La-Net

FAA 404

FISH FRY AND FINGERLINGS PRODUCTION; HATCHERY MANAGEMENT; FISH PRODUCTION AND MANAGEMENT AND FISH FOOD NUTRITION AND FISH FOOD TECHNOLOGY

Course code: FAA 404

Course title: Fish Fry and Fingerlings Production; Hatchery Management; Fish Production and Management and Fish Food Nutrition and Fish Food Technology

Course credit load: 2 Units

Series 1: Hatchery and Nursery Management Practices

Series outline

Part 1.1: Introduction to Hatchery Management

Sub Part 1.1.1: Definition, scope, and importance of hatchery management

Sub Part 1.1.2: Types of hatcheries and their facilities

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Sub Part 1.2.1: Importance of water quality for hatchery success

Sub Part 1.2.2: Key water quality parameters and their optimal ranges

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Part 1.3: Broodstock Management

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Introduction

The production of fish fry and fingerlings is the foundation of all aquaculture operations. Without a reliable supply of healthy juveniles, no grow-out system can function sustainably. The hatchery is the facility where this production begins, and the quality of hatchery and nursery management determines whether juvenile fish survive and thrive, or suffer high mortality rates that undermine the entire production cycle. Understanding hatchery management is therefore essential for anyone aspiring to work in aquaculture at any level.

The aim of this Series is to introduce you to the principles and practices of hatchery and nursery management, equipping you with the knowledge to describe hatchery facilities and equipment, explain water quality management, manage broodstock effectively, and oversee the care of fry in nursery ponds.

We shall commence this Series by examining the definition, types, and infrastructure of hatcheries. Next, we will study the critical role of water quality and how it is managed. Following that, we will cover broodstock management, including selection, conditioning, segregation, and quarantine. Finally, we will wrap up with nursery pond management and the specific feeding and care requirements of fish fry.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define hatchery management and explain its scope and importance in aquaculture (Linked to Part 1.1),
- **SLO 1.2** describe the types of hatcheries and their key facilities and equipment (Linked to Part 1.1),
- **SLO 1.3** explain the importance of water quality in hatcheries and describe the key parameters and their optimal ranges (Linked to Part 1.2),
- **SLO 1.4** describe water treatment, recirculation, and monitoring systems used in hatcheries (Linked to Part 1.2),
- **SLO 1.5** explain the principles of broodstock selection, conditioning, segregation, and quarantine (Linked to Part 1.3),
- **SLO 1.6** describe the nutritional and health management requirements of broodstock (Linked to Part 1.3),
- **SLO 1.7** explain how nursery ponds are prepared and stocked for fry production (Linked to Part 1.4),
- **SLO 1.8** describe the feed sizes and feeding regimes appropriate for fish fry at different growth stages (Linked to Part 1.4), and

SLO 1.9 explain how fry growth is monitored and mortality is managed in nursery ponds (Linked to Part 1.4).

1.1 Introduction to Hatchery Management

1.1.1 Definition, scope, and importance of hatchery management

Hatchery management refers to the coordinated set of practices and procedures used to maintain a controlled environment in which fish broodstock are conditioned, spawning is induced or facilitated, eggs are fertilised and incubated, and larvae are reared until they are large enough to be transferred to nursery ponds or grow-out facilities. The scope of hatchery management extends from water quality control and broodstock care through to the collection, incubation, and early rearing of eggs and larvae.

The importance of hatchery management in aquaculture cannot be overstated. Producing fish through natural reproduction in open water is unpredictable and season-dependent; hatcheries allow fish farmers to control the timing of reproduction, produce large numbers of juveniles on demand, improve genetic quality through selective breeding, and supply fingerlings year-round. In Nigeria, the expansion of tilapia, catfish, and carp aquaculture has been made possible by the development of hatchery technology suited to tropical conditions.

Fill in the blank: Hatchery management refers to the coordinated practices used to maintain a controlled environment for fish ________, egg incubation, and larval rearing.

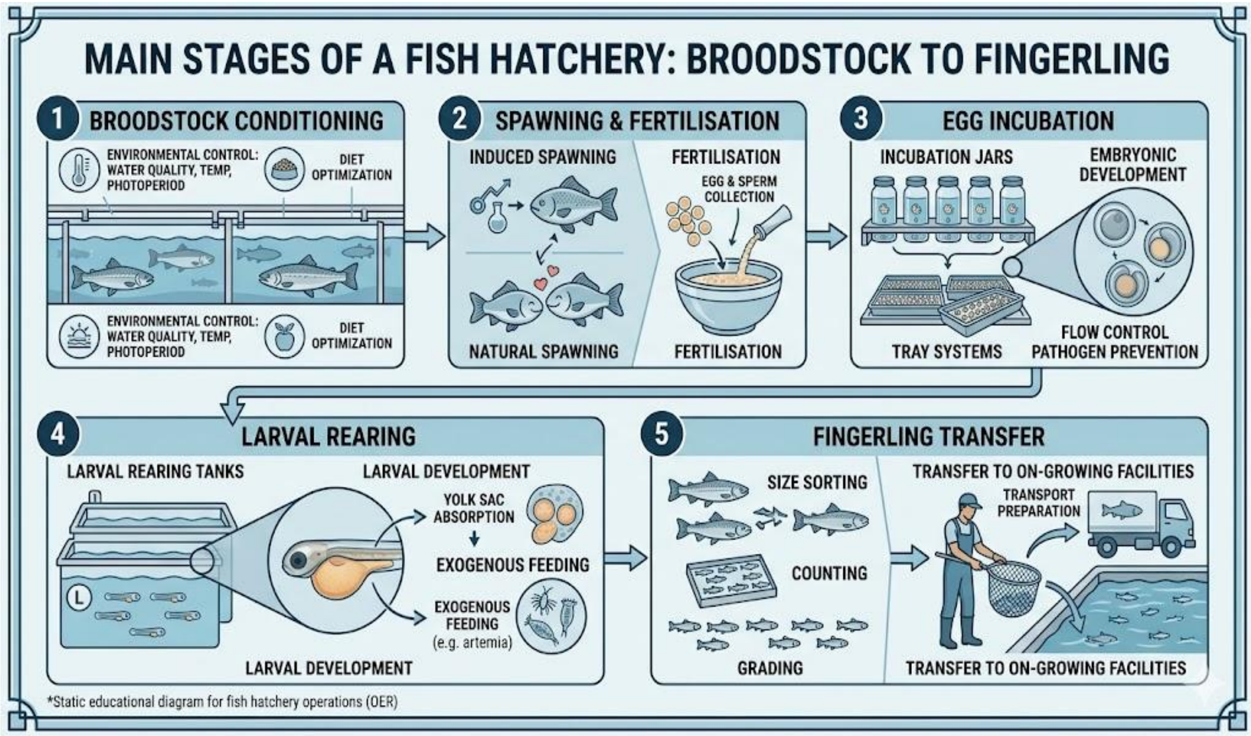

Figure 1.1: Diagram showing the main components and flow of a fish hatchery from broodstock conditioning to fingerling production

1.1.2 Types of hatcheries and their facilities

Hatcheries are classified by the degree of environmental control they provide. **Open or extensive hatcheries** rely on natural water sources and minimal intervention; they are low in cost but unpredictable in output. **Semi-intensive hatcheries** use earthen or concrete ponds with some water quality management and may employ hormone-induced spawning. **Intensive or closed hatcheries** use recirculating aquaculture systems (RAS) with full environmental control of temperature, dissolved oxygen, and photoperiod, enabling year-round production of multiple species.

Key facilities in a well-equipped hatchery include broodstock holding tanks, spawning tanks or channels, incubation jars or trays for egg development, larval rearing tanks, live food production units for algae and Artemia, a water treatment system, and laboratory space for monitoring water quality and fish health. In Nigeria, government hatcheries such as those at the New Bussa Fish Farm (Kainji) and the National Aquaculture Centre in Baga use semi-intensive systems, while private commercial hatcheries increasingly employ RAS technology for catfish and tilapia production.

Fill in the blank: ________ hatcheries use recirculating aquaculture systems with full environmental control, enabling year-round production regardless of season.


Plate 1.1: Interior of an intensive fish hatchery showing recirculating aquaculture system tanks and associated water treatment equipment

1.1.3 Hatchery infrastructure and essential equipment

Reliable infrastructure is the foundation of successful hatchery operation. A dependable water supply of adequate volume and consistent quality is the single most critical requirement; boreholes, rivers, or reservoirs may serve as source water, but treatment to remove pathogens, suspended solids, and harmful chemicals is usually necessary. An uninterrupted power supply is equally important, as even brief failures in aeration or heating can cause mass mortality of larvae.

Essential hatchery equipment includes aeration systems (air blowers, diffusers, or paddle wheels), temperature control units, incubation jars or hatching troughs, sieves and nets of graduated mesh sizes for grading juveniles, weighing balances, measuring instruments for water quality (pH meter, dissolved oxygen meter, thermometer, and ammonia test kit), and microscopes for examining eggs and larvae. Regular calibration and preventive maintenance of all equipment is a management obligation that must be scheduled and documented in a maintenance log.

Fill in the blank: An uninterrupted ________ supply is critical in hatchery operations because even brief failures in aeration can cause mass mortality of larvae.

Equipment Category	Purpose / Function
Aeration systems	Maintain dissolved oxygen levels to support fish health and growth.
Temperature control units	Regulate water temperature to optimise hatching and larval development.
Incubation jars	Provide controlled environments for egg incubation and hatching.
Water quality meters	Monitor parameters such as pH, dissolved oxygen, ammonia, and salinity.
Grading sieves	Separate fish by size to reduce competition and cannibalism.
Pumps and filtration systems	Ensure continuous water circulation and removal of waste products.
Tanks and raceways	Hold broodstock, larvae, and juveniles at different developmental stages.
Disinfection equipment	Maintain biosecurity by sterilising water, tanks, and tools.

Box 1.1: Essential equipment required for hatchery operation

Pilot questions 1.1

Define hatchery management and explain its importance in aquaculture.

Name the three types of hatcheries and briefly describe each.

List four key facilities found in a well-equipped fish hatchery.

Why is a reliable power supply critical for hatchery operation?

Name two Nigerian government hatchery facilities and the system type they use.

1.2 Water Quality Management in Hatcheries

1.2.1 Importance of water quality for hatchery success

Water quality is the single greatest determinant of hatchery success or failure. Fish eggs, larvae, and early juveniles are far more sensitive to suboptimal water conditions than older fish because their physiological regulatory systems are not yet fully developed. Small deviations in dissolved oxygen, temperature, ammonia concentration, or pH can dramatically increase mortality, reduce growth rates, cause developmental abnormalities, and predispose fish to disease.

In a hatchery, unlike in a natural water body, fish are confined at high densities in small volumes of water. This means that the metabolic wastes produced by the fish accumulate rapidly, and the buffering capacity of the system is limited. Maintaining water quality therefore requires continuous monitoring, proactive management of feeding rates to reduce waste accumulation, adequate water exchange or filtration, and prompt corrective action whenever parameters drift outside acceptable ranges.

Fill in the blank: Fish eggs and larvae are more sensitive to poor water quality than older fish because their physiological ________ systems are not yet fully developed.

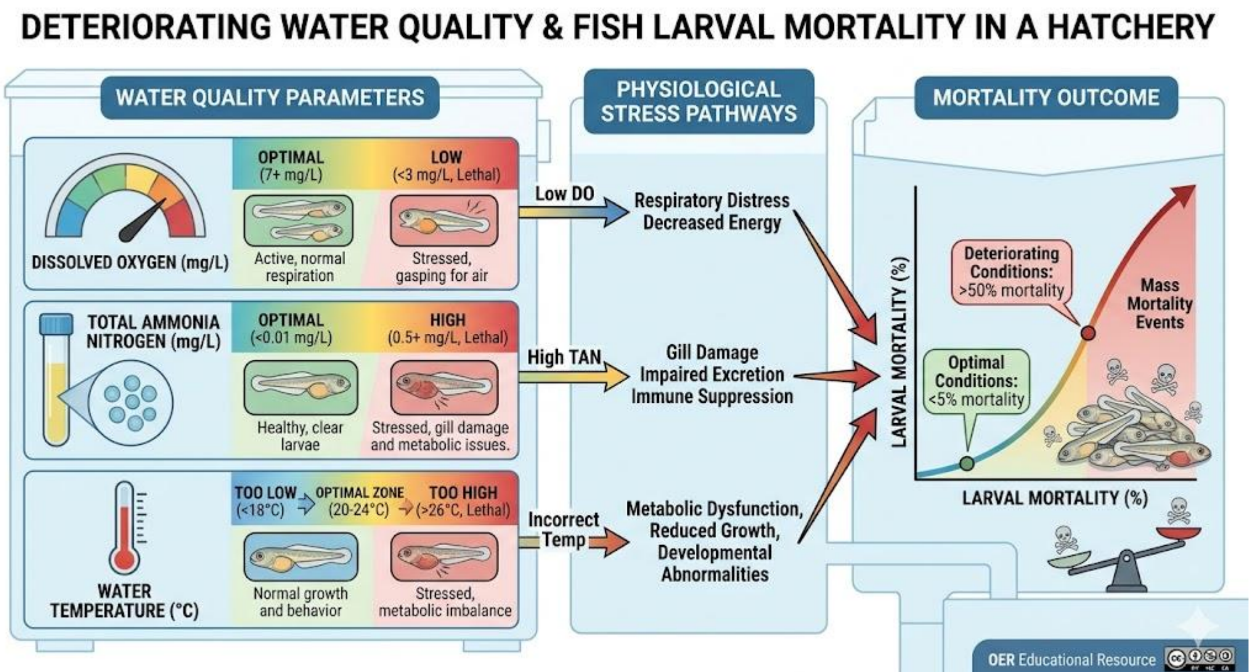

Figure 1.2: Diagram showing the relationship between water quality parameters and hatchery mortality rates in fish larvae

1.2.2 Key water quality parameters and their optimal ranges

Dissolved oxygen (DO) is the most immediately critical parameter; values below 5 mg/L stress fish and below 2 mg/L are lethal within hours. Most hatchery fish require DO between 6 and 9 mg/L. **Temperature** must match the thermal requirements of the species; tropical species such as tilapia and African catfish thrive between 26 and 30°C. Temperature affects metabolic rate, feeding activity, immune function, and the rate of egg development.

pH should be maintained between 6.5 and 8.5 for most species; extreme values inhibit enzyme activity and damage gill tissue. Total ammonia nitrogen (TAN), produced from fish metabolism and uneaten feed, is toxic even at low concentrations; un-ionised ammonia (NH_3) above 0.02 mg/L is harmful and above 0.05 mg/L is acutely toxic to larvae. Nitrite (NO_2^-) above 0.5 mg/L impairs oxygen transport in the blood. Salinity, turbidity, and carbon dioxide are additional parameters requiring monitoring in species-specific situations.

Fill in the blank: Un-ionised ammonia above ________ mg/L is considered acutely toxic to fish larvae and must be controlled through water exchange or biological filtration.

Parameter	Optimal Range	Consequences Outside Range
Dissolved Oxygen	> 5 mg/L	Low oxygen causes stress, poor growth, and mortality; supersaturation may lead to gas bubble disease.
Temperature	26–30 °C	Too low slows growth and hatching; too high increases stress, disease risk, and mortality.
pH	6.5–8.5	Acidic water (<6.5) reduces survival and growth; alkaline water (>8.5) affects metabolism and egg viability.
Ammonia (NH_3)		Elevated levels are toxic, damaging gills and reducing survival.
Nitrite (NO_2^-)		High nitrite causes “brown blood disease” (methemoglobinemia), reducing oxygen transport.

Table 1.1: Key water quality parameters and their recommended ranges for tropical freshwater fish hatcheries

1.2.3 Water treatment, recirculation, and monitoring systems

Water treatment begins before water enters the hatchery. Source water is typically passed through mechanical filters (sand filters or drum filters) to remove suspended solids, then through ultraviolet (UV) sterilisation units or chlorination to eliminate pathogens, and aerated to restore dissolved oxygen to saturation. In recirculating aquaculture systems (RAS), treated water is returned to the rearing tanks after passing through biological filters that convert toxic ammonia and nitrite to relatively harmless nitrate.

Biological filtration relies on nitrifying bacteria (Nitrosomonas converting ammonia to nitrite, and Nitrobacter converting nitrite to nitrate) colonising a high surface-area filter medium. A new RAS must be biologically conditioned (cycled) for several weeks before fish can be stocked at full density. Monitoring is conducted using portable meters and test kits at scheduled intervals, with results recorded in a daily log. Automated sensor systems with alarms for critical parameters provide an additional safety net against equipment failure or sudden water quality deterioration.

Fill in the blank: In a recirculating aquaculture system, biological filtration relies on ________ bacteria that convert toxic ammonia to nitrite and then to nitrate.

