A Manual for Tilapia Business Management

Ram C. Bhujel

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To all the trainee participants and students who travelled or will travel thousands of miles from all over the world in search of the knowledge and appropriate skills needed not only for their tilapia businesses but also to join the global team serving the mission of human food security.

To all audiences who patiently listened and will listen to the seminars associated with the topics in this book, which have been presented dozens of times in dozens of places around the world.

To my mother, wife and children, who did not get to spend adequate time with me during the writing of this book but who encouraged me and allowed me to work continuously during the day and even into the night.

To all colleagues who have helped and accompanied me during many difficult times, and to those who will do the same in the future.

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CABI is a trading name of CAB International

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A catalogue record for this book is available from the British Library, London, UK.

Library of Congress Cataloging-in-Publication Data

Bhujel, Ram C.
A manual for tilapia business management / Ram C. Bhujel.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-78064-136-2 (alk. paper)
1. Tilapia. 2. Fish hatcheries. 3. Fish culture. I. Title.

SH167.T54B48 2014
639.3'11--dc23
2013040395

ISBN-13: 978 1 78064 136 2

Commissioning editor: Julia Killick
Editorial assistant: Alexandra Lainsbury
Production editor: Laura Tsitlidze

Typeset by SPi, Pondicherry, India.
Printed and bound in the UK by CPI Group (UK) Ltd, Croydon, CR0 4YY.

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Preface

Fish is the staple food of over a billion people out of the total world population of 7 billion. This figure is expected to reach 9 billion by 2050, and more food will be needed to feed this increasing population. It has been estimated that approximately 40% more protein will be needed by 2050 to feed the additional population. The demand for fish is increasing even more rapidly in fast-growing economies such as Brazil, China and India because of the rise of middle-class families with higher income levels and the awareness of health benefits of fish consumption. However, globally, fish supplies less than 10% of the total protein as compared to approximately 40% by other animals including milk. Therefore, there is the potential to increase its share of animal protein in the human diet because fish is more efficient, as indicated by the average feed conversion ratio (FCR), whereby it is possible to achieve a value close to 1 or even lower if cultured using a green water system, as compared to most terrestrial animals such as chicken (2), pigs (3–4) and cattle (5–8).

Seafood is the collective term for all kinds of fish and aquatic animals from the sea as well as from fresh water, and is considered the best source of protein because it is more digestible, and has a better profile of essential amino acids, higher levels of unsaturated fatty acids and minerals but lower levels of saturated fats and cholesterols as compared to red and white meat. More people are becoming aware of these health benefits and demanding more fish to be included as part of their regular diet. Fish is cheaper than other animal proteins such as beef, mutton, pork and chicken in many parts of the world. However, fish and aquatic animals are still caught from the sea and inland waters in large amounts. Rapidly growing populations, increasing incomes and enhanced knowledge about human health associated with food have increased the demand for seafood. The high risk of transmission of infectious zoonotic diseases from terrestrial animals such as mad cow disease, bird flu, swine flu and several others has also driven a large population to shift from other meats to consuming fish, which carries considerably lower risks.

Total global fish production has reached over 156.2 million t, with a total value of over US$217.5 billion in 2011. Fish has been the most widely traded food item by developing countries, almost doubling every 10 years since 1989. Total fish exports exceeded $125 billion in 2011. It has created employment for over 50 million people in the world.

Due to the high demand for fish, the market is forced to either catch more wild fish or farm more in ponds, cages, tanks and so on. Catching more fish is a cause for concern because wild stocks are declining. Therefore, the focus on farmed fish like tilapia is increasing rapidly. Farming of fish is tradition in Asia and many other countries. Eight of the top ten aquaculture producing countries in the world are in Asia, where about 85% of global farmed fish is produced. Average per capita annual fish consumption in Asia is 20.7 kg, higher than the world average, which is 18.7 kg. About 90% of the total trade value of aquaculture products comes from Asia. Total world aquaculture production has reached 66.5 million t/year and the total value of farmed fish is over $130 billion. A large proportion of aquatic products are still consumed by farm families or sold in domestic markets in Asia, which may not be accounted for.

China has given a high priority to aquaculture and has always been the top producer of fish, followed by India. The other top Asian countries in aquaculture are Vietnam, Indonesia, Bangladesh, Thailand, Myanmar and the Philippines. China and India are well known for carp, while Vietnam is famous for pangasius culture, valued at about $2 billion per year. Similarly, Thailand tops the shrimp export market and earns $2–3 billion annually. Bangladesh also exports shrimp and prawns worth around $0.5 billion.

Among rural communities, protein malnutrition is rampant as meat products are too expensive to include in the regular diet. Protein intake from animal sources is very low, when it should be at least one-third for good human health (AIT, 1994). These facts clearly show that most countries are in need of concerted efforts to promote aquaculture. Aquaculture has a great potential to mitigate the problems of protein malnutrition, micronutrient deficiencies, and unemployment.

The popularity of tilapia has increased remarkably, and its production has doubled in each of the last three decades. Tilapia overtook salmon in terms of production volume in 2005 and became the second species group after carp. Its farming is booming worldwide, which has been realized by many organizations and individuals. The same trend or an even faster increment in production needs to be maintained in order to meet the demand. Many have tried culturing tilapia on a 'trial and error' basis and many have either failed completely or are not achieving the desired results. With a view to supporting the industry, a lot of research has been done, often creating confusion among farmers, farm managers and investors who want a straightforward description of the practices and methods so that they can apply and produce fry and table fish as per the target to fulfil the current and expected demand in the near future. Information on the technical aspects of farming methods is fragmented and there was no single manual to cover all aspects of tilapia farming. Therefore, this book has been written based on the practical experiences gained during the last 15 years of postgraduate teaching, research, training and consultancy services, and will hopefully serve as a practical guide, especially for field-level activities including financial analysis for each of the case studies. Information and inputs provided by hundreds of individuals, especially participants in training who came from all over the world, have been incorporated as far as possible and wherever relevant.

Moving from a traditional subsistence practie, aquaculture – including tilapia farming – is progressing well, becoming a business that offers several options. As in any farming, seed production has been the most profitable business and therefore easy to take up by the private sector. The same applies to the tilapia industry as well. This manual is a compilation of farmers' practices used for training purpose. The training programme popularly known as 'How to Produce Millions of High Quality Monosex Tilapia Fry and Table Fish' has emphasized the generation of millions of dollars from tilapia farming. A simple calculation shows that sales of 100 million monosex fry per year and 1000 t of table fish can generate over $1 million and has been achieved by many farmers. This requires only 20 ha of land for a hatchery business, 50 ha of ponds for grow-out farming and about 120 tilapia cages of 50 m^3 each.

The ultimate goal is to achieve food security, create employment and generate income. This book is an attempt to help develop the tilapia industry while keeping those goals in mind. This manual has been written to cover all aspects of tilapia farming as a business. Starting from the importance of tilapia culture, it covers detailed methods of a proven hatchery technology that has ensured production and supply of millions of high-quality monosex tilapia fry, accelerating the growth of the tilapia industry globally. In addition, it describes how to successfully grow tilapia in ponds and cages, and in polyculture and integrated farming systems. The manual also covers some biosecurity and fish health management aspects and also post-harvest handling, food safety, quality control and marketing.

Hopefully, this manual will be useful to farmers, farm managers, extension workers, policy makers, researchers, educators, consultants and students (undergraduate and postgraduate).

Ram C. Bhujel
August 2013

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Abbreviations/Acronyms

AIT	Asian Institute of Technology
ASA	American Soybean Association
ASC	Aquaculture Stewardship Council
BAP	Best Aquaculture Practices
BCWD	bacterial cold water disease
BMP	Best Management Practices
CCP	critical control point
CLB	*Cytophaga*-like bacteria
cm	centimetre(s)
CoC	code of conduct
CP	crude protein
CSR	corporate social responsibility
DAP	diammonium phosphate
DE	digestible energy
DO	dissolved oxygen
EIA	environmental impact assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCR	feed conversion ratio
g	gram(s)
GAA	Global Aquaculture Alliance
GAP	Good Aquaculture Practice
GHP	Good Hygienic Practices
GIFT	genetically improved farmed tilapia
GMO	genetically modified organism
GMP	Good Management Practice (Chapter 8); Good Manufacturing Practice (Chapter 9)
h	hour(s)
ha	hectare(s)
HACCP	Hazard Analysis and Critical Control Point
hp	horsepower

ICLARM	International Center for Living Aquatic Resources Management (now WorldFish)
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
kg	kilogram(s)
l	litre(s)
LVHD	low volume high density
m	metre(s)
mg	milligram(s)
MIB	2-methylisoborneol
min	minute(s)
ml	millilitre(s)
MT	methyltestosterone
ODA	Overseas Development Administration (now UK Department for International Development)
PDA/CRSP	Pond Dynamics and Aquaculture/Collaborative Research Support Program
ppm	parts per million
ppt	parts per thousand
QA	quality assurance
QC	quality control
QIM	Quality Index Method
QM	quality management
s	second(s)
SIDA	Swedish International Development Cooperation Administration
SRT	sex-reversed tilapia
SSOP	Sanitation Standard Operating Procedures
t	tonne(s)
TQM	total quality management
TSP	triple superphosphate
USAID	US Agency for International Development
UV	ultraviolet

Introduction

1

1.1 Tilapia Culture

While tilapia has been cultured since the early 1950s, it has become increasingly popular recently and is currently second only to carp in terms of total world production. For this reason it is often referred to as 'aquatic chicken' or the 'poor man's fish'. Tilapia farming has now spread across a wide range of culture systems – from small ditches to large ponds and reservoirs, in fresh and seawater, from peri-urban to rural areas. Tilapia plays a significant role in food security because it is consumed by the poor, especially those residing in rural areas, as well as by the inhabitants of urban areas, who buy their foods from supermarkets. Tilapia has therefore become 'everyone's fish'. It now directly or indirectly contributes to the livelihood of these people by supplying cheap animal protein, providing employment and generating income.

Although tilapia are originally from Africa, they have now been accepted in most countries of Asia and Latin America. Nile tilapia (*Oreochromis niloticus*) became a focus species although there are over 200 species available for culture in different parts of the world. There were several underlying reasons for this. In Thailand, Nile tilapia has a special history. It was first introduced to the Royal Palace in 1965 as a gift presented by the Japanese Emperor. After successful breeding in 1966 without the need for hormone injection required in other species, HM the King kindly granted 10,000 fingerlings to the Department of Fisheries, which distributed the fish to 15 inland fisheries research stations, and since 1967, common people have been receiving tilapia from them (Pullin, 1988; Bhujel and Stewart, 2007). Many Thais consider tilapia to be a precious fish, probably because it is thought to be the King's fish. Once the fish were obtained, the ease of breeding and culture were quickly realized, and improved and low-cost culture techniques began to be developed through research.

Commercial tilapia farming has taken off due mainly to mass-scale monosex seed production techniques using hormones that have been developed and successfully tested on a commercial scale. Some hatcheries in Thailand can supply over 30 million high-quality fry per month (Bhujel, 2011). Five large hatcheries in Thailand produce over 1 billion fry annually. Technology has been transferred to many Asian and African countries, including Nepal. In Thailand, around 250,000 farmers grow tilapia, mostly using green water ponds of varying sizes, from small backyard ponds to ones that are 10 ha or larger. Apart from some intensive farms, tilapia in ponds are fed with low-protein commercial pellets (20–27% crude protein, CP) or just a mixture of rice bran and oilcakes, restaurant wastes, maize meal or leftover ingredients from poultry feed mills in order to save feed costs (Bhujel, 2010). Productivity ranges from 2–10 t/crop of 8–10 months. Cage culture, on the other hand, requires feeding (5–6% biomass per day) of good-quality floating pellets containing around 30% CP. Cage culture of tilapia in rivers and lakes has been a new development over the last decade. About 3% of tilapia farmers are involved but they contribute up to one-third of total tilapia production (Belton *et al.*, 2009). Most farmers use 5 m × 5 m × 2 m or 6 m × 3 m × 3 m cages stocking 1500–2000 fish, i.e. 30–40 fish/m^3. They stock fish of 30–50 g in size and harvest about 1 t of fish per cage, i.e. 20 kg/m^3 of 0.6–1 kg size. The American Soybean Association (ASA) and its associated organizations have promoted low volume high density (LVHD) cages in various parts of the world, including China, in which up to 300 fish of 50 g size are stocked per cubic metre, to produce 500 g fish in about 4 months (Zhou *et al.*, 2012).

In Bangladesh neither pond culture nor cage culture of tilapia existed before 2000. One of the government officials trained at the Asian Institute of Technology (AIT) established a tilapia hatchery at the government station and later transferred the technology to the private sector, as a result of which the production of millions of monosex fry was made possible. Cage culture of tilapia became popular in rivers in Chandpur and Lakhipur, where over 4000 farmers culture tilapia, mostly landless people supported by various organizations. Most cages are 6 m × 3 m × 1.5 m and stock 20 g fingerlings at 37–40 fish/m^3; they harvest at about 400 g size but several times. They feed floating pellets, the feed conversion ratio (FCR) of which is about 1.75 and productivity is 350 kg per cage, i.e. 13 kg/m^3 (Baqui and Bhujel, 2011). Profitability is about US$200 per cage per 6 months. Tilapia is a booming industry (Bhujel, 2009) and people say: ‘If you want to be a millionaire, invest in tilapia.’ There are now several hundred private and public hatcheries and many companies such as poultry hatcheries, feed companies, etc. are investing in tilapia hatcheries. Within a decade, annual tilapia production in Bangladesh reached over 100,000 million t, starting from almost zero.

In Vietnam, there are many cage farmers along the Mekong River. One of the largest farms has 100 cages of 16 m × 8 m × 4 m = 512 m^3. Stocking density is up to 100 fish/m^3 and production up to 20 t/cage, i.e. a productivity of 39 kg/m^3 of cage volume. Similarly, tilapia farming is expanding rapidly in other countries in Asia, e.g. Cambodia, Laos, Indonesia, Malaysia and the Philippines. The People's Republic of China (PRC) produces the greatest amount of tilapia, i.e. 40% of the global total. However, fry are produced mainly by a hybridization technique, which results in a skewed sex ratio, i.e. 60% or higher of males. Very few mass-scale seed-producing hatcheries using hormonal sex reversal techniques are in operation. As the Chinese economy is booming, the population of middle-class families is rapidly rising and demand for seafood is also significantly increasing. Current tilapia exports from China may stop at any time and, furthermore, China may need to import more fish to feed her people. The role of tilapia has been crucial and will become more prominent as it plays a key part in food security. However fish culture, including tilapia farming, is heavily constrained by the limited availability of seed and so the establishment of mass-scale fry production hatcheries will be very important.

The difficulties involved in producing fry on a mass scale are due mainly to the fact that tilapia produce only a few eggs at a time. Although it breeds readily, large-scale production of seed is hampered by the asynchronous spawning that occurs among the females within the population, even in the same age group. As females normally spawn once a month, management of seed production completely differs from that of other fish species. Seed of tilapia can be produced using a variety of methods. However, low-cost seed production systems are very important for the average subsistence farmer in developing countries, especially where people have limited resources and where poverty alleviation is of major concern.

This manual has been written based on extensive work experience with farm managers, researchers, and practitioners throughout the world being based at the AIT near Bangkok, Thailand. It describes simple and low-cost methods of seed production and grow-out culture that are therefore applicable in rural, resource-poor areas of developing countries. Much attention has been paid to mass fry production through sex reversal technology because it is expanding rapidly in Asia and other parts of the world. Technical support to hatchery operators serving public or private institutions plays an important role in making high-quality seed available whenever farmers need it. Establishing a good hatchery means helping thousands of farmers by supplying high-quality seed.

1.2 The Importance of Tilapia

In the developing world, simple and low-cost techniques are those that have high adoption and success rates. As tilapia survive well in adverse environmental conditions, it became the species of interest among common people, known as 'poor man's fish'. Rich farmers grow shrimp, catfish and snakehead. However tilapia started to attract even richer farmers as an alternative when shrimp farming was devastated by disease. Since then, tilapia has been viewed as a potential species to become 'aquatic chicken', which can be grown and bred in culture systems ranging from backyard to intensively managed tanks and ponds (Little, 1989). Various on-station and on-farm research has shown that tilapia can rely on plankton as feed, which can be produced simply by fertilizing or manuring of ponds by adding readily available chemical fertilizers used for rice, e.g. urea, triple superphosphate, and manures available to farmers in their animal barns. Farmers can also add rice bran, oilcakes, etc. as fish feed to increase productivity, which are produced on their farms as by-products. As a result, not only in Thailand, but also in other countries in the region, e.g. China, Laos, the Philippines, Vietnam, Taiwan, Malaysia and Indonesia, tilapia has gained in popularity and people no longer treat it as exotic, but cherish it as a very important species. The importance of tilapia can be summarized as:

- They breed spontaneously in the culture systems, so farmers have no need to inject any hormone for breeding, unlike with carp, catfish and other species.
- Fry can also be produced as by-products, so farmers do not need to buy and transport fry from elsewhere, and they can also earn income by selling fry in addition to table fish.
- Tilapia have high growth and survival rates that produce a quick turnover.
- They can be grown with little input or investment and so are suitable for resource-poor farmers in rural areas.
- They consume a variety of natural foods, e.g. algae, detritus and farm by-products such as rice bran, oilcakes, vegetable leaves and fruit peel. This means farmers normally do not need to buy commercial feed from outside.
- Their muscles are white with no intramuscular bones, so are considered as ‘boneless meat’.
- Their meat has a good taste and pleasant flavour that is liked by many people.
- They are hardy and highly resistant to diseases, which means lower risks for growers.
- They tolerate poor water quality, e.g. low dissolved oxygen (DO), high ammonia, high temperature, and have the ability to grow and breed in a wide range of environments – fresh or brackish waters in small ditches, rice fields, ponds, cages, tanks or raceways.
- They are suitable for both mono- and polycultures with many other species, e.g. carp, catfish, prawns and others.
- Intensification is also possible and so richer farmers are now also attracted by tilapia; their culture at high density in tanks, cages and raceways can produce more fish in a short period.
- They are still cheap and affordable for poorer people.
- They can be cultured in a wide range of climatic and relatively adverse conditions.
- They are well established in international markets and have good potential to export fry and frozen meat, if farmers can produce large volumes while maintaining high quality.

- They have good potential for all sorts of commercial businesses, from small subsistence to large corporate farming.
- Tilapia skin has been used to make leather goods such as jackets, bikinis, shoes, handbags, sofas, etc.
- Tilapia fin soup is replacing shark's fin soup in, for example, Taiwan.
- Nutritional data show that 100 g tilapia meat contains almost the same amount of protein and calories compared to high-value fish: 19 g protein (19%), 94 calories, low fat (i.e. 2 g, but no saturated fats), zero carbohydrate. It also contains other nutrients such as niacin, vitamin B12, potassium, selenium and phosphorus.

1.3 Production of Tilapia

Annual tilapia production has been increasing two- or threefold every decade since 1990 (Fig. 1.1). Surpassing the production of salmonids in 2005, tilapia became the second most important species in terms of production volume only after carp, with annual production reaching over 3.5 million t in 2011 and 3.7 million t in 2012. It is expected to reach close to 4 million t in 2013. China remains the top producer, with over 1 million t; however other countries such as Egypt and Indonesia have shown tremendous growth. Starting only in the mid-1990s Egypt has increased production rapidly, and Indonesia is following a similar trend. Thailand and the Philippines have a steadily growing tilapia industry. More recently, Brazil has shown rapid growth and Bangladesh is also rapidly increasing

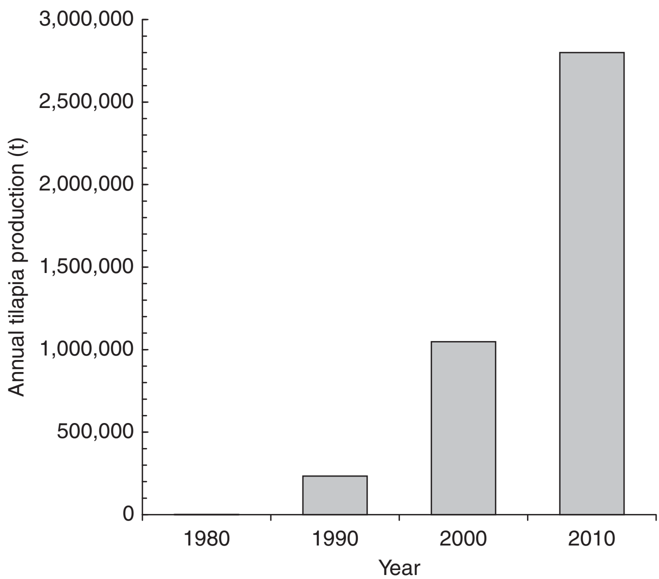


Fig. 1.1. Annual global tilapia production more than doubled each decade.

tilapia production, which has been consumed by the domestic market with no exports as yet.

Tilapia is mostly grown in tropical and subtropical areas, but its white meat with its mild flavour and taste is liked by the Western world and so it is a widely exported species. The USA has been the top importer of tilapia, with European countries just starting to import. Among the countries exporting tilapia, China supplies more than 80% of total tilapia products. Meanwhile other countries are facing price competition and are trying hard to offer value added and high-quality products.

1.4 Feeding Behaviour

Tilapia feed on a low trophic level and are somewhere between herbivore and omnivore in terms of feeding behaviour. They consume a wide variety of natural food organisms including phyto- and zooplankton, algae, some aquatic macrophytes, benthic invertebrates, other fish larvae, detritus, and decomposing organic matter. Tilapia are often considered filter feeders because they can efficiently harvest plankton from the water. They effectively browse on live benthic invertebrates and bacteria-laden detritus. However, tilapia do not disturb the pond bottom as common carp do. Tilapia are not piscivorous though fry and fingerlings may consume larvae of other fish. Tilapia also feed on invertebrates in the water column. Natural food may account for 30–50% of tilapia growth even when they receive heavy supplemental feeding. The nutritional value of the natural food supply in ponds is important, even when fish are cultured intensively, especially in outdoor systems. Dietary nutrient requirements are presented in Tables 1.1 and 1.2 (Bhujel, 2001, 2002).

Table 1.1. Dietary protein, carbohydrate and lipid requirements of tilapia.

Essential nutrients	Stage	Dietary requirements
Crude protein	Fry	45–60%
	Fingerlings	35–40%
	Grow-out	25–35%
	Broodfish	25–35%
Carbohydrate	Fry/fingerlings	<25%
	Grow-out	25–30%
	Broodfish	Not yet known
Protein:energy ratio	Fry/fingerlings	120/110 mg/kg
	Grow-out	103 mg/kg
	Broodfish	Not yet known
Lipids: Total	Fry	5–8%
	Adult	8–10%
ω-6 EFA	All stages	0.5–1.0%
ω-3 EFA	All stages	0.5–1.0%

Table 1.2. Optimum levels of vitamins and minerals for tilapia.

Essential vitamins	Dietary requirements	Minerals	Dietary requirements
A	2000–5000 IU	Ca	0.3–0.7%
B1	2–60 mg/kg	P	0.5–1.0%
B2	5–60 mg/kg	I	0.6–1.1 mg/kg
B6	2–20 mg/kg	Mg	0.5–0.8 g/kg
C	50–1250 mg/kg	Zn	20–30 mg/kg
D	375 IU	Fe	<17.05 mg/kg
E	100–500 IU or	Cu	<1.27 mg/kg
	50–100 mg/kg	Cr	2 mg/kg

Tilapia digest animal as well as plant protein efficiently. Protein requirements for their growth mainly depend on the quality of protein in the feed and size of the fish. The level of CP in the diet may be 40% or even higher for the younger stages, e.g. fry and fingerlings. However, in commercial food fish production in ponds the CP of feeds is usually 25–28% (Bhujel, 2000, 2001, 2002). The protein content and proportion of animal protein have to be higher if fish are cultured in clear water in recirculating and flow-through tank systems, and may range from 30 to 35%. Tilapia require the same ten essential amino acids as other warm water fish, and as far as has been investigated, the requirements for each amino acid are similar to those of other fish. The digestible energy requirements for economically optimum growth have been estimated at 8.2 to 9.4 kcal DE (digestible energy) per gram of dietary protein. Tilapia may have a dietary requirement for fatty acids of the linoleic (ω-6) family.

Tilapia appear to have similar vitamin requirements to other warm water fish species. Vitamin and mineral premixes similar to those added to catfish diets are usually incorporated in commercial tilapia feeds. Tilapia can even feed on home-made mash or dough more efficiently than do catfish or trout, but most commercial tilapia feeds are pelletized to reduce nutrient losses. Nowadays feed specifically formulated for tilapia can be found, but in its absence a commercial catfish feed with a CP content of 28–32% is appropriate.

1.5 Reproductive Behaviour and Breeding Techniques

The tilapia male builds a nest at the bottom of the pond, where the water depth is around 1 m or less, and then mates with a female. After a quick mating the female spawns eggs in the nest, the male fertilizes the eggs, and the female picks them up in her mouth to incubate them until they hatch and beyond. The fertilized eggs (or embryos) hatch and yolk-sac absorption takes place in her mouth. Even when they become swim-up fry, they seek shelter in her mouth for up to a week or until they become fully independent.

Most tilapia reproduce in natural as well as captive environments, such as rice fields, ponds, hapas and tanks. Of the various types of tilapia, the maternal mouth brooders, especially the Nile tilapia, has been the most important commercial species. In mouth-brooding tilapia, sexual maturity depends on the age, size and environmental conditions. Under favourable environmental conditions the fish attains sexual maturity in farm ponds at an age of 5–6 months or when their size is 60 g or above. When growth is slow but they are older, which means they are stunted, sexual maturity is delayed by a month or two. In such cases, they may reproduce at a weight of less than 40 g. Mozambique tilapia (*Oreochromis mossambicus*), on the other hand, reach sexual maturity at the age of 3 months under good environmental conditions in ponds. In poorly managed fertilized ponds, they may start breeding when they are 15 g in size. This is the reason overcrowding in ponds is common and as a result, farmers cannot harvest large fish. Many farmers see it as a nuisance species and it has been almost fully replaced by Nile tilapia in South-east Asia and is being gradually replaced in other areas.

Tilapia breed readily in captivity, without the need for any hormone injection, which was considered their main advantage over other species. Resource-poor farmers could readily adopt tilapia farming and manage their family-scale fish ponds by partially harvesting larger fish and leaving smaller ones to grow. Later farmers realized that the precocious breeding behaviour limits the growth of stocked fish. Various strategies were used to overcome the problem of breeding in food fish production systems and some of these methods are still used in various parts of the world: (i) culture of fish in cages; (ii) culture of tilapia with carnivorous species; and (iii) culture of all male fish.

Of these cultural methods, the culture of all male or predominantly male fry has been the best and most widely practised method. Farmers wish to grow all male tilapia not only to prevent breeding but also because males grow faster than females (up to twice as fast). Culturing fish in cages allows the eggs to fall through the mesh net to the bottom as the females lay them, preventing them from collecting and incubating them. Similarly, some farmers culture tilapia with carnivorous fish such as catfish, sea bass, largemouth bass, etc. so that they can eat the eggs and larvae of tilapia before they can grow any bigger. These methods have their own pros and cons. Culturing mixed-sex fry in cages and letting the egg fall through the cage means that females still lose energy needed for reproduction. If the fry are 50% female, quite a lot of energy is lost. Male tilapia have the capacity to grow twice as fast as females. If 50% of fish are smaller, total production will obviously be lower than when growing an all-male population.

Culturing tilapia with carnivorous fish will result in a similar loss but in this case, compensation for the loss may be obtained from the sales of carnivorous fish. However, farmers have to be careful about the density and the size of the carnivorous species stocked as they may put pressure on stocked tilapia and even injure them, creating stress that ultimately may favour the incidence of disease.

When intensive farming of tilapia began, farmers started looking for uniform and better quality seed or fry to stock in their ponds. Many farms started collecting fry from grow-out ponds and to supply mixed-sex fry on a commercial scale (Little *et al.*, 1994). The demand for good-quality fry increased dramatically when tilapia farming expanded rapidly and became more specialized. It was not possible for the hatcheries to produce and supply large quantities of fry of uniform size. As a female breeds once a month on average, the number of eggs a female could produce per spawning is only about 1000 eggs, or even fewer. More importantly, not all breeding females lay eggs on the same day. This asynchronous behaviour has been one of the major constraints. At the same time, quality indicators such as uniformity, growth potential and survival became questionable. As a result, it became a big challenge to produce millions of good-quality seed to fulfil the demand (Little, 1989; Little *et al.*, 1997; Bhujel, 1999, 2000).

Nevertheless, it was quickly realized that there was a problem and that tilapia culture was not expanding as expected. This led to the research programme at AIT, which aimed to develop the mass fry production techniques using hormonal sex reversal that had been adopted by thousands of hatchery operators in Asia and beyond. This manual is an attempt to describe the steps in sufficient detail, based on the experience of working with hatchery operators, grow-out farmers and other practitioners.

Although there are another four other methods (Fig. 1.2) of producing predominantly males in a fry population, hormonal sex reversal has become the most widely practised technology and has spread to almost all the countries where tilapia are grown (Bhujel, 2008). Other methods are still practised with varying degrees of success, and they have their own pros and cons. For example, manual sexing by looking at the genital papilla requires skilled labour and is time-consuming. More importantly, all females (approximately 50%) have to be discarded. Some researchers have suggested that heat treatment may result

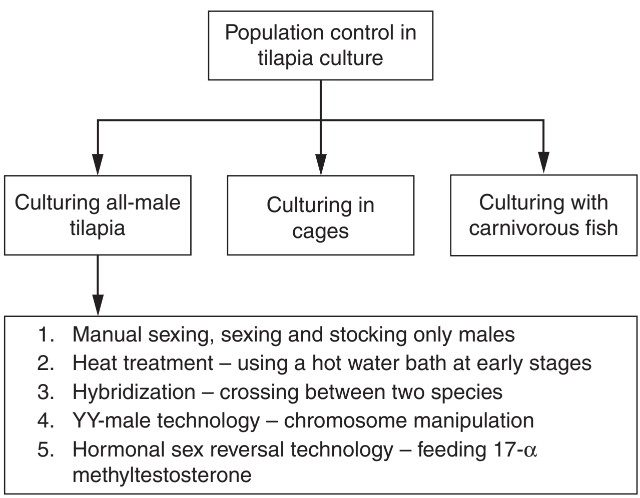


Fig. 1.2. Methods of population control in tilapia.

in a skewed sex ratio towards male; however, it is still not clear how the application of heat can convert females into males. As results are not consistent, it is still the subject of research and has not been applied by commercial farmers. Another method is hybridization between two selected species that may produce predominantly male offspring, e.g. Nile tilapia or Mozambique females crossed with blue or Zanzibar males. However, results are not consistent and it is hard to get an all-male fry population with only 80% or so male usually being achieved. That means plenty of females can still reproduce and produce lots of fry in the grow-out system. A lot of literature on the method of YY-male technology can be found, which is supposed in principle to produce all male fry by crossing YY-males with any females. However many farmers, when they have tried this method, have found that results are not consistent and are unpredictable. Therefore, they see risks in applying the technique on a commercial scale.

The hormonal sex reversal method of producing all males has become the most widely adopted standard technology. Hundreds of private hatcheries have taken up the technology in Bangladesh, Brazil, Thailand and Vietnam, including some countries in Africa such as Ghana, Malawi, Zambia, etc., producing and supplying billions of high-quality monosex tilapia fry annually. The reasons for the rapid spread of this technique are because of its major advantages:

- The production of all male fry (100%) has been possible commercially.
- The results are quite predictable and consistent.
- The high percentage of males means high growth and survival, which will ultimately result in high levels of production and profits with the same amount of inputs.
- Methyltestosterone (MT) hormone-fed fry grow faster because the hormone serves as a growth promoter.
- Slow-growing females, which make up about 50% of a normal population, are also converted into fast-growing phenotypic males, which adds to the net yield and thereby the net profit.
- Females are almost absent, which means no recruits in the production system and all the energy is used for growth. The presence of young fish, even in small numbers, which occurs when other techniques are used, has negative impacts on growth.

As MT is a steroid hormone, many people raise questions about whether it is safe from the point of view of human health and the environment. The following explanations should be helpful:

- First, MT is a synthetic substance but not harmful or toxic.
- It is very close to the natural testosterone hormone.
- The hormone is a growth promoter or strength booster that is often used by athletes.
- It is also used in animal farming as a growth promoter.
- It is also prescribed for the treatment of breast cancer in women at the rate of 20–40 mg/day.

- The hormone is also prescribed by doctors to promote growth in stunted children at the rate of 300 mg/day. With 300 mg MT hormone, about 30,000 tilapia fry can be sex reversed, which means, even if the entire hormone remains in the body of the fish, a person would have to eat 30,000 fish per day, which is impossible.
- The hormone is quickly released from the body of the fish after cessation of hormone feeding, e.g. only 1% was found after 100 h. MT is fed to small fry (0.2–0.4 g), which are consumed by humans only after growing for at least 5 or 6 more months.
- The hormone sinks into the mud and degenerates within 1 month.
- Some concerns have been raised over the health of workers but no real evidence has been reported.
- Only 10 g is required to convert 1 million fry, which means each fry contains only 0.01 mg hormone. The amount used in the tilapia industry is very little compared to the amount used for other livestock. For example globally, even if all the tilapia production (3.5 million t) per year came from hormonal sex reversal, the total amount of hormone would be less than 100 kg/year, which is insignificant compared to the 7.1 t of androgen hormone excreted by farm animals in the EU and 4.4 t in the USA (Macintosh, 2008).

Tilapia Hatchery

2

2.1 Introduction

The establishment of a specialized tilapia hatchery and supply of high-quality monosex fry has become one of the most profitable businesses in rural areas. Evidence shows that net profit from the tilapia hatchery business has been highly competitive compared to many other businesses. As a result, many hatchery operators of poultry, carp, prawn, etc. have either completely shifted to a tilapia hatchery business or at least adopted it to diversify their business risk. Therefore, specialized commercial tilapia hatchery technology is described in detail in this initial part of the manual.

The business of mass-scale tilapia fry production using hormone includes the management of broodstock in hapas, artificial incubation of eggs in down-welling incubator jars, larval rearing in shallow trays and the hormonal sex reversal technique as it has significant benefits (Macintosh and Little, 1995) and there is strong interest around the world in its use (Bhujel, 2008). The technique was developed at the AIT in Thailand, where a series of research trials were carried out over the past three decades funded by various organizations such as the EU, UK Department for International Development (previously ODA), USAID/PDA/CRSP, SIDA, among others (Little, 1989; AIT, 1994; Bhujel *et al.*, 1998). The technology has been disseminated through public organizations such as higher education institutions, extension agencies of departments of fisheries (DoF), and research institutions. However, the technology became more prominent when it was commercialized or taken up by the private sector, which began in the mid-1990s in Thailand (Little *et al.*, 1997; Bhujel *et al.*, 1998). Hundreds of hatcheries emerged in Thailand and rapidly proliferated in Bangladesh as well (Bhujel, 2008; Baqui and Bhujel, 2011), where over 300 hatcheries are now in operation. However, the demand for fry is still unmet due to rapidly increasing demand for tilapia. Using this technology, it is possible for a single hatchery to produce and supply over 30 million fry per month (Bhujel, 2008, 2009, 2011).

Trends in tilapia production show that production is doubling every decade, mainly due to advances in technologies and consumer preference. If the current trend of tilapia production and consumption continues, it will in turn lead to an increased demand for fry. More hatcheries will be needed in each country and so this manual should be useful.

2.2 Hatchery Plan

Any business starts with planning and setting up targets. Targets can be in terms of volume, the number of particular product(s) and the net profits to generate. In this case, the targets are the number of fry to be sold and amount of profits to be generated. Targets may vary depending upon the scale of the business, demand for the product and the objectives of the business.

The tilapia hatchery business can be categorized into three types: small, medium and large scale. Table 2.1 presents a preliminary plan for a hatchery for the three levels of operation. Projection of cost–benefit is based on the estimated costs of items in Asia. The capital costs have been included as depreciation costs, calculated based on reasonable lifespan of the fixed assets. This kind of hatchery is spreading rapidly, the reason being that it shows very attractive profits. Some of the hatcheries which started early in some countries took advantage of good demand and enjoyed good net profits, sometimes over 100%.

2.3 Site Selection and Development

Establishing and running a successful tilapia hatchery requires technical as well as good managerial skills, and several factors also have to be considered, of which the following are the major ones to consider.

Table 2.1. Preliminary plan for a tilapia hatchery and projection of costs and revenues.

Description	Small	Medium	Large
Fry sales target (million/year)	10	30	60
Land requirement (ha)	5	10	20
Human resource requirement			
Managerial staff	1	3	5
Labourers	6	12	20
Broodstock requirement	10,000	30,000	60,000
Estimated total costs (US$/year)	60,000	150,000	200,000
Expected revenue (US$/year)	100,000	300,000	600,000
Expected net profit (US$/year)	40,000	150,000	400,000
Expected net profit (%)	40%	100%	200%
Expected payback period (years)	2	2.5	3

2.3.1 Location

Local demand for tilapia seed and potential profit from the hatchery operation should be kept in mind when selecting a particular site for the hatchery. Hatcheries and nurseries usually tend to be located in clusters. This follows a marketing trend in which some areas might have a good name already for particular products. Therefore, that location may be preferred over a hatchery located in other areas. In clusters with easy access there is a risk of competition and so quality of fry needs to be maintained at a considerably higher level. Remote areas obviously have disadvantages. However, if the site has an access road it may not be so crucial because seed, broodfish and other hatchery materials can be transported to and from the hatchery in a reasonably short time and at low cost. Distance from grow-out farmers is important, although fry can be packed in plastic bags with oxygen and transported long distances (up to a 20-h drive or 40 h shipping including air cargo and land transportation) throughout the world. However, long journeys can exhaust fry and affect their survival.

Climate/weather should be kept in mind while establishing the hatchery. A site vulnerable to extreme weather cycles or natural disasters such as floods, storm/wind, etc. should be avoided. In temperate regions, greenhouses may be needed while in the tropics relatively deep ponds/tanks and shading may be needed, which add additional costs.

2.3.2 Hatchery farm layout

There should be enough space for the pond, hapa or tank for broodstock, incubation/larval rearing and fry nursing and holding. However, the number and size of ponds, hapas, cages or tanks depends on the scale of the operation. A combination of a hapa- and tank-based hatchery is probably the most common. Hapas are easy to install and less costly. They are also good in terms of maintaining the purity of broodstock. Most hatcheries for other species are only tank-based and are often heavily equipped with recirculation systems, aeration, light control, etc. and this is why hatchery operations are considered to be high investment and hi-tech businesses. However, this is not the case for tilapia and so hatchery businesses have proliferated, even in the most under-developed countries in the world (Baqui and Bhujel, 2011).

In most tropical and subtropical countries, management of fish stocks is done in pond-based systems because it is the cheapest method. However, survival and purity of the broodstock and fry/fingerlings in ponds cannot be guaranteed as wild fish and other predator organisms can easily enter the ponds. At the same time, stocks cannot be easily recovered from ponds, and can never be recovered completely. However, simply installing hapas in ponds can make it a lot easier to handle fish and maintain pure stock.

The artificial egg incubation system will require a simple tank-based water recirculation system, which is described in this section. Table 2.2 shows the recommended guidelines for size, number and water surface areas for broodstock, nursing and sex reversal for running successful hatcheries at three levels of operation (small-, medium- and large-scale). These serve as guidelines only though.

Figure 2.1 shows a simple layout for a farm where the office and fry sales areas are close to the road. The farm should be well protected with a strong fence such as barbed wire, a concrete wall or similar. Other parts such as broodstock ponds, egg incubation, sex reversal and nursing sections are planned for the inner part of the farm, which can have an internal fence so that any strangers, outsiders and even fry buyers need special permission to enter. A footbath should be installed at the entry to these areas.

These categories of monosex hatcheries can be described as follows:

- Small-scale – fry production of less than 1 million per month.
- Medium-scale – fry production of 1–3 million per month.
- Large-scale – fry production higher than 3 million per month.

Depending upon the design, actual land area requirements will be about 50% more to accommodate office, store and residential areas, parking, road, pond dykes, reservoir(s), and so on. More importantly, additional land may be set aside for future expansion because adding a hatchery component at another site later to increase the scale of the operation would incur huge costs.

Table 2.2. Pond space requirement for broodstock, nursing and sex-reversal systems.

	Pond requirement			
Scale of operation	Broodstock	Sex reversal	Nursery	Total
1. Small-scale				
No. of ponds	3	3	3	9
Suitable size (m^2)	1,200	400	600	–
Length × breadth (m)	24 × 50	20 × 20	30 × 20	
Total water area (m^2)	3,600	1,200	1,800	6,600
2. Medium-scale				
No. of ponds	9	3	3	15
Suitable size (m^2)	2,400	600	600	–
Length × breadth (m)	24 × 100	30 × 20	30 × 20	
Total water area (m^2)	21,600	1,800	1,800	25,200
3. Large-scale				
No. of ponds	9	4	4	17
Suitable size (m^2)	4,800	800	800	–
Length × breadth (m)	24 × 200	40 × 20	40 × 20	
Total water area (m^2)	43,200	3,200	3,200	49,600

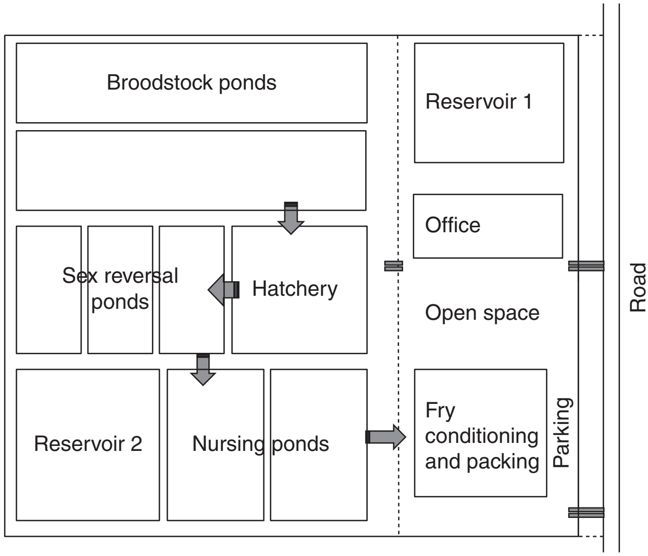


Fig. 2.1. Simple layout plan of a tilapia hatchery.

