A manual for Nile tilapia seed production and grow-out aquaculture

WorldFish

CGIAR

Funded by

BILL & MELINDA GATES foundation

USAID
FROM THE AMERICAN PEOPLE

A manual for Nile tilapia seed production and grow-out aquaculture

Authors

Krishna R. Salin and Amara Yakupitiyage

Citation

This publication should be cited as: Salin KR and Yakupitiyage A. 2023. A manual for Nile tilapia seed production and grow-out aquaculture. Penang, Malaysia: WorldFish. Manual: 2023-31.

Acknowledgments

Funding support for this work was provided by the Bill & Melinda Gates Foundation through the project Aquaculture: Increasing Income, Diversifying Diets and Empowering Women in Bangladesh and Nigeria [OPP1198810]. This publication was made possible through support provided by the United States Agency for International Development (USAID), under the terms of Contract No. G001RDN028. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of USAID. This work was undertaken as part of the CGIAR Initiative on Aquatic Foods. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: www.cgiar.org/funders.

Contact

WorldFish Communications and Marketing Department, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. Email: worldfishcenter@cgiar.org

Photo credits

Front cover, pages 3, 4, 5, 7, 10, 12, 13, 15, 16, 17, 18, 26, 28, 33, 38, 47, Krishna R. Salin/AIT.

Table of contents

1. Introduction

Introduction to tilapia aquaculture
Tilapia is a highly versatile fish that is farmed worldwide. Widely known as the "aquatic chicken," it has the potential to contribute to the food security needs of a rapidly increasing global population. As a group, tilapia species play a great role in tropical aquaculture, with Nile tilapia (*Oreochromis niloticus*), in particular, holding great economic promise to provide food and nutritional security and create rural employment. As tilapia farming has expanded worldwide, the demand for seed to stock in production ponds has also increased, and the fish continues to be introduced into many regions outside its natural habitats. Various aquaculture interventions have modified the life cycle of Nile tilapia extensively. Manipulating spawning, breeding and stocking density, feeding with formulated feeds, altering gender to produce monosex (all-male) stocks, aerating the water to supply dissolved oxygen (DO), and providing protection from predators are all interventions done to intensify tilapia production worldwide, as shown in Figure 1.

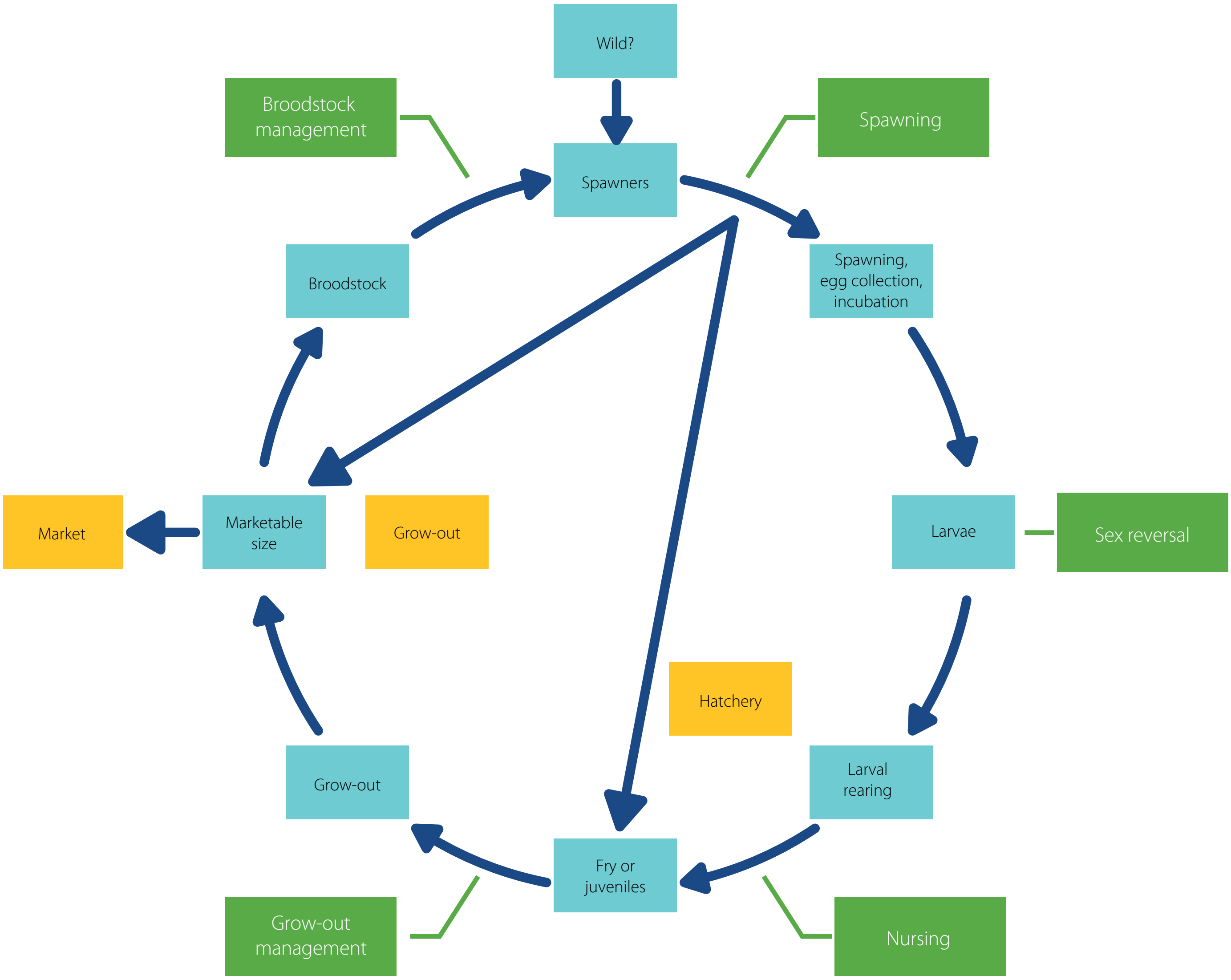


Figure 1. Aquaculture production process of Nile tilapia.

For fish like Nile tilapia, it is possible to manipulate its entire life cycle. In Africa, however, many fish farmers still collect broodstock from the wild. In commercial Nile tilapia culture, operators use hormonal manipulation to convert the sex of fish larvae into males. Larvae are then nursed using high quality feeds to produce fish fry or juveniles for grow-out culture. From there, it is possible to use healthy fish from grow-out culture as broodstock.

There are two major types of grow-out systems in Africa to rear fish up to marketable size: cage culture and pond culture. And depending on the type of operation, there are two types of seed production systems: intensive or semi-intensive. Semi-intensive tilapia seed production uses earthen ponds for breeding and for producing fry and fingerlings, and it relies on natural food for early fry rearing, often yielding mixed-sex fingerlings. This system raises male and female broodstock in a prepared pond, while the fry are grown in fingerling rearing ponds. Broodstock are then returned to ponds for conditioning.

The intensive method of tilapia seed production uses more advanced hatcheries to breed fry and fingerlings of mixed-sex and all-male fingerlings. In this case, space and management requirements favor using concrete tanks. Whether using ponds or tanks with intensive stocking, both need continuous aeration.

Intensive systems stock more fish than semi-intensive systems. Fish in these systems require nutritionally complete feeds because they do not use wild fry and because tanks and ponds are rarely fertilized. In addition, operators must exchange the water often. Commercial grow-out facilities produce all-male fry using this technology.

Earthen ponds, which many African countries use, are the simplest way to spawn tilapia. Tilapia spawn in many situations, but pond size, shape and depth will all affect harvests. Fish farmers can raised mixed-sex tilapia, monosex hybrids and sex-reversed fry in earthen ponds.

After stocking breeders in the breeding pond, farmers need to retrieve fry every 6–60 days. Fry appear 10–14 days after stocking and are harvested using dip nets, seines and traps. The fry swim in clusters, so farmers can collect them using a hand net with a very fine mesh size, and then count and transport them to a fingerling pond.

Reduced spawning frequency, cannibalism, and predation by larger fish, as well as other issues, make it difficult to produce fry in ponds. Farmers can solve most of these problems by using good pond management, which includes optimal fertilization, sediment reduction, preventing access for predatory fish and regular harvesting. Shorter harvest intervals and grading to remove large fry will provide more uniform-sized fry.

2. Nile tilapia broodstock management

2.1. Reproductive biology of tilapia

Tilapia is a member of the Cichlidae family. Three genera are well known, namely *Oreochromis, Tilapia* and *Sarotherodon*. More than 70 species of tilapia are endemic to Africa, Jordan and Israel, but only a few species are commercially important. Adult tilapia eat predominately vegetarian diets varying from macrophytes to phytoplankton, depending on the species. Many of their structural features are related to their feeding habits, such as a terminal mouth, slender notched teeth, long gill rakers and long intestines, which are seven to 14 times the standard length and are suitable for processing a plant diet.

Although fish reproduction is an extremely complex process, tilapia is a prolific breeder and presents only minimum challenges to reproduction, so seed production protocols are relatively easier than many other commercially farmed fish. Understanding the basic biology and ecology of tilapia, particularly in relation to its reproduction, will help improve the efficiency of intensive seed production and minimize the impacts of tilapia farming on the environment.

This section outlines the reproductive biology of Nile tilapia in relation to commercial seed production. We emphasize the practical aspects of seed production and provide short exercises at the end of each section to apply the skills learned.

Plate 1. Nile tilapia broodstock.

2.1.1. Size at first maturity for Nile tilapia

Species and strains of the same species can affect tilapia's size and age at first maturity. Nile tilapia reaches sexual maturity at 20–30 cm or 150–250 g in its natural environment. However, in aquaculture ponds or under stressed environmental conditions, it often reaches maturity early (30–50 g).

2.1.2. Identifying male and female tilapia

Water temperature has a significant effect on sex differentiation, sex ratio and morphological development during the early larval stages of tilapia. However, at increased temperatures, slow growth and body deformities can occur. Higher temperatures (34°C–36°C) significantly increase the proportion of males (69%–91%), but lower temperatures do not affect the sex ratio.

It is easy to identify male and female fish by the shape and size of the genital papilla. In males, it is long and pointed, and in females it is blunt. The female body has three openings on the outside: the anus, urethra and the opening of the oviduct in the form of a slit. Males are often larger than females of the same age and have two openings to the outside: the anus and the urinogenital aperture. These differences are easily distinguishable after the fish have grown to 10–20 cm or 100–150 g, and are more pronounced during the breeding season when males also develop a reddish color around the jaws. Plate 2 highlights the differences between a male and a female tilapia during spawning season.

2.1.3. Mode of reproduction of tilapia

Tilapia are nest builders and substrate spawners. Nile tilapia is a maternal mouthbrooder that incubates the fertilized eggs in the oral cavity of the female fish, like species such as Mozambique tilapia (*O. mossambicus*) and blue tilapia (*O. aureus*).

The mode of reproduction in Nile tilapia is quite unique. The males build a spawning nest (Plate 3) by defending a breeding territory where only visiting females ready for mating are allowed. The courtship lasts for a few hours followed

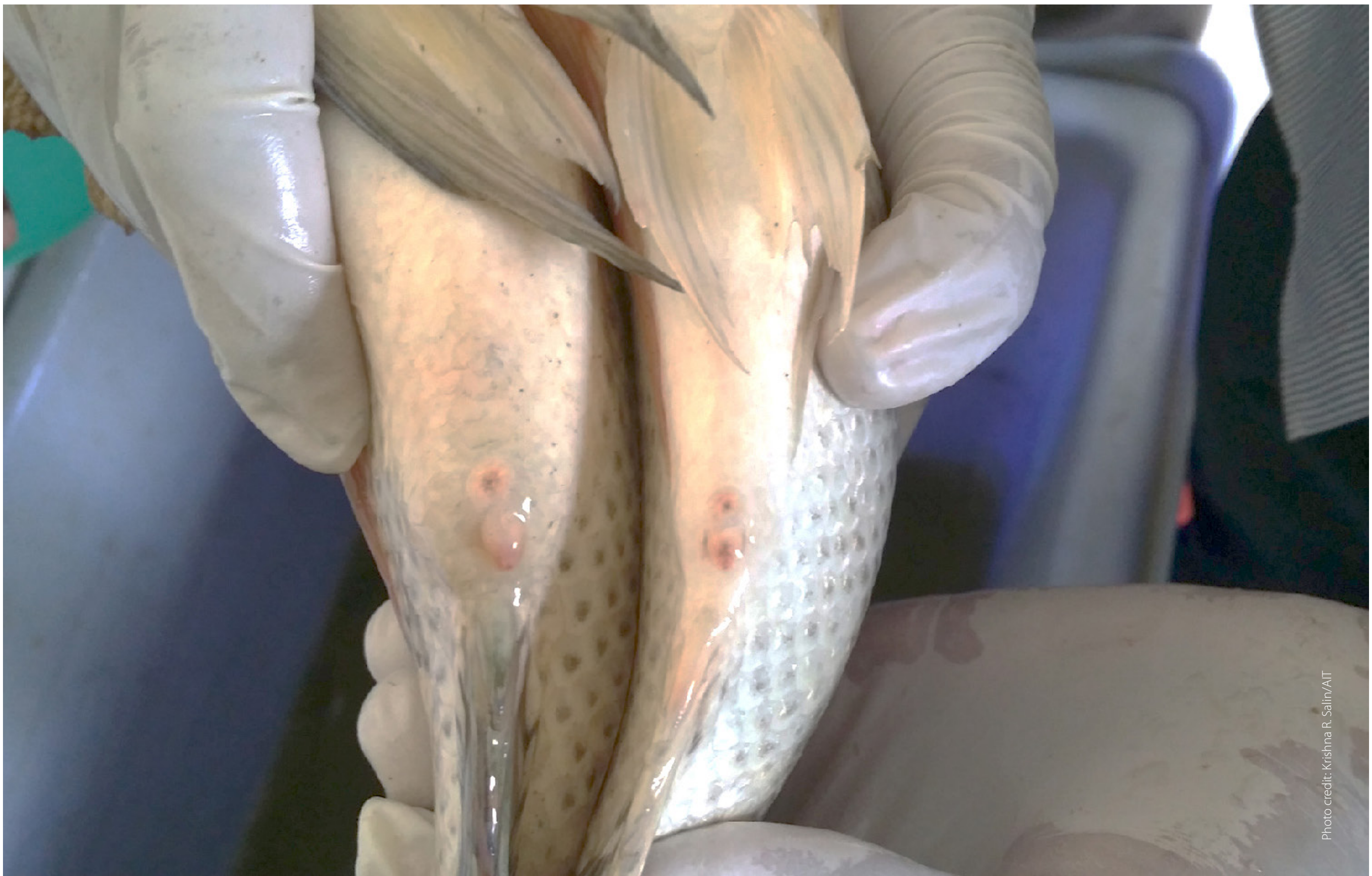


Plate 2. Identifying male (left) and female (right) tilapia through external morphology.

by spawning. The female repeatedly releases a string of about 20–50 eggs after which the male gently passes over the eggs and releases milt to fertilize the eggs. The overturning female then immediately captures all the eggs in her mouth for oral incubation (Plate 3). Fertilization often takes place inside the female's buccal cavity after the female sucks up the milt as well as the eggs into her mouth for fertilization and incubation.

Temperature and sunlight are the most important factors that influence spawning. Alone or in combination, these factors appear to trigger external impulses that influence fish. Optimal spawning temperatures for Nile tilapia range from 25^{0}C to 30^{0}C, but suboptimal temperatures inhibit the development of gonads. Besides its direct effect on gonadal development, temperature influences reproduction through the metabolic rate, which affects the endocrine process. In tropical regions, spawning can continue year-round, as ripe females school in midwater with non-territorial males and egg-brooding females. About four to seven batches of eggs are spawned in one mating.

Sunlight appears to have a significant role in the reproductive performance of tilapia. Optimal reproductive performance takes place in a normal daylength cycle, which is 12 hours of sunlight and 12 hours of darkness. Generally, high stocking densities slow the reproduction process in tilapia. Nile tilapia stocked in single compartments spawn more often than those stocked in groups. Pheromones from females can attract males. Feeding and feed quality are two other environmental factors that influence tilapia reproductive performance indicators, such as size at first maturity and broodstock productivity. For this, it is important to provide good quality feed, as it often results in larger fish at first maturity and spawning.

2.1.4. Fecundity and egg size

Tilapia has low fecundity and relatively large eggs. Fecundity is the number of mature ova in the ovary, the number of ovulated eggs or the number of eggs deposited during spawning—all of which vary for fish of equal size. Nile tilapia can produce as few as 100 eggs to more than 3000

Plate 3. Mouth incubation of eggs by a female Nile tilapia.

per spawn, with eggs ranging in size from less than 2 mm to larger than 7.9 mm. The volume of eggs ranges from 2.8 mm to 11.1 mm, each with a mean weight of up to 3.7 mg. Farmers can expect approximately 100–500 eggs from every spawning batch. For practical purposes, it is ideal to refer to the fecundity of tilapia as the "number of fry produced per year," considering the environmental variables that affect egg and fry production.

Fecundity increases during the initial period of maturity and growth, but decreases as the fish grow old. The optimal size of female breeders for tilapia seed production is 150–300 g, which produces about 200–500 fry per month. Smaller females produce many more eggs than larger fish with shorter spawning intervals of just over 100 days, while larger fish produce more eggs per clutch than smaller females. Larger eggs contain more yolk and result in larger, stronger and fast-growing fry.

2.1.5. Egg incubation

For tilapia, incubation time is inversely and linearly related to temperature. Time to hatching for Nile tilapia eggs varies from 2 to 3 days at 34^0C to 8 days at 17^0C, while the average duration of the incubation period and parental care is approximately 20 days. The number of days that the eggs take to hatch is calculated as follows:

$$Hatching\ days = (12.8 - 0.32) \times temperature\text{(degrees Celsius)}$$

Water temperature has an important effect on various biological relationships. It affects sex differentiation, sex ratio and morphological development during early larval stages of tilapia, though at increased temperatures slow growth and body deformities are likely to occur. Temperature also affects the sex ratio in tilapia by increasing the proportion of males at higher incubation temperatures of 34^0C–36^0C.