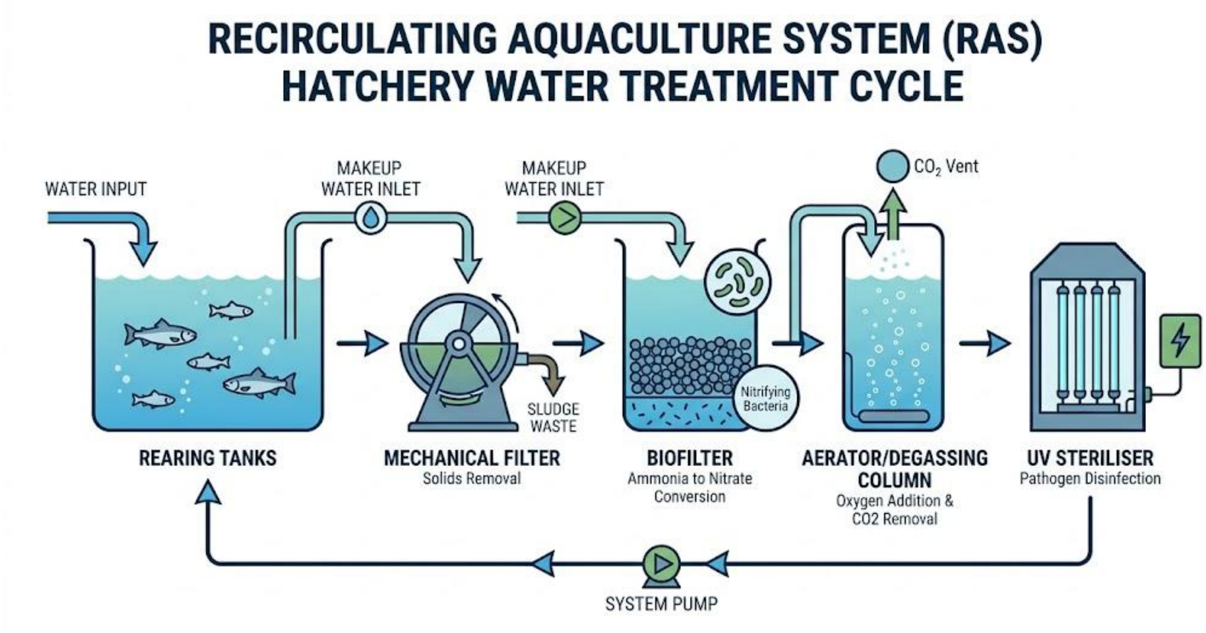

Figure 1.3: Diagram showing the water treatment and recirculation cycle in a RAS hatchery

Pilot questions 1.2

Why are fish larvae more sensitive to poor water quality than adult fish?

State the optimal dissolved oxygen range for tropical hatchery fish and explain what happens below 2 mg/L.

Name three water quality parameters that must be monitored daily in a fish hatchery.

Explain the role of biological filtration in a recirculating aquaculture system.

What is meant by biologically conditioning (cycling) a new RAS before full stocking?

1.3 Broodstock Management

1.3.1 Selection and conditioning of broodstock

Broodstock are the mature male and female fish kept for the purpose of producing eggs and sperm for hatchery operations. Selection of high-quality broodstock is one of the most consequential decisions in hatchery management because the genetic quality and physical condition of brooders directly determines the quality of offspring produced. Selection criteria include species purity, body size and conformation, absence of deformities, health status, and, where improvement programmes are in place, performance traits such as growth rate and feed conversion ratio.

Conditioning refers to the process of bringing selected brooders to optimal reproductive readiness through appropriate feeding, environmental management, and health care. Broodstock are maintained on high-quality diets with elevated levels of protein (35-45 per cent) and essential fatty acids to support gonadal development. Water temperature and photoperiod may be manipulated to advance or delay spawning in species that respond to these environmental cues. In Nigerian catfish hatcheries, African catfish broodstock are typically conditioned for four to six weeks before induced spawning.

Fill in the blank: Broodstock conditioning involves maintaining breeders on high-quality diets rich in ________ and essential fatty acids to support gonadal development.

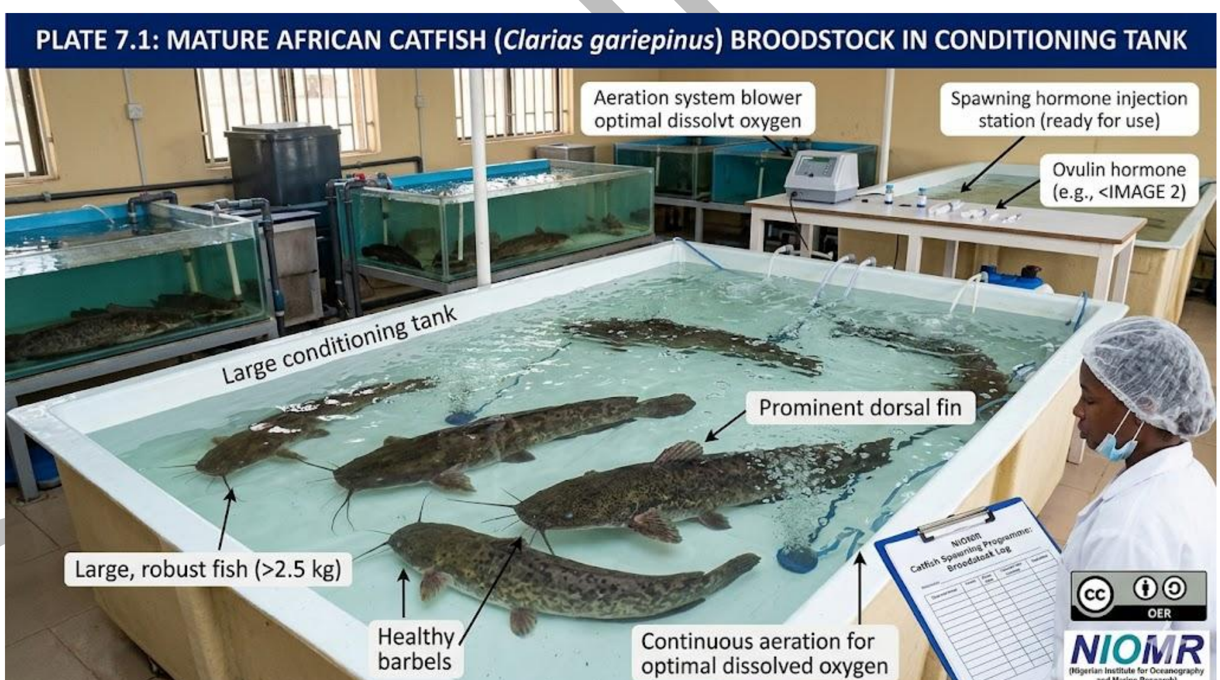

Plate 1.2: Mature African catfish broodstock being held in a conditioning tank prior to induced spawning

1.3.2 Segregation, matching, and quarantine of brooders

Segregation is the separation of male and female broodstock into different tanks or ponds prior to spawning. Keeping sexes separate prevents premature spawning, controls the timing of reproduction, and allows the condition and reproductive readiness of each sex to be assessed independently. In some species, segregation also prevents aggressive interactions between competing males that could injure females or reduce sperm quality.

Matching refers to the selection and pairing of specific males and females for breeding, which is important in controlled hybridisation and selective breeding programmes. **Quarantine** involves isolating newly acquired broodstock in a separate facility for a minimum of two to four weeks before introducing them to the main broodstock population. During quarantine, fish are observed for signs of disease, treated prophylactically if necessary, and tested for notifiable pathogens. This prevents the introduction of new diseases into an established broodstock population, which can cause catastrophic losses.

Fill in the blank: ________ of newly acquired broodstock for two to four weeks before joining the main population prevents the introduction of disease into an established hatchery.

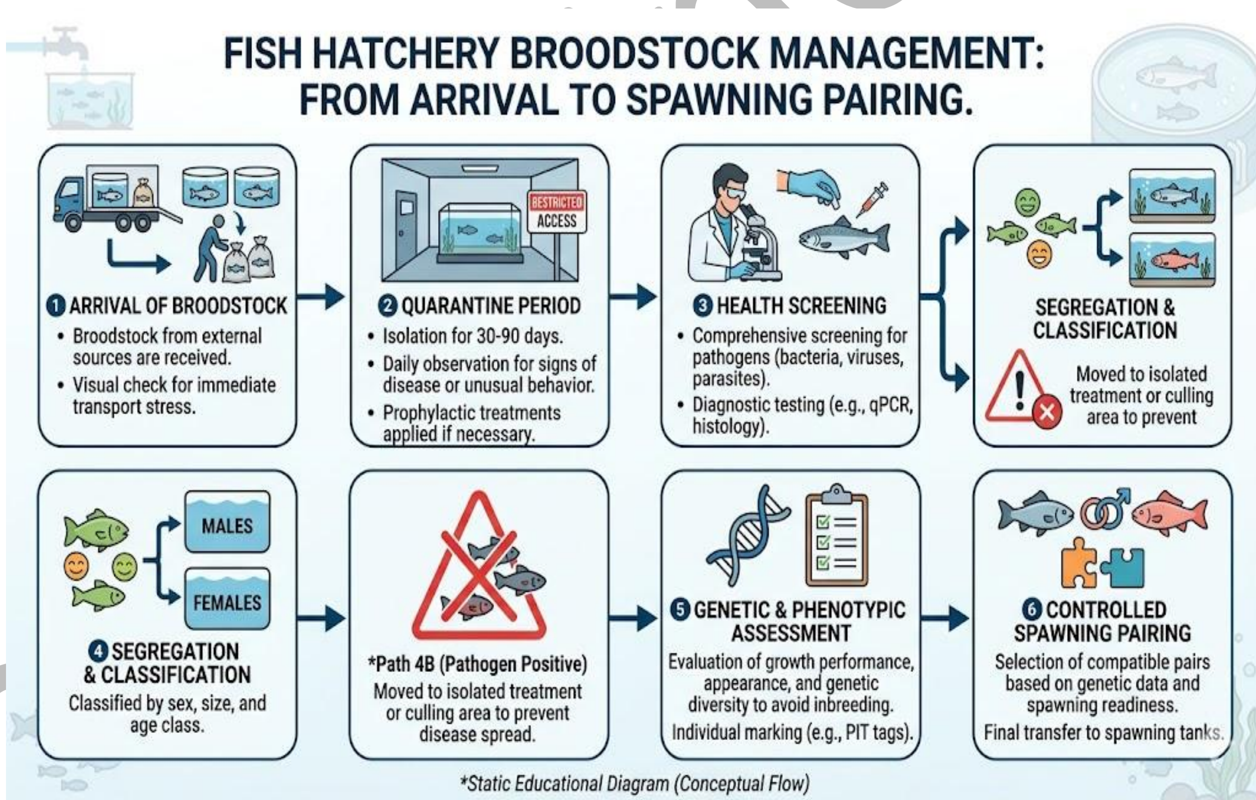

Figure 1.4: Diagram showing the quarantine, segregation, and matching process for broodstock management in a hatchery

1.3.3 Broodstock nutrition and health maintenance

Nutritional management of broodstock differs substantially from that of grow-out fish. Brooders require higher levels of protein, lipids, vitamins (particularly vitamins C and E), and minerals to support gonadal development, egg quality, and immune function. Vitamin C is essential for collagen synthesis and immune response; its deficiency leads to poor egg quality and increased susceptibility to disease. Vitamin E and essential fatty acids such as arachidonic acid influence egg lipid composition and larval viability.

Health maintenance involves regular observation of behaviour and body condition, periodic examination for external and internal parasites, prophylactic treatment where indicated, and prompt isolation and treatment of any sick individuals. Disease events in a broodstock population are particularly serious because they can reduce reproductive output, contaminate eggs and larvae, and spread rapidly to other fish in the hatchery. Maintaining detailed health records for each broodstock individual or batch, including feeding observations, treatments administered, and reproductive performance, is an important management practice.

Fill in the blank: Vitamin ________ is essential for broodstock health because it supports collagen synthesis and immune function, and its deficiency leads to poor egg quality.

Nutrient Category	Role in Broodstock Conditioning & Reproduction
Elevated protein	Supports gonadal development, gamete production, and overall reproductive performance.
Essential fatty acids (EFA)	Improve egg quality, fertilisation success, and larval survival.
Vitamin C	Enhances immune function, reduces stress, and supports collagen synthesis in eggs.
Vitamin E	Acts as an antioxidant, protecting reproductive tissues and improving egg viability.
Minerals (e.g., zinc, calcium, phosphorus)	Critical for gonadal maturation, enzyme function, and skeletal development in offspring.

Box 1.2: Key nutritional requirements of broodstock fish

Pilot questions 1.3

Define broodstock and explain the criteria used to select them.

What is broodstock conditioning, and how is it achieved?

Explain why male and female broodstock are segregated before spawning.

What is the purpose of quarantining newly acquired broodstock?

State two nutritional differences between broodstock diets and grow-out diets.

1.4 Nursery Pond Management and Fry Care

1.4.1 Nursery pond preparation and stocking

Nursery ponds are small, shallow ponds (typically 0.01 to 0.1 ha, 0.5 to 1.0 m deep) used to rear newly hatched larvae and fry until they reach fingerling size (3 to 5 cm) before being transferred to grow-out ponds. Proper preparation before stocking is critical for survival. Ponds are dried and sun-exposed to kill pathogens and parasites, then limed with agricultural lime ($CaCO_3$) or burnt lime (CaO) at 500 to 2,000 kg/ha to neutralise soil acidity and further disinfect the pond bottom.

After liming and refilling, ponds are fertilised with organic manure (poultry droppings or cow dung at 500 to 1,000 kg/ha) and sometimes inorganic fertiliser to stimulate the bloom of natural food organisms, particularly phytoplankton and zooplankton (rotifers, copepods, cladocerans), which are the preferred first food of many fish larvae. Stocking should be timed to coincide with the peak of the zooplankton bloom, typically three to seven days after fertilisation. Stocking density for fry in nursery ponds ranges from 200,000 to 500,000 fry/ha depending on species and management intensity.

Fill in the blank: Nursery ponds are fertilised before stocking to stimulate a bloom of natural ________ organisms, especially zooplankton, which are the first food of fish larvae.

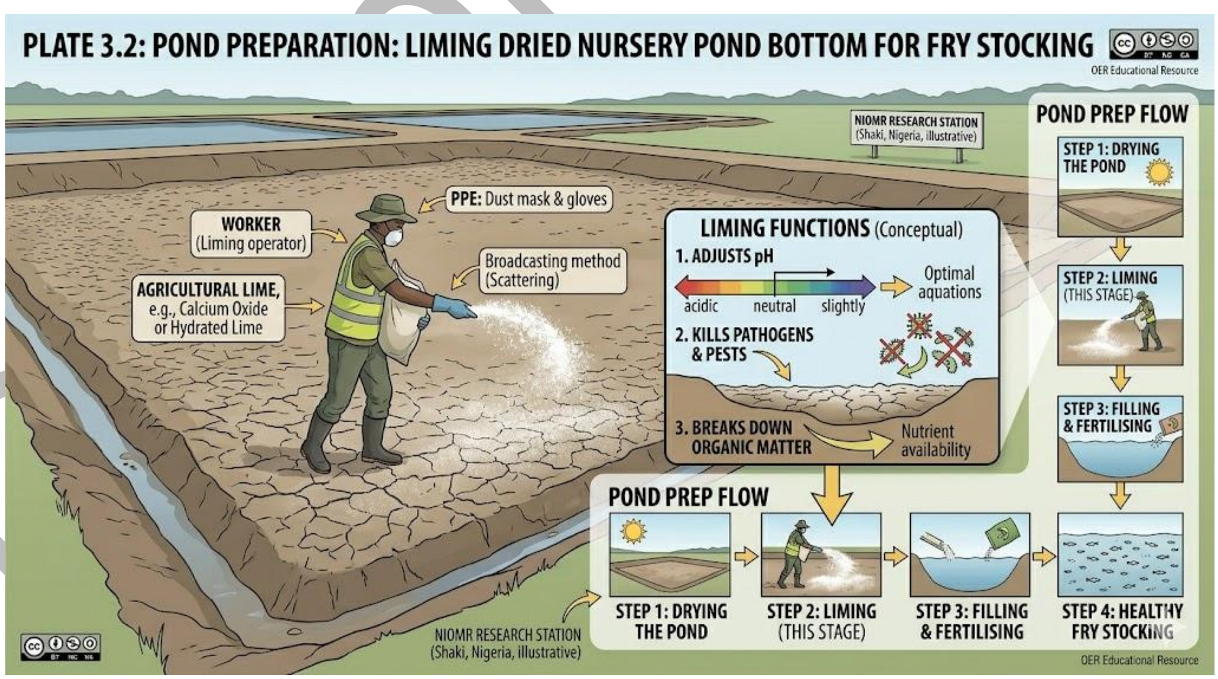

Plate 1.3: Nursery pond being prepared with lime application before stocking with fish fry

1.4.2 Feed sizes and feeding regimes for fry

Feed particle size must match the gape width of the fry at each stage of development. Newly hatched larvae of most species initially absorb their yolk sac, which provides nutrition for the first 24 to 72 hours. When the yolk sac is absorbed, the larvae begin exogenous feeding and require natural live foods such as rotifers (50 to 200 µm) as a first feed. As fry grow, they progress to larger prey: Artemia nauplii (400 to 500 µm) after five to seven days, then micro-pellets (300 to 600 µm), and eventually crumbles and small pellets (1 to 3 mm) as fingerlings.