2.3.3 Pond construction

Before constructing ponds, a farmer needs to check the type of soil, and whether or not the soil can hold water. Clay soil can hold water for a long time whereas land with sandy soil may not retain water for very long. Clay soils and similar types such as sandy clay and sandy loam soils are found in most areas, but most of the land available for aquaculture is unused or unfertile soils. It is likely that soil will not completely hold water and so a quick investigation is necessary. The following steps can be followed to find out whether soil is suitable for pond construction or not:

STEP 1. Dig a 1 m × 1 m pit in the middle of the land or potential location.

STEP 2. Fill the pit with water.

STEP 3. Let it stand for a few days.

STEP 4. If the water remains for about a week with little leakage, the soil is suitable for pond construction. If half of the water is gone, the soil is unsuitable. However this could be rectified by bringing clay soil from another area to create a layer of about 25 cm at the bottom and around the sides of the pond. This can be costly and so a decision needs to be made about whether to buy clay soil to rectify the problem or whether to buy land in another area. If the water disappears from the pit within a day, the soil is very sandy or perforated, and is not suitable for pond construction, unless extra care is taken while constructing the pond. If there is no other option, a combination of a clay layer and a pond liner or a pond liner alone can be used.

STEP 5. The following points need to be considered when constructing a pond:

- Ease of access by vehicles to facilitate transport of fish, equipment and other materials.
- A water gauge should be installed to make it easy to record water levels regularly, i.e. on a daily, weekly or monthly basis.
- The inlet pipe needs to be above the water surface and covered by a fine mesh net to prevent insects and other fish entering the pond (Fig. 2.2).
- The outlet pipe at the water surface also needs to be covered by fine mesh net.
- There needs to be space to walk around, to facilitate feeding and handling of fish when necessary.

2.3.4 Hapa set-up

Hapas are widely used in ponds to maintain broodstock, and for fry nursing and sex reversal because they make it easy to control or handle the fish, are cost-effective and also provide water exchange from the pond. Depending upon the purpose, hapa sizes vary from 5 m^2 to 120 m^2 (Fig. 2.3). A hapa is a hanging structure supported by either bamboo sticks with nylon ropes or by concrete poles tied with metal strings (Fig. 2.4). Hapas should be about 20–40 cm above (and not touching) the bottom of the pond. Normally, water depth in a hapa is maintained at 60–70 cm and its sides should be raised 20–30 cm above the water surface so that fish cannot swim away. A hapa should not cover more than 40% of the water surface. In many cases, hatchery operators install too many hapas (Fig. 2.5) and face water quality problems, which may result in the death of fish, low egg production, fry mortality, and so on.

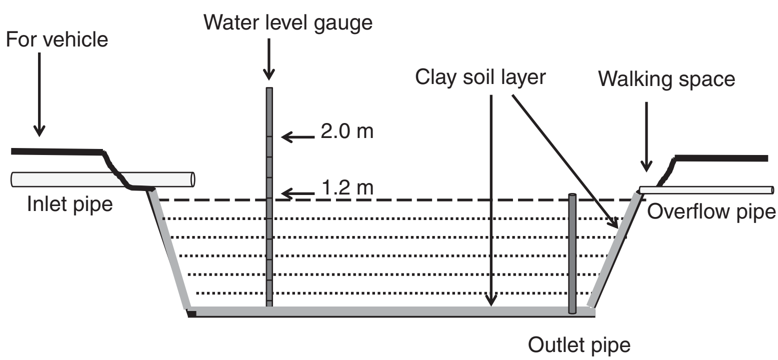


Fig. 2.2. Simple method of pond construction.

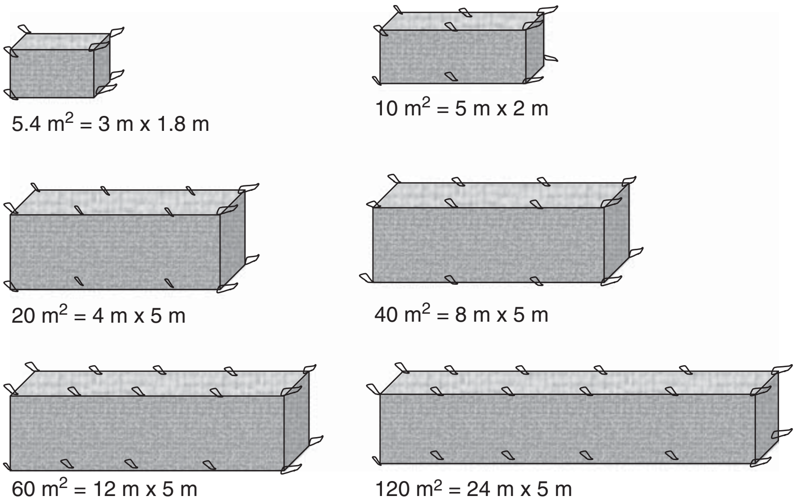


Fig. 2.3. Standard hapa sizes for various purposes, i.e. sex reversal, nursing and breeding.

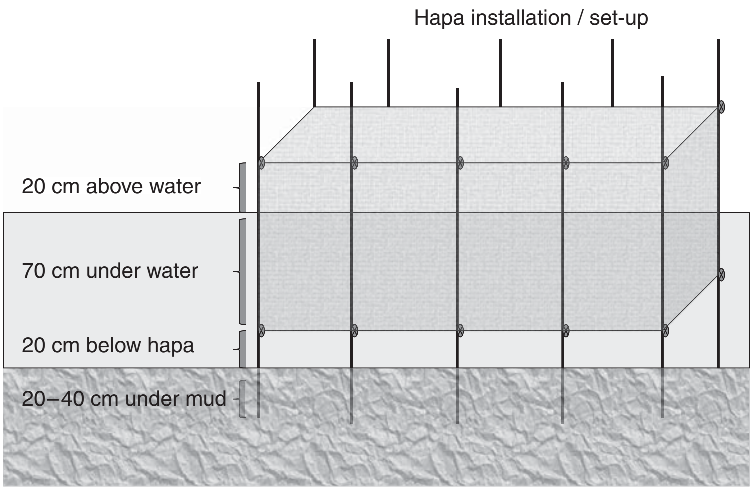


Fig. 2.4. Setting up of a hapa in a pond.

2.3.5 Cleaning of a hapa

Hapas get fouled very quickly in many cases; they need to be cleaned fairly frequently and this can be a big job and is often costly. If the colour of the water inside and outside a hapa is quite different, there is no water exchange and that indicates the need to change the hapas. Depending upon the water quality and level of feeding, breeding hapas are changed and cleaned every 2–3 months. In sex reversal ponds, hapas get fouled more quickly because the sex reversal feed contains high protein levels and other nutrients, which accelerate the growth of plankton. In this case hapas need to be changed after about 10 days. However, technicians or a manager needs to observe them daily and judge whether they need to be changed. Cleaning can be done using high-pressure water from a hosepipe (Fig. 2.6), using the following steps:

STEP 1. Observe the wall of the hapa and see how dirty the walls are near the surface of the water. If they look dirty, compare the colour of the water inside and outside the hapa. If the colour is different they need to be changed.

Fig. 2.5. Too crowded hapa set-up in a pond.

Fig. 2.6. Hapa cleaning with a water jet.

STEP 2. Use a clean hapa to replace the fouled one. Changeover is usually done on completion of the egg harvest in the case of breeding hapa. Broodfish are gathered in one corner or in another small hapa.

STEP 3. Dry the dirty hapa in the sun for 2–3 days, either on the pond dyke itself or in any other open area, so that algae will die completely.

STEP 4. Soak the hapa in tanks of clean water for 1–2 days.

STEP 5. Use either a hard brush to clean the hapa manually or use a high-pressure water hose.

STEP 6. Clean the hapa again and store in a dry room.

2.3.6 Water source and supply system

The water source for any fish farm varies from underground tube wells, irrigation canals, streams, rivers, reservoirs, or thermal plants. Because water is scarce in most areas, a major part of any tilapia hatchery system is a water recirculation system for the artificial incubation of eggs. Water supply is one of the most important factors to be considered when selecting the site for a hatchery, as a 24-h continuous supply is required. Hatchery water should be adequate, cheap, and free of microorganisms and pollutants. The water temperature in a hatchery (tanks and ponds) should be within the range of 25–35°C, although 28–32°C is the optimum range. The pH should be 6.5–9.5 and unionized ammonia (NH_3) should be lower than 0.1 mg/l.

While some hatcheries are fortunate enough to obtain clear and well oxygenated water from streams and rivers by simple diversion, most hatcheries use pumps to bring underground water up to the header tank (Figs 2.7 and 2.8), usually from very deep tube wells that may reach up to 100 m. Underground water is low in DO, and green water can have DO as low as 0 mg/l in the morning at around 6 am. DO should ideally not be less than 4 mg/l, although tilapia can still survive for short periods under these conditions. To oxygenate the water, a simple splash can be created at the tip of inlet pipes before pouring into the pond or tanks (Fig. 2.9).

A water storage tank 4–5 m high (also called a header tank), of about 25,000 l capacity, is required when the water source is underground. The header tank can be either rectangular or circular in shape. Some hatcheries build rectangular tanks of 6 × 3 × 1.5 m raised on four strong concrete pillars; others build a circular tank of radius 2–3 m, 1.5 m tall, to store the same volume of water. The cheapest method of building the water tank is to combine the large rings of concrete pipes made for large road drainage systems in municipalities. If the rings are 1 m tall, five of them can be stacked

Fig. 2.7. Header tank with a filter on top that also helps oxygenate the underground water at Mian Channu Hatchery in Pakistan (left). Another header tank used for tilapia hatchery made from stacking eight large rings of concrete drainage pipes (right).

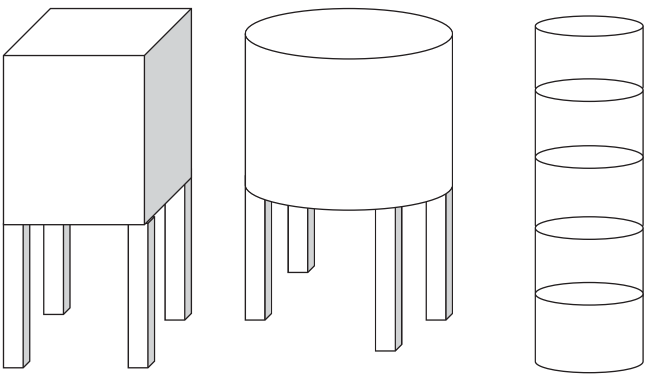


Fig. 2.8. Three types of header tanks to supply water to the hatchery by gravity.

to make a 5 m high tank, which can store the same amount of water as one of radius 1.3 m. The calculations are as follows:

- Header tanks raised on concrete pillars:
  - Rectangular tank = 6 × 3 × 1.5 m = 27 m^3 = 27,000 l
  - Circular tank = 3.14 × (2.3)^2 × 1.5 m = 25 m^3 = 25,000 l
- Circular tank raised by stacking five rings = 3.14 × (1.3)^2 × 5.0 = 26.5 m^3 = 26,500 l

Fig. 2.9. Splashing the water for oxygenation before pouring into the pond. (From Reliance Aqua Hatchery in Mymensingh, Bangladesh.)

Water filtration system: As shown in Fig. 2.10, a combination of slow sand and biological filtration systems is required in order for the hatcheries to be able to reuse water. Incoming water from rivers, canals, etc. and the water from incubation and larval rearing systems come to the settling tanks, from where water passes to a biological filtration compartment, then to slow sand filters. After filtration through sand, clean water from the sump is lifted to the header tank by a pump (5.0–7.5 hp) run by diesel or electricity. Heavy soil and sand particles settle in the settling tanks. Some plants also include *Nitrosomonas* bacteria, which can take dissolved nitrogen and convert it from ammonia to nitrite and nitrate. Similarly, the sand filtration system separates the coarse solid particles from the water and also filters or blocks some organisms entering into the system. A sand filter is usually composed of three layers: fine sand on the top layer, coarse sand in the middle and gravel at the bottom, with approximately 0.5 m for each layer. The bottom of the sand filtration system should have perforated pipes underneath so that they can hold adequate filtered water for pumping and lifting to the header tank.

Ultraviolet (UV) light: This has been found to be the cheapest method of sterilizing the water, especially for egg incubation systems. Water can be passed through a simple UV light tube installed inside a 4-inch PVC pipe (Fig. 2.11) just before it is supplied. As UV light kills all the germs it can also be dangerous to eggs/larvae if the intensity is too high and so agents supplying UV lights should be consulted for the specifications.

Ozonation: Ozone (O_3) also kills all germs, and has been found to be useful in sterilizing the water. However, it is relatively costly and it may not last long as the amounts of bacteria and water are huge. Therefore, more research is needed to make it suitable.

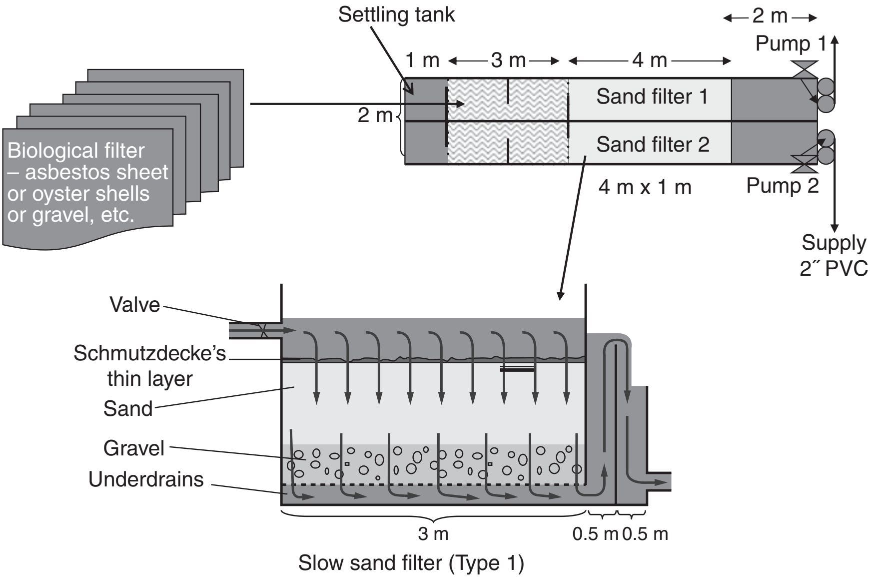


Fig. 2.10. Filtration system including biological and slow sand filters.

Fig. 2.11. UV light system used in Chiang Mai, Thailand. (From Randy Bevis.)

2.3.7 Electricity and power requirements

Running a fish hatchery does not require much electricity, but it is crucial because egg incubation systems or hatching and larval rearing in aluminium trays needs a continuous flow of filtered and clean water to churn them so that they are supplied with oxygen. A simple pump of about 3 hp would be adequate if the incubation and larval rearing is done in a single recirculation system. Some hatcheries require two pumps because they keep these two systems separate so that when one system fails another can still run the hatchery without interruption. In most hatcheries, another air pump may be used to supply aeration in conditioning tanks and also in any sex reversal system, as the fry densities are high during these stages and fry mortality can occur. A simple aeration system using an air pump and several air stones connected by small rubber pipes can improve survival significantly.

2.3.8 Other factors

The site should be protected from poaching. Tilapia are easy to catch, and even more so when they are in hapas/cages. Special attention should be paid to their security. Red tilapia are vulnerable to predation by birds because they can be seen easily. The success of a farm also largely depends on the availability of investment in time and season for equipment and operational costs. It is advisable to place the hatchery in a site or location promoted or facilitated by the government.

2.4 Broodstock Source and Management

2.4.1 Broodstock source

The first broodstock should be from a reliable source because it will form the basis of the stock for a considerable time. Although it can be collected from natural or feral stocks, domesticated stock should be purchased from well-established hatcheries. After that, hatchery operators can produce their own broodstock on-farm with proper management, because it is more reliable and cheaper. Moreover, they can then have full control over the stock. It is necessary, however, to maintain purity and avoid inbreeding, and this can require significant knowledge, skill and facilities. In order to avoid inbreeding at least 10,000 broodfish with an expected sex ratio of 1:1 should be obtained to start a new hatchery. Some medium-sized hatcheries acquire 10,000–20,000 brood fry while large-scale hatcheries may acquire as many as 100,000 in order to immediately start breeding and fry production without having to wait for another batch.

2.4.2 Species and strain selection

The selection of species depends on the purpose and market demand. The main species of tilapia being farmed today include the following.

O. mossambicus appeared in Java, Indonesia, in 1939 and so is generally called Java tilapia. It has a high reproductive capability, enabling the species to quickly spread all over Asia. However, growth of this fish is very limited because so much energy is spent on reproduction. Stunting was found to be common in systems where males and females reproduce rapidly due to overcrowding and when limited food is available. For this reason, Java tilapia became a nuisance, appearing in rivers, lakes, canals and other water bodies and creating the notion that tilapia was a problem species. However, it has a high salinity tolerance and so is normally used for hybridization with Nile tilapia to produce a species with a relatively higher salinity tolerance, as well as red tilapia.

Nile tilapia (*O. niloticus*, Fig. 2.12) is considered the best among all tilapia and has several strains. It has a special history in Thailand. It was first introduced in 1965 to Thailand as a gift by the Japanese Emperor when he was a prince. The fish were kept in a pond in the Chitralada Royal Palace. After seeing that the fish were able to breed without the need for hormone injection, His Majesty Bhumibol Adulyadej (Rama IX) asked for them to be distributed to the people of Thailand, in particular the rural poor. After successful breeding in 1966, unlike in other species, the Thai king gave 10,000 fingerlings to the DoF, which distributed the fish to 15 inland fisheries research stations. Common people started to receive tilapia from them in 1967 (Pullin, 1988; Bhujel and Stewart, 2007). Many Thais consider tilapia to be precious fish because they know that they came from the Royal Palace. After obtaining the fish, people quickly realized how easy it was to breed and began to research improved and low-cost cultural techniques. It became popular especially among rural people and was widely known as the Chitralada strain. It was ascertained later that the fish were originally from Egypt. DNA analysis showed that this Nile tilapia was one of the purest strains (Fig. 2.12). The Chitralada or Thai strain has a high growth rate and reproductive ability. A GIFT (genetically improved farmed tilapia) strain developed by ICLARM (now WorldFish) through selective breeding has been popular because of its rapid growth. Breeding programmes continued and further GIFT generations were developed (1, 2, 3 and up to 15 generations).

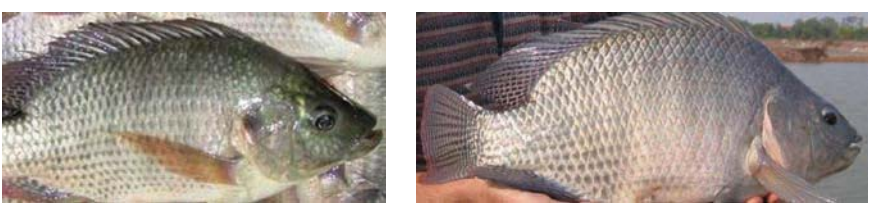


Fig. 2.12. Nile tilapia (*O. niloticus*).

Red tilapia were first developed by crossing blue tilapia (*Oreochromis aureus*) with Mozambique tilapia (*O. mossambicus*) in Florida and were therefore known as Florida red tilapia. Crossing with blue tilapia is popular because it has better cold tolerance than other tilapia. Most red tilapia found in Asia are crosses of Mozambique tilapia and Nile tilapia such as Malaysian, Taiwanese and Thai red tilapia (Fig. 2.13), which are salinity tolerant and can be cultured in brackish and saline waters up to 30 ppt, in contrast to Nile tilapia, which grow well only in less than 10 ppt. The hybrid between Taiwan red and Nile tilapia are known to grow as fast as the Nile tilapia. Taiwanese reds are an attractive red colour while Malaysian reds are pale and whitish-red. The Thai red popularly known as 'Thap thim' is somewhere between these two. Red tilapia are becoming popular in restaurants and supermarkets in Asia for their attractive colour (Fig. 2.13, left).

There are various other crosses of different names found in Asia and Latin America but the two mentioned above, i.e. Nile tilapia and red tilapia, are the main well-established strains. There are other indigenous mouth-brooding tilapia available in several countries, such as three-spotted tilapia (*Oreochromis andersonii*) in Zambia (Fig. 2.13, right), *Oreochromis karongae* and *Oreochromis shiranus* in Malawi, and so on. These countries are somewhat reluctant to promote the culture of Nile tilapia, considering it as an exotic species and fearing that it might have a negative impact on indigenous species.

Nile tilapia are found in over 100 countries throughout Africa and Asia, and various different strains are found in, for example, the Ivory Coast, Ghana, Stirling, Vietnam and the Philippines. A number of breeding programmes are also claiming the development and emergence of several improved strains by crossing different strains.

2.4.3 Brood requirements

Those wanting to start a large hatchery should start with new and the best original stocks available anywhere in the world. Hatchery operators who want to establish large hatcheries and expand further should normally start with

Fig. 2.13. Red tilapia (left) and three spotted tilapia, *O. andersonii* (right).

20,000–30,000 fry as a founder stock and keep them permanently in well-managed tanks or hapas in ponds. The total number of broodstock required can also be calculated based on the production target, assuming that an average 500 eggs can be collected from a female per month, and eggs have about 30% overall survival until ready to be sold. If a hatchery has an initial target of producing/supplying 1 million fry per month, the number of mature broodfish required would be:

No. of mature females required = 1,000,000/(500 × 0.30) = 6667 females
No. of mature males required (1:1 sex ratio) = 6667 males
Total number of mature broodfish = 6667 females + 6667 males = 13,333

Assuming 75% survival during nursing, 90% during second nursing, 90% during maturation and 95% during handling, the number of broodfish fry required would be:

No. of broodstock fry required = 13,333/(0.75 × 0.90 × 0.90 × 0.95)
= 23,102

The final number of broodstock fry required would be 25,000, taking into account transport and handling losses.

2.4.4 Broodstock procurement

If the brood fry requirement is 25,000, swim-up fry to be collected from a tray system can be packed in seven cartons/foam boxes. Each carton contains four plastic bags and each bag contains approximately 900 swim-up fry (0.02 g or larger) in about 2 l of water and 3 l of oxygen. If procurement is from abroad (cross-border movement), a health certificate for the brood fry based on the samples tested within a week of departure is needed. Normally, a certificate is issued by the government agency in the exporting country. A certificate of origin may also be necessary. Some countries do not allow importation of exotic live species while others may issue licences to importing parties with the provision of strict rules and regulations, including a long process of quarantine and surveillance. Fry that are well conditioned before packing, i.e. have been maintained for 24 h or more without feeding in clear water, can survive up to 36 h of travel (land and air). This means that brood fry can be imported from anywhere in the world.

2.4.5 Facility preparation and fry release

A small nursing hapa of 10 m^2 with a net protection against birds or a concrete tank of about 5 m^2 in area, outdoor or indoor, is adequate for the arrival of new brood fry. If ponds are to be used, they need to be prepared well in advance by draining, cleaning, disinfection and liming, so they should not have any other fish or living organisms that may potentially harm or predate the new and young fish. If hapas are to be used, they need to be installed at least 1–2 days before fry are stocked. In tank systems, if tap water is used to fill up the tanks, this must be done at least 3–4 days before to ensure that all chlorine has evaporated from the water (because it can kill the young fish).

STEP 1. Open all cartons and remove all the plastic bags, but do not open the bags.

STEP 2. Allow all plastic bags to float on the water surface for about 20–30 min so that the water temperature inside the bags will be similar to the temperature of the pond/tank water.

STEP 3. Open the bags and gradually add the pond/tank water into the bags before finally releasing all the fry into the water. This is to avoid drastic changes/shock to the swim-up fry due to differences in water temperature and other parameters.

STEP 4. Broadcast some rock salt into the water inside the hapa as a means of stress release and only start feeding on the following day.

2.4.6 Broodfish fry rearing and maturation

As broodstock fish are the key element of the hatchery, their quality and management affects the quality and quantity of seed production, which are ultimately the major indicators of success or failure of the hatchery. Feed the fry with fishmeal powder (or mixed with up to 50% rice bran) to a satisfaction level (or 20–30% body weight/day for the first month and then reduce to 15% in the second month, and then 10% in the third month or after) separated into 4–6 feeds a day or every 3–5 h. The following points are important to consider, while Table 2.3 provides a summary of management methods.

- If the pond has bird protection cover, but no other fish, the hapa can be removed and fry can be released into the pond water after about 3–4 weeks. If not, they can still be kept in a larger hapa (20 m^2) or split into two hapas of 10 m^2 for another month. Again they can be separated gradually, reducing the density by half each month.
- Fish will grow rapidly in the pond if the water is green; this can be achieved by fertilization at the rate of 60 kg urea and 30–60 kg triple superphosphate (TSP)/diammonium phosphate (DAP) per ha per week (see Section 4.2).
- When they are around 100 g in size, which may take around 6–8 months, they are ready to stock into the breeding hapas with 200–300 females and 150–200 males per hapa of 60 m^2 (12 m × 5 m).
- Eggs should be harvested every 5–7 days, incubated artificially using clean water and passed through a slow sand filter.

Table 2.3. Stocking and feeding management of brood fry.

Month	Stage	Stocking (no./m^2)	System	Feeds and feeding
0–2	First nursing	1000	Hapa	Rice bran and fishmeal (2:1), five times daily to satiation
2–4	Second nursing	200	Hapa	Rice bran and fishmeal (2:1), five times daily to satiation
4–6	Maturation	1	Pond	As above or pellets (30% CP), twice daily to satiation

2.4.7 Individual selection

Tilapia can be used for breeding from the age of 6 months or when females are about 100 g and males about 150 g. When selecting the broods from the maturation pond/tank/hapa, fish of good shape and attractive colour should be selected; any deformed fish or those that are larger or smaller than standard should be avoided. Males with a pink colour on their dorsal and caudal fins are preferred. Broodfish can be continuously used until the age of 2–3 years, depending upon their size. Smaller females will lay smaller eggs and so the fry will be smaller. Therefore, some hatcheries stock larger females of about 150 g in weight, together with 200 g males to stock in breeding hapas. Females above 350 g and males above 400 g are generally difficult to handle during seed harvesting; therefore, they are isolated and transferred to fattening ponds/tanks or hapas so that they can be sold in a month or two to generate an additional return. Figure 2.14 shows suitable sizes for males and females for commercial tilapia fry production.

2.4.8 Sexing and counting

Separation of males and females is done by looking at the genital papillae or the vent. Females have red round vents with short papillae, while males have long and pointed papillae. Males have only one pore in the papilla from where urine and sperm are released while females have two pores – one for releasing ova/eggs and another for urination (Fig. 2.15).

Males and females are counted and kept separate for 2–3 days so that they can be transferred as required to stock into the breeding ponds, hapas/cages or tanks.

2.4.9 Breeding or spawning

Induced breeding in tilapia is not possible because they do not respond to hormone injection (Srisakultiew and Wee, 1988). But they breed naturally and easily

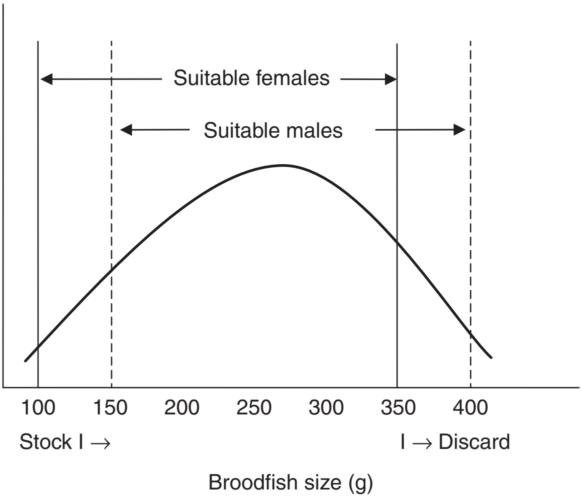


Fig. 2.14. Size selections for breeders for commercial production of fry.

Fig. 2.15. Separation of broodstock by sex. Male has pointed and long papilla, and female has round papilla.

in ditches, rice fields, ponds, hapas/cages or tanks, depending upon the available facilities and the scale of operation. Males and females are stocked at either 1:1 or 1:2 ratios. Stocking density varies with facilities. Normal stocking density of broodfish is 2 fish/m^2 (1 male:1 female) in ponds, 6 fish/m^2 (1 male:2 females) in hapas (Fig. 2.16; Little, 1992) and 10 fish/m^2 (4 males:6 females) in tanks.

As a female tilapia normally spawns once a month, they need to be adequately supplied with nutrients throughout the breeding period. Floating pellets are recommended for broodfish if available and affordable. Resource-poor farmers

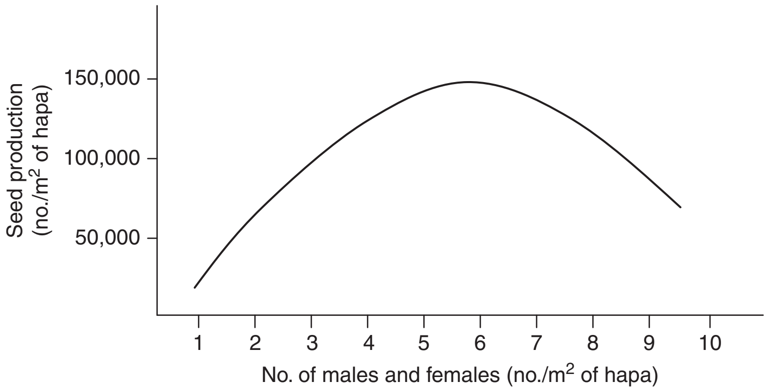


Fig. 2.16. Relationship between seed output and the stocking density of Nile tilapia broodfish reared in hapas suspended in fertilized ponds. (Modified from Little, 1992.)

can use simple rice bran alone or in combination with oilcakes and/or fishmeal. The type of feed may depend on the breeding system used. In green water or hapa-based systems (Fig. 2.17), broodfish are fed on a diet containing 25% CP at 0.6–0.8% biomass per day split into two meals. On the other hand, in clear water systems, a 35% CP diet is used to feed broodfish at 1.5–2.5% biomass twice daily (Bhujel *et al.*, 2007). As broodfish are stressed by handling, it is not advisable to feed the fish on the day of seed harvest. However, some farmers think it better to feed broodfish in the afternoon if the eggs are harvested in the morning as the females with eggs would be hungry because they normally do not eat when they have eggs in their mouth or during the mouth-brooding period. In order to maximize egg production per female or per unit hapa space, broodstock exchange methods have been developed (Little, 1989; Little *et al.*, 2000). However, considering the time and labour needed to separate males and females during egg collection, hatchery operators did not see any advantage in changing females or males after a week or two. They are continuously used for 2–3 years and then are replaced by new batches.

Broodstock can also be maintained in a tank system (Fig. 2.18), and although it can be expensive to have many tanks, it can be easier when collecting eggs, as workers can keep out of the pond mud. Some of our research showed that stunted (1 year old but still 40–50 g) broodfish of Nile tilapia showed significantly higher numbers of seed (Bhujel *et al.*, 2007), which can be used as a method of boosting egg production, especially when demand is high.

2.4.10 Broodstock replacement

Broodfish should be maintained in a controlled environment (tanks or hapas in ponds) so that they will not crossbreed with wild fish. Purity of the stock is

Fig. 2.17. Trainees learning how to collect tilapia eggs.

Fig. 2.18. Series of breeding hapas (12 m × 5 m) in a private hatchery in Bangladesh that supplies over 60 million monosex fry per year.

very important. As large broodfish are difficult to handle during egg collection, they have to be replaced frequently; normally every 2–3 years or when they get bigger than 400 g. There is no need to purchase from outside again. Fry of the same stock can be randomly selected from different trays before being taken for hormone treatment. They should be completely replaced following the all-in–all-out system. When replacing old stock, ponds should be dried and hapas should be cleaned. New broodfish should be stocked in clean hapas installed in well-prepared ponds.

In order to avoid inbreeding at least 10,000 fry should be selected for new stock to replace original ones. In order to have 10,000 newly maturing broodfish when they are mature, assuming 75% survival during nursing, 90% during second nursing, 90% during maturation and 95% during handling, at least (10,000/(0.75 × 0.90 × 0.90 × 0.95)) = 17,333 fry are required. However, this number should represent the lowest estimate.

It can also be calculated for a particular target. For example, after 2–3 years if a farmer is supplying 2 million fry per month, i.e. double the number of initial capacity, then the number of mature females required would be:

No. of mature females required = 2,000,000/(500/0.30) = 13,333 females
No. of total mature broodfish (1:1 sex ratio) = 13,333 × 2 = 26,667
Minimum no. of broodstock fry required = 26,667/(0.75 × 0.90 × 0.90 × 0.95) = 46,206

Medium- to large-scale commercial hatchery operators usually randomly select over 50,000 fry while they are in the larval stage.

After procuring brood fry from outside or selecting from the on-farm hatchery, broodstock fry are nursed normally. However, special care should be taken to avoid contamination from feral tilapia to ensure that they have sufficient nutrients for somatic growth and gonadal development. If broodstock are reared in clear water, a higher protein diet (35% CP) is required, but for green water systems, a 25% CP diet would be sufficient.

2.4.11 Fattening and sale of old broods

When broodfish are bigger than 400 g, it is difficult for workers to handle them or catch the fish to collect eggs or yolk-sac fry from their mouth. Normally, broods can be used for 2–3 years. Depending upon the feeding regime and the condition of the water, they may attain 400 g in 2 years or it may take another year. When they reach 400 g, the broods can be transferred to a fattening pond where they can be fed for a month or two at a higher feeding rate, e.g. 3% biomass, so that they can gain weight and can be sold as normal fish at a reasonably good price.

2.4.12 Stock management and brood fry production

Well-maintained broodstock can produce good-quality eggs for the farm and with special care their offspring can be produced separately to establish another stock for sale or to be used by the same farm. Mass selection methods are used to maintain or improve certain characteristics in tilapia such as red colour in red tilapia, high growth and various shapes. After selecting for about 3–4 generations or when the majority of offspring possess desired characteristics predictably, a separate line can be established.

2.5 Egg Collection and Incubation

2.5.1 Why collect eggs?

In natural breeding each sexually active male tilapia builds a nest, a similar phenomenon to that found in birds (Fig. 2.19). When a mature female with well-developed eggs sees a nest she will follow. The males and female encircle the nest showing breeding behaviour. The female then lays her eggs and the male releases sperm to fertilize them. After fertilization the eggs (embryos) are picked up by the same female in her mouth to incubate them. She continues to keep them in her mouth for up to 2 weeks or until they are fully capable of swimming freely and are able to survive by themselves. Even when fry swim freely, the mother stays around. If she sees other fish or predators approaching to attack them, she opens her mouth to provide a safe haven for the free-swimming fry. This is an intrinsic characteristic of the maternal mouth brooding of Nile tilapia and resembles the characteristics of terrestrial animals, which are at a higher stage of evolution.

Hatchery operators need to understand the breeding behaviour so they can manage the artificial breeding system in which fertilized eggs (embryos)

Fig. 2.19. Nests of Nile tilapia (*O. niloticus*) in an earthen pond.

are collected from the mouths of females and incubated in artificial jars containing continuously flowing water. When females lay eggs in nests full of mud, it is difficult to take up the fertilized eggs without also picking up mud and debris, and some of the eggs may also be lost in the nest. Hapa systems are therefore better because all the eggs can be collected. However, hapas may become fouled or dirty if the water quality is poor, and dirty hapas need to be changed for clean ones about every 2–3 months, following an egg harvest. Furthermore, when females keep embryos and yolk-sac fry in their mouths, they do not feed, which means they may lose weight. They try to protect their young and themselves as much as possible but may sometimes lose some of the embryos and yolk-sac fry when they are attacked by other fish or predators and also when environmental conditions or water quality makes survival difficult. In most ponds, water quality is not particularly favourable for these delicate embryos and so collecting embryos as soon as they are laid and fertilized, and transferring them to an artificial system with clean water for incubation will increase the productivity. The collected eggs, embryos, yolk-sac fry or swim-up fry are collectively known as 'seed'. In most fish, fecundity is the main indicator or measure of seed productivity. However, in tilapia fecundity does not directly correlate with seed productivity because several of the above-mentioned factors affect the number of eggs or embryos that can be collected. Therefore, seed productivity in mouth-brooding tilapia is normally estimated as:

- Productivity of females:
    - No. of females with eggs
    - Per cent of spawning females
    - No. of seed per total female
    - No. of seed per kg of total female
    - No. of seed per spawning female
    - No. of seed per kg of spawning female
- Productivity of space:
    - No. of seed per unit area of hapa, tank or pond space
    - No. of seed per unit area of total water surface area used

As not all females release eggs on the same day, it is necessary to keep records of the females that provide eggs for each harvest. Environmental factors such as temperature, rainfall, humidity, light, pH, ammonia, nitrite, feed and other management factors affect breeding (Bhujel, 2000; Bhujel *et al.*, 2001). Keeping records and observing trends in relation to water quality parameters will provide information on favourable conditions which the manager needs to try to maintain and also the unfavourable conditions that the hatchery operators should try to avoid.

In order to assess the performance of females, the number of females with eggs or larvae needs to be counted while harvesting the seed. Although it can be time-consuming, the counting of females and recording should be done for each stage of seed collection. The assessment method is described as follows.

2.5.2 Yolk-sac fry/egg collection methods

Tilapias show a high degree of parental care to their eggs and fry. Females of the mouth-brooding tilapia incubate eggs in their mouths until the young can swim independently (swim-ups). These free-swimming fry can be collected from the edges of the pond, hapa or tanks at intervals of 7–21 days using long scoop nets. This system is cheap and easy, but net fry production per unit area of space is very low because it is impossible to collect all the fry from the system. For this reason it is often called the 'partial harvesting method'. Survival is also low due to predation and adverse environmental conditions. Furthermore, fry vary in size and age and if sex reversal techniques are to follow, partial harvesting does not yield good results. If harvesting is done more frequently, e.g. two or three times a day, a more uniform age and size of fry can be obtained. Grading of fry is therefore important in partial harvesting and can be done using various sizes of mesh.

In the case of a larger hatchery, fertilized eggs or yolk-sac larvae should be collected from the mouths of brooding females once every 5–7 days, using the following steps:

STEP 1. Prepare incubators and trays in the hatchery.

STEP 2. Check the water quality and that the flow rate is consistent.

STEP 3. Arrange the scoop nets for collecting the eggs from the mouths of females.

STEP 4. Arrange adequate bowls to collect eggs and transfer.

STEP 5. Prepare to get wet, wear woollen hand globe and protective shoes/ boots.

STEP 6. Untie the hapas from the bamboo poles or concrete pillars at the bottom.

STEP 7. The broodfish should be gathered in a corner of the breeding hapa by moving bamboo poles underneath the hapa and gradually towards the corner. To do this two people are needed to hold the bamboo on each side, lifting it on to their shoulders and moving slowly.

STEP 8. Care should be taken so that fish do not jump over the bamboo and out of the hapa.

STEP 9. Fish can be gathered in a corner making a triangular shape so that bamboo poles can be tied with rope to the vertical bamboo poles that support the hapa.

STEP 10. Two hand nets (large mesh and small, Fig. 2.20) can then be used together to scoop up the broodfish (Fig. 2.21). The large mesh net can be used to scoop the fish from the hapa, with the fine mesh net underneath to collect any eggs that the females release.

STEP 11. Scoop two or three fish from the water, holding both nets in the left hand so that the right hand is free.

STEP 12. With the right hand, catch every fish and observe the mouth and papillae. If they are male, they can simply be thrown back into the hapa or tank.

STEP 13. If eggs or larvae are found, they can be dislodged by putting a forefinger into the mouth of brooding females and shaking to release eggs or yolk-sac fry, which are collected in the small mesh nets (Fig. 2.22).

STEP 14. Eggs and larvae are then transferred to plastic bowls with sufficient water to remain submerged.

STEP 15. Eggs and larvae are cleaned and separated by the development stage (Figs 2.23–2.25) and kept in different bowls so that they can be transferred to separate incubators or aluminium trays.

STEP 16. Bowls are kept floating on the water surface and more eggs/larvae of the same stage are mixed from other females.

STEP 17. Once all the broods in each hapa or tank are checked, seeds are transferred to the hatchery for cleaning, keeping them in separate bowls (Fig. 2.23) at each stage described in the following section.

Fig. 2.20. Green and white scoop nets for seed collection from mouths of female tilapia.

Fig. 2.21. Catching brooders for egg collection.

Fig. 2.22. Egg collection from the mouth of tilapia.

2.5.3 Staging of eggs

During harvesting, eggs or yolk-sac larvae are separated by stage (Little *et al.*, 1993). Normally, each stage takes roughly one day for embryonic development. These are arbitrary stages (Fig. 2.24) that can be observed with the naked eye and used for the purpose of making field work easier:

Stage I. Just fertilized, yellow in colour without any eye spots.
Stage II. With two eye spots.

Fig. 2.23. Eggs and larvae are cleaned with tap water after collection (left) and are passed through a metal sieve (right) to separate stones, soil, fish scales and other larger particles.