Tilapia eggs pass through four stages before transforming into free-swimming fry (Figure 2). In Stage I, the eggs are light to dark yellow, Stage II they are golden yellow and in Stage III they become golden brown with dots. Stage IV is the hatched yolk sac fry. The fry become free swimming when their yolk sac is absorbed.

2.1.6. Larval development

Larval development involves the functional development of the mouth, 4–5 days after hatching, along with the absorption of yolk and the development of the swim bladder, which helps control buoyancy. Feeding begins between 8 and 10 days after hatching when the larva reaches a size of about 8 mm total length. The females leave the brooding areas when the fry become 9–10 mm total length. The main food for fry are diatoms and some amphipods, insects and copepods.

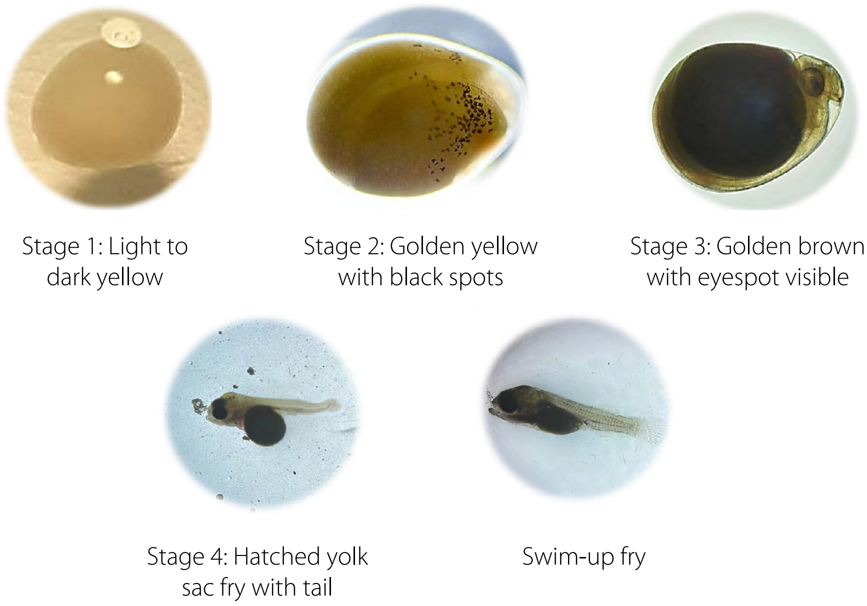


Figure 2. Stages of egg development in Nile tilapia.

In tilapia seed production, there are mainly two types of systems for incubating eggs and rearing larvae. In the natural breeding system, farmers can leave mouthbreeding females in the pond to incubate the eggs and release the free-swimming fry into the pond, where they can collect them for further rearing to fingerlings. In the artificial incubation and hatching system, farmers collect the eggs and yolk sac fry from the mouth of incubating females and incubate the eggs separately in specialized hatchery systems. This system is best suited for large-scale production of good quality tilapia fry.

2.1.7. Exercises

This exercise involves stocking breeders in hapas fixed in a pond and examining the male and female broodstock of Nile tilapia maintained in breeding hapas for the following tasks:

- Identify the distinguishing features of male and female breeders and draw sketches in a record book.
- Dissect the male and female fish and identify the internal organs.
- Observe the mouths of the females, and collect the eggs or yolk sac fry 1 week after stocking them.
- Record the fecundity and different stages of eggs obtained.

2.2. Broodstock management and improvement

Fish broodstock comprises a group of mature individuals maintained for breeding purposes either as a source of replacement or for enhanced fry production destined for grow-out. Good management involves manipulating environmental and genetic conditions around the broodstock to ensure maximum survival and enhanced reproductive performance, including proper gonadal development, high fecundity and high fry survival. Producing Nile tilapia seed sustainably requires careful broodstock selection and management. Important information on broodstock includes stocking density, nutritional management, fecundity, sex ratio and environmental conditions in which the fish are maintained. Considering these factors will help ensure maximum hatchery production efficiency.

2.2.1. Broodstock selection

The first step in broodstock management is stock selection. Ideally, the farm establishes its own broodstock by selecting the best performing female and male fish of known genetic background. It is important to handle the broodstock very delicately, causing the least amount of stress to the fish during their segregation and to select for pairing in breeding ponds. While holding or carrying broodstock fish by hand, wear gloves and cover the eyes of the fish with one hand so that the fish will remain calm. Fish farmers should maintain slightly more stock (25%–50% extra) than the actual quantity planned to breed every year. This will help meet seed production targets and make it easier to select the best pairs from the stock to adapt them to captivity for a reasonable period.

Important considerations for selecting tilapia broodstock include the following:

- Select genetically pure fish, avoiding ones of unknown or doubtful origin.
- Select fish that do not have any physical deformities or injuries, diseases or parasites.
- Select reasonably large fish and avoid ones that are too small, as smaller fish could have a lower reproductive quality.
- Maintain broodstock belonging to different lines in separate holding facilities with no chance of mixing.

Plate 4. Collecting eggs from tilapia broodstock in hapas.

- Avoid broodfish that are too old and have spawned several times, as fecundity drops as fish get older. Cull broodstock older than 1.5 to 2 years.
- Make sure that no fish from the previous breeding cycle remain in the pond when starting a new breeding cycle.
- Take reasonable measures to avoid inbreeding (breeding closely related stocks) by maintaining a large founder population and ensuring that a large proportion of them have a chance to breed.
- Select juveniles for new broodstock from as many parents as possible while selecting for new broodstock.
- Maintain proper records of all the stock held and the breeding trials carried out.
- Prevent the entry of any inferior quality stock (of the same or other inferior tilapia species) to the broodstock pond by filtering incoming water into the ponds efficiently.

2.2.2. Rearing broodstock from fingerlings

To rear fish into broodstock, it is important to stock fingerlings in ponds at lower stocking densities of 1–2 fish/m^2. The fish reach optimal breeding size of 150–250 g in 5–6 months, but proper fertilization of ponds using organic and inorganic manure will help fingerlings grow into broodstock size faster. Organic manure includes chicken manure applied at a dose of 100 kg/ha per month. In addition, farmers can also use inorganic fertilizers like ammonium phosphate at 50 kg/h every month. Commercial pellet feeds containing about 30% crude protein are fed at a rate of 3%–5% of the weight of the fish at least twice daily.

When broodstock reach breeding size, segregate the male and female breeders and hold them separately for conditioning. After conditioning, visual morphological changes will show when females are ready to spawn (Table 1). When the females are ready, introduce them into the hapa with the males for breeding. Each fish can go through at least 10–15 spawning cycles before they need to be culled.

Synchronicity in spawning lets many females spawn at about the same time so that several batches of similar-sized fingerlings are available for grow-out. For synchronous spawning, it is important to select males and females that are almost the same size when the females are ready to spawn. If the males are significantly larger (30%–40%) than the females, they will become very aggressive, frequently nipping at them, which can even lead to female mortality.

Category	Days to spawning	Description	Timing of fry collection from open ponds/hapas
Ready to spawn (RS)	3–7	Pink to red and protruding genital papilla, fully opened genital pore, distended abdomen	10–14 days
Swollen (S)	5–10	Pink to yellow genital papilla, slightly opened genital pore, slightly distended abdomen	12–16 days
Not ready to spawn (NRS)	21–30	White to clear and flat genital papilla, normal to swollen abdomen	Further conditioning required
Already spawned (AS)	15–30	Red genital papilla, shrunken to compressed abdomen	Further conditioning required
Immature	No imminent spawning	Papilla very small with no sign of maturity	Further rearing required

Source: adapted from Nandlal and Pickering (2004).

Table 1. Maturity stages of Nile tilapia.

2.2.3. Stocking density and sex ratio

It is important to maintain the correct stocking density and sex ratio of broodstock in ponds or hapas for efficient hatchery production. Stocking densities often depend on the culture system, water quality, and broodstock size and condition. High or low stocking densities will make seed production less efficient. Higher densities result in increased aggression and fighting among males, drastically reducing courtship, fertilization, incubation and thus seed production. The optimal stocking density for better seed production and spawning synchrony is 4–6 fish/m^2.

Optimal sex ratio is another important consideration to maximize seed production (Figure 3). A ratio of one male for every two females is optimal for synchronous spawning. Ideally, the hatchery operator makes their own assessment of the best sex ratio based on the farming systems and broodstock conditions.

2.2.4. Spawning interval

Tilapia can spawn several times a year in suitable environmental and culture conditions. Fish size, age, stocking density, sex ratio, nutrition status, culture conditions and environmental factors all influence spawning intervals. Removing the eggs and fry from the female's mouth at 5- to 7-day intervals accelerates egg development, shortens the interspawning interval and enhances daily seed production per kilogram of each female compared to seeds produced from natural incubation. Leaving females to undertake parental care in ponds can significantly reduce their reproductive potential and increase the interspawning interval. This is more evident because females do not eat while incubating their eggs, which prolongs the time for later egg development in starving females.

2.2.5. Conditioning and broodstock exchange

Conditioning refers to the maintenance of Nile tilapia broodstock at moderate densities for a short period, allowing them to prepare for breeding or for post-spawning to rest and recuperate from the stressful phase of breeding. Conditioning males or females, or both, and feeding them a high quality diet can significantly enhance the reproductive efficiency of broodstock. Exchanging male and female tilapia for spawning after a period of conditioning is a useful way to improve seed production, spawning synchrony and spawning frequency.

However, prolonged conditioning can also have negative impacts. Longer durations of conditioning and more frequent disturbance might adversely affect broodstock quality,

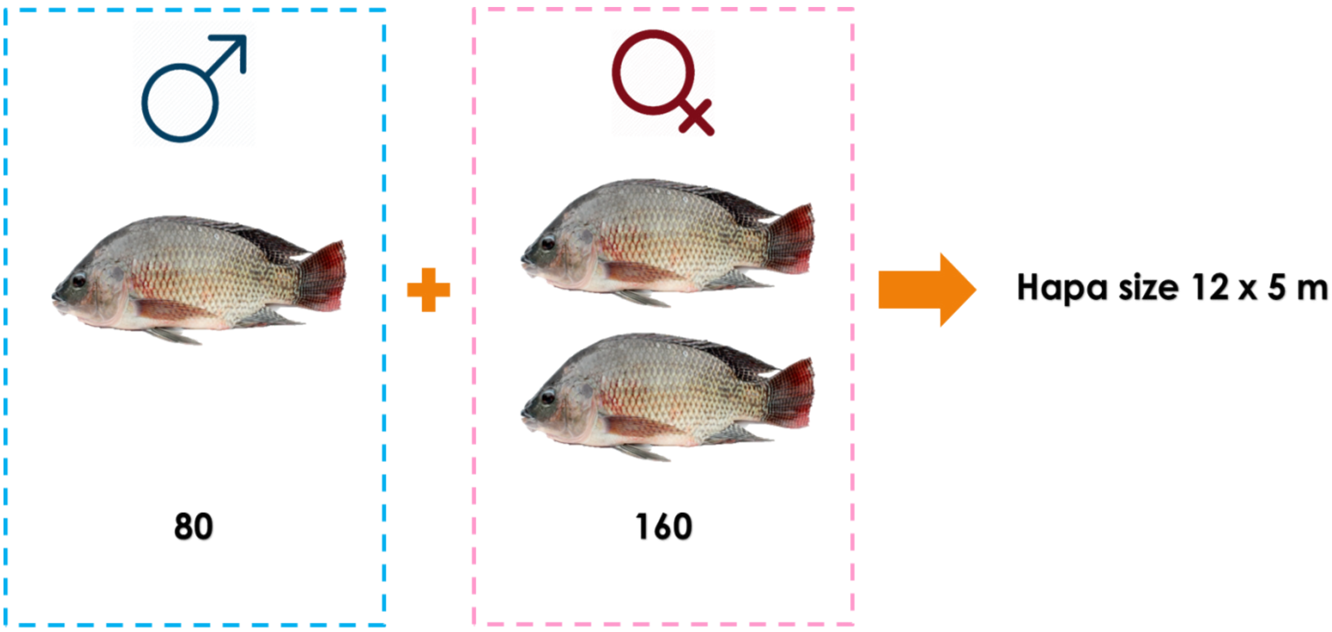


Figure 3. Recommended sex ratio for tilapia broodstock in breeder hapas.

particularly in the case of males with lower sperm quality. Resorption of ripe eggs can also occur if the female does not spawn in about a week, so the recommended amount of rest is short intervals of 5–15 days. Replacing old broodstock with 1-year-old fish also improves egg production and overall juvenile production in tilapia.

2.2.6. Broodstock nutrition

The performance and reproductive efficiency of tilapia broodstock depends greatly on the quality of their diet. Although eggs can absorb some nutrients directly from the water, the major source of nutrition for developing embryos is the egg yolk. The exogenous nutrition from supplementary feed to broodfish provides the essential nutrients required for gonadal development in females and the quality of the seed produced. As such, supplementing nutrition from a high quality diet for broodstock is essential to produce the best quality fingerlings for grow-out.

2.2.6.1. Protein requirements

Dietary protein significantly affects the reproductive performance of tilapia broodstock, particularly their size at first spawning, fecundity, spawning frequency and egg hatchability. Broodstock need relatively higher levels of protein in their diets, generally in the range of 30%–45% for Nile tilapia.

2.2.6.2. Feed management

Proper feed management of tilapia broodstock is essential to improve its reproductive performance, hatchery efficiency and profitability. Feeding Nile tilapia a diet containing optimal nutrients, including protein and lipids, significantly influences reproduction. It might not be economical to feed tilapia abundantly during egg incubation, as the mouthbreeding fish do not feed during this period. So the recommended practice is to increase the feeding rate immediately after harvesting the eggs or fry, followed by a lower

Plate 5. Feed formulated for tilapia in Thailand.

feeding rate or no feeding at all for fish raised in green water pond systems. Decreasing their feed could also stimulate reproduction in tilapia. Although restricting food can slow growth and reduce total fecundity, it tends to increase spawning frequency, the total number of eggs over a discrete period, and the amount of energy allocated to egg production.

Feeding frequency can also affect fish reproduction. It could be better to feed broodstock twice a day, as a greater feeding frequency might not be cost-effective. Feeding tilapia broodstock high-energy diets at low feeding rates might also be better than giving them larger amounts of a low-energy diet. As such, it is important to consider feed quality, feeding schedules and feed costs to achieve optimal reproductive performance. This also gives hatchery operators an option in feed management for their tilapia broodstock.

2.2.7. Environmental factors in broodstock management

Several environmental factors play a key role in enhancing the genetic and reproductive potential of Nile tilapia for improved seed production. It is important to maintain optimal water quality parameters in broodstock ponds for successful reproduction. These include pH, DO, temperature, salinity, hardness, water level and water exchange.

2.2.7.1. Dissolved oxygen

Nile tilapia has an inherent ability to survive in low DO conditions. However, oxygen levels as low as less than 0.5 mg/L, often encountered in early morning hours in outdoor ponds, can lower ovarian growth, courtship, seed production and mouthbreeding efficiency in females. Low DO also makes fish eat less and causes behavioral and morphological changes, such as the concentration of melanin pigments in the skin. These stressful conditions lead to disease, inhibit reproduction and spawning activities, and decrease fecundity and hatchability.

2.2.7.2. Temperature

Tilapia are eurythermal fish and can tolerate a wide range of temperatures, ranging from 8°C to over 40°C. Most tilapia species can reproduce successfully at about 22°C. Tilapia reproduction generally slows at 21°C–24°C, while the optimal temperature for reproduction ranges from 25°C to 30°C. At temperatures higher than 35°C, reproductive performance is very poor, so it is important to design and construct spawning units in such a way as to protect the facility from severe weather changes. Using a greenhouse for tanks or ponds makes it easier to maintain a uniform temperature and year-round production of fingerlings.

2.2.7.3. Salinity

Salinity is an important parameter for reproduction among tilapia. Although tilapia are generally salt-tolerant, Nile tilapia can tolerate only a narrow range of salinity. Farmed tilapia have been tested in a wide range of salinity levels—in freshwater, brackish water and seawater. The salinity-tolerant species of tilapia reproduce more efficiently in low and moderate salinity than at high salinity. At high salinities, resorption of eggs takes place in tilapia, which reduces reproductive success. The aggressive behavior of dominant males also subsides at high salinities. Maintaining male broodfish in saline water at times of lower seed demand could be a good approach to overcome their aggression.

2.2.7.4. Sunlight and light intensity

There are many studies on the effect of sunlight and lunar periodicity on reproduction in tilapia. Sunlight plays a significant role in fish growth, metabolism and reproduction through the secretion of melatonin, which is a key hormone for regulating endogenous rhythms. The photoreceptor cells in both the eye and pineal organ of fish appear to play a role in proper responses to light signals, though this depends on the species and developmental stage.

2.2.7.5. Water level and exchange

The water level in a pond appears to have a major effect in increasing the reproductive activity of tilapia females, resulting in smaller males being recruited into the breeding population. Partial water change at frequent intervals could also improve seed output and spawning synchrony. Some studies suggest that tilapia mucus contains a hormone-like substance that inhibits reproduction, especially at high densities. Replacing pond water regularly could remove this substance and improve reproduction efficiency. Water exchange also improves DO and flushes out harmful substances, such as undigested food, feces and other metabolites, like ammonia, nitrite and nitrates. Seed output from ponds filled with new water is higher than from ponds with water used for long periods. This suggests that hatchery operators should change their pond water frequently, either partially or completely; however, the exchange rate and frequency depend on water availability and cost, as well as the type of culture system.

2.2.7.6. Broodstock maintenance in tanks

Concrete tanks are best for intensive seed production systems for tilapia. Although tanks are expensive to construct, they have several advantages over earthen ponds, and are more suitable in areas with limited freshwater available or where the soil is too sandy to build earthen ponds. Although the tank volume limits the number of fish that farmers can stock, tanks are amenable to better water management, by filtration or flow-through arrangement. They are also easy to harvest, as they give a greater yield of fry per unit area compared to earthen ponds. Factors affecting spawning efficiency include tank size, shape, color, water depth and the material used for construction. Deep tanks (1–2 m) are better for optimal reproductive performance of Nile tilapia. Artificial spawning shelters provided in tanks improve seed production by increasing courtship behavior and spawning intensity, as well as synchronous spawning of the fish. In addition, a tank often needs aeration for the high densities of fry that it supports.