Feeding frequency for fry should be high, typically four to eight times per day, because larvae have small stomachs, fast digestion rates, and high energy requirements for growth. Feeding rates are expressed as a percentage of body weight per day; for fry this is typically 10 to 20 per cent, declining to 3 to 5 per cent by the fingerling stage. Overfeeding must be avoided as uneaten feed rapidly deteriorates water quality in small rearing units, causing oxygen depletion and ammonia accumulation that can kill fry quickly.

Fill in the blank: Newly hatched fish larvae first absorb their ________ sac before beginning exogenous feeding on small live food organisms such as rotifers.

Developmental Stage	Feed Type	Particle Size	Feeding Frequency (per day)
Yolk sac absorption	Endogenous reserves	Not applicable	No external feeding required
First feeding (larval stage)	Live rotifers	50–100 µm	4–6 times
Early fry	Artemia nauplii	150–250 µm	3–5 times
Advanced fry	Micro-pellets	0.3–0.5 mm	3–4 times
Juvenile transition	Crumbles / formulated feed	0.5–1.0 mm	2–3 times

Table 1.2: Recommended feed sizes and feeding frequencies for fish fry at successive developmental stages

1.4.3 Monitoring fry growth and managing mortality

Monitoring fry growth involves regular measurement of a subsample of fry from each batch to track mean length and weight, calculate specific growth rate (SGR), and compare actual growth against expected growth benchmarks for the species. SGR is calculated as:

$$SGR\ (\%\ \text{per day}) = [(\ln W2 - \ln W1) / (t2 - t1)] \times 100$$

where W1 and W2 are body weights at times t1 and t2. Any significant deviation from the expected growth trajectory suggests a problem with feeding, water quality, disease, or stocking density that must be investigated and corrected promptly.

Mortality management begins with daily observation of rearing units for dead or moribund fish, which are removed immediately to prevent water quality deterioration and disease spread. Mortality rates above five per cent per day in larvae or above two per cent per day in fry require investigation. Common causes include oxygen depletion, ammonia toxicity, bacterial or fungal infection, and predation by insects in outdoor nursery ponds. Survival rate from egg to fingerling is the key performance indicator of nursery pond management and should be targeted at 60 to 80 per cent in well-managed operations.

Fill in the blank: Specific growth rate (SGR) is expressed as a percentage per day and is calculated from the natural logarithm of fish ________ at two time points divided by the time interval.

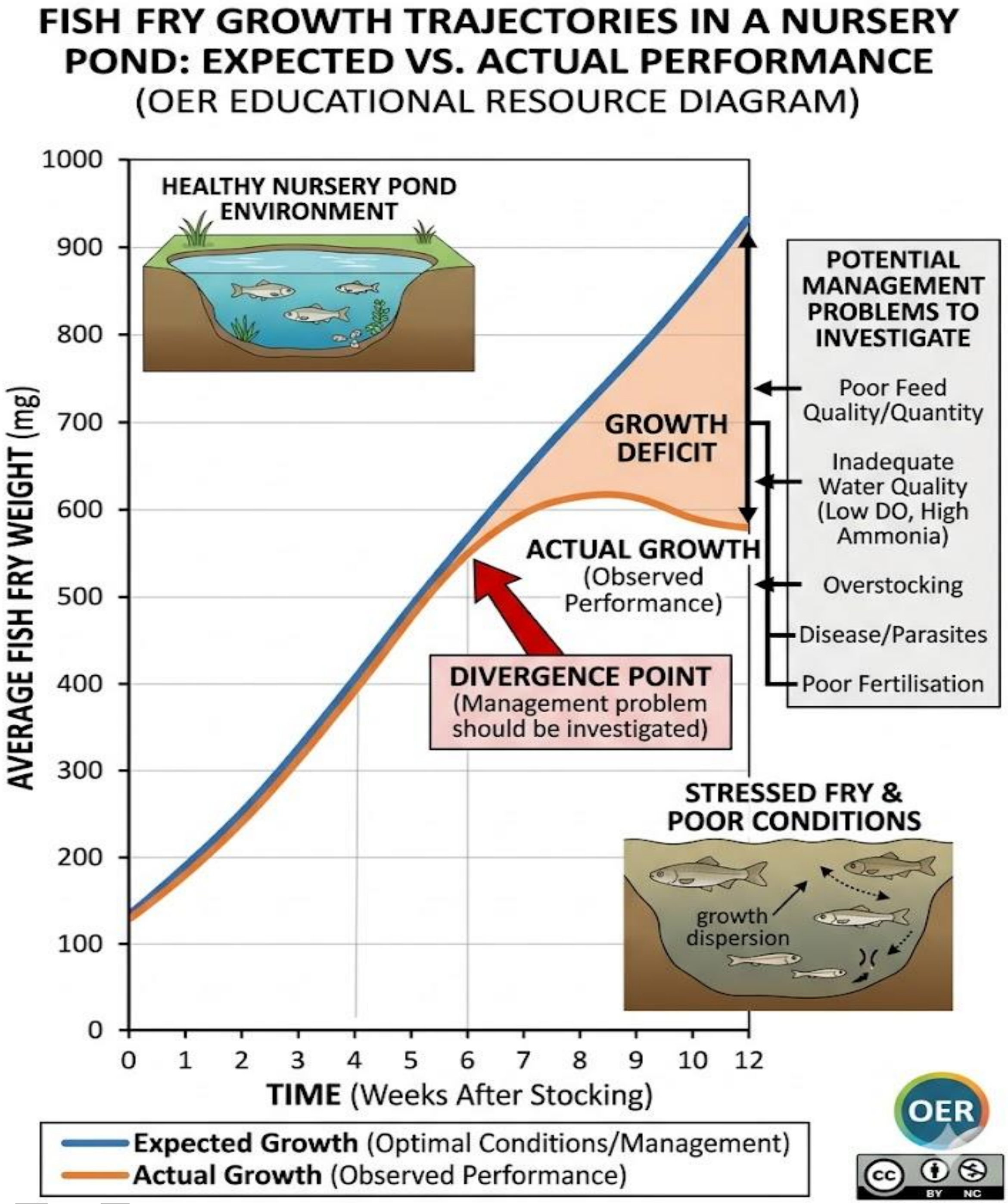

Figure 1.5: Graph showing expected versus actual fry growth trajectory over time in a nursery pond, illustrating how deviations signal management problems

Pilot questions 1.4

Describe the preparation steps for a nursery pond before stocking with fry.

Why is the timing of fry stocking relative to the zooplankton bloom critical?

Describe the progression of feed types and sizes as fry develop from larvae to fingerlings.

Explain why high feeding frequency is important for fish fry.

How is specific growth rate (SGR) calculated and what does it indicate?

Series Summary

This Series has introduced the principles and practices of hatchery and nursery management, which form the foundation of fish fry and fingerling production in aquaculture. We began by defining hatchery management and examining the types of hatcheries, from open to intensive RAS systems, and the infrastructure and equipment required for their operation. We then studied water quality management in depth, identifying the critical parameters, their optimal ranges, and the treatment and recirculation systems used to maintain them, recognising that water quality is the single greatest determinant of hatchery success.

Following that, we examined broodstock management, covering the selection and conditioning of breeders, the importance of segregation and quarantine, and the nutritional and health requirements specific to broodstock. Finally, we studied nursery pond management, including pond preparation and fertilisation, the progression of feed types and sizes from yolk-sac absorption through to fingerling-stage crumbles, and the monitoring of growth and mortality as key performance indicators. By completing this Series, you should now be able to achieve all nine Series Learning Outcomes (SLO 1.1 to SLO 1.9).

Glossary of Terms

Artemia nauplii: the newly hatched larvae of the brine shrimp Artemia salina; a widely used live food for hatchery fish larvae at the stage when they have outgrown rotifers.

Biological filtration: the removal of toxic ammonia and nitrite from hatchery water by nitrifying bacteria colonising a filter medium; an essential component of recirculating aquaculture systems.

Broodstock: mature male and female fish maintained for the purpose of producing eggs and sperm for hatchery operations.

Conditioning: the management process of bringing broodstock to optimal reproductive readiness through appropriate feeding, environmental management, and health care prior to spawning.

Crumbles: small broken or ground pellets of intermediate particle size (1 to 3 mm) fed to fish fry after they have outgrown micro-pellets and before they can accept standard pellets.

Exogenous feeding: the stage at which a fish larva begins to obtain nutrition from external food sources after absorbing its yolk sac; the transition from endogenous to exogenous feeding is a critical and vulnerable period.

Fingerling: a juvenile fish that has grown to a length of 3 to 5 cm and is ready to be transferred from the nursery to grow-out facilities; the target product of nursery management.

Hatchery management: the coordinated set of practices and procedures used to maintain a controlled environment for broodstock conditioning, egg fertilisation and incubation, and larval rearing in aquaculture.

Liming: the application of agricultural lime or burnt lime to a dry pond bottom to neutralise soil acidity, kill pathogens and parasites, and improve water quality before restocking.

Micro-pellet: a very small, manufactured feed particle (300 to 600 μm) used to wean fish larvae from live foods to formulated diets.

Nitrification: the biological process by which ammonia is oxidised to nitrite (by Nitrosomonas bacteria) and then to nitrate (by Nitrobacter bacteria) in biological filters.

Nursery pond: a small, shallow pond used to rear newly hatched larvae and fry until they reach fingerling size before transfer to grow-out ponds.

Quarantine: the isolation of newly acquired fish in a separate facility for two to four weeks to observe for disease, test for pathogens, and treat as necessary before introduction to the main population.

Recirculating aquaculture system (RAS): a closed or semi-closed water management system in which treated water is continuously recycled through rearing tanks, reducing water use and enabling year-round production.

Rotifers: microscopic aquatic animals (50 to 200 μm) of the phylum Rotifera; commonly the first live food provided to newly hatched fish larvae after yolk sac absorption.

Segregation: the separation of male and female broodstock into different holding units prior to spawning to control timing, prevent premature reproduction, and allow independent assessment of reproductive readiness.

Specific growth rate (SGR): the percentage increase in body weight per day, calculated as $[(\ln W2 - \ln W1) / (t2 - t1)] \times 100$; the standard measure of fish growth performance.

Total ammonia nitrogen (TAN): the sum of ionised ammonium (NH_4^+) and un-ionised ammonia (NH_3) in the water; un-ionised ammonia is the toxic fraction and must be kept below 0.02 mg/L in larval rearing.

Yolk sac: the nutrient-rich sac attached to newly hatched fish larvae that provides endogenous nutrition for the first 24 to 72 hours before exogenous feeding begins.

Zooplankton bloom: the rapid increase in abundance of small aquatic animals (rotifers, copepods, cladocerans) in a fertilised nursery pond; timed to provide natural live food for newly stocked fry.

Concept Check Questions [Series 1]

Objective Questions

Define hatchery management. (Linked to SLO 1.1)

Which type of hatchery uses a recirculating aquaculture system for year-round production? (Linked to SLO 1.2)

Fill in the blank: Dissolved oxygen below ________ mg/L is lethal to fish larvae within hours. (Linked to SLO 1.3)

The process of isolating newly acquired broodstock before introducing them to the main population is called ________. (Linked to SLO 1.5)

Newly hatched fish larvae first absorb their ________ sac before they begin exogenous feeding. (Linked to SLO 1.8)

Short-Answer Questions

Explain why intensive hatcheries are preferred for year-round fingerling production. (Linked to SLO 1.2)

Describe the role of biological filtration in a recirculating aquaculture system. (Linked to SLO 1.4)

Explain the purpose of segregating male and female broodstock before spawning. (Linked to SLO 1.5)

Describe the sequence of feed types given to fish fry from yolk sac absorption to fingerling stage. (Linked to SLO 1.8)

Explain how a deviation from expected growth trajectory is detected and what it may indicate. (Linked to SLO 1.9)

Long-Answer Questions

Analyse the importance of water quality management in fish hatcheries, describing the key parameters, their optimal ranges, and the treatment and monitoring systems used to maintain them. (Linked to SLOs 1.3, 1.4)

Discuss the principles of broodstock management in fish hatcheries, explaining the criteria for selection, the process of conditioning, the roles of segregation and quarantine, and the nutritional requirements specific to broodstock. (Linked to SLOs 1.5, 1.6)

Evaluate the management of nursery ponds for fish fry production, covering pond preparation and stocking, appropriate feeding regimes at each developmental stage, and the monitoring of growth and mortality as key performance indicators. (Linked to SLOs 1.7, 1.8, 1.9)

Answers to Concept Check Questions [Series 1]

Objective Questions

Hatchery management is the coordinated set of practices and procedures used to maintain a controlled environment for broodstock conditioning, egg fertilisation and incubation, and larval rearing in aquaculture.

Intensive hatchery.

2 mg/L.

Quarantine.

Yolk.

Short-Answer Questions

Intensive hatcheries use recirculating aquaculture systems that maintain full control of temperature, dissolved oxygen, and photoperiod regardless of external conditions; this independence from seasonal variation allows spawning to be induced at any time of year, ensuring a continuous supply of fingerlings to meet farm demand throughout the year.

Biological filtration uses colonies of nitrifying bacteria (Nitrosomonas and Nitrobacter) growing on a high surface-area filter medium to convert toxic ammonia first to nitrite and then to the relatively harmless nitrate; this process removes the main toxic metabolic waste product from the recirculated water, allowing high fish densities to be maintained without frequent total water replacement.

Segregating male and female broodstock prevents premature spawning, allows the reproductive readiness of each sex to be assessed independently, controls the exact timing of breeding by reuniting sexes only when both are fully conditioned, and avoids aggressive male-male interactions that could injure females or reduce sperm quality.

Newly hatched larvae first absorb their yolk sac (endogenous nutrition for 24 to 72 hours); they then require live rotifers (50 to 200 μm) as first exogenous food; after five to seven days they progress to Artemia nauplii (400 to 500 μm); then micro-pellets (300 to 600 μm) as weaning begins; and finally crumbles and small pellets (1 to 3 mm) at the fingerling stage.

Deviation is detected by regularly subsampling fry, measuring their mean weight, and calculating the specific growth rate (SGR); if the actual growth curve falls significantly below the expected benchmark for the species, this indicates a management problem such as insufficient feeding, poor water quality, disease, or excessive stocking density that requires immediate investigation.

Long-Answer Questions

Basic response: Key parameters include dissolved oxygen (6-9 mg/L), temperature (26-30°C for tropical species), pH (6.5-8.5), ammonia (un-ionised NH_3 below 0.02 mg/L), and nitrite (below 0.5 mg/L). Water is treated by mechanical filtration, UV sterilisation, and biological filtration in RAS. Monitoring is performed with portable meters and daily log entries.

Value-added response: Fish eggs and larvae are more sensitive to poor water quality than older fish because their regulatory systems are not yet developed and they are held at high density in small water volumes. Even brief deviations can cause irreversible mortality. Proactive management including automated sensors and alarms, scheduled partial water changes, and strict feeding control to minimise waste are essential safeguards that distinguish high-performing hatcheries from those with inconsistent survival rates.

Basic response: Broodstock are selected for species purity, body size, health, and absence of deformities. Conditioning involves high-protein diets rich in fatty acids and vitamins for four to six weeks. Males and females are segregated to control timing. Newly acquired fish are quarantined for two to four weeks to prevent disease introduction.

Value-added response: The quality of the broodstock directly determines the quality and survival of the offspring produced. Poor conditioning produces eggs with low fertilisation rates, developmental abnormalities, and susceptible larvae. Neglecting quarantine is one of the most common causes of catastrophic disease outbreaks in hatcheries; even apparently healthy fish can carry pathogens that manifest under the stress of handling. Investment in rigorous broodstock management is therefore the highest-return activity in the entire hatchery operation.

Basic response: Nursery ponds are dried, limed, refilled, and fertilised to stimulate a zooplankton bloom before stocking. Fry are stocked at the peak of the bloom (three to seven days after fertilisation). Feed progresses from rotifers through Artemia to micro-pellets and crumbles. SGR is calculated from periodic weight measurements; mortality above five per cent per day in larvae requires investigation.