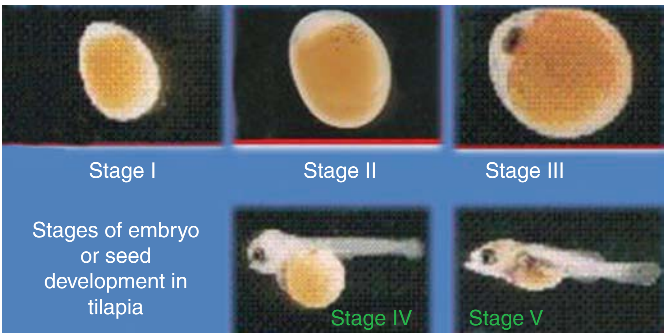


Fig. 2.24. Stages of tilapia eggs.

Fig. 2.25. Tilapia of different stages separated by age when they are collected from the mouths of breeding females.

Stage III. Darker in colour and with small tail and protruding eyes.
Stage IV. With longer tail and head.
Stage V. Swim-up fry.

2.5.4 Cleaning and disinfecting

The harvested eggs and yolk-sac larvae are transferred to the hatchery. Before putting them into the incubators and trays, the following steps should be carried out:

STEP 1. Wash the eggs, keeping them separate in bowls with clean tap water so that any floating dirt can be taken out.

STEP 2. Pass the eggs or yolk-sac fry through a fine metal net (500 micron) so that heavy soil, sand, fish scales, etc. can be separated out.

STEP 3. Put all the eggs from each stage into a small hand net so that water from the bowl passes through the net and into the sink.

STEP 4. While eggs are still in the small hand net (Fig. 2.26), dip them in a 40% formalin (4 ml/2 l = 200 ppm) solution for 1–3 min to disinfect. Younger eggs (Stage I) need to be in this solution for longer, i.e. 3 min, while swim-up fry only need 1 min.

STEP 5. Rinse them using clean water in a separate bowl for 30 s.

STEP 6. Again dip them in acriflavin (1 g/200 l water) solution for about 30 s for each stage.

STEP 7. Rinse again in clean water for another 30 s.

Fig. 2.26. Trainees learning how to disinfect tilapia eggs before putting them in an incubator and tray system.

STEP 8. Weigh them separately using a digital balance to an accuracy of 0.1 g.

STEP 9. Place the disinfected eggs into downwelling incubator jars (Fig. 2.27), which are supplied with constantly flowing water filtered through slow sand.

STEP 10. If the eggs are hatched (Stage IV or later) they are directly placed in the tray system.

2.5.5 Sampling and estimation

Estimation of eggs, yolk sac larvae and swim-up fry is quite difficult. Some hatcheries use volumetric methods while most hatcheries do not bother even to estimate the number they harvest or collect. However, as part of good management practice and from the point of view of making decisions based on the information, recording of seed before and after passing through each stage of the production process is required so that the efficiency of each system can be determined or evaluated. More importantly, it can be predicted whether the hatchery is going to meet its target. For this purpose the following steps should be taken.

STEP 1. Take a sample from each stage of seed after cleaning.

STEP 2. Count 200 eggs from each stage.

Fig. 2.27. Series of incubators and trays in a hatchery in Bangladesh.

STEP 3. Weigh them using a two digit precision electronic balance (0.01 g).

STEP 4. Weigh the total seed by stage.

STEP 5. Then calculate the number of seed per stage using the following equation:

Total no. of seed = (200/weight of 200 eggs) × weight of total eggs

STEP 6. Record the data on each harvest day in an Excel spreadsheet as shown in Table 2.4.

Table 2.4. Sample of seed harvest record.

Harvest date: 6/3/2013							
Pond A	Sample 1	Sample 2	Sample 3	Average	Total gram	Total no.	Grand total
Stage 1	1.04	1.10	1.11	1.08	650	20,000	
Stage 2	0.96	1.13	0.99	1.03	26	5,065	
Stage 3	1.00	0.95	1.05	1.00	246	49,200	
Stage 4	1.44	1.39	1.44	1.42	422	59,297	
Stage 5	1.55	1.38	1.69	1.54	30	3,896	
	Total			1.21	1,374	237,458	237,458
Date: 13/3/2013							
Pond B	Sample 1	Sample 2	Sample 3	Average	Total gram	Total no.	
Stage 1	1.08	1.12	1.12	1.11	300	54,217	
Stage 2	0.96	1.13	0.98	1.02	60	11,726	
Stage 3	1.00	0.98	1.05	1.01	200	39,604	
Stage 4	1.50	1.39	1.45	1.45	600	82,949	
Stage 5	1.58	1.37	1.60	1.55	20	2,581	
	Total			1.23	1,180	191,077	191,077
Date: 20/3/2013							
Pond C	Sample 1	Sample 2	Sample 3	Average	Total gram	Total no.	
Stage 1	1.03	1.10	1.11	1.08	650	120,370	
Stage 2	0.95	1.13	0.99	1.02	26	5,081	
Stage 3	1.01	0.95	1.05	1.00	146	29,103	
Stage 4	1.46	1.39	1.44	1.43	402	56,224	
Stage 5	1.54	1.38	1.69	1.54	30	3,905	
	Total			1.21	1,254	214,683	214,683
	Grand total						643,219

2.5.6 Incubation system designs and technique

After eggs are collected from the mouths of females they are incubated artificially in simple jars supplied with water filtered by a slow sand filter with or without a biological filter in a water recirculation system.

Initially, the use of conical vessels, shaking tables and various containers was tried such as simple coke bottles and white water bottles (Macintosh and Little, 1995). However, locally made semi-transparent fibreglass jars were found to be suitable because their rough walls accelerate the process of removing egg shells and so facilitating egg hatching. Various hatcheries continued to explore the possibilities of using new and cost-effective containers including simple plastic jugs, tall glass jars, and so on. Recently, simple plastic jars with a special spout on top (Fig. 2.27) have become commonplace, mainly because they are easily available in local markets at low cost, and are more transparent so that the hatchery operators can easily see the eggs, and they are also lighter and easier to handle or transport.

As tilapia eggs are heavy and remain at the bottom, they need to be moved gently so that they are not damaged or stay at the bottom without getting adequate oxygen. For this purpose, up- and downwelling water flows into the jars were compared and the downward water flow was found to be better; this has become the standard method and is used by most hatchery operators across the world. The flow of water is adjusted in such a way that all the eggs are gently churned or agitated constantly throughout the day and night. Normally, freshly laid eggs (yellow eggs) take about 4 days to hatch at a water temperature of about 26–28°C. Embryos from each subsequent stage take one day less to hatch because each stage takes approximately one day to develop.

Figure 2.28 provides a layout view of the hatchery system to be within the covered area. Figure 2.29 shows sand and biological filtration systems and two twin header tanks from where clean water is supplied to the incubators and tray systems and recirculated back again and again throughout the day and night. Figure 2.30 shows a cross-section of the hatchery and Fig. 2.31 provides a closer look at an incubator in which 50,000–100,000 eggs can be incubated in small 2–4 l jars, whereas large fibreglass incubators (6 l, Fig. 2.32, right) can accommodate more than double this number.

In the hatchery it is advisable to have a separate recirculation system for incubation jars and larval rearing trays because if one system fails, the other will still work, avoiding interruptions in the production and supply of fry. However, due to cost implications, many smaller hatcheries tend to combine them in one. The hatchery system is relatively cheap and no sophisticated equipment is needed. Other than one pump, no other machinery is required. A few metres of simple PVC pipe, 15–20 plastic jars or jugs (Fig. 2.33), 40–50 aluminium trays and 10,000–20,000 l of water lifted up to a header tank by a pump and flowing down by gravity can run this million-dollar tilapia hatchery business. In order that technicians and trainees are careful and realize the value of what they are doing, they are told that one egg is equivalent to US$1 because ultimately, one egg will be 1 kg fish, which can earn at least $1 at farm gate

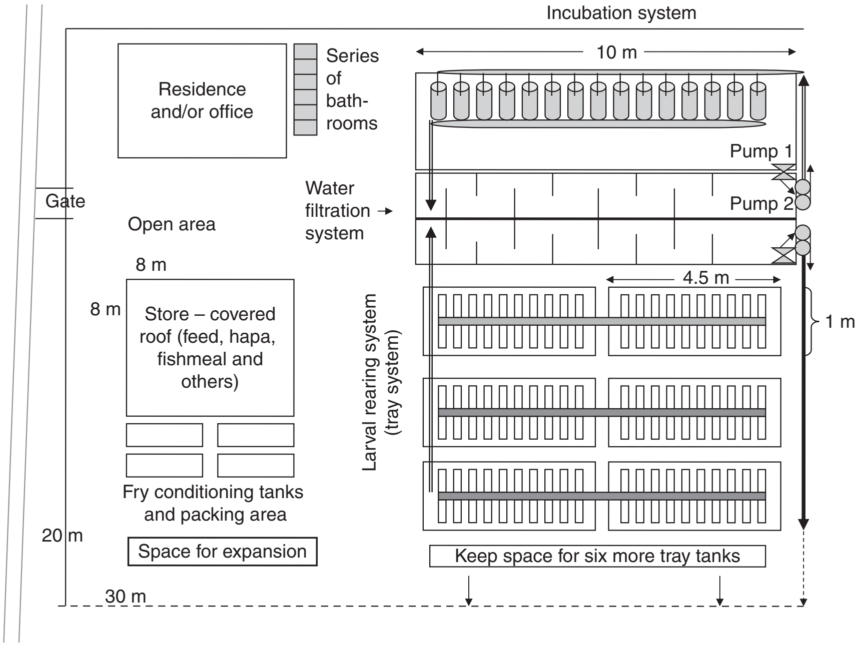


Fig. 2.28. Layout of a hatchery.

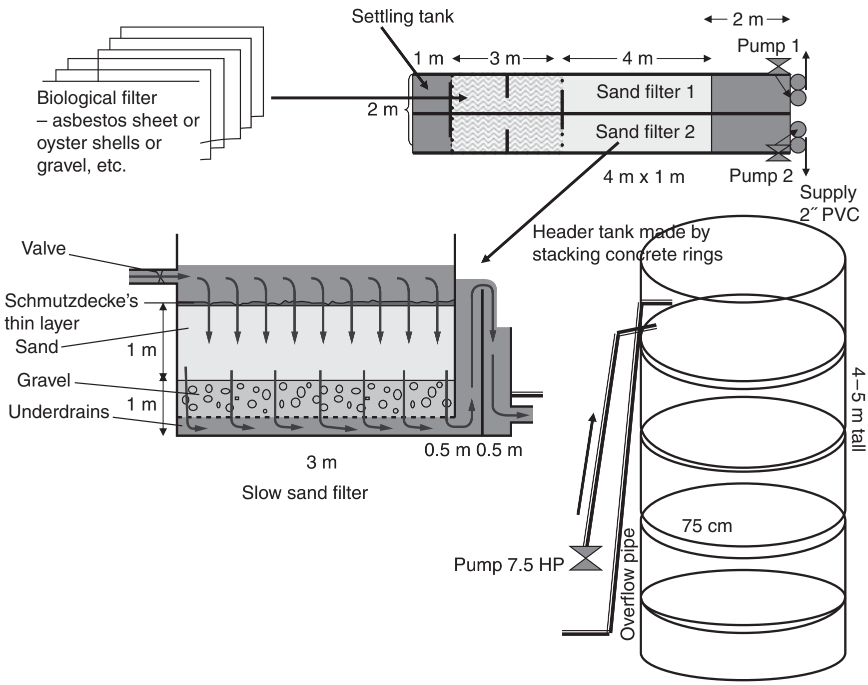


Fig. 2.29. Sand and biological filtration system including header tank.

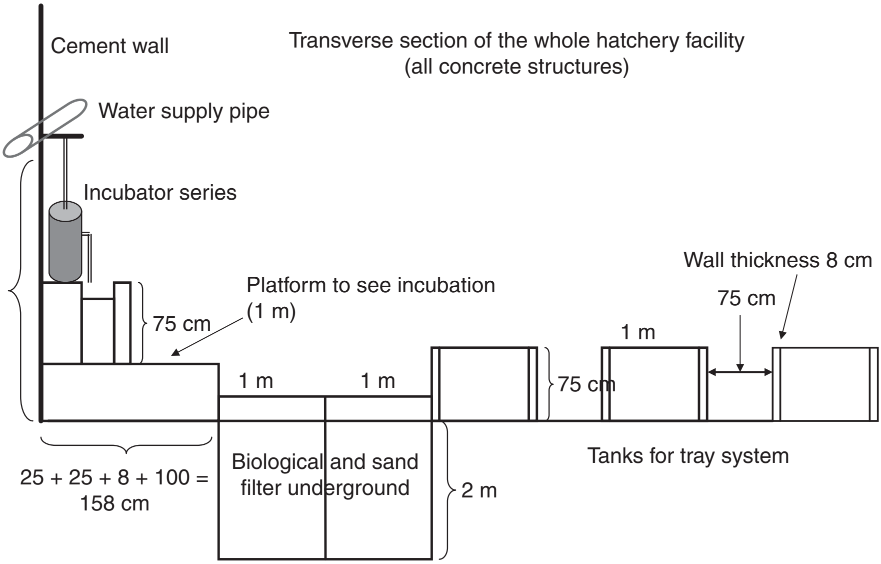


Fig. 2.30. Transverse section of a tilapia hatchery.

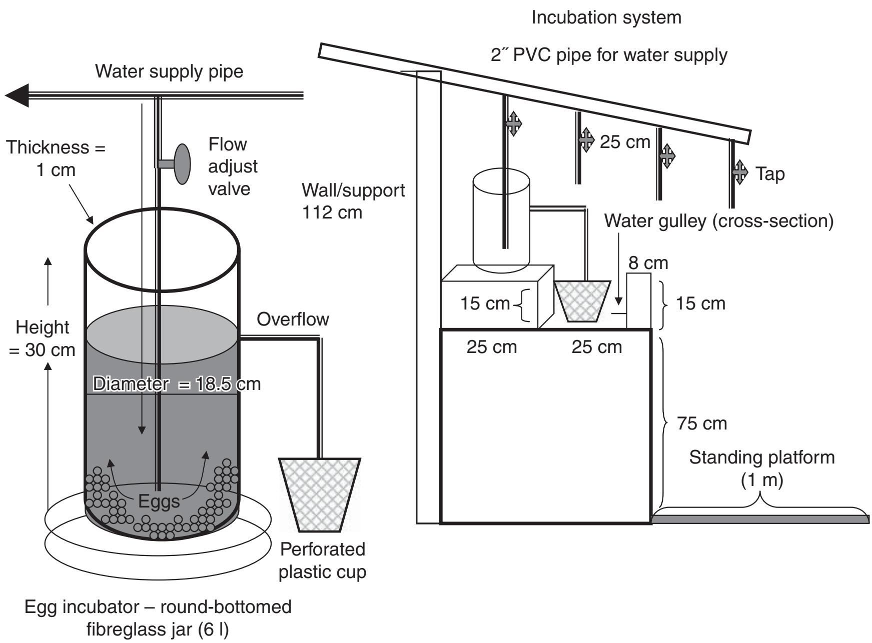


Fig. 2.31. Egg incubation system.

prices. This can help them realize that if something goes wrong, all the eggs in an incubator can die overnight, especially if the electricity is cut off for any reason. If this happens, someone needs to be awake to start up the generator. If no one notices, just one day means thousands of eggs may be wasted. For example,

Fig. 2.32. Transferring the eggs from bowl to incubator using siphoning (left) and tilapia eggs in a locally made fibreglass incubator jar used in Thailand (right), which can accommodate about 1 kg of eggs, i.e. about 200,000 eggs.

Fig. 2.33. Plastic jugs used in Chiang Mai, Thailand as low-cost incubator jars.

an incubator (Fig. 2.27) can contain 100,000 eggs, with potential earnings of $100,000. Similarly, each tray (Figs 2.34 and 2.35) contains 10,000–30,000 yolk-sac or swim-up fry. A little effort put into caring for the eggs and larvae can have a huge impact on the profitability of the hatchery business.

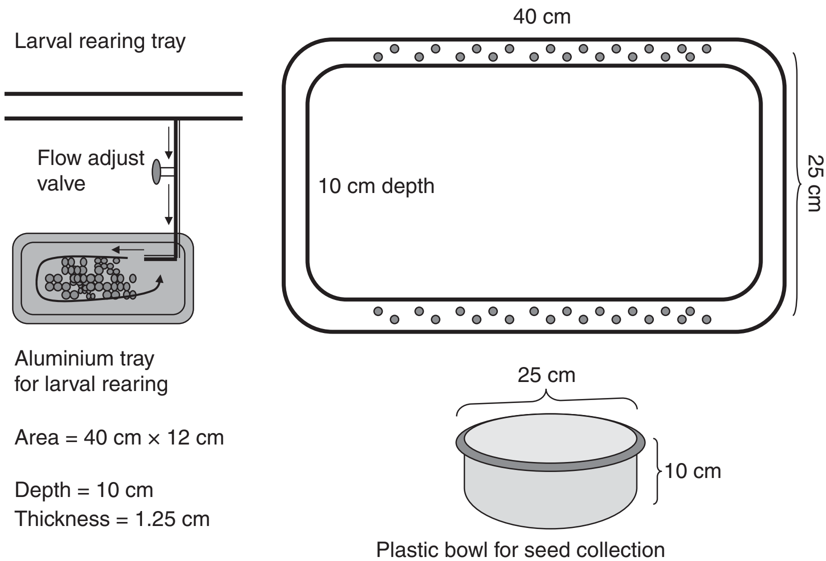


Fig. 2.34. Diagrammatic descriptions of tray and bowl.

Fig. 2.35. Aluminium trays are prepared by making holes on the long side of the wall. A piece of hapa net is glued with silicone gel so that water can go out but yolk-sac fry or swim-up fry remain in the trays, which can hold a few thousand up to 40,000 fry.

2.5.7 Larval rearing

Finding a suitable system for post-hatch fry rearing was another challenge. The use of shallow trays for yolk sac-fry was another innovation that made it possible to rear a large number of fry in shallow metal or plastic trays supplied

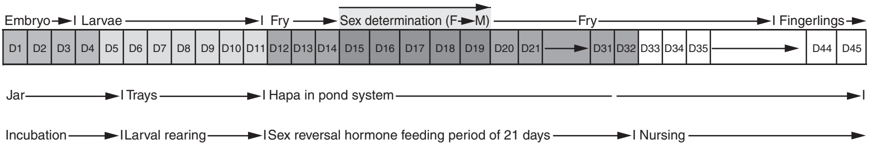


Fig. 2.36. Stages of seed and activities from the collection of eggs until fry sales.

with water that is oxygenated by gentle movement, created by the water itself falling from a simple tap connected to a slow sand filter and/or a biological filter. Depending on the stage of egg harvest and temperature of water in the hatchery, hatching may occur within 4 days for the Stage I eggs or the freshly laid 1-day-old eggs, within 3 days for Stage II, and within 2 days for Stage III seeds. If the Stage IV and V swim-up fry are harvested, they are directly placed in the trays, bypassing the incubation jars for larval rearing for about 7 days (Fig. 2.36).

Immediately after hatching takes place, all yolk-sac fry from incubation jars are transferred to shallow trays supplied with recirculated clean water. Some hatcheries wait until fry become swim-up in the jar and come out by themselves. However, if fry are allowed to come out by themselves, time is lost which means fry remain longer in the hatchery before they are moved to the sex reversal system. If the fry are older they cannot be converted to all males because sex determination takes place 12–15 days after hatching.

A number of trials studying the effects of factors such as fry density per day and water flow rate on fry survival showed that higher densities, e.g. 20,000–30,000 yolk-sac fry, are better, although a few hundred to a couple of thousand fry can be reared in a tray depending upon the scale of the hatchery.

2.5.8 Data recording and performance evaluation

Table 2.5 is used to record the incoming eggs or yolk-sac larvae in the hatchery for incubation and Table 2.6 for the larval rearing fry coming in from incubation and outgoing swim-up fry for sex reversal. Percentage outputs are considered the performance indicators for both these systems.

2.6 Monosex Fry Production

2.6.1 Why monosex?

Normally male Nile tilapia grow approximately 50% faster than females and can sometimes be double the size of the females. Therefore farmers want all male fry so that they can harvest more biomass. In addition, by growing all

Table 2.5. Data sheet template for the incubation performance records.

Date of seed out from the hatchery	Incubator jar no.	Number of eggs in (a)	No. of yolk-sac fry out (b)	% output = (b/a × 100)	Remarks
11/03/2013	#1	80,000	60,000	75%	Good
18/03/2013	#2	75,000	50,000	67%	Low
–					
–					
–					
–					
–					
–					
–					
–					
Total		155,000	110,000		
Average		77,500	55,000	71%	

Table 2.6. Data sheet template for the larval rearing (tray) performance records.

Date of seed out from the hatchery	Incubator jar/try no.	Number of yolk-sac fry in (a)	No. of swim-up fry out (b)	% output = (b/a × 100)	Remarks
15/03/2013	#1	60,000	40,000	67%	Good
22/03/2013	#2	50,000	36,000	72%	Good
–					
–					
–					
–					
–					
–					
–					
–					
Total		110,000	76,000		
Average		55,000	38,000	69%	

male fry, energy is saved that would be required for reproductive activities such as nest building, guarding and release of sperm and ova. More importantly, using hormones can convert females into phenotypic males, so all the fry can be used as monosex fry. Some earlier methods suggested manual sexing to separate males and grow them on, discarding the females, but this means that 50% of fish are lost. At the same time, separating by sex is time- and labour-intensive. As a result the hormonal sex reversal technique has become very common.

2.6.2 Hormonal sex reversal

Early nursing of fry can be carried out in hapas, ponds, canals, tanks, etc. and is usually done for about a month. Although there have been many attempts at producing all male tilapia fry, the hormonal sex reversal technique has been the most reliable and common method. The period of sex reversal can be divided into two phases: a 21-day hormone treatment phase followed by 10–30 days of nursing. Feeding young fry with a male hormone (17α-methyltestosterone) produces phenotypically (not genetically) all male fry. This stops breeding in grow-out systems, diverting the energy that otherwise would have been lost in the form of gamete production and performing reproductive activities. For sex reversal, 60 mg of 17α-MT is mixed with 1 kg of fishmeal together with 20 g of vitamin C or vitamin mixture.

Swim-up fry are then transferred to a sex reversal system (hapa in pond or tanks). Up to this point, fry are not fed. By the time they are transferred and MT feeding starts, fry are 10–11 days post-hatching. It is essential to start MT feeding from this age because sex determination takes place 12–15 days post-hatching. When they start taking MT feed, the level of testosterone hormone in their body increases, which directs the sex towards male. If MT feeding begins late, or when they are older than 15 days, sex reversal will not be possible. This is one of the fundamental principles the hatchery operators need to keep in mind if they want to achieve the goal of producing all or nearly all male fry.

Several trials have been conducted to try and improve survival and increase the percentage of males in the fry populations. These included determining the optimum dose of MT in feed, frequency and length of feeding period and so on. As a result a high percentage of males (100% or close to) has been consistently achieved. Methods of nursing and advanced nursing, when fry need to be kept for a longer period, have also been developed through research (Little *et al*., 2003).

2.6.3 Sex reversal feed preparation

STEP 1: STOCK SOLUTION PREPARATION. As the hormone is insoluble in water, ethyl alcohol or ethanol (organic solvent) is necessary to dissolve it. The alcohol then helps distribute the hormone evenly in each particle of feed/fishmeal; it can then be evaporated off easily and quickly at room temperature. When making stock solution, normally 5 g of 17α-MT hormone is dissolved in 1 l of ethyl alcohol using a magnetic stirrer. The volume is then made up to 10 l (by adding 9 l), which serves as a stock solution and can be stored for about 6 months in a refrigerator at about 7°C. The stock solution contains 0.5 mg of MT hormone per ml of alcohol, which means that 120 ml of stock solution is required per kg of feed or fishmeal to deliver the required dose of 60 mg/kg feed. Another 120 ml of fresh alcohol per kg fishmeal is added when preparing the feed.

STEP 2: MT FEED PREPARATION. When preparing MT feed, 10 kg of feed (high quality fishmeal or shrimp starter diet) is churned in a mixer, with the gradual addition of 600 ml of stock solution and then another 600 ml of fresh alcohol (Fig. 2.37). This process is repeated, again doubling the stock solution and hormone. After churning feed for about 15–20 min, it is ready to collect (Fig. 2.38) and dry in the shade. The alcohol is evaporated by spreading the mixed feed out in the shade for about 1 h. Feed should not be dried under intense sunlight because the hormone will degrade. After drying, the feed should be packed in a plastic bag or kept in a container with a tight lid and stored in a room at a low temperature (4–7°C).

ALTERNATIVE METHOD FOR STEPS 1 AND 2. The method described above is practised in Thailand and other South-east Asian countries. Another way of preparing stock solution and MT feed which is practised in Bangladesh is to calculate the amount of feed requirement. For example, if total feed requirement is 40 kg for a week, the amount of hormone required will be 60 mg × 40 = 2400 mg or 2.4 g. This is dissolved in 2 l of ethanol and kept in a freezer as stock solution. When preparing feed, e.g. 10 kg at a time, they take 500 ml, i.e. one-quarter of the stock solution prepared for 40 kg total feed, and mix it with 1500 ml of fresh ethanol, which is sprayed on to the fishmeal while churning in the mixer.

Fig. 2.37. Mixing MT hormone while preparing sex reversal feed.

Fig. 2.38. MT feed is spread to dry in a large, flat bowl and kept in a dry area.

2.6.4 Feeding MT feed

Normally 20,000–30,000 swim-up fry are stocked in small hapas of 3 × 1.8 m (= 5.4 m^2, often referred to as a 5 m^2 hapa) in size at a density of 5600/m^2. They are fed with the MT mixed feed at 15, 30, 50 and 84 g/day for the period of days 1–5, days 6–10, days 11–15 and days 16–21, respectively (Table 2.7). When preparing the daily amounts of feed, each day's feed for a batch of fry is filled into a plastic bag (which should have an opening but that can be closed to make it airtight). Feed is divided into five equal portions and the fry are fed five times a day. The person feeding them estimates one-fifth of the amount for each meal and feeds that amount each time. Normally feeding times begin after the sun becomes strong, e.g. at 8 am, then every 2 h. However, in some cases it is difficult to obtain 20,000 fry ready to start sex reversal. In this case, some hatcheries use a rule of thumb such as that below 20,000, they feed half of the normal rate. Similarly, if below 10,000 then the rate becomes one-quarter. The calculation of feed is shown in Table 2.7. Alternatively the calculation can be done using a conversion factor, i.e. amount of feed for normal density/30,000 × estimated number of fry.

Using Tables 2.7 and 2.8, feed requirements for a day or more can be calculated. As an example, on 2 July, if a technician needs to calculate the requirement of SRT feed to prepare for the following day (3 July)

STEP 1. Count the number of hapas to feed for days 1–5, i.e. 3 + 2 + 3 + 1 = 9 hapas.

STEP 2. Calculate the amount of feed, i.e. number of hapas × normal daily rate × conversion factor for specific number, e.g.

= 3 × (75/2) + 2 × (75/4) + 3 × (75/4) + 1 × 75 = 281.25 g

STEP 3. Number of hapas to feed for days 6–10, i.e. 1 + 1
Amount of feed, i.e. 150 + 150 = 300 g

Table 2.7. Feeding amount during sex reversal period of 21 days.

	Amount of feed (g)			
	Normal density (30,000 fry)		Low density (15,000 fry)	
Days	Per meal	Per day	Per meal	Per day
Day 1	15	75	7.5	37.5
Day 2	15	75	7.5	37.5
Day 3	15	75	7.5	37.5
Day 4	15	75	7.5	37.5
Day 5	15	75	7.5	37.5
Day 6	30	150	15	75
Day 7	30	150	15	75
Day 8	30	150	15	75
Day 9	30	150	15	75
Day 10	30	150	15	75
Day 11	50	250	25	125
Day 12	50	250	25	125
Day 13	50	250	25	125
Day 14	50	250	25	125
Day 15	50	250	25	125
Day 16	84	420	42	210
Day 17	84	420	42	210
Day 18	84	420	42	210
Day 19	84	420	42	210
Day 20	84	420	42	210
Day 21	84	420	42	210
Total amount		4895		2448

STEP 4. Number of hapas to feed for days 11–15, i.e. 1 + 1 + 2
Amount of feed = 250 + 250/2 × (250)/2 = 625 g

STEP 5. Number of hapas to feed for days 16–21 = 2
Amount of feed = 2 × 420 = 840 g

Therefore, the total amount of feed required for 3 July = 281.25 + 300 + 625 + 840 = 2046.25 g (i.e. approximately 2.05 kg). In similar ways, feed can be calculated for a week, prepared all at once and kept in cold storage or a simple refrigerator at 4–7°C.

The size of the hapas during hormone treatment for sex reversal depends on the scale of operation. For larger hapas, e.g. 10 m^2 or 40 m^2 or even larger, the number of fry will be multiples of the density used for 5.4 m^2 and so will the amount of feed. For example, the maximum number of fry to be stocked and the amount of feed for a 10 m^2 hapa for the first day will be 60,000 fry and 150 g (75 × 2), respectively.

Table 2.8. Feeding records for sex reversal.

Date of fry stocking	Batch no.	Pond no.	No. of hapas	Sex reversal period (days)				No. of fry per hapa (5.4 m^2)
				1–5	6–10	11–15	16–21	
17/6/2013	10th	A1	2	18–22	23–27	28–2	3–8	20,000
18/6/2013	11th	A1	1	18–23	24–28	29–3	4–9	25,000
20/6/2013	12th	A1	1	21–25	26–30	1–5	6–10	15,000
21/6/2013	13th	A1	2	22–26	27–1	2–6	7–12	12,000
23/6/2013	14th	A1	1	24–28	29–3	4–8	9–14	30,000
25/6/2013	15th	A1	1	26–30	1–5	6–10	11–17	20,000
28/6/2013	16th	A2	3	29–30	4–8	9–13	14–20	15,000
30/6/2013	17th	A2	2	1–5	6–10	11–15	16–21	8,000
1/7/2013	18th	A2	3	2–6	7–11	12–16	17–22	6,000
2/7/2013	19th	A2	1	3–7	8–12	13–17	18–23	22,000
..								
..								
..								
To continue…								

Feeding of SRT fry is very important because it will ultimately impact on the quality of fry, especially the percentage of males. Feed has to be spread out well so that all the fry in each hapa have an equal chance to get hormone mixed feed. Normally, a cup tied to a long bamboo stick is used to take the feed close to the middle of the hapa while feeding (Fig. 2.39). Some hatcheries are feeding more than five times a day while others are feeding for more than 21 days, both of which are unnecessary – more frequent feeding is time-consuming and more days of feeding wastes both hormone and feed.

Keeping records is a tedious job, but it helps managers to assess the real-time situation and correct it if anything goes wrong, preventing a huge loss. More importantly, analysis of time series data and seeing simple trends can help steer the production line based on the seasonal variation in demand and sales. There are always good lessons to be learned and more recently keeping such data has also been necessary from the point of view of Best Management Practices (BMP) and obtaining certification.

Sex reversal can also be done using a tank system (e.g. Fig. 2.40) with water recirculation. Some hatcheries either feed hormone for 7 days, keeping fry in tanks, followed by 14 days in a hapa-in-pond system or an entire 21 days in the tank system. The idea of feeding fry kept in tanks is to make the fry more liable to accept feed containing the hormone compared to a green water hapa-in-pond system where plankton is available. Extra care should be taken in tanks, as fry will be at high stocking densities, and feeding high-protein feed means high ammonia production. Space is limited and there may be heavy mortality. Aeration becomes necessary, which adds an extra cost to the farmers. Because of the high cost of operation, as well as capital investment, very few large farms or companies use a tank system,

Fig. 2.39. MT feed being distributed to fry.

Fig. 2.40. Sex reversal in indoor tanks with aeration and water recirculation system.

although they are easier for staff to work and manage. Therefore, the vast majority of hatchery operators do not think it necessary and stock fry directly into hapas installed in ponds; hapas should cover only one-third of the water surface area so that excess feed and ammonia can be diluted in the pond water.

2.6.5 First grading and nursing

Grading of fry is very important after the initial development stages to minimize mortality caused by cannibalism and social dominance, as tilapia fry are aggressive in nature. The first grading is done 1 month after hatching, followed by a second grading event 1 week later (or a day before sale). Fry are grouped into three to five categories such as small, medium, large and very large (Figs 2.41 and 2.42). During nursing (10–30 days), fry should be kept at a density of 1000–2000 fry/m^2 in the hapa. The size of the hapa can be between 20 and 120 m^2, depending upon the scale of production.

Fig. 2.41. Fry graders with float.

Fig. 2.42. Grading of fry by size after sex reversal.

2.6.6 Feeding after sex reversal

High-quality starter rations (35–40% CP) are available, which may be specially prepared for tilapia or other species. However, tilapia fry do not need to be fed with a high-quality diet. Normally, fry are fed on a locally prepared mixture of rice bran and fishmeal (2:1 ratio) four or five times a day at about 25–50 g/m^2 of hapa per day. Assuming that fishmeal contains about 60% CP and rice bran contains 10%, this mixture contains approximately 27% CP ($60 \times 1/3 + 10 \times 2/3 = 27\%$), which is adequate for a green water system. However, if fry are raised in a clear water tank system, a higher protein diet, i.e. about 35%, may be necessary.

2.6.7 Data recording and performance evaluation

Table 2.9 can be used as a template to record data on sex reversal and see the performance of the system as percentage output.

Table 2.9. Data sheet template for sex reversal survival records.

Date of seed out from the sex reversal hapa	Sex reversal hapa no.	Number of swim-up fry in (a)	No. of SRT fry out (b)	% output = (b/a × 100)	Remarks
2/4/2013					
9/4/2013					
–					
–					
–					
–					
–					
–					
–					
–					
To continue……					

3 Fry Nursing

3.1 Background

Fry nursing can be a separate and independent business. It requires little time and so nursing farmers can get a quicker and more regular income, possibly monthly. However, in most cases the hatcheries themselves do the fry nursing. On the other hand, grow-out farmers may also want to nurse fry in order to make sure they have enough fry whenever they need them. Purchasing smaller fry can be economical for them as the price of small fry is low. However smaller fry, i.e. less than 5 g, are more susceptible to predation by other fish, especially carnivorous species such as catfish and snakehead, as well as other animals such as snakes, birds, frogs, and so on. Smaller fish are also less tolerant to poor water quality, which is a common feature of ponds with organic manures. Factors such as these increase mortality rates, particularly in the first month of growth. Therefore, if they are nursed for at least a month before stocking them into grow-out ponds, their survival can be increased considerably.

Fry nursing methods can be briefly described by the following steps:

STEP 1. Use a small pond (50–500 m^2) or a hapa in a pond (Fig. 3.1), reservoir or lake, any of which are ideal for nursing. The system should be well protected from birds and other predatory fish or animals, e.g. net cover, barbed wire fence or walls.

STEP 2. Drain the pond and dry it completely in the sun for at least a week or so, until cracks appear in the mud at the bottom.

STEP 3. Broadcast lime at the rate of 300–500 kg/ha.

STEP 4. Fill with clean water using nets in the inlet pipe to prevent the entry of predators.

Fig. 3.1. Nursing of fry in hapas installed in a green water pond.

STEP 5. Fertilize the ponds at least a week in advance with 60 kg urea/ha/week and 30–60 kg TSP or DAP to develop the green colour. Later on, uneaten feed and the fish excreta will maintain the green colour. Overly green water is also undesirable during nursing and so organic manures are not recommended.

STEP 6. Stock fry at a density of 500–1000 fry/m^2 in a hapa or cage and 100–200 fry/m^2 in a pond.

STEP 7. Feed the fry with floating pellets or with a mixture of rice bran and fishmeal (2:1) three or four times a day at about 5–12% of biomass or to satiation level. Feeding rate should be higher at the start and be reduced by 1% on a weekly basis.

STEP 8. Nurse the fry for about 1–2 months, depending upon the demand. When fry are around 5 g (fingerlings) or bigger they are suitable to stock into grow-out ponds. The bigger the fingerlings the higher will be the survival.

STEP 9. Separate the fry based on their size: small, medium or large.

STEP 10. Stock the fingerlings into separate ponds based on their sizes.

STEP 11. It is necessary to manage the timing of fry purchase with the period of nursing, fry harvest, preparation of the grow-out pond and fry stocking.

Grow-out farmers should obtain fry 1–2 weeks prior to harvest of the previous crop. After harvesting it takes at least 2 weeks to prepare (draining, drying, liming, filling and fertilizing) a pond, during which fry can be nursed in other smaller ponds or hapas. Some hatcheries use large ponds covering more than half the space including the middle part of the pond. It is advisable to construct rectangular ponds (Fig. 3.2) so that hapas can be installed along the four sides or dykes. This makes it easier for feeding and reduces turbidity caused by workers walking around.

Fry nursing can also be done in indoor tanks or outdoor shaded tanks made of cement or fibreglass (Fig. 3.3) where land is expensive and extra security is required. However, in such cases a water recirculation system has to be built and maintained.

3.2 Advanced Nursing

The level of seed demand is unpredictable in different seasons and also differs year to year for the same season. Tilapia culture is mostly dependent on rainfall, which is the main source of water to fill the ponds. It is common to have large numbers of unsold fry during the dry season. Similarly, fry can be kept at

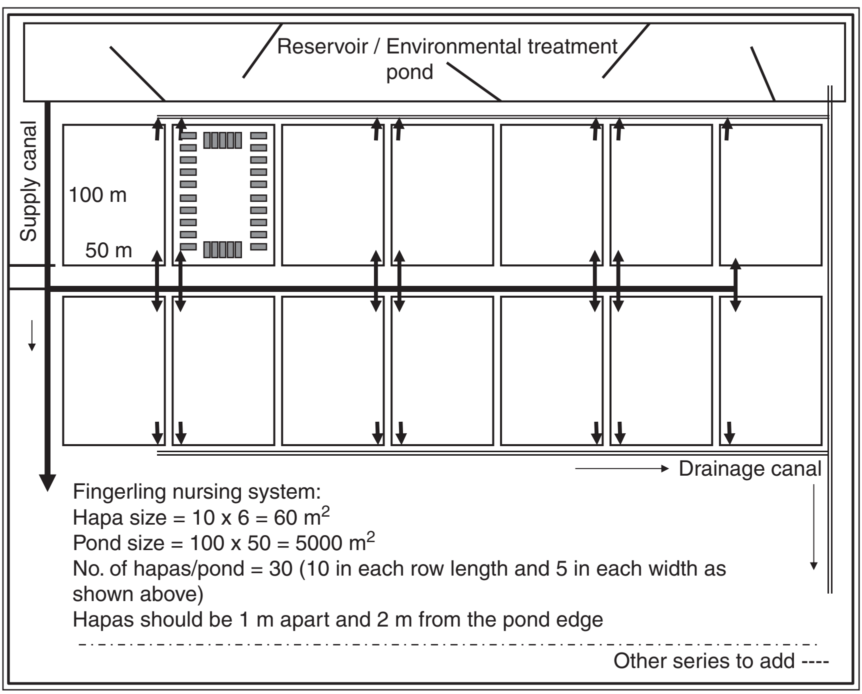


Fig. 3.2. Fry nursing facility: hapas in ponds.

Fig. 3.3. Fry nursing in fibreglass tanks with aeration and water recirculation system.

high densities during the cold season, and sold early in the next warm season at higher prices. Advanced nursing is necessary for the following reasons:

- to hold fry during low fry demand;
- to keep stock of fry for the high demand season;
- to minimize feed and feeding costs;
- to grow fry to a larger size, which means more protection from predators;
- to have high potential growth (compensatory growth); and
- to fetch higher prices from bigger fry.

Advanced nursing is sometimes called ‘stunting’ or ‘overwintering’, depending upon the purpose and the facilities used.

Intentional storing of fish at high densities with the minimum amount of feed to keep them alive is stunting. This can be done at any time of the year and hapas or cages in ponds can be used. About 2000 fry/m^2 can be stocked in the hapa or cage and fed with a mixture of fishmeal and rice bran (1:2). Feeding rate is maintained at 3, 2 and 1% biomass per day for the first, second and third months, respectively.

Overwintering is a common practice in countries where winter temperatures are generally below 20°C, in which fish do not eat and grow normally. The main objective is to save the fry/fingerlings during these cold season periods. Overwintering of fry/fingerlings can be done in several ways: using warm water from a heating facility or geothermal water, greenhouses or plastic coverings for insulation, and stocking in deep ponds and tanks, or deep hapas in ponds. The former methods are cost intensive although survival is usually higher. The most popular overwintering method used by farmers in northern Vietnam (where winter temperatures can be around 12°C) is stocking seed in deep ponds. This method can be summarized as follows:

- A pond is constructed in a position where the maximum light intensity can be received.
- The pond depth is more than 2.5 m.
- Prior to stocking, the pond is limed and filled with fresh clean water.
- After stocking, feed and fertilizers are not usually applied.
- Fry/fingerlings are fed at a rate of 1–2% body weight per day when the water temperature rises above 16°C.

3.3 Fry Marketing and Sales

Marketing is an important aspect of seed production. In order to increase seed production and sales, a good marketing strategy is needed. The fundamental principle is that it is wise to produce seed at a time when there is a high demand. Demand for fry is seasonal. As fry cannot be stored for long periods (3–4 months), production has to be streamlined with the demand. It is extremely difficult to forecast, but an experienced manager can possibly determine demand patterns over time. Advanced nursing or overwintering (see Section 3.2) can be a valuable tool to produce returns in the following season on previously unsold fry.

When fry/fingerlings are sold and transported, the following steps should be taken:

STEP 1. Nurse the fry/fingerlings in small hapa(s) before delivery.