It is necessary to maintain enough tanks to hold male and female broodstock 10–12 days separately for conditioning before transferring them to breeding tanks. The conditioning and production tanks can be over 30 m^3, with a water depth of 80–90 cm. Select females weighing 150–300 g that are ready to spawn and transfer them to the breeding tanks along with male broodstock of the same weight at a stocking density of 7–14 breeders/m^2 and at a male to female ratio of 1:2 or 1:3. Collect fry 10–14 days after stocking breeders and then transfer them to nursery tanks or hapas set in nursery ponds for further rearing.

2.3. Exercises

- Discuss the important considerations for selecting Nile tilapia broodstock.
- Set up a short trial testing different sex ratios of fish in breeder hapas and record the behavioral pattern. Discuss the observations in the class.

Plate 6. Concrete tanks used for tilapia broodstock.

3. Nile tilapia hatchery systems

Recent interest in tilapia farming on a global scale, coupled with the rapid spread of hatchery technology, has greatly helped expand tilapia farming into many parts of the Asia-Pacific, Africa and the Americas, though at various scales. Tilapia seed production systems are fairly well established in many Asian countries and are getting more popular in Africa. Intensities of production and the seed production methods vary among these regions, but the production efficiency is gradually increasing.

Based on the intensity of operations, there are two types of systems for tilapia seed production: semi-intensive and intensive. The semi-intensive method uses a medium level of technology, including earthen ponds for breeding, fry and fingerling production, and often for producing mixed sex fingerlings (depending on natural food for rearing fry). In this system, hatchery operators place male and female broodstock into a suitably prepared pond for breeding, and transfer the resulting fry to rearing ponds where they grow into fingerlings. They then remove the broodstock from the breeding pond and return them to the broodstock conditioning ponds.

The intensive method of tilapia seed production mainly uses a high level of technology to produce both mixed-sex and all-male fingerlings. Operators carry out the operation in a specially constructed hatchery for breeding, fry production and fingerling production. Concrete tanks are preferred for space requirements and management considerations, and continuous aeration is required in both ponds and tanks at intensive stocking densities.

Stocking densities are higher in intensive systems than semi-intensive. Fry require nutritionally complete feeds because there is little or no dependence on natural food for early rearing, and there is usually no fertilization of the tanks and ponds. Frequent water exchange is also required. Commercial grow-out operations usually use this system to produce all-male fry.

3.1. Seed production in earthen ponds

The easiest way to spawn tilapia is in earthen ponds, and this method is widely used in many countries, including Africa. Although tilapia can spawn in a wide range of environmental conditions,

Plate 7. Nile tilapia spawning nests (round cones) in a harvested breeding pond in Uganda.

there are important parameters affecting fry harvest, such as the size, shape and depth of the pond. Rearing in earthen ponds is often suitable for producing mixed-sex tilapia, monosex hybrids or first-feeding of fry for sex reversal.

After stocking breeders in the breeding pond, hatchery operators collect the fry at different intervals ranging from 6 to 60 days. In the breeding ponds, the first fry appear around 10–14 days after stocking the breeders. Operators then harvest the fry completely by draining the pond or partially by using dip nets, seines and traps. The fry are easily visible during the early morning and early evening, when they swim in clusters, so they can be caught using a hand net with a very fine mesh size, and then counted and transferred to a suitably prepared fingerling pond.

Major challenges in pond production of fry include reducing the spawning frequency, cannibalism among the fry, and predation of small fry by other bigger fish. To overcome these challenges, hatchery operators must use proper pond management to optimize fertilization of the water, decrease sediments, prevent wild predatory fish from entering the pond, and harvest the fry regularly. Harvest fry at shorter intervals and grade them to remove large individuals, as this results in higher production of uniform-sized fry. The stocking rate for fry in a fingerling pond is 10 fish/m^2 of pond surface area. Feed the fry supplemental feed containing 28% to 30% protein about 7 days after stocking.

3.2. Seed production in hapas

A hapa is a fine-meshed net cage set up in a tank or earthen pond, like an inverted mosquito net, for stocking fish or small fry. It is made of polythene netting, while the joints are sewn with nylon thread with double-stitched seams to prevent splitting. The four corners of the top and bottom of the hapa can be tied to bamboo or wooden poles that are driven into the pond bottom to fix them in place.

Hapas have long been used as an excellent hatchery system for tilapia, especially in the developing world. They are easy and inexpensive to construct and set up, and they make management and harvesting seed easier, allowing greater and more consistent yield of uniform-sized fry per unit area than from the pond method.

Hatchery operators can use hapas in conjunction with ponds by suspending them in fertilized earthen ponds or in concrete tanks with a clear water supply. Using hapas also allows operators to avoid draining ponds completely to harvest fry so that fry production can continue.

Hapas work well in both semi-intensive production of fry, by collecting the fry from breeder tanks at regular intervals, and in intensive seed production similar to that in tanks. When hapas are suspended in ponds, tilapia spawning depends on broodstock density and sex ratio, broodstock conditioning and exchange, and other environmental factors, like wind, water turbidity and varying water levels. Sometimes, operators use a double hapa hatchery. Operators stock the broodfish in the inner hapa with a larger mesh size, allowing the newly hatched swim-up fry to freely come to the outer hapa or to the surrounding water tanks or ponds. This system provides the least disturbance to spawning fish and reduces cannibalism among the fry.

Depending on their use, hatcheries choose hapas of different sizes, designs and meshes. Smaller meshes (1–2 mm) are best for fry and holding fingerlings, while the larger ones (B-net; 5–6 mm) are good for holding bigger fish, such as broodstock for conditioning. A standard size for a hapa is 1 x 1 x 1 m, and a hapa measuring 3 x 3 x 1.5 m is suitable for fry and fingerling production. The sides of the hapa, when installed, should extend about 40 cm above the surface of the water to prevent fish from jumping out.

Hapas are the most economical means of producing tilapia seed compared to using ponds or tanks. However, they need regular cleaning to keep them free of fouling and to avoid clogging that will deteriorate the water quality inside. Hapas are also affected by strong winds and storms and can become soft targets for poaching.

The standard protocols for seed production in hapas are similar to that of other methods. When hapas are fixed in ponds, hatchery operators have to follow standard preparation procedures to get the pond ready for breeding tilapia. After draining the water, check the pH and apply lime at a rate of 1–3 t/ha, depending on the acidity and texture of the soil. If needed, apply organic chicken at 200–300 kg/ha to stimulate plankton growth in the pond. Allow filtered water into the pond and fill it up to at least 1 m. Fix the hapa in the pond by tying the corners to long bamboo or wooden poles driven into the pond bottom. Be sure to give adequate space between each hapa to allow sufficient water movement for better water quality. Clean the mesh regularly to maintain good water quality inside the hapas.

After stocking the broodstock at the appropriate stocking density (four to five broodstock per square meter) and sex ratio of one male for every two females, feed the fish in the hapa at 3%–5% of their weight. If following a hapa-based hatchery system, it is possible to harvest the fry partially from the broodstock hapa every 2 weeks, and then transfer them to the hapas for sex-reversal set in a different pond. It is best to produce fry in indoor incubation units if such facilities are available. Wait 5–7 days after stocking in breeding hapas, then collect the eggs from the female's mouth and transfer them to the hatchery for incubation. Section 3.3 contains the details of the indoor hatchery system for Nile tilapia. After about 10–12 successive spawnings, and when the yield of fry starts to drop, transfer the breeders to the conditioning hapas to get them ready for subsequent breeding.

In Africa, most farms collect wild broodfish from lakes with an initial average size of about 250 g, while some farms grow broodfish from seeds collected from other hatcheries. Perhaps the quality of broodstock collected from lakes is questionable. Therefore, hatchery operators must identify good quality broodfish and grow their offspring as the next batch of brooders on the farm to avoid collecting broodstock repeatedly from nature. This requires developing indoor hatchery facilities using incubation jars in African farms.

3.2.1. Exercises

- Prepare a breeder hapa using a blue net with an appropriate mesh size.
- Fix the breeder hapa in the pond and select tilapia broodstock for stocking.
- Prepare another concrete or fiberglass tank of about the same size, and stock the same density and ratio of breeders.
- Observe the behavior of breeders in both systems, and record any details.

Plate 8. Hapas fixed in a pond for rearing fry for sex reversal and for nursing before grow-out.

3.3. Indoor jar hatchery systems for seed production

Collecting fry from mouthbrooding female breeders in ponds or tanks is a less productive method of producing tilapia seed in view of its known disadvantages. However, incubating tilapia eggs naturally is still a common method of fry production in countries or regions with limited resources for advanced hatchery production. Incubating eggs artificially is a more popular method for producing good quality fry on a mass scale.

There are several benefits of artificial incubation: greater fecundity and production of uniform-sized fry, improved spawning synchrony, more frequent spawning and reduction of interspawning interval, reduction of hatching time, and elimination of cannibalism among fry. This method also allows for experiments on tilapia genetics and reproduction. Specialized incubation units are used to artificially incubate and hatch tilapia eggs, and operators can design and develop these systems conveniently and at lower costs compared to modern hatchery systems of other freshwater fish.

3.3.1. Incubation units for Nile tilapia eggs

Simple, inexpensive and easy-to-make units are often used to artificially incubate tilapia eggs. These range from soft drink bottles and round-bottom containers, such as carboys and plastic containers, to more advanced conical upwelling jars. In a commercial hatchery, operators collect the fertilized eggs or yolk sac fry from the mouths of females and incubate them in a series of round-bottom plastic jars and flat trays connected to a recirculating system supplied with freshwater from an overhead tank. They then transfer the hatched larvae into separate trays until their yolk sacs are resorbed and they become free swimming, at which time the larvae start feeding.

The fertilized eggs pass through the embryonic and larval stages in 10–12 days to complete one development cycle at an optimal water temperature between 27⁰C and 30⁰C. This creates at least three cycles of first feeding fry every month in this hatchery system. The factors affecting the efficiency of the incubator systems include the developmental stages of the eggs, water quality and flow, and the type, size and

Plate 9. Incubation jar for tilapia eggs.

shape of the incubators. For example, round-bottomed incubators have better survival rates of fry (85%) compared to conical-shaped containers (60%), but the latter have shorter hatching times. The hatching time and survival rate of fry are also significantly better in downwelling round-bottomed jars than upwelling conical containers.

The following are important considerations when setting up an incubator system for Nile tilapia eggs with 30 hatching tray units:

- Hatching jar volume: 20 L
- Estimated number of eggs in each jar: 25,000
- Water flow rate: 4 L per minute
- Hatching time: 65–72 hours
- Estimated number of hatched fry per tray: 23,000
- Estimated total first feeding fry per batch: 690,000 (23,000 x 30 trays)
- Estimated total first feeding fry production per month: approximately 2 million (690,000 x 3 cycles).

3.3.2. Hatching eggs and yolk sac resorption

The fertilized eggs start hatching about 60 hours after being loaded into the incubation jar, while the resorption of yolk sac is completed in about 6 days. Various factors affect the hatching time, such as the developmental stage of the egg, water temperature, water flow rate and broodstock nutrition. The optimal temperature for proper egg hatching and larval development lies between 27^{0}C and 32^{0}C. Lower (below 22^{0}C) or higher (33^{0}C–35^{0}C) temperatures drastically reduce reproductive efficiency, egg quality and hatchability in Nile tilapia, whereas increasing pond depth, using deeper hapas, and shading all enhance seed production by improving the pond temperature.

The water flow rate in jars appears to play a major role in determining hatchability and larval growth in Nile tilapia. A rate of 4 L per minute in a 20 L jar is optimal for producing tilapia seed. Broodstock nutrition also affects hatching and larval development. Higher protein levels (35%–40%) in the diets of broodstock favor faster hatching (3–4 days) while lower protein levels of 25% result in

Plate 10. Egg hatching trays for tilapia (left) and free-swimming fry after yolk sac resorption (right).

hatching in 4–6 days. The optimal stocking density for broodstock is three females per square meter, and the best daily feeding rate is 1% of weight.

3.3.3. Larval development

Several factors such as stocking density, food, feeding, sunlight, water flow and water replacement all affect larval development and growth in incubation systems in a tilapia hatchery. A stocking density of five fry per liter appears to be optimum for hatchery-reared Nile tilapia fry. High stocking densities can cause excessive cannibalism and mortalities, as well as deteriorating water quality and stress to the fry. Because cannibalism is the major cause of fry mortalities in hatcheries, it is recommended to adopt size-grading fry in nursery units to separate large fry from the stock and to use uniform broodstock of approximately the same age and size to produce uniform-sized eggs and fry.

Larval nutrition is also important to ensure high survival and growth of tilapia fry. The optimal crude protein requirement in larval feeds of Nile tilapia ranges from 35% to 45%, though it also depends on the protein source and culture system. The optimal daily feeding rate of fry appears to range between 30% and 45% of weight. Food color also appears to have some effect on acceptance among tilapia fry, with fry preferring darker (red and blue) rather than lighter feed. The larval stages of tilapia are more sensitive to sunlight than fingerlings or juvenile stages. Fish fry subjected to longer (18 and 24 hours) sunlight grew better than those exposed to intermediate or shorter (6 or 12 hours) sunlight.

3.3.4. Exercises

- Harvest the eggs from the mouths of females in the breeding hapas.
- Set up and monitor egg incubation and larval rearing (jar and tray system).
- Calculate the fertilization rate, hatching rate and larval survival rate.

3.4. Seed production in tanks

Apart from being used for broodstock, concrete tanks are also used to rear fry and fingerlings. They are ideal for intensive tilapia seed production. Tanks are expensive to build, but they are better than earthen ponds in places with limited freshwater or with sandy soil. Tanks make it easier for hatchery operators to manage water, using a filtration or flow-through system, and yield more fry per unit area than earthen ponds. Because of the high fry densities, tanks require aeration. In concrete tanks, operators can collect fry 10–14 days after stocking breeders and transfer them to nursery tanks or hapas set in nursery ponds for further rearing.

The size of fry and nursery tanks can range from less than 1 m^3 to 10 m^3. To collect the eggs from incubating females, use fine-meshed scoop nets, beginning 5–7 days after stocking breeders in the tank. Place the eggs gently in small basins with water, and then count and transfer them to the hatchery for incubation. Depending on the availability, operators can continue to collect eggs from a set of breeders in a tank for as long as 10–12 weeks. They can then transfer breeders back into the conditioning tanks once egg production declines.

3.5. Preparing MT feeds and nursing fry for sex reversal

There is a remarkable difference in the growth rate between male and female tilapia, with males growing almost 50% faster than females under the same environmental conditions. This disparity often affects the success of tilapia farming when carried out in a mixed-sex population of males and females together. Furthermore, in a mixed-sex culture system, the tendency for reproduction is high, which consumes a lot of energy at the cost

Plate 11. Concrete tanks used for rearing tilapia fry in Thailand.

of growth and biomass. Unwanted reproduction in culture ponds also leads to excessive production of fry within the pond, which often results in stunted growth and water quality issues. Farming monosex tilapia, particularly all-male culture systems, has become popular to take advantage of the superior growth performance of males. By growing all-male fry, the energy for reproductive activities, such as nest building, courtship and guarding, are saved and potentially oriented toward attaining more growth and size.

There are several methods of producing monosex fry of Nile tilapia, including manual segregation of sexes, hormonal sex reversal and several other techniques, such as genetic manipulation. Among these, manual sexing is easy for hatchery operators to do. In the past, examining the sexually dimorphic characters between male and female fish was the most common method. However, this is extremely labor-intensive. It causes significant stress to the fish and often leads to inaccurate results because of human error. Lately, using hormones that can convert females into phenotypic males has become the most popular method for sex reversal and production of all-male tilapia fry. Section 3.5.1 highlights the salient features of monosex tilapia production, particularly the preparation of hormone feed, the feeding protocol and success rates of all-male production.

3.5.1. Preparation of sex reversal feed

The male hormone 17α-methyltestosterone (MT) is the most common hormone used for successful production of all-male tilapia fry. There are several ways to administer hormones to fish, including dietary supplementation, egg immersion and systemic transfer by injections or silastic implants. Of these techniques, adding a hormone into feed is safe and successful. At an early stage of development, the fish ingest the hormone at the desired concentrations through the feed they are given, allowing sexual differentiation to bias more toward males rather than females. In Nile tilapia, adding 60 mg/kg of feed is an optimal dose for feeding tilapia fry to attain nearly 100% sex reversal to males. The hormone-incorporated feed is given to the early developing larvae 7–21 days after hatching to get the most desired results. These fry are then further fed with normal fry feed for one more month until they reach the fingerling stage for stocking in grow-out culture systems.

The protocol for preparing hormone and hormone-incorporated feed is as follows:

Materials required:

- synthetic hormone, 17α-MT
- ethyl alcohol
- magnetic stirrer
- pelleted shrimp starter feed or fishmeal of good quality
- mixer for feed
- glassware and plasticware.

Preparing stock solution:

- Dissolve 0.5 g (500 mg) of 17α-MT hormone in 1 L of ethyl alcohol using a magnetic stirrer. This serves as a stock solution containing the hormone at a concentration of 0.5 mg/ml of ethanol.
- Store the stock solution in a refrigerator at 4^{0}C for up to 6 months.
- Use 60 mg of hormone for every 1 kg feed for the fry. Add 2 g/kg of vitamins and 1 g/kg of minerals to the feed and mix well.
- Use 120 ml of stock solution per kilogram of feed or fishmeal to deliver the required dose of 60 mg/kg of feed, with the stock solution containing 0.5 mg of hormone per milliliter of alcohol.
- Add another 120 ml of fresh alcohol per kilogram of fishmeal when preparing the feed for optimal mixing of feed with the hormone.
- Dry the prepared hormone feed under shade and store in a refrigerator at 4°C.

Preparing 10 kg of MT feed:

- Prepare the stock solution by mixing 5 g of 17α-MT hormone in 1 L of ethyl alcohol using a magnetic stirrer.
- Add 9 L of ethanol to make up the volume to 10 L. Weigh 10 kg of feed using either high quality fishmeal or a shrimp starter diet. Add 20 g/kg of vitamins and 10 g/kg of minerals to the feed and mix well.
- Use 1200 ml of the stock solution for 10 kg of feed.
- Churn the feed well in a mixer and gradually add 600 ml of stock solution first and then another 600 ml of fresh alcohol to mix it properly.
- Repeat this mixing with another 600 ml of the stock solution and alcohol.