Value-added response: Survival from egg to fingerling of 60 to 80 per cent is the target for well-managed operations. Common causes of failure below this target include missing the zooplankton bloom peak (larvae starve before live food is available), overfeeding (rapid water quality deterioration), insect predation (backswimmers, diving beetles) in outdoor ponds, and failure to remove dead fish promptly. Each of these is preventable with attentive daily management and good record keeping.

Answers to Pilot Questions [Series 1]

Part 1.1: Introduction to Hatchery Management

Hatchery management is the coordinated set of practices used to maintain a controlled environment for broodstock conditioning, egg incubation, and larval rearing; it is important because it allows year-round production of fish juveniles, independent of season, and enables genetic improvement through selective mating.

Open (extensive): relies on natural water sources, minimal intervention, low cost, unpredictable output. Semi-intensive: uses earthen or concrete ponds with some water management and hormone-induced spawning. Intensive (closed): uses RAS with full environmental control, enabling year-round production.

Any four: broodstock holding tanks; spawning tanks; incubation jars or hatching troughs; larval rearing tanks; live food production units; water treatment system; laboratory for water quality and fish health monitoring.

Even brief power failures interrupt aeration, causing dissolved oxygen to drop to lethal levels for larvae within hours; heating systems may also fail, causing temperature drops that stress or kill fish.

New Bussa Fish Farm (Kainji): semi-intensive system. National Aquaculture Centre, Baga: semi-intensive system.

Part 1.2: Water Quality Management in Hatcheries

Fish larvae lack fully developed physiological regulatory systems, making them far more sensitive than adult fish to deviations in dissolved oxygen, temperature, pH, and toxic metabolites; they are also held at high density in small water volumes, meaning wastes accumulate rapidly with little buffering capacity.

Optimal DO for tropical hatchery fish is 6 to 9 mg/L; below 2 mg/L, fish cannot obtain sufficient oxygen for aerobic metabolism and will die within hours from asphyxia.

Any three: dissolved oxygen; temperature; pH; total ammonia nitrogen (TAN); nitrite.

Biological filtration uses nitrifying bacteria colonising a high surface-area filter medium to convert toxic ammonia first to nitrite (Nitrosomonas) and then to relatively harmless nitrate (Nitrobacter), removing the main toxic metabolic waste product from the recirculated water.

Cycling a new RAS means allowing nitrifying bacteria to colonise the biofilter medium before fish are stocked at full density; this is done by adding a small ammonia source and waiting several weeks for bacterial populations to establish and reach sufficient density to process the full ammonia load of the stocked fish.

Part 1.3: Broodstock Management

Broodstock are mature fish kept for reproduction; selection criteria include species purity, body size and conformation, absence of deformities, health status, and in improvement programmes, performance traits such as growth rate and feed conversion ratio.

Broodstock conditioning is the process of bringing breeders to optimal reproductive readiness; it is achieved through feeding high-protein diets (35 to 45 per cent) rich in essential fatty acids, vitamins C and E, and minerals, combined with environmental management of temperature and photoperiod where applicable, over a period of four to six weeks.

Male and female broodstock are segregated to prevent premature spawning, to allow independent assessment of the reproductive readiness of each sex, to control the exact timing of breeding, and to avoid aggressive interactions between males that could injure females.

Quarantine prevents the introduction of diseases from newly acquired fish into the established broodstock population; newly acquired fish may carry pathogens that are not visible externally and that can cause catastrophic losses if introduced to a healthy population.

Any two nutritional differences: broodstock require higher protein (35 to 45 per cent vs 25 to 35 per cent for grow-out); broodstock require elevated vitamins C and E and essential fatty acids for gonadal development; broodstock feeding rates may be lower in absolute terms but diet quality is higher; broodstock diets must support gonad rather than muscle growth.

Part 1.4: Nursery Pond Management and Fry Care

Dry the pond; apply lime to the dry bottom (500 to 2,000 kg/ha) and expose to sunlight; refill with water; apply organic manure (500 to 1,000 kg/ha) to stimulate plankton bloom; wait three to seven days for peak zooplankton development; then stock fry.

Fry that are stocked before the zooplankton bloom peaks will find insufficient food and starve; fry stocked after the bloom has declined will also find insufficient food; precise timing maximises availability of live natural food at the critical point when larvae transition from yolk sac to exogenous feeding.

Newly hatched larvae absorb yolk sac (0-72 hours); first exogenous food is rotifers (50 to 200 μm); then Artemia nauplii (400 to 500 μm) after 5 to 7 days; then micro-pellets (300 to 600 μm) for weaning; then crumbles and small pellets (1 to 3 mm) at the fingerling stage.

Fry have small stomachs, fast digestion rates, and high metabolic demands for growth; high feeding frequency (4 to 8 times per day) ensures continuous availability of food at a size they can ingest and process, maintaining the constant energy supply needed for rapid larval development.

SGR (% per day) = $[(\ln W2 - \ln W1) / (t2 - t1)] \times 100$; it indicates the percentage daily rate of weight gain; comparing actual SGR with expected species benchmarks reveals whether fry are growing at the expected rate or whether a management problem is reducing growth performance.

References and Attributions [Series 1]

Textual References (Books and External Sources)

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Bromage, N. R., & Roberts, R. J. (Eds.). (1995). Broodstock management and egg and larval quality. Blackwell Science.

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Pillay, T. V. R., & Kutty, M. N. (2005). Aquaculture: Principles and practices (2nd ed.). Blackwell Publishing.

Stickney, R. R. (Ed.). (2000). Encyclopedia of aquaculture. John Wiley and Sons.

FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable aquaculture. FAO.

Figures, Plates, Tables, and Boxes

Figure 1.1: Main components and flow of a fish hatchery Attribution: AI generated using prompt "Generate a diagram showing the main stages of a fish hatchery: broodstock conditioning, spawning and fertilisation, egg incubation, larval rearing, and fingerling transfer." Suggested OER search string: "fish hatchery components flow diagram OER".

Plate 1.1: Interior of an intensive fish hatchery with RAS tanks Attribution: AI generated using prompt "Generate an image of the interior of an intensive fish hatchery showing circular rearing tanks with a recirculating aquaculture system." Suggested OER search string: "intensive fish hatchery RAS tanks interior OER image".

Box 1.1: Essential equipment required for hatchery operation Attribution: AI generated using prompt "Generate a text box listing the essential equipment required for fish hatchery operation." Suggested OER search string: "essential fish hatchery equipment list OER".

Figure 1.2: Water quality parameters and larval mortality relationship Attribution: AI generated using prompt "Generate a diagram showing how deteriorating water quality parameters lead to increased fish larval mortality in a hatchery." Suggested OER search string: "water quality hatchery larval mortality relationship diagram OER".

Table 1.1: Water quality parameters and optimal ranges for tropical hatcheries Attribution: AI generated using prompt "Generate a table listing key water quality parameters for tropical fish hatcheries with their optimal ranges." Suggested OER search string: "water quality parameters optimal ranges tropical fish hatchery OER table".

Figure 1.3: RAS water treatment and recirculation cycle diagram Attribution: AI generated using prompt "Generate a diagram showing the water treatment and recirculation cycle in a RAS hatchery." Suggested OER search string: "recirculating aquaculture system RAS water treatment cycle diagram OER".

Plate 1.2: African catfish broodstock in conditioning tank Attribution: AI generated using prompt "Generate an image of mature African catfish broodstock being held in a conditioning tank with aeration, ready for hormone-induced spawning." Suggested OER search string: "African catfish broodstock conditioning tank hatchery OER image".

Figure 1.4: Broodstock quarantine, segregation, and matching flowchart Attribution: AI generated using prompt "Generate a diagram showing the quarantine, segregation, and matching process for broodstock in a fish hatchery." Suggested OER search string: "broodstock quarantine segregation matching hatchery flowchart OER".

Box 1.2: Key nutritional requirements of broodstock fish Attribution: AI generated using prompt "Generate a text box listing the key nutritional requirements of fish broodstock." Suggested OER search string: "broodstock nutrition requirements vitamins minerals OER".

Plate 1.3: Nursery pond preparation with lime application Attribution: AI generated using prompt "Generate an image of a worker applying lime to the dried bottom of a nursery pond before stocking with fish fry." Suggested OER search string: "nursery pond preparation liming fish fry OER image".

Table 1.2: Feed sizes and feeding frequencies for fish fry developmental stages Attribution: AI generated using prompt "Generate a table showing feed types, particle sizes, and feeding frequencies for fish fry from yolk sac absorption through to fingerling stage." Suggested OER search string: "fish fry feed size feeding frequency developmental stages table OER".

Figure 1.5: Expected versus actual fry growth trajectory in nursery pond Attribution: AI generated using prompt "Generate a line graph showing expected versus actual fish fry growth trajectories in a nursery pond." Suggested OER search string: "fish fry growth trajectory expected actual nursery pond OER diagram".

Course code: FAA 404

Course title: Fish Fry and Fingerlings Production; Hatchery Management; Fish Production and Management and Fish Food Nutrition and Fish Food Technology

Course credit load: 2 Units

Series 2: Spawning Techniques and Breeding Methods

Series outline

Introduction

In the previous Series, we established the infrastructure, water quality management, broodstock conditioning, and nursery care practices that underpin hatchery operations. This Series moves to the heart of fish reproduction in captivity: the techniques used to induce spawning, the biological agents employed to trigger ovulation and spermiation, the manipulation of sex ratios through sex reversal, and the improvement of genetic stock through hybridisation. Together these techniques give the aquaculturist control over the timing, quality, and genetic composition of fish production.

The aim of this Series is to equip you with a thorough understanding of the spawning and breeding methods used in modern aquaculture, including natural spawning, induced breeding, hypophysation, the use of HCG and pituitary extract, sex reversal, hybridisation, and the incubation and early care of eggs and larvae.

We shall commence this Series by examining natural spawning in captivity and the principles and methods of induced breeding, including hypophysation. Next, we will study the hormonal and chemical agents used to induce spawning. Following that, we will cover sex reversal and hybridisation as tools for stock improvement. Finally, we will wrap up with fertilisation, egg quality assessment, incubation methods, and early larval care.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 2.1 describe the conditions required for natural spawning of fish in captivity (Linked to Part 2.1),

SLO 2.2 explain the principles and methods of induced breeding in fish (Linked to Part 2.1),

SLO 2.3 describe the hypophysation technique and explain its application in hatchery management (Linked to Part 2.1),

SLO 2.4 explain the use of human chorionic gonadotropin (HCG) and fish pituitary extract in induced breeding (Linked to Part 2.2),

SLO 2.5 describe other hormones and synthetic analogues used in induced breeding (Linked to Part 2.2),

SLO 2.6 explain the principles and methods of sex reversal in fish and their application in aquaculture (Linked to Part 2.3),

SLO 2.7 describe hybridisation and cross-breeding techniques and explain their use in stock improvement (Linked to Part 2.3),

SLO 2.8 explain fertilisation procedures and methods for assessing egg quality (Linked to Part 2.4), and

SLO 2.9 describe the incubation methods and early larval care practices used in fish hatcheries (Linked to Part 2.4).

2.1 Natural and Induced Spawning

2.1.1 Natural spawning in captivity

Natural spawning occurs when fish in captivity spawn spontaneously without human hormonal intervention, responding to environmental cues that mimic the conditions triggering reproduction in their natural habitat. For natural spawning to occur reliably in captivity, the hatchery must replicate the key environmental stimuli the species responds to, which may include changes in water temperature, photoperiod, rainfall simulation, flood-like water level changes, the provision of appropriate spawning substrates, and the introduction of conditioned mates.

Species such as common carp (Cyprinus carpio) and some tilapia respond to flooding cues and will spawn naturally in well-managed earthen ponds with spawning substrates. However, many commercially important tropical species, including the African catfish (Clarias gariepinus) and the Nile tilapia (Oreochromis niloticus), do not reliably complete their full reproductive cycle in captivity without hormonal assistance because the precise combination of environmental cues cannot easily be replicated. Natural spawning is therefore most useful for extensive and semi-intensive operations, while intensive hatcheries rely predominantly on induced breeding.

Fill in the blank: Natural spawning in captivity requires the replication of key environmental stimuli such as changes in temperature, ________, rainfall simulation, and appropriate spawning substrates.


Plate 2.1: Common carp spawning naturally in an earthen pond with submerged vegetation serving as spawning substrate

2.1.2 Principles and methods of induced breeding

Induced breeding is the stimulation of ovulation and spermiation in sexually mature fish through the administration of exogenous hormones or pituitary extracts that bypass the natural environmental triggers. The principle underlying induced breeding is that in the natural reproductive cycle, the hypothalamus releases gonadotropin-releasing hormone (GnRH) which stimulates the pituitary gland to release gonadotropins (luteinising hormone, LH, and follicle-stimulating hormone, FSH); these in turn act on the gonads to trigger final oocyte maturation, ovulation, and spermiation.

When environmental cues are absent or incomplete in captivity, the hypothalamic-pituitary-gonadal (HPG) axis stalls at various points, preventing spawning. Induced breeding overcomes this block by directly supplying the missing hormonal signals. The three main methods are: injection of fish pituitary extract (which contains gonadotropins); injection of mammalian gonadotropins such as HCG; and injection of GnRH analogues (synthetic GnRH with or without a dopamine antagonist to prevent inhibition of the pituitary). Each method targets a different point in the HPG axis.

Fill in the blank: The hypothalamic-pituitary-________ (HPG) axis is the hormonal cascade responsible for regulating fish reproduction that induced breeding methods are designed to stimulate.

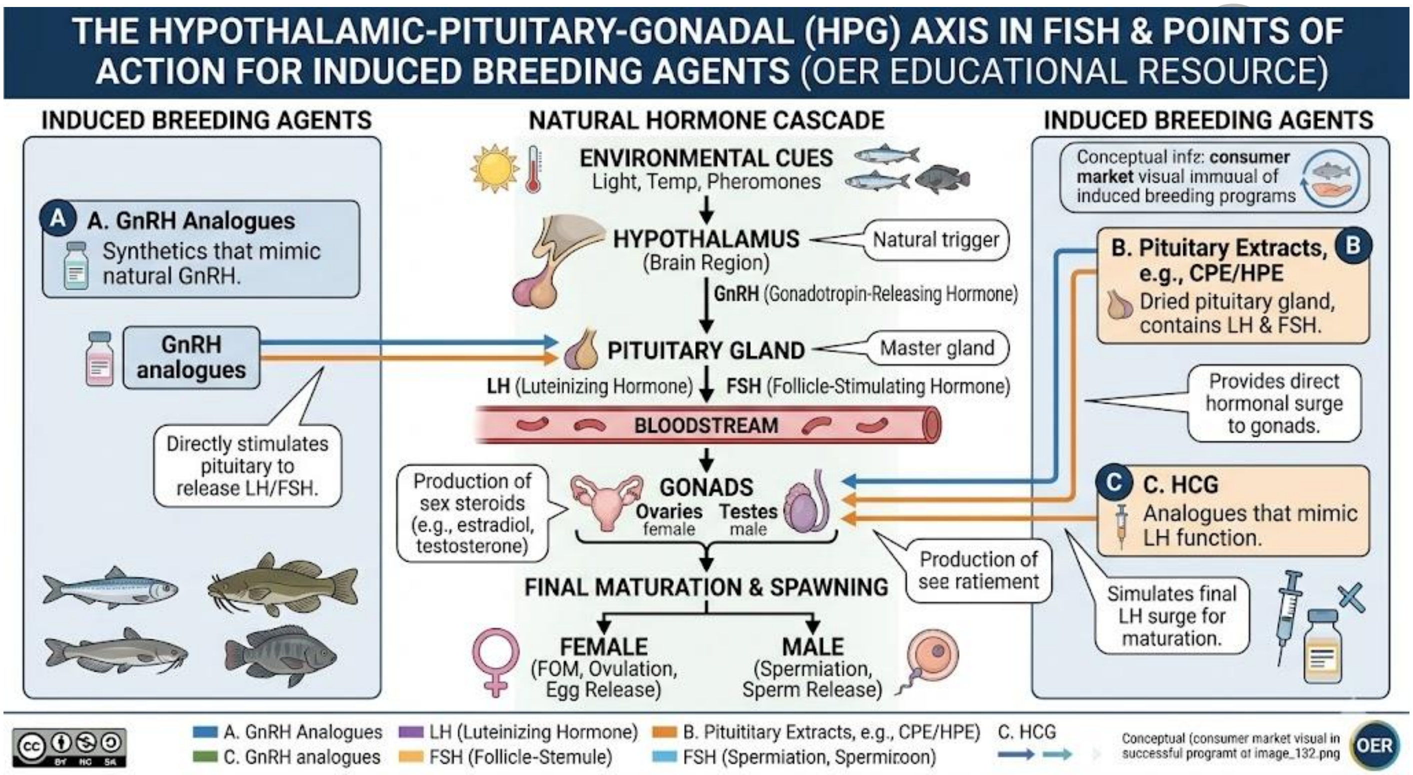

Figure 2.1: Diagram showing the hypothalamic-pituitary-gonadal axis in fish and the points at which induced breeding agents act

2.1.3 Hypophysation technique

Hypophysation is the induction of spawning by injecting fish with pituitary gland extract (hypophysis) taken from sexually mature donor fish of the same or a closely related species. The pituitary extract contains gonadotropins (LH and FSH) that directly stimulate the gonads to complete final oocyte maturation and ovulation in females, and to increase sperm production and release in males. Hypophysation is the oldest and most widely practised form of induced breeding in Nigerian and tropical aquaculture.