STEP 2. Keep them in an area easily visible and accessible to potential customers, e.g. close to the side of the road.

STEP 3. Use media or contacts to inform farmers or fry traders about the quantity, quality and the price of fry, for which appropriate media have to be selected.

STEP 4. If there is over-production, advertise on TV, radio or other mass media. TV and radio have been found to be very effective but are expensive. News articles and small advertisements in aquaculture/agriculture magazines can be very effective.

STEP 5. Develop a feedback form and ask farmers who purchase fry to fill them in and return them by post, or bring them back the next time they come to buy a batch of fry/fingerlings. Customer satisfaction is key to attracting more clients and word of mouth advertising should not be overlooked. A satisfied local customer can bring many of their neighbours, relatives and friends.

STEP 6. If necessary, decrease the price for a limited period, giving a deadline, and advertise because this can attract more customers even though it may decrease overall profits.

3.4 Final Grading and Preparation

As the size uniformity of fry at sale is one of the most important apparent indicators of quality, final grading is an important task in tilapia hatcheries or nursery farms. If the farmers see the uniform sized fry actively swimming, they immediately feel that fry quality is good. Although the percentage of males is the main quality indicator in monosex tilapia seed, it can only be detected when farmers grow fish and do not see any fry in their ponds, which may take

3–4 months or even longer. Another purpose of grading is to offer a wide range of fry with varying price tags. Figure 3.4 shows the mesh size used to make graders and Table 3.1 shows the normal process and size categories of commercial hatcheries.

3.5 Fry Conditioning

Fry need to be prepared for transport before they are packed. The main problems during fish transportation are shortage of oxygen, high ammonia production from excreta, high temperatures (in hot seasons or areas), and stress due to handling. In order to avoid these problems, the following steps are taken:

Fig. 3.4. Grading (left) using varying mesh sizes which categorize fry into seven size classes as shown in Table 3.1.

Table 3.1. Grading fry to separate by size category.

Size category	Size groups	Size of fish (g)	Mesh size (cm)	Price of fry (Baht[a])
1	Too small	<0.1	–	0.28
2	Very small	0.1–0.2	0.5	0.30
3	Small	0.2–0.5	0.75	0.32
4	Medium	0.5–1.0	0.9	0.35
5	Large	1–3	1.0	0.50
6	Very large	3–5	1.25	1.00
7	Extra large/ fingerlings	>5	1.5	2.00

[a]Note: US$1 = 30 Baht.

Fig. 3.5. Fry transportation from nursery pond to conditioning tank.

STEP 1. Harvest fry from hapas, cages, tanks or ponds using scoop nets at least one day before sale for conditioning. Transport the fry to the hatchery from nursing ponds/tanks in large containers (50 l) using a simple vehicle (Fig. 3.5) with an aeration facility. If fry are to be transported a long distance (taking 30 h or more), fry should be kept in clean water supplied with oxygen to let the fry empty their stomachs, so that they will not excrete in the containers/plastic bags during transportation. This process is called conditioning and should be done for 2 days. Heavy mortality can occur if fry are not conditioned adequately, due to the high ammonia and low pH caused by excreta.

STEP 2. Grade the fry/fingerlings using various mesh size graders and keep them in separate hapas based on their size.

STEP 3. After grading, count the fry and transfer to containers/tanks filled with clean water from conditioning tanks. They should be transported to conditioning tanks immediately. Fry are kept at high density in hapas in conditioning tanks supplied with air stones (Fig. 3.6) or with clean water using water splashes or sprinklers (Fig. 3.7).

STEP 4. Before putting fry into the conditioning tanks, dip them in a formalin bath (400 ml/100 l water) for 5–10 s, which ensures parasites or other disease-causing organisms are not transferred to the conditioning tanks and to the farmer's ponds via fry.

Fig. 3.6. Conditioning of fry for 8–10 h or overnight in tanks using air stones that are connected to an aerator to supply oxygen.

Fig. 3.7. Conditioning of fry for 10–15 h or even more in tanks supplying oxygen using water sprinklers from perforated PVC pipes.

STEP 5. It is essential to condition the fry/fingerlings by starving overnight so that they empty their stomachs and intestines. This reduces the production of excreta in plastic bags/transport containers and avoids mortality during long transportation periods.

STEP 6. Acclimatize the fry or fingerlings as described in Section 3.6 if tilapia is to be grown in brackish or saline water, or in lower temperature areas.

3.6 Acclimatization to Salinity and Low Temperature

Tilapia may survive better than other animals in adverse conditions, especially high salinity and low temperature. Nile tilapia grow well when salinity is below 10 ppt; therefore, it has some limitations as it cannot be cultured in coastal and brackish water areas. However, acclimatization of fry during conditioning may help to some extent. Nile and blue tilapia fry need gradual acclimatization to brackish water before transferring to these systems. The salinity of the water in the conditioning tank should be increased by 2–3 ppt daily until it reaches the same salinity level as the grow-out farm where they are going to be stocked. Red tilapia fry acclimatize to brackish water more quickly and they can grow well at higher salinity (up to 30 ppt).

As a tropical fish, tilapia grow slowly in areas where water temperature falls below 20°C. This is the reason why northern hemisphere areas such as Europe, North America and northern Asia cannot grow tilapia unless they use warm water from thermal plants or other sources. They have to depend on tropical and subtropical countries. They may do reasonably well if the fry are acclimatized gradually at lower temperatures. For instance, reducing the temperature of water in conditioning tanks by 2 or 3°C daily may also work, but this is yet to be put into practice.

3.7 Health Certification

If fry are exported to another country, health certification is necessary – a certificate to show that they are pathogen-free and/or a certificate of origin. A sample of about 100–300 fry is taken randomly from the batch of fry being prepared for sale and taken to a government laboratory assigned to the test. Testing involves microscopic evaluation for parasites as well as bacterial culture. The certificate is valid for a week and so sampling has to be done 2–3 days ahead of fry transport.

3.8 Seed Quality Test and Certification

In the case of monosex seed, the main indicator of fry quality is the percentage of males in the population. In a competitive market hatchery, operators have to produce fry with higher than 99% males, which is possible. In other countries where competition is not as fierce and technology has not been applied widely, above 95% is acceptable. But farmers are demanding better and better quality as they can see that even 5% of females in grow-ponds will produce a lot of recruits or small fry, which occupy space and compete for feed, hampering the growth of the stocked fish. Some experienced farmers know by movement, colour, shape, size and responses to feed and strangers at the time the fry is sold. Nevertheless, a method called the 'gonad squash method' has been widely accepted and practised. In this method, the gonads of 5–10 g fingerlings are checked under a microscope to identify their gender. The steps taken to scientifically assess the quality of fry applied by specialized hatcheries are as follows:

STEP 1. When there is fry for sale, especially large numbers, collect a sample of 300–500 fry randomly from all corners and the middle of the conditioning tank just before packing is begun.

STEP 2. Keep them in small hapas, e.g. 5.4 m^2.

STEP 3. Cover them with a fine mesh net so that no fish from outside can enter.

STEP 4. Nurse them for about 1–2 months or up to an average size of 10 g.

STEP 5. Feed them two or three times daily to satiation with starter feed prepared for nursing fry or a mixture of fish or soybean meal (30%) and rice bran (70%).

STEP 6. Test the sex of each fingerling when they are 5–10 g in size. Sex testing is done on a regular basis, weekly or at least monthly.

STEP 7. For sex testing, collect the fish in a small bucket with water. Some salt or any anaesthesia can be used to calm their movement.

STEP 8. Prepare carmine stain by mixing acetocarmine. Add 0.5 g of indigo carmine to 100 ml of acetic acid (45%) and boil for 5 min. After cooling, filter the solution and transfer it to a dark bottle. (Guerrero and Shelton, 1974).

STEP 9. A microscope with 4, 10 and 40× magnification lenses is required along with slides, a dissecting box or at least sharp and pointed scissors, and pointed forceps.

STEP 10. Dissect the fingerlings, removing the viscera carefully and taking the gonads (male or female organ, i.e. testes and ovary) from the deeper part or underneath the viscera with the help of forceps.

STEP 11. Cut a small piece and place on a slide.

STEP 12. Pour a drop of carmine stain prepared in Step 8 on to the sample and allow the colour to develop.

STEP 13. Place a cover slip on top and apply gentle pressure so that the gonad specimen becomes a thin layer.

STEP 14. Mount the slide, then examine under the microscope, initially at 4× magnification and then 10× or higher.

STEP 15. Count the number of males and females. If there are any females, clear and different sizes of ova (Fig. 3.8) can be seen. In the case of males, it requires practice to differentiate intersex and sterile.

STEP 16. Calculate the percentage of males and keep records (Table 3.2) for each batch.

STEP 17. Perform this for at least 300 fry for each batch sold.

Techniques have not so far been developed to assess the quality of fry on the spot before sale. DNA analysis might be able to identify male and female at that age but its cost can be prohibitively expensive. For the time being, checking the percentage of males in the fry population using the basic biological principles shown in Fig. 3.8 and summarizing the results as shown in Table 3.2 is all that can be done.

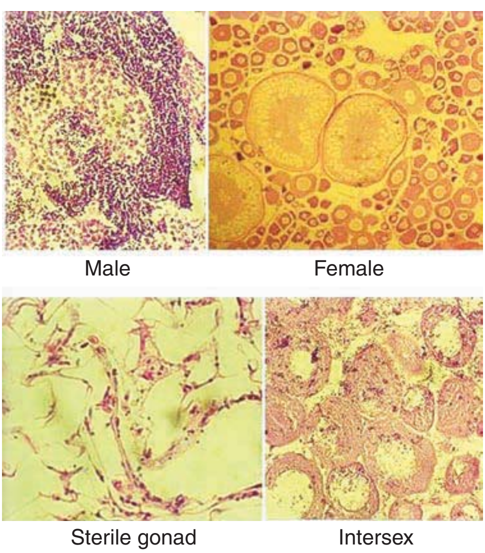


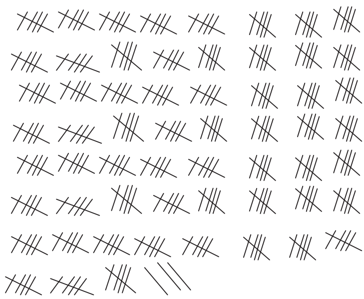
Fig. 3.8. Eggs seen in the female ovary under microscope.

Table 3.2. Data sheet for the monitoring of quality of monosex tilapia fry produced.

Quality monitoring of sex-reversed tilapia fry

(Data sheet)

Sample source:__________________ Date:____________

Sex	No. of sample/slide	Total	%	Remarks
Male		298	99.3	"Excellent"
Female		2	0.67	
Others		0		
Total		300	100	

Signature of technician: ________________________________

Name: ____

Other techniques for assessing the strength of fry have been tried with limited success, for example the salinity challenge test (MacNiven and Little, 2001), the bacterial exposure test, and so on. Of these, the salinity test is the cheapest and may be applicable:

STEP 1. Select 100 fry, randomly sampling from a population.

STEP 2. Prepare a 24 ppt salt solution using common salt dissolved in tap water.

STEP 3. Submerge the fry in the salt solution for 2 h.

STEP 4. Count how many dead and alive fry there are.

STEP 5. Repeat the process two or three times for each batch.

The normal survival (LC_{50}) should be about 50%. Fry batches with higher survival rates are considered to be stronger fry and of better quality. This indicator may be useful for marketing purposes.

In addition, monitoring of overall hygienic conditions, record keeping and other operational procedures are checked as part of Good Aquaculture Practice (GAP), and certification is provided by the government in some countries (e.g. Fig. 3.9) or a competent private or international organization can serve the same purpose.

3.9 Packing

Fry can be transported using various methods, but using polythene bags (5 l capacity) is the easiest and most popular method. As counting of fry is a time-consuming and tedious job, three batches of 1000 fry are counted and weighed. The average weight is used to estimate the remaining fry and transferred to each bag. Another way of estimating number is by volume; a small cup can be used to record the samples of 1000 fry and the same volume can be used for the rest of the packing process.


กษ 01-22-07401-1301005515-102
GAP
AC 01-22-07401-1301005515-102
GAP
DEPARTMENT OF FISHERIES
THAILAND
กรมประมง
(Department of Fisheries)
ใบรับรองการปฏิบัติทางการเพาะเลี้ยงสัตว์น้ำที่ดี
(Certificate of Good Aquaculture Practice : GAP)
ชนิดสัตว์น้ำ (Species) ปลานิล (Nile tilapia)
เลขที่ (Certification number) 13201-13-GAPF0-03-48-00004
ใบรับรองฉบับนี้ให้ไว้แก่ (Given to)
สถาบันเทคโนโลยีแห่งเอเชีย (Asian Institute of Technology)
โดยมี (Owner) สถาบันเทคโนโลยีแห่งเอเชีย AIT เป็นผู้ดำเนินกิจการ ที่ตั้งฟาร์ม (Farm address) บ้านเลขที่ 58 หมู่ที่ 9
ตำบล (Tambon) คลองหนึ่ง Klongneng อำเภอ (Amphoe) คลองหลวง Klongluang จังหวัด (Changwat) ปทุมธานี Pathumtani ทะเบียนฟาร์มเลขที่ (Farm registration number) 1301005515
เพื่อแสดงว่าเป็น ฟาร์มเพาะพันธุ์และอนุบาล สัตว์น้ำตามมาตรฐานการปฏิบัติทางการเพาะเลี้ยงสัตว์น้ำที่ดี พ.ศ. 2548 ของกรมประมง
(This is to certify that aquatic animal mentioned above is maintained under standard on good aquaculture practice)
วันที่ออกใบรับรองครั้งแรก (Date of First certified) 29 มิถุนายน 2550 (29 June 2007)
วันที่ออกใบรับรอง (Date of Issue) 29 มิถุนายน 2552 29 June 2009 วันที่หมดอายุ (Date of Expiry) 28 มิถุนายน 2554 28 June 2011
ลงชื่อ (Signature) ผู้รับรอง
ตำแหน่ง (Position)

Fig. 3.9. Example of certificate of Good Aquaculture Practice (GAP).

The steps of the method used widely by most of the tilapia hatchery operators are:

STEP 1. Use two plastic bags for extra strength.

STEP 2. Prepare a salt solution of 5 ppt as an anaesthetic and acriflavin (1 g in 200 l water) as an antiseptic to protect from wounds or any injuries during transportation. In case of unavailability of acriflavin, iodine and potassium permanganate can also be used.

STEP 3. Fill the inner bag with 2.5–3.0 l of clean water.

STEP 4. Add the salt and acriflavin solution.

STEP 5. Estimate the fry by counting 500 or 1000 fry and use a cup of the right size to count by the number of cups for required fry order.

STEP 6. Put in 1000 for a distance of less than 12 h total transport time. But number should be only 500 if the transport time is over 15 h.

STEP 7. Add 3 l of oxygen to each bag from a cylinder so that the plastic bag remains inflated.

STEP 8. Use a rubber band to tie the neck of each plastic bag (Fig. 3.10).

STEP 9. Float the plastic bags on the surface of the water in tanks or ponds, under shade (Fig. 3.11).

STEP 10. If transportation is to be done by bicycle or motorbike, put each plastic bag with fry in an empty sack of feed or rice to keep them safe.

STEP 11. If transportation is to be done by a car, pick-up or truck, cover the bags with thick cloth or jute, or the same sacks that are holding the bags and spray water on top of the plastic bags with fry. After transporting for a few hours, stop and spray water on the cover again. This can be done several times if travelling a long distance.

STEP 12. If fry are to be transported by aeroplane, use foam boxes. Put four plastic bags in each foam box and position them firmly so they will not move much during transportation.

STEP 13. Cover the foam boxes with their lids and seal with tape.

Fig. 3.10. Packing of fry in plastic bags for transportation.

Fig. 3.11. Fry packing for transportation.

3.10 Transportation

The number of fry should be reduced to 500 if they are to be transported for longer periods, i.e. over 12 h. After the 1000 fry are isolated they are transferred into the polythene bags. Excess air should be removed and the bags refilled with oxygen from a cylinder before being tied and sealed with strong rubber bands.

Water and oxygen can be changed during transportation if the travel time is over 12 h, especially if land transportation is involved, based on requirement and available facilities. However, it is not recommended, rather it should be avoided by adjusting the period of conditioning. The longer the distance in terms of time, the longer the period of conditioning should be. Well-conditioned fry packed with oxygen can be transported to any part of the world, by air cargo at low temperature for up to 35–40 h including land transport, and for up to 18 h by road.

More importantly, fry density in the plastic bags depends on the size of the fry. Larger fry will have lower survival rates and so smaller fry are preferred if long distances are involved. As an example from Table 3.3, if a hatchery

Table 3.3. Relationship between packing density (fry/bag) and transportation time (hours).

Swim-up fry/bag	Normal/acceptable mortality at varying transportation time					
0.2 g size	6 h	12 h	18 h	24 h	30 h	36 h
500						
600						
700						
800						
1000						
0.3 g size	6 h	12 h	18 h	24 h	30 h	36 h
500						
600						
700						
800						
1000						
0.65 g size	6 h	8 h	10 h	12 h	14 h	16 h
500						
600						
700						
800						
1.0 g size	6 h	12 h	14 h	16 h	18 h	24 h
300						
350						
375						
400						
2.0 g size	6 h	12 h	14 h	16 h	18 h	24 h
125						
150						
175						
200						

manager needs to transport fry for a total of 30 h, then 0.2 g fry can be selected and density should be 500–600 per bag. If larger fry are to be transported, such as 1 g size, transporting to a location that takes more than 12 h will be risky.

About 5–10% of fry may be lost during conditioning and packing. Sometimes high mortality rates can be experienced in cases of electricity failure, rough roads or shaking of fry, hot weather or any other causes that create adverse conditions such as low temperature, low pH, low DO and physical stress.

Fry transport should be avoided during the daytime, especially in hot and dry seasons. If necessary, plastic bags should be covered with thick sacks. Water can also be spread over the bags to keep temperatures down before and during transportation.

Any means of transport can be used to carry fry. A simple bicycle or a motorbike is useful to carry fry for short distances, as is done in Bangladesh and Vietnam. Cars, pick-ups and trucks can be used to transport fry for a full day by road.

Fry can be sent anywhere in the world. Usually four bags containing at least 2000 fry are packed in each foam box (Fig. 3.12), which should be clearly labelled with the name and proper address of the recipient. In the case of cross-border transportation, a health certificate issued by a government agency to guarantee that fry are free of parasites and disease-causing organisms is required. At the same time, importing farmers may need a licence and to observe quarantine regulations.

Fry or fingerlings can also be transported using plastic or steel tanks with an aeration system. In Bangladesh farmers use aluminium or earthen vessels carried by bicycle or from their shoulders, hanging two vessels from either end of a bamboo stick. They manually agitate the water using their palms during transportation to introduce oxygen from the atmosphere.

When releasing fry into the culture system, the plastic bags should first be allowed to float in the receiving tank or pond so the fry gradually acclimatize to the new water temperature. In cases of transportation in tanks or other vessels, water from the pond can be added to the container, gradually

Fig. 3.12. Fry packed in plastic bags and placed inside foam boxes to send by cargo.

replacing the original water and decreasing the thermal gradient, which may affect the fry.

3.11 Data Recording and Performance Evaluation

The performance can be assessed using data recording as shown in Table 3.4.

3.12 Economic Analysis

The tilapia hatchery business has been very popular in Asia since around 2000, which clearly indicates that the technology that has been developed and disseminated has been very successful. In other words, it has been economically sustainable despite its relatively high investment. Table 3.5 shows the economic analysis of a hatchery including pre-nursing in Bangladesh, which was carried out by a group of hatchery operators. According to this estimation gross as well as the net profit margin is over 75% of the investment.

Among the costs, feed for broodfish is quite significant – more than a quarter (26%) of the total costs – followed by personnel and MT hormone. Total variable cost is 65% and the rest is the fixed costs. Of the fixed costs, marketing and transportation of fry is the highest, followed by electricity and fuel.

Table 3.4. Data sheet template for fry/fingerling sales records.

Date of seed sale	Customer details (name, address and contact)	Date of sex reversal completion	Number of fry sold (a)	Price of fry (Baht) (b)	Total revenue = (b × a)	Remarks
4/04/2013	Mr Ali	6/03/2013	50,000	0.30	15,000	
9/04/2013	Ms Pornthip	7/03/2013	100,000	0.32	32,000	
–						
–						
–						
–						
–						
–						
–						
–						
Total (Baht)					47,000	
Total (US$)					1,567	

Note: 30 Thai Baht = 1 US$.

Table 3.5. Economic analysis of tilapia hatchery, Bangladeshi contexts (1US$ = 80 Taka).

Cost items	Unit	Rate (Taka)	Total Taka	Total US$	Per cent
A. Variable costs					
1. Personnel	15	8,667	130,000	1,625	16
2. Broodstock feed (kg)	4,197	50	209,850	2,623	26
3. SRT feed (kg)	710	80	56,834	710	7
4. MT hormone (g)	43	2,080	88,662	1,108	11
5. Alcohol (l, 95% ethanol)	171	189	32,206	403	4
6. Vitamin mix (kg)	14	220	3,126	39	0
7. Miscellaneous			10,000	125	1
Subtotal			530,678	6,633	65
B. Fixed costs					
1. SRT hapa	142	24	3,355	42	
2. Brood hapa (60 m²)	97	83	8,096	101	1
3. Nursing hapa (10 m²)	142	42	5,920	74	1
4. Hand nets (white)	15	250	3,750	47	0
5. Hand nets (green)	15	250	3,750	47	0
6. Land rent			20,800	260	3
7. Pond digging	1	12,500	12,500	156	2
8. Repair	4	5,200	20,800	260	3
9. Pump			167	2	0
10. Generator			1,333	17	0
11. Deep tube well			1,111	14	0
12. Internal piping			1,667	21	0
13. Fencing			3,333	42	0
14. Office and overhead tank			4,167	52	1
15. Store			4,167	52	1
16. Electricity			30,000	375	4
17. Fuel			30,000	375	4
18. Others			4,167	52	1
19. Marketing and transport			100,000	1,250	12
20. Miscellaneous (taxes, CSR, etc.)			30,000	375	4
Subtotal			289,082	3,614	35
Total			819,760	10,247	
C. Income					
1. SRT fry (per month)	3,333,333	0.60	2,000,000	25,000	
2. Spent broodfish (kg)	583	100	58,292	729	
Subtotal			2,058,292	25,729	

Continued

Table 3.5. Continued.

Cost items	Unit	Rate (Taka)	Total Taka	Total US$	Per cent
Monthly basis					
D. Gross profit			1,527,614	19,095	
E. Gross profit (%)			186	186	
F. Net profit			1,238,532	15,482	
G. Net profit (%)			151	151	
Annual basis					
D. Gross profit			9,165,683	114,571	
E. Gross profit (%)			144	144	
F. Net profit			7,431,190	92,890	
G. Net profit (%)			76	76	

4 Grow-out in Ponds

4.1 Introduction

This section covers the possible methods of growing table fish in ponds as a separate business after stocking fry or fingerlings obtained from the hatcheries or nurseries. The existing systems commonly practised in most countries are earth ponds, floating cages, and concrete or plastic tanks. Considering each of these as an independent and specialized business, pond culture systems are described in detail and economic analyses have been carried out using some case studies so that interested individuals can choose and apply as business occupation for profits based on the resources available to them.

Tilapia culture in ponds ranges from small-scale subsistence to large-scale commercial farming. Ponds may vary from as small as 100 m^2 to as large as 10 ha or so (Fig. 4.1). Ponds are the most popular culture system, followed by cages. Tilapia are also grown in tanks and raceways but this is costly and unaffordable for small-scale farmers. Hence, tank and raceway tilapia culture is not described here.

A good plan is a must before stocking fry/fingerlings into any pond. It requires adequate homework to determine when, where, and how many fry/fingerlings should be stocked. The following are guidelines that can be used while planning:

STEP 1: WORK OUT FRY/FINGERLING REQUIREMENT. Work out the number required, which depends on the size of your farm (i.e. pond or tank area) and the stocking density required.

No. of fry required = stocking density per m^2 × total area (m^2)

For example, if we have total of 1000 m^2 pond (water surface) area and we want to stock 4 fish/m^2, then the number of fry required = 4 × 1000 = 4000.

If we will actually need to order 10% more fry to compensate loss for during stocking and nursing, you will need an additional number of fry = 4000 × 10/100 = 400.

Fig. 4.1. Fry nursing before stocking in a small pond in mid-hills in Nepal (left) and 10 ha tilapia pond in Central Thailand (right).

Therefore, the total fry requirement for ordering would be 4000 + 400 = 4400. Just for the sake of convenience we need to order 5000 fry.

STEP 2: WORK OUT THE INVESTMENT REQUIRED. For example, if the price of fry ≈ US$0.01, total amount = 5000 × 0.01 = $50.

Fry transport logistics: if international transport is required, cargo cost may be significant, but if the source is local, land transportation may cost a lot less. However, there can be high mortality during transport, depending upon the road conditions.

STEP 3: FIND A GOOD SOURCE OF FRY/FINGERLINGS. Contact an authorized person to check fry availability and price of fry for your expected date of fish stocking. If everything is ready, order the fry and arrange for transport.

STEP 4: CONSTRUCT A POND. Site selection and methods of new pond construction have been described in Section 2.3. In this section, more information on the size, depth and uses are discussed.

Ponds should be ready and filled with water at least 2 weeks in advance of stocking with fry. Figure 4.2 shows a complete recycling system as farms are normally not allowed to drain untreated water. If the water can be stored in a reservoir, it will save on any treatment processes.

With either new or old ponds, the following information will be helpful when preparing ponds:

- Normally pond depth varies from 1 to 1.5 m. Ponds of less than 1 m depth are not recommended because they will contain less water. During the hot season there is a risk of water shortages and water temperature may increase, resulting in fish mortality. Ponds deeper than 1.5 m may be used in rain-fed areas where a large volume of water is required to prevent drying out during the dry season.
- There is no ideal pond shape and size for growing tilapia. Square or rectangular ponds are usually used, with a rectangular shape being easier during

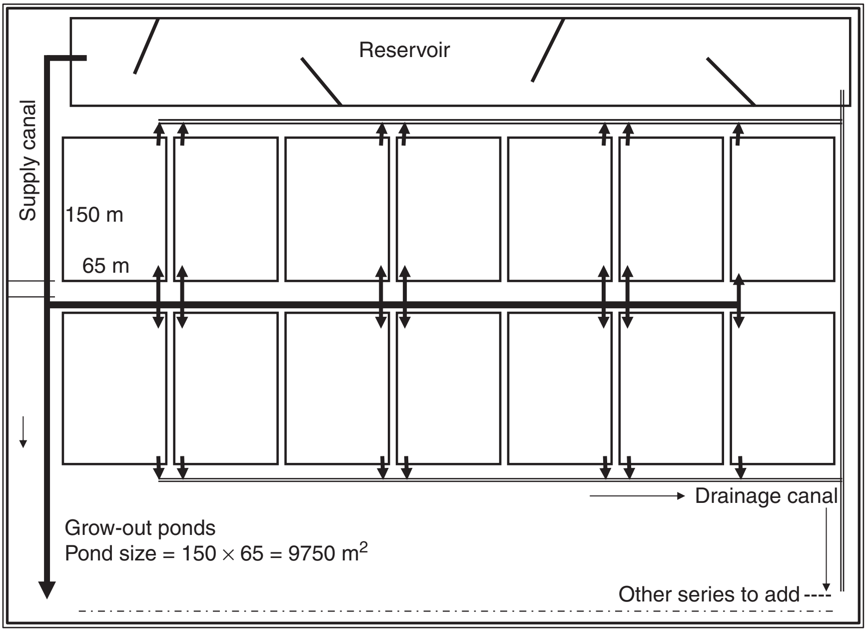


Fig. 4.2. Layout of pond system.

harvesting as the nets can be used across the pond length. However, in some areas contour types of ponds are used to suit and for maximum utilization of available land.

- Similarly, pond size may vary from 100 to 500 m^2 for small-scale farmers while it can be up to 1 ha or more for large-scale farming. Small ponds are easier to manage and may be used for high-density culture with feeding and aeration by the farmers where land is limited. Table 4.1 shows the pros and cons of small and large ponds.

4.2 Pond Preparation

There are four important steps in pond preparation:

STEP 1: DRAIN AND DRY. Ponds should be drained and dried for at least 2 weeks or until cracks can be seen on the pond bottom. Drying helps oxidize and break down chemicals and their residues in the mud, and eradicates all wild fish, remaining fish from the last harvest, insects and other predators from the pond. If complete draining and drying is not possible or very costly, it is recommended to use one of the commonly used pesticides, e.g. rotenone, tea seed cake or potassium cyanide on the remaining water in the pond.

Table 4.1. Advantages and disadvantages of small and large ponds.

Activities/ characteristics	Small ponds	Large ponds
Normal size	100–500 m^2	0.5 ha or larger
Purpose	Subsistence farming	Commercial-scale farming
Digging cost per unit area	More costly	Cheaper
Filling and fish harvesting	Easier	Difficult
Draining ponds	Easier	Difficult and often not possible
Feeding and fertilization	Time-consuming	Time saving
Use	Fry nursing or intensive culture	Low intensive and often used for polyculture
Target	Home consumption or local or retail market	Wholesale market

STEP 2: APPLY LIME. After draining the pond, lime (e.g. CaO or $Ca(OH)_2$) should be applied to the pond bottom. This can be done by manual broadcasting. This is the recommended practice in aquaculture as it neutralizes the pH of the pond and also kills disease-causing organisms. The amount of lime depends on the type and quality of soil and its pH. In general, 300–600 kg/ha (or 30–60 g/m^2) is recommended. If the soil at the bottom of a pond is too acidic, i.e. below pH 6, the amount of lime needs to be doubled.

STEP 3: FILL THE POND. Before filling the pond, ponds and dykes need to be cleared out, e.g. cut away pond grasses, etc. Make sure that the water source is reliable and of good quality. Measurement and analysis of important water quality parameters such as calcium, pH, etc. may be necessary. A filter should be tied over the inlet pipe to prevent insects, other fish and their eggs entering with the water. The use of a combination of nylon nets (mesh size 20 holes/inch) and an outer fine mesh tightly fitted over the pump discharge pipe is recommended.

STEP 4: FERTILIZE THE POND. Apply chemical fertilizers after filling the pond as this is the cheapest method of enhancing phytoplankton as natural food and has been very common around the world (Fig. 4.3), which is indicated by the green colour of the water. Green water contains freshwater algae, which are a good source of protein and several vitamins, e.g. *Chlorella* and *Spirulina* contain 47.2% and 58.6% CP on a dry matter basis, respectively.

As tilapia consume plankton, they can be raised in a green water system cheaply. The suitable range of chlorophyll-*a* in the hatchery water is 100–300 mg/m^3 of water. Organic manures, e.g. chicken and pig manure, and chemical fertilizers are commonly used. Animal (chicken) manure is normally applied at the rate of 500–2000 kg/ha/year, depending upon the fertility of the soil.

Fig. 4.3. Well-fertilized green water pond, Chirundu Farm, Zambia.

However, the use of organic manure has been an issue in terms of health hazards, because chicken and pigs are fed with high levels of growth hormones and antibiotics. At the same time, animal manures have very low N and P concentrations. They are bulky and difficult to transport if they are to be procured from outside. On the other hand chemical fertilizers are nutrient dense and therefore easy to handle. They also create better water quality, thus ensuring higher survival of the fish, and they enhance plankton growth. The process will take about 1 week, after which time fish can be stocked. Chemical fertilizers are considered safe and available even in rural areas for the use of crops and vegetables, e.g. urea and TSP or DAP. They are very common and produce green water rapidly. Urea contains 46% nitrogen (N) while TSP and DAP contain 20% phosphorus (P). Weekly application of 28 kg N and 7–14 kg P/ha, which means about 60 kg of urea and 30–60 kg TSP/ha, is recommended. These fertilizers should first be dissolved in water in a bucket before spraying into the pond water. If not dissolved, fertilizers will sink and stay at the bottom, attached to the mud. Ponds need to be fertilized weekly after that, using the same fertilizers at the same rate. However, depending upon the greenness of the pond water, the rate can be altered. Calculating how much fertilizer is needed can be done as follows:

- Amount of urea (kg) per week = daily rate/% of N in urea × 7 days
  = 4/46% × 7
  = 61 kg/ha

- Amount of triple superphosphate (TSP) = daily rate/% P in TSP × 7 days
  = 1 kg/20% × 7
  = 35 kg/ha

If a farmer has a pond of 1000 m^2, he or she can calculate the amount required for weekly application to fertilize ponds:

Amount of urea (kg) = 61/10,000 × 1000 = 6.1 kg
Amount of TSP (kg) = 35/10,000 × 1000 = 3.5 kg

The amounts of other alternative fertilizers can also be calculated in a similar way using the percentage of nitrogen and phosphorus in them. For example, if NPK (16-20-0) fertilizer is available, farmers may choose it because it contains both N and P. First of all, the requirement to supply adequate P is calculated as:

Amount of NPK fertilizer required = 1 × 100/20 × 7 = 35 kg/ha/week

As it does not fulfil the N requirement, urea has to be added. This is calculated deducting the amount supplied by NPK, as shown below:

Urea = [4 × 7 – (35 × 0.20)] × 100/46 = 45.7 kg

This means the amounts of NPK and urea needed are 35 kg and 45.7 kg, respectively.

The amounts of other alternative fertilizers such as DAP can also be calculated in similar way. As DAP has 18% N and 46% P_2O_5 or approximately 20% phosphorus, the DAP requirement for P is calculated first. Then the amount of nitrogen supplied from that amount of DAP is deducted from the amount of urea to be worked out.

STEP 5: MONITOR WATER QUALITY. Fish differ from terrestrial animals in many ways, including the fact that they live in water, from where they get food and oxygen for their survival and growth. Therefore, the quality of the water we use to grow fish matters greatly. The most important water quality parameters in tilapia farming are temperature, DO, salinity and pH. These parameters should be monitored at around 6 am and 2 pm on the same day every week. At the lowest temperature, pH and DO will be lowest early in the morning and highest in the afternoon. Although some farmers monitor these parameters daily, under normal circumstances this is not required and weekly measurements would be adequate.

The best temperature range is 28–32°C. Although they can survive, growth and breeding are negatively affected if the water temperature is higher than 35°C and lower than 20°C and fish become stressed outside their comfort zone (Bhujel *et al*., 2001), which favours the bacterial infections or diseases described in Section 8.2.

The second most important water quality parameter is DO, measured as ppm or mg/l. DO in pond water varies throughout the day, being lowest in the morning at around 5–6 am (at dawn) and highest in the afternoon (2–3 pm). If the DO drops below 3 mg/l, aeration may be needed. Similarly, if the DO rises above 12 mg/l in the afternoon it may cause fish to suffocate and cause gas bubble disease; churning of the water is needed so that excessive oxygen is released into the atmosphere. For this purpose a pedal wheel aerator is recommended. However, it is only necessary to run it for about 3–4 h early in the morning (say 2–6 am) and for another 3–4 h in the afternoon when the temperature and DO are highest at around 1–4 pm. Similarly, pH indicates some chemical property of the water. If pH drops below 6.5, liming is necessary. If pH shows a higher reading than 9.5, fertilization may help to reduce it. Monitoring of salinity (ppt) is necessary if the site is in a brackish water area. As salinity affects tilapia growth and reproduction, and it fluctuates during dry and rainy seasons, monitoring of salinity and planning fish stocking and harvesting is important in order to maximize production and profitability.

STEP 6: ANALYSE POND WATER. Analyse other chemical properties of the pond water such as ammonia, nitrite and nitrate, dissolved solids, phosphorus, conductivity, etc. Analysis can be done in a simple laboratory but in some countries simple test kits are also available similar to litmus paper to roughly measure the pH. These are quite important if tilapia are cultured at high densities, especially in a water recirculation tank system.

STEP 7: MEASURE VISIBILITY. Measure Secchi disc visibility to assess the plankton growth in pond water. A Secchi disc can be made locally by painting a metal plate black and white, as shown in Fig. 4.4. Follow the recommendations as shown in Table 4.2.

STEP 8: STOCK FRY. Fry are stocked directly into the grow-out ponds (Fig. 4.5) after transportation or after nursing for 1–2 months. Normally fry/fingerlings

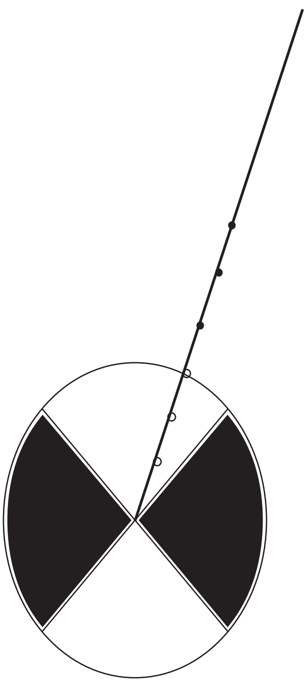


Fig. 4.4. Secchi disc with a stick marked at every 10 cm from the bottom to measure visibility.

Table 4.2. Implications of Secchi disc visibility or depth.

Secchi disc depth (cm)	Remarks	Recommendations
<20	Too green	Stop fertilization and feeding for 1 week
20–30	Very green	Stop fertilization and reduce feed
30–40	Appropriate	Feed and fertilize normally
50	Too little plankton	Increase fertilization rate

Fig. 4.5. Releasing the fingerlings gradually into the pond after water temperature is similar in the pond and in the plastic bags.

are transported in plastic bags with oxygen. Stocking is done either in the morning or late afternoon so that water temperature is not at its maximum. The plastic bags with fry are kept on the surface of the pond for at least 30 min so that the temperature of the plastic bags and the pond water becomes the same (equilibrium). Plastic bags should be opened and fry should be released gradually. In some cases, fry are transported in plastic drums or fibreglass tanks with an aeration system. In such cases, drums or fibreglass tanks are lifted by cranes, which reduces excessive movement of water and the stress caused by it. In this method as well, fry are released gradually by allowing pond water to enter the drums.

Stocking density depends entirely on the size of fish desired at harvest and the method used for culture. It is recommended not to exceed a grow-out period of longer than 7 months because production decreases after the sixth month. At a stocking density of 2–3 fish/m^2, market-sized fish can be attained in 6 months using fertilization only. At stocking densities in excess of this, supplementary feeding is necessary to get the fish to the size within the recommended grow-out period. The stocking density and method of culture used will depend on economics. As stocking density increases, more investment is required in feed, and overall production costs will increase. As a general rule, 2–3 fish/m^2 is an ideal stocking density, while higher stocking densities (which means smaller size at harvest) can be used if the market accepts smaller sizes, e.g. 200 g. Table 4.3 can be used as a guideline to determine stocking density: if the fish are nursed prior to stocking, then the stocking densities given above can be reduced by 10% to achieve the same expected biomass.

4.3 Feeding

Tilapia vary in their feeding habits. Apart from phytoplankton, most tilapia eat zooplankton, detritus, aquatic plants, insects and even small fish fry. Commercial pellets, waste food and almost any other type of feed, with perhaps the exception of meat, are all eagerly devoured. Very little investment is therefore required in their nutrition if they are cultured in green water ponds. Production costs will increase with increasing stocking density. Feed will only be required if stocking density exceeds 2 fish/m^2. If fish are stocked at higher densities, then the type of feed will be determined by fish price. If the price of tilapia is very low, as it is in most of Asia, then it will not be economic to feed large amounts of commercial floating pellets. Only cheap feed inputs will be cost-effective in such a situation. Such feeds might include: waste food from restaurants, hospitals and schools, maize meal, rice bran and broken rice – if

Table 4.3. Rearing techniques and production from monoculture (expected size 500 g).

Culture systems and inputs	Stocking density/m^2	Feed (t/ha)	Expected production (t/ha)	FCR	Expected average fish size (g)
1. Extensive (fertilization only)	1	0	2	0.0	250
2. Semi-intensive systems					
Fertilization + limited feeding	2	1	5	0.3	300
Fertilization + feed 1 month	3	2	8	0.5	350
Fertilization + feed 2 month	4	6	13	0.8	400
Fertilization + feed 3 month	5	10	20	0.9	500
Fertilization + feed 4 month	6	24	29	1.5	600
3. Intensive system (commercial pellets)	15	76	96	1.4	800
4. Super-intensive (pellets, water exchange, aeration, etc.)	25	126	160	1.4	800

available, very cheap bread or wafer and swept up animal feed. Many types of supplemental feeds are used by farmers. It is essential to test out any new feed inputs before using them extensively. Farmers should consider: (i) whether the feed is attractive to the fish or not; (ii) whether the additional feed inputs give enough return to cover the costs and labour; and (iii) how safe they are to use.

Various commercial feeds (crumbles or pellets) are available in many countries to use as supplementary feeds such as:

- fry booster powder form (40–50% CP);
- fish starter mass (35–40% CP);
- fish grower pellets (30–35% CP); and
- fish finisher pellets (25–30% CP).

Although ultimate profit may not differ, farmers are afraid of using high-priced feed. High-protein feed may result in high growth and higher profit whereas low-protein feed may result in low growth and low profits because more low-protein feed will be required to achieve the same growth. Nevertheless, low-protein feed is normally more cost-effective as tilapia can make up the extra protein they require from eating natural food, provided that ponds are sufficiently green.

In general, commercial pellets are quite expensive and in many cases farmers may not be able to make the expected profits. Therefore, they should try to prepare home-made feed, but this is sometimes hindered by a lack of knowledge and skill. A simple Pearson's Square technique can help, as shown in Fig. 4.6 and described below.