- After mixing the feed for about 15–20 minutes, collect and spread the feed-hormone mixture under shade and dry it for about 1 hour so that the alcohol evaporates. Do not dry it under intense sunlight, as this will degrade the quality of the hormone.
- Pack the dried feed in a plastic bag or keep it in an airtight container and store it at room temperature, or at 4°C–7°C.

3.5.2. Feeding hormone feed to early developing fry

The recommended practice for sex reversal of newly hatched fry is to rear them in nursery hapas set in earthen ponds and feed them hormone incorporated feed. A common size for a rectangular nursery pond is 0.4 ha with a depth of 1.5–2 m and both water intake and drainage. To fix nursery hapas in place, tie them to bamboo or wooden poles using nylon thread, the same way as breeding hapas are set. Doing regular water exchange and monitoring the required parameters will maintain water quality in the pond. Maintaining appropriate water quality, particularly the temperature (29ºC–32ºC) is critical to the success of sex reversal in tilapia fry. To maximize fry survival, it is important to cover the pond completely with net shading to protect them from birds and other predators. The regular protocol for feeding hormone-incorporated feed to fry for sex reversal is shown in Table 2.

Week	% of feeding
1	30% of weight of fish
2	20% of weight of fish
3	15% of weight of fish

Table 2. Daily feeding protocol for tilapia fry for sex reversal using hormone-incorporated feed.

As an example, the parameters for producing 2 million sex-reversed fry monthly are as follows:

- Size of hapa: 8 x 2.5 x 0.75 m
- Number of hapas set up: 25
- Stocking density of fry in each hapa: 100,000
- Approximate number of total stocked fry: 2.5 million
- Daily feeding rate: 15%–30% of estimated weight
- Feeding frequency: 5 times daily
- Duration of feeding hormone mixed feeds: 21 days
- Monosex all-male fry production: approximately 2 million per month.

3.5.3. Handling fry

For maximum production of good quality tilapia fry, it is important to handle them in a stress-free manner. Avoid handling fry around noon under

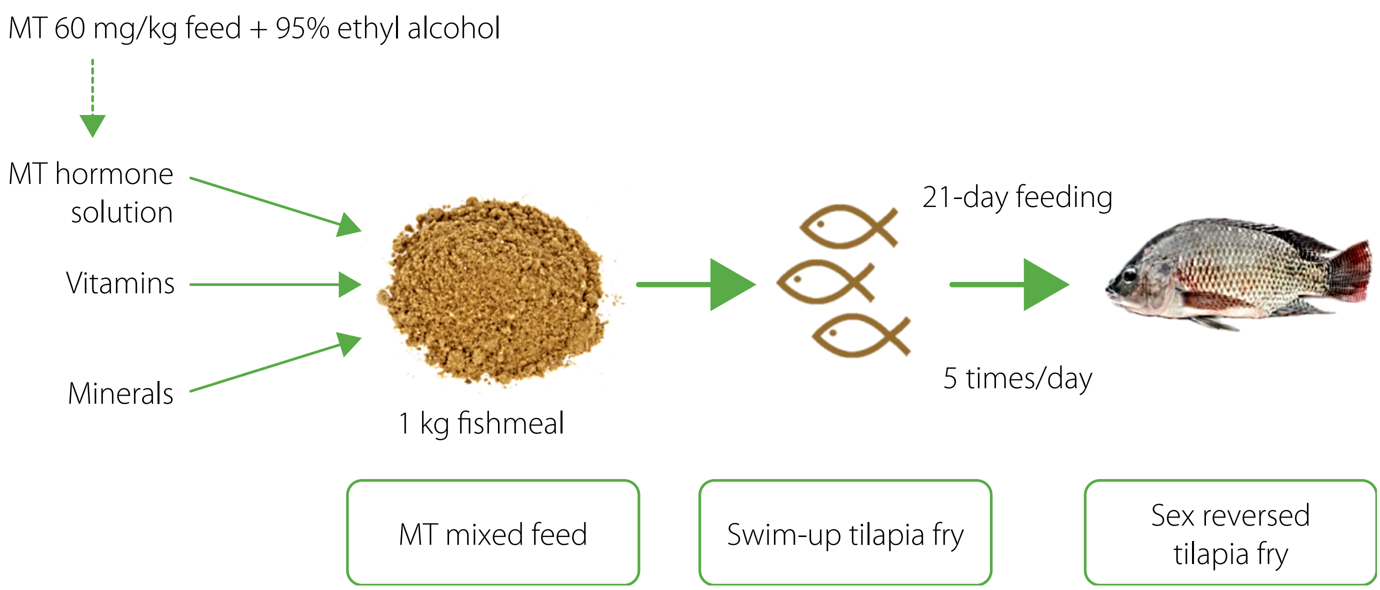


Figure 4. Feeding hormone feed for sex reversal of tilapia fry.

intense sunlight, and as much as possible limit handling to mornings and evenings, mostly under shade. Never keep them in extremely crowded conditions, concentrate them in small containers or put them at the bottom of hapas or tanks with little water. If the fry have to be held in crowded conditions (no more than 200 per liter), always provide adequate aeration or place them in a clean, flow-through water system to avoid any damage or mortalities. If the fish are gasping for air at the water surface, this is a sign that DO levels are too low. When this happens, aerate the water immediately or exchange it with clean and oxygenated water. Ensure the netting used for handling fish, such as for hand nets, is made of a soft material and an appropriate mesh size that will not injure the fry. A slightly bigger mesh size than required will trap the fry by their gills, causing permanent injury. Avoid panicking the fish with any sudden movements that startle them or dropping them on the ground.

Nurse the sex reversed fry in well-prepared nursery ponds or in hapas set in earthen ponds to grow them into fingerlings before stocking them in grow-out facilities. Follow standard protocols for preparing and managing the ponds and hapas to produce good quality Nile tilapia fingerlings that are suitable for further grow-out.

3.5.4. Pond preparation in nursery

Drying the pond properly will ensure that the organic matter in the soil gets oxidized and increases the amount of nutrients available in the pond bottom. Drying also kills most of the predators and pests and removes any disease-causing pathogens. However, drying ponds in areas with acid sulfate soils requires caution. Filter the water intake with an appropriate mesh size (preferably 150 µ) to avoid predatory and weed fish from entering the pond. Small ponds from 400 to 100 m^2 are suitable for nursing tilapia fry. Protecting them from birds is also necessary to the survival of the stock. It is possible to adopt standard protocols for pond preparation and management for nursery ponds as well, as explained in Section 2.2.

3.5.5. Testing the success rate of sex reversal in Nile tilapia

After sex reversal of tilapia fry, it may be necessary to determine the sex of juveniles grown in grow-out ponds to evaluate the success rate. Although it is easier to determine the sex of larger fish, it is difficult to do so with juveniles or other smaller fish before they reach maturity because there is no externally dimorphic character to distinguish males from females. In tilapia, it is possible to identify the sexes after they reach 20–30 g in size by visually examining external sexual characteristics, like the urogenital papilla. The acetocarmine squash method is widely used for juvenile fish when no phenotypic identification of sex is possible, as in tilapia, to evaluate the success rate of sex reversal at an early stage of production.

3.5.6. Acetocarmine squash preparation

This method works equally well for juveniles when their gonads are immature and for mature individuals during seasons when their gonads have regressed, whether fresh or preserved. To prepare the acetocarmine stain, add 0.5 g of the granular stain to 100 ml of 45% acetic acid and then boil for 2–4 minutes. When cooled, use paper to filter the solution.

Take a small random sample of the 30–50 juveniles for examination. Kill the fish and dissect them using sharp pointed surgical scissors, with the help of a dissecting microscope. The gonad will look thread-like, lying along the anterodorsal cavity. Using fine forceps, remove a portion of the gonadal tissue and place it on a glass slide. Add a few drops of acetocarmine stain and then lightly squash the tissue with a cover slip. The gonadal tissue will absorb the acetocarmine. Next, examine the gonads under the microscope using magnifications of 25 to 100x. The male gonad is composed of fine granular like structure of spermatogonia, and the female is characterized with the structure of circular oogonia.

3.5.7. Exercises

- Discuss the key steps in the sex reversal process for all-male production of Nile tilapia.
- Prepare and feed the fry with MT feed using standard protocols.
- Visit an operating tilapia hatchery and discuss the seed production process and various components of the hatchery.
- Conduct a comparison of manual segregation and sex determination using the squash technique.

4. Nile tilapia grow-out systems

4.1. Principles of Nile tilapia grow-out aquaculture

There are six interrelated aspects to consider during the planning stage of grow-out culture (Figures 4 and 5):

1. acquisition of high quality seed
2. water quality and waste management
3. health management and biosecurity
4. stock management and animal welfare
5. nutritional requirements, feed manufacture, storage and feeding
6. harvesting and marketing.

4.1.1. High quality healthy seed

This is one of the most important parameters for successful grow-out culture. Seed should ensure both high growth rate and survival that lead to the highest possible yield at harvest. Seed quality also determines culture duration, as fast growing seed reach marketable size quicker than slow growing seed.

4.1.2. Water quality

If the temperature and DO are not in the optimal range, fish will not grow at their maximum rate because they are unable to use the feed efficiently. It is not possible to manipulate the temperature in grow-out systems, but doing so for all other parameters such as DO, ammonia and nitrite management is essential for tilapia culture (Section 2.5). Nile tilapia grows best in water with 0–10 ppt salinity.

4.1.3. Nutrition and feeds

Either on-farm produced or commercially purchased feeds should satisfy the nutritional requirements of fish. Section 2.4 describes how to select feeds and feeding regimens.

4.1.4. Health management and biosecurity

Nile tilapia is relatively resistant to disease. However, bacterial and viral disease incidents are common during the cold and/or hot seasons. Disease occurs when animals are stressed either because the water quality parameters

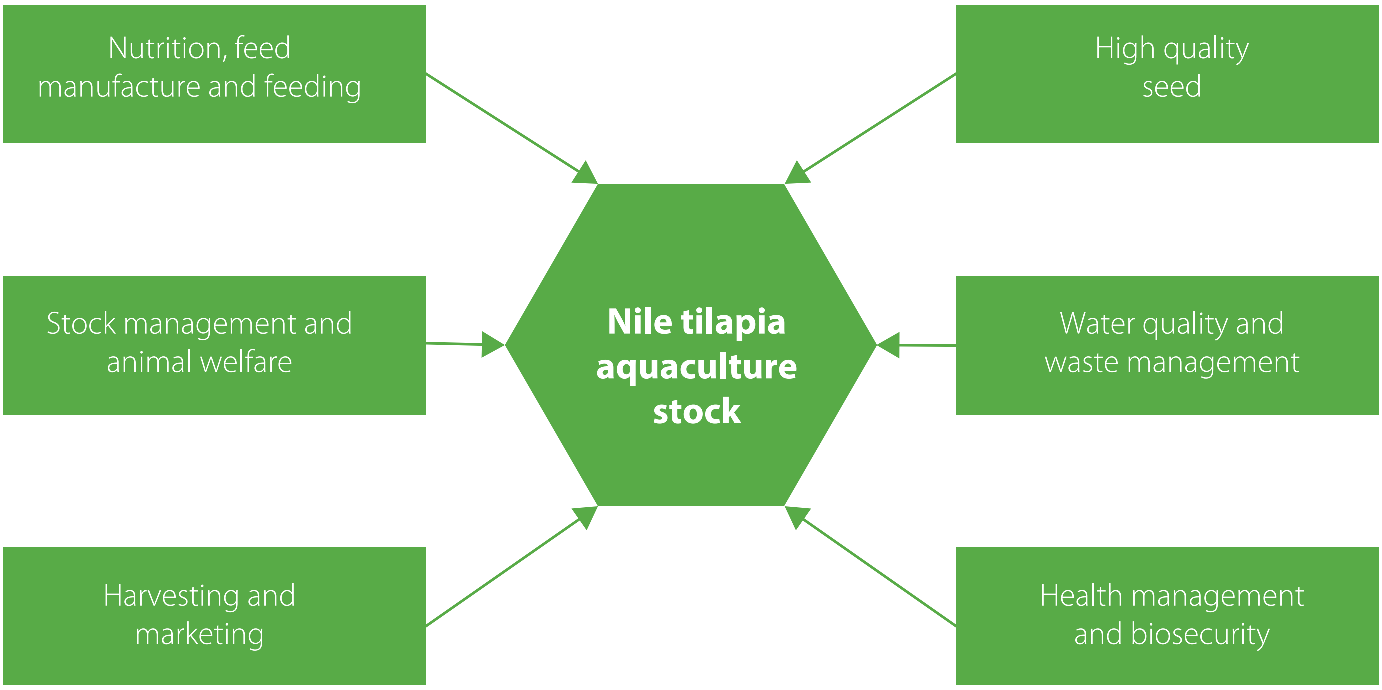


Figure 5. Six areas of grow-out management in aquaculture.

are unsuitable or the stocking density is too high. When this happens, preventing diseases is important because treating fish during grow-out is not practical. Adding antibiotics to feed is also ineffective because sick animals do not eat. The only way to reduce disease incidents is to develop biosecurity and culture environmental management programs (Section 2.6).

4.1.5. Stock management and animal welfare

Stock management is not only important for managing health but also for providing optimal space for cultured fish to behave normally. Providing good water quality and maintaining the health of the culture stock will guarantee the welfare of the fish.

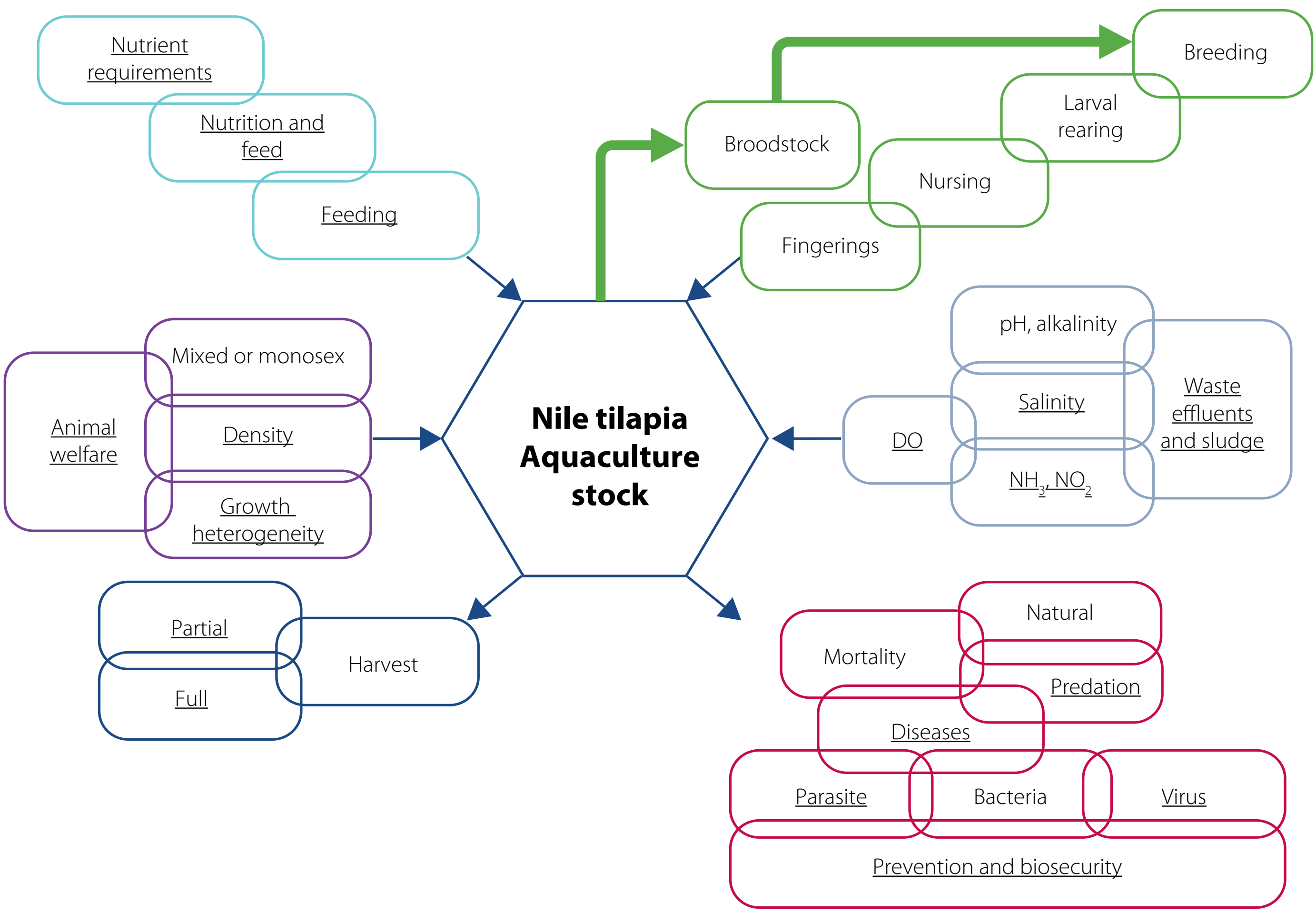
4.1.6. Harvesting and marketing strategies

Fish farmers can harvest their culture stock either partially or fully. Partial harvesting strategies are suitable when fish are sold locally or the market size is small. (Market size is the number of potential buyers/sellers of a product in a certain market.) Farmers can do a full harvest when they are certain that they can sell the entire harvest to an agent or a processor.

4.1.7. Requirements for certifications

If Nile tilapia are produced for export, overseas buyers will demand a certified production process. There is no standard certification system for Nile tilapia aquaculture, but international certification schemes usually look for the following aspects of culture management:

- Legality: property rights of the aquaculture site, and national regulatory compliances
- Social relations: good community relations, no child labor, safe working conditions and employee welfare
- Environment: sediment and effluent management, no habitat damage, fishmeal and fish oil use or biodiversity conservation, control of escapes, use of genetically modified organisms, culture animal-wildlife interactions, and storage and disposal of farm supplies or chemicals



Note: Underlined = parameters to manage during grow-out.

Figure 6. Six areas of grow-out management in aquaculture.

- Animal welfare: water quality management and the welfare of cultured animals (crowding effect) as well as biosecurity, health and disease management
- Food safety: food safety, control of residues and contaminants, harvest, transportation and sanitation
- Traceability: recordkeeping requirements.

It may be prudent for producers to pay attention to these aspects of culture management if they intend to export the product.

