplii of *Copepoda* in the water as:

$$N\ (ind./l) = (v * n)/(V * c)$$

with

v = Volume of condensed sample (ml)

n = average number of the counting

V = volume of water sample fixed (litre)

c = volume of the sample of each counting (ml)