	Ingredients	% CP	Required CP	Parts	Calculation	Composition of the feed (%)
Mix 1	Protein source: Fishmeal Soybean meal Mustard cake	42		25−7 = 18	18 / 35 × 96 =	49.4
			25			
Mix 2	Carbohydrate source: Rice bran Cassava flour	7		42−25 = 17	17/35 × 96 =	46.6
Others	Soybean oil (2%) Mineral mix (1%) Vitamin mix (1%)					2 1 1
			Total	35		100

Fig. 4.6. Simple feed formulation method for home-made feed.

Table 4.4 shows the assumptions that the listed ingredients are locally available and their compositions are known, but now the question is what amounts should be mixed to produce reasonable fish feed.

In order to find out the appropriate proportions of available ingredients in a feed that is required to have at least 25% CP, a simple Pearson's Square method can be used as follows.

STEP 1. Categorize the ingredients into two: those that contain higher protein levels than the required CP in the feed to be prepared (i.e. 25%) as a protein source and those that have lower CP as a carbohydrate source. For example, fishmeal, soybean meal and mustard cakes are protein sources; rice bran and cassava flour are carbohydrate sources.

STEP 2. Make Mixture 1 from protein-rich ingredients. For example, among the available ingredients fishmeal, soybean meal and mustard oilcake, fishmeal is the most expensive and sometimes unavailable in many rural areas. Some farmers may therefore want to avoid it. However, if it is available it is good to use because it has the best profile of amino acids, some of which may not be available in plant proteins. Therefore, it can be included at a level of 5%, with the remaining 95% distributed equally between soybean meal and mustard oil cake. Therefore, the protein level of Mixture 1 can be calculated as follows:

$$\begin{aligned}\text{Protein \% of Mixture 1} &= 5 \times 60\% + 95/2 \times 44\% + 95/2 \times 38.5\\ &= 3 + 20.9 + 18.3\\ &= 42\% \text{ (approximately)}\end{aligned}$$

STEP 3. Similarly, make Mixture 2 from a combination of carbohydrate-rich ingredients such as rice bran and cassava flour. Cassava flour has very low protein, but high starch serves as a binder. If cassava cannot be obtained, other starch-rich ingredients have to be explored. Mixture 2 can be 25%

Table 4.4. List of ingredients and their protein level.

Ingredients available	Crude protein (% CP)	% composition	Price
Fishmeal	60.0	?	
Soybean meal	44.0	?	
Rice bran	8.0	?	
Cassava flour	1.4	?	
Soybean oil	0.0	?	
Mustard oilcake	38.5	?	
Vitamin mix	0.0	?	
Mineral mix	0.0	?	
Total		100	?

cassava flour and 75% rice bran. The protein content of Mixture 2 can be calculated as:

$$\text{Protein \% of Mixture 2} = 75 \times 8\% + 25 \times 1.4\%$$
$$= 6.8 + 0.21$$
$$= 7\% \text{ (approximately)}$$

STEP 4. Apply the Pearson's Square method to find the proportion of each mixture, placing the required protein (25% CP) in the middle.

STEP 5. As a rule of thumb, keep 2% for soybean oil, 1% for vitamin mixture and 1% for mineral mixture; therefore, the remaining 100 – (2 + 1 + 1) = 96% from the ingredients from Mixture 1 and Mixture 2. Therefore, while calculating the proportion, use a factor of 0.96 to multiply by as shown in Table 4.5.

Table 4.6 shows the composition of feed that contains only 5% fishmeal and the highest amount of rice bran, i.e. 39.6%. After finding out the composition of a diet, a farm operator may want to check the price of the feed and also whether the protein level is close to that required. Table 4.6 shows the detailed calculation, and shows that the feed has close to 25% (24.6%) CP and the price of feed is $0.71/kg, which is reasonable. If the price is higher than expected, reformulation is needed by reducing the proportion of high-price feed.

Once the feed formula is acceptable, farm operators will use it to prepare feed. As an example, when making a feed of 5 kg:

STEP 1. Arrange ingredients and check their quality.

STEP 2. As shown in Tables 4.5 or 4.6 weigh the amount of fishmeal, soybean meal, mustard oil cake and rice bran (Fig. 4.7) separately and mix them together in a large container of over 5 kg capacity.

STEP 3. Weigh minerals and vitamins separately, then mix with the mixture of above-mentioned ingredients in step 2.

Table 4.5. Ultimate feed composition obtained from the above exercise.

Ingredients	Calculation	Composition (%)
Fishmeal	5% set aside	5.0
Mustard oilcake	(49.4–5)/2	22.2
Soybean meal	(49.4–5)/2	22.2
Rice bran	46.6 × 85%	39.6
Cassava	46.6 × 15%	7.0
Soybean oil	2% set aside	2.0
Vitamin mix	1% set aside	1.0
Mineral mix	1% set aside	1.0
Total		100.0

Table 4.6. Cross-checking the protein level and price of the feed.

Ingredients	Composition (%)	Protein calculation	Protein	Ingredient price (US$)	Price calculation	Price (US$)
Fishmeal	5.0	5% × 60	3.0	1.33	5% × 40	0.07
Mustard oilcake	22.2	22.2% × 38.5	8.5	0.50	22.2% × 15	0.11
Soybean meal	22.2	22.2% × 44	9.8	1.00	22.2% × 30	0.22
Rice bran	39.6	39.6% × 8	3.2	0.25	39.6% × 7.5	0.10
Cassava	7.0	7% × 1.4	0.1	1.17	7% × 35	0.08
Soybean oil	2.0			1.67	2% × 50	0.03
Vitamin mix	1.0			8.33	1% × 250	0.08
Mineral mix	1.0			1.67	1% × 50	0.02
Total	100.0		24.6			0.71

Fig. 4.7. Feed ingredients: soybean meal, rice bran, etc.

STEP 4. Weigh the cassava flour and add 2.25 l of tap water.

STEP 5. Heat the cassava in a large pan gradually and keep churning with a shovel (Fig. 4.8, left).

STEP 6. When it starts to become glue-like, i.e. gelatinized, stop heating and pour into the mixture of ingredients (Fig. 4.8, right).

STEP 7. Mixing should be continued until it becomes uniform in colour and a firm dough.

STEP 8. Pass through the extruder or mincer to produce long noodle-like pellets. In some cases the mixture may not appear as pellets but crumbles, which means not enough water has been used; add about 10% water and repeat the process from step 7. In other cases, pellets may appear too soft which means too much water has been added. Add more ingredient mixture in the same proportions and repeat the whole process from step 7. For the next batch of feed, reduce the water by 5–10%.

Fig. 4.8. Cooking cassava to gelatinize (left) and pouring gelatinized (glue-like) cassava into ingredient mixture (right).

STEP 9. Gently break the long pellets into shorter ones and spread them out on a tray.

STEP 10. Put the tray in a drier at low temperature, i.e. 50°C for about 6 h or until it is dry. It should not be too dry and too hard, but not too soft either.

STEP 11. If a drier is not available, drying can be under shade in the tropics, which may take a day or two to adequately dry the feed (moisture 10–12%), but in temperate regions, a simple and cheap drier to be run by energy from the sun or firewood can be developed using plastic sheet and black zinc sheet (Fig. 4.9).

STEP 12. After drying, put the feed in paper bags of the required size and store in a cool place protected from rats and insects.

Home-made feeds can be in powder, crumble or dough form and they sink into the water (Fig. 4.10). Therefore, it is advisable to use a feeding tray (Fig. 4.11, left) so that feed does not stick to the mud at the bottom and farmers can also monitor whether fish are eating the particular type of feed or not. Feeding trays can be made using nets or can simply be bamboo mats tied at the four corners and hung from a stick or a bamboo pole as shown in Fig. 4.11, right.

Fig. 4.9. Simple drier that can work with solar power and/or firewood.

Fig. 4.10. Making fish feed (sinking) pellets using simple mincer.

Fig. 4.11. Setting up of a feeding tray (left) for sinking pellets (right) so that farmers can see whether the fish are eating the feed or not.

4.4 Subsequent Pond Fertilization

The most important factor in the rearing of tilapia is maintaining a green pond. The greener the pond, the more natural food will be available and the faster the fish will grow. However, too green is detrimental as well. ‘Greenness’ is measured using a Secchi disc. Optimal transparency/turbidity of the ponds should be indicated by a reduction in visibility of the Secchi disc between 20 and 30 cm. If a pond is too green (<20 cm), it may cause fish mortality due to low oxygen levels early in the morning. Pond greenness is controlled by fertilization with chemical fertilizer and/or animal manure. The more fertilizer added, the greener the pond will be.

The amount of fertilizer needed can be calculated as described in Section 4.2 and should be determined by water colour. If the pond is not very green (>30 cm Secchi disc visibility) then increase the amount of fertilizer. If the pond is too green, and fish begin gulping in the morning then stop fertilizing. Generally, there will be an increase in fertilizer/manure requirements throughout the growth period. Depending upon the availability and the choice of farmers, Table 4.7 can be used as a guideline for fertilizer/manure requirements. Some farmers convert these rates to daily and use them continuously for several days until plankton growth appears. Once the water becomes green, then they apply weekly.

Chemical fertilizer should be applied weekly (or more frequently if possible) by dissolving it in water and then broadcasting the solution over the surface of the pond (Fig. 4.12) from at least two locations depending upon the size of the pond. There are no strict guidelines for the application of animal manure. Most farmers either use general broadcast or they apply the manure to a few selected spots located around the edge of the pond. Frequent manuring in small amounts is advisable, but once a week can be sufficient. Some farmers put manure in bags and hang it on ropes.

4.5 Fish Sampling

Fish are sampled monthly to monitor their growth and estimate the amount of feed requirement. Sampling should be done either in the morning or late

Table 4.7. Types and rates of fertilizers that can be used depending upon the availability and the cost–benefit analysis.

Options	Type of input	Amount required (/ha/week)
1	Fresh chicken manure	1000–2000 t
2	Fresh chicken manure + urea	1.2 t + 20 kg
3	Urea + TSP or DAP	60 kg + 60 kg

Fig. 4.12. Dissolving urea with water (left) and splashing the urea dissolved in water (right).

afternoon to avoid stress during the daytime. Normally, farmers use a cast net to catch fish from all the corners and the middle of each side. A total of 100 fish per pond would be adequate, which means 20–30 fish per side or per location is adequate. Each time sampled fish are weighed in bulk then counted and released back into the pond. The calculation is done as shown in Table 4.8.

Average weight of the fish in a particular pond is 331 g (standard deviation 46.1 g). Therefore, the amount of daily feed can be calculated as follows:

Suppose:

Total no. of fish in the pond = 30,000
Average size of fish is = 173.5 g
Feeding rate = 2%
Amount of feed required = 30,000 × 173.5 × 2%
= 104 kg

This amount should be split into two meals if feeding is done twice a day and into three meals if feeding is done three times a day, which means $104/3 \approx 35$ kg.

4.6 Fish Harvest and Marketing

When fish are ready, sampling (Section 4.5) is also done to estimate the total biomass of fish before sale, especially when harvesting is done

Table 4.8. Sampling of fish.

Sampling	Bulk weight (kg)	No. of fish	Average weight (g)
1	7.6	51	149.0
2	8.2	47	174.0
3	6.4	34	188.0
4	6.2	34	182.0
Total	28.4	166	
Mean	7.1	42	173.5
SD	1.0	9	17.3

on a contract basis. The amount of fish biomass can be calculated as follows:

Total stocked fish = 30,000
Suspected mortality = 10%
Expected survival = 90%
Total estimated biomass = 30,000 × 0.90 × 173.5
= 4685 kg
Estimated revenue @ $1.2/kg = $5466

Depending upon the country and location, there are generally a number of choices with regards both to fish harvesting and marketing in the later section. Fish can be either partially or completely harvested.

4.7 Data Recording and Performance Evaluation

Table 4.9 can be used as a template to record the data on fish sales.

4.8 Economic Models

Profitability and the economic models actually depend on the management system, especially stocking density and feeding regime. Figure 4.13 presents simple guidelines on how a farmer should manage pond culture of tilapia.

Without feeding, a farmer may stock 1 fish/m^2 of pond space and can harvest about 1 t from 1 ha of pond. Farmers want to maximize production from the available land or pond space by adding more fish to the pond. However, every culture system has a certain carrying capacity, which means the maximum amount of fish biomass that system can support. This capacity varies with quantity of food and quality of water available in the system, which are subject to management. If a farmer wants to stock more, say 2–3 fish/m^2, then he or she needs to increase its carrying capacity so that

Table 4.9. Data sheet template for table fish sales records.

Date of sale	Customer details (name, address and tel)	kg of fish sold (a)	Price (US$) of fish per kg (b)	Total revenue = (b × a)	Remarks
2/10/2013	Mr Manoj	120	3.0	360	
9/10/2013	Ms Pornthip	300	2.5	750	
–					
–					
–					
–					
–					
–					
–					
–					
Total US$				1110	

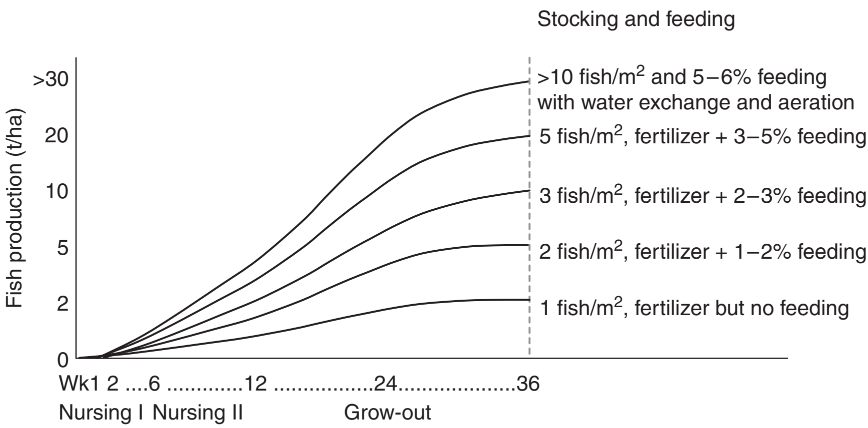


Fig. 4.13. Fish production is directly related to the stocking density up to certain level only.

adequate food is available in the system. Pond fertilization is a cheap option. Similarly, addition of some agriculture by-products such as rice bran or home-made feed as supplementary feed, e.g. 1–2% or in combination, helps to increase this. However, if stocking density is raised to 5 fish or higher per m^2, complete diet or commercial pellet feed is necessary to supply in larger quantities, e.g. 3% of biomass or even higher. The use of large amounts of feed will produce a lot of waste, which limits the carrying capacity. Increasing the carrying capacity requires removal of such wastes, which is normally done by exchanging a certain portion of the water, e.g. 10–30% daily, and/or provision of aeration using pedal wheels, water splash or air injectors. Based on these inputs and productivities, aquaculture systems are categorized into six levels of management models as shown in Table 4.10.

Although higher productivity and total volume of fish produced can be achieved with higher levels of feeding and higher stocking densities, net profit will not necessarily be higher. Due to high levels of investment, farmers may even lose money if they are not careful and don't calculate correctly. This is the main problem among farmers as most of them do not keep records and cannot work out the cost–benefit calculations. The most profitable is likely to be a combination of both fertilization and supplementary feeding.

In order to help farmers or attract potential investors to the aquaculture business, simple economic models have to be developed with detailed financial information. They need to know about the scale of investment and the levels of profits they can expect from varying scales of aquaculture systems. Details of economic analysis per ha of a fish pond are given in Table 4.11 and assumptions used for the models are also given.

Management systems, availability of materials and equipment and their costs vary widely depending upon local circumstances. Therefore, models have to be modified according to the contexts. In this section, two models for grow-out, one each from Bangladesh and Thailand, are described (Tables 4.11 and 4.12).

Based on the economic model developed for the Bangladeshi situation, there is a good profit (36%). Feed is the main cost, which accounts for 65% of total cost. However, the profit is actually the cost for management which is performed by the farmer themselves. If the farmer manages the farm themselves, it is possible to generate a total of nearly $7900, which is $658 per month. This is attractive enough for an entrepreneur to start with.

Table 4.10. Production levels of tilapia culture systems in Asia. (Modified from Edwards *et al.*, 1988.)

Culture systems	Production (t/ha/crop)
Extensive (no input, natural food)	<1.0
Semi-intensive (fertilization with no feed)	1–5
Semi-intensive (fertilization + supplementary feed)	5–10
Intensive-1 (in ponds, complete commercial feed with emergency aeration)	10–20
Intensive-2 (in ponds, recirculating water, complete commercial feed, 24-h aeration, probiotics, etc.)	20–100
Intensive-3 (in tanks, recirculating water, complete commercial feed, 24-h aeration, probiotics, etc.)	100–1000
Super-intensive (cages, raceways, commercial feed, 24-h aeration, probiotics, etc.)	>1000

Table 4.11. Tilapia grow-out farming business model in Bangladesh (per ha of pond).

Description	Taka	US$	Assumptions
Fry including transportation	121,150	1,425	Stocking@3.75 fish/m^2
Land rent (per ha)	123,500	1,453	Annual rent rate/ha
Fertilizers and lime	20,000	235	Lump sum
Electricity/fuel cost	40,000	471	Lump sum
Staff – technicians/ guards	216,000	2,541	Three people
Marketing and communications	10,000	118	Lump sum
Commercial pellets	1,190,417	14,005	US$0.5/kg, FCR 1.2 and 350 g fish
Total (taka)	1,721,067	20,248	
Interest on capital	120,475	1,417	14%/year for 6 months only
Total (cost)	1,841,541	21,665	
Fish sale (350 g harvest size)			
Survival no. (two crops)	62,985	741	85% survival
Production (kg/crop)	20,943	246	Handling loss (5%)
Total revenue (Taka)	2,513,102	29,566	
Total net profit	671,560	7,901	
Net profit (%)	36	36	
Net profit as income for the farmer as the manager	55,963	658	

Note: US$1 = approx. 85 Taka.

Based on the model, a farm with about a 1 ha pond is expected to generate close to the amount required to cross the poverty line, i.e. $2/day. If a farmer rents land with a 1 ha water surface area, they can earn a basic income as the manager. Farmers can actually integrate tilapia farming with vegetables, fruits, e.g. banana, animals in the same land area, without much additional cost and can generate additional income for a good living. While working to develop an economic model, it was found that tilapia grow-out farming could be five to ten times more profitable than crops such as maize and rice. Similar comparisons can be made with other sectors of agriculture to inform farmers. If farmers knew the potential profits, it would not take long to attract more farmers into the tilapia farming business.

In another case in Thailand (Table 4.12), analysis shows that total cost is a lot lower, i.e. $7358, while the cost of management has not been included, considering the owner or an entrepreneur serves as the manager and analysis

Table 4.12. Economic analysis of tilapia grow-out system in ponds in Thailand (per ha of pond).

Costs	Thai Baht	US$	Per cent	Assumptions
Fry and transport	10,500	362	5	3/m² @ 0.35 Baht/fry
Land rent (per ha)	29,000	1,000	14	Lump sum
Fertilizers	41,796	1,441	20	@ 60 kg N @ 30 kg P/ha/week
Lime	870	30	0.4	Lump sum
Electricity and fuel	6,000	207	3	Lump sum
Feed	92,400	3,186	43	Suppl. feeding, FCR <1.0
Depreciation	9,367	323	4	6 years long
Interest rate	13,295	458	6	7% interest rate/year
Miscellaneous	10,161	350	5	5% of the total cost
Total	213,390	7,358		
	For different harvest sizes			
Revenues	300 g	400 g	500 g	800 g
Survival no.	27,000	27,000	27,000	24,000
After handling loss	25,650	24,840	22,950	18,000
Total revenue	223,155	397,440	688,500	864,000
Total net profit	9,765	184,050	475,110	856,642
Net profit (%)	5	86	223	401
Net profit (US$)	337	15,338	39,593	71,387
Net profit (US$)/month	28	210	542	978

Note: US$1 = 30 Thai Baht.

was done to determine whether the net profit would be attractive enough to continue or adopt as anew for family occupation. Most tilapia farmers who are culturing in ponds are trying to reduce the use of commercial feed cost by fertilizing ponds. The analysis revealed that feed (43%) and fertilizer costs (20%) still cost about two-thirds (63%) of the total cost. Therefore, farm operators have to carefully manage feeds, feeding and fertilization in order to make tilapia grow-out farming profitable. In Thailand, as in many other countries, the harvest size makes a big difference to price. Larger tilapia fetch almost double the price compared to smaller tilapia. The analysis shows that if farmers can produce large tilapia (>500 g), profits could be attractive with a potential of earning \$500–1000 per month. But it is only possible to produce large fish when they grow monosex tilapia and these have to be of a really good quality, i.e. at least 99% male. This is one of the main reasons monosex hatcheries have proliferated in Thailand as well as in other countries worldwide.

It is important to note that producing 300–400 g tilapia has a small marginal profit (\$28–210/m), which may not be attractive enough for most entrepreneurs unless large-scale farming is done to take advantage of economies of scale. Therefore, many commercial farmers have around 30–40 ha in total, with a pond size of 3–4 ha, sometimes up to 10 ha. However, it is not easy to find large plots of land. In some areas, farmers are trying to intensify the production system using aeration, commercial feed and even introducing cage culture in ponds (see Chapter 5) or even go for cage culture in rivers, canals and lakes or reservoirs.

Grow-out in Cages

5

5.1 Background

Growing tilapia in cages in lakes, reservoirs and rivers has become a popular aquaculture activity in many parts of the world. Cage culture of tilapia is important to those farmers who wish to culture mixed-sex fish. Reproduction would not be a problem in their systems because both eggs and spermatozoa get lost through the net mesh. Hence, mixed-sex tilapia can be grown in cages without the problems of an excessive presence of small fish competing for food with the original stock. This is the main constraint in pond culture when using mixed-sex fingerlings. The advantages and disadvantages of cage culture are as follows.

5.1.1 Advantages

- It is applicable to landless people because it can be done in open water without the need to have land for fish farming.
- Females lose eggs through the holes if they breed in the cages. Therefore, it does not matter as much if there are some females in the monosex seed.
- There is no accumulation of ammonia or nitrite, and other waste products are easily flushed out from the system.
- High feeding rates are possible and very high fish growth can be achieved.
- Predators can be easily controlled, especially birds, otters, etc.
- It requires low capital investment.
- Fish harvest is easy and flexible.
- Fish farming can be more enjoyable as the caretakers can live on a boat.

5.1.2 Disadvantages

- It is basically a feed-based culture system; therefore it is more expensive than pond culture.
- It is difficult to treat disease and parasites if fish are infected.

- Poaching is easy and so there is a higher risk of fish loss.
- There is a high risk of fish loss due to pollution by industries/factories.
- Fouled cages require frequent cleaning.
- There can be conflict over water use for other purposes, e.g. transportation, irrigation, etc.
- It causes more eutrophication in water bodies.
- Fish may escape from the cage if there is a small hole.
- It can be a target for criticism by environmentalists.

5.2 Site Selection and Planning

When selecting a site for cage culture of tilapia and other species, the following points should be considered:

Accessibility: It is preferable that the site is easily accessible by road and water so that fish, feed, other inputs and equipment can be easily and cost-effectively transported.
Water flow rate: The site should have enough water current to make DO available to fish and remove metabolites from around and underneath the cages.
Physical and chemical properties of water: These are very important factors for cage culture, especially temperature, DO, pH, turbidity, etc. Minimum DO concentration in water should be higher than 3 mg/l. DO below this negatively affects tilapia growth. The recommended temperature and pH range for tilapia cage culture are 22–32°C and 6.5–8.5, respectively.
Protection from waves and winds: The site should be free of strong winds and waves as these may displace cages, possibly even destroy them, allowing fish to escape.
Protection from theft: As most natural water bodies are away from residential areas, one of the major problems is protection from poaching. The area or access road should be well fenced with barbed wire and an alarm system. If possible, each cage should be covered with a lockable net on the top. This would protect fish even when nets are shaken and displaced by strong currents or waves.
Security and lighting: The cage area should be protected by either fence or security guards 24 hours a day. Good lighting in the area will help to prevent poaching as well as making harvest easier.
Cage orientation: Arranging cages in a rectangular compact way might not be good for water flow. In rivers cages are arranged across the river so that all the cages receive fresh water. However, if the river is used for transportation, cages cannot be arranged across the river and will have to be positioned along the river (Fig. 5.1). In lakes and reservoirs, cages can be arranged in various ways depending upon water current and its direction, and potential winds, and often simply depends on the farmer's choice.

Fig. 5.1. A row of tilapia cages in central Thailand.

5.3 Cage Design

Cages can be of two types – fixed and floating. Fixed cages are attached to the substrate, whereas floating cages are facilitated by floating devices such as metal or plastic drums, Styrofoam or sealed PVC pipes. Fixed cages are suitable in shallow water (<5 m) while floating cages are suitable in deep waters. Cages made from bamboo frames and nylon nets are popular among farmers. However, they do not last long; the expected life of bamboo is only 2–3 years in water. Cage size varies from 1 m^3 to 1000 m^3, and rectangular shapes are preferred. The most common size of cages in Asia is 50 m^3 (5 m × 5 m × 2 m). Round cages might be preferred where water currents are strong and there will be spaces between cages to facilitate air circulation. Recently, low-volume cages (1–4 m^3) have been used because per unit area their productivity is higher than in high-volume cages. The cage should be covered with a net with a lockable door to prevent fish loss from jumping and predation by birds. The cage should be placed 1 m above the substrate to facilitate water circulation, thereby promoting rapid fish growth and reducing parasitic infection and diseases.

Steps in installing the cages:

STEP 1. Select a suitable site in terms of water quality parameters, i.e. temperature, DO, pH, salinity, hardness, free of pollution, turbidity, etc. The site should not have very fast-flowing water if it is in the river, but water should be moving gently to flush wastes from the cages. Cages should be arranged in a single row across the flow of water, not along the flow to prevent waste from one cage entering the others. Care should be taken to avoid disturbance from boats and other human activities.

STEP 2. Bring the materials needed to build the cages (floats, rope, net materials, etc.) to the site.

STEP 3. Cage nets should be prepared outside using an iron rod or PVC frame.

STEP 4. Prepare some floats, e.g. empty airtight plastic or metal drums (Fig. 5.2). Check the drums do not have any holes by submerging in water for a short time.

Fig. 5.2. Cage installation using metal drums and bamboo or iron frames. (From Asadul Baqui, Bangladesh.)

STEP 5. Position the drum based on the size of cage to be installed.

STEP 6. Place two metal rods (coated iron or steel, bamboo poles or wooden planks) on each side of the drums.

STEP 7. Tie the two rods/poles by a strong nylon rope (Fig. 5.2) so that they stay on top of the floating drums.

STEP 8. Hang the cage by making strong knots on the metal rods or bamboo.

STEP 9. Either anchor the cage from the outside by tying with rope at each corner of the cage or use a PVC pipe frame inside the cage so that the cage retains its shape and provides enough space for fish.

STEP 10. Cover with a net if there is a problem with predators.

5.4 Fry Nursing for Cage Culture

There is a tendency to extend the nursing period, adding second or even third nursing phases; this is often called advanced nursing (Figs 5.3 and 5.4). This is because the larger the fish at stocking, the larger the mesh net that can

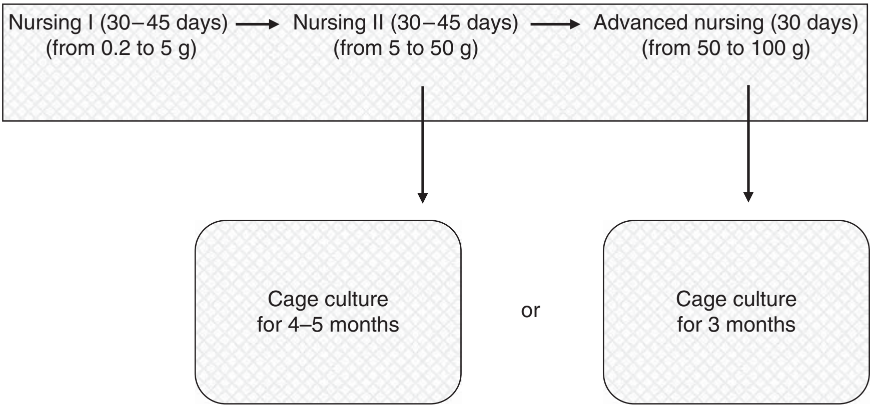


Fig. 5.3. Tilapia farming has become segmented in Asia, allowing farmers to choose any one of the components to adopt as a business and earn income in the shortest time possible.

Fig. 5.4. Advanced nursing to supply large fish for cage culture, Vietnam.

be used to make the cages, which means water circulation will be better. Farmers gain two benefits from such larger fish at stocking – they survive better and it exploits the faster growing phase of tilapia so that the grow-out period can be shortened.

Before stocking into cages, monosex fry of standard average size 0.2 g from a hatchery are nursed in hapas or ponds/tanks in two stages: first nursing for about 30–45 days (by which time fish can be around 40–50 g) and second nursing for another 30–45 days. By the end of second nursing, fish are ready to stock in the cages. Recently, farmers have become increasingly attracted to stocking larger fish, i.e. up to 100 g in size, into their cages so that they can harvest the fish at around 750 g in 3 months instead of 4 or more months needed when they stock smaller fingerlings with higher chance of mortality and slower growth.

5.5 Stocking

As in pond culture, fish should be stocked either early in the morning or late in the afternoon when the water is relatively cool. The same rules apply as when releasing fry, i.e. gradually after allowing the water temperature in the plastic bags or plastic containers to equilibrate. The stocking density of tilapia varies with cage volume, desired harvest size, production level and length of culture period. In Asia, farmers stock 20 fish/m^3 in limited or no feeding cages and 40–60 fish/m^3 in feeding cages. The optimum stocking rate of Nile tilapia is 50 fish/m^3. However in Thailand, farmers stock around 70–80 fish/m^3 (Fig. 5.5)

Fig. 5.5. Cage culture with heavy feeding in an irrigation canal in Central Thailand. About 1500 fingerlings of 50 g size are stocked in each cage of 50 m^3 (5 m × 5 m × 2 m) size that can produce about 1 t of 600–1000 g tilapia in 5–6 months.

and in Vietnam stocking densities can reach 100 fish/m^3 as the cages are in either fast-flowing rivers or a large-volume water body such as the Mekong River (Fig. 5.6). Very intensive systems may achieve 300 fish/m^3 stocking density but these use specially designed small cages (1–4 m^3) promoted by the American Soybean Association (ASA) and popularly known as LVHD cages (Zhou *et al*., 2012).

Recently, some farmers are shifting from cage culture in rivers to cage culture in ponds (Fig. 5.7), especially after a large loss of fish due to river water pollution. Communal water bodies are used for various purposes such as transportation of goods like rice, cement, molasses, and so on, and there have been cases of large barges capsizing. Similarly, there have been cases of river water pollution from pesticides draining from agricultural land upstream. In order to avoid these problems some farmers install cages in their own ponds.

Farmers stock large fingerlings and/or young adults, i.e. 50–100 g, in cages and feed with high-quality pellets at high per cent of biomass or near to satiation so that their fish grow rapidly. In this way, farmers can reduce the grow-out period to 3–4 months and harvest at 600 g to 1 kg in size – these fish look quite fat and fetch high prices. Another benefit is that fish in the pond do not need to be fed. The uneaten feed and nutrients leached into the water are utilized by fish directly or by plankton, which will be ultimately consumed by the fish in the pond. Some farmers grow carp, pangasius and other fish, but many grow only

Fig. 5.6. Red tilapia culture in cages in the Mekong River in Vietnam. A cage of 512 m^3 (16 m × 8 m × 4 m) size can produce up to 20 t/crop.

Fig. 5.7. Tilapia in cages and pangasius are in the pond in Chiang Mai, Thailand.

tilapia both inside and outside cages. Then after harvest, young fish from the same pond are seined, graded and then put into the cages for subsequent crops. The space outside the cages is used for nursing of fry and fingerlings.

5.6 Feeding

Tilapia grown in cages are managed intensively by providing complete commercial pellets but they can also be grown semi-intensively. A mixture of rice bran and fishmeal can be mixed together as a home-made feed and fed to tilapia in a semi-intensive system with low-density culture. Both floating and sinking pellets containing 25–35% CP are used. Feeding rings are usually used to confine floating pellets inside the cage. Because sinking pellets disintegrate quickly in the water, feed should be given on a feeding tray submerged below the water surface. The feeding tray can be made from metal or plastic. Feeding can be done once or twice per day, in the morning (8–9 am) and late afternoon (4–5 pm). Most farmers feed tilapia 3–5% of their body weight daily. However, higher feeding rates are common among others who expect rapid growth and larger tilapia harvests such as in Thailand, where farmers have been advised to feed 5–8% biomass daily so that they can harvest large fish that look like they have more meat.

5.7 Water Quality Monitoring

Monitoring water quality is quite important but if cage culture is carried out in communal water bodies, there is no way that a farmer or a group of farmers can control or improve the water if the quality deteriorates. The following water quality parameters should be monitored or analysed on a regular basis, preferably weekly:

- temperature (°C or F);
- DO (mg/l);
- pH;
- salinity (ppt), if the site is in a brackish water area; and
- chlorophyll or Secchi disc visibility.

5.8 Cage Fouling

Cages can be blocked by algae, plant debris and other material preventing the exchange of water between the inner and outer parts of the cages. If algal growth is extremely high outside the cage, stocking fish that consume algae can be beneficial. Cleaning of cages is not easy and so prevention is a better strategy. Antifouling cage nets are available in various parts of the world but they can be quite expensive.

5.9 Sampling and Harvesting

The grow-out culture period may vary from 3 to 7 months, depending upon feeding and other management. If fish are stocked at 40–50 g size, it may take 4 months to grow to 750 g size. But farming is now becoming more specialized and farmers stock about 100 g large fish and in 3 months they can grow to 750 g size with survival rates in cages generally higher than 70–80%.

In the Philippines, an average production of 540 kg is obtained from a 100 m^2 cage. During harvesting, the cage is partially lifted out of the water so that the fish are collected in a corner and can be caught using a scoop net.

Cages are usually in rivers or lakes, which are below the level of the road. Farmers in Thailand use pulleys to lift the fish while harvesting using a motorbike engine to pull the load from the cage. They weigh the fish after lifting to the roadside and then upload to a pick-up truck.

5.10 Socioeconomic Analysis

The profitability of cage culture depends on feed, labour and other costs, which may differ from country to country. In Thailand, red tilapia culture shows a good margin (28%) when family labour costs are excluded (Table 5.1),

Table 5.1. Cost–benefit analysis of red tilapia cage culture belonging to a family who own 15 cages of 6 m × 3 m × 3 m in Chaophraya River in Ang Thong Province, Thailand.

Cost items	Total unit	Unit price (Baht)	Total (Baht)	Total (US$)
Fingerlings (no.)	6,000	6	36,000	1,200
Feed (20 kg bag)	300	668	200,250	6,675
Electricity	4	1,500	6,000	200
Cage depreciation cost			22,500	750
Other costs (15%)			13,238	441
Total costs			277,988	9,266
Income	4,500	79	355,500	11,850
Net profit per cycle (as family labour)			77,513	2,584
Net profit per year (as family labour)			232,538	7,751
Net profit margin (%)			28	28

Note: US$1 = Thai Baht 30.

but when these costs are included very little margin remains. However, farmers appear to be satisfied because they have found it an easy job in terms of time, especially because housewives can take care of feeding and other simple management when cages are installed, and so they do not need to work in the fields as agricultural labour or in other low paid jobs. It has created jobs in rural areas for people who would otherwise be either unemployed or have worked as labourers. It is possible in a country where either government or private companies provide good extension services and supply fingerlings, feed and also buy back the fish for processing and marketing.

However, revenue and profit very much depend on the size of fish that farmers can harvest. Table 5.2 shows the cost–benefit analysis per cage. Net profit is possible only when fish achieve a size of more than 400 g and if a considerable proportion of fish is small, farmers will lose money. Therefore, the quality of fingerlings is crucial to profitable cage culture. This is the reason farmers in Asia look for monosex fingerlings to stock in their cages. If there is 20% of females that do not grow larger than 400 g this may reduce the revenue, resulting in net losses.

In other countries, this has to be carefully analysed to see whether it will work – it may not work in countries where there is a lack of such services and even if they exist, in many cases the quality of services, fingerlings and feed can be a problem. In such cases, vertically integrated corporate farming is necessary so that fingerlings are produced by the same farm and there is a market so that fish can be sold easily, either locally or exported to other countries. Although feed is normally available, it may need to be

Table 5.2. Cost–benefit analysis for different sizes of fish at harvest.

Cost items	Unit cost (Baht)	Unit	Total (Baht)	Total (US$)
Fingerlings (no.)	1,800	3	5,400	174
Electricity and fuel	7	43	300	10
Feed (kg)	22	1,400	30,800	994
Depreciation	250	4	1,500	48
Interest rate (18%)	855	4	3,420	110
Miscellaneous	125	4	500	16
Total	3,059		41,920	1,352

	Harvest sizes (g)			
Revenues (Thai Baht)	300	400	500	800
Fry stocked (no.)	1,800	1,800	1,800	1,800
Survival (no.)	1,440	1,440	1,440	1,440
Total revenue	25,920	37,440	50,400	91,008
Total net profit	−16,000	−4,480	8,480	49,088
Net profit (%)	−38	−11	20	117
Net profit (US$)	−516	−145	274	1,583
Net profit/loss (US$/month)	−43	−12	23	132

Note: US$1 = Thai Baht 30.

produced by the same farm because it can be too costly to purchase from other commercial companies. This is the situation in most African countries with the exception of a few. Therefore, commercial farming of tilapia has been possible only for large corporate companies. Hopefully, this situation will gradually improve and farming of tilapia will become more common even in rural areas.

One good example is Bangladesh, where cage culture is now considered an excellent occupation for landless families who live near water bodies but live temporarily on others' land or on communal land, and who struggle to earn a living from wages earned as labourers. Cage culture of tilapia can provide a reasonable income without the need for land ownership. Considering it to be a community welfare activity, the government has given them the rights to use the water. In this case, the government and other community development organizations see the creation of jobs, producing fish for family nutrition and some income from surplus fish as the important factors, rather than maximizing production volumes and profits, which would be the priority if cage culture was being carried out by the private sector. If organized in groups and cooperatives together with private companies or trading groups, these community groups may also be able to produce large volumes of fish to supply to the market to fulfil the demand. However, it has not been easy and policy makers need to be clear about the purposes of developing a cage culture industry. There are two clear objectives. Choosing the private sector would give faster results but it may not be easy for the private sector to decide to invest in an aquaculture business until there is a good market potential.

6 Polyculture

6.1 Introduction

Freshwater fish culture has developed over the last five decades. A decline in capture fisheries has further promoted the development of aquaculture. Fish culture might have evolved simply from the tradition of holding wild caught small fish in enclosed water for later consumption. In most countries, common carp (*Cyprinus carpio*) was the first species introduced for aquaculture but several other species have been introduced and recently cultivated species include a wide variety of carp, tilapia, catfish, gouramies, freshwater prawn and several others. To minimize risk and to have fish of different flavours, people began to culture many species in the same pond but later realized that different species have different feeding habits (such as bottom, column and surface feeders), so began to select fish that are compatible, or will not compete in terms of space and food. Culturing two or more species together in the same system is called 'polyculture'. The following combination is an example of traditional polyculture in China:

- Grass carp (*Ctenopharyngodon idella*) – feed on grass or herbivorous material
- Silver carp (*Hypophthalmichthys molitrix*) – phytoplankton feeder
- Big head carp (*Aristichthys nobilis*) – zooplankton feeder
- Mud carp (*Cirrhinus molitorella*) – detritus feeder

Similarly, another traditionally practised polyculture, often referred to as composite culture, is found in India using the following combinations:

- Rohu (*Labeo rohita*) – herbivorous column feeder
- Catla (*Catla catla*) – zooplankton feeder
- Mrigal (*Cirrhinus mrigala*) – bottom dweller

Common carp, a bottom dweller and omnivorous feeder that was introduced to many countries along with its hatchery technique, has been well integrated into the above-mentioned polyculture systems. Similarly, efforts have been made to introduce tilapia into these polyculture systems. Results have shown that tilapia can grow well without affecting the growth and performance of other species when stocked at reasonable densities. However, trials have been conducted to use tilapia as the main species and the carp mentioned above as minor species. Mouth-brooding tilapia can also be raised together with other species of fish and Table 6.1 shows some species combinations. The main aim of doing this is to utilize natural foods (phytoplankton, zooplankton, detritus, grasses and macrophytes) available in the system and thereby increase fish production. This is possible because tilapia feed on the one or two sources of food they prefer, i.e. phytoplankton and/or detritus. By stocking a variety of different fish, any food not eaten by the tilapia will be eaten by other species and will not be wasted. Adding one or a few other species of fish would not add to the cost for the farmer but would increase the yield, increasing the net profit when they are sold.

Polyculture is normally practised in ponds. The type of species and number of fish stocked is entirely a matter of the farmer's preference and experience, but the feeding habits of the available fish species have to be kept in mind as well as whether there is a market for them. Grass carp, for example, would be very useful as it feeds on grasses and cleans up the pond dykes. Grasses grown on the dyke can also be chopped up for feed. In China it is considered the main species for polyculture as it consumes a lot of grasses and its excreta produces the green water that supports other species. More importantly, it can be sold at high prices to Chinese communities. Chinese farmers grow tilapia as the main species and silver carp as a cleaner fish as it can filter plankton. Another reason is that if water quality deteriorates, silver carp die first, which serves as an indicator. Similarly, in Thailand, silver barb (*Puntius gonionotus*) is an indicator because it is prone to die if water quality changes.

Table 6.1. Natural food and stocking ratio of polyculture species.