4.1.8. Exercises

Among farm operators, form groups of producers who practice similar types of culture systems, such as pond culture, cage culture, supply fish for local markets or urban markets or a processor, etc. Then, let the groups discuss the following questions:

1. What are the seed sources? Are the practitioners satisfied with seed quality? If not, what are the alternative seed sources?
2. What are the market characteristics?
3. What aspects (physical properties such as size and chemical contaminants) of products does the market demand?
4. What quantities can be supplied?
5. What are the constraints?
6. How can the constraints be resolved?

4.2. Nile tilapia pond culture

The grow-out phase is when fish reach marketable size. The demand for specific sizes of fish varies according to whether the market is local or international, or the fish are being used as raw materials for further processing. Although fish farmers might be able to sell fish around 200–300 g at the local market, processors producing tilapia fillet will demand 800 g fish.

Pond culture is one of the most widely used methods for growing tilapia, as it has several advantages:

- The fish can eat natural feed, such as plankton, bacteria and detritus.
- Using fertilizers containing nitrogen and phosphorous at a ratio of 3 to 1 can increase natural food production.
- No external feed is required in extensive and lower-level semi-intensive culture systems.
- It is possible to increase production through a supplemental feeding regimen that provides the fish with 50% of the nutrients they need from pelleted feed and extracting the rest from natural feed.
- The risk of disease is relatively low, and it is easy to develop a biosecurity system.
- Farmers can avoid theft and poaching easily.

Pond culture systems are classified according to the intensity of production (extensive, semi-intensive, intensive) or the nature of the culture facility (earthen pond, concrete tank, fiberglass tank, raceways, water recirculation systems). The relationships between intensity and different types of pond culture systems are shown in Table 3.

4.2.1. Pond design

Pond design and construction is a complex engineering process, so consulting a civil engineer is recommended. In general, the selected site should have the following minimum characteristics:

- There is an open sunlit area that is accessed legally.
- It has enough space for the pond and service supply, such as stocking, harvesting and feeding fish.
- Access to transportation and markets is easy.
- It has legal year-round easy access to a clean water source, either surface water or groundwater.
- It has clay soil that can hold water, as sandy soil is not suitable for pond aquaculture.
- There are no flood risks in the area.
- It has an area dedicated for waste treatment (sludge and effluents) before discarding it into nature.

The number of ponds per site depends on the production plan or targets. There is no strict guideline for determining the size of a pond. However, it should be manageable, as ponds larger than 0.5 ha are often difficult to manage. An individual pond should have following characteristics:

Physical structure	Water use	Intensity		
		Extensive	Semi-intensive	Intensive
Earthen static water ponds/tanks	Water is exchanged intermittently to compensate for evaporation and seepage losses.	The stocking density is no more than one fish per square meter; natural feed is the food source.	One or two fish are stocked per square meter; ponds are fertilized using organic manure in combination with chemical fertilizers and supplementary feeding.	Aeration devices supply oxygen; the stocking density is high at five fish per square meter; commercial or farm-made nutritionally complete feed is used.
Earthen pond/ concrete tank water recirculation systems	Nearly 90% of the water is recirculated daily.	NA	NA	Stocking densities are high; juvenile fish are stocked at 10–50 fish per square meter.
Raceways	Water flow through systems.	NA	NA	The stocking density is as high as recirculation systems.

Table 3. Classification of pond culture systems for tilapia.

- Sloped pond walls are just high enough to retain desired water volume and prevent fish from escaping.
- There is a sloped bottom toward one deep end for draining.
- The walls and bottom are well packed to avoid erosion and seepage. Use rollers to compact the bottom, if necessary.
- The pond depth is preferably 1 m at the shallow end, sloping to 1.5–2 m at the drainage end.
- Construct a collection pit at the deep end where sludge can accumulate and is easily removed.
- The deep end also serves as the harvesting area.
- There is a standing pipe to maintain the water level and drain the water.

4.2.2. Nursing for grow-out

4.2.2.1. Hapa nursing

Small fish (0.1–0.2 g) are nursed in hapas installed in earthen ponds at a stocking density of 1000–2000 fry/ m^2. Hapa sizes vary, but most are in 8 x 5 m , though smaller hapas (3 x 2 m) are also used. Fish are fed a mixture of fishmeal and rice bran at a ratio of 1:2–3.

4.2.2.2. Pond nursing

Tilapia fry are also nursed in small ponds of 100–500 m^2. Ponds are drained, dried and limed at 500 kg/ha. After filling it with water, fertilize the pond with inorganic fertilizers (urea and triple super phosphate (TSP) or any other fertilizer mixture containing nitrogen and phosphorus) to stimulate plankton growth and then stock the fish at a rate of 100–200/m^2. Feed the fish a mixture of rice bran and fishmeal to start and then use small (1 mm) commercial floating pellets two to four times a day. Nurse the fish for 30 days until they reach 1–2 g. Then either sell them for grow-out pond culture or nurse them further up to 20–25 g to sell them to cage or pond grow-out farmers.

4.2.2.3. Grow-out phase

A wide range of techniques is used in the grow-out phase, depending on the target market. For example, Nile tilapia culture in Asia is done using a variety of inputs such as agricultural by-products (brans, oil cakes, vegetation, manure), inorganic fertilizers and farm-made or commercial feed.

4.2.2.4. Fertilized pond culture

Common inputs for Nile tilapia pond culture in Thailand are manure (usually from chickens but also pigs) and inorganic fertilizers (urea and TSP). Farmers can use rice bran and bakery waste as supplementary feed. If farmers adopt an appropriate fertilization regimen, they can harvest fish from 200 to 250 g for local markets within 5 months.

Although diverse in its amount of nutrients, animal manure greatly encourages the growth of phytoplankton and zooplankton as well as bacterial flocs, which Nile tilapia eat when filter feeding. Compared to duck and chicken manure, buffalo manure has substantially lower quantities of nutrients. The maximum rate at which farmers can add organic matter daily to a Nile tilapia pond is 100 kg of dry matter (DM)/ha, as higher rates can deplete the oxygen supply. As a result, manure and inorganic fertilizer are combined while fertilizing ponds. Research at the Asian Institute of Technology (AIT) revealed that applying urea at a weekly rate of 28 kg of nitrogen/ha, TSP at a rate of 7 kg of phosphorus/ha, and chicken manure at a rate of 200 kg of DM/ha can produce a net tilapia harvest of about 4 t/ha in 150 days at a stocking rate of 3 fish/m^2 (the extrapolated net annual yield is about 10 t/ha).

Trials have been done in Thailand using inorganic nutrients alone: 3–4 kg of nitrogen/ha per day and 1 kg of phosphorus/ha per day with highly alkaline waters. (Alkalinity as bicarbonate (HCO_3^{-1}) acts as a buffer as well as a carbon source.) These trials resulted in comparable yields. Stocking 2 fish/m^2, a yield of 3.7 t/ha was reported from Honduras following weekly addition of chicken manure at 750 kg of DM/ha and urea at 14.1 kg of nitrogen/ha in waters with sufficient natural phosphorus.

4.2.2.5. Fed-aquaculture of Nile tilapia

Farmers who supply fish to a niche market (supermarket or export) practice monoculture using commercial feeds. At lower stocking densities of 1–3 fish/m^2, fish grow from 5–10 g to an average of 300–600 g in 7–8 months without aeration. With aeration, farmers can stock fish at relatively higher densities (five to 10 per square meter) to reach 600–700 g in 7–8 months. The yield without aeration is in the range of 3.5–7.5 t/ha and 12–18 t/ha with aeration.

To fetch a higher market price for larger fish, it is important to feed fish formulated feeds. There are two main approaches to lower production costs for domestic markets in developing nations: delayed feeding and supplementary feeding. Research at the AIT showed that stocking Nile tilapia at 3/m^2 could attain a weight of up to 100–150 g in about 3 months with fertilizer alone. After that, the fish received supplemental feeding at 50% satiation until they weighed 500 g. The average net harvest was 14 t/ha, translating to a net yearly production of 21 t/ha.

Plate 12. Farm-grown tilapia for sale in a supermarket in Thailand.

4.2.3. Exercises

The following summarizes information on tilapia pond grow-out culture in Asia:

- Pond size: 0.2–0.5 ha
- Aeration: one to three paddlewheel aerators per hectare of surface area
- Stocking density: 30,000–37,500/ha (3–4/m^2)
- Feeding: pelleted feed containing 28%–35% crude protein fed two to three times daily
- Feeding rate: 6%–10% of weight for fish under 100 g, 3%–6% for fish 100–250 g, and 1.5%–3% for fish 300–800 g
- Culture period: 150–180 days
- Gross yield ranges: 15–20 t/ha
- Harvest weight: 600–800 g per fish
- Food conversion ratio (FCR): 1.5–2.

Questions for discussion:

1. Assuming pond size is 0.2 ha and the culture duration is 5 months (two crops per year), how many ponds are required to obtain 20 t of fish annually?
2. If the survival rate is 80%, how much pond area is required to obtain 20 t annually?
3. If feed and paddlewheels are not available, how much fish can be produced using pond fertilization methods in the area calculated under the scenario as in question 2?
4. If the daily fertilization rate is 3 kg of nitrogen/ha and 1 kg of phosphorus/ha, how much urea and TSP should be added to ponds weekly?

4.3. Cage culture of Nile tilapia

Nile tilapia is cultured in cages installed in freshwater rivers, irrigation canals, reservoirs and lakes, while salinity-tolerant red tilapia (*O. niloticus* x *O. mossambicus*) is cultured in freshwater as well as in brackish water lagoons, estuaries and shallow seas. Relative to pond culture, capital investment in cage farms is lower than that of pond culture, as land requirements and cage construction costs are low (Table 4). However, the feed cost is high because natural food plays a minimal role in tilapia nutrition in cage culture.

Criteria	Cage culture relative to pond culture	Pond culture relative to cage culture
Capital investment	Low	High
Operation costs	High	Medium
Reported range of stocking densities (SD) (m^3)	50–150 (aeration might be needed at higher stocking densities; the maximum initial stocking density is 30–40 kg/m^2)	1–2 (no feeding, only fertilization) 2–3 (feeding at 50% satiation without aeration) 4–10 (feeding and aeration)
Maximum harvest biomass (kg/m^3)	Approximately 120	1–5
Disease risk	High	Medium
Escape risk	High	Low
Growth rate	High	Same (the lower the SD the higher the growth rate)
Environmental pollution	High	Low (if sludge and effluents are not disposed to nature)

Table 4. Comparison of Nile tilapia cage and pond culture.

The advantage of cage culture is that this system supply with ample DO and removes metabolic waste from the cage provided with there is sufficient water flow. However, if the DO of the waterbody is low in the morning hours, emergency aeration devices should be readily available. As for disadvantages, cage culture carries with it a risk of disease and parasites, fish escaping from the cages, a greater chance of poaching, and a high potential for environmental pollution.

4.3.1. Cage design

There are several types of cages (Table 5), and these designs take into account environmental parameters and available resources. There are two ways to install cages: (1) fix them to piles or poles installed at the bottom of the waterbody or let them float using various devices such as empty barrels, Styrofoam floats or other buoyant materials. Fixed cages are less expensive and can be designed without any engineering support. They are usually installed in shallow waterbodies near the shore to make it easy to stock, feed and harvest fish. The widely used floating cages have a buoyant frame or collar that supports the net bag. The cage is anchored to the bottom or to a structure on the shore. It is important to shelter the cages to protect them from strong waves and wind, so be sure to select a suitable site for cage culture.

The dimensions are 3 x 3 x 3 m to 5 x 5 x 3 m for square cages, though some farmers use 6 x 3 x 3 rectangular cages. They are made of knotted polythene nets with a 2–3 cm mesh size for smaller fish. The frame of the cage is usually made of galvanized 1-inch steel pipes with barrel floats for a walking platform made of wood or bamboo. Some farmers, especially those with cages in irrigation canals, use bamboo frames with either barrels or Styrofoam blocks as floats. The latter require a boat, as people cannot walk on them.

Plate 13. Tilapia cages set in the Chao Phraya River, Thailand.

Parameter	Cage type
Placement in water	1. Surface: fixed or floating 2. Submerged: submersible or permanently submerged
Place of operation	1. Freshwater 2. Marine 3. Estuarine/lagoon
Protection from wave energy	1. Sheltered 2. Exposed: open water
Means of support for fixed or floating cage	1. Fixed: fixed to piles or poles 2. Floating: buoyant placed on the collar
Structure’s rigidity or flexibility	1. Rigid collar/structure and net mesh 2. Flexible: rigid collar and flexible mesh (nets)
Service access	1. With a walkway 2. Without a walkway, usually accessed and serviced using a boat/barge
Operating parameters	1. Biomass: low, medium or high based on culture intensity 2. Feeding method: manual or automatic feeders

Table 5. Classification of cage culture systems.

Among the many cage designs and models, high-density polyethylene (HDPE) cages are widely used because of the versatility of the materials used, the relative simplicity in the performance of the various farming operations and the comparatively limited investment capital required. Technological improvements of HDPE cages are evolving with the availability of new materials and various equipment items needed to service all cage farming operations.

4.3.2. Site selection for freshwater cage culture

Since cage culture operations usually take place in public waters, there are three major factors to consider at the planning stage:

1. Environmental parameters relevant to cultured organisms:
    - water quality (temperature, salinity, DO, suspended solids or turbidity)
    - water exchange
    - water current
    - algal blooms
    - disease organisms
    - pollution
    - fouling.
2. Environmental parameters relevant for the cages:
    - water depth
    - water current
    - shelter from waves and wind
    - sea, lake, riverbed or bottom
    - pollution
    - fouling.
3. Legal/logistic criteria:
    - legal issues
    - tenure rights
    - lease permit process
    - security from theft or poaching
    - proximity to market
    - political issues.

When selecting a site, be sure to follow the country's permit process for obtaining legal tenure rights and leases. Make sure the site is in an area where you can transport both seed and harvested fish to and from the market, and that is free from poaching.

Farmers should select a site that has an optimal temperature range of 25°C–32°C, a DO level above 4 mg/L, a pH of 6–8 and an ammonia level under 1 mg/L. The water should also be free of chemical pollutants. Install the cages at least 1 m above the bottom. The optimal water current is around 10–20 cm per second. This will supply sufficient DO and remove metabolic waste; however, do not exceed 40 cm per second as this can damage the cage. When algal blooms occur in lakes, this lowers the level of DO in the early morning. This often happens because of domestic or industrial pollution, so install the cages in areas away from human settlements and industries. Fouling in the cage nets is unavoidable, but drying and cleaning the net bag after each harvest can minimize it.

4.3.3. Effects of cage fish farming on the environment

When selecting a site, it is important to consider the effects of cage fish farming on the environment. Choose a site that is located away from sensitive habitats, such as breeding grounds of natural fish populations, as feed waste and sediment deposition of the bottom sediment can damage sensitive sites.

To remove any sediment accumulated under the cages, set up sediment traps with a submersible pump. Growing floating aquatic vegetables near the cage site (integrated multitrophic aquaculture) can partially dissolve nutrients like nitrogen and phosphorous.

4.3.4. Nursery cages

The stocking size of Nile tilapia in grow-out cages is about 20–30 g, and even 100 g in some cases, so be sure to further nurse seeds bought from hatcheries. Stock small fish (0.25 g) in 2 mm mesh nylon cages at stocking densities ranging from 500 to 700 fish that grow up to 1 g in 2 weeks. Then transfer the fish into cages with Raschel nets with a 4 mm mesh to grow them up to 25 g in 4 more weeks. These types of nets are used to nurse fish larger than 0.5–1 g. Start by giving the fish powdered feed containing 30%–40% crude protein. In Asia, fishmeal and rice bran are the ingredients that are used the most in powdered feeds, but some farmers use corn and soybean meal in addition to the mixture to feed small fish. Feed the fish three to four times daily for satiation. For bigger fry, feed them with pellets containing 28%–32% protein.

4.3.5. Grow-out cages

4.3.5.1. Stocking density and yield

Stocking density is based on three parameters: (1) water quality, (2) water flow-through rate or water current and (3) cage size, as smaller cages have a higher flow-through rate than large cages. Stock fish weighing 20–100 g in grow-out cages at densities ranging from 20 to 50/m^3. Lower stocking densities work best in rivers and streams during the dry season when both water quality and flow rate drop.

When the water quality is good and the weather is cooler (October–February), use a relatively higher stocking density, such as 40–50/m^3. Lower the stocking density to about 20/m^3 in the dry season (March–June) as the water quality can deteriorate, especially with high water temperatures. The average maximum yield of 6 x 3 x 3 m cages installed in the Chao Phraya River is about 2 t per cage or 45 kg/m^3 of water volume (6 x 3 x 2.5 = 45 m^3). Fish grow from an initial weight of 25 g to a final weight of 700 g in 4 months.

4.3.5.2. Feeding

Give fish commercial feed containing 28%–32% protein two or three times a day. The average FCR is 1.5, meaning a cage with 1500 fish requires 2250 kg of feed for 4 months. Some farmers achieve a lower FCR by constantly monitoring and carefully measuring the feeding response of fish. A fish nutritionist or a trained person can determine whether the fish are satiated by observing their feeding behavior to see if it changes from vigorous and active to slow and sluggish, which is the satiation point.

4.3.6. Exercises

1. Analyze the following data taken from cage culture literature in China. Can the system be improved to double the fish yield?
    - Commonly used cage dimensions: 6 x 4 x 3 m
    - Stocking size: more than 50 g
    - Stocking density: 100–150/m^3
    - Feeding: pelleted feed containing 28%–35% crude protein two to three times daily
    - Feeding rates: 7%–10% of weight for fish under 100 g, 4%–6% of weight for fish 100–250 g, 1.5%–4% of weight for fish 300–800 g
    - Culture period: 120–150 days
    - Harvest size: 600–800 g
    - Gross yield: 30–60 kg/m^3 (average yield is around 30–40 kg/m^3)
    - FCR: 1.5–2.
2. Modify the following example if the expected yield is 120 kg/m^3.