The standard procedure involves collecting pituitaries from ripe donor fish, grinding and homogenising them in saline or acetone, and injecting the suspension intramuscularly or intraperitoneally into the recipient broodfish. A priming dose (approximately one-third of the total dose) is given first, followed by a resolving dose (the remaining two-thirds) 6 to 12 hours later. The dose is expressed in pituitary equivalents per kilogram of body weight (typically 1 to 4 pituitaries per kg for females). Ovulation typically occurs 8 to 14 hours after the resolving injection at tropical water temperatures.

Fill in the blank: In hypophysation, a ________ dose of approximately one-third of the total is given first, followed by the resolving dose 6 to 12 hours later.

Plate 2.2: Technician injecting pituitary extract into an African catfish broodstock as part of the hypophysation procedure

Pilot questions 2.1

Define natural spawning in captivity and state two environmental cues that trigger it.

Explain why many tropical commercial fish species do not spawn reliably without hormonal intervention.

Describe the principle underlying induced breeding in fish.

Explain what hypophysation is and from where the pituitary extract is obtained.

Describe the dosing protocol used in hypophysation, including the priming and resolving doses.

2.2 Hormones and Agents Used in Induced Breeding

2.2.1 Human chorionic gonadotropin (HCG)

Human chorionic gonadotropin (HCG) is a glycoprotein hormone produced by the human placenta during pregnancy. It has strong luteinising hormone (LH) activity and acts directly on the gonads of fish to stimulate final oocyte maturation and ovulation in females and spermiation in males. HCG is commercially available as a lyophilised (freeze-dried) powder measured in international units (IU) and is reconstituted in physiological saline before injection.

HCG is widely used in Nigerian catfish hatcheries because it is commercially available, has a long shelf life when stored correctly, and produces reliable and repeatable results in Clarias gariepinus and other tropical species. Typical doses range from 1,000 to 3,000 IU per kg body weight for females and 500 to 1,000 IU per kg for males. A single injection is usually sufficient, with ovulation occurring 10 to 16 hours post-injection at 26 to 28 degrees Celsius. HCG is less effective in some species because fish gonadotropin receptors do not always respond fully to mammalian HCG.

Fill in the blank: HCG is measured in international ________ and reconstituted in physiological saline before injection into broodstock fish.

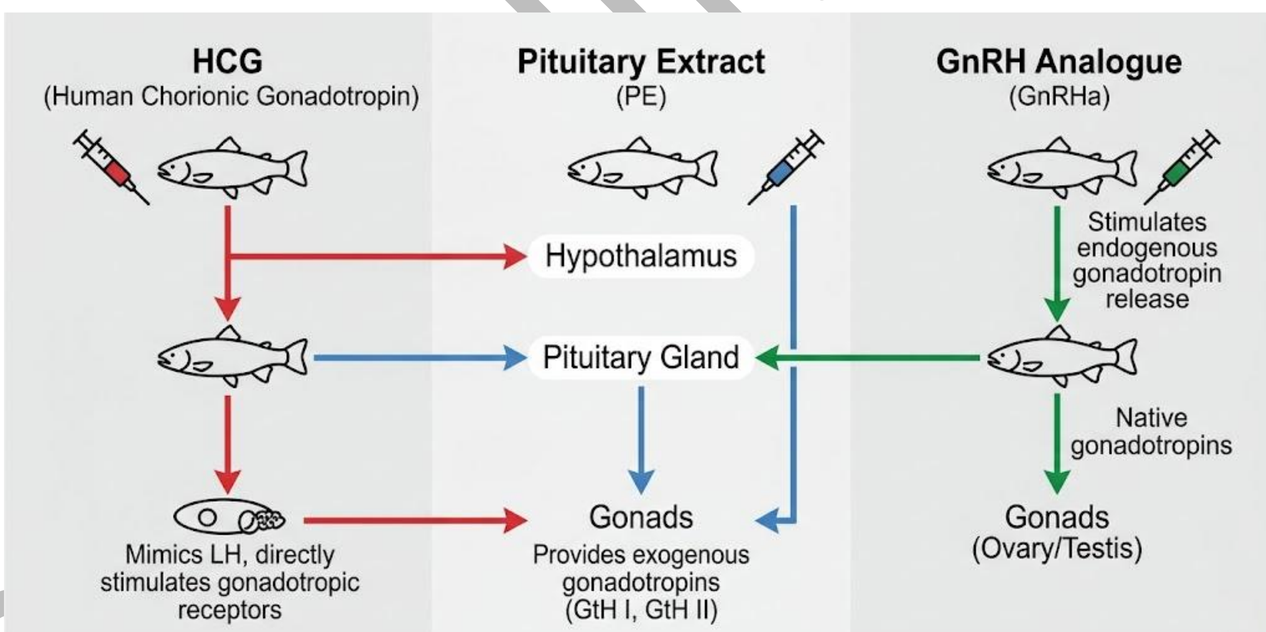

Figure 2.2: Diagram comparing the modes of action of HCG, pituitary extract, and GnRH analogues on the fish reproductive axis

Figure 2.2: Diagram comparing the modes of action of HCG, pituitary extract, and GnRH analogues on the fish reproductive axis

2.2.2 Fish pituitary extract

Fish pituitary extract (FPE) is prepared from the pituitary glands of sexually mature fish of the same or a closely related species. Because the gonadotropins in fish pituitary extract are species-homologous (they match the receptors of the recipient fish), FPE is generally more effective than mammalian hormones such as HCG, particularly for species that do not respond well to HCG. The extract is prepared fresh or stored in acetone-preserved form, which maintains biological activity for several months at room temperature or years when refrigerated.

The effectiveness of FPE depends on the reproductive stage of the donor fish: pituitaries collected from fish in peak spawning condition contain the highest concentrations of gonadotropins and produce the best results. Common donor species in Nigeria include the African catfish itself and the common carp. The main disadvantage of FPE compared with commercial hormone preparations is the variability in gonadotropin concentration between batches, which makes it difficult to standardise doses precisely. Quality assessment of batches by bioassay or ELISA is recommended but not always practical in field conditions.

Fill in the blank: Fish pituitary extract is more effective than mammalian hormones in many species because the gonadotropins it contains are ________ to the fish receptor, matching the reproductive physiology of the target species.

Plate 2.3: Pituitary glands collected from donor fish being prepared for extraction and injection into broodstock

Plate 2.3: Pituitary glands collected from donor fish being prepared for extraction and injection into broodstock

2.2.3 Other hormones and synthetic analogues

Gonadotropin-releasing hormone analogues (GnRHa) are synthetic peptides that mimic the action of the natural hypothalamic hormone GnRH but with greater potency and longer duration of action. When injected alone, GnRHa stimulates the pituitary to release endogenous gonadotropins. However, in many fish species the pituitary response is suppressed by dopamine (an inhibitory neurotransmitter); for this reason, GnRHa is frequently combined with a **dopamine antagonist** such as domperidone or metoclopramide, which blocks dopaminergic inhibition and greatly enhances the pituitary response.

Commercial products combining GnRHa with a dopamine antagonist include Ovaprim (salmon GnRHa + domperidone) and Ovatide (GnRHa + domperidone). These products are widely used for many farmed fish species including catfish, tilapia, carp, and seabass. Their advantages include standardised dosage, long shelf life, reliable efficacy across species, and simplicity of administration (a single injection). Luteinising hormone-releasing hormone analogue (LHRHa) is another widely used synthetic GnRH analogue, available as pellet implants for controlled slow-release stimulation of gonadal development in broodstock conditioning.

Fill in the blank: GnRHa is often combined with a ________ antagonist such as domperidone to block the inhibitory effect of dopamine on the pituitary response in fish.

Hormonal Agent	Mode of Action	Advantages	Limitations
HCG (Human Chorionic Gonadotropin)	Mimics luteinizing hormone, stimulating final oocyte maturation and ovulation.	Widely available; effective in many species.	Variable response; relatively expensive; less effective in some fish.
Fish pituitary extract	Provides natural gonadotropins (FSH, LH) to induce maturation and spawning.	Proven effectiveness; traditional method; inexpensive in regions with supply.	Requires sacrifice of donor fish; batch variability; biosecurity concerns.
GnRHa (Gonadotropin-Releasing Hormone analogue)	Stimulates pituitary release of gonadotropins, enhancing reproductive hormone cascade.	Highly potent; consistent results; effective across species.	Alone may be inhibited by dopamine; requires careful dosage.
GnRHa + dopamine antagonist (e.g., Ovaprim)	Combination removes dopamine inhibition, ensuring strong gonadotropin release.	Reliable induction; widely used in aquaculture; easy to administer.	Commercial cost; dependence on availability; requires cold-chain storage.

Box 2.1: Summary of hormonal agents used in induced breeding and their key characteristics

Pilot questions 2.2

What is HCG, and what hormone activity does it possess that makes it useful for induced breeding?

State the typical HCG dose range for female African catfish and when ovulation is expected after injection.

Explain why fish pituitary extract is often more effective than HCG in some species.

What is a GnRHa and why is it often combined with a dopamine antagonist?

Name two commercial products combining GnRHa with a dopamine antagonist and state one fish species each is used for.

2.3 Sex Reversal and Hybridisation

2.3.1 Principles and methods of sex reversal

Sex reversal is the process of changing the phenotypic sex of fish from what their genotype would normally determine, using hormonal or environmental treatment. In fish, sex determination is more plastic than in mammals, and the gonadal sex of many species can be manipulated during the critical period of gonadal differentiation, which occurs during early larval or fry development. The primary reason for practising sex reversal in aquaculture is to produce monosex populations (all-male or all-female), which often grow faster, are more uniform, and are easier to manage than mixed-sex populations.

In tilapia aquaculture, all-male populations are particularly valuable because male Nile tilapia grow approximately 30 to 50 per cent faster than females and do not divert energy into egg production or brooding. All-male tilapia populations also eliminate the problem of uncontrolled breeding and overpopulation of ponds, which causes stunted growth due to overcrowding. Two main approaches to sex reversal are used: direct hormonal treatment of fry and indirect sex reversal using YY supermales.

Fill in the blank: Sex reversal in tilapia is commercially important because all-male populations grow ________ to ________ per cent faster than females and do not engage in reproduction that diverts energy from growth.

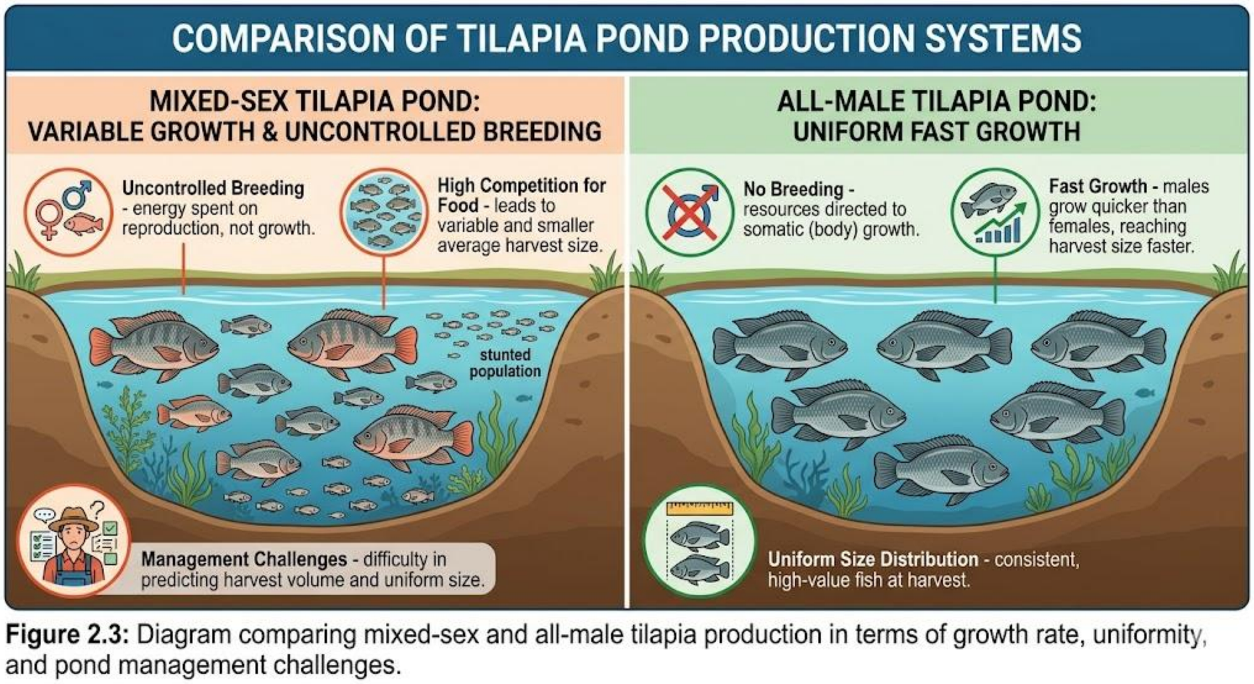

Figure 2.3: Diagram comparing mixed-sex and all-male tilapia production in terms of growth rate, uniformity, and pond management challenges

2.3.2 Natural and artificial sex reversal techniques

Hormonal sex reversal is achieved by feeding fry with feed containing synthetic sex steroids during the critical period of gonadal differentiation, which in Nile tilapia occurs between 10 and 30 days post-hatch. Male sex reversal (feminisation is rarely used commercially) is achieved by incorporating 17α-methyltestosterone (MT), a synthetic androgen, into the fry feed at a concentration of 60 mg/kg for 28 days. This treatment redirects gonadal differentiation towards the male phenotype in genetically female fry, producing populations of 95 to 99 per cent males.

After the treatment period, the medicated feed is withdrawn and replaced with untreated feed; the treated fish are grown out normally. MT is not retained in the flesh of treated fish at detectable levels in market-sized fish, but concerns about environmental contamination from hatchery effluents have led some producers to adopt alternative approaches. The YY supermale technique produces genetic all-male offspring by crossing a normal female (XX) with a YY supermale, theoretically yielding 100 per cent XY (male) progeny without hormonal treatment. Producing YY supermales requires a multi-generation selective breeding programme.

Fill in the blank: Hormonal sex reversal in tilapia fry uses ________ (MT) incorporated into feed at 60 mg/kg for 28 days during the critical period of gonadal differentiation.

Plate 2.4: Tilapia fry being fed hormone-treated feed in a sex reversal tank during the critical period of gonadal differentiation

2.3.3 Hybridisation and cross-breeding for stock improvement

Hybridisation is the controlled mating of individuals from two genetically distinct strains, populations, or species to produce offspring (hybrids) that may exhibit superior performance traits compared with either parental line, a phenomenon known as **hybrid vigour** or heterosis. In aquaculture, hybridisation is used to improve growth rate, feed conversion, disease resistance, cold or heat tolerance, or to produce monosex populations as an alternative to hormonal sex reversal.

In Nigerian tilapia aquaculture, the most commercially important hybrid is the cross between male Oreochromis niloticus (Nile tilapia) and female Oreochromis aureus (blue tilapia), which produces predominantly male offspring due to the sex determination genetics of the two species. Cross-breeding of African catfish (Clarias gariepinus) with the sharptooth catfish (Clarias macrocephalus) produces hybrids with superior growth rate and feed conversion in some production systems. Successful hybridisation programmes require careful control of parent selection, accurate sex determination of broodstock, controlled mating to prevent backcrossing, and verification of hybrid identity.

Fill in the blank: The superior performance of hybrid fish compared with either parent is known as hybrid ________ or heterosis.