		Stocking/ha	
Species	Benefits/purpose	Per cent	Number
Nile tilapia (*Oreochromis niloticus*)	As the main species utilizes normally phytoplankton	90	27,000
Grass carp (*Ctenopharyngodon idella*)	Utilizes grasses/macrophytes grown on the dykes or around	5	1,500
Mirror/common carp (*Cyprinus carpio*)	Clears debris in the pond bottoms and oxygenates	3	900
African catfish (*Clarias gariepinus*)	Controls tilapia recruits (unwanted fry) and dead fish	2	600
Total		100	30,000

Common or mirror carp is good at clearing up the debris on the pond bottom but it may create turbid water and even damage dykes if more fish are stocked.

African catfish is useful for controlling the recruits (unwanted fry) of tilapia, especially in mixed-sex tilapia farming systems. They are also good for monosex culture because there can still be a few females producing fry. Catfish are purposely stocked to control tilapia recruits in broodstock ponds if the brooders are managed in hapas. Whatever type and number of fish stocked, one point to bear in mind is that they should attain market size in the same time frame, e.g. in 6–7 months, like tilapia. Table 6.1 should serve as a guide for polyculture.

Nile tilapia reproduce in culture systems without the need for hormone injection, which is useful in some rural areas where fish farming is subsistence level and mainly for family consumption. Small fry, often called 'recruits', are produced as a by-product and can serve as fish seed for sale or to stock in other ponds, which can be an additional source of income for the farmers. However, excessive reproduction has been a major disadvantage of this species for commercial farming because almost a quarter of fish are small and unsaleable. The main problem of having fingerlings in grow-out ponds is that they compete for feed and space with the adult tilapia and hamper their growth. This is the reason farmers are attracted to monosex tilapia fingerlings. However, production of monosex fry is not possible in many areas, especially rural areas, and so most farmers in these areas use some carnivorous fish species as a means of controlling tilapia recruits. The recruits can be reduced by rearing tilapia in combination with a predator fish. For example, the following predator fish have been successfully used in polyculture with Nile tilapia in various parts of the world:

- *Lates calcarifer*: Asian sea bass or barramundi is a good predator fish and has higher economic value.
- *Clarias gariepinus*: African catfish is widely used as a predator and works well as long as they are stocked at low densities (900–1000 fingerlings/ha).
- *Lates niloticus*: Nile perch is a good predator, but difficult to obtain fingerlings.
- *Ophiocephalus obscuris*: African snakehead is a highly effective predator that is completely piscivorous and eliminates all tilapia fingerlings if stocked at a density of 800–1000/ha.
- *Channa micropeltes*: Asian snakehead.
- *Channa marulius*: Giant snakehead.

As tilapia consume various microorganisms, detritus and provided feed, they can be grown in polyculture. Trials were carried out at the AIT to include carp in tilapia ponds in polyculture (Hossain *et al.*, 2003). There was no difference in production between polyculture with carp and monoculture of tilapia. Polyculture is a complex system, but almost every pond farmer (except very intensively managed set-ups) stocks many species and practises polyculture, which is considered to be the best method because farmers get the benefit of multiple harvests and diversify their risk.

6.2 Feeds and Feeding

As polyculture is practised mostly in a semi-culture system, the type of feed and its amount depends on the management and largely depends on the species used. In the case of grass carp, grasses from the dyke or the surrounding area can be chopped up and spread on the pond water surface. For other species, vegetables and succulent plants and the leaves of banana, water hyacinth, ipil ipil, etc. can be minced up to mix with trash fish, rice bran or any other ingredients to produce home-made feed in the form of dough or sinking pellets.

Some farmers feed rice bran, cornmeal or oilcakes, alone or in combination as supplementary feeds. Feeding is done once or twice a day; however, there is no hard and fast rule and some farmers may feed only once every few days. Pond fertilization is an important part of polyculture farm management. Organic manures from chickens, pigs, cows or any other animals, or chemical fertilizers such as urea, TSP or DAP can be used, as described above in the previous section on pond culture.

6.3 Harvesting

Polyculture is normally semi-intensive – harvesting is done many times (multiple harvests) instead of one final harvest (Edwards *et al.*, 1988). Farmers can maximize both their total fish production and their income. More importantly, they can harvest whenever there are good market prices for certain species or whenever they need to for family purposes or for community ceremonies, perhaps several times a year. Figure 6.1 shows a 2-year cycle, in which a farmer may harvest only twice but they are complete harvests. There will be a slack period between the two harvests because the farmer will need to drain and dry the pond before filling, fertilizing and stocking the fry for the second crop. In other cases (Fig. 6.1, lower graph), a farmer may harvest his or her fish many times, e.g. six times as shown in the figure, or more if necessary. The total amount of fish produced can be a lot higher than in a single harvest method.

Farmers with polyculture ponds normally use multiple harvests for several years. Assuming 2 years as the shortest period to compare with monoculture, the total number of fish harvests can be five or six, which may depend on the species stocked and method of management. Some harvests can be one species and another harvest can be another species. The total amount of fish can be higher than the two crops of monoculture (Edwards *et al.*, 1988). As shown in Fig. 6.1, the amount of fish per harvest = 4 + 3 + 4.5 + 2.5 + 3 + 5 = 22 t.

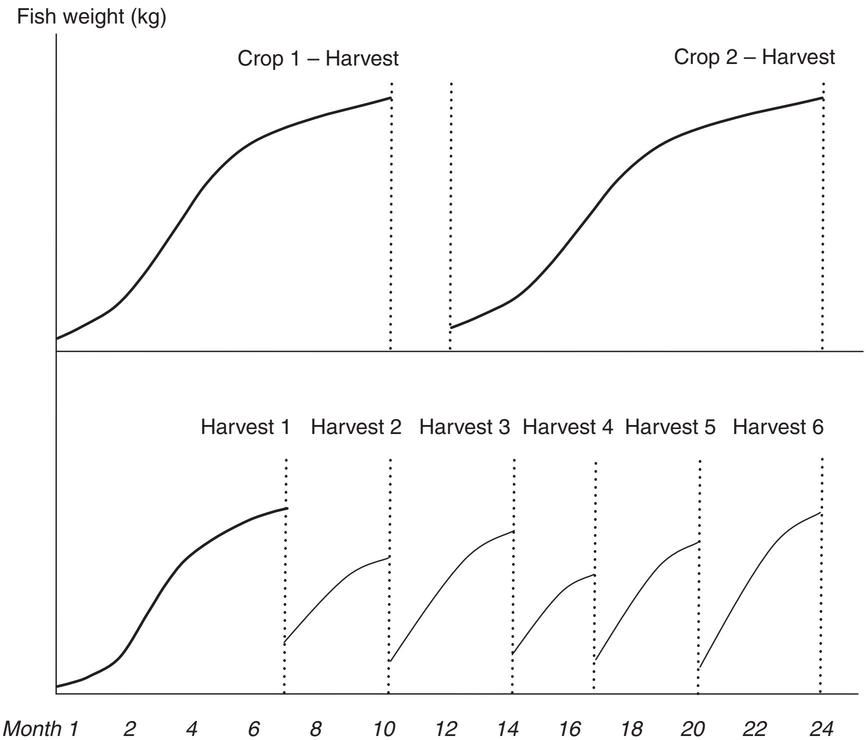


Fig. 6.1. Two-year cycle of fish stocking and harvest.

This clearly shows that multiple harvests give higher production and more flexibility for farmers, as they can harvest based on market demand; it also provides more stable cash flow.

In the case of single-species culture, there will be a pond preparation period before stocking new fingerlings. Two crops can be harvested in 2 years. Therefore, if the productivity is 6 t/ha/crop then two crops will produce $6 \times 2 = 12$ t.

6.4 Socioeconomics

Polyculture has been practised for a long time for socioeconomic reasons. It is said that polyculture is always the best method, although monoculture systems dominate commercial farming. Well-managed polyculture systems could result in high profits but it will largely depend on the management – it needs to be done properly, understanding the requirements of each species. Although there are advantages of polyculture systems, a farmer who wants to practise it needs to understand the disadvantages as well so that he or she can either avoid or overcome them.

6.4.1 Advantages

- Maximum utilization of available food in the culture system, which results in the highest production per unit of culture system.
- Farmers can enjoy different species if they consume at home.
- Fewer risks as some species may still survive if there are any water quality or other management problems.
- Less risk of market price fluctuation. If the price of one species is low, the price of another species may still be high.
- Low feeding costs are possible because fish mostly consume natural food from various parts of the culture system such as the bottom, column and surface.

6.4.2 Disadvantages

- Relatively more complicated and difficult to manage.
- Farmers have to know about the culture methods of more than one fish species.
- Farmers need to worry about marketing many species, and it is sometimes difficult to find a good price for all the culture species.
- The total cost of management and operation is high because it requires additional items, facilities and skilful people.

7 Integrated Farming

7.1 Introduction

Since the very beginning of farming, people in various parts of the world have been raising animals along with growing crops, fruits, vegetables and spices. With the commercialization of agriculture mono-crops became popular because of their high productivity and profitability which was a result of the development of specialized knowledge and technologies. However, the sustainability of commercial mono-crop systems has been questionable. Revisiting and reviewing the traditional systems, academicians and researchers have tried to understand the linkages or interactions between the various sectors of the farming system. Interestingly, systems of growing many crops, vegetables and fruits along with raising animals have been found to be more sustainable as well as more efficient in recycling available resources. Such farming practices, in which a farmer effectively utilizes their available resources such as land, water, by-products or wastes to produce more food for consumption by their family and/or for sale is called 'integrated farming'. Basically, in an integrated farming system, an output from one subsystem that otherwise would have been wasted becomes an input to another subsystem, resulting in greater efficiency. For example, rice bran is used as animal feed and animal manures are used to fertilize rice fields, vegetable gardens, fruit orchards and, more recently, fish ponds.

A traditional integrated farming system practised by poor families in rural Vietnam is known as the VAC system (Luu, 2001) (V = *vuon* (garden); A = *ao* (pond); C = *chuong* (livestock house)). The system centres around a pond – the farmer grows vegetables using the pond water and raises animals, especially pigs, which fertilize the pond as well as the vegetable garden. According to these farmers the most profitable activity is aquaculture and the second is agriculture, horticulture or gardening.

Commercial integrated livestock–fish farming systems began in the early 1980s. Livestock farming had been the main source of income and plenty of animal manures were available, produced as farm by-products. Some farmers use these manures to fertilize their crops, vegetable gardens and fruit orchards.

In livestock–fish systems, farmers throw manures into the pond as a source of nutrients for phytoplankton and to be a substrate for bacteria and micro-fauna that are eaten by the fish.

In many parts of Asia, ponds are used to store water that can be used for livestock. At the same time, animal manures can be inputs for fish ponds. The use of chicken and pig manures has been the most common way of developing green water in fish ponds. Chicken manure contains 1.5–8.5% N, whereas pig excreta ranges from 1.8 to 7.4% N. Similarly, in some countries cattle faeces/manure are used, which normally contain 0.5–4.4% N. As these manures contain very low levels of nutrients, farmers have to use quite large amounts in order to develop green water and support good fish growth. Ponds should not be loaded with excessive amounts of manure because overloading of organic matter creates an anoxic environment at the bottom. The range of manure or organic matter (dry weight) should not be more than 100 kg/ha/day. Pig sheds are constructed on the pond dyke connected by drainpipes to flush urine and litter directly to the ponds; poultry houses are built over the fish ponds.

Traditionally, farmers grow cereal crops, vegetables, fruits and spices, and also raise animals such as buffalo, cattle, chicken, pigs, goat, sheep and so on, living together with them on a plot of land. Knowingly or unknowingly, they have been utilizing wastes from one component to feed another so that they do not need to bring inputs in from outside. These traditional systems are naturally sustainable because nutrients are recycled within the system, and their value has been realized recently. Much research has been carried out and these various types of systems have been under the spotlight around the world.

It has been traditional in most countries for a long time for a farmer to grow crops, vegetables, fruits and raise animals in the same area. By-products of crops can be used to feed livestock and a small part goes to the fish pond, e.g. rice bran, wheat bran, etc. Figure 7.1 shows how farm by-products are reused in an integrated system. Livestock consumes most of the inputs and produces a large amount of manure, which in the past was used mainly for crops, vegetables and fruits. However, recently, farmers saw an opportunity to use it as a pond input to produce fish, which is more efficient in terms of nutrient utilization and provides a higher income. This shows that farmers need very little external inputs. If a large amount of external inputs need to be purchased, this may not be sustainable in the long run. In integrated farming, a farmer can maximize their produce from all the components of agriculture including livestock, fish, crops, fruits and vegetables. Farmers may consume quite a lot of their produce, which provides nutrition to the family members. However, farmers are becoming more commercial and they may trade their produce and purchase food items later whenever they need. They often tend to grow high-value products and purchase cheaper ones for family consumption.

Although not as common, other animals such as cattle, buffalo, goats and sheep are also farmed, which feed mainly on grasses, and their manures are

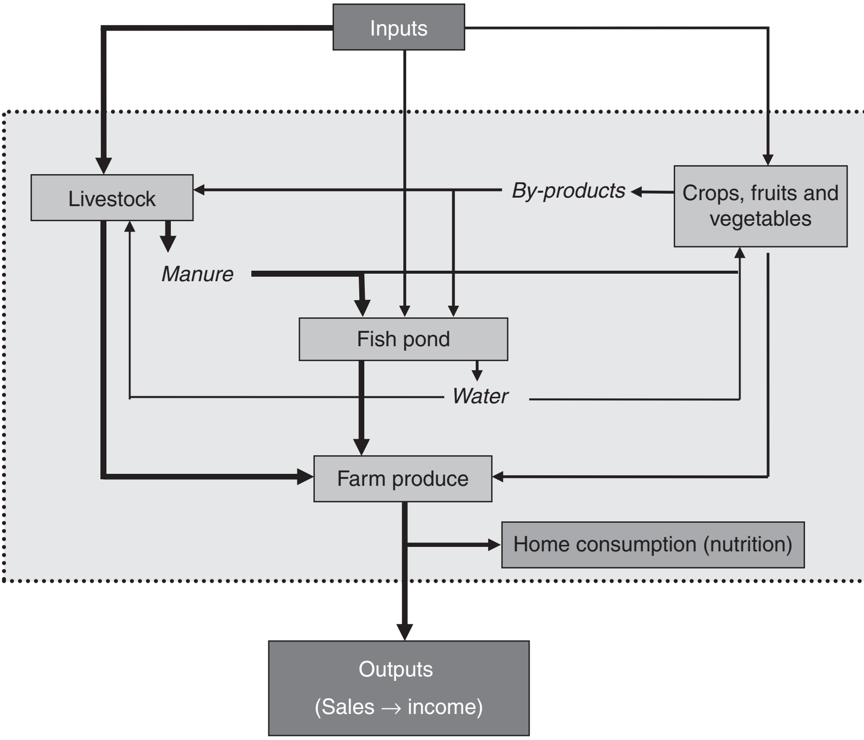


Fig. 7.1. Integrated farming system. (Modified from Edwards *et al.*, 1989.)

considered organic if antibiotics are not fed. The recent trend towards increased demand for organic products and its expanding market share indicates that integration of aquaculture with these animals is likely to have greater scope in the near future. More importantly, tilapia is the species considered to be most suitable for culture in manured ponds.

This livestock–fish farming system became more popular recently due to an increase in agricultural input costs and low output prices. Farmers see this system as an alternative way of reducing costs of production and increasing their incomes. Large commercial farms are still using manures as the main fish pond inputs. Only a few commercial farms that are exporting fish are using commercial pellets due to the requirements set by the importers.

7.2 Chicken–Fish Farming

One of the most important types of integrated farming is fish with chicken. As tilapia is a hardy fish and can be grown in a wide range of environments, it has been tried in various culture conditions including waste waters from industry and municipalities; this is known as a waste-fed aquaculture system. The main purpose of this type of aquaculture is to clean such waste waters; often the fish are stocked in drainage canals or specially constructed waste water storage tanks or ponds but fish grown in this type of water are not suitable for consumption. However, this might have opened the door for tilapia as a species suitable for integrated culture with other animals and plants, with the aim of utilizing nutrients from the wastes and producing edible fish at low cost. Examples include constructing pig sheds on the dykes of tilapia ponds and culturing tilapia using pig manure and urine, building chicken houses over the fish ponds, and so on.

Chicken manure has been considered the best among animal manures. Both broilers and layers can be raised above the pond (Fig. 7.2) so that uneaten chicken feed (remaining or spilled over), excreta and litter such as rice husks, straw, sawdust, etc. used as litter can fall into the pond and as a result the pond water becomes green – rich in phytoplankton and zooplankton, the natural food of tilapia. Large amounts of nutrients are wasted in chicken houses. For example, in the case of egg-laying hens, only 20% of the energy/nutrients are assimilated as eggs but up to 80% are wasted. This is the reason that research is being done into utilizing the wasted energy or nutrients by developing integrated systems which allow these by-products or wastes to be used as inputs for another component of the farming system, such as fish.

The followings guidelines are recommended:

- Build chicken house(s) 1–2 m above the water surface so that farmers do not require additional land, which is scarce and expensive.
- Ponds should be rectangular in shape with 1.5 m water depth. Square ponds are difficult during fish harvesting.
- Normally, about 1000 to 10,000 broiler chicken per ha of pond area can be raised.
- Farmers normally start with 1-day-old chicks to grow to 1.5–2.0 kg in 45–50 days.
- In the case of egg-laying chickens, they are confined in a small row cage above the fish pond and stocking rate is 3000 birds/ha. More can be raised but the amount of manure produced will be more than is needed for the pond.
- Harvest the fish and arrange for depuration if necessary (fish grown in manured ponds tend to have off-flavour). Depuration involves keeping fish in clear water for 3–4 days, feeding with commercial pellets just before sales.

Having chicken houses over the fish pond provides good air circulation inside the chicken house. It also helps save time and labour as farmers do not need to collect chicken manure and clean the floor frequently. This reduces the risk of disease. However, farmers have to be aware of the fact that there are some disadvantages of farming chickens over the fish ponds so that they are prepared for potential challenges, for example:

Fig. 7.2. Chicken houses over the fish pond in Thailand.

- Frequent occurrence of chicken diseases such as bird flu and others may affect the acceptance of fish grown in ponds underneath.
- Use of antibiotics and other chemicals in chicken farming may be an issue in many countries and may also be a problem for fish farming and its markets.

- Construction of chicken houses is expensive and growing chickens has a high operational cost because farmers have to feed chickens and buy feed every day or at least every week.
- Farmers require more knowledge to understand chicken farming, which can overshadow or distract from the farming technique and income generated from fish.
- In some cases, fish ponds receive excessive chicken manure and the water becomes too green as a result. DO will drop to zero in the morning, which is detrimental to fish.
- Collection of manure, if it is needed for other purposes, is difficult.
- Chickens are exposed to extreme temperatures because of excessive circulation of air. Low temperatures during winter and high heat during summer can be problematic.

7.3 Duck–Fish Farming

As ducks need water to graze, rearing ducks close to fish ponds has been a tradition in Asia for a long time. However, systematic scientific studies and development of techniques are in their infancy and it is an often poorly understood subject. As with chickens, some farmers build duck houses over the fish pond so that duck manure and uneaten feed can drop directly into the pond; other farmers may choose to build the house on the dyke or nearby. In the latter case, farmers need to collect the duck manure or use water to flush the area every day so all the nutrients are transferred to the pond. Normally duck houses are made of bamboo or wood.

Ducks can be either raised in confinement or left to graze during the day time. If small fish are stocked in the pond, ducks should not be allowed to graze as they may eat fish fry and fingerlings. Where ducks are grazing, larger fingerlings (at least 5 cm) should be stocked. Alternatively, ducks can be allowed to graze in a pond with a fence confining them to some shallow water areas. Tilapia can be grown together with ducks. Growing mixed-sex tilapia can be good because the ducks may consume small tilapia recruits. Tilapia, together with other species in a polyculture system, can also be beneficial in the raising of ducks. Other species may include small-scale mud carp (*Cirrhinus microlepis*) at a stocking density of 10,000–15,000 fingerlings of 5 cm in size per ha. Unlike chicken, a lower number of ducks is recommended, e.g. 1500/ha Khaki Campbell type (AIT, 1994). However, other intensive farming systems have tried much higher levels than that, perhaps up to 10,000/ha of pond area.

One-day-old ducklings are first raised for a month before stocking in the duck house. It takes about 4–6 months for the ducks to start laying eggs. Duck feed can be prepared at home by mixing rice bran (30%), feed concentrate (20%) and broken rice (15%). A duck will need approximately 150 g/day. If they are fed more than necessary, their feed can be washed into the pond, which serves as feed for the fish. As ducks also feed on natural food, especially succulent plants, they help remove grasses from the pond area.

More importantly, they can clear up the small molluscs, snails and other insects that may carry parasites, and so ducks are beneficial to the fish.

7.4 Pig–Fish Farming

Pigs are raised as a good source of animal nutrition and cash income in various parts of the world. Pigs consume large amounts of food and also produce a lot of excreta, which contains high levels of undigested nutrients that can play a part in pond fertilization. With this in mind, pig sheds are normally built on dykes (Fig. 7.3) so that when they are cleaned out, the pigs' dung and urine are flushed into the fish pond. At the same time, part of the pond can be used by the pigs to clean themselves and to cool down when it is hot. If the pig sheds are built above the fish ponds (Fig. 7.4), uneaten food and excreta drop directly into the pond, which avoids the labour costs of cleaning the sheds.

Pig integrated with fish farming is very popular in China and Vietnam as an option for subsistence livelihoods, as well as commercial farming for income generation. Fish do not need to be fed because the pond water becomes so green and full of natural food from the pig manure; this can mean savings of up to 50% or sometimes even 70% of production costs and so this is the cheapest method of producing fish. The system was initially practised by pig farmers in China to increase revenue when the prices of pig feed went up and they found it hard to make a profit. This Chinese system of raising pigs on the dykes of large fish ponds has spread all over the world.

When pigs are young and small (<50 kg), fish need to be fed with supplementary feed, e.g. rice bran, food waste, vegetable leaves, etc. When pigs are larger, they start producing adequate manure to supply nutrients to enhance plankton in the pond, which is required for fish growth. Pigs are normally fed with low protein (around 15% CP) home-made feed or a mixture of cassava, broken rice and some concentrate.

Fig. 7.3. Series of pig sheds on a pond dyke in Kafue Fisheries, Zambia.

Fig. 7.4. Pig sheds over the fish ponds in foothills of Nepal.

As a pig can produce a large amount of manure daily, relatively few, i.e. around 100 pigs, would be enough to fertilize 1 ha of pond in which 10,000–30,000 tilapia fingerlings can be stocked alone or in combination with other species such as African catfish or striped catfish fingerlings at a rate of a few hundred to 1000 fingerlings/ha. Subject to water temperature and market prices, the first tilapia harvest or fish sale could be after 5–6 months. Several partial harvests of larger fish can be carried out to allow smaller fish to grow, which in turn maximizes total fish production and hence profits. Total production of fish from pig integrated farming can range from 5 to 15 t/ha/year. Depending upon the systems used and their management, a farmer may earn 30–50% net profit from integrated systems.

One of the major issues with pig–fish farming is the human health hazards. Concerns have been raised over whether there is any chance of parasites or their spores passing from pigs to fish and then to humans, especially tapeworms. This could happen if fish are eaten raw or partially cooked. Similarly, as Muslims do not eat pork, fish cultured in ponds fertilized with pig manure are not acceptable to that particular community.

7.5 Tilapia with Rice

'Where there is water there is fish' is a popular saying in Asia. As rice needs water throughout the growing period, fish can be stocked and grown in the same plot. Fish farming in rice fields started in China 2000 years ago. In traditional Chinese systems it is normal to dig small ponds to irrigate rice fields as well as to culture fish and turtles, and also to grow lotus and water chestnuts. Rice–fish farming is very common in Asia – indeed Asian society is often called the 'rice–fish' society and a common saying is 'rice in the field and fish in the water'. It is the most basic integrated farming system in Asia.

Fish can grow in rice fields without any nutritional inputs being given directly to the fish. They consume natural food in rice fields, including pests, which is beneficial for the rice. Fish are stocked after rice transplanting. Farmers continue to keep fish in deeper parts of the rice plots when rice is ready to harvest (Fig. 7.5). They also use a rotational system, alternating with rice crops in areas where water remains even after rice harvest. Normally, a trench of about 1 m deep and 1–2 m wide along the dyke is made as a shelter for fish, so that water remains even when the rice field dries up, especially near the time of rice harvesting. The best species for rice–fish culture found so far are common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*). In fact recently tilapia has been found to be more suitable because it has a short culture period that suits and fits with the high-yielding varieties of rice which require about 3–4 months to grow. The nursing of fry installed in hapas at the corners of rice plots can be even more appropriate.

Figures 7.5 and 7.6 show some examples of rice–fish systems. In many parts of Asia, especially in Bangladesh, Indonesia, Thailand, the Philippines

Fig. 7.5. Rice–fish in Bangladesh. Rice has been harvested and fish are in the water at the deeper corner of rice field.

Fig. 7.6. Rice–fish in Thailand: fish are protected by net material.

and Vietnam, many rice fields have been converted to fish ponds because of the high profits from fish.

Fish can provide supplemental income and/or protein, but are not normally the primary crop. The addition of fish culture to rice paddies is an additional management consideration for farmers. Fish culture in rice fields is practised in a variety of ways. A simple modification of a rice field is to dig a trench with a gate that can be opened for wild fish to enter the paddy field during flooding season, and then the gate can be closed to capture the fish at the end of the rice growing season. This method of raising fish together or concurrently with rice is an old practice in Asia, and probably began with rice culture itself. Production of rice and fish can be done in several ways, but the two shown in Fig. 7.7 are the most popular.

Rice–fish culture is widely practised in Asia but has not spread as expected around the world. Most information comes from Asian countries, particularly PR China, Indonesia, Japan and the Philippines, where traditional rice farming methods have been refined over centuries. As rice is the staple food and an economically important crop, farmers may be reluctant to convert rice fields into fish ponds even though the latter may give them profits that are at least double. This is because rice is the main item of family food security. Experience shows that fish farming intervention has been easier when farmers are approached to try a small pond at a corner of a rice plot where rice is not growing well. Direct comparison of the higher income from fish with the low revenue that rice can generate from the partially used land makes it a lot easier

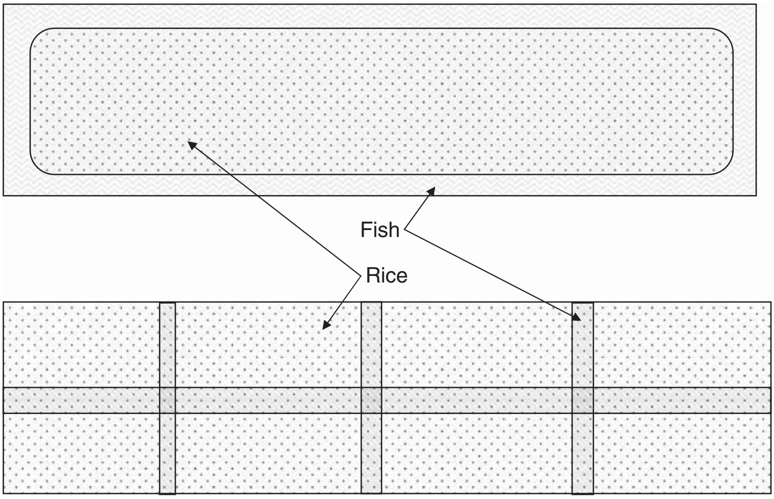


Fig. 7.7. Trench for fish culture around all sides (top) and across the fish pond (bottom).

to convince farmers. Many farmers gradually expand the pond, leading them to become commercial fish farmers and so rice–fish culture can be an entry point to commercial fish farming, especially in rural areas.

7.5.1 Advantages

- Fish is an additional source of income for the farmers, often earning them more than from rice per unit area.
- The family can consume the fish, a high-protein food.
- The fish control molluscs and insect pests, which may help increase rice production.
- Rice production increases as the fish stir up soil nutrients, making them more available for rice.
- Continued flooding of the paddy and the rooting activity of fish help to control weeds.
- Integration of rice and fish reduces the risk of crop failure.
- Organic farming is possible with rice–fish integration.

7.5.2 Disadvantages

- Requires more water than rice culture alone.
- Requires more labour than rice culture alone.
- Requires more investment in rice field modification.

- Pesticides cannot be used because they may kill the fish.
- Digging 40–50 cm below the paddy bottom is required, which makes drainage difficult.
- Total rice yield per area is usually reduced because the paddy area used for trenches is not planted with rice.
- Fish produced with this system are often small.
- The total fish harvest may be lower than what could be produced in a pond of equal size.
- In most cases, it is difficult to synchronize the activities. As rice production is seasonal, fish are harvested at the same time by every farmer and marketing may be a problem.
- Rice–fish culture may be more appropriate for small-scale paddies where fish are consumed by the producing family.
- As rice paddies may be irrigated from a common water supply, it is difficult to ensure that water used to supply the paddy will be pesticide-free. This may make rice–fish culture impractical.

7.6 Tilapia with Vegetables and Fruits

Growing fish in ponds together with vegetables or fruits on the dyke or nearby is a very good combination. If the green water from the fish ponds, rich in nutrients, is used to irrigate vegetables/fruits, their production may be enhanced. In many cases, farmers use water from canals or taps directly to irrigate vegetables. However, it is highly recommended that this water be stored in small ponds that can be fertilized using organic manures or inorganic fertilizers and some fish can then be stocked to grow and generate additional income. When the water in the fish pond becomes green, it can be used to irrigate vegetables using a pump or manually using buckets or jugs. Vegetables grow far better with the green water compared to the clear water poured directly on to them from taps or diverted from the canal. If the vegetables are grown on the dykes, the excess water or nutrients provided to them will eventually reach the fish pond to keep the water green. More importantly, the leaves and stumps of vegetables/fruits can be used to feed fish. Some fish such as grass carp can directly eat plant leaves whereas other fish get nutrients when ponds become green due to the vegetable leaves. Suitable vegetables are cabbage, cauliflower, mustard or rapeseed, tomatoes, pumpkin and several others. It has been common in many rural areas to grow vegetables on the dyke as well as above the fish ponds extending from dykes (Fig. 7.8, top).

Among the fruits, banana (Fig. 7.9), mango, lychee, lemon and others can be grown on dykes. Their fallen leaves can serve as fertilizers, supplying nutrients. Banana leaves can be consumed by fish such as grass carp. In some places, farmers collect leaves of vegetables, fruits and animal manure and keep them in the middle of a fish pond along the long side of the dyke by making a small area surrounded by wooden poles or planks, so that they remain there

Fig. 7.8. Vegetables grown over and on the side of a fish pond in Bangladesh (top) and series of cemented fish ponds in vegetable gardens, popularly known as 'kitchen ponds', behind the staff quarters at the Institute of Agriculture and Animal Science in Chitwan, Nepal (bottom).

and decompose. Nutrients will be released gradually to fertilize the pond. Some farmers pack these composted materials in jute sacks or plastic sacks with holes and hang them on ropes across the pond. More interestingly, farmers grow spices such as chillies, ginger, garlic, lemon grass, onions, mints and so on, which are normally used to prepare fish and other foods as part of the cooking method and also to suit the tastes of people from particular communities and countries.

The size of ponds used varies with the availability of land and the interest of the farmer. The smallest ponds may be only 10 m^2 (5 m × 2 m) with a depth of 1 m. In many rural areas, fish ponds or tanks are integrated with home or kitchen gardens and are often called kitchen ponds (Fig. 7.8, bottom). The reason for this is that any leftover food from the kitchen and/or the plates can be thrown into the fish pond as inputs instead of throwing into rubbish bins.

Fig. 7.9. Tilapia culture in a large pond with banana planted on a dyke in Thailand.

This is another option for farmers as normally they may have small pets such as scavenging chickens, dogs or cats, and it is a good use of wastes to produce healthy animal protein at home.

7.7 Crop–Livestock–Fish Farming

In fact, the majority of farmers in Asia grow rice as the main crop in order to ensure they have enough food for the family throughout the year. They may also have some vegetables in a small plot near the house and also fruit trees around the house. If they have someone to take care of them, they also raise a few animals on their farms such as village chickens, local ducks and some goats (Fig. 7.10), sheep, cows or buffalo. The use of dung from grazing cows (Fig. 7.11) has been popular in Myanmar because it can be considered an organic input for ponds. This might be an option for other parts of the world where organic aquaculture is becoming popular.

In rural areas, some families may have fish in small (200 m^2) to medium size (500–1000 m^2) ponds. Integration of all sorts of agriculture components can be found in rural areas. Although farmers tend to grow everything they need to support the family; as commercial farming, integration of two components such as fish with chicken, pigs, ducks, rice or vegetables is popular. The abundance of fish ponds to integrate with another component depends on the availability of water. Tradition and customs strongly influence the adoption of farming systems. Until now, integration of fish has been found more with feedlot animals such as chicken, pigs and ducks. Excessive use of

Fig. 7.10. Farming goats saves the cost of grass cutting as goats graze on the pond dykes, their excreta fertilize the water and their meat can add to farm income.

Fig. 7.11. Cow dung kept on the dyke, which is pushed gradually to the fish pond. The rope is supporting the sacks of animal manure held under the water.

chemicals, antibiotics in the feedlot animal industry and the frequent occurrence of diseases and parasites such as bird flu, swine flu and so on, mean that people are attracted to fish and, at the same time, organically grown vegetables. Integration of fish and vegetables is likely to expand very soon and one system being promoted is aquaponics. This system allows people to grow fish and vegetables organically within a limited space, and it has created much interest. Because of such increasing interest in organic farming, the integration of fish with ruminant animals such as cattle and buffalo, goats and sheep may also have reasonably good scope in the near future. It is not yet very common, so more research and testing are necessary.

7.8 Conclusions

Although various forms of integrated farming systems have traditionally been practised for many years and plenty of research has been carried out, integrated farming is not fully understood. It is generally accepted that integrated farming is sustainable, but it requires careful management. When it comes to commercial farming, monoculture dominates, probably because it is easy to manage one component. Various forms of integrated farming are still practised but are considered to be traditional farming. Because of the complexity of the interactions among the sub-components within the farming system, there have been cases of failures. Farmers need to understand each component and how they affect others, and need to spend a lot of time feeding animals, cleaning, and so on. One of the main points of integrated farming is that animal manures contain a low percentage of nutrients and high amounts of organic and dry matter and there is a limit to maximum loading in the pond, which stands at around 100 kg/ha/day. Above that level, ponds become anoxic/anaerobic and as a result mass mortality of fish may occur. On the other hand, if nutrients in the pond are not adequate, fish may not grow fast enough to produce the desired results.

More recently, food safety and human health hazard issues have been raised, especially when fish are exported to the Western world. Farmers are required to feed the fish with commercial pellets and their use is not easy for many farmers because they make it difficult for them to make a profit. One good practice can be the use of animal manures, indirectly or by making compost first before applying to the pond. Another method can be fencing of two or more corners of a pond where animal manure is applied. The nutrients are released and dispersed gradually throughout the pond but fish have no direct access to the animal manure.

8 Fish Health Management and Biosecurity

8.1 Fish Health Management

Most farmers seek help when they see some of their fish have either died or are about to die and they are unable to prevent it. Unlike terrestrial animals, all the fish are exposed to the same environment, i.e. water where pathogens can spread very quickly. There is a chance that all the fish in the same system, apart from some that may have a better immune system than others, will eventually die because they are exposed to the same pathogens. The application of drugs would not be effective because of the huge volume of water; it would not be possible to obtain a sufficient concentration of the active ingredients in the drug. Some drugs can be successful if fish are dipped or bathed in a small volume of water using troughs or tanks but this takes time and labour. Some drugs may work when they are injected into the body of individual fish but this is also very time- and labour-intensive, and as a result the treatment becomes more expensive than the value of the fish. Therefore, prevention is the only way to stop losses due to disease.

Prevention requires a proper understanding of fish health management, which involves the management of feed, water and pathogens (Fig. 8.1). First, broodstock or fry fingerlings should be free of pathogens so that they will not transmit disease-causing organisms (pathogens) later on. Some hatcheries or research organizations strategically carry out research programmes and develop broodstock resistant to specific disease-causing organisms. In some species, vaccination is common and required, but these measures take time and labour. The majority of hatcheries do not have the capacity both in terms of technical and financial resources, but want to acquire ready-made stock. Even though some hatcheries claim their stocks are disease-free or resistant, their customers may not trust them. For this reason many hatcheries now want to receive certification so that they themselves are confident and can reassure their customers if they are certified by third parties proving their fish are pathogen-free. Although certification of hatchery farms is not yet very

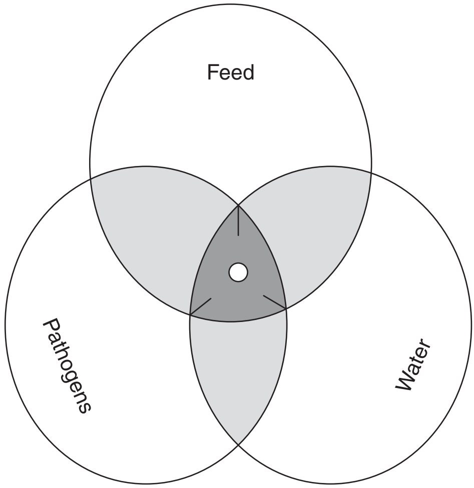


Fig. 8.1. Health condition of fish depends on feed, water and pathogens, and their interactions.

common, it is gradually happening. However, the use of certified seed does not mean their fish will not have disease problems. Other conditions favour the occurrence of diseases, for example fish raised in poor water quality can be easily infected, as can poorly fed fish. Therefore, feed and water are other main factors that fish have to interact with or depend on.

Feed is the most important factor for growth and survival of any animal. The popular saying 'you are what you eat' is true for fish as well. However, some feed ingredients can serve as a source of pathogens while others may contain anti-nutritional factors that cause illness in fish, e.g. soybean has trypsin inhibitors, phytic acid, saponins and isoflavenes, but most of these can be destroyed by roasting, boiling or cooking. Therefore, appropriate measures must be taken when preparing feed. More importantly, even a good feed stored in humid and damp conditions can contain moulds that will produce toxins. Fish receive a large quantity of natural food from the water in addition to the feed supplied.

Water plays a vital role as it supplies oxygen for respiration as well as some minerals, vitamins, amino acids and fatty acids, including omega-3s. Therefore, enrichment of water either by supplementation of these directly or through fertilization is done to enhance the growth of natural food. However, water can be a source of heavy metals and other chemicals. Feed itself can be a cause for concern if fish are over-fed. Therefore, careful selection of farm site and the consideration of water source are critical in making fish farm projects successful. Similarly, nitrogen from uneaten feed can be a source of ammonia, which can kill fish. Feed and the management of feeding are other important aspects of successful fish farming. If fish are fed, the person feeding the fish has more opportunities to observe them, their movement and their response to the feed. There should be a system of reporting any abnormal behaviour in a book/ on a noticeboard, or reporting to a technical manager/team in person, so that problems can be identified and solved before it is too late.

In many farms, feeding is done by unskilled labour who may not notice any odd behaviour in the fish or provide any indication of problems. Many farm managers themselves neglect to take note if they see a few dead fish floating on the water, but this can be an indication that other fish may soon die. In Asia many commercial farmers grow tilapia in polyculture with carp such as Chinese carp, Indian major carp or silver barb. Even in an intensively managed monoculture system of tilapia, smart farmers stock a few of these carp because they are less tolerant to adverse water quality. They die first, indicating that water quality needs to be improved; otherwise, the entire stock may very quickly die.

Providing water with suitable physical and chemical properties is a very important aspect of fish health management. Physical properties are mainly temperature, DO, pH, etc. and chemical properties include the presence of unionized ammonia (NH_3), nitrite and nitrate.

The temperature of the water is an important parameter that can affect survival and reproductive performance. The temperature comfort zone for tilapia within which they show best growth and reproduction is in the range of 24–34°C (Fig. 8.2). When water temperature rises above 34°C, tilapia become stressed, which favours bacterial infection, e.g. *Streptococcus* spp. On the other hand, when the water temperature falls below 24°C, parasite infestation can occur. Therefore, monitoring water temperature regularly (such as daily or at least weekly) is very important. Water temperature should be measured early in the morning (around 6 am) when it will be at its lowest and in the afternoon around 2 pm when it will be at its highest. Water temperature differs with the depth of the water – the highest temperature will be on the surface, i.e. 10 cm below the top, whereas the lowest temperature will be in the deepest water, and so temperatures are usually measured at depths of about 10, 30 and 50 cm below the water level. Avoiding these extreme temperature conditions are a major objective of good management practice. However, in case of disease outbreaks or parasite infestations due to adverse conditions, some cures are necessary, which are described later in this chapter.

Similarly, other water quality parameters have such comfort zones, e.g. pH. Although tilapia have a fairly wide comfort zone, i.e. 6.5–9.5 in the case of pH (Fig. 8.3), this is just an indication of the presence of some chemicals, and their reactions in the water. The presence of excessive organic matter can cause low pH due to anoxic conditions. Simple addition of lime would help in such cases. High pH is normally caused by high CO_2.