The stocking density for cages is calculated using previous experience for the expected yield. For example, for 2.5 or 3 deep cages in a pond with an average depth of 2 m and a previous mortality rate of 10%:

IF:
Expected yield = 30 kg/m^{-3}
Desired final weight of fish = 700 g
Water volume = 5 x 5 x 2 m = 50 m^3
Expected survival rate = 90%

THEN:
Number of fish to harvest = 30/0.7 = 43/m^{-3}
Stocking density with 10% mortality = 43/0.9 = 48/m^{-3}
Stocking density per cage = 48 x 50 = 2381

4.4. Nutrition, feeds and feeding for Nile tilapia

Feed is the main operating cost of any fish culture. In intensive aquaculture, it can account for over half of the farmgate price, or gross revenue of the farm. Reducing feed costs is challenging for fish farmers, and to do so requires a better understanding of the concepts of aquaculture nutrition. To optimize feed costs, farmers must meet the nutritional requirements of their fish. This section is mainly designed to show practitioners ways to lower their feed costs in Nile tilapia culture.

4.4.1. Issues to consider at the feed management design stage

4.4.1.1. Feeding objectives

Feeding systems have different objectives for different stages. Design the feeding system in a way that it will achieve the objectives of feeding fish at the various stages of their life cycle.

4.4.1.2. Feed characteristics

There three main characteristics that influence feed: nutrient specification, physical qualities and natural feed. Nutrient specification refers to the percentage of nutrients in the feed, such as how much protein, fat, etc. Physical qualities refer to whether feed is wet or dry and the feed type. The moisture level for dry feed is under 10% and for wet feed more than 20%, while feed type is either sinking or floating pellets. Floating feed is best for Nile tilapia. The amount of natural feed in a pond determines how much pelleted feed to add to the culture system.

4.4.1.3. Fish characteristics

There are three main fish characteristics that influence feed, and the nutrient requirements of fish depends on their age or weight:

- nutrient requirements
- age of size of larvae, fry, fingerlings, juveniles
- physiological state.

Smaller fish need a higher percentage of feed per kilogram than larger fish. As for the physiological state of fish, its influence on nutrient requirements is less known. If fish are infected with bacterial or viral diseases, they will not eat.

4.4.1.4. Biotic factors

Stressed fish eat less, as do fish stocked at extremely high densities. Both lead to slower growth.

4.4.1.5. Abiotic factors

There are two main abiotic factors that influence feed: the culture system and water quality. Ponds, cages and recirculating systems are different types of culture systems, and all of these affect water quality parameters such as DO and ammonia. If the oxygen concentration in the water is too low, the fish will not eat. Be sure to maintain a DO level of at least 4 mg/L and ammonia and nitrite levels below 1 mg/L, as both are toxic to fish. Also, fish eat the most when the water temperature is around 30°C.

Growth rate increases as fish eat until they are satiated. Physiologically, the maximum growth rate is the ability of the fish to process nutrients per unit of time (day). The amount feed that fish eat fluctuates at the highest growth rate, so the most economic feeding rate is about 80% of satiation. Feeding fish at this level will also reduce waste and result in the lowest FCR possible.

Natural feed can supply sufficient nutrients to support a certain biomass of fish, called the "critical standing crop" (CSC). Provided that water quality parameters are optimal, Nile tilapia's growth is a function of the amount of natural food available, fish size and stocking density (biomass) under a given fertilization regimen for a fishpond. The system is said to contain a CSC when the fish use the natural food available for maintenance and maximum growth. Above the CSC, nutritional deficits develop, so fish will need sufficient nutrients to reach the desired growth. For further increases in fish yield, add supplementary feed.

Research at the AIT showed that natural feed can meet the nutrient requirements of Nile tilapia until the fish biomass reaches 200 g/m^2 or 200 g/m^3 (e.g. two fish weighing 100 g each/m^2). Research also showed that the FCR of fish reared in clear tanks and given pelleted feed with 28%–30% protein is on average around 1.5. Fish grown at a density of 2–3/m^2 in fertilized pond systems can have an FCR as low

Fish stage	Weight range (g)	Reported range of protein specifications by various authors (%)
Larvae (sex reversal stage)	0.01	40–50
Fry	0.1–1	35–40
Fingerlings	1–5	28–40
Juveniles/adults	>20	24–32
Broodstock	>100	35–40

Table 6. Protein specifications for Nile tilapia.

as 0.75, indicating that natural food and pelleted feed each account for half of the nutritional requirements. As such, instead of feeding fish to 100% satiation for the entire grow-out period, it is best to delay feeding until they reach 100 g, at which point half satiation rations will suffice. This will lower the feed cost as well as environmental pollution.

4.4.2. Exercises

1. Discuss the classification system for intensification of aquaculture based on nutritional inputs.
2. Discuss the nutrient losses during the growth process. How can practitioners reduce the losses?
3. Define FCR.
4. Feed conversion efficiency (FCE) = weight gain/ feed intake. If the FCR is 1.5, what is the FCE?
5. A fish eats 5 g of DM from a diet containing 30% protein and produces 1 g of feces containing 50% protein. Calculate the DM and the protein digestibility of the feed.

4.5. Production of on-farm feed for tilapia

The objective of manufacturing small-scale feed is to give the fish feed that is nutritionally balanced to meet the requirements of the culture system being practiced in a form that is palatable, digestible, cost-effective and enables maximum feed ingestion.

One problem on-farm feed producers encounter is that formulations often meet the nutrient requirements in solid form but then disintegrate in water before the fish can eat them, so the feed does not actually end up meeting requirements for the fish (or fish farmers). We can use functional properties of feed ingredients to solve this problem, as shown in Table 7.

A cold-extruded feed mixture, shown in Table 8, without subject to cooking is not water stable. Steam conditioning or cooking the mixture will give some stability to the pellets.

Nutrient	Form	Functional state
Protein uncooked	Un-denatured polymer	Soluble, gel forming, thermosetting—acts as a binder
Protein cooked	Denatured polymer	Insoluble and inert—not a good binder
Starch uncooked	Digestible polymers Native granules	Insoluble and inert—not good as a binder
Starched cooked	Gelatinized polymer	Soluble viscous gel—acts as a binder

Table 7. Different nutrient forms affecting the functional properties in feed formulation for tilapia.

Ingredient	% added	Functional form	Comments
Rice bran	15	Inert	Dough balls rapidly disintegrate in water.
Fishmeal	12.5	Inert	
Cassava	15	Inert	
Soybean meal	35	Inert	
Ground nut cake	17	Inert	
Fish oil	3	Inert	
Vitamins	1	Inert	
Minerals	2.5	Inert	

Table 8. Formulation of a cold-extruded and uncooked feed mixture for tilapia.

Ingredient	%	Functional form
Wheat flour	10	Extensible protein
Rice bran	5	Inert
Sun-dried fishmeal	12.5	Partly soluble protein
Pre-gelled cassava	15	Viscous gel
Soybean meal	35	Inert
Groundnut cake	15	Inert
Fish oil	2	Inert
Vitamins	1	Inert
Minerals	2.5	Inert
Guar gum	2	viscous gel

Table 9. A diet with water stability (30 minutes).

Heating helps convert inert nutrients to soluble gel:

- Cassava starch → insoluble → heat → soluble gel
- Rice bran starch → insoluble → heat → soluble gel
- Fish/sun-dried fishmeal → semi-soluble protein → heat → soluble gel
- Full fat soybeans → semi-soluble protein → heat → soluble gel

Soluble gel acts as a binder and makes feeds water stable. Fair stability as dough balls, steam conditioned in a pelletizer to activate wheat gluten and cassava, can provide a more stable diet.

Plate 14. Feed stored in a tilapia cage farm in Thailand for regular feeding.

4.5.1. Maintaining feed quality (quality control)

It is critical to confirm that the finished product's composition matches the feed formula. Therefore, it is important to examine the chemical composition of finished feeds on a regular basis. The moisture content of the final feed is a critical parameter. At temperatures ranging from 20°C to 30°C for storage, fish farmers can expect changes in the feed shown in Table 10. As a result, there will be weight losses, quality losses and a combined economic loss as a consequence of both issues.

Store feed bags in a waterproofed and well-ventilated area away from sunlight. Do not subject to high temperatures and temperature fluctuations. Stack the bags a few inches above the floor on wooden pallets, and away from walls to avoid condensation.

Moisture content (%)	Relative humidity (%)	Consequences
0–8	0–30	No significant biological activity
8–14	30–70	Possible insect infestation; mites can infest feeds when the relative humidity is above 60%.
14–20	70–90	Insect infestation and mold growth
20–25	90–95	Mold and bacteria growth
> 25	> 95	Bacteria growth and seed germination

Table 10. Expected changes in feed quality in response to different moisture levels in feed.

4.5.2. Exercises

Prepare a water-stable fish feed in the laboratory using the following ingredients:

Ingredients	% added
Wheat bran	16
Fishmeal	5
Cassava	20
Soybean meal	35
Groundnut cake	20
Fish oil	2
Vitamins	1
Minerals	1

Procedure:

- Weigh all ingredients to prepare 1 kg of feed.
- Keep the cassava starch separate.
- Mix all the other dry ingredients together. Add vitamins and minerals little by little and mix well.
- Add the oil and mix well.
- Add 500 ml of water to the cassava and cook. Do not let dry.
- As soon as the gel forms, add the dry mixture to the cassava gel, mix and make it into a dough.
- Extrude the dough through a mincer.
- Dry under shade at a low temperature. If possible, use a fan.
- Collect the feed in a paper bag, seal it and store in a cool place.

4.6. Water quality management

Successful aquaculture depends on maintaining the health of the fish. Poor water quality reduces growth and has negative health effects.

Proper water quality management is necessary to not stress the fish so that their immune system can resist pathogenic bacteria in water. Typically, poor water quality stresses fish, which in turn leads to disease. Water quality management is also crucial if the water supply is limited or the quality of the primary source of water is poor. Nile tilapia is able to withstand a wide range of water quality parameters, including salinity, temperature, ammonia and DO.

4.6.1. Salinity

Nile tilapia tolerate up to 15 ppt of salinity but grow best around 10 ppt. However, they spawn best at 5–10 ppt, and fry perform better at levels under 5 ppt.

4.6.2. Temperature

Nile tilapia eat and grow best at 30°C but can tolerate a temperature range of 18°C–33°C.

4.6.3. Dissolved oxygen

Nile tilapia can withstand DO levels as low as 0.3 mg/L for a few hours, but maintaining levels above 4 mg/L will achieve the best growth rate. High density grow-out conditions require aeration.

4.6.4. pH

Nile tilapia can survive in pH ranging from 5 to 10. However, the optimal pH is between 6 and 9.

4.6.5. Ammonia

Increased ammonia concentrations above 1 mg L^{-1} stress Nile tilapia.

4.6.6. Nitrite

Lethal concentration of Nitrite-N to Nile tilapia fingerlings is around 80 mg/L and for adults 8 mg/L. Adding chloride to the water, as either calcium chloride or sodium chloride, protects both small and large fish from nitrite toxicity, though it is advisable to maintain nitrite below 2 mg/L.

4.6.7. Nitrate

Nile tilapia can tolerate higher nitrate levels than many other farmed freshwater fish. However, high concentrations harm fish because nitrate reduces the ability of hemoglobin to transport oxygen throughout the body. For optimal growth, keep nitrate concentrations below 27 mg/L. In recirculating systems, maintain chloride concentrations at 100 to 150 mg/L to prevent nitrate-related issues.

Still, water quality problems can develop if (i) the water source is substandard, (ii) there is a sudden environmental phenomenon, such as the pond overturning during heavy rains and storms or (iii) because of pond mismanagement.

4.6.8. Phytoplankton management

Phytoplankton are microscopic algae that drift freely in water. Large plankton populations can produce enough oxygen through photosynthesis during the mid-afternoon on bright sunny days, causing oxygen supersaturation in water. Too much phytoplankton can drop DO levels overnight through respiration. At the same time, it can also increase pH. Phytoplankton respiration can account for as much as 80% of oxygen consumption in water at night, and large phytoplankton populations can deplete oxygen during sustained periods of cloudy weather. As such, monitoring DO daily is an important management practice.

Ammonia level	Effect on tilapia
0.1–0.9 mg/L	Reduced feeding, and some mortalities can occur.
1–2 mg/L	Mortalities increase, especially in fry and juveniles.
>2 mg/L	High mortalities can occur.

Table 11. Effect of various ammonia levels on tilapia.

However, if there is not enough phytoplankton in the water, ammonia and nitrite can accumulate, so it is important to maintain a balanced phytoplankton population. Added nitrogen and phosphorous, through what is called "eutrophication," is what stimulates phytoplankton growth. This principle is used in pond fertilization.

Phytoplankton bloom stimulated by nutrient inputs can crash when the nutrients are depleted. When this happens, DO levels drop because of bacterial decomposition of organic materials. As such, it is important to fertilize ponds regularly to maintain a healthy plankton population.

Phytoplankton can cause the water to turn blue-green, red or brown in addition to green. If plankton populations are the primary source of turbidity in ponds, fish farmers can determine population densities using the following two methods:

1. Measure visibility with a Secchi disk: A Secchi disk is a flat, weighted disk, 20 cm in diameter, with alternating black and white quadrants. To determine the water quality, submerge the disk in water until it is no longer visible. Visibility should be 20–30 cm. Lower visibility indicates excessive plankton.
2. Measure DO levels: Low DO in the early morning is a sign of phytoplankton blooms. If DO is lower than 2 mg/L in the morning, reduce the phytoplankton density in the water.

One way to control the phytoplankton population is to partially drain the water and replenish the pond with clean water. It is preferable to drain water from the bottom, as this removes accumulated sludge and excess nutrients from the pond.

4.6.9. Feed and feeding

Fecal and excretory waste generated from feeding fish is also a principal source of mineral nutrients in fishponds, both nitrogen and phosphorus. Unless DO is supplied through aeration, feeding rates should not exceed 100 kg/ha, preferably 50–75 kg/ha. Table 12 shows feed input per hectare at a stocking density of two and five fish fed at 100% satiation. A feeding rate that exceeds 100 kg/ha indicates why it is not possible to conduct high density fishpond aquaculture with feeding without aeration to supply DO.

4.6.10. Dissolved oxygen management

It is important to monitor DO levels regularly. Nile tilapia can withstand DO levels as low as 1 ppm for a few hours, but 4 kg/L is best for fastest growth. DO levels lower than 2 mg/L stress fish, so they will eat less and growth slower. It might not affect the FCR or survival rates, but low DO coupled with high pH and un-ionized ammonia (NH_3) will make fish susceptible to disease and increase the mortality rate. Accumulated sediment at the bottom associated with a large microbial population and high phytoplankton density is the main cause of low DO.

If fish come to the surface to breathe in the early morning, the DO level in the water is likely too low. If DO levels are around 2 mg/L, fish will eat less. The best way to measure DO is using a DO meter, and the best time to measure levels is the early morning before sunrise. To fix low DO levels, reduce the phytoplankton density in the pond, exchange water, use a submersible pump to remove accumulated sludge and nutrients from the bottom of the pond, or use an aerator to increase oxygen concentration.

Weight (g)	Stocking density (fish/m²)	Feeding rate (100% satiation)	Feed input for 100% satiation (kg/ha)	Stocking density (fish/m²)	Feed input for 100% satiation (kg/ha)
100	2	4	80	5	200
200	2	3	120	5	300
300	2	3	180	5	450
400	2	2	160	5	400
500	2	2	200	5	500

Table 12. Feed input for a tilapia pond.

4.6.11. Managing toxic metabolites

In fishponds, it is important to maintain low levels of ammonia, nitrite and hydrogen sulfide—all of which are toxic to Nile tilapia. Carbon dioxide is a by-product of respiration and can make temperate fish sluggish. However, this has not been observed in tropical fishponds as phytoplankton readily use carbon dioxide.

4.6.12. Ammonia

Ammonia is a by-product of deamination of amino acids in protein. Fish can excrete it passively through their gills. At a pH lower than 7 in water, ammonia becomes ionized ammonium ion (NH_4^+). It is relatively nontoxic to fish, but un-ionized ammonia (UIA - NH_3) is toxic to fish. The median lethal concentration (LC50) of UIA is around 1.5 mg/L after 24 hours of exposure, 1.3 after 48 hours and 1 after 96 hours.

Total ammonia nitrogen (TAN) is the sum of NH_3 and NH_4. It is common to have a TAN around 1–2 mg/L (ppm) in ponds with intensive fish culture. However, if the temperature is 30°C and the pH is 7, the corresponding UIA range is 0.008–0.016 ppm, which is not toxic. (Refer to an ammonia-pH-temperature chart on the internet to calculate the concentration of UIA in water.)

4.6.13. Nitrite

Nitrite (NO_2^{-1}) is a by-product of the bacterial reduction of ammonia and can react with hemoglobin in blood to form methemoglobin. When concentrations of methemoglobin in catfish reach 20%–30%, the fish develop brown blood disease in which their gill filaments turn chocolate brown. To reduce nitrite toxicity, add calcium carbonate (agricultural limestone) to soft water or add salt to both soft and hard water. Maintaining chloride concentrations between 15 and 30 ppm usually prevents problems associated with brown blood disease from developing.

4.6.14. Hydrogen sulfide

Hydrogen sulfide (H_2S) is a product of anaerobic decomposition of organic waste on the pond bottom by bacteria. Any detectable level is detrimental to fish production. Hydrogen sulfide smells similar to rotten eggs, so it is easy to detect. It also turns the pond bottom black. An effective treatment is to remove sludge from the bottom using a submersible pump.

4.6.15. Soil pH and acidity

Pond water can be acidic, alkaline or neutral. Depending on which one it is, water will react differently with dissolved substances. It will also have varying effects on aquatic plants and animals. The quantity of hydrogen ions (H+) in water determines whether it is acidic or basic.

The measure of the alkalinity or acidity of water is expressed by its pH value. The pH scale ranges from 0 to 14, with a pH of 7 representing neutral water. Values less than 7 indicate acidity, while values greater than 7 indicate alkalinity. The pH values between 6.5 and 9 are typically considered appropriate for fish culture, while levels that are exceedingly low or high will affect production. Apply lime to rectify pond water that is unfavorable for fish production.

Managing the water's alkalinity, hardness and pH requires keeping the soil's pH and acidity within permissible limits. The key is to maintain a soil pH of 6.5 or higher, which will typically maintain desirable water pH, hardness and alkalinity levels. Correcting soil pH requires drying the pond for at least 2 weeks after each harvest and applying lime (preferably agricultural limestone) prior to replenishing and restocking.