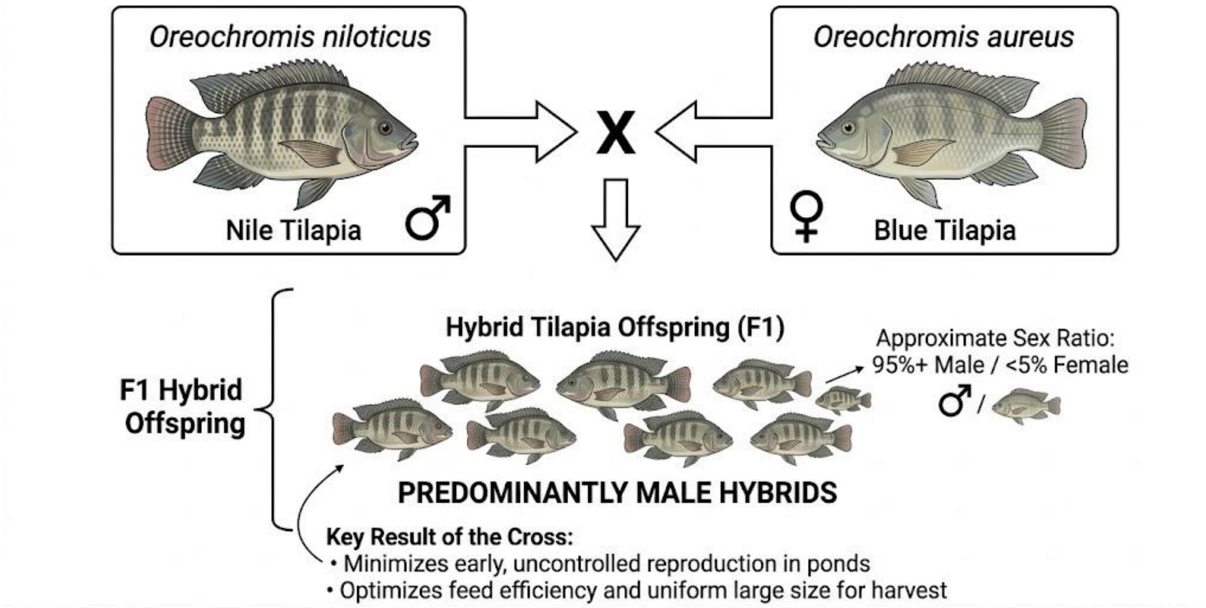

Figure 2.4: Diagram showing the crossing scheme for producing predominantly male hybrid tilapia from *O. niloticus* male and *O. aureus* female parents.

Figure 2.4: Diagram showing the crossing scheme for producing all-male tilapia hybrids from O. niloticus male and O. aureus female parents

Pilot questions 2.3

Define sex reversal and explain why all-male tilapia production is commercially desirable.

Describe the hormonal sex reversal procedure for tilapia fry, including the compound used, dose, and duration.

What is the YY supermale technique and what is its advantage over hormonal sex reversal?

Define hybridisation and explain what is meant by hybrid vigour.

Describe one commercially important fish hybrid produced in Nigerian aquaculture and state its advantage.

2.4 Egg Incubation and Larval Rearing

2.4.1 Fertilisation and egg quality assessment

Fertilisation in hatchery operations is typically performed artificially (dry or wet method) immediately after stripping eggs and collecting milt from the broodstock. In the **dry method** (preferred for most species), stripped eggs are placed in a dry bowl, milt is added directly without water, and the gametes are gently mixed for 60 to 90 seconds before water is added to activate the sperm. In the **wet method**, eggs are placed in a saline or water solution before milt is added; this is used for species where sperm are activated by specific ion concentrations.

Egg quality is assessed immediately after fertilisation and again at the blastula stage (2 to 4 hours post-fertilisation). Quality indicators include fertilisation rate (percentage of eggs showing cell division at the blastula stage, target above 80 per cent), egg colour and opacity (clear, uniform eggs indicate high viability; opaque or white eggs are unfertilised or dead), and buoyancy (pelagic eggs should float freely; sinking in normally buoyant species indicates poor quality). Low fertilisation rates prompt investigation of broodstock conditioning, sperm quality, gamete handling procedures, and water quality at fertilisation.

Fill in the blank: In the dry fertilisation method, stripped eggs and milt are mixed without water for 60 to 90 seconds before water is added to ________ the sperm and initiate fertilisation.

Plate 2.5: Hatchery technician stripping eggs from a ripe female catfish into a dry bowl for artificial fertilisation

2.4.2 Incubation methods and conditions

Egg incubation must provide optimal physical and chemical conditions for embryonic development while protecting the eggs from mechanical damage, fungal infection, and oxygen depletion. The main incubation systems used in tropical hatcheries are incubation jars (McDonald jars or similar), which maintain gentle upwelling water flow through a mass of eggs, ensuring oxygenation and preventing egg aggregation; flat incubation trays with gentle aeration; and net hapas suspended in ponds, used for mouth-brooding species such as tilapia.

Water flow through incubation jars must be sufficient to keep eggs tumbling gently (preventing adhesion and ensuring uniform oxygenation) but not so strong that eggs are damaged or ejected. Water temperature must be maintained within the optimal range for the species: 26 to 28 degrees Celsius for African catfish and tilapia. Fungal infections (primarily Saprolegnia) are a major cause of incubation failure; eggs are treated prophylactically with malachite green solution or more recently with hydrogen peroxide baths. Dead and unfertilised eggs, which appear white and opaque, must be removed daily as they provide a substrate for fungal growth that can spread to viable eggs.

Fill in the blank: Fungal infections of fish eggs during incubation, primarily caused by ________, are treated prophylactically with malachite green or hydrogen peroxide.

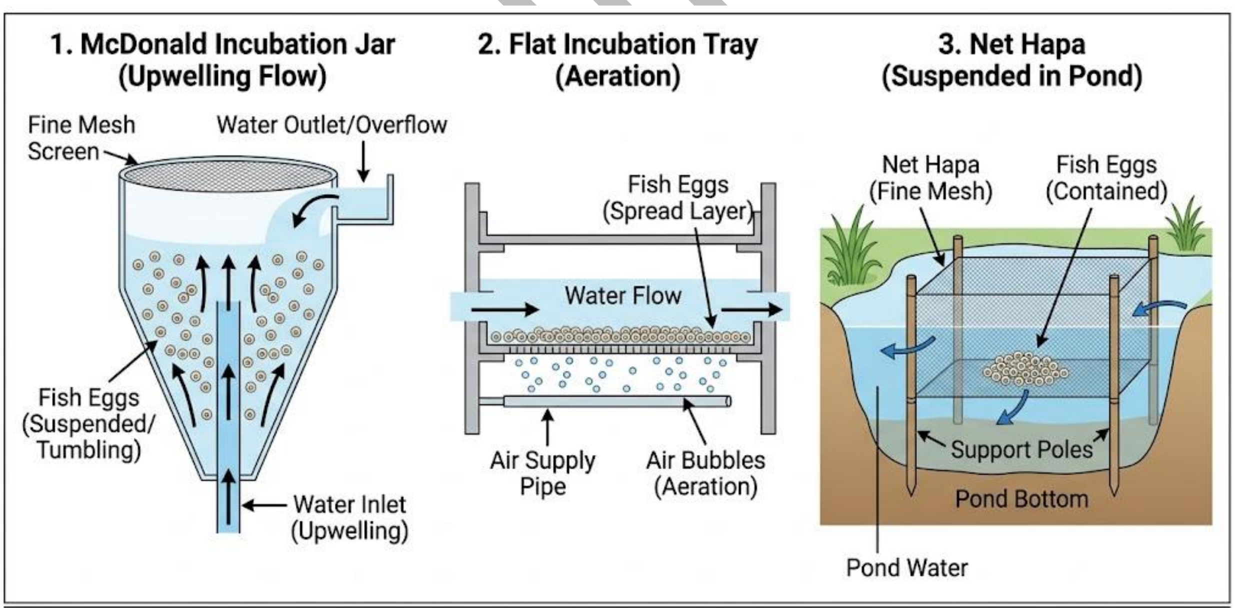

Figure 2.5: Diagram showing the main egg incubation systems used in tropical fish hatcheries: McDonald jar, flat tray, and net hapa.

Figure 2.5: Diagram showing the main egg incubation systems used in tropical fish hatcheries: McDonald jar, flat tray, and net hapa

2.4.3 Early larval care and transition to exogenous feeding

Newly hatched larvae are highly vulnerable and require careful management during the yolk sac stage. Larvae should be maintained at high water quality standards, particularly dissolved oxygen above 6 mg/L and minimal ammonia, because they lack functional gills at hatching and rely on skin respiration. Crowding must be avoided as it accelerates oxygen depletion and increases the risk of bacterial infection. Larvae are typically transferred from incubation jars to larval rearing tanks at hatching or within 24 hours.

The transition from endogenous (yolk sac) to exogenous feeding is the most critical period in larval development. In African catfish, the yolk sac is absorbed within 72 to 96 hours at 26 to 28 degrees Celsius, after which larvae must find food within 24 to 48 hours or they enter irreversible starvation (the point of no return). First feeds should therefore be available before or immediately at the time of yolk sac absorption. For catfish, the first exogenous food is typically Artemia nauplii or finely chopped tubificid worms; for tilapia, green water (dense phytoplankton suspension) or rotifers. Feed presentation must be continuous or very frequent to match the larvae's small stomach capacity.

Fill in the blank: If fish larvae do not find food within 24 to 48 hours of yolk sac absorption, they enter irreversible starvation known as the ________ of no return.

Plate 2.6: African catfish larvae at 72 hours post-hatch showing yolk sac almost fully absorbed and larvae beginning to search for food.

Plate 2.6: African catfish larvae at 72 hours post-hatch showing yolk sac almost fully absorbed and larvae beginning to search for food

Pilot questions 2.4

Describe the dry method of artificial fertilisation in fish.

What fertilisation rate is considered acceptable in hatchery operations, and how is it assessed?

Describe the McDonald incubation jar system and explain how it maintains egg quality.

Why are dead and unfertilised eggs removed daily during incubation?

Explain the point of no return in fish larval development and how it is prevented.

Series Summary

This Series has examined the spawning techniques and breeding methods that enable aquaculturists to control fish reproduction in hatcheries. We began with natural and induced spawning, explaining the environmental cues that trigger natural reproduction in captivity, the principles of the hypothalamic-pituitary-gonadal axis that induced breeding overrides, and the hypophysation technique as the foundational method of induced spawning. We then studied the hormonal agents used to induce breeding, including HCG, fish pituitary extract, and GnRH analogues combined with dopamine antagonists, comparing their modes of action, advantages, and limitations.

Following that, we examined sex reversal, covering hormonal treatment with methyltestosterone for all-male tilapia production and the YY supermale approach as a hormone-free alternative, and hybridisation as a tool for producing commercially superior offspring through hybrid vigour. Finally, we covered egg fertilisation using the dry method, egg quality assessment, incubation systems including McDonald jars, flat trays, and net hapas, and the critical management of early larvae through the yolk sac stage to first exogenous feeding. By completing this Series, you should now be able to achieve all nine Series Learning Outcomes (SLO 2.1 to SLO 2.9).

Glossary of Terms

Artificial fertilisation: the manual combination of stripped eggs and milt outside the body of the fish to achieve controlled fertilisation in a hatchery setting.

Dopamine antagonist: a compound such as domperidone or metoclopramide that blocks the inhibitory effect of dopamine on the fish pituitary, enhancing the response to GnRHa in induced breeding.

Dry method: a fertilisation technique in which stripped eggs and milt are mixed without water before water is added to activate sperm; the preferred method for most farmed fish species.

Fertilisation rate: the percentage of eggs that show cell division (cleave) at the blastula stage, typically assessed 2 to 4 hours post-fertilisation; a target of 80 per cent or above is considered acceptable.

Fish pituitary extract (FPE): a preparation of gonadotropin-rich pituitary glands from mature donor fish, injected into broodstock to induce ovulation and spermiation.

GnRH analogue (GnRHa): a synthetic peptide mimicking the natural hypothalamic gonadotropin-releasing hormone but with greater potency and longer duration; used alone or combined with a dopamine antagonist to induce spawning.

Heterosis (hybrid vigour): the superior performance of hybrid offspring compared with either parental line, arising from the complementary interaction of alleles from genetically distinct parents.

Human chorionic gonadotropin (HCG): a glycoprotein hormone produced by the human placenta with strong LH-like activity; used commercially to induce ovulation and spermiation in farmed fish.

Hybridisation: the controlled mating of individuals from two genetically distinct strains or species to produce offspring that may exhibit hybrid vigour or a desired phenotype such as all-male sex ratio.

Hypophysation: the induction of spawning by injection of pituitary gland extract from sexually mature donor fish; the oldest and most widely practised form of induced breeding in tropical aquaculture.

Induced breeding: the stimulation of ovulation and spermiation in captive fish through exogenous hormonal agents when natural environmental cues are absent or incomplete.

McDonald incubation jar: a cylindrical glass or plastic vessel through which water flows upwards, gently tumbling fish eggs to ensure oxygenation and prevent adhesion during incubation.

Monosex population: a group of fish of a single sex produced by sex reversal or hybridisation for the purpose of improving growth uniformity and preventing uncontrolled reproduction in ponds.

Natural spawning: reproduction that occurs spontaneously in captive fish responding to environmental cues that replicate their natural habitat conditions, without hormonal intervention.

Net hapa: a net enclosure suspended within a pond or tank used as an incubation or rearing unit, particularly for mouth-brooding species such as tilapia.

Ovaprim: a commercial product combining salmon GnRHa with domperidone used to induce spawning in a wide range of farmed fish species.

Point of no return: the stage in fish larval development at which irreversible starvation begins if exogenous food is not available within 24 to 48 hours of yolk sac absorption.

Priming dose: the initial injection in a two-injection hypophysation protocol, comprising approximately one-third of the total dose, given to prime the reproductive system before the resolving dose.

Resolving dose: the second and larger injection in hypophysation, comprising approximately two-thirds of the total dose, given 6 to 12 hours after the priming dose to complete ovulation.

Saprolegnia: a genus of water mould (oomycete) that causes fungal infections of fish eggs and larvae during incubation; dead eggs are a primary substrate for its growth.

Sex reversal: the modification of phenotypic sex in fish from what the genotype would normally determine, achieved through hormonal or genetic means during the critical period of gonadal differentiation.

17α-methyltestosterone (MT): a synthetic androgen used to produce all-male tilapia populations by incorporating it into fry feed at 60 mg/kg for 28 days during the critical period of gonadal differentiation.

YY supermale: a genetically YY male fish that, when crossed with a normal XX female, theoretically produces 100 per cent XY (male) offspring without hormonal treatment.

Concept Check Questions [Series 2]

Objective Questions

Define induced breeding. (Linked to SLO 2.2)

Which hormone activity does HCG possess that makes it useful for inducing spawning in fish? (Linked to SLO 2.4)

The induction of spawning by injection of pituitary gland extract from donor fish is called ________. (Linked to SLO 2.3)

All-male tilapia populations are produced by incorporating ________ into fry feed at 60 mg/kg for 28 days. (Linked to SLO 2.6)

The superior performance of hybrid offspring compared to either parent is known as hybrid ________ or heterosis. (Linked to SLO 2.7)

Short-Answer Questions

Explain the principle of the hypothalamic-pituitary-gonadal axis and how induced breeding overcomes its disruption in captivity. (Linked to SLO 2.2)

Compare fish pituitary extract and HCG as agents for induced breeding, explaining one advantage of each. (Linked to SLO 2.4, 2.5)

Describe the priming and resolving dose protocol used in hypophysation. (Linked to SLO 2.3)

Explain why dead eggs must be removed during incubation and describe one method of preventing fungal infection. (Linked to SLO 2.9)

Describe the point of no return in fish larval development and explain how it is avoided in hatchery management. (Linked to SLO 2.9)

Long-Answer Questions

Analyse the hormonal agents used in induced fish breeding, comparing HCG, fish pituitary extract, and GnRH analogues with dopamine antagonists in terms of mode of action, efficacy, advantages, and limitations. (Linked to SLOs 2.4, 2.5)

Discuss the techniques of sex reversal in tilapia aquaculture, explaining the biological basis of sex reversal, the hormonal method using methyltestosterone, the YY supermale alternative, and the commercial and environmental considerations involved. (Linked to SLO 2.6)

Evaluate the process of egg fertilisation, incubation, and early larval care in fish hatcheries, explaining the fertilisation methods, egg quality assessment indicators, incubation systems, and the management of the critical transition from yolk sac to exogenous feeding. (Linked to SLOs 2.8, 2.9)

Answers to Concept Check Questions [Series 2]

Objective Questions

Induced breeding is the stimulation of ovulation and spermiation in captive fish through the administration of exogenous hormones or pituitary extracts that bypass the natural environmental triggers required for reproduction.

Luteinising hormone (LH) activity.

Hypophysation.

17α-methyltestosterone (MT).

Vigour.

Short-Answer Questions

The HPG axis works as follows: the hypothalamus releases GnRH, which stimulates the pituitary to release gonadotropins (LH and FSH), which in turn stimulate the gonads to complete final oocyte maturation, ovulation, and spermiation. In captivity, the absence of natural environmental cues stalls this cascade; induced breeding overcomes the block by directly supplying the missing hormonal signal at the appropriate point in the axis.

