Food and Agriculture
Organization of the
United Nations

Doing aquaculture as a business for small- and medium-scale farmers

Practical training manual

Module 1: The technical dimension of commercial aquaculture

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Abstract

The "Doing aquaculture as a business for small- and medium-scale farmers. Practical training manual" is composed of two modules: **Module 1** "The technical dimension of commercial aquaculture" and **Module 2** "The economic dimension of commercial aquaculture".

The target users of both modules are trainers, educators, extension officers as long as are small- and medium-scale fish farmers.

The purpose of this module is to enhance their knowledge and capacities in understanding and applying the **basic technical principles and concepts of commercial aquaculture** in their daily activities.

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Abbreviations and acronyms

ASTF	Africa Solidarity Trust Fund
AU	African Union
$Al_2(SO_4)_3$	Alum
$AlPO_4$	Aluminium Phosphate
BGI	Blue Growth Initiative
BOD	Biological Oxygen Demand
C	Carbon
$C_6H_{12}O_2$	Carbohydrates
Ca	Calcium
$Ca(HCO_3)_2$	Calcium Bicarbonate
Ca++	Bivalent Ions of Calcium
$Ca_3(PO_4)_2$	Tricalcium Phosphate
$CaCl_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate
$CaSO_4{\cdot}2H_2O$	Gypsum
CC	Carrying Capacity
Cl-	Chlorine
Co	Cobalt
CO_2	Carbon dioxide
CO_3^{2-}	Carbonate
CSC	Critical Standing Crop
Cu	Copper
DO	Dissolved oxygen
FCR	Feed Conversion Ratio
Fe	Iron
FMM	FAO Multipartner Programme Support Mechanism
GR	Growth Rate
GY	Gross Yield
H_2CO_3	Carbonic Acid
H_2O	Water
HCO_3-	Bicarbonate
I	Iodine

K	Potassium
K+	Ions of Potassium
K_2CO_3	Potassium Carbonate
$KHCO_3$	Potassium Bicarbonate
Mg	Magnesium
Mg++	Bivalent Ions of Magnesium
$MgSO_4$	Magnesium Sulphate
N	Nitrogen
N_2	Nitrogen Gas
Na+	Ions of Sodium
Na_2CO_3	Sodium Carbonate
NaCl	Sodium Chloride
NH_3	Unionized ammonia
NH_4^+	Ionized Ammonia
NO_2^-	Nitrite
NO_3^-	Nitrate
NY	Net Yield
O_2	Oxygen
OH-	Hydroxide
P	Phosphorous
PP	Primary Production
PPR	Primary Productivity
PR	Production Rate
PTO	Power Take-Off
SAE	Standard Aeration Efficiency
SC	Standing Crop
Se	Selenium
SiO_3^{--}	Silicate
SO_4^{--}	Sulphate
TAN	Total Ammonia Nitrogen
TP	Total Production
UNECA	United Nations Economic Commission for Africa
Zn	Zinc

Introduction

The “Doing aquaculture as a business for small- and medium-scale farmers. Practical training manual” is composed of two modules: **Module 1** “The technical dimension of commercial aquaculture” and **Module 2** “The economic dimension of commercial aquaculture”.

The target users of both modules are trainers, educators, extension officers as long as small- and medium-scale fish farmers.

The purpose of both modules is to enhance their knowledge and capacities in understanding and **applying the concepts necessary to commercial aquaculture** in their daily activities. Specifically, Module 1 addresses the **technical dimension** of commercial aquaculture.

Module 1 will introduce the factors affecting primary productivity, carrying capacity, growth rate and yield in water (Chapter 1), the general criteria for classifying the aquaculture systems (Chapter 2) and the main features of both pond- and cage-based fish farming systems (Sections 3.1 and 3.2, respectively). In Chapter 4, the pond-based fish farming system will be further explored by introducing, in general terms, the design and construction of pond farms. The concepts of seed production (Chapter 5), nutrition and feeds (Chapter 6) and harvest and post-harvest practices (Chapter 7) will be also introduced.

1 Principles of aquaculture

The foundation for successful aquaculture is the understanding of the ecological principles which determine the weight of an organism that can be harvested from a unit of water in a given period and level of culture.

In order to be successful, the farmer needs to develop an understanding of the relationship between the farmed organism, its stocking density, the nutrient inputs into the culture unit and the effect of all these elements on water quality.

These principles hold true regardless of the aquaculture product (e.g. fish, shrimp, and molluscs) and the farming system (e.g. pond, cage, and tanks). However, biological principles must be combined with socio-economic principles to assure that the aquaculture is profitable and sustainable.[1]

1.1 Key definitions

Aquaculture

Aquaculture is “the **farming of aquatic organisms** including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of **intervention in the rearing process** to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate **ownership of the stock** being cultivated” (FAO, 2002).

Standing crop

The **Standing Crop** (SC) indicates the biomass in a unit of area at a given moment. It can be expressed as, for example, pounds per acre (lb/acre), kilograms per hectare (kg/ha), kilograms per cubic metre (kg/m^3).

The **Carrying Capacity** (CC) measures the maximum biomass of a farmed species that can be supported without violating the maximum acceptable impacts to the farmed stock and its environment in a given unit of area (Stigebrandt, 2011). Time is not a factor in determining when CC is reached.

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[1] Economic principles are addressed in Module 2: The economic dimension of commercial aquaculture.

The **Critical Standing Crop** (CSC) indicates the biomass in a unit of area at a given moment, when the growth slows from the maximum growth line.

Yield

The **Gross Yield** (GY) defines the total biomass of the organisms harvested per unit of area (volume) in a given period. It can be expressed as, for example, pounds per acre per year (lb/acre/yr), kilograms per hectare per year (kg/ha/yr), kilograms per cubic metre per year (kg/m^3/yr).

The **Net Yield** (NY) indicates the total weight of the organisms harvested minus the total weight of organisms stocked per unit of area (volume) in a given time.

Primary production

The **Primary Production** (PP) measures the increase in plant biomass over a given period. It is usually reported as kilograms per hectare (kg/ha) or grams per square metre (g/m^2).

The **Primary Productivity** (PPR) is the rate of formation of new organic matter (Equation 1). It can be expressed as, for example, kilograms per hectare per day (kg/ha/day) or grams per square metre per day (g/m^2/day). The net PP, or net PPR, measures the organic matter created by the photosynthesis[2] process less the organic matter used in respiration (Boyd, 1990).

$$PPR = \frac{PP}{Time} \qquad (1)$$

Production

The **Total Production** (TP) shows the total weight of the organic matter assimilated by an organism in a given area (volume) in a given period. The assimilated organic matter includes both living and dead organisms. TP is measured by summing up the weight of the organisms harvested (Yield) and the weight of dead organisms (Mortality), as shown in Equation 2.

$$TP = Yield + Mortality \qquad (2)$$

The **Production Rate** (PR) measures the increase in weight (growth) of a population of organisms per unit area in a given time. It can be expressed as, for example, pounds per acre per day (lb/acre/day), kilograms per hectare per day (kg/ha/day), kilograms per cubic metre per year (kg/m^3/yr).

1.2 Factors influencing primary productivity in water

All fish (animals) are directly or indirectly dependent upon green plants for food. Microscopic plants are the principal food-producing plants for most cultured aquatic species.

Phytoplankton is the most desirable microscopic plant because of its high nutritive value, high productivity, mobility and small size. Moreover, phytoplankton do not provide hiding places and/or substrate for mosquito larvae, snails and unwanted small fish.

Rooted aquatic plants compete with phytoplankton for sunlight and nutrients, and they make fish more difficult to harvest. Normally, phytoplankton and rooted aquatic plants cannot exist in high concentrations in the same pond at the same time.

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[2] "The process by which green plants and algae use the energy of light to manufacture carbohydrates from carbon dioxide and water; oxygen is given off as a by-product" (FAO, 2017).

Rooted aquatic plants have a competitive advantage in shallow, clear water ponds where sunlight can reach the pond bottom and the plants can obtain nutrients through their roots from the pond bottom soil.

Rooted aquatic plants can be beneficial to: remove excess nutrients from pond bottom mud, prevent pond margin erosion, provide food for some species of fish (e.g. grass carp) and crustaceans (e.g. crayfish), provide spawning substrate (e.g. common carp), provide cover for small fish from predators, and precipitate suspended clay particles from pond water.

However, if/when rooted plants become established, phytoplankton will not be able to dominate. Rooted plants have to be eliminated by chemical, mechanical or biological means before a good phytoplankton bloom will flourish. Grass carp are a good way to control aquatic weeds biologically.

Fish are difficult to harvest with nets from a pond crowded with rooted plants. In shallow ponds, recently filled ponds should be fertilized immediately to establish a phytoplankton bloom that will shade rooted plants and hinder their growth.

The weight of fish that can be produced in fertilized ponds is dependent upon the ability of water to produce the necessary plants.

Box 1. Factors influencing primary productivity in water

The ability of water to produce plants is dependent upon:

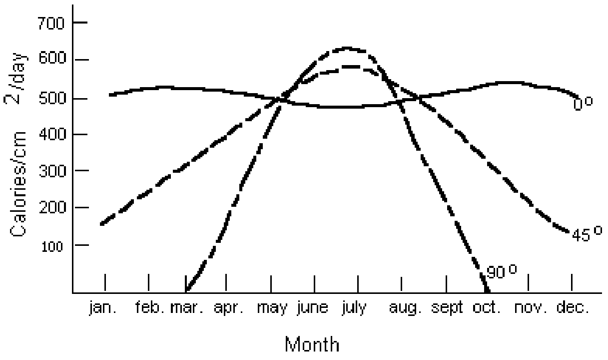
- Sunshine
- Temperature
- Minerals
- Carbon
- Dissolved oxygen

Sunshine

Photosynthetic activities stop in the absence of light or slow down when light is reduced.

In a temperate climate, late spring and early summer are potentially the most productive times of the year because of the length of the day. During the same period, primary production can be higher in northern latitudes. However, on a year-round basis, the tropics receive more solar radiation than temperate zones (Figure 1).

Figure 1. Total energy received from direct solar radiation at different latitudes



Source: (Reid, 1961)

Primary producers use only 1 to 5 percent of incoming solar radiation. Increasing light intensity will only increase photosynthesis to a certain point; thereafter increases in light intensity do not result in an increase in photosynthesis. Some phytoplankton (some types of blue-green algae) and aquatic plants (*chara*) cannot grow well in environments with high light intensity.

Sunlight is reduced or blocked by clouds, ice, floating aquatic plants, trees and turbidity due to soil particles or phytoplankton. To control photosynthetic activity in aquaculture ponds **inorganic turbidity** can be managed by applying:

- **Organic matter** (e.g. manures, cottonseed meal, rice bran) at a rate of, for example, 500–2 000 kilograms per hectare (kg/ha) to settle out muddy ponds and stimulate phytoplankton production. The organic matter has an oxygen demand so the quantity to apply depends on the tolerance of the cultured species (Hargreaves, 1999).
- **Alum** ($Al_2(SO_4)_3$) which is very effective at precipitating inorganic turbidity but can reduce pH[3] in water with low alkalinity[4] (Yi *et al.*, 2003). 10–15 milligrams per litre (mg/l) of alum usually clears up ponds. Alum below 50 mg/l is seldom toxic to fish. 1 mg/l of alum destroys 0.5 mg/l of alkalinity, producing 0.44 mg/l of carbon dioxide (CO_2).
- **Gypsum** ($CaSO_4 \cdot 2H_2O$) may be less effective at precipitating inorganic turbidity than alum — but is much cheaper, does not affect pH, and is often relatively effective. At an application rate of 1 000 lbs/acre, gypsum is often the recommended strategy for reducing inorganic turbidity in aquaculture ponds (Hargreaves, 1999).

Any treatment to reduce inorganic turbidity will have only a short-term effect if the source of turbidity continues. Often, it is not cost-effective to treat ponds for turbidity if they have frequent inflow of muddy water (e.g. from muddy streams or rainwater runoff from open fields), or have heavy standing crops of certain fish such as common carp, or are accessible to cattle (Yi *et al.*, 2003).

Organic turbidity, i.e. phytoplankton, can reduce photosynthetic activity and cause an off flavour in fish. Some types of blue–green algae release chemicals into the water that are absorbed by the fish through their gills and can cause fish flesh to taste and smell muddy. Muddy tasting, off-flavour fish are disagreeable to many consumers (Tucker, 2000). Excessive phytoplankton "blooms" can be controlled by:

- **Aquashade** (an inert blue dye) to reduce light penetration for 3–6 months. Aquashade will lower the phytoplankton population by reducing the amount of light available to phytoplankton for photosynthesis.
- **Algaecide** to be applied to ponds to eliminate a portion of the phytoplankton population. Copper sulphate is cheap and effective but must be used carefully, especially in low alkalinity waters, otherwise fish mortality can occur. Copper sulphate should not be applied in water with a total alkalinity of under 50 mg/l, since it may cause fish mortality, or over 300 mg/l, since copper is ineffective because it would precipitate out of solution too quickly to kill phytoplankton. The formula for determining the correct amount of copper sulphate to apply is (Equation 3):

$$Copper\ sulphate(mg/l) = \frac{Total\ alkalinity\ (mg/l\ as\ Calcium\ Carbonate\ [CaCO_3])}{100} \quad (3)$$

Water temperature

Low water temperature lowers the metabolic activity of cultured aquatic species, by reducing their productivity. High standing crops of plants[5] are possible in cold waters but productivity is low since their growth and reproduction are slow (Azaza *et al.*, 2008). Highest yearly plant productivity is possible in tropical climates where water temperatures are warm enough to permit year-round plant growth and

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[3] "A term used to describe the hydrogen ion activity of a solution or a soil. The pH of pure water is seven and is referred to as neutral. A solution of pH less than seven is said to be acid whereas a solution of pH above 7 is said to be alkaline" (FAO, 2017).

[4] Alkalinity is a measure of the total bases reacting with a strong acid expressed as calcium carbonate ($CaCO_3$). Alkalinity is normally a measure of ions of bicarbonate (HCO_3-) and carbonate (CO_3^{2-}). See "Other minerals" section.