4.6.16. Alkalinity

Total alkalinity is the sum of bicarbonates (HCO_3^{-1}) and carbonates (CO_3^{2-}), expressed as mg/L (ppm) of calcium carbonate ($CaCO_3$). Alkalinity is the capacity of the water to neutralize acids without an increase in pH, known as the "buffering capacity." Adding bicarbonates and carbonates to water increases alkalinity. A suitable range is 100–300 mg of calcium carbonate.

Certain waters might only contain bicarbonate alkalinity and no carbonate alkalinity. Adding or removing carbon dioxide to a solution does not change its alkalinity. Adding it to a solution lowers the pH, but it has no effect on its alkalinity as at all pH values the reaction is as follows: $CO_2 + H_2O \rightleftharpoons HCO_3^- + H^+$, as the net reaction produces the same number of equivalents of positively contributing species (H^+) as negative contributing species (HCO_3^- and/or CO_3^{2-}). Regardless of the production method used, this carbonate buffering system is important for fish farming. Carbonates and bicarbonates function as a storage system for surplus carbon dioxide in pond production systems, where photosynthesis is the primary natural source of oxygen. By storing carbon dioxide, the buffering system prevents wide daily pH fluctuations. Without a buffering system, free carbon dioxide will produce significant quantities of a weak acid (carbonic acid) that could reduce the pH level at night to 4.5. During periods of peak photosynthesis, phytoplankton will use the majority of free carbon dioxide, causing the pH to rise above 10, which can be lethal.

4.6.17. Monitoring water quality

This is an essential part of managing intensive aquaculture. The important parameters to monitor are DO, temperature, pH, ammonia, nitrite and alkalinity. Fish farmers can monitor the first two using a DO meter, while pH is measured with a pH meter and the last three using test kits. However, assuming the phytoplankton density is optimal, if fish are stocked below $2/m^2$, fed at a rate around 75 kg/ha and harvested at around 300 g, regular monitoring might not be necessary.

4.6.18. Exercises

Collect the following equipment: DO meter, pH meter, test kits for ammonia, nitrite and alkalinity measurements. Then visit a pond site, take a water sample 30 cm below the surface using a bottle and measure the parameters.

4.7. Harvesting, transportation and marketing

At the end of the pond and cage culture period, it is time to harvest the fish for sale, storage, consumption or further processing. Throughout the globe, most small and medium entrepreneurs sell fish at their farmgate to a third party (an agent, broker or intermediary) at an agreed price. In some instances, the broker carries out the harvest; in others, the farmer harvests and the broker packs and transports the fish, or the farmer carries out the transportation. Farmers can harvest and sell directly (retail) to customers.

4.7.1. Harvesting

There are three main harvesting methods:

1. partial harvesting without pond drainage in which farmers harvest marketable-sized fish using a seine net with a larger mesh size and leave the smaller fish to grow (or re-stock with new fish fingerlings)
2. partial or full harvest with partial pond drainage
3. full harvest with complete pond drainage.

The best harvest method to use depends on market size, water availability, pond depth and workforce availability. If the pond is in a water-stressed area, harvest fish with a cast or seine net without draining the pond to conserve the water for subsequent culture cycles. For deeper ponds, which are difficult to seine, use cast nets to harvest them. For optimal harvests, drain the pond partially before using a seine net.

4.7.1.1. Partial harvest

Seining is often a labor-intensive operation. Even a small pond requires three to four people to operate a sein net. Start from the deep end and steadily draw the net toward the shallow end. Then collect the fish as the net is pulled from the pond. One person can cast the net, either standing on the dike or in a canoe/boat. To catch only larger fish while leaving behind smaller ones, use a wider mesh size in either the cast or seine. Decrease the mesh size for a more complete harvest.

Plate 15. Tilapia harvested from a cage site in Uganda.

4.7.1.2. Complete harvest

A complete harvest of Nile tilapia does not often require complete pond drainage. This is in contrast to harvesting catfish, in which total drainage is required because of their ability to burrow into the pond beyond the reach of the seine net.

However, total fish harvesting for subsequent stocking and grow-out in a tilapia pond necessitates complete drainage. If the farm has been properly designed to allow drainage from one pond into another, it is possible to drain the entire pond water and reuse it for subsequent production cycles. When the pond is drained using a drainpipe or a pump, use baskets or hand nets to catch the fish that are left in the water. Complete drainage after each production cycle is more prevalent in regions with an abundance of water, allowing fish farmers to harvest all the fish and to wash out, lime, dry and refill the pond bottoms for subsequent stocking.

4.7.1.3. Sanitation

Appropriate handling during and after harvesting is critical for sanitation and to prevent the introduction of pathogenic microorganisms. It is also important to use harvesting equipment that causes the least damage to fish and is easy to clean and disinfect. Furthermore, only harvest in the morning when temperatures are lower, rather than midday or mid-afternoon. Immediately after harvesting the fish, wash them under flowing water to remove mud and other debris.

4.7.1.4. Post-harvest processes

In Nile tilapia, rigor mortis occurs within 1–6 hours depending on whether the fish is partially alive or dead, so it is essential to process the fish as quickly as possible. Rigor mortis makes it difficult to fillet fish.

4.7.1.4.1. Rigor mortis

When fish die during or after harvest, the heart stops beating and the circulatory system ceases to supply the muscles with oxygen and fuel, such as glucose from glycogen. Since no oxygen is available for aerobic respiration, the muscle mitochondrial system ceases to function. To replenish ATP used to power the various energy-consuming activities, skeletal muscle cells rely upon anaerobic metabolism. For most teleost fish, glycolysis is the only possible pathway to produce ATP (energy) by using creatine phosphate and adenosine diphosphate (ADP) after death. Anaerobic glycolysis continues to regenerate some ATP and, as the end product, lactate accumulates in the muscles—similar to live muscles after vigorous exercise. Glycolytic activity then slows down, ATP concentration decreases because of continuing various enzymatic activities in the membrane systems, and most of the nucleotides deplete in a few hours. As a result of depletion of ATP, biosynthetic reactions come to a halt, and the cell's ability to maintain its integrity is lost, especially with respect to membrane systems. Both ATP and ADP act as plasticizers for muscle fibers actin and myosin and maintain muscles in a state of relaxation. When the intracellular level of these nucleotides declines post-mortem below 1 μ mole per gram of tissue, actin and myosin interact and the muscle enters rigor mortis. A muscle with rigor mortis turns stiff, hard and inextensible and cannot be stretched significantly without breaking. The body of the fish becomes hard and often bent from the tension. Rigor mortis makes filleting the yield and further processing difficult.

The onset of rigor mortis in Nile tilapia occurs more rapidly. Fish at ambient temperature reach rigor mortis relatively slower than fish stored on ice. Cold shortening is when tropical fish become stiff after death after being stored on ice. Cold shortening occurs when the fish muscle is chilled prior to the use of all ATP. The chilling has an inhibiting effect on Ca^{2+}pump in the muscle, and this creates a state of muscle contraction. In Nile tilapia, and other tropical finfish, the level of ATP is still high enough to exclude the fish from being in rigor mortis, but muscle contraction still occurs. Cold shortening in tilapia has major implications in terms of handling fish in the tropics for post-harvesting processes. This is because the muscle never appears relaxed after rigor mortis, even days after death. As such, if fish are produced for sale to a processing company, it is recommended to fillet the fish on ice within 60 minutes after death, and fish at ambient temperatures within 120 minutes. Farmers should plan out what they are going to do with the fish before harvesting begins. There are three options:

1. Transport the fish live in water containers, if fish are sold to a processor for filleting.
2. Transport the fish fresh to local markets, without using ice in order to delay rigor mortis or with ice if it does not affect market price.
3. Transport the fish on ice into cold storage for export.

4.7.1.5. Cold storage

There are several techniques for preserving harvested fish to prolong their shelf life (or storage time) and reduce their rate of decomposition. To chill fish, bring their body temperature down to 0°C by placing them on ice or in a refrigerator as soon as they are caught. When chilling with ice, the typical rule of thumb is to employ a 2:1 ratio of ice to fish, leaving no fish exposed above the ice. Freezing, meanwhile, lowers the core thermal temperature of fish to around minus -18°C. Fish can be frozen for up to a year, whereas chilling preserves it only for up to 15 days. Because of the intense sunshine and inconsistent power supply in the tropics, salting and drying is a common preservation technique. It diffuses the water in the flesh by infusing it with salt. Fish can be efficiently dried and then preserved for years thanks to the effect of this dehydration.

4.7.2. Exercises

Harvest Nile tilapia from a pond, then leave a few fish at ambient temperature and put the others in an ice slurry (ice in water). Inspect the fish manually for hardness. Fillet the fish immediately after harvest and before rigor mortis sets in. Discuss the experienced differences.

4.8. Health management and biosecurity in Nile tilapia aquaculture

The objective of health management and biosecurity in aquaculture is to reduce the risk of contamination from introducing, establishing and spreading pathogenic and/or invasive agents. This requires a set of management measures. This section covers the current issues of major diseases in Nile tilapia culture and introduces potential biosecurity measures that farmers should take into consideration.

4.8.1. Introduction

Pathogens (bacteria, parasites, fungi, viruses) and infectious diseases are one of the major business risks of aquaculture. Diseases have led to boom and bust cycles in aquaculture for the past 30 years, so prevention requires paying attention at the production and business planning stages.

	Disease control	Health management	Biosecurity
Management basis	Disease-based	Farmed animal-based	Risk assessment-based
Place of application	Culture facility (hatchery and grow-out)	Culture facility (hatchery and grow-out)	Culture facility and industry
Management target	Disease and pathogenic agent	To keep pathogenic agent away from farmed fish or shrimp	To keep farms and industry (in a country, province, region) free of pathogens
Goal	To cure disease	To prevent disease	To reach disease-free status
Mechanism of action	Treatment of disease	Good aquaculture management practice	Biosecurity plan and standard operating procedures
Reason for action	Disease control	Cost-benefit, avoid boom and bust	Secure national or farm economics
When to act	Disease occurrence	Production planning stage	Aquaculture planning stage
Emphasis	Technology	Management strategy and technology	Management strategy and technology

Table 13. Definition for terms in this document.

Diseases	Symptoms
Motile aeromonas septicaemia: causative agents, *A. hydrophila* and others	• Erratic swimming from loss of balance • Gasping at the surface • Hemorrhaged or inflamed fins and skin • Bulging of eyes and opaque corneas • Swollen abdomen containing cloudy or bloody fluids • Chronic daily mortalities
Columnaris: caused by *Flavobacterium columnare*	• Frayed fins and/or irregular whitish to gray patches on skin and/or fins • Pale, necrotic lesions on gills
Edwardsiellosis: caused by *Edwardsiella ictaluri*	• Very few external symptoms • Bloody fluid in body cavity • Pale and mottled liver • Swollen, dark-red spleen • Swollen and soft kidneys
Streptococcosis: caused by *Streptococcus agalactiae* and *S. iniae*	• Lethargic and erratic swimming • Dark skin pigmentation • Exophthalmia with opacity and hemorrhage in eye, and abdominal distension • Diffused hemorrhaging in operculum, around the mouth, anus and base of fins • Enlarged, nearly black spleen • High mortality
Tilapia lake virus (TiLV)	• Lethargy, ocular alterations, skin erosions and discoloration (darkening) and exophthalmia (in Israel) • Discoloration (darkening) abdominal distension, scale protrusion and gill pallor (in Ecuador) • Loss of appetite, lethargy, abnormal behavior (e.g. swimming at the surface), pallor, anemia, exophthalmia, abdominal swelling, and skin congestion and erosion (in Thailand)

Table 14. Symptoms of common bacterial and viral diseases in Nile tilapia.

Nile tilapia is susceptible to a range of pathogens, including the following:

- parasitic protozoans, such as *Ichthyophthirius multifiliis*, *Trichodina* sp., *Eimeria* spp., *Myxosoma* sp., *Nosema* sp., *Henneguya* sp., Hexamita
- monogenean flukes and helminths such as *Acanthostomum* spp. and *Acanthogyrus* sp.
- bacteria such as *Pseudomonas* sp., *Aeromonas* sp., *Flavobacterium columnare*, *Francisella* sp., *Streptococcus* sp.
- viruses such as TiLV.

One of the most recent viral infections affecting Nile tilapia is TiLV. Asia, Africa and South America have all recorded cases of TiLV , and the number of countries afflicted has rapidly expanded. It is important to note that most viral infections in aquaculture are still incurable. In the past, vaccines and selective breeding have historically been effective at reducing the severity of certain viral diseases. However, there is a significant lack of knowledge about viral diseases such as TiLV, and currently no effective, cost-effective vaccines are available.

Antibiotics can cure bacterial diseases. However, antibiotics for humans are not recommended to treat fish diseases. Misuse (and overuse) of antibiotics reduces their effectiveness in treating human diseases. Moreover, consumers reject antibiotic residue-contaminated fish products, which cannot be exported to most other countries in the world. For these reasons, preventing diseases is more important than curing them.

This requires setting up farm-level biosecurity procedures. There are two related biosecurity programs to choose from:

1. biosecurity for the aquaculture industry in a particular country or a region
2. biosecurity of a farm, such as a hatchery and/or grow-out system.

4.8.2. Industry-level biosecurity

Biosecurity for the industry can be defined as the measures and activities aimed at preventing the spread and escape of pathogens in a farming environment. This requires developing a legal and regulatory framework that is especially related to transporting aquatic animals from one place to another, including importing and exporting live animals. The issues addressed in an industry-level biosecurity program include developing and implementing regulatory and legislative procedures concerned with the following:

- industrial layout or zoning, depending on the province, country or region)
- disease notification and monitoring
- quarantine procedures for imports and exports
- quarantine procedures for disease-affected areas or farms
- surveillance plan of epidemiology
- management for live fish transportation or potential disease carriers
- role of veterinary services
- farm surveillance or a traceability system
- disease treatment
- treatment of dead fish
- disinfection measures
- managing slaughterhouses
- following procedures of farms
- vaccinating non-infected animals
- training program for personnel.

4.8.3. Farm-level biosecurity

Farms should follow established industry-level regulations. However, these regulations normally do not specify what farmers should do inside their farms. The most important biosecurity issue for the farms is to establish and implement a system or procedures to prevent the introduction of pathogens into a fish culture facility from outside or introducing a pathogenic agent from one section of the culture facility to another in the same farm, such as the grow-out system contaminating the hatchery or vice-versa.

Addressing a biosecurity plan at farm level requires planning measures, personnel management, sanitary measures, input management and disease management.

Planning measures include

- the placement of a farm in a zone, as well as design and construction;
- production planning, including water quality, culture stock and feed management;
- disease risk assessment, especially identifying the points where diseases can enter the farm facility, such as through seed, feed, other inputs and visitors.

Personnel management includes

- training and managing farm personnel.

Sanitary measures include

- disinfecting inputs, facility and equipment.

Input management (quality and contaminations) includes

- inlet and outlet water treatments;
- pathogen-free seed;
- uncontaminated feed;
- other inputs, such as net material and equipment.

Disease management measures include

- disease diagnosis;
- disease control, if preventive measures fail;
- an emergency and contingency plan.

Day-to-day biosecurity for farms involves common sense sanitary measures and management procedures to prevent contact between cultured animals and pathogens. These precautionary biosecurity measures reduce the occurrence of disease outbreaks, avoid high fish mortalities, avoid high financial losses from the loss of fish and continue the farm production process. For hatcheries, biosecurity avoids the loss of clients, who will no longer trust the quality of the fry/fingerlings, and also high operation costs to clean up the premises after an outbreak.

Biosecurity does not have to cost any extra money for farm management, as it is based on improved culture management practices. If biosecurity measures are not followed, more time and money are spent trying to cure a disease when it does occur. Section 4.8.4 highlights these common-sense methods.

4.8.4. Biosecurity in fish hatcheries

- Use uncontaminated broodstock, as TiLV transmits from mother to offspring. If contaminated broodstock are used, the hatchery will spread the disease among farms.
- Do not take live fish from outside without checking for diseases. Bringing in fish carrying pathogens (mostly without showing signs of disease) from other farms can introduce pathogens into the hatchery.
- Do not give fish live feed from outside the hatchery.
- Maintain sanitary conditions in the hatchery. Clean and sterilize all tanks and equipment.
- Do not use contaminated equipment without disinfecting it.
- Check the water source for contamination.
- Do not let outsiders enter the hatchery without sterilizing their hands and legs. Do not allow shoes from outside.
- Treat disease in broodfish and larvae. This can only be done in hatcheries, as the number of fish (and tanks) is relatively lower than in grow-out systems.
- Make sure the hatchery has controlled access areas (CAAs), which visitors can access, and restricted access areas (RAAs), which they cannot. To accomplish this, establish the sales center away from the hatchery.

4.8.5. Biosecurity for grow-out pond and cage culture

- Use uncontaminated seeds by buying disease-free seeds from a certified hatchery. Check the hatchery certificate before buying them. If the seeds are of substandard quality, with low survival and growth rates, use a different hatchery during the next culture cycle.
- If possible, send a sample of the fish to a laboratory to test whether they are pathogen-free.
- Buy seed from a nearby hatchery, as long transportation stresses fish and makes them vulnerable to common pathogens.
- For both pond and cage culture, do not build the farm next to another one. Maintain at least 500 m between farms.
- Maintain CAAs and RAAs.
- Use less water from outside sources and treat the water before adding it to the fishponds.
- Assess the risk of disease and identify critical control points to develop management procedures, such as contamination of the water source in the dry season and contaminated feeds, especially live feed.

4.8.6. Maintaining healthy fish

Maintaining the health of fish decreases the risk of disease. The grow-out stage includes three interrelated aspects in relation to their effect on stress in fish potentially initiating a disease. Stress is an important indicator, and it is important to manage (i) water quality and quantity, (ii) standing stock, including stocking and harvesting techniques and (iii) feeds and nutrition.

Stressed fish catch diseases easily. To limit stress, maintain optimal water quality parameters by keeping the DO high and temperatures between 25°C– 30°C. Do not use toxic chemicals. Keep stocking densities below 5 fish/m^2 in pond culture and below 30 kg/m^3 in cage culture. Also, be sure to provide all essential nutrients. When fish are healthy, their immune system and immune activities continue to function properly, thus avoiding diseases.