Fish pituitary extract advantage: contains species-homologous gonadotropins that match the fish's own receptors, making it generally more effective across a wider range of species, especially those that do not respond well to mammalian hormones. HCG advantage: commercially available as a standardised product with a defined number of international units per vial, stable shelf life when stored correctly, and no need for donor fish, making it more convenient and consistent than self-prepared FPE.

A priming dose of approximately one-third of the total calculated dose is injected intramuscularly or intraperitoneally; 6 to 12 hours later, the resolving dose of approximately two-thirds of the total is administered; ovulation typically occurs 8 to 14 hours after the resolving injection at tropical water temperatures of 26 to 28 degrees Celsius.

Dead and unfertilised eggs are white and opaque and provide an ideal substrate for the water mould Saprolegnia to colonise; once established, Saprolegnia spreads rapidly to adjacent viable eggs, causing mass incubation failure; fungal infection is prevented by removing dead eggs daily with a pipette or fine sieve and by treating eggs prophylactically with malachite green solution or hydrogen peroxide baths.

The point of no return is the stage at which fish larvae that have not yet found food enter irreversible starvation, from which they cannot recover even if food is subsequently provided; it occurs approximately 24 to 48 hours after yolk sac absorption; it is prevented by preparing live food cultures (Artemia, rotifers, or green water) in advance so that first exogenous food is available at or before the expected time of yolk sac absorption.

Long-Answer Questions

Basic response: HCG acts directly on the gonads with LH-like activity; it is commercially available, standardised, and convenient, but less effective in species whose gonadotropin receptors do not respond strongly to mammalian hormones. FPE contains species-homologous gonadotropins and is generally highly effective but variable in potency between batches. GnRHa stimulates the pituitary to release endogenous gonadotropins; combined with domperidone (dopamine antagonist) it is highly effective across many species, standardised, and available commercially as Ovaprim or Ovatide.

Value-added response: The choice of agent depends on species, available resources, and management context. In Nigerian catfish hatcheries, HCG and FPE are most widely used because they are familiar, affordable, and have well-established dosing protocols for Clarias gariepinus. GnRHa-domperidone combinations offer the advantage of standardisation and broad-spectrum efficacy and are increasingly used as commercial hatchery operations scale up. Understanding the HPG axis allows the practitioner to troubleshoot failed inductions by identifying which step in the axis was insufficiently stimulated.

Basic response: Sex reversal exploits the plasticity of sex determination in fish during the critical window of gonadal differentiation. MT-treated feed (60 mg/kg for 28 days from hatching) redirects genetically female fry to develop as phenotypic males, producing 95 to 99 per cent male populations. The YY supermale technique produces genetic all-males (100 per cent XY) without hormonal treatment by crossing normal XX females with YY supermales.

Value-added response: Environmental concerns about MT-contaminated hatchery effluents entering natural water bodies and causing feminisation of wild fish have prompted scrutiny of hormonal sex reversal. YY supermale technology offers a hormone-free alternative but requires a multi-generation selective breeding investment to produce and maintain YY fish. In Nigerian aquaculture, where hatchery effluent management standards are variable, this is a relevant consideration for farm operators seeking to adopt best practices in responsible aquaculture production.

Basic response: The dry fertilisation method mixes stripped eggs and milt without water for 60 to 90 seconds before water is added to activate sperm. Egg quality is assessed by fertilisation rate (target above 80 per cent) and egg appearance. McDonald jars use upwelling water to tumble eggs gently. Dead eggs are removed daily to prevent fungal spread. Larvae must receive first food before or at yolk sac absorption to avoid the point of no return.

Value-added response: Each step in this process is a potential source of hatchery failure. Sperm quality deteriorates rapidly after stripping and must be used within minutes; mixing ratios of eggs to milt affect fertilisation success; water temperature at fertilisation affects sperm motility duration. During incubation, the balance between water flow (sufficient for oxygenation, insufficient for mechanical damage) requires daily observation and adjustment. Preparing first feed in advance of expected yolk sac absorption, timed precisely to the species's development rate at the current water temperature, is a discipline that separates high-performing hatcheries from those with erratic larval survival.

Answers to Pilot Questions [Series 2]

Part 2.1: Natural and Induced Spawning

Natural spawning is reproduction that occurs spontaneously in captive fish responding to environmental cues without hormonal intervention; two environmental cues include changes in water temperature and the provision of spawning substrates (e.g. aquatic vegetation for carp).

Many tropical commercial species such as African catfish and Nile tilapia do not complete the full reproductive cycle in captivity because the precise combination of environmental cues required to drive the HPG axis to ovulation cannot easily be replicated in a hatchery or pond, so the reproductive cascade stalls before spawning.

The principle is that fish reproduction requires a cascade of hormonal signals from the hypothalamus (GnRH) to the pituitary (LH and FSH) to the gonads (ovulation and spermiation); induced breeding supplies the missing hormonal signal at the appropriate point in this cascade when natural environmental cues are absent.

Hypophysation is the induction of spawning by injection of pituitary gland extract; the extract is obtained from the pituitary glands (hypophysis) of sexually mature donor fish of the same or a closely related species.

A priming dose of approximately one-third of the total dose is administered first; 6 to 12 hours later a resolving dose of approximately two-thirds of the total dose is given; ovulation typically occurs 8 to 14 hours after the resolving injection at tropical water temperatures.

Part 2.2: Hormones and Agents Used in Induced Breeding

HCG is a glycoprotein hormone produced by the human placenta with strong luteinising hormone (LH) activity; this LH-like activity stimulates the gonads directly to complete final oocyte maturation and ovulation in females and spermiation in males.

Typical HCG dose for female African catfish: 1,000 to 3,000 IU per kg body weight; ovulation is expected 10 to 16 hours post-injection at 26 to 28 degrees Celsius.

Fish pituitary extract contains species-homologous gonadotropins whose molecular structure matches the gonadotropin receptors of the target species, producing a more complete and effective hormonal stimulus than mammalian HCG in many fish species.

GnRHa is a synthetic peptide that mimics natural GnRH with greater potency and longer duration; it is combined with a dopamine antagonist because dopamine inhibits the pituitary's response to GnRH in many fish species, and blocking this inhibition with domperidone or metoclopramide greatly enhances gonadotropin release.

Ovaprim (salmon GnRHa + domperidone): used for African catfish, tilapia, carp, and many other species. Ovatide (GnRHa + domperidone): used similarly for catfish, carp, and other farmed fish.

Part 2.3: Sex Reversal and Hybridisation

Sex reversal is the change of phenotypic sex from what the genotype would normally determine, using hormonal or genetic treatment during gonadal differentiation; all-male tilapia production is commercially desirable because males grow 30 to 50 per cent faster than females, are more uniform, and do not engage in reproduction that diverts energy from growth or causes pond overpopulation.

17α-methyltestosterone (MT) is incorporated into fry feed at 60 mg/kg; fry are fed this medicated diet from hatching for 28 days during the critical period of gonadal differentiation; the treatment produces 95 to 99 per cent male populations by redirecting gonadal differentiation in genetically female fry.

The YY supermale technique uses genetically YY male fish crossed with normal XX females to produce 100 per cent XY (male) offspring without any hormonal treatment; its advantage over MT treatment is that no hormone is used, eliminating environmental contamination concerns and producing genetically verified all-male offspring.

Hybridisation is the controlled mating of individuals from two genetically distinct strains or species; hybrid vigour (heterosis) is the phenomenon where the hybrid offspring show superior performance compared with either parental line, arising from the complementary interaction of alleles from genetically distinct parents.

O. niloticus male x O. aureus female tilapia hybrid: produces predominantly male offspring without hormonal treatment; advantage is high male ratio combined with good growth rate and market acceptance. Clarias gariepinus x Clarias macrocephalus hybrid: produces offspring with superior growth rate and feed conversion compared to either parent in some production systems.

Part 2.4: Egg Incubation and Larval Rearing

Stripped eggs are placed in a clean dry bowl; milt is added directly to the dry eggs; eggs and milt are gently mixed for 60 to 90 seconds without adding water; water is then added to activate the sperm and complete fertilisation.

A fertilisation rate of 80 per cent or above is considered acceptable; it is assessed 2 to 4 hours post-fertilisation by counting the proportion of eggs showing cell division (blastula stage) in a representative subsample, identifying fertilised eggs as those with visible cleavage and unfertilised eggs as opaque white spheres without cell division.

A McDonald incubation jar is a cylindrical vessel through which water flows upward from the bottom; the upwelling current gently tumbles the eggs, preventing them from adhering to each other or settling and developing anoxic zones, while ensuring each egg receives a continuous supply of oxygenated water for embryonic respiration.

Dead and unfertilised eggs are white, opaque, and provide an ideal substrate for the water mould Saprolegnia; once established on dead eggs, Saprolegnia spreads to viable adjacent eggs, causing mass fungal infection and incubation failure; daily removal breaks this cycle and is one of the most important routine tasks in egg incubation management.

The point of no return is the stage where larvae that have not found exogenous food after yolk sac absorption enter irreversible starvation; it is prevented by preparing live food cultures (Artemia nauplii, rotifers, or green water) in advance so that first food is available at or immediately before the expected time of yolk sac absorption, calculated from the species' known development rate at the current water temperature.

References and Attributions [Series 2]

Textual References (Books and External Sources)

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FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable aquaculture. FAO.

Figures, Plates, Tables, and Boxes

Plate 2.1: Common carp natural spawning in earthen pond Attribution: AI generated using prompt "Generate an image showing common carp engaged in natural spawning behaviour

around submerged aquatic vegetation in a shallow earthen pond." Suggested OER search string: "common carp natural spawning earthen pond vegetation OER image".

Figure 2.1: Hypothalamic-pituitary-gonadal axis and induced breeding agents Attribution: AI generated using prompt "Generate a diagram showing the HPG axis in fish with arrows indicating where HCG, pituitary extract, and GnRH analogues act." Suggested OER search string: "fish HPG axis induced breeding hormones diagram OER".

Plate 2.2: Hypophysation injection into African catfish Attribution: AI generated using prompt "Generate an image of a hatchery technician administering an intramuscular injection of pituitary extract to an African catfish broodstock." Suggested OER search string: "hypophysation pituitary extract injection African catfish OER image".

Figure 2.2: Comparison of HCG, pituitary extract, and GnRHa modes of action Attribution: AI generated using prompt "Generate a diagram comparing the modes of action of HCG, pituitary extract, and GnRH analogues on the fish reproductive axis." Suggested OER search string: "HCG pituitary extract GnRH analogues fish reproductive axis comparison OER".

Plate 2.3: Fish pituitary glands prepared for extraction Attribution: AI generated using prompt "Generate an image of fish pituitary glands collected from donor fish laid out for preparation into extract." Suggested OER search string: "fish pituitary glands collection preparation extract hatchery OER image".

Box 2.1: Summary of hormonal agents used in induced breeding Attribution: AI generated using prompt "Generate a text box comparing HCG, fish pituitary extract, GnRHa, and GnRHa with dopamine antagonist for induced fish breeding." Suggested OER search string: "induced breeding hormones HCG pituitary GnRH comparison OER".

Figure 2.3: Mixed-sex versus all-male tilapia production comparison Attribution: AI generated using prompt "Generate a diagram comparing mixed-sex tilapia pond management with all-male tilapia production." Suggested OER search string: "all-male tilapia production sex reversal comparison OER diagram".

Plate 2.4: Tilapia fry receiving hormone-treated feed for sex reversal Attribution: AI generated using prompt "Generate an image of small tilapia fry in a tank being fed hormone-treated feed during the sex reversal period." Suggested OER search string: "tilapia sex reversal hormone treatment fry feeding OER image".

Figure 2.4: O. niloticus x O. aureus tilapia hybrid crossing scheme Attribution: AI generated using prompt "Generate a diagram showing the hybridisation cross between male O. niloticus and female O. aureus tilapia." Suggested OER search string: "Oreochromis niloticus aureus tilapia hybrid cross sex ratio OER diagram".

Plate 2.5: Egg stripping from female African catfish for artificial fertilisation Attribution: AI generated using prompt "Generate an image of a hatchery technician manually stripping

eggs from a ripe female African catfish into a dry bowl." Suggested OER search string: "egg stripping artificial fertilisation African catfish hatchery OER image".

Figure 2.5: Egg incubation systems: McDonald jar, flat tray, and net hapa Attribution: AI generated using prompt "Generate a diagram showing three fish egg incubation systems: a McDonald jar, a flat incubation tray, and a net hapa in a pond." Suggested OER search string: "fish egg incubation systems McDonald jar tray hapa diagram OER".

Plate 2.6: African catfish larvae at 72 hours post-hatch Attribution: AI generated using prompt "Generate an image of African catfish larvae at 72 hours post-hatch showing nearly fully absorbed yolk sacs." Suggested OER search string: "African catfish larvae yolk sac absorption 72 hours post-hatch OER image".

Course code: FAA 404

Course title: Fish Fry and Fingerlings Production; Hatchery Management; Fish Production and Management and Fish Food Nutrition and Fish Food Technology

Course credit load: 2 Units

Series 3: Fisheries Management Structures and Record Keeping

Series outline

Part 3.1: Fisheries Management Policy and Structure

Sub Part 3.1.1: Objectives and principles of fisheries management

Sub Part 3.1.2: Fisheries management institutions in Nigeria

Sub Part 3.1.3: Rights-based fisheries management

Part 3.2: Appraisal of Management Effectiveness

Sub Part 3.2.1: Criteria for evaluating fisheries management policies

Sub Part 3.2.2: Pros and cons of rights-based management in tropical fisheries

Sub Part 3.2.3: Co-management and stakeholder participation

Part 3.3: Fish Farm Production and Management

Sub Part 3.3.1: Stocking rate and its influence on fish growth

Introduction

The technical skills of fish breeding and hatchery operation covered in the previous two Series must be placed within a management and governance framework if they are to contribute to sustainable fish production. Fisheries and aquaculture do not exist in isolation; they operate within regulatory structures, policy environments, and market systems that shape how production decisions are made. Understanding how fisheries management works, how to evaluate its effectiveness, and how to maintain accurate records of farm operations is therefore as important as mastering the technical aspects of fish production.

The aim of this Series is to equip you with the knowledge to describe and evaluate fisheries management structures and policies, explain the principles of rights-based management and co-management in the Nigerian context, apply principles of stocking and feeding to maximise fish production, and maintain the records and accounts that are essential for running a well-managed fish farm.

We shall commence this Series by examining fisheries management policy, institutions, and the rights-based approach. Next, we will critically evaluate management effectiveness, including the particular challenges of rights-based approaches in tropical settings. Following that, we will study practical fish farm production management including stocking, feeding, and health management. Finally, we will wrap up with record keeping and accounting procedures that every fish farmer must practise.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 3.1 describe the objectives and principles of fisheries management and identify the main management institutions in Nigeria (Linked to Part 3.1),

SLO 3.2 explain the rights-based approach to fisheries management and describe how it is applied (Linked to Part 3.1),

SLO 3.3 evaluate the effectiveness of fisheries management policies using established criteria (Linked to Part 3.2),

SLO 3.4 analyse the pros and cons of rights-based management in tropical fisheries contexts (Linked to Part 3.2),

SLO 3.5 explain co-management and describe the role of stakeholder participation in fisheries governance (Linked to Part 3.2),

SLO 3.6 explain how stocking rate and feeding regime influence fish growth in production systems (Linked to Part 3.3),

SLO 3.7 describe health management and disease prevention practices on fish farms (Linked to Part 3.3),

SLO 3.8 identify the types of farm records required for effective fish farm management and explain their importance (Linked to Part 3.4), and

SLO 3.9 describe accounting procedures and explain how financial and production records are used to evaluate farm performance (Linked to Part 3.4).

3.1 Fisheries Management Policy and Structure

3.1.1 Objectives and principles of fisheries management

Fisheries management is the integrated process of collecting information, analysing it, planning, consulting, making decisions, allocating resources, and implementing and enforcing regulations to achieve the productive and sustainable use of fisheries resources. Its fundamental objective is to ensure that fish stocks and aquatic ecosystems remain productive over the long term while supporting the livelihoods and food security of those who depend on them.

The guiding principles of fisheries management include sustainability (maintaining stocks at levels that can be harvested indefinitely), equity (fair access to fisheries resources among users), efficiency (maximising economic and social benefits per unit of resource used), and the precautionary approach (acting cautiously when information is uncertain to avoid irreversible harm). The ecosystem approach to fisheries management extends these principles to encompass the broader aquatic ecosystem, considering habitat, biodiversity, and trophic interactions alongside target stock productivity.

Fill in the blank: The precautionary approach to fisheries management requires acting ________ when information is uncertain to avoid irreversible harm to fish stocks and ecosystems.