[5] The weight of plant material that can be sampled or harvested at any one time from a given area (Boyd, 1990).

reproduction. Extremely high water temperatures can also reduce primary productivity by speeding up the metabolic processes to such an extent that photosynthesis and reproduction are harmed.

Minerals

The natural fertility of water — i.e. its quantity of minerals — is dependent upon the fertility of watershed, pond soils, and the quality and quantity of water used to fill the ponds.

Water is a universal solvent and can dissolve many materials. In general, water in high rainfall areas is low in minerals due to excessive leaching of the soils; on the other hand, water in low rainfall areas is high in minerals due to evaporation, which leaves the minerals behind.

If fertilizers and pesticides placed on watersheds gain access to the culture unit, they can influence the productivity of the cultured organisms.

The principal limiting minerals are the macronutrients nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and the micronutrients (or trace minerals).

The Redfield ratio, i.e. the ratio of carbon (C), nitrogen and phosphorus of phytoplankton, is $50:10:1\ (C:N:P)$, so ponds should have about $10:1\ (N:P)$, i.e. ten parts of nitrogen to one part of phosphorous for the best phytoplankton growth (Goldman, 1979).

Nitrogen

The principal sources of nitrogen in pond waters are from fertilizers and feeds. Nitrogen enters into water principally in the form of un-ionized ammonia excreted by the fish through their gills and by decomposing (heterotrophic) bacteria.

Box 2. Forms of nitrogen found in water

- Gas (N_2)
- Un-ionized ammonia (NH_3)
- Ionized ammonia (ammonium ion) (NH_4^+)
- Total Ammonia Nitrogen (TAN) $= {NH_4}^+ + NH_3$
- Nitrite (NO_2^-)
- Nitrate (NO_3^-)
- Organic nitrogen, nitrogen in amino acids, proteins, etc. found in plant and animal bodies

On a dry weight basis, 60 to 70 percent of the nitrogen in fish feed is excreted. For every kilogram of feed with 32 percent protein fed, 34 grams of nitrogen is excreted (Avnimelech and Kochba, 2009).

Typically, 35 percent of the protein in commercial feeds is excreted as ammonia: for every 100 grams of dietary protein fed, 5.6 grams of ammonia is excreted by fish (Lovell, 1989). The ammonia production rate can be expressed as (Soderberg, 1994):

$$A = 56 \times PF \qquad (4)$$

Where *A* is the ammonia production rate in grams of total ammonia nitrogen (TAN) per kilogram of feed and *PF* is the percentage of protein contained in feed.

Box 3. How to calculate the ammonia production rate

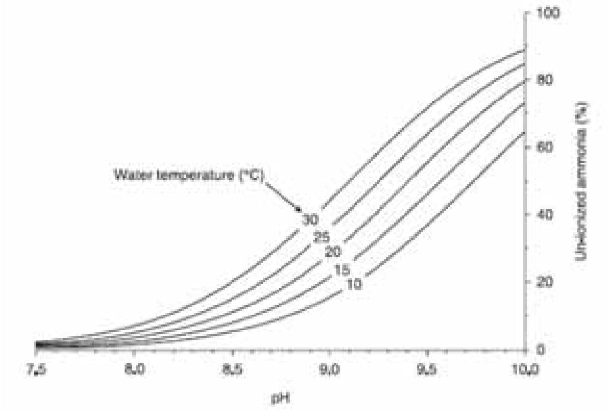
For example, for one kilogram of feed with 32 percent protein, the ammonia production rate is 17.92 grams of TAN per kilogram of feed.

$$A = 56 \times\ PE = 56 \times 32\% = 17.92\ TAN\ (g)\ \text{per kilogram of feed}$$

Two forms of nitrogen are toxic to aquatic animals: un-ionized ammonia (NH_3) and Nitrite (NO_2^-). **Un-ionized ammonia** is excreted by fish and bacteria and quickly reaches equilibrium with ionized ammonia (NH_4^+) depending on the water temperature and pH. The fraction of the total ammonia in the toxic un-ionized form increases with an increase in water temperature and pH. Acid waters thus have low levels of un-ionized ammonia and high levels of the less toxic ionized ammonia, while alkaline waters are the opposite. Problems with ammonia toxicity are most likely in high alkalinity waters or in fertile, low alkalinity waters, when afternoon pH levels increase from 9.0 to 10.0 due to photosynthetic activity. Un-ionized ammonia levels of 0.2 mg/l to 0.5 mg/l are stressful to fish and 1.0 mg/l to 1.5 mg/l can kill fish (Ip *et al.*, 2001).

Figure 2 shows that the proportion of un-ionized ammonia increases as a function of pH and temperature. Un-ionized ammonia levels can be reduced by lowering the pH (e.g. buffer soft waters with lime), water exchange, aeration and stop feeding.

Figure 2. The influence of water temperature and pH on the percentage of un-ionized ammonia



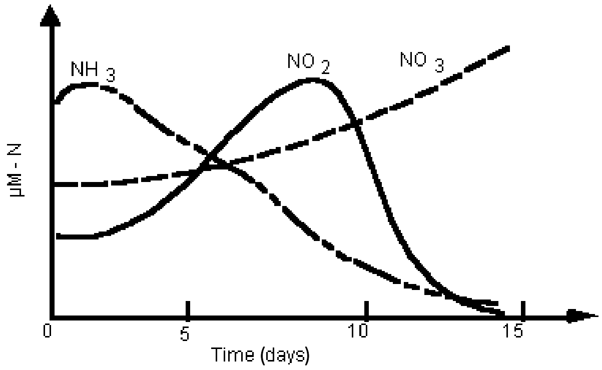
Source: (Hargreaves and Tucker, 2004)

Nitrite toxicity is known as brown blood disease. Fish appear to be suffering from oxygen deficiency even though dissolved oxygen levels are high (Atwood *et al.*, 2001). Nitrite interferes with the ability of the blood to transport oxygen. Levels of 1.5 mg/l to 20 mg/l have been reported to kill fish. Levels of nitrite can be reduced by exchanging water and stop feeding. Maintaining a ratio of 6 to 1 of chloride ion to nitrite will reduce the chances of nitrite toxicity (Atwood *et al.*, 2001). The cheapest source of chloride ion is usually rock salt (Sodium chloride [NaCl]). Many USA channel catfish farmers add rock salt to their ponds to prevent nitrite toxicity. However, salted ponds should not be flushed or drained so as to retain the chloride ion.

Ammonia and nitrite are not usually a problem during the summer months when phytoplankton removes most of the ammonia in the water. Ammonia levels can jump after phytoplankton dies naturally or is killed. This happens because, in addition to the ammonia released by the fish, ammonia is also released by the bacteria which decompose the dead phytoplankton, and the phytoplankton is no longer available to remove the ammonia. However, increased bacterial respiration releases carbon dioxide (CO_2) which is not utilized by photosynthesizing phytoplankton and the pH is lowered, reducing the amount of un-ionized ammonia in the water.

Most ammonia and nitrite problems occur in the autumn, winter and spring when phytoplankton populations are undergoing seasonal changes and the metabolic rate is reduced due to lower water temperature; ammonia removal from pond water is therefore reduced. Ammonia and nitrite will eventually be oxidized to non-toxic nitrate (NO_3^-) by bacteria (Figure 3). However, the bacterial response to rapid increases in ammonia and nitrite requires several days to allow bacterial populations to multiply.

Figure 3. Changes in the levels of NH_3, NO_2^- and NO_3^- in response to bacterial oxidation



Source: (Shilo and Rimon, 1982)

Nitrogen is both a necessity in fertilized ponds and an impediment in ponds where fish are fed. Where the principle source of fish food is based on phytoplankton and the related food chain, nitrogen is necessary to produce the phytoplankton. However, where the principle source of fish food is feed obtained outside the pond, nitrogen waste products commonly limit the amount of fish produced.

Phosphorous

The major sources of phosphorous (P) in pond water are fertilizers, feeds and — infrequently — pond water source. Phosphorous in plant proteins such as phytic acid (soybean meal) cannot be digested by catfish and is excreted. In the catfish diet, 70 percent of the phosphorous in a 32 percent-protein feed is excreted.

Phosphorous is not toxic to fish and does not cause problems in aquaculture ponds directly. Indirectly, however, an excess of phosphorous in the water can cause heavy phytoplankton blooms, which can cause dissolved oxygen (DO) and an off flavour in the fish.

Phosphorous is commonly considered the principal limiting mineral for phytoplankton growth. Phosphorous is quickly lost to pond soils and little is returned to the water.

Other minerals

Potassium (K) is rarely limiting in aquatic systems and is not toxic to fish in the amounts found in pond waters. Calcium (Ca) and Magnesium (Mg) are the other minerals commonly found in pond waters.

Extremely low levels of calcium (< 5 mg/l) may cause slowed growth or bone deformities. Fish normally obtain the needed calcium from culture water by absorption through the gills. For good growth, crustaceans require more calcium in the water than fish.

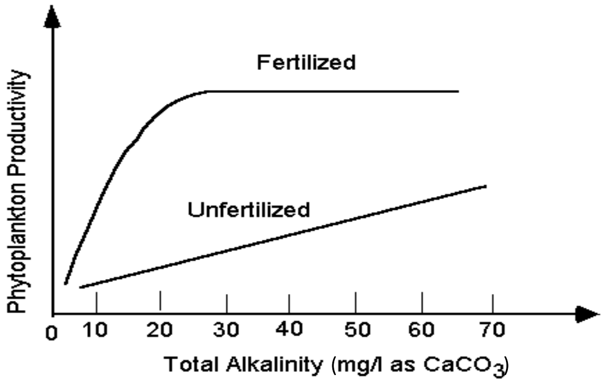
Magnesium, and therefore some dietary magnesium, is also needed for good growth of fish. However, the ingredients used to formulate fish feeds normally have enough magnesium to meet fish requirements. Trace minerals (cobalt [Co], iodine [I], zinc [Zn], selenium [Se], iron [Fe] and copper [Cu]) are also needed for good fish growth and health. A trace mineral mix is commonly added to fish feeds to assure good fish growth in culture systems, where fish obtain little nutritional benefit from natural foods.

Water hardness is a measure of the total amount of divalent salts and is normally found as bivalent ions of calcium (Ca++) and magnesium (Mg++). Water low in minerals is called soft water and water high in minerals is called hard water.

Alkalinity is a measure of the total bases reacting with a strong acid expressed as Calcium Carbonate ($CaCO_3$). Alkalinity is normally a measure of ions of bicarbonate (HCO_3-) and carbonate (CO_3^{2-}).

Figure 4 shows the relationship of phytoplankton productivity and total alkalinity in fertilized and unfertilized ponds. Fertilized waters with a total alkalinity of 25 mg/l are sufficient for maximum phytoplankton productivity and additional alkalinity will not result in increased phytoplankton productivity.

Figure 4. Relationship between phytoplankton productivity and total alkalinity in ponds



Source: (Boyd, 1990)

Alkaline waters are normally more fertile and productive than acid waters because alkaline waters have more minerals (nutrients) available for plant growth. Freshwater between pH 6.5 and pH 5.5 should be limed to improve the productivity. While, freshwater with a pH below 5.5 should be avoided for aquaculture purposes as the cost of neutralizing the water with lime is often costly.

Precise liming requirements can be determined by measuring the soil capacity to resist changes in pH levels.

Box 4. Example of lime supply

In heavily fed ponds with low alkalinity and with soil buffering analysis not available, between 1 000–2 000 kg/ha of agriculture lime could be added.

The alkalinity of pond water could then be measured again after three weeks.

If alkalinity remains below 25–30 mg/l of $CaCO_3$, the liming procedure should be repeated.

It should be noted that a total alkalinity above 40 mg/l is hard to obtain using agricultural lime.

Carbon

Carbon (C) is needed for photosynthesis. The main sources of carbon for phytoplankton are carbon dioxide (CO_2), from the atmosphere and respiration, and bicarbonate (HCO_3-), from alkalinity. The photosynthesis process stops when free carbon dioxide or bicarbonates are unavailable to provide carbon dioxide.

Carbon is not a limiting factor in natural or low fertility waters. However, in heavily fertilized and/or fed ponds, a heavy bloom of phytoplankton can exploit the available carbon dioxide during sunny days, thereby slowing down or stopping the photosynthesis process.

Carbon dioxide is highly soluble in water and the solubility is inversely related to temperature, i.e. 1 mg/l at 3 °C and 0.4 mg/ l at 30 °C. Bicarbonate and carbonate are more soluble in water than carbon dioxide, and they can disassociate to provide more carbon dioxide than that provided by the atmosphere.

Box 5. Solubility of carbon dioxide, calcium bicarbonate and calcium carbonate

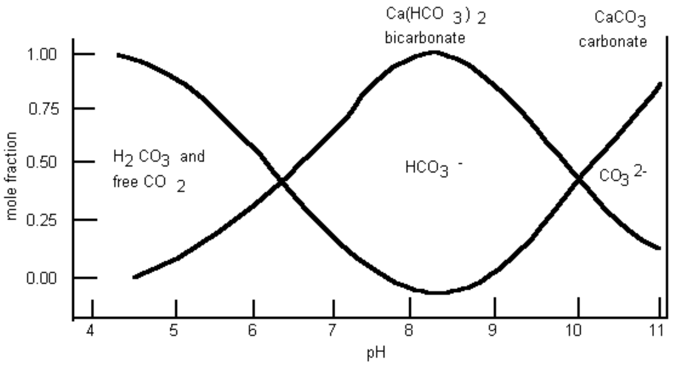
Solubility in freshwater with a temperature of 25 °C of carbon dioxide (CO_2), calcium bicarbonate, also called calcium hydrogen carbonate ($Ca(HCO_3)_2$), and calcium carbonate ($CaCO_3$) and the following pH (Figure 5):

$$\left\{ \begin{array}{l} \qquad\qquad\qquad 6\,pH \\ = 0.5\,mg\ of\ \ CO_2/l\,, which\ provides\ 0.5\,mg\ of\ CO_2/l \end{array} \right.$$

$$\begin{cases} 8\,pH \\ = 66\,mg\ of\ \ Ca(HCO_3)_2/l\,, which\ provides\ 16\,mg\ of\ CO_2/l \end{cases}$$

$$\begin{cases} 10\,pH \\ = 20\,mg\ of\ \ CaCO_3/l\,, which\ provides\ 4.4\,mg\ of\ CO_2/l \end{cases}$$

Figure 5. Effects of pH on the mole fraction of H_2CO_3, free CO_2, HCO_{3^-} and CO_3^{2-} in freshwater



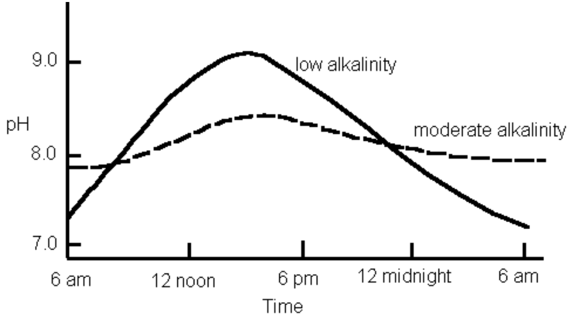
Source: *(Boyd, 1990)*

Acid water with low pH can be limited in carbon dioxide, thereby reducing primary productivity compared to alkaline water with a higher pH. In acid waters lime should be added to increase alkalinity (bicarbonate) and provide more carbon dioxide in order to increase the pH and improve the availability of phosphorous to plants. pH affects the abundance of free carbon dioxide:

- at a pH of less than 5 almost all carbon is in the form of carbonic acid (H_2CO_3) and carbon dioxide (CO_2);
- at a pH of 8.3 almost all carbon is in the form of bicarbonate (HCO_3-).