4.8.7. Exercises

Ask farmers or practitioners to share their experience on biosecurity threats to their farms and to identify where the threats come from (critical points)? What are the common sense sanitary and management measures that enhance the biosecurity of their farm? Make a list on the board. Discuss the following: What are the costs of implementing the identified procedures? What are the benefits? What are the constraints?

4.9. Aquaculture business management

4.9.1. Business basics

The main goal of commercial aquaculture is to maximize profits:

- Profits = Total revenue – Total cost
- Total revenue = Sum of all the sales receipts (gross income)

So, to earn higher profits, fish farmers must maximize total revenue and minimize costs.

Total revenue depends on fish yield and the farmgate price per kilogram. Yield is a function of survival rate, as a percentage of initial stocking density, and the average weight of the fish. The farmgate price is mainly a function of supply for a given demand of a particular market. When supply is high, the farmgate price is low, and vice-versa.

So for a grow-out farm:

Total revenue = Initial stock x % survival/100 x Average weight of fish (kg) x Farmgate price ($/kg)

Market forces beyond the control of producers are what dictate farmgate prices. There are three technical factors that producers can control to increase their revenue: (1) initial stocking density, (2) survival rate and (3) final weight of fish.

Total cost has two components: (1) fixed cost for land and equipment for fishpond farmers and (2) cage frame, net bag and equipment for cage fish farmers. Except land, all others depreciate in value over time and have to be replaced by new ones, such as pumps, aerators, cage frames and net bags. Operation costs include feed, fertilizers, electricity and labor. Feed is the main cost.

Total cost = fixed cost + total operation cost

Fixed cost = cost of land, pond, cage, equipment, etc.

Total operation cost = seed (fingerlings), feed, oxygen supply, water pumping/exchange, electricity, etc.

Reducing these costs requires best farm management procedures:

- Total revenue > the total costs → the business is generating a profit – economically sustainable aquaculture
- Total revenues < the total costs → the business is generating a loss – economically unsustainable aquaculture

Aquaculture businesses generate losses when costs exceed revenue. Both occur if an initial business plan and production management procedures are not in place.

To develop an initial business plan, consider the following questions:

- What to produce? For example, table-sized Nile tilapia.
- Which quality? For example, weight of the fish, flesh quality, thin and long or fat and round.
- How much to produce? For whom? Identify the target markets or agent, booker or intermediaries. What is the target market size? Can farmers switch buyers or middlemen when they bargain the farmgate price?
- How to produce efficiently? Define the resources required, such as seed, feed and fertilizers. Define how to combine them, such as stocking density and feeding regimen.

4.9.2. Commercial aquaculture

The goal of commercial aquaculture is to maximize profits, where profits represent revenues minus costs. Table 15 summarizes the major differences between commercial and non-commercial farming operations.

The following is a summary of the production economics, the pricing of the product, recordkeeping, and preparing a financial portfolio and business plan.

4.9.3. Developing a business plan for commercial aquaculture

A business plan is a document that details the fish farm business, its products, how it generates revenue, its leadership and workforce, finance sources and operational framework. It addresses the major aspects of the farm business, allows the owner to monitor the financial performance of the farm, and provides a guide for potential investors to make a decision on whether to invest (or provide a loan) or not. A generic business plan includes a description of the aquaculture enterprise, a marketing strategy and financial records or statements.

4.9.3.1. Business description

This describes the farm site and the production system, the legal structure and management capacity and the financial history of the farm. If it is for a new farm, the description shows the proponent's vision on how it will earn money with the proposed operations model of the business and products, and other details essential to the business' success.

4.9.3.2. Marketing plan

The marketing plan is divided into two sections: market analysis and marketing strategy. The marketing strategy is straightforward if the product is sold to an agent or broker. The marketing plan outlines the markets, the distance between markets and the farms, accessibility of the markets, transportation expenses, product delivery schedules and frequencies, the volume and size requirements of the market, and market price or price history. Use a SWOT analysis to create a marketing plan by determining the farm's strengths, weaknesses, opportunities and threats.

4.9.3.3. Financial documents/statements

The third section presents the estimated financing requirements and shows all financial statements. An essential part of farm management is maintaining farm inventory, such as what equipment is in the farm and how much feed is in stock, for example). Other recordkeeping, such as assets, resources, economic and financial data, is also important. This is the starting point for the preparation of financial statements for the farm. There are four important financial statements: (1) enterprise budget, (2) income statement, (3) balance sheet and (4) cash flow statement.

4.9.3.3.1. Enterprise budget

The enterprise budget is an estimate of the costs, revenues and profitability of a fish farm for a specific time period that assumes output targets and market prices. This demonstrates whether the planned fish farm is likely to be profitable over a specified timeframe, such as 5 years. Table 15 shows the structure of an enterprise budget. If the farmer or producer uses their own money for investment and the facility has been constructed on their own property, and assuming the depreciation cost of land is negligible (but accounting for the depreciation cost of equipment), they can make a partial budget for the enterprise to see whether the gross margin is positive.

Non-commercial aquaculture	Commercial aquaculture
Aquaculture is one economic activity, not the main one.	Aquaculture is the core economic activity.
Family food and livelihood security are the main drivers.	Making money is the main driver.
Use food for family consumption and sell surplus in the local market.	Sell products in local and foreign markets.
Consumer satisfaction is a secondary goal.	Business success depends on the satisfaction of buyers and consumers.
It generates profits for family income.	It generates profits for the business.
It uses family labor.	It depends on hired labor.
There are no wages.	Employers receive salaries.
It creates employment within the family.	It creates employment, either directly or indirectly, by supporting industry.
It creates input supply, output processing and supporting markets.	It creates input supply, output processing and supporting markets.
No taxes are paid.	It provides tax revenue to the government.

Table 15. Major differences between commercial and non-commercial aquaculture.

Item	Description	Unit	Quantity produced	Unit price	Total income/year
Sales of marketable tilapia	Average revenue from sales of whole table-sized tilapia	kg	A	B	A x B
Sales of other fish species	Average revenue from sales of other fish, if polyculture is practiced	kg			
Total gross receipts or gross revenue					
Variable costs					
Fingerlings	Average cost of fish stocked	no			
Feed	Average cost of artificial feed	kg			
Fertilizer					
Urea	Average cost of nitrogen-based inorganic fertilizers	kg			
TSP	Average cost of phosphorus-based inorganic fertilizers	kg			
Lime	Average cost of material used to correct water acidity	kg			
Organic fertilizer	Average expenditure of compost, organic manure, etc.	kg			
Veterinary and pharmaceutical products					
Product 1	Average cost of this disinfectant or sanitizer	kg			
Product 2	Average cost of this disinfectant	kg			
Employees					
Field workers	Average level of compensation paid to full-time field employees	no			
Guards	Average level of compensation paid to security staff	no			
Managers	Average level of compensation paid to directors	no			
Secretaries	Average level of compensation paid to people involved in the secretarial activities of the farm	no			
Accountants	Average level of compensation paid to people involved in the accounting activities of the farm	no			
Drivers	Average level of compensation paid to drivers of vehicles and other farm machinery	no			
Annual cost of service providers	Average level of compensation paid to temporary specialized staff	no			
Other variable costs					
Maintenance and repairs	Average annual cost for repair and maintenance of facilities				
Fuel and lubricants	Average annual amount spent on all fuels and lubricants required by the farm	L			
Electricity	Average annual amount spent on electricity required by the farm	kwh			
Water	Average annual amount spent on water resources consumed by the farm	m^3			
Interest on operating loan	Average annual amount paid to lenders as interest on operating funds	%			
Total variable costs					
Fixed costs					
Interest on investment loan	Average annual amount paid to lenders as interest on investment funds	%			
Farm insurance	Average annual amount paid to insure the farm and its facilities	ha			
Property taxes	Average annual amount paid as property taxes by the farm				
Other fixed costs	Average annual amount paid by the farm as other fixed costs not identified above				
Depreciation					
Support infrastructure	Average annual amount as the estimated annual reduction in the value of support infrastructure				
Equipment and machinery	Average annual amount as the estimated annual reduction in the value of equipment and machinery				
Ponds	Average annual amount as the estimated annual reduction in the value of ponds				
Total fixed costs (TFC)					
Total costs (TC)	TC = TVC + TFC				
Gross margin (GM)	GM = TGR - TVC				
Net returns (NR)	NR = TGR - TC				

Table 16. Enterprise budget for a Nile tilapia farm.

4.9.3.3.2. Income statement

This is a financial statement that summarizes the fish farm's financial transactions over a specified period, typically 1 year. It includes revenues, expenses and net returns.

Revenue includes sales of marketable Nile tilapia, sales of other fish species and total revenues. Expenses include variable cash expenses, fixed cash expenses and total cash expenses.

Variable cash expenses include veterinary and pharmaceutical products, wages of employees, other variable cash expenses (maintenance, repairs, fuel, electricity) and total variable cash expenses. Fixed cash expenses include interest on investment loans, farm insurance, property taxes, other fixed costs and total fixed cash expenses.

Net cash farm income is income above cash expenses, calculated as Net cash farm income = total revenues – total cash expenses.

4.9.3.3.3. Balance sheet

A balance sheet is a financial statement showing farm assets, liabilities and net worth of the farm.

4.9.3.3.4. Cash flow statement

This is a financial statement documenting the overall cash inflows and outflows for the fish farm over a specific period of time. This statement can determine the farm's borrowing requirements, loan repayment capabilities and probable loan repayment timeframes. It is crucial for obtaining bank loans.

4.9.4. Exercises

1. In groups of 10 or more, conduct a SWOT analysis for aquaculture in an African or a selected country or region.
2. As another group exercise, develop a crude business plan for a selected farm.

Plate 16. Feed stored in a tilapia cage farm in Thailand for regular feeding.

References

Baroiller J, Desprez D, Carteret, Tacon P, Borel F, Hoareau M, Mélard C and Jalabert B. 1997. Influence of environmental and social factors on the reproductive efficiency in three tilapia species, *Oreochromis niloticus*, *O. aureus*, and the red tilapia (Red Florida strain). In Fitzsimmons K, ed. Proceedings of the Fourth International Symposium on Tilapia in Aquaculture. 238–52.

Beveridge MCM. 1984. Cage and pen fish farming: Carrying capacity models and environmental impact. FAO Fisheries and Technical Paper T255. Rome: FAO. http://www.fao.org/3/AD021E/AD021E00.htm

Boyd CE. 1998. Water quality for pond aquaculture. http://soiltesting.tamu.edu/publications/AU43.pdf

Boyd CE and Tucker CS. 1998. Pond Aquaculture Water Quality Management. Boston, US: Kluwer Academic Publishers.

Boyd CE. 2015. *Water Quality: An Introduction*. 2nd ed. Auburn, US: Springer. https://www.mobt3ath.com/uplode/book/book-23387.pdf

Cardia F and Lovatelli A. 2015. Aquaculture operations in floating HDPE cages: A field handbook. FAO Fisheries and Aquaculture Technical Paper No. 593. Rome: FAO. http://www.fao.org/3/a-i4508e.pdf

Dong HT. 2018a. Emerging, re-emerging and new diseases of tilapia. Paper presented at the FAO/China Intensive Training Course on Tilapia Lake Virus (TiLV), Sun Yat-sen University, Guangzhou, China, June 18–24, 2018. http://www.fao.org/fi/static-media/MeetingDocuments/TiLV/p5.pdf

Dong HT. 2018b. Bacterial diseases of tilapia. Paper presented at the FAO/China Intensive Training Course on Tilapia Lake Virus (TiLV), Sun Yat University, Guangzhou, China, June 18–24, 2018. http://www.fao.org/fi/static-media/MeetingDocuments/TiLV/dec2018/p15.pdf

El-Sayed AFM. 2006. *Tilapia Culture*. Wallingford, UK: CAB International. doi:10.1079/9780851990149.0000

Engle CR and Neira I. 2005. *Tilapia Farm Business Management and Economics: A Training Manual Aquaculture*. Pine Bluff, Arkansas: University of Arkansas. http://pdacrsp.oregonstate.edu/pubs/engle_manual.pdf

[FAO] Food and Agriculture Organization. 2018. FAO workshop in China on TiLV. Sun Yat University, Guangzhou, China, June 18–24, 2018. http://www.fao.org/fi/static-media/MeetingDocuments/TiLV/dec2018/Default.html

Garcia F, Romera DM, Gozia SK, Onaka EM, Fonseca FS, Schalch SHC, Candeira PG, Guerra LOM, Carmo FL, Carneiro DJ et al. 2013. Stocking density of Nile tilapia in cages placed in a hydroelectric reservoir. *Aquaculture* 410–411:51–56.

Guerrero RD III and Shelton WL. 1974. An aceto-carmine squash method for sexing juvenile fishes. The Progressive Fish-Culturist 36(1): 56 doi:10.1577/1548-8659(1974)36[56:AASMFS]2.0.CO;2

Hishamunda N, Martone E and Menezes A. 2017. Doing aquaculture as a business for small- and medium-scale farmers: Practical training manual; Module 2: The economic dimension of commercial aquaculture. Rome and Addis Ababa: FAO. http://www.fao.org/3/a-i7798e.pdf

Homziak JC, Veal CD and Hays D. 1996. Design and construction of aquaculture facilities in dredged material containment areas. Technical Report EL-93-11 Aquaculture Program July 1993, U.S. Army Corps. of Engineers. https://www.researchgate.net/publication/235044540_Design_and_Construction_of_Aquaculture_Facilities_in_Dredged_Material_Containment_Areas

Kumar V and Karnata G. 2004. Engineering consideration for cage aquaculture. *IOSR Journal of Engineering* 4(6):11–18. http://iosrjen.org/Papers/vol4_issue6%20(part-6)/C04661118.pdf

Lin CK, Shrestha MK, Thakur DP and Diana JS. 1997. Management to minimize the environmental impacts of pond draining. Corvallis, US: Oregon State University. http://pdacrsp.oregonstate.edu/pubs/technical/15tch/15tech_TOC.html

Macintos DJ and Little DC. 1995. Nile tilapia (*Oreochromis niloticus*). In Bromage NR and Roberts JR, eds. Brood stock management and egg and larval quality. Oxford: Blackwell Sciences. 277–320.

Menezes A, Hishamunda N, Lovshin L and Martone E. 2017. Doing aquaculture as a business for small- and medium-scale farmers: Practical training manual; Module 1: The technical dimension of commercial aquaculture. Rome and Addis Ababa: FAO. http://www.fao.org/3/a-i7461e.pdf

Moe H. 2009. Strength analysis of net structures. [PhD thesis] Norwegian University of Science and Technology, Norway. https://www.researchgate.net/profile/Heidi_Moe_Fore/publication/277860417_Strength_analysis_of_net_structures/links/5a4b94a60f7e9b8284c1ab04/Strength-analysis-of-net-structures.pdf

Mohamed Din MS and Subasinghe R. 2017. Basic biosecurity manual for tilapia hatchery technicians in Bangladesh. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Manual: FISH-2017-10. https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/664/FISH-2017-10.pdf

Mukami NM. 2010. Assessing the potential of small-scale Aquaculture in Embu district, Kenya, using GIS and remote sensing. [MSc thesis] Moi University, Kenya. https://www.oceandocs.org/bitstream/handle/1834/9087/MSc%20Thesis%20Mukami.pdf?sequence=1&isAllowed=y

Mwera P. n.d. Tilapia biology: On farm biosecurity. Bluechip Fisheries International. http://www.fao.org/fi/static-media/MeetingDocuments/TiLV/dec2018/p11.pdf

Nandlal S and Pickering T. 2004. *Tilapia Fish Farming in Pacific Island Countries, Vol. 1. Tilapia Hatchery Operation*. Noumea, New Caledonia: Secretariat of the Pacific Community. 190–203.

[NRC] National Research Council. 1993. Nutrient requirements of fish. Washington DC, US: National Academy Press. http://www.bouillettes-dependance-baits.com/res/site19627/res588041_nutriments.pdf

Olivares AAV. 2003. Design of a cage culture system for farming in Mexico. United Nations University, Fisheries Training Programme. http://www.unuftp.is/static/fellows/document/alfredo03prf.pdf

Ridler N and Hishamunda N. 2011. Promotion of sustainable commercial aquaculture in Sub-Saharan Africa. FAO Fisheries Technical Paper 408/1 Rome: FAO. https://www.fao.org/3/X9894E/x9894e00.htm#Contents

Siraj SS, Smitherman RO, Castillo-Gallusser S and Dunnham RA. 1983. Reproductive traits for three year classes of *Tilapia nilotica* and maternal effects on their progeny. In Fishelson L and YaronInternational Z, eds. Symposium on Tilapia in Aquaculture, Proceedings. 210–18.

Towers L. 2010. How to farm Nile tilapia. Accessed on 20 May 2023. https://thefishsite.com/articles/cultured-aquaculture-species-nile-tilapia

Towers L. 2011. Better management practices for tilapia cage farming in Viet Nam. Accessed on 20 May 2023. https://thefishsite.com/articles/better-management-practices-for-tilapia-cage-farming-in-viet-nam

World Wildlife Fund. 2009. International Standards for Responsible Tilapia Aquaculture. Gland, Switzerland: WWF. http://d2ouvy59p0dg6k.cloudfront.net/downloads/wwfbinaryitem14693.pdf

World Wildlife Fund. 2011. Better management practices for tilapia aquaculture: A tool to assist with compliance to the International Standards for Responsible Tilapia Aquaculture Version 1.0. Gland, Switzerland: WWF. https://www.asc-aqua.org/wp-content/uploads/2017/07/ASC-Tilapia-Better-Management-Practices_v1.0.pdf

Yi Y, Lin CK and Diana JS. 1996. Influence of Nile tilapia (*Oreochromis niloticus*) stocking density in cages on their growth and yield in cages and in ponds containing the cages. *Aquaculture* 146:205–15.

WorldFish CGIAR

About WorldFish

WorldFish is a leading international research organization working to transform aquatic food systems to reduce hunger, malnutrition and poverty. It collaborates with international, regional and national partners to co-develop and deliver scientific innovations, evidence for policy, and knowledge to enable equitable and inclusive impact for millions who depend on fish for their livelihoods. As a member of CGIAR, WorldFish contributes to building a food- and nutrition-secure future and restoring natural resources. Headquartered in Penang, Malaysia, with country offices across Africa, Asia and the Pacific, WorldFish strives to create resilient and inclusive food systems for shared prosperity.

For more information, please visit www.worldfishcenter.org