In tropical areas, water temperature in outdoor tanks or ponds during early afternoon may reach higher than 35°C, which is stressful to the fish. More importantly, the temperature of the water at a depth of more than

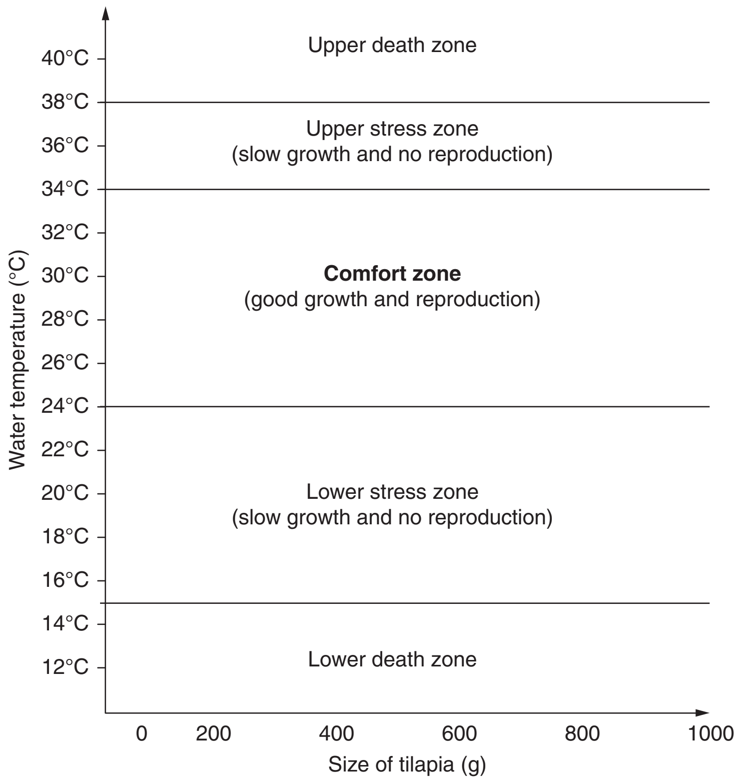


Fig. 8.2. Comfort, stressed and death zones of tilapia with reference to water temperature.

50 cm may be cooler but the surface water temperature can be even higher (Fig. 8.4). As hot water at the surface is lighter, it remains on top and cool water does not come to the surface and this results in stratification. If fish are fed during this time, they have to come up to the surface where the temperature is unexpectedly higher. As a result, fish may die due to heat shock. In some cases, fish may exhibit a swirling or spinning movement. It can be that when the weather gets too hot, especially in tropical areas, heavy rain will fall and there may be hailstorms. Fish will be exposed to hot and immediately cold water and this can kill them, or at least stress them and make them more liable to bacterial attack. Using pedal wheelers or other aerators to churn the water during the summer should be done only during the hottest time of the day, e.g. 1–4 pm, to avoid the stratification of water in ponds or tanks, especially in the tropics.

If the temperature of the water goes above 35 or 36°C, tilapia do not breed and, as a result, hatcheries cannot produce and supply seed. Provision

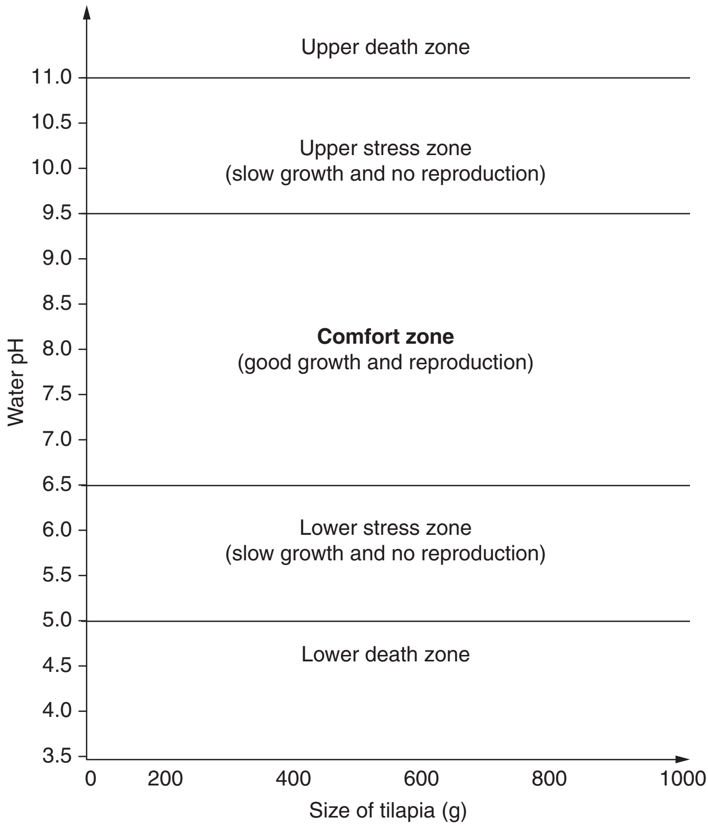


Fig. 8.3. Comfort, stressed and death zones of tilapia with reference to water pH.

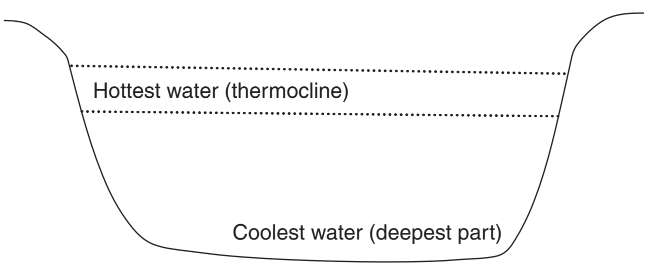


Fig. 8.4. Pond water temperature rises highest at the surface but it remains cooler at the bottom.

of shade might help as it can reduce temperatures by 2–3°C. Similarly, the use of water sprinklers and constructing deeper ponds for broodstock helps to some extent. Tilapia may also stop breeding during winter, when water temperature drops below 24–25°C. In subtropical climates, tilapia hatcheries have to stop breeding and let the fish remain in deep areas of the pond where the water temperature stays above that in the shallower ponds.

Similarly, DO fluctuates widely during the day and night (Fig. 8.5), ranging from 0 to 15 mg/l or even higher depending upon the level of phytoplankton. During the day, phytoplankton produce oxygen in the presence of sunlight. If the water is too green, which indicates the presence of a high concentration of phytoplankton, the production of oxygen is much higher than its consumption by fish, other living organisms and phytoplankton themselves. After sunset, however, all organisms including phytoplankton continue to consume oxygen but phytoplankton cannot perform photosynthesis to produce oxygen. Therefore, overnight, most oxygen dissolved in the water will be used up and so there will be a shortage of DO, especially early in the morning, which may kill the fish. Low DO can also occur due to low levels in the source water, especially if the water is pumped from underground.

Identifying the signs of low DO can be done by regularly observing both fish behaviour and the water itself. Fish showing their heads above the water surface and gulping the air is the most obvious sign; this happens in the early morning or even during the day during the rainy season or on cloudy days when there is not enough sunlight for photosynthesis. Low DO generally occurs due to overload of organic fertilizers, especially chicken manure.

If there is excessive DO in the water, skimming and gas bubbles can be seen on the surface. In addition, algal die-off may occur as indicated by changes in colour of intensively bloomed blue-green algae, often resulting from photo-oxidation due to high temperature and intense light.

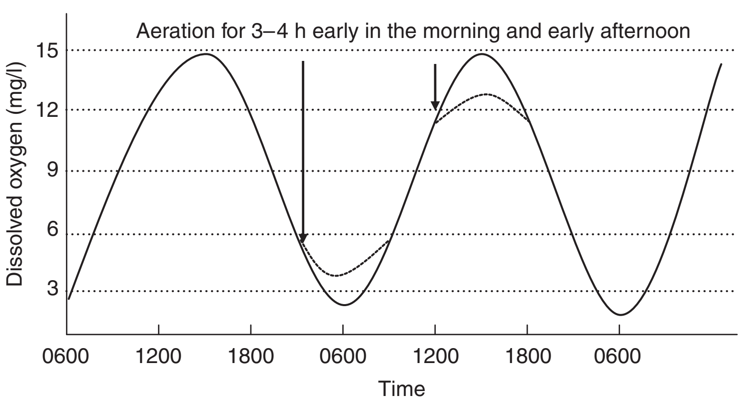


Fig. 8.5. Diurnal variations in dissolved oxygen in outdoor tanks, ponds, lakes or reservoirs.

Aeration can help prevent fish kill due to low DO. Depending upon the level of plankton bloom, aeration can be started from 2 to 3 am so that DO will not drop to zero. It can be difficult in terms of management to switch on the aerator machine but a cheap timer switch can be installed for this purpose. Some immediate solutions include:

- Replace pond water with higher quality source water.
- Top up water if complete change is too costly and not possible.
- Apply mechanical aeration, e.g. pedal wheel, aspirator, air diffuser (air stones) or even use a boat to churn up the water if ponds are large and deep.

Ammonia is one of the most important wastes produced in fish culture systems as fish utilize protein for energy. When protein is catabolized or used, ammonia will be produced and excreted as a by-product by the fish. In aqueous solution, it remains in two forms: unionized ammonium (NH_3) and ionized ammonia (NH_4). The unionized form, i.e. NH_3, is toxic. It can kill the fish or at least exert stress if its concentration exceeds 0.5 mg/l or so. The proportion of NH_3 in the water depends on pH and temperature (Table 8.1). At lower pH (i.e. <8.0), a negligible amount remains as unionized ammonia. Therefore, the level of NH_3 should be considered critical when water pH is higher than 9.0, which may occur in the afternoon in fish ponds due to excessive photosynthesis, which absorbs the carbon dioxide. At the same time, the proportion of NH_3 remains higher at high temperatures. For example, at a water temperature of 28°C, only 15% ammoniacal nitrogen is in the form of NH_3 at pH 8.4, but rises to 64% at a pH of 9.4. Similarly at pH 9.0 only about one-third (34%) is in the form of toxic ammonia when the water temperature is 24°C but it can reach close to half (49%) at 32°C. Therefore, farm managers need to measure the temperature and pH when the ammonia nitrogen is analysed so that NH_3 concentration can be calculated by multiplying the percentages shown in Table 8.1.

Table 8.1. Per cent of toxic unionized ammonia (NH_3) in aqueous solution at different pH and temperatures (rounded figures from Boyd, 1990).

	Temperature (°C)								
pH	16	18	20	22	24	26	28	30	32
7.0	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	1
7.4	0.7	0.9	1	1	1	2	2	2	2
8.0	3	3	4	4	5	6	7	8	8
8.4	7	8	9	10	12	13	15	17	19
9.0	23	26	28	31	34	38	41	45	49
9.4	43	46	50	53	57	60	64	67	71
10.0	75	77	80	82	84	86	88	89	91
10.2	82	84	86	88	89	91	92	93	94

8.2 Diseases of Tilapia

With a view to maintaining the security of stocked animals it is necessary to understand some aspects of the diseases and parasites which have recently affected tilapia production in a few countries. Disease is the most important factor and needs more attention.

Tilapia are well known for their resistance to disease. However, when environmental conditions are extremely unfavourable they become stressed and can be infected by bacteria and viruses. One of the most important factors to be considered is water quality, especially temperature, pH, DO, ammonia and nitrite. Another important factor is feeding management. If managers and technicians are careful about these two factors, i.e. water quality and feeding management, most diseases can be avoided.

There are basically two types of diseases – infectious and non-infectious. Infectious diseases are due mainly to entry or attack by bacteria, viruses, fungi, moulds, protozoa and parasites, which are collectively known as pathogens. Without attack by these pathogens, fish may exhibit similar symptoms but they are not transmissible, for example nutritional deficiencies, presence of toxic substances, other chemicals or heavy metals.

There are various types of bacteria that can attack tilapia: *Streptococcus iniae* and *Streptococcus agalactiae*, *Edwardsiella tarda*, *Edwardsiella ictaluri*, *Flavobacterium* and *Yersinia ruckeri*. There are others such as *Cytophaga*-like bacteria (CLBs), e.g. *Flexibacter columnaris* (columnaris disease) and *Flexibacter psychrophilus* (BCWD), *Pseudomonas* septicaemia, *Aeromonas salmonicida* (furunculosis), and so on.

The most common symptoms of these bacterial diseases are gill damage and tissue necrosis (Fig. 8.6). Among the bacterial diseases, those caused by *Streptococcus* spp. have emerged as common diseases in tilapia. They appeared in Thailand especially during the summer due to stress caused by high temperature (>38°C) coupled with the intensification of cultural practices. Similar cases occurred in Bangladesh, PR China, Indonesia and Malaysia. Common symptoms of *Streptococcus* infections are erratic swimming, bulging eyes or corneal opacity disease, tissue necrosis with red spots, haemorrhage on the

Fig. 8.6. Tissue necrosis near the tail fin (left) and gill damage (right).

opercula and the base of fins. Ultimately, the result is high mortality – up to 80%. Dead fish have ulceration on the body surface while inside the body a pale liver and enlarged spleen can be seen.

Several methods have been tried to cure or prevent these bacterial infections, e.g. use of common salt (5 ppt) and antibiotics such as Aquaflor® (active ingredient florfenicol), oxytetracycline, etc. Others have claimed that erythromycin can be useful in the field. However, none were effective at the time of outbreaks.

Nevertheless, some hatcheries selected fish that had survived an outbreak because they must be resistant to these pathogens, and developed them as specific pathogen-free (SPF) broodstock, which seems to be working. Responding to the tilapia industry, some pharmaceutical companies such as Skretting/AquaVac have developed two types of vaccines, i.e. *S. iniae* and *S. agalactiae* (Strep *Si*, Strep *Sa*, Fig. 8.7), which have been tried by some farmers. However, there are several strains of *Streptococcus* and they always mutate or reappear in other forms making them very difficult to control. At the same time, because vaccines administered through immersion and feed are ineffective, every fish has to be injected and vaccines have to be directly delivered to the peritoneal cavity (Fig. 8.8). Injecting thousands of fish individually before stocking into grow-out ponds is time-consuming. Nevertheless, vaccines and vaccination methods have been developed that can be used to reduce a farmer's potential losses. Research is still going on to develop further vaccines and improve the methods.

Fig. 8.7. Vaccines for *S. iniae* (left bottle) and *S. agalactiae* (right bottle).

Fig. 8.8. Demonstration of vaccination method for *Streptococcus*.

Although it is time-consuming to vaccinate every fish, methods have been developed. Efforts have been made to make it more efficient and faster. Some hatcheries are now using a method whereby one person helps to place anaesthetized fingerlings (5–10 g) on a glass platform without water so that the fish will not jump. The technician holds a fingerling upside down in one hand, inserts the needle, and presses the syringe using the other hand to quickly inject the vaccine into the peritoneal cavity. The syringe is directly connected to a bottle of vaccine solution, which can pump the vaccine solution when the syringe is pulled back.

It may not be possible to produce a vaccine to protect fish from all bacterial diseases. It is not easier to protect fish stocks when a disease occurs.However, if they are identified early, it might be possible to treat some diseases by administering drugs through feed. In order to identify problems, urine and faeces, blood and some tissues are sampled and tested to diagnose the disease, as in the case of terrestrial animals. However in the case of fish, farmers can take the whole body of the fish and ask technicians to take samples and do the tests. There is a lack of disease or health management expertise in fish farming and so fish farmers or managers should follow the steps below.

Aquaculturists will usually need to seek help from vets. Although very few vets know about the diseases of aquatic animals, they can at least take samples from scales, gills, blood, liver, and so on, and can perform bacterial culture in the lab to identify and even to carry out antibiotic sensitivity tests. If the disease is caused by bacteria, it is easy to identify and to recommend the most effective antibiotics within a day which should be helpful for the farmers. Information about other diseases is not covered in this manual – the intention was to emphasize BMP so that the risks of diseases and parasites are minimized.

STEP 1. The person who feeds the fish should be observant and keep records or report to their manager if fish show abnormal behaviour, movements or responses to the feed.

STEP 2. Collect dead fish or remove, even if just a single dead fish is seen on the surface of the pond water, and record/report.

STEP 3. Observe the dead fish and try to determine where the damage is; take pictures to keep as records.

STEP 4. If more fish have died by the next feeding time, collect the dead fish, handling them carefully so that tissues are not damaged.

STEP 5. Sample some live fish from the ponds/tanks to see whether any of them have any wounds or damaged tissues.

STEP 6. Observe/record and take pictures of the general appearance (shape, colour, etc.) of the whole body as well as that of scales, fins, tails and gills of both the dead fish and those that are alive but suspected to be infected.

STEP 7. Contact the nearest veterinary laboratory as soon as possible whenever any signs of diseases or abnormalities are seen.

STEP 8. Ask the vet/technicians to observe and perform some diagnostic tests. If they have the facility for bacterial culture, they should take samples and culture them to identify bacteria. At the same time, they may test the efficacy of potential antibiotics.

STEP 9. If they identify and prescribe any antibiotics with appropriate doses, apply them to try and save any remaining fish.

STEP 10. When fish mortality occurs, stop mixing of water and moving of fish from one pond/tank to another. Workers should take extra precautions to sterilize their clothes and the materials they used when working in the pond with fish mortality and move to another one.

STEP 11. If fish continue to die, harvest as soon as possible, discarding any dead or dying fish. Drain, dry and lime the pond heavily before using again.

8.3 Parasites

Trichodina spp. are one of the most prevalent parasites in tilapia, appearing mostly during the swim-up fry stage while they are in the larval rearing system and then passing on to the subsequent stages. It is a protozoan parasite that looks like a flower or saucer, or is bell-shaped (Fig. 8.9) with a sucking disc from the lateral view. It occurs especially in winter when temperatures fall below 25°C. They feed on bacteria and are found on the skin and gills.

Parasites can be identified by simple scratching of skins and gills and observing the material under microscope (10× magnification). Although they may not be critical, they can be dangerous, as they make the fry and fingerlings weak and ultimately may lead to death. Infected fish show abnormal coloration, sluggishness and loss of weight.

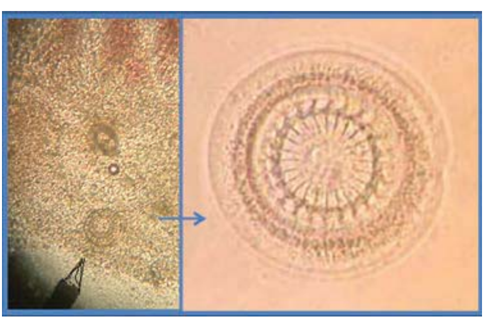


Fig. 8.9. Protozoan parasite (*Trichodina* sp.).

Hatchery operators usually use saline water or common salt to raise the salt levels up to 5 ppt. This parasite actually comes from brooders via eggs or yolk-sac larvae. Therefore, dipping eggs and fry in 200 ppm salt solution immediately after cleaning the eggs before transferring to the incubators and trays can break the cycle. Similarly, other bath/dip treatments may include malachite green (1.25–5.0 ppm) and formalin (250 ppm) for 5–10 min.

Argulus spp. or fish louse and several other parasites may appear when environmental conditions are not favourable. However, they have not been reported to cause any big losses. More importantly, most of the parasites can be controlled by using simple salt solution and the other treatments mentioned above.

8.4 Biosecurity

Biosecurity has become a popular word because it covers a wide area, including the security of animals cultured for food and profits, the surroundings they depend on, and the human beings who consume them. In other words, biosecurity is a set of preventive measures designed to reduce all sorts of risks. It entails the prevention of cultured species being attacked by disease-causing organisms and parasites, minimization of impacts of invasive alien species on the environment and avoiding the possibility of zoonosis or any human health hazards through the consumption of food, and genetically modified organisms (GMOs).

Security of cultured animals has a direct relationship with economic losses. Sudden outbreaks of disease have often caused huge losses. For example, in penaeid shrimp aquaculture, losses due to white spot syndrome virus in Asia during 1992 to 2001 were US$4–6 billion. Similarly, taura syndrome virus has been blamed for losses of $1–2 billion during 1991/92. Most of these viruses were due to the haphazard movement of cultured animals.

Biosecurity is an integrated approach that encompasses the policy and regulatory frameworks that analyse and manage risks. The ultimate goal of biosecurity is to prevent, control and manage risks to human health, achieve food security and improve livelihood of people. In order to address these issues, various biosecurity measures have been developed and implemented, for example CoC, GAP, BMP, Hazard Analysis and Critical Control Point (HACCP), etc. Biosecurity is a broad term, which normally covers the following major areas:

- fish health management or the security of cultured fish (Section 8.1);
- zoonosis (human security);
- GMOs – production/profit versus human security;
- environment and invasion by alien species; and
- human security through producing safe food to eat (biosecurity measures).

8.5 Zoonosis

Fortunately, there is no serious problem of diseases coming from fish. Terrestrial animals share the same atmosphere and so some disease-causing organisms can transmit to humans via respiration or by simply inhaling the air. Unlike terrestrial animals, fish are in the water and the environment is completely different. Very few pathogens are common to fish and humans. Airborne disease-causing organisms may not survive in water and even if they do survive they are inactive and diluted in or flushed out by the water. Pathogens have few chances to enter the human body through water. However, some issues are raised when fish are cultured with pigs, chickens or other farmed animals in which the occurrence of pathogens such as *Salmonella*, *E. coli* and others is quite common. Therefore, care must be taken to ensure these pathogens do not contaminate the fish while harvesting or handling. Another possibility is that fish can serve as intermediate hosts for certain phases of the life cycle of some parasites. Transmission of spores or other phases from fish to humans may take place, e.g. liver fluke. Parasites mostly stay in the digestive tracts, gills and scales, which are normally discarded. Therefore, if fish are well prepared and well cooked (boiled, smoked, steamed or deep fried), most pathogens will be killed by the heat.

8.6 Tilapia as an Invasive or Alien Species

As mentioned in Section 2.4.2, there are several types of tilapia found in different parts of the world, although they originated from Africa. *O. mossambicus* was the one that first appeared in Asia. This species spread like wildfire because of its self-recruiting behaviour. When farmers began to grow this species, they were discouraged because it did not grow but reproduced so frequently that it resulted in crowding and stunting of fish, which in turn reproduced more and more. Over time, this created a poor image of tilapia as a pest and unwanted fish. Although Nile and red tilapia are becoming popular, some professionals still have that poor image in mind and this has influenced the policy of promoting tilapia culture in several countries, e.g. Australia and India. However, with biosecurity measures, some of these countries have started allowing the culture of tilapia, e.g. India. This is because commercial/private farmers want to grow tilapia, which has the potential of increasing productivity and earning more profit per unit area of space/water volume and investment. It also has proven and better technologies, which many other countries are taking advantage of. Similarly, Pakistan has realized and opened the door for tilapia; even the government is promoting and facilitating import of tilapia.

In fact, tilapia is still considered an invasive alien species in many countries and is categorized as such by IUCN and other environmental organizations. But many of them are based on speculation since scientific studies on this aspect are limited. Therefore, there are still questions over whether Nile and red tilapia can affect other species, their habitats, reproduction, etc. if they escape into the wild from the culture system; particularly the effects on indigenous species are not clear yet. They may compete for food and space but they are not as aggressive as some of the carnivorous species, e.g. African catfish, sucker-mouth catfish, trout and sea bass. One study in South-east Asia tried to investigate and compile published and unpublished evidence, organizing national workshops in Cambodia, Laos, Thailand and Vietnam separately; no substantial evidence was shown in any of these countries. Instead, there was consensus among the scientists, policy makers and private sector that the Nile tilapia, along with some introduced carp species, has far more benefit to the national economy, employment creation and supporting family nutrition as compared to the risk it may pose, if any.

8.7 Biosecurity Measures (GAP, BAP, BMP, HACCP, etc.)

Biosecurity is a set of preventive measures designed to reduce the risk of transmission of pathogens. One of the main applications of biosecurity measures is reduction or avoidance of unnecessary movement of live animals for aquaculture from one territory to others beyond their natural habitat. The principles of aquatic animal health management should be applied as intervention. Emphasis should be given to strengthening the development of locally available domesticated stocks with genetic improvement. In cases where import is unavoidable, a contingency plan should be worked out to prevent transboundary diseases being introduced together with the aquatic animals. This should include the application of a proper programme on quarantine systems.

There are several measures of biosecurity. All government agencies are monitoring the production of alien species and trans-boundary movement of fish. Codes of conduct (CoCs), GAP (Fig. 8.10), Best Aquaculture Practices (BAP), BMP, HACCP, etc. are the major biosecurity measures developed so far and constitute stepwise processes in the food supply chain such as:

STEP 1. Good Aquaculture Practice (GAP; voluntary).

STEP 2. Good Management Practice (GMP; mandatory for processors).

STEP 3. Sanitation Standard Operating Procedures (SSOP; voluntary).

STEP 4. Hazard Analysis and Critical Control Point (HACCP; voluntary).

GAP has been implemented by the governments of various countries. At the same time, some private organizations have their own systems. For example in aquaculture, GlobalGAP is becoming widely accepted, especially by large companies that intend to export fish to Europe and

Fig. 8.10. An example of Good Aquaculture Practie (GAP) certification in Thailand.

the USA. Similarly, various other measures have been developed such as BMP, in which all the facilities, materials, vehicles, equipment, personnel and sanitation, etc. are monitored as part of the management practices.

In Thailand, a letter 'Q' is printed on food packets to indicate that the food has been processed and packed according to GMP, whereas Q with 'food safety' is to certify that food satisfies both sets of standards, GAP and GMP. An important part of this system is that every certified producer has a code number, and products can be traced from the point of detection up to the source of any contamination.

The first CoCs were developed by the FAO in 1995, and provide a necessary framework for national and international efforts to ensure sustainable exploitation and management of aquatic resources. More importantly, the FAO helps its Member States, particularly developing countries, to implement the Code of Conduct for Responsible Fisheries. Although it is not binding and is a voluntary CoC, many countries are implementing it as a good and necessary practie.

The HACCP system is a preventive measure developed specifically to manage and ensure food safety. It is a management tool used to protect the food supply chain and production processes against microbiological, chemical and physical hazards contamination. It involves identification and analysis of critical points in the whole value chain of a food product. The following are the steps involved in HACCP:

STEP 1. Conduct a hazard analysis of the whole value chain.

STEP 2. Identify the critical control points (CCPs).

STEP 3. Establish the critical limits of hazardous activities or chemicals.

STEP 4. Establish a system to monitor the CCPs.

STEP 5. Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.

STEP 6. Set up a verification system to confirm that the HACCP system is working effectively.

STEP 7. Document, record or report all procedures and records appropriate to these principles and their application.

In the case of tilapia farming, a HACCP plan can be developed to monitor and control all potential risk points such as broodstock acquisition, management, incubation of eggs, larval rearing, sex reversal, nursing of fingerlings, preparation/acquisition of feed and feed ingredients, application of chemicals such as MT hormone (quality and doses), and overall water quality parameters. Use of chemicals on the farms such as alcohol, acriflavin, formalin, etc. should be in line with national or international regulations and standards. Similarly, all steps of the biosecurity measures need to be put in place at every stage of the farming process.

These certifications or measures have been developed and implemented by various agencies, including government and the private sector. They are becoming popular and are being adopted by more and more aquaculture farms. Those farms exporting fish have to be certified by a third party. Even for products sold in the domestic market these measures have become quite common due to tough competition.

One of the most comprehensive and recent certifications is BAP, the standards of which were established by the Global Aquaculture Alliance (GAA). It is a voluntary certification for aquaculture facilities which addresses environmental and social responsibility, animal welfare, food safety and traceability. BAP certification has included the most important elements of responsible aquaculture and has provided quantitative guidelines. It outlines standards for each type of facility, from hatchery and feed mill to farm and processing plant. It has specific standards available for tilapia farms (BAP, 2013) There are 11 standards, three of which are related to the community, seven to the environment and one to food safety. These are as follows:

Standard 1. Community: Property rights and regulatory compliance.
Standard 2. Community: Community relations.
Standard 3. Community: Worker safety and working relations.
Standard 4. Environment: Wetland conservation and biodiversity protection.
Standard 5. Environment: Effluent management.
Standard 6. Environment: Fishmeal and fish oil conservation.
Standard 7. Environment: Soil and water conservation.

Standard 8. Environment: Control of escapes and use of GMOs.
Standard 9. Environment: Storage and disposal of farm supplies.
Standard 10. Environment: Animal welfare.
Standard 11. Food Safety: Drug and chemical management.

These standards show clearly that any aquaculture activity in the future will have to comply with similar guidelines so that it benefits the surrounding community, does not harm the environment and the food items or products are safe to eat.

9

Post-harvest Handling: Marketing and Processing

9.1 Preparation for Harvesting

Fish should be closely and more frequently watched near to harvesting. As for any agricultural crops or vegetables, use of antibiotics should be avoided for at least 2 weeks beforehand to avoid any risk of residues in the products. Fish mortality can occur during this period because some farmers tend to feed their fish more in the hope they will gain additional weight. This may create problems with water quality at a time of highest biomass in the system when a better quality of water is needed. Near harvesting time, farmers should explore the market before taking any bookings – comparing prices and transport costs can add a huge profit for them and farmers may lose out if they do not make some effort.

9.2 Tilapia Harvest

As fish are perishable products, producers need to find suitable and reliable markets. Keeping fish for an extra day or two may lead to farmers making a loss because they need to feed large amounts of feed as the fish get bigger and provide extra care. The final stage is very critical because the fish are more vulnerable to adverse environmental conditions. Finding a market at the same time as the fish harvest may be easy, and if farmers sell fish locally, most of them will have their own contacts. However, if they find it difficult, they may advertise, targeting specific groups in suitable newspapers, on radio or via any government or NGO run market information systems.

As with any other fish, tilapia has three distinct growth phases. The first phase starts with slow growth in absolute terms, although growth is actually exponential. Based on our experience, less than 1 g to 40 or 50 g takes longer, i.e. 2–3 months, depending upon the management. After that phase tilapia gain weight faster, but the growth rate is more or less constant per unit body weight. After reaching 600–800 g, they start growing slowly again – they still grow but at a decreasing rate (asymptotic phase). The early slow growth phase coincides with the nursing phase. More recently, farmers have begun to apply advanced nursing, often called Nursing II, which will produce fingerlings of larger size (40 or 50 g). Grow-out farmers then immediately stock into their ponds or cages to take advantage of their fast growth. As growth cannot continue at the same rate, it starts to decline and so growing fish for longer than this period may not be economical. More commercial farmers should harvest when the average weight of their fish is around 800 g, although some fish may reach 1 kg in size. Although traditional farming would not consider growth phases and maximizing profit, commercial farming is becoming more and more specialized and moving towards maximizing profits rather than maximizing the weights only. Based on economic principles, maximum profit will be at a point where an additional input will generate an equal amount of output. This can be worked out after producing several crops, but in general harvesting time is more or less at the size of around 800 g or at the end of the fast-growing phase, i.e. week 36 counting the nursing phase but about week 24 of the grow-out phase, as shown in Fig. 9.1. This phase may vary with culture management regime. In the case of semi-intensive culture in ponds with supplementary feeding, the harvesting size of fish may not reach that level. It may only be half the size shown in the figure, but the grow-out time can be the same. However, if the farmers want to harvest a larger size then the grow-out period can be extended to almost double.

Harvesting methods differ with the scale of operation. Small amounts can be manually harvested using a seine net and fish are collected from the

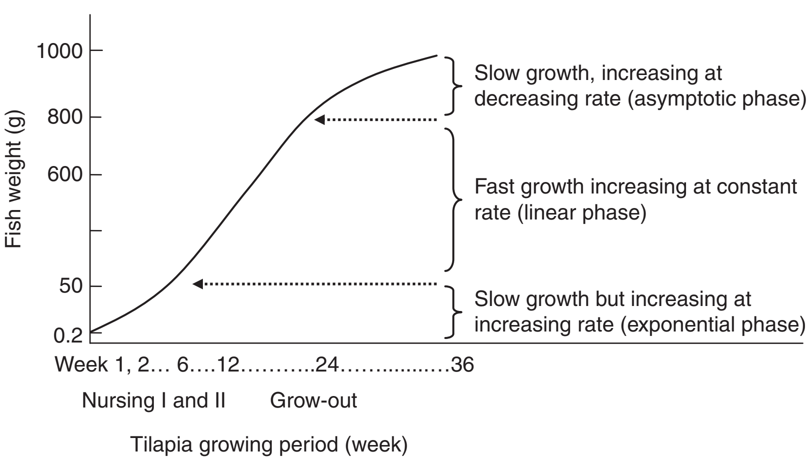


Fig. 9.1. Growth phase in commercial tilapia (week).

pond after it has been drained (Fig. 9.2). Large farms may use a crane to lift a large bucket containing fish transferred from cages or ponds. However, farmers are smart at finding cheap and easy methods, for example Fig. 9.3 shows a farmer using a long wooden or metal pole as a lever to lift the fish from the pond bottom directly to the vehicle. More interesting, using pulleys and ropes connected to a motorbike engine (Fig. 9.4) has been found to be even more efficient in lifting the fish on to the road side from the cages which are a way down the river. After lifting, the fish are weighed and loaded on to the trucks.

Fig. 9.2. Traditional harvesting of fish to sell to the wholesale market (Kafue, Zambia).

Fig. 9.3. Easy method of harvesting fish from a deep pond: lifting by a lever.


Fig. 9.4. Tilapia harvesting from cages lifting by using pulleys and metal strings connected to a motorbike engine.

9.3 Off-flavour Problem

Off-flavour is one of the problems of tilapia farming, especially in ponds when they are growing in green water systems. Certain species of cyanobacteria or blue-green algae produce geosmin (1,10-*trans*-dimethyl-*trans*-9-decanol), 2-methylisoborneal (MIB), in fresh water. Tilapia absorbs the smell of the surrounding environment and their flesh can develop a muddy flavour or an earthy or metallic flavour. However, these flavours may not be a problem when tilapia is grown in brackish water (Yamprayoona and Noomhormb, 2000), possibly because cyanobacteria cannot survive in such water.

Purging of fish for 5–14 days in clear/fresh water before sale is recommended. Addition of common salt (10 ppt) or sodium thiosulfate helps destroy the organisms that produce off-flavours. Alternatively, fish can be harvested when the off-flavour organisms die off at low temperatures or, when preparing fish for consumption, soaking in 80% NaCl solution and/or smoking can reduce the off-flavour.

In order to avoid off-flavour, excessive organic matter should not be allowed to accumulate and anoxic conditions at the pond bottom should be prevented. When preparing ponds, bottom mud with excessive organic matter should be removed and allowed to dry in the sun. Application of chemicals such as $CuSO_4$ and simazine to ponds where off-flavour has been a problem in previous crops may help reduce its intensity. Salinity of 10 mg/l inhibits Streptomycete growth and so the problem may be avoided if tilapia is grown in saline water or if, close to harvesting time, they can be transferred to saline water ponds or saline water can be pumped into the ponds.

9.4 Grading

After harvesting the grading of fish according to different size classes is important. Although it is expected that fish are of uniform size, they will grow at different rates. Prices of fish depend on the size, and mixed size fish do not appear to be of good quality and may only fetch low prices. Therefore, grading is important for adding value and pricing the products appropriately. Although machines are available and are used by large commercial farms, it is a lot cheaper to hire people, especially in developing countries where tilapia are widely grown. Size classes may vary by country, but Table 9.1 gives an idea of how tilapia are graded based on size. After harvesting, tilapia can be sold live, dead but fresh, whole frozen, fresh or frozen fillets, and so on, in various parts of the world.

9.5 Fish Sale

9.5.1 Selling live fish

There is a perception that fish caught from the wild, i.e. from rivers, lakes and seas, have lean meat with good flavour. At the same time there is a widespread rumour or reality that fish are treated with formalin or other chemicals to keep them fresh as they are from faraway places and need long-distance travel. People like to buy live fish because they are perceived to be fresh and free from any chemicals. Live fish can be sold at higher prices in many countries. Fish are normally kept either in aquaria in restaurants or superstores (Fig. 9.5), or in tanks specially built by the fish vendors. Red tilapia has been very popular in Asia due to its attractive colour.

9.5.2 Fresh fish on the pond site or nearby

In most rural areas or in small towns where fish are grown farmers will announce when they are going to harvest their fish and buyers may book the amount they want to buy, e.g. 2 kg, 5 kg, 10 kg. Farmers will often provide some fish free of charge to their relatives as a goodwill gesture. In some cases, fish are sold to the family who may use them for wedding ceremonies or other social functions. Quite often, middlemen/women may order or buy larger fish for cash or even using a loan so that they can carry them on their heads, or by bicycle, motorbike or pick-up, and travel through villages or small towns selling the fish (Fig. 9.6).

Table 9.1. Size category of fish at harvest.

Category	Size	Remarks
Smallest	Smaller than 300 g	Home consumption, local market
Small	300–500 g	Local market
Medium	500–750 g	Good for small size fillets
Large	750–1000 g	Good for good size fillets
Very large	Larger than 1 kg	Good for big fillets or selling by making small pieces

Fig. 9.5. Live red tilapia (Thabthim) in aquaria for sale in a superstore in Thailand.

Fig. 9.6. Two women selling fresh tilapia: one in Pokhara, Nepal (left) and the other in Kafue, Zambia (right) on the roadside.

9.5.3 Sale to pond harvesters

In this case the farmer negotiates a price before harvesting the fish. The price is typically around 15 cents cheaper than the wholesale price as the fish harvester is responsible for draining the pond, bringing in their own workers for harvesting, transporting and selling fish. Farmers will simply record the weight or number of fish. This method is frequently employed by small farms, especially those involved in animal integration.

9.5.4 Wholesalers or processors

In this case the farmer harvests his own fish and delivers them to the wholesale fish market. This enables a farmer to get a better price, but necessitates investment in a net, labour, transport, ice, etc. Many farmers find that wholesale fish markets will only quote a price once they see the fish. This leaves the farmer in a weak position because he has to harvest his fish first and is then at the mercy of the fish wholesaler, who will often give a very poor price.

In most cases, tilapia are sold to the wholesalers who distribute them to the retailers or to the processing companies, which produce fillets for export, or sell to supermarket chains.

9.5.5 Retailers

This method enables a farmer to cut out the middleman and gain control over the price of his fish by selling to shops, market stalls and the public (Fig. 9.7). The disadvantage is that the fish must be sold in small volumes and it takes

Fig. 9.7. Fish market along the roadside (Mazabuka, Zambia).

time to sell a whole pond's harvest. It also takes time to build up a market and it is essential that the farm always has a supply of fish to keep regular customers supplied. This method is employed by most farms in Asia because the consumer here will only pay a good price for live fish. Live tilapia in the market can only be achieved cost-effectively by purchasing the fish directly from the farmer.

9.6 Post-harvest Handling and Processing

The handling of fish after harvesting and before it reaches the dining table is important. Consumers want fish as fresh as possible and as fast as possible because quality deteriorates with time. It is best to transport live fish wherever possible. Common salt (5 ppt or so) is often added to reduce stress to the fish so that they can survive longer after harvest and quality can be maintained. However, in most cases this is costly because of the weight and volume of the water. Therefore, some farmers transport whole fish using ice in foam boxes; others do more preparation, such as degutting the fish (taking viscera and gills out), deheading (cutting off the head) and more recently even filleting the tilapia because fillets are becoming very popular because of the lack of bones in tilapia. These activities require sophisticated handling and hygienic conditions and many farmers may not wish to, or are unable to, carry out these activities, and they are mostly done by specific groups of farmers or other business groups as specialized businesses.

After fish harvest, the following steps are usually involved in further processing:

STEP 1. Bleeding by hand cutting, piercing or machine cutting.

STEP 2. Scale removal (descaling) is done by hand or machine. Most processors use rotating drum descalers.

STEP 3. Head removal (deheading) – most people use food-grade band saws but some still cut by hand.

STEP 4. Gut removal (degutting) or evisceration. The manual method requires low investment, and there is no equipment to malfunction or maintain; others use a vacuum method as it uses less labour, and waste is concentrated in a collection tank, which is cleaner.

STEP 5. Chilling on ice or especially designed vehicles.

STEP 6. Packaging and storage in environmentally controlled conditions.

STEP 7. Further processing such as filleting. Fillets may have small bones that must be removed for international markets. Buyers are requesting better trimming of margins of fillets for more consistent appearance.

STEP 8. Skinning – most plants use automated skinning and require deep skinning as it leaves more flesh on the skin.

STEP 9. Trimming.

STEP 10. Value addition and packaging, e.g. ozonated water baths, carbon monoxide (CO) or liquid smoke. CO infuses into fillets and reacts with the myoglobin, giving the fillets a fresh appearance for longer.

STEP 11. Blow drying of fillets.

STEP 12. Freezing.

STEP 13. Packaging.

STEP 14. By-products.

STEP 15. Bacterial testing – samples should be checked for bacterial contamination. HACCP procedures and CODEX should be followed, as well as other guidelines. Many plants are using ozone dips to reduce surface bacteria.

STEP 16. Application of either 'liquid smoke' or some other kind of preservatives, including natural preservatives (spices/herbs, etc.)

9.7 Preservation and Value Addition

The main objective of preservation and packaging is to prolong the shelf life of the product. Spoilage of fish takes place mainly for three reasons: microbial activity, enzymatic action and chemical reactions. Therefore, preservation methods are directed towards stopping these actions or minimizing them to safe levels. On the other hand, the main purpose of value addition is to make the products more attractive to customers by improving the appearance and/or their quality so that they are willing to pay premium prices. The major preserved and value added fish products are described in this section.

9.7.1 Frozen fish

The main principle of freezing foods is to reduce the temperature to very low levels. Fish are kept in deep freezes for sale in the market (Fig. 9.8) and buying fish from the market and keeping in a refrigerator is a common practie. Fish can be stored in a refrigerator (4–10°C) for 2–3 days or more depending upon the type of fish, temperature and wrapping methods. However, in a deep freeze (i.e. 0°C), fish may be stored for a month or more as at this temperature

Fig. 9.8. Fresh tilapia on ice in a superstore in Thailand (left) and whole frozen tilapia for export (right).

the growth of microorganisms is reduced to a significantly lower level or prohibited completely. Whole tilapia or fillets are frozen and transported long distances, even across borders. Well frozen products can have a shelf life of up to 6 months, but 2–3 months is usually sufficient and should be long enough to transport to anywhere in the world.

However, this method of fish preservation requires a deep freeze and an electricity supply and can be costly. It is not possible in many parts of the world, especially in rural areas.