Figure 6 shows the diel cycle of pH in low and moderate alkalinity ponds. When carbon is limited, the photosynthesis process increases the pH, especially in low alkalinity waters.

Figure 6. Fluctuation of pH in low and moderate alkalinity ponds



Source: *(Boyd, 1990)*

In fertile ponds phytoplankton consume carbon dioxide (CO_2) faster than it is produced through respiration. When the CO_2 is depleted, pH rises to at least 8.3.

When the carbonate (CO_3^{2-}) is from calcium carbonate ($CaCO_3$), CO_3^{2-} precipitates at a high pH, so pH will not be driven much higher than 10.5. If the CO_3^{2-} comes from sodium carbonate (Na_2CO_3) or potassium carbonate (K_2CO_3), these are more soluble than $CaCO_3$ so pH can be driven even higher. Waters with a high, early morning total alkalinity should be avoided for feed-based aquaculture because of problems with un-ionized ammonia toxicity. Waters in which alkalinity is derived from Na_2CO_3 and K_2CO_3 are difficult to correct by lowering pH.

Dissolved oxygen

Plants also need dissolved oxygen (DO) for life processes. However, low levels of dissolved oxygen normally kill the farmed organism before the phytoplankton. Bacterial decomposition of organic and inorganic matter is speeded up when dissolved oxygen levels are ideal. Mixing the pond water to keep the entire water column aerobic will speed up bacterial decomposition and the recycling of nutrients.

1.3 Factors influencing carrying capacity in water

A unit of water can produce and maintain only a certain weight of fish (known as the 'carrying capacity'), depending on a number of factors and their interactions (Box 6).

Box 6. Factors influencing carrying capacity in water

- Nutrient inputs
- Water quality
- Fish species
- Polyculture

Nutrient inputs

The primary productivity of a unit of water and its ability to produce natural food organisms can be increased by adding inorganic and organic fertilizers (e.g. Nitrogen [N], Phosphorous [P] and Potassium [K]) to the water to increase its carrying capacity.

Fertilizers

Granular and liquid inorganic fertilizers (chemical) provide benefits by releasing nutrients for plant growth and increasing primary productivity.

Organic fertilizers (manure) provide benefits by releasing nutrients for plant growth through bacterial decomposition directly, as a feed source for animals that can utilize them, and by acting as a substrate for bacterial growth. The organic particles are consumed by some species of fish.

Best fertilizing results are usually obtained by combining inorganic and organic fertilizers.

Supplemental feeds

If fish species are consuming all the natural food organisms existing in a pond and the carrying capacity of the pond itself has been reached, an increase in carrying capacity can be obtained by providing supplemental feed.

When a ration is supplied as a pond supplement, its quality must be upgraded by natural fish food organisms eaten by the fish. Supplemental feed is not nutritionally complete but provides a source of energy to complement protein rich natural feed. Examples are rice bran, wheat bran, cottonseed meal, etc. Conversion of supplemental feeds by tilapia is usually 3–5 kg of feed per kilogram of weight gained.

Box 7. How to calculate the feed conversion ratio

Feed Conversion Ratio (FCR) includes nutritional growth factors obtained from natural foods and is a measure of growth resulting from feeds and natural foods. FCR is the ratio between the dry weight of feed fed and the weight of yield gain. It is a measure of the efficiency of conversion of feed to fish, e.g. a FCR of 2.8 means that 2.8 kg of feed is needed to produce one kilogram of fish live weight) (FAO, 2017).

$$FCR = \frac{dry\ weight\ of\ feed\ fed}{wet\ weight\ gain\ of\ fish}$$

Complete feeds

When natural fish food organisms are reduced due to cropping by fish and are no longer supplementing the ration, a complete ration containing essential nutrients must be provided to gain an increase in carrying capacity.

A nutritionally complete feed contains all the amino acids, lipids, carbohydrates (energy), vitamins and minerals to allow fish to grow well in the absence of natural foods.

Water quality

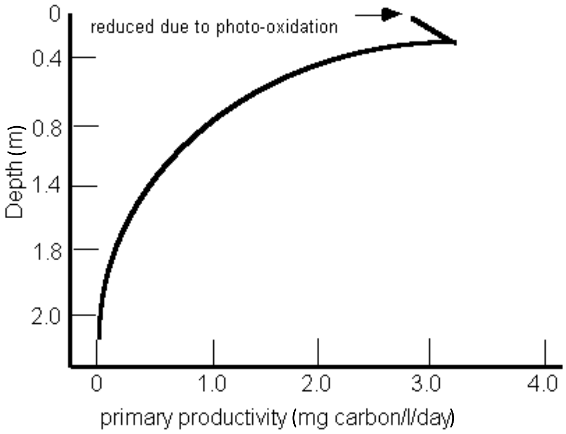
As reported in section 1.2, the weight of fish that can be produced in fertilized ponds is dependent upon the ability of water to produce the necessary plants. The ability of water to produce the plants is dependent upon the following factors: light, temperature, minerals, carbon and dissolved oxygen. Any of these resources alone or in combination can be a limiting factor and reduce photosynthetic production.

Dissolved oxygen

Maintenance of suitable dissolved oxygen (DO) levels is more dependent on photosynthesis than on diffusion from the air.

In the absence of rooted vegetation, the more fertile the water, the denser the phytoplankton concentration, shallower the light penetration, and lower the photosynthetic levels, thus reducing dissolved oxygen in deeper waters (Figure 7). Heavy phytoplankton concentrations in top waters cause high dissolved oxygen in surface waters and low dissolved oxygen in deeper waters. Photosynthesis cannot proceed at rates exceeding respiration at depths where the light intensity is lower than one percent.

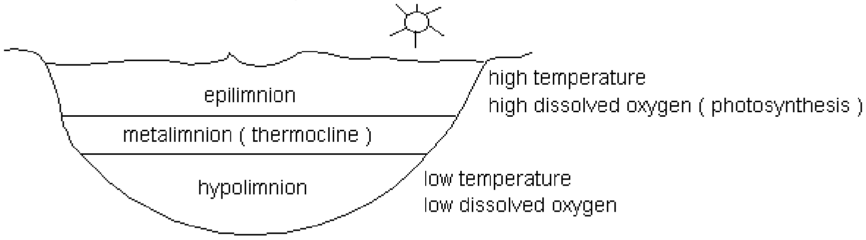
Figure 7. Relationship of depth and primary production in a fertile pond



Source: adapted from (Boyd, 1990)

The deeper the fishpond, the higher the percentage of the total volume that is lacking in dissolved oxygen and the greater the danger of fish dying as a consequence. Thermal stratification is common in deep-water ponds during the summer months. As the summer progresses, a greater percentage of the total pond volume becomes devoid of dissolved oxygen. In the summer months, the mixing of oxygen deficient water in the *hypolimnion* with the *epilimnion* rich in oxygen can lower the dissolved oxygen and cause fish deaths (Figure 8).

Figure 8. Thermal stratification

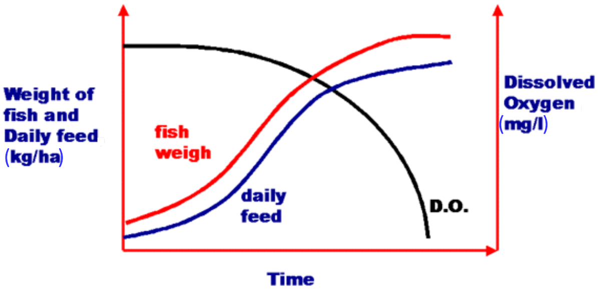


The mixing of pond water layers is called **turnover**. Turnover is caused by the cooling of the surface waters, usually because of heavy rainfall accompanied by strong winds during a thunderstorm. The best way to avoid thermal stratification is to mix the pond water with an aerator or water blender.

The maximum biomass of fish that can be produced in static water, without aeration, depends on the quality and quantity of ration that can be daily distributed, without causing the dissolved oxygen concentrations in the pond to drop to levels which would prove stressful or fatal to the fish (Figure 9).

The quantity of ration that can be fed per unit area per day is limited by the waste disposal and reoxygenation efficiency of the ecological system. The amount of feed that can be fed per unit of water per day is influenced by the fish species raised.

Figure 9. Relationship of fish weight, feeding rate and dissolved oxygen level



Source: (Lovshin, 1995)

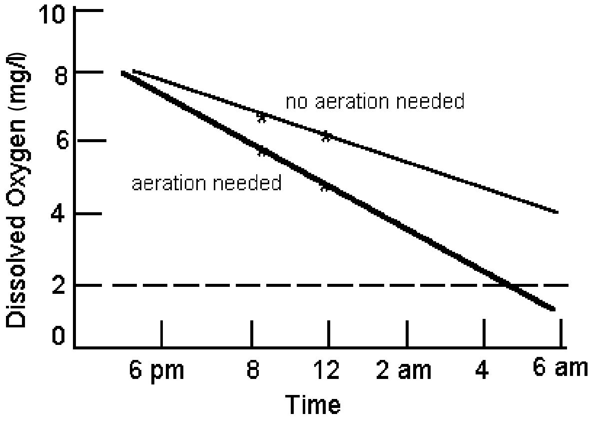
A depletion in dissolved oxygen is caused in three ways, or a combination thereof:

- Biological Oxygen Demand[6] (BOD) – By carefully monitoring the early morning dissolved oxygen, farmers can observe the slow decline in dissolved oxygen concentrations and predict when dissolved oxygen could reach critical levels. If phytoplankton populations remain, dissolved oxygen increases rapidly with photosynthesis during the day. Figure 10 shows the calculation of early morning DO based on the rate of DO decline between two earlier DO readings.

---

[6] BOD gives «the amount of dissolved oxygen necessary to oxidize the readily decomposable organic matter» (Boyd, 1990). It measures the rate of removal of O_2 by organisms using the organic matter in water (Soesanto *et al.*, 1980). In fisheries wastewaters, BOD originates mainly from carbonaceous and nitrogen-containing compounds (Gonzalez, 1996). An extreme increase in BOD may asphyxiate the fish, while smaller increases can cause stress due to O_2 deficiency (Takács, 1989).

Figure 10. Calculation of dissolved oxygen

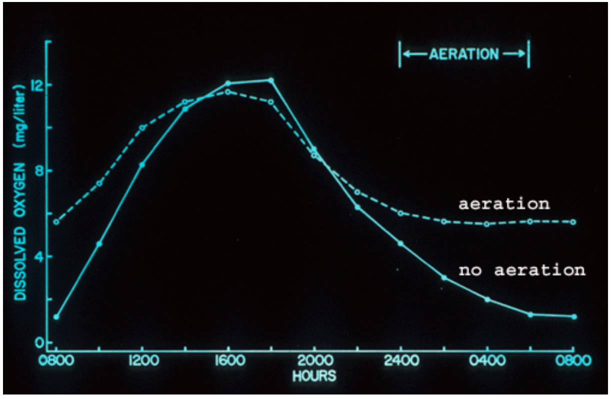


Source: (Boyd, 1990)

- **Turnover** is difficult to forecast since the storms causing turnover are hard to predict too. Once turnover occurs, DO levels can decline rapidly and fish can die quickly, within minutes.
- **Phytoplankton die-off** – complete or partial phytoplankton deaths are difficult to predict because the causes of such die-offs are not known. An experienced farmer can tell if a phytoplankton die-off is near by the colour of the pond water reflected in the amount of phytoplankton in the water. After a complete phytoplankton die-off, the water colour will change from green to muddy or tea coloured. DO levels will drop slowly after a die-off: critical concentrations are normally reached about 12 hours later. DO levels will remain low for several days, as the phytoplankton that replenishes the DO during photosynthesis is not present. Some farmers who manage heavy phytoplankton populations reduce chances of die-offs by killing a portion of the population with chemicals (copper). Phytoplankton-eating fish will also control phytoplankton and reduce the chances of a die-off. Low DO is best controlled with aeration together with water exchange (if water is available to exchange large volumes of water), and lowering or stopping feeding until DO increases.

When dissolved oxygen levels become a limiting factor in fed, standing water ponds, aeration can be used to raise DO concentrations, permitting increased feeding rates, and thus increasing the carrying capacity per unit area of the pond (Figure 11).

Figure 11. Influence of aeration on dissolved oxygen in a fed fishpond



Source: (Boyd, 1990)

Table 1 shows the influence of aeration on the yield of channel catfish stocked at 10 grams and at 10 000/ha and grown for 220 days in 0.04 hectare-earthen ponds.

Table 1. Influence of aeration on the yield of channel catfish

Performance measure	Aerated ponds*	Non-aerated ponds*
Harvest weight (g)	469	389
Yield (kg/ha)	4 813	3 567
Survival (%)	97	94
Feed applied (kg/ha)	6 229	6 229
FCR	1.32	1.75

** Aerated ponds received 6 hr/night aeration; non-aerated ponds perceived occasional emergency aeration*

Source: (La-fa and Boyd, 1988)

The types of aerators are paddle wheel (electric- and tractor-powered), propeller aspirator pump, vertical pump, pump sprayer and diffused air.

Plate 1. Cages with paddle wheel aerator

Credit: @FAO Aquaculture photo library

Standard Aeration Efficiency (SAE) is measured as pound O_2/ horsepower-hour or kg O_2/kw-hour under standard conditions. SAE is expressed as per horsepower or kw, e.g. 1 horsepower at 0.75 kw. A 1-horsepower motor is designed to perform, for example, 0.75 kw of work. However, since motors are not fully efficient, a 1-horsepower motor could typically consume 1.4 kw –1.6 kw. Table 2 shows data on aerator efficiencies.

Table 2. Measured aerator efficiencies

Aerator type	Average SAE (lbs O_2/hp/h)	SAE Range (lbs O_2/hp/h)
Vertical pump	2.3	1.1–3.0
Pump sprayer	2.1	1.5–3.1
Propeller-aspira-tor pumps	2.6	2.1–3.0
Paddle wheels	3.6	1.8–4.9
Diffused air	1.5	1.1–2.0

Source: (United States Department of Agriculture, 2011)

Other factors to consider when selecting an aerator: cost, durability, ease of service, mobility, water movement. Standard Oxygen Transfer Rate and mobility are also critical for fish under stress. When selecting an aerator for emergency aeration, these considerations may be more important than economic efficiency.

Ammonia

Water exchange can reduce ammonia and organic matter and lower oxygen demand, thereby allowing higher rates of feeding. The amount of exchange water greatly influences the carrying capacity. In general, the more water exchanged, the higher the carrying capacity. The maximum carrying capacity per unit area can be obtained from flow-through farming systems, e.g. raceway and cage. However, McGee and Boyd (1983) found that four exchanges of water a season did not increase the standing crop of catfish compared to a 0.04 hectare earthen ponds with no water exchange.

In catfish aquaculture, water exchange in large ponds, higher than two hectares, is not economical. This is due to the high cost of pumping the large volumes of subsurface water needed to significantly improve water quality.

In shrimp mariculture, 10–20 percent of the water volume is exchanged daily in large ponds to improve water quality. In marine shrimp ponds, water exchange is profitable due to the high price of marine shrimp on the international market and because large amounts of water can be pumped cheaply from neighbouring estuaries.

Intensive culture systems using partial water exchange daily are becoming popular. Culture units are small (100–1 000 m^2) and usually circular, with a drain located in the centre of the unit. Circular water currents draw the solid waste to the central drain where the solids can be removed by lowering the water level between 1 and 5 percent. Fresh water is added to make up for the drain water. In farmed units with a stocking density of 5–10 fish/m^2, partial water exchange, solid waste removal and aeration, around 4–8 kg/m^2 (40 000– 80 000 kg/ha) of fish can be harvested.

Raceways have **continual water exchange**, often 2–10 exchanges per hour. Raceways require:

- Water supplied by gravity, given the high cost of pumping large volumes of water.
- Complete feed, since natural foods are flushed from the culture unit.
- Effluent treatment before releasing water into natural waterways because solid wastes are flushed from the culture unit. The effluent treatment is required by law in many countries.

Plate 2. Raceways fry rearing

Credit: @FAO Aquaculture photo library

Even though the highest carrying capacity (yield) per unit of area can be obtained from flow-through farming systems, the result is the lowest carrying capacity (yield) per unit of water.

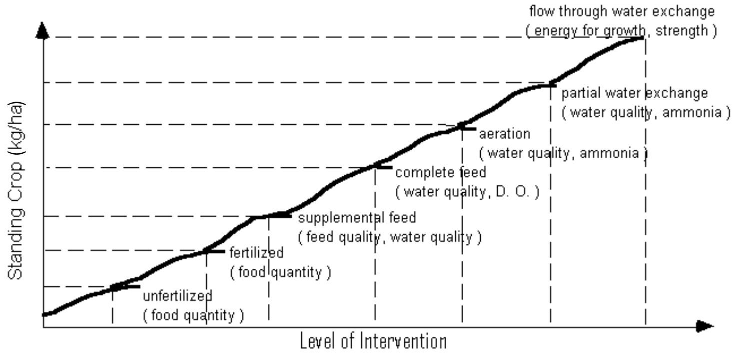
Cages are enclosed structures suspended in water bodies. Cages are distinguished from pens by the presence of an enclosed bottom while pens are fenced areas with a natural substrate floor. Cages can be located in the ocean, lakes, reservoirs and slow flowing rivers. Cages can be densely stocked, up to 400 fish/m^3, because water currents continually flush fish wastes from the cage maintaining good water quality. Fish are easily harvested from cages and yields can be as high as 300 kg/m^3. Fish raised in cages at high density require a nutritionally complete feed for good growth.

Level of interventions

Figure 12 shows the increase in carrying capacity with improved nutrition and water quality control. Specifically, it presents the data by level of intervention, from unfertilized to flow through water exchange aquaculture, and the reasons why carrying capacity is reached, e.g. food quantity or water quality. Once carrying capacity is reached, the methods used to extend fish growth and increase carrying capacity for a given unit of water consist in an increase of the level of intervention. With an increase in the level of intervention, the complexity of technology, managerial skill, cost of production and risk changes.

Farmers wishing to start an aquaculture operation should match the level, complexity and risk of the culture system with the socio-economic environment in which the farm is to be located. For example, chances of success are low if a high-technology enclosed water reuse system is located in a developing country where nutritionally complete feeds are not available and energy costs are high.

Figure 12. Level of interventions



Source: (Lovshin, 1995)

Cultured fish species

Fish size

If water quality is not a limiting factor during the farming period, for a given carrying capacity, the weight of fish can be composed of a large number of small fishes or a small number of large fishes of the same species.

For example, if carrying capacity is 4 000 kg/ha, fish farmers might harvest 8 000 fishes of 500 grams each or 16 000 fishes of 250 grams each. **If water quality is not a limiting factor**, carrying capacity is not influenced by the size of farmed fish.

If an estimate of carrying capacity is available, it can be used to determine the stocking rate needed to harvest a given sized fish (Equation 5) or the harvest weight of a fish for a given stocking density (Equation 6).

$$Stocking\ Density = \frac{Carrying\ Capacity/Weight\ at\ Harvest}{Survival\ Rate} \qquad (5)$$

$$Weight\ at\ Harvest = \frac{Carrying\ Capacity}{Stocking\ Density - Mortality\ Rate} \qquad (6)$$

Where, the Survival Rate is the percentage of stocked fish that are harvested:

$$Survival\ Rate = \frac{Number\ of\ Harvested\ Fish}{Number\ of\ Stocked\ Fish} \times 100 \qquad (7)$$

The Mortality Rate is the percentage of stocked fish that die before harvest[7]:

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[7] Where: $\text{Survival Rate} + \text{Mortality Rate} = 100\%$
or: $\text{Number of Harvested Fish} + \text{Number of Dead Fish} = \text{Number of Fish Stocked}$

$$Mortality\ Rate = \frac{Number\ of\ Stocked\ Fish - Number\ of\ Harvested\ Fish}{Number\ of\ Stocked\ Fish} \times 100 \quad (8)$$

The Standing Crop (SC) at Harvest can be calculated as:

$$SC\ at\ Harvest = (Stocking\ Density - Mortality\ Rate) \times Individual\ Weight\ at\ Harvest \quad (9)$$

Determination of carrying capacity is difficult and based on personal culture experience and/or information published by others.

If water quality is a limiting factor during the farming period the carrying capacity will be affected by fish size. For the same fish species, large fish will have a higher carrying capacity than small fish.

Small fish have a higher metabolic rate[8] per unit of weight than large fish. Thus, oxygen (O_2) demand and ammonia excretion will be higher for a given weight of small fish when compared to the same weight of large fish of the same species. For example, at a water temperature of 27 °C a 45 gram channel catfish will consume 684 mg of O_2/kg of catfish/hr, while a 450 gram channel catfish will consume 370 mg of O_2/kg of catfish/hr (Tucker and Robinson, 1990). Less feed can be put in to a unit of water per day for small fish compared to large fish, and still maintain satisfactory water quality. Lower daily feeding rates per unit area required by small fish will cause a reduction in the carrying capacity compared to large fish of the same species.

Food habits

The lower the trophic level[9] a fish feeds on, the higher the biomass of fish a pond can carry. Only about 10 percent of the energy consumed by an organism is utilized for growth, the remainder is lost as heat to metabolic processes.

Food habits could be a factor determining the fish species to farm. Under specific conditions, if the goal is to provide food fish for a population suffering from hunger, fish that feed low on the food chain could be selected (low-cost protein). On the other hand, fish that feed high on the food chain could be selected (high-cost protein) if the fish farmer is profit-oriented and consumers can afford the fish price.

Feeding a low-cost protein fish as forage (feed) to a predator fish species is usually uneconomical. It could be economical if the feed fish is very cheap, e.g. caught in the wild, and is provided as feed to a high-value fish species. Yellowtail tuna farmed in Japan is an example of a high-value predatory fish that is fed with wild-caught ocean fish of low value.

The more resistant a fish species is to poor water quality, the more feed per unit area per day can be fed without causing fish mortality. The more feed fed per unit area per day, the higher will be the carrying capacity.

If water quality is not a limiting factor during the growing cycle, carrying capacity can be the same for fish species with similar feeding habits and weights.

Polyculture

Rearing two or more fish species with different food habits in the same culture unit (FAO, 2017) is called polyculture — as opposed to monoculture. An example is the Chinese polyculture of carp (Plate 3).

If growth is not limited by waste from feed and/or the biota, the greatest biomass of fish that can be maintained in a pond is produced by a combination of fish species differing in their feeding habits.

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[8] “The amount of oxygen used for total metabolism per unit of time per unit of body weight” (FAO, 2017).

[9] “The position an organism occupies in the food web (e.g. herbivore, omnivore, detritivore or carnivore” (FAO, 2017).

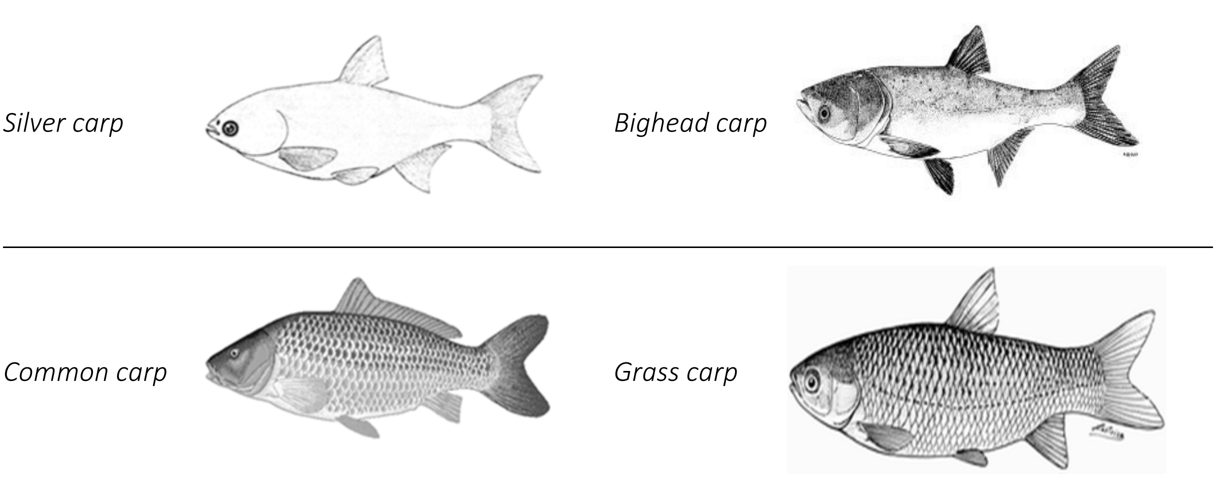
Silver carp
Bighead carp
Common carp
Grass carp

Plate 3. Farmed carps show food habits for each fish
Credit: @FAO Cultured Aquatic Species

Farming two or more fish species together with differing water quality requirements can lead to a reduction in the carrying capacity of the primary culture species, or in some cases, to a lowering of the overall pond carrying capacity. Carrying capacity is determined by the amount of feed that can be placed daily in a unit of water without lowering the water quality to levels which might be stressful to the fish. If one species is less resistant to poor water quality than the other species, the amount of feed that can be fed per area per day is based on the less resistant fish. In polyculture, the fish species more resistant to poor water quality will therefore receive a restricted feed allotment and not reach the standing crop they could reach if raised without the less resistant species.

Table 3 shows the influence of common carp on the yield of male tilapia raised in 0.04-hectare earthen ponds in Brazil for 245 days. Higher yield was obtained in the tilapia monoculture because more feed was fed and because the carp could not withstand the low dissolved oxygen (DO), which restricted feeding. However, given the high FCR in a monoculture, profitability should be used to decide whether monoculture is better than polyculture[10].

Table 3. Influence of common carp on the yield of male tilapia

Performance Measures*	Male tilapia	Common carp	Male Tilapia + Common Carp
Stocking Rate (N°/ha)	9 000	2 240	9 000 + 1 785
Yield (kg/ha)	3 993	812	3 567
Average Harvest Weight (g)	353	379	285 + 361
Feed Fed (kg/ha)	12 337	1 756	8 263
Feed Conversion	3.8	2.3	2.6

* Fertilizer = cattle manure, same amount in all ponds; Feed = rice bran at 3% of fish body weight in monoculture and 3% of tilapia body weight in polyculture, 6 days/week.

Source: (Lovshin, 1975)

The primary fish species should be determined before polyculture is attempted. If the primary fish species — usually the most valuable fish — has low resistance to poor water quality, then a species with different feeding habits and greater resistance to poor water quality can be stocked in order to increase the total pond carrying capacity. However, if the primary species is resistant to poor water quality and the secondary species less resistant then the daily feed amount fed to the primary species may have to be restricted, reducing the carrying capacity of the primary species and, often, the total pond carrying capacity compared to a monoculture of the primary species.