9.7.2 Dried fish

The basic principle is to reduce water content and possible chemical reactions. The most common method of drying is oven drying at 100°C or higher for a few hours, to reduce the level of moisture to 8–12%. However, this can take a lot of energy, especially electricity. Drying fish in the sun, especially in tropical countries where sunlight is very strong, has been an alternative and cheap method (Fig. 9.9). Cutting fish into thin pieces after gutting and skinning helps the fish to dry faster. Sun drying is the cheapest method, which can also be done in rural areas where there is no electricity supply. Drying can be accelerated by using fans although again, electricity is needed. Drying using firewood in various types of kiln has been common in rural areas but this is mainly for family consumption and local markets.

9.7.3 Smoked fish

Smoking is a method in which bacterial growth is inhibited by reducing the moisture level as well as killing them by smoke. Smoking fish is normally done by burning wood – the wood contains three major components that are broken down in the

Fig. 9.9. Skinned, gutted and sun-dried tilapia.

burning process to form smoke. The heat during burning causes chemical decomposition, called pyrolysis. Fish are usually salted before smoking. Smoking can also be cold smoking, which means passing the smoke at low temperatures (28–32°C); in hot smoking, temperatures reach 70–80°C. Cold smoking maintains the freshness of the flesh but does not eliminate the food pathogens. Fatty fish absorbs the flavour of smoke easily and quickly but it needs to be kept in mind that polyunsaturated fatty acids (per cent of total fatty acids), already in low amounts in tilapia, decrease significantly ($P < 0.05$) during the smoking process (Bouriga *et al.*, 2012).

9.7.4 Fermented fish

Fermentation is a traditional method of fish preservation under conditions of low pH, i.e. below 4.5, created mainly due to lactic or acetic acid, at which most bacteria or other microorganisms cannot survive or grow. Various types of pickles, fish pastes and whole fish are fermented in different countries. Fermented fish has a putrid smell which many people find unpleasant. However, some traditional items are still prepared using this technique because it has historically been the easiest method of preserving food, especially in rural areas and many people like the taste.

9.7.5 Canned fish

Packing well-cooked fish inside strong metal containers (cans) is probably the safest method of food preservation. Well-prepared canned fish can be kept for a year or even longer. However, it requires a sophisticated process that involves selection of raw materials, pre-cooking of fish, filling, exhausting and sealing of the container, and washing followed by thermal processing. It is costly and cumbersome and so other methods of modified atmospheric packaging methods are becoming more popular.

9.7.6 Modified atmospheric packaged (MAP) fish

Food is placed in airtight containers (which may be plastic bags, foam boxes, glass, metal, and so on) (Fig. 9.10), in which the gaseous environment has been changed or modified, for example without oxygen (O_2) but with increased nitrogen (N_2) and/or CO_2. The presence of oxygen creates an environment in which microorganisms can survive and grow and so the oxygen is replaced by other harmless gases such as nitrogen. By creating a shortage of oxygen or anaerobic conditions and infusing with nitrogen or CO_2, microorganisms are either destroyed or their growth is prohibited. As a result, the shelf life of fish products can be increased. Most common food deterioration is a result of rancidity in fat, caused by microbial activity in the presence of oxygen.

Fig. 9.10. Fresh tilapia wrapped with plastic cover sold in supermarket in Yangon, Myanmar.

9.7.7 Other products

Fish have been found to be preserved in a variety of ways using principles such as control of microstructure; compartmentalization of aqueous phases in water-in-oil emulsions, and so on. More importantly, the addition of some preservatives or chemicals has been common, but not all of them are healthy or safe for human consumption and the use of such chemicals has to be properly scrutinized. One of the most commonly used is probably the formalin solution used with the aim of maintaining the fresh look of fish for several days. In some countries, there is regular monitoring of fish markets/vendors and strict regulations have been enforced. However, in many developing countries, monitoring has not been so easy. In such cases, consumer awareness is more important. For example, consumers can be made aware of the fact that if formalin-treated fish is submerged in water, a white layer of formalin can be seen on the surface of the water. Because of the use of such preservatives and chemicals consumers in some countries prefer to purchase live fish and so live fish markets have become popular, for example in Nepal, Thailand and Vietnam, among others.

Many farmers and their relatives sell cooked products, such as barbequed tilapia, either on the roadside or at local markets. Similarly, there is a tradition that fish are deep-fried, steamed or cooked in soup and sold in local markets (Figs 9.11 and 9.12). Cooking can help farmers preserve their fish for at least a day and makes it easier to transport to somewhere else where there may be a demand for it. There is an increasing trend worldwide towards cooked or partially cooked food items wrapped in plastic bags or foam boxes, which are convenient as they can be prepared simply by warming or microwaving, perhaps especially suitable for busy people who work in offices.

Fig. 9.11. Barbequed tilapia using salt cover commonly seen in Myanmar, Laos and Thailand.

Fig. 9.12. Popular steamed (left) and deep-fried (right) red tilapia dishes in Thailand.

9.8 By-products

When the production of tilapia takes off and consumption increases, by-products such as skin can be processed to make leather which can be used to produce goods such as shoes, wallets, bags and jackets. Tilapia leather has been found to be strong and soft. Some tilapia leather goods are being produced on a commercial scale in Brazil and Thailand. Similarly, fish oil and fishmeal may be produced from viscera, head and other inedible parts – scales have even been used to make artificial flowers. Similarly, recent news was published about the use of tilapia fins to make soup, as an attempt to replace shark fin soup.

9.9 Food Safety and Quality Control

The quality of fish produced can be assessed based on several properties: physical, chemical, microbial and sensory. Of these, the most noticeable by consumers are physical properties such as colour of the flesh, its firmness, texture and general appearance. By experience, some people are better than others in distinguishing good-quality fish from bad, but in some cases physical appearance alone is inadequate. Most people simply use a sensory method – if a fish has a bad odour then they may not buy it. There may sometimes be an opportunity to taste the fish, but it may not be common practice to test a fish to determine its quality. However, a method called the Torry or EU scheme for cooked fish, the Quality Index Method (QIM), for raw/whole fish has been developed and adopted.

The most reliable method is to test for the presence or absence of microorganisms in the flesh under a microscope but this requires laboratory facilities and skilled staff and farmers usually need to get help from vets or other similar professionals.

Chemical analysis can also be done to determine whether the fish contains any heavy metals or other harmful chemicals. Some environmental laboratories can test for these. Farmers with any doubts about the quality of the water they use on their farm or to produce any food fish can take appropriate samples for analysis, so that they can be confident when it comes to selling their products. There have been cases of people disseminating rumours about mercury and other heavy metals being absorbed from the environment by tilapia and so laboratory analysis can be helpful. Food safety measures are a continuous process to prevent contagious diseases or minimize the risks of food-borne hazards to humans being carried into the food chain via fish or fishery products. These risks can be from zoonotic pathogens, residues, antibiotic resistance, etc. that begin on the farm and end on the fork.

As with any food items, fish has a shelf life, i.e. the length of time during which fish is good for consumption. The end of its shelf life can be determined using sensory, chemical or microbial methods. Shelf life depends largely on storage conditions, especially temperature, humidity, pH and other environmental parameters.

9.10 Quality Certification

There are various biosecurity practices and recently a number of private organizations as well as government agencies have been monitoring the production and movement of fish. CoCs, GAP, BMP, HACCP and organic certification are the major biosecurity measures developed so far. These are described briefly in Section 8.7.

There are several related phrases such as quality control (QC), quality assurance (QA)/quality management (QM), i.e. ISO standards, and so on. In the case of processing of foods, Good Hygienic Practices (GHP) and Good Manufacturing Practice (GMP) are commonly used but basically they are the same. They refer to measures and requirements which any establishment should meet to produce safe food. These requirements are prerequisites to other and more specific approaches such as HACCP, and are often called prerequisite programmes.

In recent years the term SSOP has also been used to encompass best practice. Another popular phrase has been total quality management (TQM), a management approach centred on quality and based on the participation of all its members, aimed at long-term success through customer satisfaction and benefits to the members of the organization as well as to society. Thus TQM represents the organization's 'cultural' approach and together with the quality systems provides the necessary philosophy, culture and discipline to be committed to by everybody in the organization to achieve managerial goals related to quality.

Specific certification of tilapia farms and processing plants is now necessary, especially for those who want to export products to the Western world and Europe. Due to the amount of concern about the environment and climate change, consumers have become very much more aware of the products they buy. Consumers are demanding more and more ethical products and

Table 9.2. Star level grading of tilapia fillets.

Off-flavour causing chemicals	Fillet grades		
	5-star	3-star	1-star
Geosmin (ppt)	<250	<500	>500
Methylisoborneal (MIB)	<100	<200	>200

so demand for certified products, including seafood, is increasing globally. Tilapia was mainly exported to the USA but the market is now expanding to Europe as well, due mainly to the certification programmes. GlobalGAP and the Aquaculture Stewardship Council (ASC) are certifying the tilapia farms and plants, e.g. Trapia Malaysia and Regal Springs of Indonesia. In particular, the well-established Regal Springs products which have been widely sold in the USA are now available in European countries such as Austria, Belgium, Canada, Denmark, France, Germany, the Netherlands, Spain, Switzerland and Sweden.

A quality certification programme called the 'five-star level' grading system has been established in the USA, which is based on the level of geosmin and MIB in the tilapia fillets determined by gas chromatography, as shown in Table 9.2 (Hong, 2011).

9.11 Organic Certification

The term organic farming means producing agricultural products without the use of artificial chemicals. It has become popular mainly because of the excessive use of pesticides in vegetables and crops which is linked to reduced immunity in humans and increased incidences of cancer and other types of diseases. Farming tilapia is close to organic because it does not require the use of antibiotics or other chemicals. However, most tilapia farmers culturing in ponds use urea and TSP or DAP to enhance natural food, i.e. plankton. The definition of organic prohibits the use of any chemical fertilizers. At the same time, the use of chicken manure is common. As chickens are fed with antibiotics, growth hormones and so on, their leftover feed and manure are not considered to be organic inputs. Therefore, organic farming provides a limited option of the use of cow or goat manure reared on grass without the use of any chemicals. This limits the productivity of the culture system and its growth potential. In addition, fish have to be fed with a special diet certified as an organic product, the price of which is obviously higher than normal feed, which again adds to the production cost. Therefore, there is a trade-off to consider when a farmer is choosing to farm organically or not. It is really only possible where high demand and high prices exist to compensate the farmers for their higher production costs.

9.12 Export Markets

As tilapia can be grown in a wide range of environments, they can be supplied fresh even in rural areas, unlike sea fish which may not reach these areas, or if they do it can take several days. Therefore, fresh seafood is only available in coastal areas and so tilapia play an important role in supplying high-quality animal protein in rural areas. Most tilapia produced today are consumed locally where there are fish-eating communities. However, experience has shown that if tilapia is a new fish to consumers in a particular market, it may take some time for them to understand its value. A farm operator needs to have a good promotional plan in advance so that consumers are aware that a new product is coming to market. A promotional campaign is beneficial, perhaps with the help of local or national government together with academicians and researchers. This has worked well in several countries where tilapia was not a new product, e.g. Bangladesh, Thailand, Pakistan. In order to establish tilapia as a new food item and penetrate a market, branding as a new product to suit local taste may be necessary and could turn out to be highly profitable.

An example can be taken from CP Foods Co. Ltd in Thailand, which runs a few tilapia hatcheries using the hormonal sex reversal technique that has played a key role in promoting red tilapia. Initially they planned to strategically develop a separate line of breeding stock and use it to produce fingerlings for distribution to groups of farmers under contract farming. The company requested HM the King of Thailand to suggest a name, similar to the tradition of giving family names to people in the country. The name was 'Thapthim' which in Thai means 'ruby', a precious gem. This became a brand name, giving the impression to ordinary people that it is something special and completely different from the commonly found tilapia. Many people may not know that Thapthim is actually a kind of tilapia, i.e. the red variety. For marketing, the company promoted Thapthim by producing and distributing attractive pictures of several food items of red tilapia to almost all the restaurants in Thailand in order to boost domestic demand. The company now has several tilapia growers in groups in various pocket areas under contract farming. Under the agreement, farmers get a complete package of technology, and inputs such as fingerlings and feed. They also buy back the fish so that farmers do not need to worry about markets. This is a very good lesson in how to market and promote tilapia as a new product.

Globally, wild catch has either declined or remained constant but farmed tilapia production is more than doubling every decade. The USA has been the largest market for tilapia, with an annual import value of over US$1 billion. Latin American countries such as Colombia, Costa Rica, Ecuador, Honduras, and others benefit from the proximity of markets to supply of fresh tilapia or fresh fillets (Fig. 9.13), whereas from Asia fish have to be either whole frozen or fillet frozen. China has been the largest producer and supplier of tilapia, offering the lowest price possible and other countries find it difficult to compete with

Fig. 9.13. Attractive fish fillet for which tilapia has been the most suitable fish.

them for price. China's exports of frozen fillet are rapidly rising, accounting for nearly 50% of total exports. Of course, the USA is the main importer with more than half, but interestingly, eastern Europe and its surrounding countries such as Russia, Ukraine, Iran and Kazakhstan are also increasing their import share.

Several EU countries are top of the list in terms of seafood consumption. However, due to the cold climate and expensive labour, inputs and equipment, most of these countries have to depend on imports. More importantly, a decline in wild catch is forcing them to accept farmed fish. Although tilapia has not been well accepted as a seafood item, in recent years EU countries have been more attracted to tilapia, especially the Czech Republic, France, Greece, Poland, Spain and the UK. Major suppliers are Asian countries such as China (>80%) followed by Thailand, Vietnam, Taiwan, Indonesia and Malaysia.

Although tilapia are native to African countries, due to a shortfall in tilapia production and a declining wild catch, these countries are now importing more and more tilapia, mostly in whole frozen form, especially from China, but also from Latin American countries, e.g. Colombia. African aquaculture is only growing slowly, so African countries will need to import large amounts of tilapia. Within Asia, the Middle East has been the emerging market, especially Bahrain, Kuwait, Qatar, Saudi Arabia, and the UAE, where tilapia cannot be produced so easily due to shortages of water and technologies. Awareness of the health benefits of seafood, as well as a decline in wild catch in some of these countries, means they are importing more fish. India, a country of a billion people, is an emerging market where a small door (introduction allowed only with appropriate biosecurity measures in place) has been recently opened for Nile tilapia after a long ban. As a result, its farming as well as the demand for tilapia has increased. If awareness can be increased and quality boneless fillets made available, India could be a huge market. Various private companies and some public organizations are putting a lot of effort into establishing tilapia as a good source of protein.

Emerging economies such as Brazil, Bangladesh, Indonesia, Thailand, the Philippines, and others are offering higher quality frozen tilapia fillets, the prices of which may range from $5 to 10 per kg, whereas China is still able to produce at half that price. Therefore, tilapia producers are facing tough competition, mainly from China. However, if the current trend of economic growth continues, the cost of production in China is likely to increase and more people are likely to consume seafood. As a result, China may not be able to maintain the lowest production prices and may need to import fish, including tilapia. Those who want to produce tilapia for export need to keep these facts in mind.

Business Models and Plan

10

10.1 Business Models

When selecting a business there are always several options available to farmers or investors. First, farmers or investors have to be convinced that the tilapia business will give them the highest profit compared to others in a particular situation. In some situations, it may not necessarily be the highest earning but will have other good reasons for being chosen.

Whether a farmer should choose a hatchery or nursing business, or grow-out farming, depends on several factors (Fig. 10.1). In general, a hatchery business requires specific skills and techniques and so needs to be done with proper planning of financing and human resource training. In the case of tilapia, it is capital- and labour-intensive, but it is more profitable than nursing and grow-out farming. Some farmers may choose nursing of fry to fingerlings as a business, acting as middlemen between hatcheries and grow-out farmers. They are often leader farmers in a community and play vital roles in supporting the aquaculture industry by supplying seed, feed and other materials to the grow-out farmers. In addition, they provide valuable market information, growing techniques and also supply inputs on credits/loans, for example in Bangladesh. They have more knowledge about quality of seed and farming techniques and provide inputs at the farm gate. Farmers can rely on them and they are the key players in aquaculture development, whereas in other countries, e.g. Thailand, grow-out farmers themselves can directly reach the hatcheries. Farmers either stock fry directly into the ponds or nurse in one or two stages for stocking in cages. As nursing gives a quick turnover and requires limited investment, some poorer farmers have been helped or encouraged to choose a nursing business. A grow-out farming business is relatively easier but takes a longer time to get a return and requires more space.

Aquaculture in Asia is becoming more specialized and segmented. Some farmers produce only small fry of 0.2–0.3 g while others do the nursing of these fry to 5–10 g fingerlings (30–45 days). A second nursing (45–60 days) is done to produce larger fingerlings of 30–50 g in size to stock in ponds or cages so that grow-out farmers can produce 600 g to 1 kg fish in 4–5 months. Larger

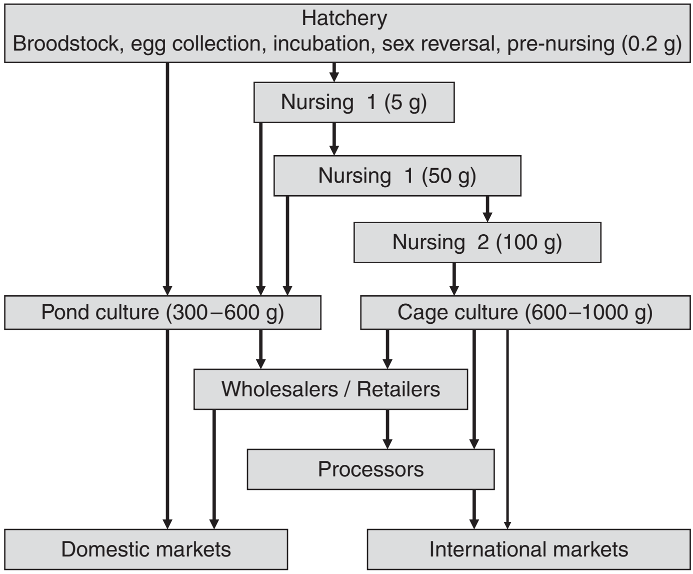


Fig. 10.1. Tilapia farming system and major business components.

fingerlings are more suitable to stock in cages because the cage net mesh can be bigger to allow better water exchange.

A successful model in Asia has been contract farming in which large corporates invest in hatcheries. Hatchery businesses are the most profitable part of aquaculture, but require relatively high investment and skilled human resource. There is a trend that larger commercial operations are more capable of investing and managing it as a business. They can supply high-quality seed to the farmers along with a package of grow-out technology including the feed. Farmers grow the fish and sell back to the companies so that they neither need to worry about inputs nor the market. Grow-out is relatively easier and so large numbers of farmers can do it in groups. This gives back to the communities a chance of doing business and allows them to get involved in income-generating activities. The corporate businesses often claim this is part of giving back to the community and they may even have a programme of helping to educate the children of farmers as part of their corporate social responsibility (CSR). However, some farmers complain that corporates take advantage three times – from the seed, from the feed and also from the fish. This needs to be clarified and worked out for the benefits of all parties involved, otherwise contract farming may not be applicable in these cases.

However in many other parts of the world, e.g. many countries of Africa, the situation is that it has been difficult for farmers to depend on others for fry and fingerlings, for several reasons including transportation. Transporting fry and fingerlings long distances adds to the difficulties. In such cases, entrepreneurs have little or no choice than to invest in vertically integrated large farms. Therefore, most farms are vertically integrated, i.e. hatchery, nursery and grow-out, which require high investments.

The most successful businesses are specialized hatcheries. However, depending upon the situations in various sites and countries, farms are either vertically integrated or have at least two components such as hatchery and nursing, or nursing and grow-out. As grow-out farming is the easiest, most farmers who are not as interested in learning techniques do it as an occupation along with other traditional farming.

10.2 Management of Risks

In general aquaculture is a high-risk business that is highly prone to environmental factors. There are risks due to natural phenomena, as well as due to demand and price fluctuations in local as well as international markets.

Depending upon the type of farming, when selecting a site several factors have to be considered, such as the likelihood of strong winds, tropical storms, flooding, diseases, algal blooms, waves, currents, contaminants, etc. and how these can be avoided. Similarly, during farming adequate measures have to be put in place so that variations in temperature and salinity, and adverse water quality parameters are under control. In some countries, there are insurance provisions for agriculture or aquaculture businesses, but this is not available in many countries. In such cases, investors have to be ready to accept the loss. Therefore extra care must be taken. The most important factor is that managing these will add to the costs, and it is a question of whether these costs will be within the expected level of investment so that the ultimate net return remains reasonably and acceptably high.

In many countries, there is a lack of general infrastructure facilities such as roads for transportation of inputs and products, and the electricity required for pumping, lighting, chilling, and so on. For successful fish farming other accessory businesses have a significant part to play. Entrepreneurs/managers have to consider whether there are reasonably good-quality feeds available in the market, or whether trash fish and other feed ingredients are available throughout the year at affordable prices so that farms can make their own feed, equipment and necessary materials. They also need to consider other service providers, including those for fish health management, and also possible research and development support from universities or research institutions and/or government. When making a business plan a number of points have to be taken into account, and the following checklist gives some examples:

- *Species* – Nile tilapia (*O. niloticus*) possibly most widely used GIFT, *Chitralada*, red varieties, or locally available tilapia if introduction is not allowed.
- *Land* – availability of adequate land and its suitability for building ponds/tanks or other facilities; whether it can be leased or rented on a long-term basis or needs to be purchased.

- *Climate or weather* – tropical, warm climate and freshwater area.
- *Legal conditions* – countries that encourage farming by policies and legal frameworks.
- *Infrastructures* – with good roads, electricity.
- *Technology and products* – for example hormonal sex reversal for monosex tilapia fry, black or red tilapia for boneless fresh or frozen fillets, whole frozen, or live fish.
- *Availability of technical staff and labour* – what sorts of organizational structure are required and availability of technical staff and labour.
- *Market* – analyse the market trend, demand, prices and potential sales and profits.
- *Competition* – any others to compete with for the product, plans on how to beat them.
- *Investments* – level of investment required and business friendliness.
- *Financial projections* – will depend on site/country, business type; therefore, comparisons have to be made among all the possible business options and for all possible sites/countries.
- *Financing* – sole ownership or partnership/shareholders' investment or bank loan.
- *Risks* – what are the risk factors and work out the costs of avoiding them.

All these factors can be arranged in a matrix and scores can be given with varying weights in order to select the best option for a particular locality, products and available land or other resources. A simple table can be prepared and compared among the sites or countries, e.g. Table 10.1. In this example, score weights are given at different ranges. For the least important factors scores can be given within the range of 20–40, while the most important factors such as revenue and profits can be given scores of 80–100. Similarly, scores ranging from 40 to 60 are used for other moderately important factors. The table shows that Site 3 with the highest score (825) should be selected. If it cannot be selected for any reason, Site 2 is the next best option. The purpose of presenting this table is to show a method of scoring that can help to make the right decision when there are problems. However, investors can establish their own criteria for scores and add/omit some parameters.

10.3 Production Targets and Scenario Comparison

A farmer may choose any one of the various culture systems for the same production target. For example, in Table 10.2 a scenario analysis has been shown for 20 t tilapia production. The land requirement is lower when intensive systems are used. For an extensive system, 20 ha of land may need to be purchased or rented to produce 20 t of fish, whereas only 4 ha and 2 ha can be used to produce the same amount of fish in semi-intensive

Table 10.1. Scores for tilapia hatchery for different sites.

Factors considered	Score weights	Scores			
		Site 1	Site 2	Site 3	Site 4
Availability of good species	40–60	40	45	60	42
Land (rent, lease or purchase)	20–40	20	30	30	40
Technical staff and labour	20–40	20	30	30	20
Availability of good water	20–40	40	40	40	30
Suitability of climate or weather	20–40	20	30	40	40
Insurance facility	20–40	20	20	20	20
Legal conditions	20–40	20	30	40	30
Government supports and subsidies	20–40	20	40	40	30
Infrastructures					
a. Road	40–60	40	50	50	50
b. Electricity	40–60	40	50	60	40
c. . . .	40–60				
Market price	40–60	40	50	60	40
Market competition (none or tough)	40–60	50	40	60	40
Investments friendly	40–60	40	50	60	50
Financial projections					
a. Costs	40–50	40	50	60	40
b. Revenues	80–100	90	80	90	80
c. Net profits	80–100	90	80	85	90
. . .					
. . .					
Total score		630	715	825	682

and intensive systems, respectively. The productivity of these common systems are approximately 1 t, 5 t and 10 t for extensive, semi-intensive and intensive systems in ponds, respectively, and about 20 kg/m^3 for cages.

Cage culture does not need any land. It is the best way of utilizing unused water bodies such as lakes, reservoirs and rivers wherever available. However, there should be suitable water for fish to grow and the farmer should have access rights to grow tilapia. As stocking density varies with the management, which can alter the carrying capacity, the number of fry and the number of staff/labour, so their associated costs differ. Stocking densities for extensive systems are normally 1/m^2, 3/m^2 and 15/m^2 for pond culture systems and 25/m^3 in the case of cage culture. The amount of feed has been calculated using FCR values and used to estimate feed costs of 0, 0.8, 1.2 and 1.5 for respective production systems. Feeding is not applied in the case of extensive systems and it is expected that fish will grow slowly, taking approximately 10–11 months, and the size variation will be very wide which means the price of fish may also vary, with the lowest prices for the smallest fish. However, in

Table 10.2. Comparative planning for tilapia grow-out farms (figures are indicative and close to reality in Asian context but not exact).

Description	Pond culture: Extensive	Semi-intensive	Intensive	Cage culture
Production target (t/crop)	20	20	20	20
Land requirement (ha)	20	4	2	20 cages
Cost for land lease (US$)	20,833	4,167	2,083	3,333
Human resource (persons)	5	8	10	5
Operational cost (US$/crop)				
a. Fry	2,000	4,800	12,000	8,640
b. Feed	–	117,333	200,000	304,000
c. Fertilization	667	267	–	–
d. Labour	20,000	32,000	40,000	20,000
e. Others: electricity, fuel, etc.	2,267	15,440	25,200	33,264
Interest on investment	2,244	15,286	24,948	32,931
Total cost (US$/crop)	27,177	185,126	302,148	398,835
Revenue (US$/crop)	100,000	224,900	297,500	447,667
Net profit (US$/crop)	57,167	66,600	43,417	111,693
Net profit (%)	210	36	14	28

Assumptions:
Respective productivity figures are 1 t/ha, 5 t/ha, 10 t/ha and 20 kg/m^3 of cage.
Stocking density 1/m^2, 3/m^2, 15/m^2 and 25/m^3 for cages.
FCR values used to estimate feed costs are 0, 0.8, 1.2, 1.5 for respective production systems.
Labour costs are the average wages (approx. US$350/month).
Other costs were calculated based on 10% of the total costs.
Interest on investment was calculated using 18%/year rate of total cost for 1/2 year.
Revenue was calculated based on the differential survival or recovery of fish, i.e. 50% for extensive and about 85% for other systems.
Differential prices of fish, i.e. US$1, 1.3, 1.75 and 2.6/kg were used for the respective culture systems as the price differs with the sizes and the quality of fish produced.

a country or region where price does not vary with the size, extensive systems may be the best option. As feed is the main cost and there is no feed involved, extensive systems with some fertilization results in the highest profit. This is the way a lot of tilapia has been produced in Asia traditionally, including China where pigs are raised on the pond dykes and chickens are raised in a house built above the fish ponds. Uneaten feed and their manures fertilize the pond, enhancing the growth of plankton which is the natural food of fish, especially tilapia. However, the fish are not of export quality and also recent demand has been for fish grown by feeding with pellets. But intensive systems require more investment, particularly to buy commercial pelletized feeds, due to which profitability (14% in this case) goes down. Therefore, a combination of fertilization and commercial pellets as supplementary feed has been considered the most profitable option. In countries where animal manure is acceptable, chicken and pig manures have been used, but in other countries where they are not acceptable, simple chemical fertilizers such as urea and TSP can replace the animal manures. They are less bulky and easy to use and more importantly, are easily available and extensively used for cereals, vegetables and fruits. They are acceptable to most people apart from advocates of organic farming. The analysis also shows that a semi-intensive system is the second most profitable farming business, as shown in Table 10.2. Although the extensive system may result in the highest profit, it may not be a good choice if the time it takes and the quality of fish it produces are taken into account. This is the reason the majority of tilapia farmers use a semi-intensive system. Cage culture has recently become popular because it provides opportunities for those who do not have adequate land and also it requires only a small space that can be managed easily to produce a large volume of fish. The only conditions required are access to a body of water and the availability of reasonably cheap and good-quality floating feed.

10.4 Economies of Scale

Financing, staffing and all other planning depend on production and sales targets. There is always an advantage from economies of scale – planning for expansion or 'thinking big' is always good even if starting up on a small scale. In many cases, farmers start off by planning on a small scale and then eventually expand their businesses, which requires everything to be replicated and often means investment needs to be doubled. But if an expansion plan is put in place from the beginning, there will be a huge cost saving when the time comes for expansion. In other words, levels of production and sales can be easily doubled without the need to double up on everything. For example, producing 1 million fry a month can be achieved by 5 ha land and ten staff, but 2 million per month can be achieved by adding only another 2 ha and four or five staff instead of doubling the amounts.

10.5 Financing Plan

How the farm will be financed is the most important and critical consideration. Investors may wish to own 100% of the equity of the farm as a family business. But in most cases, a group of individuals may join forces to run a larger commercial scale operation, distributing shares within the group. When a group is involved, it can be successful if everyone's suggestions and ideas are discussed and the best options chosen. On the other hand, however, there is a risk that the group members may not agree with each other and this might create friction within the group. The group may want to take out a loan where private or government banks may have a policy of low interest rates for agricultural businesses.

In some cases, an investor may want to invest in a foreign country or a foreign national in a country may be willing to partner. Policies differ from country to country regarding the ownership of a farm or company. In very few countries can a foreign shareholder(s) own 100% of a company. In most cases, they can hold up to a 49% share of the company and need local partners. However, the processes can be too bureaucratic, complicated, cumbersome, or lack appropriate policies and transparency to make investment attractive.

Even if a farmer has funds available, questions should be asked about whether the fund should be invested in farming. In most countries, agriculture and livestock businesses may get subsidies and low interest loans, e.g. 3–5% depending upon the type. Smart farmers may choose to invest the available funds in a high profit earning business and take out a loan for farming. For example, if a farmer has US$100,000 and if they invest in the stock market, keep the money in a bank or buy a bond, they may get an interest rate or profit margin of 8% per year. But if their government is providing a low interest loan, such as 5%, they can benefit by a further 3% (8–5%) because of the difference. However, in many countries, taking a loan out can be a very cumbersome process, which may ultimately cost more, or it may take a long time, affecting implementation of the programme and causing the farmer to miss the season or window of opportunity.

In most countries an environmental impact assessment (EIA) of any aquaculture project is required but this can be very costly for small companies and so often there is a policy that certain levels of investment and production require no EIA. A recent example is in Zambia, where EIAs are not required for farmers who produce less than 100 t/year. Many countries still ask for an EIA, but due to a lack of appropriate organizations and capable individuals, EIA reports have merely been paperwork to be enclosed with the application.

10.6 Human Resource Plan

As in any business, hiring the right people to the right position has a tremendous impact on achieving business goals. The human resource aspect is rarely discussed in any farming manuals. This section provides simple guidelines with a view to helping entrepreneurs and investors.

For small-scale hatcheries family labour is usually used, but professional and competent technical staff are required for large-scale operations and if the farming is done in a proper and profitable way. Staff can be hired permanently or temporarily based on the requirements, but should be reasonably cheap and adequate. Only a few skilled labourers are usually needed; staff can be trained if necessary but should be willing to get wet and work irregular hours, and have a strong work ethic and high levels of commitment.

Tilapia farming requires very specific skills, especially the hatchery aspects. In some countries, it is very new and so good training may not be available. In such cases, overseas training may be required, which adds to the human resource investment needed.

In this section, the organizational structures of a tilapia farm and job responsibilities are presented with a view to helping farm managers establish a good team.

In order to register a company, a group of seven investors (Board of Directors) is needed in most countries. One of the directors may serve as CEO or Managing Director. In other cases, a person may be hired as General Manager or Director and will take care of all aspects of the farm/company, as shown in Fig. 10.2.

A tilapia farm is normally divided into two sections: technical and non-technical. Each section should have the following sections/departments.

10.6.1 Technical section

Broodstock section

A manager with a background in fish breeding and genetics is needed to lead this section. They should understand research and continuously carry out some sort of trials in order to develop the best performing broodstock, feeding strategies and other management practices. This section is responsible for broodstock handling, egg collection and hapa set-up, and may include four to six staff who can work in the pond collecting eggs.

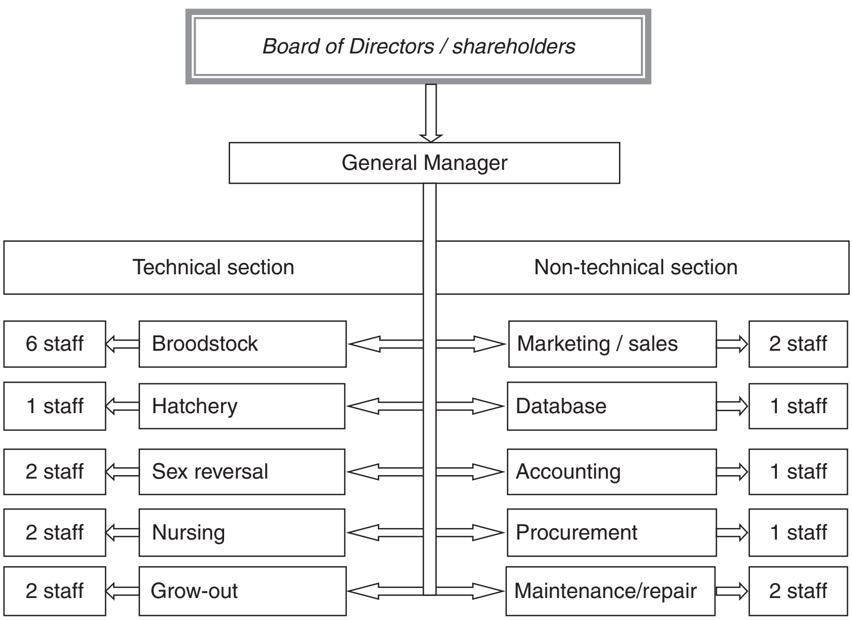


Fig. 10.2. Organizational structure of a tilapia hatchery and grow-out farm.

Hatchery section
A technician is needed to take care of the eggs and their artificial incubation, transferring them to a larval rearing system and then to a sex reversal system. They should also look after the water circulation and electrical power systems.

Sex reversal section
This section should be led by a manager, with one or two more staff to help prepare sex reversal feed, and feed fry several times a day. Regular hapa exchange, fry grading and quality monitoring (sex testing) are additional responsibilities of this section.

Nursing section
At the start, this section can be handled by the same two people assigned to sex reversal, but later, when the scale of the operation increases, two people will be needed. The main responsibilities will be feeding fry, grading and conditioning for sale.

Grow-out section
A general technician can handle a large number of grow-out ponds, as the main job will be feeding the fish two or three times a day. However, they need to be able to arrange temporary workers for pond preparation and fish harvest, and to manage sales and post-harvest techniques.

10.6.2 Non-technical section

Marketing/sales
Someone preferably with a business management degree/background and some biology knowledge should lead this section. The main responsibilities would be to handle customer bookings/orders and deliveries, as well as, if necessary, advertising products, i.e. fry and table fish, promotional activities such as organizing, participating in and presenting at conferences, arranging food fairs, marketing booths, showrooms, publishing posters, flyers, brochures, web page maintenance, use of social media, and so on. The person should understand branding of products to offer unique items, e.g. use of logo stamps on plastic bags of fry when sold to farmers or tags on fish when sold to the supermarkets (e.g. Fig. 9.8, left).

Accounting
An accountant is required to maintain all financial data, preferably someone who knows the taxation system. They need to be experienced with computer programs and have good accountancy skills, as well as knowing about how

to enter data into a database or simple spreadsheet, how to prepare reports of sales and cash flow, and about income forecasting using MS Excel, MS Word, or MS PowerPoint presentations.

Database maintenance

There will be lots of data to collect at each step of the production process, for example the number of ponds, broodstock, eggs, fry and fingerlings. In order to track the performance of each stage, key performance indicators are established such as percentage of hatching, and survival in the hatchery, and during sex reversal, nursing and handling. Maintaining a sound database helps to pinpoint any problematic stages or people. This person needs to be good with spreadsheet and database programs, e.g. MS Access.

Procurement

A person may be needed to handle the procurement of materials such as feed, fertilizers, hapas, pumps, and so on. Although the General Manager may be able to do it at the early stages, later on a specific person may be needed, when the scale of the operation starts to increase.

Maintenance and repair

There will be lots of materials and equipment that need repair, e.g. hapas, cages, fences, wires, gates and even electrical appliances.

Figure 10.2 shows an organizational structure and Table 10.3 shows examples of staffing of a tilapia farm that includes a hatchery and nursing and grow-out activities for a medium-scale commercial farm based on the developing country context.

Table 10.3. An example of staff for a tilapia farm (hatchery, nursery and grow-out) and their expected salaries, which vary with countries as well as locations.

Position	Monthly salary (US$)
General Manager (GM)	1,650
Assistant Manager (AM)	1,020
Accountant/Data Manager (DM)	850
Marketing Manager (MM)	740
Hatchery Manager (HM)	650
Grow-out Fish Production Manager (PM)	550
Hatchery Technician 1 (HT)	450
Hatchery Technician 2	450
Sex Reversal Technician 1	450
Sex Reversal Technician 2	450
Nursery Technician 1	450
Nursery Technician 2	450

Continued

Table 10.3. Continued.

Position	Monthly salary (US$)
Egg Harvest Labourer 1	320
Egg Harvest Labourer 2	320
Egg Harvest Labourer 3	320
Egg Harvest Labourer 4	320
Egg Harvest Labourer 5	320
Egg Harvest Labourer 6	320
Grow-out Staff 1	320
Grow-out Staff 2	320
Grow-out Staff 3	320
Feeding Staff 1	320
Feeding Staff 2	320
Equipment Maintenance	320
Maid or Cleaner	320
Total	12,320
Mean	493
SD	305
Maximum	1,650
Minimum	320

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Conclusions

- Tilapia was considered to be cheap and a 'poor man's fish' but it has now become everyone's fish, also popularly known as 'aquatic chicken' and likely to become as common as chicken.
- Annual global tilapia production has doubled each decade and has now reached over 3.5 million t; tilapia is currently the second most farmed group of fish after carp. The demand will be even higher as more people realize its potential.
- Tilapia are freshwater fish indigenous to Africa but have been introduced into many countries all over the world, especially in Asia. The highest producing countries in the world are China, Egypt, Indonesia, the Philippines, Thailand and Vietnam; all are in Asia apart from Egypt. Approximately three-quarters of the volume is produced in Asia. More and more countries are accepting the species and promoting its culture.
- A large volume of tilapia produced is consumed locally, which means it makes a great contribution to food security, income generation and employment. Farming tilapia and getting involved in the tilapia industry serves the community.
- An export market is well established and is likely to expand, with more demands for food safety, quality assurance, improved packaging and environmental safeguards (with little if any increase in price). Therefore, it is likely that farmers will need to meet stricter criteria for food safety, quality and environmental protection and that farmers and processors will need to meet these demands by increasing efficiency.
- Opportunities for tilapia farmers, researchers, traders and professionals are growing tremendously.

Recommendations

- Farmers or groups of farmers who want to start a tilapia hatchery business should acquire a good quality of broodstock from a reliable source.
- Hatchery managers and a few other staff should be trained at a reputable institution. Starting a hatchery or grow-out farm may lead to failure.
- Emphasize the importance of high-quality seed and create an image or build trust in hatcheries and fish seed.
- Some hatchery managers try to test some feed and other materials and have faced problems. Therefore, it is recommended to stick to standard protocols without any modifications in order to maintain the quality of fry and fingerlings. They can try something new only after they are successful in achieving the target production with expected quality. There is always room for further improvement, but if they start derailing standard protocols they will fail to reach their targets.
- Those countries wanting to develop a tilapia industry need to establish at least one good functional model hatchery in a suitable location where the tilapia industry is to develop. Then the hatchery can serve as a training and technology dissemination centre.
- Professionals should attempt to run a profitable hatchery, preferably to be run by the private sector.
- Train farmers on standard grow-out methods with proper workout or records of inputs–outputs and financial records.
- Conduct demonstration trials and disseminate the proven technologies for the benefit of thousands of farmers.
- Emphasize a participatory approach to producing tilapia with farmers, establishing cooperatives or self-help groups so that more communities or societies reap the benefits.
- Training on production of cost-effective home-made feeds using locally available ingredients is needed in rural areas where commercial feeds are not available at affordable prices.
- Problems with off-flavours for pond farmers need to be avoided by balancing natural foods and home-made feed and carrying out research into treatment for the chemicals causing the off-flavours.
- It may be possible to develop an alternative to synthetic MT hormone using plant extracts, but this needs proper, well-designed scientific research.
- Feeding cheap feed may produce more waste but it is necessary to minimize dry matter loading and minimize potential environmental problems.
- More tilapia dialogues and forums, conferences and workshops are needed.
- Appropriate certification such as GAP, CoC, BMP, HACCP, etc. are needed but too much emphasis on these and other environmental issues may slow down the growth of the tilapia industry.
- More research and development is needed to develop strains that are more cold tolerant, salinity tolerant and disease resistant.

Continued

Continued.

- More mass media campaigns and promotion are need to create networks, establish markets and build consumer confidence.
- More printed materials are needed to distribute such as manuals, flyers, scientific articles and books in English as well as in local languages.

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