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[10] The criteria to assess aquaculture profitability are addressed in Module 2: The economic dimension of commercial aquaculture.

1.4 Factors influencing the growth rate in water

Growth Rate (GR) measures the speed at which an organism, or a population of organisms, gains weight over a given time period (Equation 10).

$$GR = \frac{(Final\ weight_{T2} - Initial\ weight_{T1})}{Days} \qquad (10)$$

The growth rate of an organism can be expressed in grams per day (g/day). On the other hand, the growth rate of a population (or production rate) can be expressed in kilograms per hectare per day (kg/ha/day), kilograms per cubic metre per day (kg/m^3/day) or pound per acre per day (lb/acre/day).

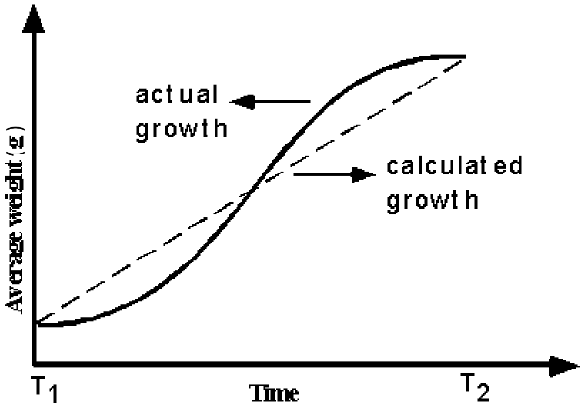
Box 8. How to calculate the average growth rate

Stocking weight = 50 g
Harvest weight = 750 g
Growth period = 300 days

$$GR = \frac{750 - 50}{300} = 2.3\ g/day$$

The growth over a long period, the actual growth rate, is not constant or linear (Figure 13).

Figure 13. Increase in average individual fish weight between stocking (T_1) and harvest (T_2)



Source: (Lovshin, 1995)

Growth rate is dependent on a number of factors and their interaction (Box 9).

Box 9. Factors influencing growth rate in water

- Water quality
- Water temperature
- Age
- Health
- Genetics
- Size
- Stocking density

Water quality

For farmed fish species, the maximum growth rate occurs in water with an optimum level of pH, dissolved oxygen (DO), carbon dioxide (CO_2), salinity, un-ionized ammonia (NH_3), etc. This optimum water quality needs to be determined, since it varies for each fish species. In general, a good growth rate will occur in waters with:

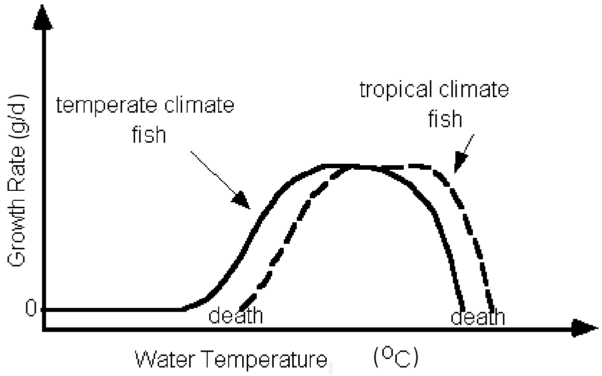
- DO above 5 milligrams per litre (mg/l)
- pH between 6.5 and 8.5 in the morning

- CO_2 less than 10 mg/l
- NH_3 less than 0.05 mg/l

Water temperature

The growth rate slows and stops in waters that are too hot or too cold. Optimum growth is obtained in waters of optimum temperatures for the farmed fish species (Figure 14). The optimum temperature range needs to be determined, since it varies for each fish species.

Figure 14. Influence of water temperature on fish growth



Source: (Lovshin, 1995)

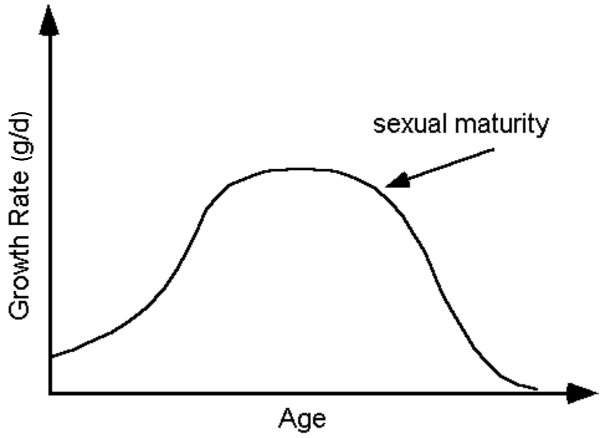
Age

The growth rate of fish normally increases with age up to the maximum growth capacity — which is maintained with adequate food and environmental conditions — until sexual maturity (in most fish), or to a certain age at which point growth rate declines (Figure 15).

Age is not usually an important factor in fish farming because young fishes (e.g. juveniles and fingerlings) are raised and harvested before they reach sexual maturity and their growth rate slows.

When fishes mature at a young age, before reaching the harvest size, the growth rate may be affected negatively (e.g. in tilapia and common carp). In most cases, the factors age and size are directly correlated, i.e. small fish are young; large fish are old.

Figure 15. Influence of age on fish growth rate



Source: (Lovshin, 1995)

Health

Fish that are in poor health will not grow as rapidly as fish that are in excellent health. Poor health is usually caused by stress due to:

- handling during stocking and harvesting
- poor water quality
- unfavourable water temperatures
- nutritional deficiencies

Most health-related stress is caused by poor water quality. Fish farmers usually stock fish at densities and with feed amounts that are too high for the culture level and for the water area used. The overfeeding per unit of water may result in poor water quality and chronic stress, which eventually leads to disease. Maintaining proper water quality conditions results in good fish health and fast growth. Often, fish farmers must lower fish standing crop to maintain good water quality.

Genetics

A cultured animal must grow to a minimum acceptable size in a growing period or season. Fish species with equal marketable sizes may grow at different rates, varying by as much as 100 percent or more. Genetics or inherent growth potential plays a strong role in fish growth. A fast growth potential is an important criterion when selecting a fish species. In general:

- Environmental and nutritional factors excluded, growth rate is directly proportional to the maximum potential size attainable. Fish which are large at maturity grow more rapidly than fish which are small at maturity.
- Warm-water species grow at a faster rate than cold-water species of comparable maximum potential sizes.

Genetics-influenced growth differences can be seen within a fish population. Fish stocked at the same size will grow at different rates, causing size variation at the point of harvest. Large size variation at the point of harvest can cause marketing and processing problems. However, growth variation within a population can be used to select faster-growing individuals that could be used as broodstock. Over a period of several generations, a faster-growing fish can be developed through genetic selection.

Size

Relative growth rate ($GR_{Relative}$) is a measure of the growth rate per unit of weight and is reported as a percentage increase in body weight (Equation 11).

$$GR_{Relative} = \left(\frac{Weight\ Gain}{Initial\ Weight}\right) \times 100 \qquad (11)$$

Absolute growth rate ($GR_{Absolute}$) is a measure of the time required to grow a given unit of weight (Equation 12).

$$GR_{Absolute} = \left(\frac{Weight\ Gain}{Growing\ Period}\right) \qquad (12)$$

Figure 16. Relative growth rate

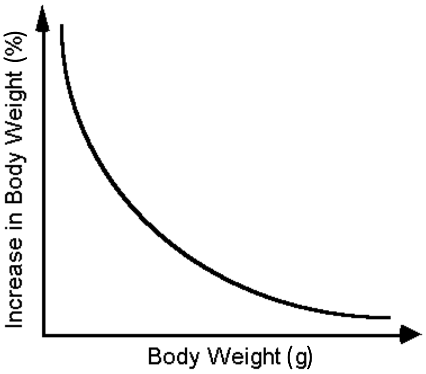
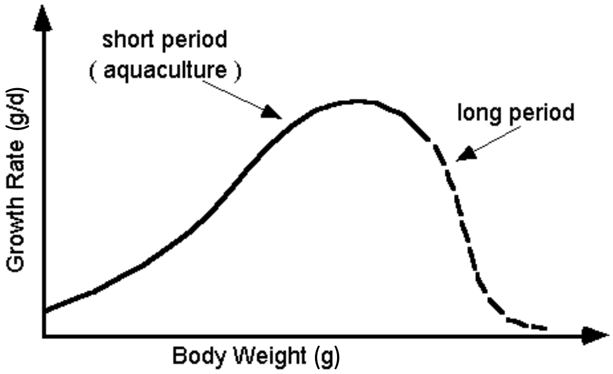


Figure 17. Absolute growth rate



Source: (Lovshin, 1995)

Box 10. How to calculate the relative and absolute growth rate

Example 1: a fish is stocked at 10 grams and grows to 40 grams in 30 days.

$$GR_{Relative} = \left(\frac{40-10}{10}\right) \times 100 = 300\%\ increase\ in\ body\ weight$$

$$GR_{Absolute} = \left(\frac{40-10}{30}\right) = 1\ gram\ per\ day\ growth$$

Example 2: a fish is stocked a 100 grams and grows to 160 grams in 30 days.

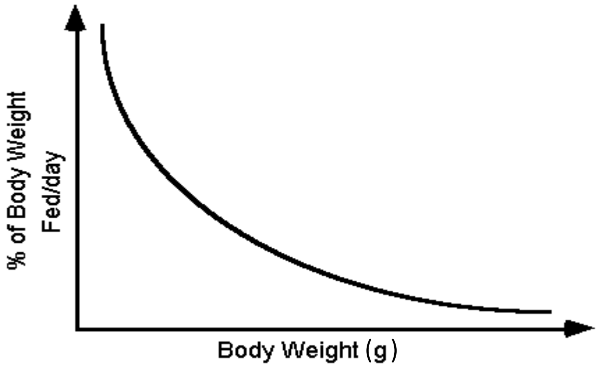
$$GR_{Relative} = \left(\frac{160-100}{100}\right) \times 100 = 60\%\ increase\ in\ body\ weight$$

$$GR_{Absolute} = \left(\frac{160-100}{30}\right) = 2\ grams\ per\ day\ growth$$

The smaller the fish, the higher its relative growth potential, but the lower its absolute growth potential. The larger the fish, the lower the relative growth potential and the higher its absolute growth potential.

Fish farmers are mainly interested in absolute growth rate because they want to produce the greatest amount of edible product in the shortest time per unit of water area. The faster the absolute growth, the shorter the time needed to reach harvestable size. Stocking a large fish will allow the fish to grow at a fast absolute growth rate immediately after stocking and reach market size in a shorter period. The smaller the fish, the higher its basic metabolic rate. Thus, more food per unit of body weight is needed for a small fish to reach and maintain maximum growth capacity than for a larger fish. The smaller the fish, the higher is the daily feed allotment based on the percentage of the fish's body weight for maximum growth (Figure 18). Feeding at the maintenance rate (about 1 percent of body weight in the summer) is uneconomical when water temperatures allow maximum growth.

Figure 18. Relationship of body weight to percentage of body weight fed/day



Source: (Lovshin, 1995)

Box 11. Examples of feed allotment based on fish species weight

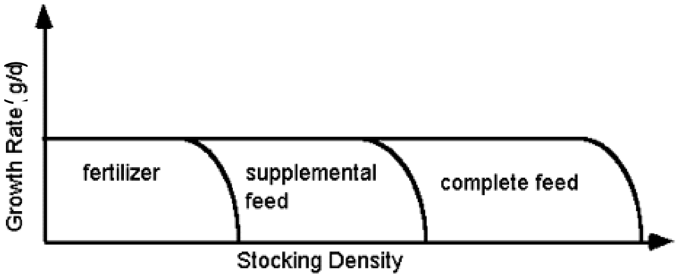
For example, for channel catfish and many other fish:

- Fry are fed 8 percent to 10 percent of body weight per day;
- Fingerlings (1 gram to 100 grams) are fed 5 percent of body weight per day;
- Stockers (100 to 500 grams) are fed 3 percent of body weight per day;
- Food-sized (500 to 1000 grams) are fed 2 percent of body weight per day.

Stocking density

As the stocking density of fish increases, the standing crop per unit of water increases; the amount of food available per fish therefore decreases and growth slows and eventually stops (Figure 19).

Figure 19. Relationship between the stocking density of 50 gram-fish and growth rate at different levels of nutrient inputs

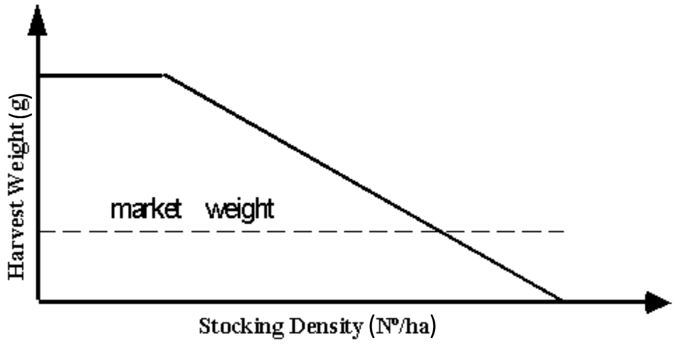


Source: (Lovshin, 1995)

At the lower stocking densities (Figure 19) growth is equal for 50-gram fish in a fertilized pond, or when provided with supplemental or complete feeds. In theory, providing 50-gram fish stocked at low densities with feed is wasteful, because the fish are growing at their maximum rate on natural foods alone. The problem is determining the stocking density (standing crop) for which providing feeds will result in a growth-rate increase. If the number of fish stocked is so high that stocking weight is equal to the carrying capacity, no growth will result and average-stocking weight will equal average harvest weight.

When the critical standing crop is reached during the culture period, the higher the stocking density, the lower the average weight of fish harvested. At lower stocking densities, average harvest weight is the same because food resources and water quality allow for optimum growth. Differences in harvest weight are observed only at higher stocking densities when the critical standing crop is reached during the culture period, as a result of limitations in the food and/or water quality (Figure 20).

Figure 20. Relationship between average harvest weight and stocking density of 50-gram fish over time at one level of nutrient input



Source: (Lovshin, 1995)

Table 4 shows the relationship between the stocking density and individual harvest weight and yield for farmed male Nile tilapia in earthen ponds in Honduras. The final harvest weight was higher (249 grams per fish) at the lower stocking density (10 000 fish per hectare), while the yield and feed conversion ratio increased at the higher densities.

Table 4. Stocking density, individual harvest weight and yield of male Nile tilapia, Honduras

Stocking Rate* (fish/ha)	Final Weight (g/fish)	Survival Rate (%)	Yield (kg/ha)	Food Conversion
10 000	249	97	2 410	2.0
20 000	200	93	3 709	2.7
30 000	166	96	4 817	2.4

*Tilapia were stocked at 17 grams and fed a 23 percent protein pelletized ration for 150 days

Source: (Green et al., 1994)

The aim of fish farmers is to stock fish at the **maximum possible density** allowing them to grow at a rate that permits them to reach a **harvestable size in one growing period or season**.

For short culture periods, the final average weight of fish can be regulated by the number of fish stocked. In order to control the stocking density of farmed species, the pond must be drained or seined approximately every one or two years, in order to remove all or almost all farmed fishes. Farmed fishes must not reach sexual maturity — or if they reach sexual maturity they should be not be able to spawn in the pond.

For long culture periods, when reproduction is possible or when fish spawn at a young age, the density and size of fish can be controlled by biological means. When the farmed fish reproduces during the culture period, polyculture with a predator can be used to control density. The use of carnivorous species to control fish density increases the average growth rate and percentage of harvestable fish but decreases the total yield. For example, Table 5 shows the yield and percentage of harvestable mixed-sex Nile tilapia stocked at 10 000 per hectare, in a monoculture farming system (tilapia only) or with a predator (Peacock bass – *Cichla ocellaris*), in 0.04 hectare-ponds for 180 days in Brazil.

Table 5. Yield and percent of harvestable mixed-sex Nile tilapia, Brazil

Performance Measures*	Tilapia Only	Tilapia plus Predator
Initial weight of tilapia (g)	14	14
Final weight of tilapia (g)	-	300
Tilapia yield (kg/ha)	4 950	2 500
Percent of tilapia greater than 100 g	0	95

* Tilapia were fed agricultural by-products equivalent to 3 percent to 5 percent of body weight daily, 6 days/week; one predator for every ten tilapia stocked

Source: (Lovshin, 1977)

Other methods for density control include a limitation of the spawning area or habitat (e.g. limit spawning cavities in catfish aquaculture, remove aquatic plants for egg substrate in common carp aquaculture), monoculture according to sex (e.g. all male tilapia), sterile fish (e.g. triploid grass carp), and spawning repression.

The loss of control of fish density in a farmed pond makes calculating standing crops and feeding amounts based on body weight percentages difficult. Floating feed has helped alleviate this problem by basing feeding practices on observed fish appetite.

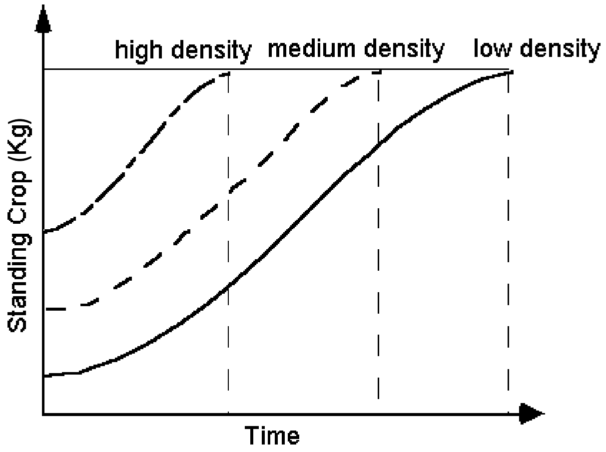
For one level of nutrient input the time required to reach the maximum standing crop (i.e. the carrying capacity) can be reduced by increasing the stocking density or individual fish weight at stocking (Figure 21). Standing crop at stocking can be increased by increasing the density or individual fish weight.

It should be noted that early on in the culture period, fish growth at all densities is equal; only when the critical standing crop is reached does the growth rate begin to differentiate (Figure 22). The time required to reach carrying capacity for each density has the same relationship as shown in Figure 21.

For a given stocking rate, growth of the fish population (i.e. the production rate) per day will increase with an increase in individual fish growth rate — until the maximum absolute growth rate is reached, and daily production rate reaches a maximum (Figure 23).

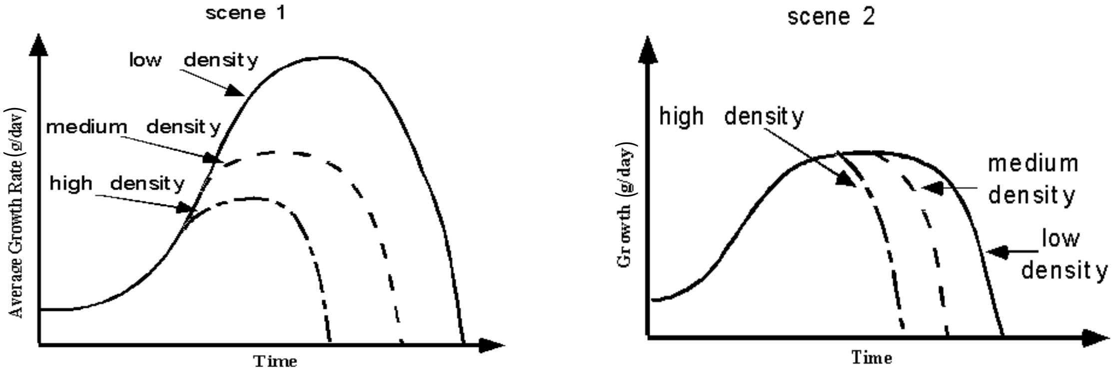
The production rate per unit of area is the product of the average gain per fish, and the density of fish per unit area. When the growth rate is not affected by the stocking rate, the production rate increases with an increase in density (Figure 24).

Figure 21. Relationship between carrying capacity and stocking density at one level of food abundance



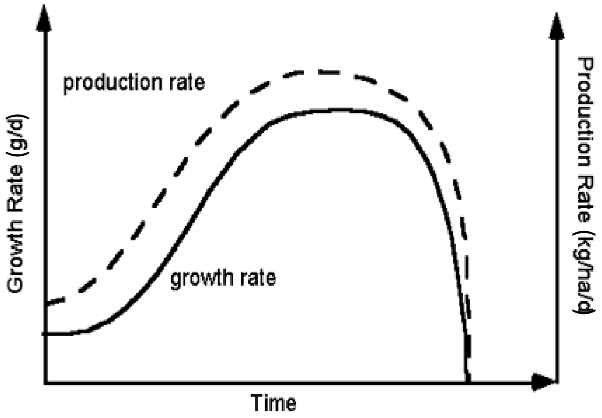
Source: (Lovshin, 1995)

Figure 22. Relationship between growth rate and stocking density of a 50 gram-fish at one level of nutrient input



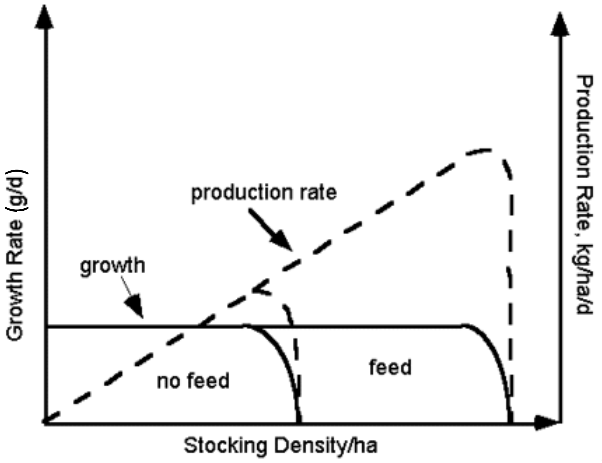
Source: (Lovshin, 1995)

Figure 23. Relationship between growth rate and production rate



Source: (Lovshin, 1995)

Figure 24. Relationship between stocking density, growth rate and production rate over time for a given fish weight



Source: (Lovshin, 1995)

Above the critical standing crop, as long as the growth rate decreases at a smaller rate than the increase in stocking density, there is an increase in production rate. When the growth rate decreases at a higher rate than the increase in stocking rate, the production rate drops. The maximum production rate is obtained at a point between the critical standing crop and carrying capacity. Table 6 shows an example of how stocking density and individual fish growth influence production rate.

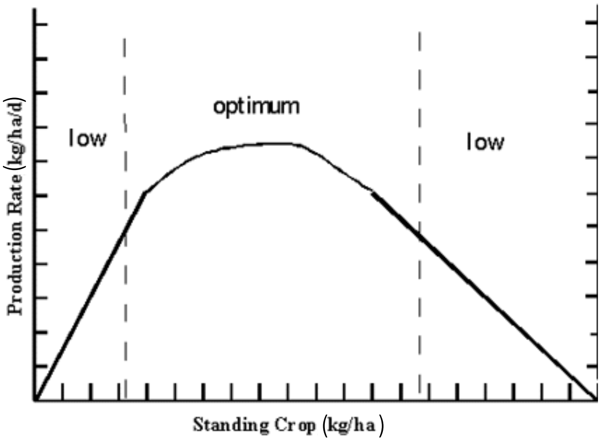
To maximize yield potential the standing crop should be controlled, in order to remain in the range for optimum production rate through most of the culture period (Figure 25). Low production rates at low standing crops are due to the slow growth of small fish or low stocking densities — even of large fish that are able to grow rapidly. Low production rates at high standing crops are caused by a lack of food or poor water quality, which are needed for optimum growth.

Table 6. Stocking density and growth rate influence on production rate

Stocking Rate (ha)	Growth (g/day)	Production Rate (kg/ha/day)
1 000	2	2
3 000	2	6
5 000	2	10
10 000	2	20
15 000 = 50% increase	1.5 = 25% decline	22.5
20 000 = 33% increase	1.2 = 20% decline	24
25 000 = 25% increase	1.0 = 17% decline	25
30 000 = 20% increase	0.8 = 20% decline	24
35 000 = 17% increase	0.5 = 37% decline	17.5

Source: adapted from (Lovshin, 1977)

Figure 25. Relationship between standing crop and production rate



Source: (Lovshin, 1995)

1.5 Factors influencing yield in water

Yield is affected by a number of factors and by their interaction (Box 12). Yield (weight/area/time) can be calculated by bringing together the carrying capacity (weight/area) and individual fish growth rate (weight/time)[11].

Box 12. Factors influencing yield in water

- Carrying capacity
- Growth period
- Harvest weigh
- Survival
- Harvest frequency

Carrying capacity

The maximum potential yield is highest in water, which has the highest carrying capacity (CC) per unit of water.

In monoculture farming systems, the yield in one culture period can never be greater than the carrying capacity of a unit of water.

In general, yield should be smaller than carrying capacity. Since fish are harvested at, or close to, the critical standing crop (CSC), the reduction in the growth rate would reduce Feed Conversion Ratio (FCR), thereby lowering the profits.

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[11] See “Yield” section.

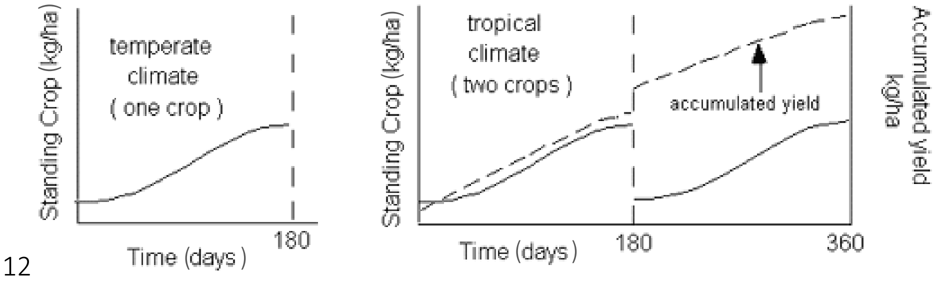
Growth period

The potential yield per unit area per year is higher in longer growth periods permitted by water temperature high enough to allow maximum growth.

The production rate can be the same in both temperate and tropical climates, over short periods, for a given fish species raised under similar culture conditions. However, high production rates can be maintained for longer periods in tropical climates compared to temperate ones, resulting in higher annual yields.

One or two crops of fish per year can be raised in temperate climates depending on the weight of fish stocked and harvested. In the tropical climates this extends to two or three crops of fish per year (Figure 26).

Figure 26. Relationship between fish yield and length of the growing season in tropical and temperate climates



Source: (Lovshin, 1995)

Harvest weight

The potential yield from a unit of water for a given period is higher at the point of harvest with fish of a smaller marketable size.

A fish that can be marketed at a small size requires less time to grow to marketable size than the same fish marketed at a large size. Marketing a small fish often allows more crops per year, thereby increasing the annual yield.

However, if the price paid per kilogram for a larger fish is higher than for the smaller fish, economic considerations must be taken into account.

If a small fish can be marketed, stocking density can be increased so that the standing crop at harvest is equal to the standing crop of the larger fish at harvest. As a result, the total weight of fish harvested is the same for both the small and large fish. However, a shorter period of time was required to grow the small fish to marketable size compared to the large fish. If the same total weight for small and large fish can be harvested, yearly yields are potentially higher with the small fish because an additional crop or two can be farmed per year. The fact that farming a small fish has a higher yield compared to large fish assumes that the increase in stocking density does not significantly reduce the individual fish growth rate and that fish stocked at the higher density will continue to grow equal or only marginally slower than fish stocked at the lower density. If two crops of fish are raised per year instead of one, the additional labour and fingerlings needed should be taken into account, as well as more water if ponds are drained to harvest fish.

Survival

High yields are obtained by stocking the maximum number of fish per unit area, as part of which the fish are able to grow at — or close to — their maximum capacity; this means that marketable fish can be produced within a given growing period (Box 13). If mortality leads to a reduction of fish below the optimum number per area, then the yield will be reduced.

Box 13. How to calculate the yield

Example 1: If fishes are stocked at 10 000 fish/ha and grow to 500 grams in 180 days with no mortality; the yield will be 5 000 kg/ha.

$$Yield = 10\,000\ fish/ha \times 500\ g = 5\,000\,000\ g/ha = 5\,000\,kg/ha$$

Example 2: If fishes are stocked at 10 000 fish/ha and grow to 500 grams in 180 days but survival is 90 percent, our yield will be 4 500 kg/ha.

$$Yield = 10\,000\ fish/ha \times 500\ g \times 90\% = 4\,500\,000\ g/ha = 4\,500\,kg/ha$$

The above example assumes that the reduction in fish density due to mortalities does not cause an increase in the growth rate of the remaining fish; a larger individual fish weight at harvest weight compensates for the lower fish number.

The causes of low survival are:

- Mortality due to handling stress at stocking. Ponds should be checked for dead fish 24 and 48 hours after stocking to determine mortality. If mortality is high, ponds should be restocked.
- Predators, e.g. frogs, snakes, mammals — and worst of all, birds (Plate 4). Bird predation can cause the failure of an aquaculture enterprise, yet eliminating it is a difficult chore.
- Disease, poor water quality and thievery.

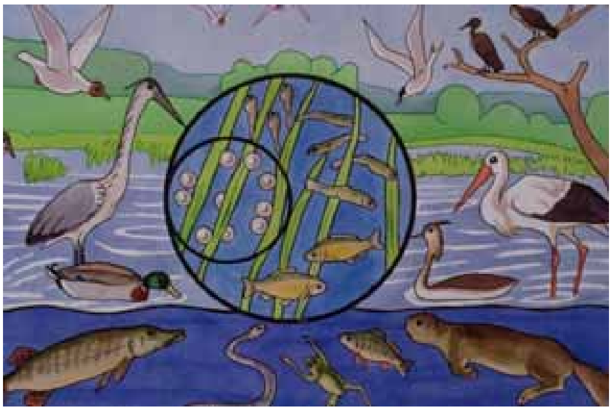


Plate 4. Predator, carp culture

Credit: @FAO Aquaculture photo library

Harvest frequency

Yields per unit of area can be increased by increasing stocking densities, by stocking a wide range of fish sizes, and partial harvest.

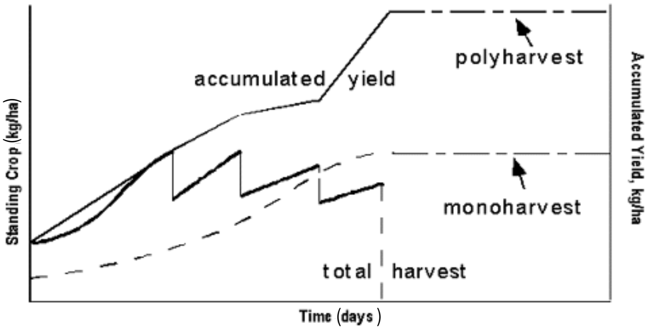
In a single- or monoharvest system, fish are stocked at a small size, grown to market size and totally harvested either by pond draining or careful, frequent harvests. However, when fish are small, the standing crop per unit area is small and a lot of production potential is lost (Figure 25).

To overcome the potential loss of production caused by stocking small fish at a low density (low standing crop), the stocking density of the small fish can be increased (increase the standing crop). Generally, a critical standing crop is reached before fish achieve a marketable size: frequent harvesting or thinning and restocking to a lower density is required to allow fish to reach a marketable size. Fish may be raised in a number of stages (e.g. fry, fingerling, grow out) at high stocking densities to take advantage of high daily production rates. The following is needed to grow fish in stages:

- careful planning of pond space;
- additional labour to harvest and restock fish;
- careful handling of fish, especially small fish, to avoid mortality.

A range of fish sizes can be stocked at high densities so that the larger, marketable fish can be partially harvested early in the culture period, lowering the standing crop and allowing the smaller fish space to grow without having to restock. This system results in high daily production rates and high yields (Figure 27).

Figure 27. Relationship between standing crop and accumulated yield over time in a polyharvest system



Source: (Lovshin, 1995)

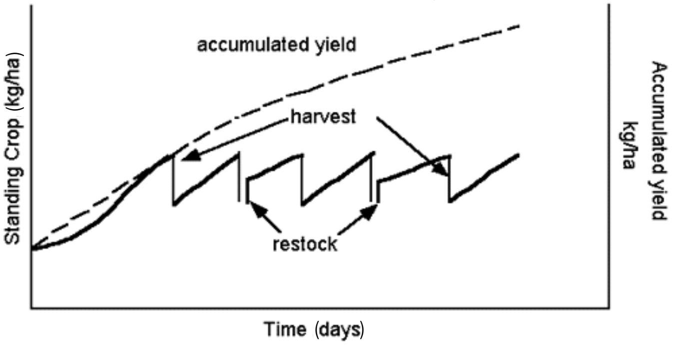
Over time, after several harvests, the fish density is lowered so much that even though individual fish growth is high, daily production rate is low because individual fish growth cannot compensate for reduced fish density. At this point, the pond is totally harvested and restocked.

Plate 5. Partial harvesting of farmed carps in ponds, Bangladesh

Credits: @FAO Aquaculture photo library/M.R. Hasan

Higher yields per unit area can be obtained by stocking optimum numbers of variously sized fingerlings, partial harvesting, and then restocking with a number of small fingerlings equivalent to the number of fish harvested (Figure 28).

Figure 28. Relationship between standing crop and accumulated yield over time for a partial harvest and restock system



Source: (Lovshin, 1995)

Box 14. Advantages and disadvantages of partial harvest and restock

Pros	Cons
•It can be continued for as long as is practical without draining the pond, thereby conserving water, water fertility and chemical supplements to the ponds. •Less effluent release compared with yearly draining. •Fish yields per unit area per year are high. •Fish are available for harvest year-round, improving farm cash-flow and allowing processors to provide the consumer with fish year-round. •As many ponds may have market-size fish, normally a few ponds can be found with fish that are not off-flavour and can be harvested.	•Fish must be easily harvestable with a seine. •Fish should not reproduce in the grow-out pond or a predator fish will be needed. •The wide size variation at harvest makes mechanized processing more difficult. Filleting machines are calibrated for a specific size of fish. •Feed conversion efficiency is higher than in monoharvest ponds. Large, aggressive fish escape harvest, eat more feed than is necessary for efficient conversion, and small fish often do not get enough food for best growth. •Diseases transfer when small fish are stocked in the same pond with large fish.

In standing water where fish growth is not limited by waste from feed and/or the biota, the highest yields per unit area can be obtained with a polyculture, stocking optimum numbers of variously sized fingerlings, partial harvesting, and restocking.

In standing water where fish growth is limited by waste from feed and/or the biota, the highest yields per unit area can be obtained with a monoculture (or polyculture) of fish resistant to poor water quality, stocking optimum numbers of variously sized fingerlings, partial harvesting, and restocking fish (fishes) that will grow in water of poor quality.

2 Classification of farming systems

Aquaculture systems are often classified according to:

- salinity of water, i.e. mariculture, freshwater and brackish water;
- business orientation, i.e. non-commercial and commercial aquaculture[12];
- type of farming system, e.g. pond, cage, pen, tank or raceway;
- aquaculture product, e.g. trout, tilapia, shrimp, oysters, seaweed;
- management intensity, i.e. extensive, semi-intensive and intensive.

The intensification of aquaculture includes complex interventions that often defy quantitative and qualitative categorization, making definitions about levels of intensity a subjective matter.

Extensive systems rely on primary production in the water. The element of human control affects only a part of the life cycle of the cultured species. Fish seed is usually obtained from the wild. This system is characterized by a low input-output ratio, i.e. the proportion of inputs introduced in the farming system relative to the outputs produced, because production inputs such as feed and fertilizer are seldom used.

Semi-intensive systems include some intentional human addition of fertilization and/or supplementary feed material, such as agro-industrial waste, in addition to the natural food from primary production. Fish seed is also purposely stocked.

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[12] The concepts of commercial and non-commercial aquaculture is addressed in the Module 2: The economic dimension of commercial aquaculture.

In **intensive systems** more output is produced from a specified production unit. In these systems, the farmer provides all of the nutritional requirements of the cultured species. In addition, all aspects of the system, including the physico-chemical environment, are controlled.

3 Introduction to pond and cage culture systems

3.1 Pond-based aquaculture

Pond-based fish farming systems are characterized by depressions in a piece of land, filled with water, containing the culture species under various levels of management intensity.

Pond-based systems can be classified in several ways, including management intensity, salinity, and elevation or temperature (Section 2). The general principles of pond culture are similar for all these categorizations.

A typical pond farm should be located close to a reliable water source, on a soil type that can hold water. In order to reduce pumping costs the farm should be sited on a gentle slope to allow water to flow into and out of ponds by gravity, and ideally not too far from the farmer's house.

Ponds need to have an average depth of approximately 1.5 metres to allow for adequate cover from predatory birds and hot surface water during the day. A farm shed is required to store equipment, feed and other inputs, in addition to farm records.

The most basic inputs in a pond-based farm are water and land. Without a good supply of good quality water all the other processes or management units will come to a standstill. Other important factors for production include good-quality feed and seed (fingerlings); well-trained labour is also essential.

Equipment and machinery used include aerators, seine nets, chemical application boats and water-quality testing kits.

Plate 6. Tilapia earthen pond farm showing gravitational water in-flow, Rwanda

Credit: @Yaw Ansah (FAO)

3.2 Cage-based aquaculture

A cage-based fish farming system refers to the farming of fish in culturing units consisting of a framed net open at the top and floating on the surface. Otherwise, when completely enclosed, the cage is kept below the water surface by adjustable buoyancy or suspending from the surface (FAO, 1984). Cages are usually employed in bodies of water such as rivers, deep lakes, and the sea.

Given the relatively small size of cages, the harvesting practices are simple and fast to perform. The investment per unit weight of fish produced is relatively low compared to pond-based farming systems (FAO, 1984). Moreover, cage construction is cheaper and easier to execute compared to ponds.

One major characteristic of a cage-based system is that the farmer has little control over the physical and chemical parameters of a chosen site. Therefore, site selection needs to ensure that factors such as water current, quality and depth, wind and wave action are all conducive to cage farming.

The main inputs into a cage-based system are feed and fingerlings. All the nutrient requirements for the fish need to be provided by the farmer.

Equipment includes the cage system, which is made up of materials such as netting, floats and the frame. A farm shed is also needed on shore for storing feed and other inputs, as well as serving as an office for record-keeping and other management activities. A canoe or boat is required for feeding and harvesting activities.

Plate 7. Tilapia cage farm on Lake Kivu, Rwanda

Credit: @ Yaw Ansah (FAO)

4 Design and construction of pond farms

4.1 Criteria for the site selection of a pond farm

Water source

Much like any fish farming system, the most important factor to be considered when selecting a site for a pond farm is the availability of a constant supply of good-quality water (FAO, 2006a; Mulonda, 2014). Examples of water sources include: natural springs, rainfall, irrigation canal, reservoir, dug wells, and streams or rivers. Chemical properties such as pH, dissolved oxygen, ammonia, and biological factors (e.g. primary production potential) and physical characteristics such as temperature, turbidity, etc. must all be favourable year-round, or within the growing cycle[13] (FAO, 2006a).

Land and soil characteristics

The suitability of the selected land must be confirmed. However, land that is considered a wasteland or unsuitable for agriculture will be cheaper. Sandy clay or clay loam soils are recommended, both for their water retention and their abilities to support primary production (FAO, 2006d). Laboratory analysis of the chemical characteristics of the soil (pH, phosphorus, etc.) is also recommended. Hydrological factors such as the susceptibility to flooding by virtue of adequate elevation and slope — two percent steepness or less — must also be considered. The water table level[14] needs to be checked to allow for complete drainage, and avoid flooding as a result of rainfall events (FAO, 2006a).

Socio-economic factors

Several social, economic, and even cultural factors could affect either the operation of the farm or the marketing of the products. Some of these factors include the political climate, land tenure systems, credit and financing facilities, area development plans, location of markets, acceptability of fish (or particular species) in the wider area, and proximity to amenities such as major roads and electricity. In

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[13] See Section 1. Principles of aquaculture.

[14] The level at which groundwater is found in the soil is known as the water table.

order to decide on a site for any aquaculture operation, the farmer needs to consider the scale and intensity of production, whether mono- or polyculture, and the production target. These factors are used when calculating the area of land required for the operation (FAO, 2006a).

4.2 Design and construction of ponds

Pond size, depth, and shape

A pond could have a surface area of between 1 000–2 000 m^2 (and no less than 300 m^2) (Mulonda, 2014). In general, pond dimensions should not allow for a total production exceeding 100 tonnes per pond, for ease of management and to reduce potential risks. Ideally, it should take no more than 10 days to fill a pond. For intensive operations complete drainage is essential.

The days needed to complete drainage should not exceed:

$$\sqrt{Pond\ surface\ area\ (hectares)} \quad (13)$$

Box 15. How to calculate the draining days

For example, in a pond with a surface area of 0.4 hectares the number of days needed to drain the pond completely should not exceed (FAO, 2006c):

$$\sqrt{0.4} = 0.6\ days$$

The maximum depth should range between 1.2 and 2 metres. In regions with elevated temperatures, ponds should be deeper, between 1.8 and 2 metres. Square or rectangular shapes are easiest to construct and manage. However, any shape can be chosen based on the layout of the land.

Farm layout design

The following factors should be considered when laying out the locations of the farm (FAO, 2006c):

- The distances to be covered when transporting feed from storage to ponds, and hauling harvested products to the holding facilities, should be as short as possible.
- The farm buildings should be accessible by road (Mulonda, 2014).
- Areas that require attention or frequent attendance, such as hatcheries, should be close to the farm operating buildings.
- Each pond should have its own filling and draining system, if possible, independent from other ponds.
- The dike crests used as unpaved roadways should be at least three metres wide. Paved roadways on dike crests should also have one-metre-wide unpaved shoulders.
- The dimensions of the canals that carry water from the intake to the individual ponds should allow all ponds to be filled within the recommended time. All ponds on a farm should be filled within 50 days.
- The drain (outlet) ditches should be at least 0.3 metres below the surrounding terrain, and not be allowed to overflow. Drain ditches serve as conduits for seepage and external runoff, as well as a mechanism to prevent this water from entering directly into surrounding water bodies.

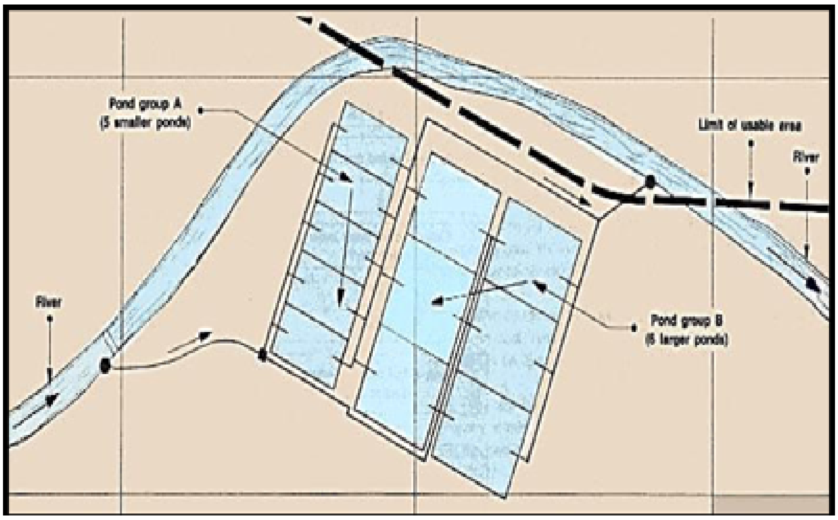

Plate 8. Layout of a typical commercially-oriented small fish farm

Source: (Mulonda, 2014)

4.3 Water

In pond-based farming systems, there are various existing water supply options. **Rainfall** is the primary source of water for pond farm operations. Secondary sources of water result from either subsurface (groundwater) infiltration, or the overland flow of rainwater.

Groundwater is subsurface water that has not been absorbed by the soil. The level at which groundwater is found in the soil is known as the **water table**. Lakes, swamps, and streams are formed when the water table is higher than the land which immediately surrounds them.

An **aquifer** is the groundwater located above an impermeable rock formation. An aquifer flowing above the surface of the surrounding land, is known as a **spring**. Springs and aquifers need to be replenished by rainfall. Otherwise, the volume and flow interval will be reduced. Sometimes, a hole needs to be dug or drilled to reach an aquifer. This hole is called a **well**.

The quantity of water needed to fill a pond to the required level is known as the **volume of the pond**. The volume of a pond can be determined by multiplying the surface area by the average pond depth (Equation 14). Given the fact that depth varies across the pond, the average pond depth is the outcome of different depth measurements spread all over the pond.

$$Volume = surface\ area\ \times average\ depth \qquad (14)$$

Avoid depending on an above ground water table to fill your pond, as the water table's level fluctuates significantly according to the seasons. Moreover, using an above ground water table would also make complete draining impossible.

Streams, springs, and rivers can be used as sources of water for pond operations, with ponds constructed well above the water table. If the water supply from these sources fluctuates significantly within the year, the farmer might consider building a reservoir to store water to even out supply over the year.

It is important to have control over the level of water in the pond. This is to prevent water overflowing the pond dike, allowing fish to escape, or the water level getting too low. An overflow pipe can be used to let excess water flow from the pond. The overflow pipe could be a bamboo, plastic, or metal pipe. This is placed in the deep end of the pond near the outlet and leads away from the pond through the drainage ditch.

It is recommended that some rocks be set at the bottom of the pond, below the inlet, prior to filling: this will prevent the erosion of the pond bottom, which would muddy the water. The process of the water falling on rock will also incorporate dissolved oxygen into the pond water.

The farmer needs to maintain water quality conditions conducive to fish growth.

The quality of the pond water changes over the course of a day and the seasons. The quality of the water therefore needs to be monitored constantly. This allows for corrective action to be taken before a catastrophe occurs.

5 Seed production

The choice of a particular seed production method depends on the available facilities, the reproductive biology of the fish, and on local conditions. There are three main methods for reproducing culture species: natural, semi-natural, and artificial (FAO, 2006b). In each of these methods male and female fish (the broodstock), or their sperm and eggs, are brought together for the purpose of propagation.

Natural reproduction is especially used to propagate tilapia. A set ratio of males and females are placed together in a breeding pond or other enclosure, and allowed to spawn naturally. Other species might require additional changes to the environment. For example, African catfish (*Clarias*) will only spawn with a sudden rise in the pond level; American and European catfishes (*Ictalurus* and *Silurus*, respectively) require the presence of artificial nest containers; the Common carp requires grassy vegetation.

In **semi-natural reproduction**, female fish are injected with pituitary hormones to instigate spawning, before males and females are placed together. Fertilized eggs are then collected for hatchery procedures.

In **artificial reproduction**, female fish are injected with a chemical to ripen the eggs in their ovaries, after which they are stripped of ripe eggs. The eggs are then fertilized artificially with male sperm, and then sent through hatchery procedures.

Broodstock can either: be obtained from the wild and transported to the farm; or they can be raised on the farm through selective breeding, which allows for progressive stock improvement. Broodstock pond conditions should be conducive to the particular farmed species. Temperature, dissolved oxygen, and natural food suited to the species all contribute to successful reproduction (FAO, 2006b).

Small-sized, young broodstock is preferred to larger, older ones. The former are easier to handle and produce eggs of a higher quality. Broodstock should be replaced regularly to improve spawning synchrony (Badiane, 2015).

6 Nutrition and feeds

Unlike plants, fish cannot combine sunlight and nutrients to synthesize body tissue. Instead, fish require organic material—such as other animals and plants, or formulated feed containing these materials—to survive, grow, and reproduce (Gopalakrishnan and Coche, 1994).

The efficiency with which feed is converted by fish into flesh is known as the feed conversion ratio (FCR). An FCR of 1.2 implies that 1.2 kg of fish is required to produce 1 kg of fish. A lower FCR refers to a higher efficiency. For example, Nile tilapia has an FCR of about 1.8 (Mulonga, 2014).

Fish food can be grouped into three main categories: natural food, supplementary feed, and complete feeds.

Natural food is created by natural processes in the pond, and includes phytoplankton and zooplankton, detritus, snails, insects, worms, other fish, and aquatic plants. The abundance of these food items depends directly on the concentration of various levels of water quality parameters, and can be improved by pond liming and fertilization.

Supplemental feeding[15] is used to compensate for nutrient and quantity deficiencies in natural food. This is the most common feeding method in semi-intensive systems. Supplemental feed is usually made up of agro-industrial by-products such wheat, maize, and rice brans, as well as kitchen waste such as leftovers (Gopalakrishnan and Coche, 1994). Leaves (e.g. cocoyam and potato leaves) and grass, chopped or administered whole, can also be used for herbivorous species, such as *Tilapia zillii* (Mulonga, 2014). Commercially formulated feeds are considered supplementary when used in combination with pond fertilization. In several cases, dry agro-industrial by-products are mixed together and pelletized with a feed machine; the feed is then dried before being fed to fish.

Complete feeds[16] are formulated to meet all nutritional needs, to enable the fish to grow well. It is usually made commercially, and is expensive.

The major nutrients[17] targeted for fish feed are carbohydrate, protein, lipids, vitamins, and minerals. It is essential for feed milling companies to have laboratory facilities to conduct proximate analysis of both the raw materials and the finished feeds as a way of ensuring quality. However, the types and quantities of nutrients needed by fish differ based on species and size.

Fry are fed at a daily rate of 15 percent of their body weight (bw). By the end of the culture period, the feeding rate should be decreased to six percent bw (Mulonga, 2014). Looking at Tilapia specifically, the feeding table using formulated feed under semi-intensive pond farming is shown in Table 7. It is important to know the total weight of fish in a pond in order to calculate the daily feed ration. A few individual fish can be caught randomly and weighed for an estimate.

Table 7. Feeding table for tilapia using formulated feed under semi-intensive pond farming

Life stage	Fish size (g)	Stocking density (no./ha)	Feed type	Feed size (mm)	Feeding rate (% body weight)	Feeding frequency (no./day)
Early fry	0–1	10 000–30 000	Powder	0.2–1	15–10	4
Fry	1–5		Crumble	1–1.5	10–5	2
Fingerling	5–20		Sinking pellets, balls	1.5–2	5–3	
Juvenile	20–100	< 10 000		2	3–2	1–2
Grower	> 100			3–4	2	
Broodstock	150–300			4		

Source: (FAO, 2016a)

The fishes' ability or efficiency to utilize available nutrients is influenced by several factors including nutrient source, water temperature, species, size, feeding frequency, and interaction with other nutrients.

All finfishes require varying concentrations of ten essential amino acids (the building blocks of protein) in their diet. These are arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (FAO, 2016a). Generally, fish feed should have a crude protein proportion of 25–30 percent for most grow-out operations (Mulonda, 2014).

Carbohydrates are the main energy source for fish. They also serve as binding agents in feed formulation. Starches and other complex carbohydrates are better utilized by fish than di- and polysaccharides.

Lipids generally affect how efficiently fish use nutrients such as vitamins. Different types of lipids are required by different species from different environments. For example, marine fish species require

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[15] See the "Nutrient inputs" section.

[16] See the "Nutrient inputs" section.

[17] See the "Food habits" section.

n-3 highly unsaturated fatty acids (HUFAs). Hybrid tilapia (*O. niloticus x O. aureus*), on the other hand, requires both n-3 and n-6 polyunsaturated fatty acids (PUFAs), but not HUFAs (FAO, 2016a).

Vitamins and minerals, though essential, generally make up only a minor proportion of fish diet. As culture intensifies, the proportion of these nutrients in fish feed should increase, since natural foods decrease. It is generally recommended that minerals be included to prevent instances of mineral deficiency. Plant-based ingredients included in fish feed result in reduced bio-availability of minerals, by binding to metal ions such as manganese, magnesium, calcium and phosphorus (FAO, 2016a).

Fish feed constitutes up to 60 percent of total costs on a typical fish farm (Badiane, 2015). Feed should therefore be managed to prevent wastage and increase the efficiency of use. Dry feed, which is more common than wet feed, is either prepared by the farmer or purchased commercially. The farmer should avoid preparing or purchasing feed that will be stored beyond its shelf life. Dry feeds should be kept in a dry environment, away from pests. In addition, farmers should observe the feeding activity of fish and adjust feeding accordingly, instead of the practice of just administrating a calculated quantity of feed (Gopalakrishnan and Coche, 1994). This is because factors such as temperature and dissolved oxygen influence the rate of feeding. Feeding is usually done twice a day, in the morning and in the evening for grow-out, when temperatures are not too high. Fry are fed 8–10 times daily, while fingerlings are fed 4–6 times daily (Mulonga, 2014).

7 Harvest and post-harvest practices

At the conclusion of the culture period, the fish have to be removed from the pond for selling, storage, or consumption. This removal of fish is known as harvesting. A number of small- to medium-scale fish farms sell fish at the farm gate on days agreed with potential buyers. Fish can also be provided for sale at sales points closer to potential buyers. It is important to have a clear plan on what to do with the fish before harvesting, because most species will die almost immediately after harvesting. Fish flesh also starts to decompose immediately, after death.

Three main harvesting methods are: **without pond drainage**, **with partial pond drainage**, and **with complete pond drainage** (FAO, 2006a). The choice of harvest method depends on different factors, such as the species cultured, water source and availability, proportion of fish intended for harvest, pond depth, and the labour available.

For example, if the pond is located in a water-stressed area it is best to harvest fish with a cast or seine net without pond drainage, in order to conserve the water for subsequent cycles (FAO, 2006a). However, for effective harvesting partial pond drainage is necessary for deep ponds prior to using a seine net (seining). Seining is typically labour-intensive. Even a relatively small-sized pond requires 3–4 people for effective seining. Seining is started from the deep end; the net is then pulled slowly towards the shallow end where it is pulled from the pond and fish are collected. A cast net is operated by a single person, who either stands on the dike or in a canoe/boat. A bigger mesh size is used in either the cast or seine to harvest larger-sized fish and leave smaller fish. Decreasing the mesh size will result in a more complete harvest.

Species such as the African catfish (*Clarias spp.*) require total pond drainage in most cases, since they have the ability to burrow into the pond beyond the reach of the seine net. Moreover, the complete harvesting of all fish in the pond mostly requires complete drainage. If the layout of ponds allows, it might also be possible to drain the entirety of pond water from one pond into another, and then reuse the water for subsequent production cycles. Complete drainage after each production cycle is more common in water-abundant areas, and enables all fish to be harvested and pond bottoms to be cleaned. As the water is being drained out, baskets or hand nets can be used to collect fish.

During and after harvesting fish, proper handling is essential in order to maintain fish market value, to prevent contamination and increasing the rate of decomposition. Harvesting equipment should be designed so as to cause only minimal physical damage to fish. This equipment should also be easy to clean and disinfect (FAO, 2016b). In addition, harvesting should not be conducted in the afternoon under hot temperatures.

Fish must be washed free of mud and other debris with running water immediately after harvesting. In the case of *Clarias*, if the fish is harvested live it is important to keep it in clean running water for as long as possible in order to purge it of pollutants that might be found in the digestive tract (FAO, 2006a).

There are a number of methods for preserving harvested fish to slow down decomposition and increase the shelf life (or storage time) of fish. Chilling is the process of lowering fish body temperature to 0˚C, using ice or refrigeration. If fish is to be chilled, it has to be put in ice or a refrigerator immediately after harvest. The general rule of thumb is to use an ice-to-fish ratio of 2:1 for chilling with ice, with no fish left exposed above the ice (FAO, 2016c).

Freezing involves lowering the core thermal temperature of fish to about -18 ˚C. While chilling preserves fish for up to 15 days, fish can be frozen for up to one year (FAO, 2016d). Salting and drying is a common preservation method in the tropics due to the abundance of sunshine and the intermittent power supply, which makes freezing unwise. Salting diffuses the water in the fish flesh, infusing it with salt. This dehydration allows fish to be stored for years after effective drying (FAO, 2016e).

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