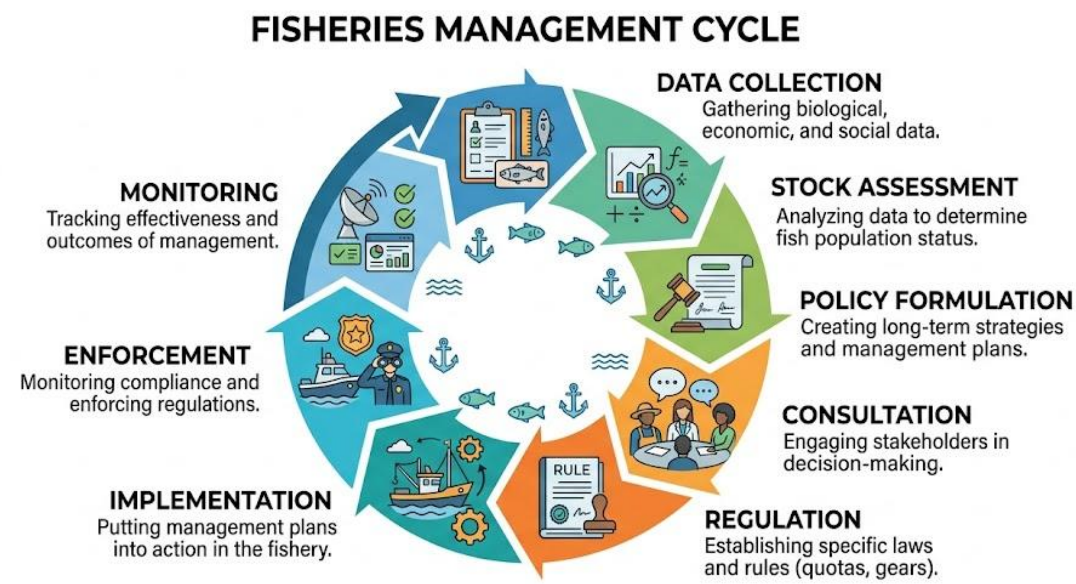

Figure 3.1: Diagram showing the fisheries management cycle from data collection through decision-making to implementation and monitoring.

Figure 3.1: Diagram showing the fisheries management cycle from data collection through decision-making to implementation and monitoring

3.1.2 Fisheries management institutions in Nigeria

In Nigeria, fisheries management responsibility is shared between federal and state institutions. At the federal level, the **Federal Department of Fisheries (FDF)** under the Federal Ministry of Agriculture and Rural Development is the primary regulatory authority, responsible for policy formulation, licensing of industrial fishing vessels, setting mesh size regulations, and coordination of national fisheries data collection. The **Nigerian Institute for Oceanography and Marine Research (NIOMR)** conducts scientific research to support management decisions in coastal and offshore fisheries.

At the state level, State Ministries of Agriculture and Natural Resources manage artisanal fisheries within their jurisdictions. The Nigerian Agricultural Quarantine Service (NAQS) is responsible for disease surveillance and the regulation of live fish imports and exports to prevent the introduction of exotic pathogens. The Federal Department of Fisheries also oversees Nigeria's participation in international fisheries bodies including the Fishery Committee for the West Central Gulf of Guinea (FCWC) and contributes data to FAO's global fisheries statistics system. Despite this institutional framework, enforcement capacity remains limited, particularly in artisanal fisheries.

Fill in the blank: The ________ Department of Fisheries is the primary federal authority responsible for fisheries policy formulation and the licensing of industrial fishing vessels in Nigeria.

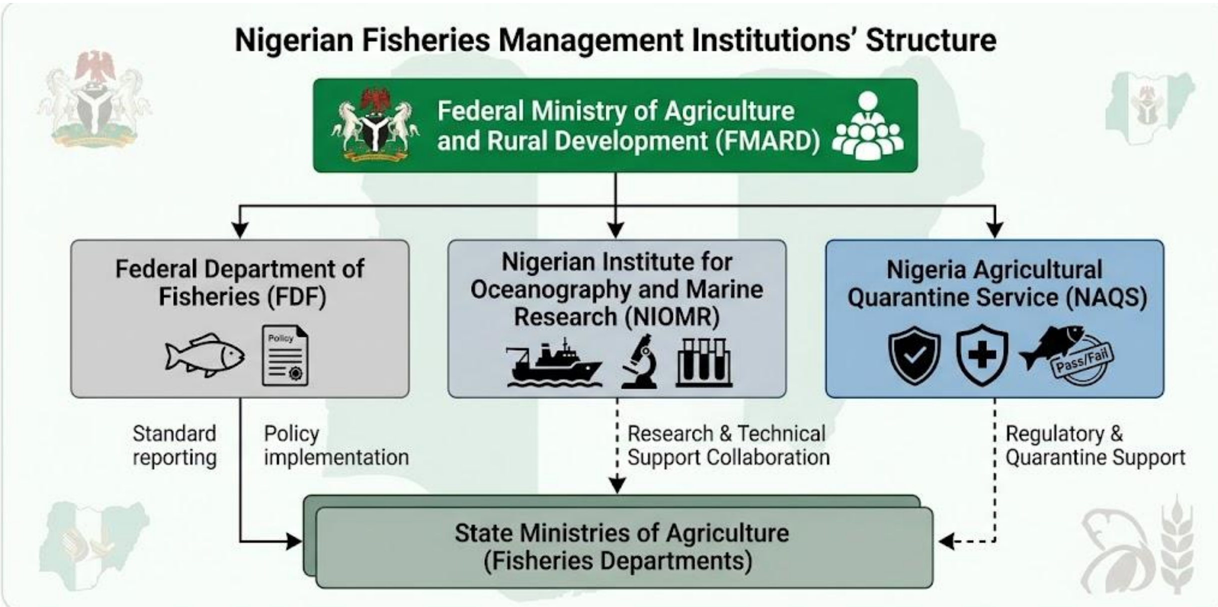

Figure 3.2: Organisational chart showing the structure of fisheries management institutions in Nigeria from federal to state level

Figure 3.2: Organisational chart showing the structure of fisheries management institutions in Nigeria from federal to state level

3.1.3 Rights-based fisheries management

Rights-based fisheries management (RBFM) is an approach that allocates secure, exclusive, and transferable rights to fish or fishing opportunities to specific individuals, communities, or companies, rather than allowing open access where anyone may fish. The purpose of RBFM is to create incentives for sustainable resource use by giving rights-holders a personal stake in the long-term health of the resource: if a fisher owns the right to catch a defined share of the allowable harvest, depleting the stock reduces the value of that right.

The main types of fishing rights include individual transferable quotas (ITQs), which allocate a specific share of the total allowable catch (TAC) to individual fishers or companies; territorial use rights in fisheries (TURFs), which allocate exclusive access to defined fishing areas to communities or individuals; and licences, which grant permission to fish under specified conditions without necessarily allocating a specific quantity. RBFM is most widely applied in developed-country industrial fisheries, but adaptations for artisanal and small-scale tropical fisheries are increasingly being explored.

Fill in the blank: Individual transferable ________ allocate a specific share of the total allowable catch to individual fishers or companies as a form of rights-based management.

Type of Fishing Right	Description / Key Characteristics
Individual Transferable Quotas (ITQs)	Assign a share of the total allowable catch to individuals; quotas can often be bought, sold, or leased.

Type of Fishing Right	Description / Key Characteristics
Territorial Use Rights in Fisheries (TURFs)	Grant exclusive fishing rights to a group or community within a defined geographic area.
Licences and Permits	Provide legal authorization to fish, often specifying gear type, area, or species; usually non-transferable.
Community-based rights	Rights allocated collectively to local communities, promoting stewardship and shared responsibility.
Cooperative rights	Rights granted to cooperatives or associations, enabling collective management and benefit-sharing.

Box 3.1: Main types of fishing rights used in rights-based fisheries management

Pilot questions 3.1

Define fisheries management and state its fundamental objective.

Name four guiding principles of fisheries management.

State the role of the Federal Department of Fisheries in Nigeria.

What is rights-based fisheries management and what is its main purpose?

Distinguish between an individual transferable quota and a territorial use right in fisheries.

3.2 Appraisal of Management Effectiveness

3.2.1 Criteria for evaluating fisheries management policies

Evaluating the effectiveness of fisheries management policies requires assessing performance against multiple criteria simultaneously. **Biological effectiveness** asks whether the policy has maintained or improved the condition of the target stock, as measured by trends in stock biomass, fishing mortality, and recruitment. **Economic efficiency** asks whether the policy has maximised the net economic benefit from the fishery, measured by profitability, rent generation, and the ratio of benefits to management costs.

Social equity examines whether the benefits and burdens of management are fairly distributed among different user groups, including artisanal and industrial fishers, and between present and future generations. Compliance and enforceability assess whether regulations are understood and followed by fishers and whether enforcement is practically possible given the resources available. Adaptability evaluates whether the management system can respond to new information, environmental change, or shifts in the fishery. No single criterion is sufficient; effective management requires satisfactory performance across all dimensions.

Fill in the blank: ________ equity in fisheries management examines whether the benefits and burdens of management are fairly distributed among different user groups.

Evaluation Criterion	Example Indicators
Biological effectiveness	Stock biomass relative to BMSY; recruitment trends; species diversity indices.
Economic efficiency	Net economic returns; cost-benefit ratio of management measures; profitability of fleets.
Social equity	Distribution of benefits among small-scale vs. industrial fishers; gender participation; community access rights.
Compliance	Levels of enforcement; rate of illegal, unreported, and unregulated (IUU) fishing; fisher adherence to regulations.
Adaptability	Ability to adjust harvest control rules; responsiveness to environmental change; incorporation of new scientific data.

Table 3.1: Criteria for evaluating fisheries management policy effectiveness with indicators for each criterion

3.2.2 Pros and cons of rights-based management in tropical fisheries

Rights-based management has several potential advantages in well-functioning markets. It eliminates the open-access race to fish by giving rights-holders a secure share of the allowable catch, reducing the incentive to maximise short-term catch before others do. This can lead to more orderly, cost-efficient fishing, less capital over-investment, and a stronger incentive to support conservation measures that protect the long-term value of the quota. ITQ systems in Iceland, New Zealand, and some developed-country fisheries have produced significant economic efficiency gains.

In tropical developing-country fisheries such as those of Nigeria, however, RBFM faces serious challenges. **Defining catch limits** requires reliable stock assessment data that are often absent. Allocating initial quotas raises difficult equity questions, particularly in fisheries where thousands of small-scale artisanal fishers depend on open access for subsistence. **Enforcement capacity** to prevent illegal fishing by non-rights-holders is typically limited. Quota concentration through market-driven transfers can exclude small-scale fishers over time. These challenges mean that the direct application of ITQ systems from developed fisheries is rarely feasible without substantial adaptation.

Fill in the blank: A major challenge of rights-based management in tropical fisheries is the difficulty of defining ________ limits without reliable stock assessment data.

Aspect	Advantages	Disadvantages
Sustainability	Encourages responsible harvest levels; reduces overfishing pressure.	Enforcement can be weak due to limited institutional capacity.
Economic outcomes	Provides secure access rights, improving fisher investment and efficiency.	Risk of quota concentration among wealthier operators, marginalising small-scale fishers.
Social equity	Community-based rights can empower local groups and promote stewardship.	Inequitable distribution of rights may exclude vulnerable groups (e.g., women, youth).
Compliance	Clear rights improve accountability and reduce illegal fishing.	Monitoring and enforcement costs may be high in resource-limited settings.
Adaptability	Flexible rights systems can be tailored to local ecological and social contexts.	Requires strong governance frameworks, which may be lacking in tropical developing countries.

Box 3.2: Pros and cons of rights-based fisheries management in tropical developing-country contexts

3.2.3 Co-management and stakeholder participation

Co-management is a fisheries governance arrangement in which responsibility for management is shared between government authorities and resource users, typically fishing communities. Rather than top-down government regulation, co-management involves fishers in setting rules, monitoring compliance, and adapting management measures in response to changing conditions. This participation increases the legitimacy of rules, draws on local ecological knowledge, and increases compliance without relying solely on enforcement by government officers.

Stakeholder participation in fisheries management in Nigeria is promoted through artisanal fisheries associations such as the Nigerian Artisanal Fishermen Association of Nigeria (NAFAN) and community-based management arrangements in some riverine communities. Effective co-management requires clearly defined boundaries for the managed area, rules developed by the affected users, mechanisms for monitoring and sanctioning, and formal recognition by the state of community management rights. In the Niger Delta and freshwater systems, community-based management of fishing grounds represents an important and pragmatic alternative to state-led enforcement.

Fill in the blank: Co-management shares responsibility for fisheries governance between ________ authorities and fishing communities, increasing the legitimacy of rules and improving compliance.

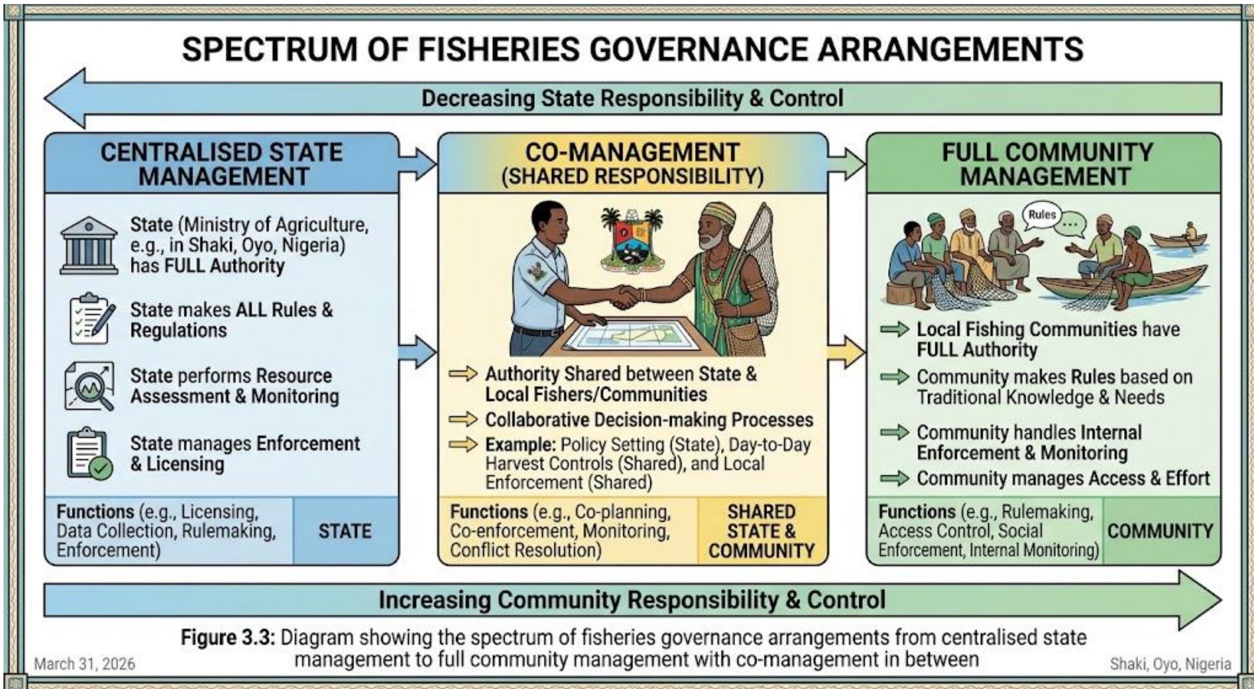

Figure 3.3: Diagram showing the spectrum of fisheries governance arrangements from centralised state management to full community management with co-management in between

Pilot questions 3.2

State four criteria used to evaluate the effectiveness of a fisheries management policy.

Explain one advantage of rights-based management in well-functioning fisheries markets.

State two challenges that limit the applicability of ITQ systems in Nigerian artisanal fisheries.

Define co-management and explain one benefit it offers over purely government-led management.

Name one Nigerian artisanal fisheries association involved in co-management arrangements.

3.3 Fish Farm Production and Management

3.3.1 Stocking rate and its influence on fish growth

Stocking rate (also called stocking density) is the number of fish stocked per unit area or volume of the production system. It is one of the most critical management decisions on a fish farm because it directly determines the intensity of competition for feed, oxygen, and space, all of which affect individual growth rate and final yield. At low stocking densities, individual fish grow rapidly because resources are abundant and competition is minimal, but the total production per unit area is low.

As stocking density increases, total yield per unit area rises up to a maximum, beyond which crowding stress, oxygen depletion, disease pressure, and competition cause individual growth rates to fall sharply and mortality to increase. The optimal stocking density therefore depends on the management intensity: extensive systems relying on natural food production can sustain lower densities (500 to 5,000 fish/ha), while intensive systems with continuous aeration and formulated feed inputs can support much higher densities (50 to 150 fish/m³ in tanks). In Nigerian catfish pond production, typical stocking densities are 1 to 3 fish/m² for earthen ponds.

Fill in the blank: As stocking density increases beyond the optimum, ________ stress, oxygen depletion, and competition cause individual growth rates to fall and mortality to increase.

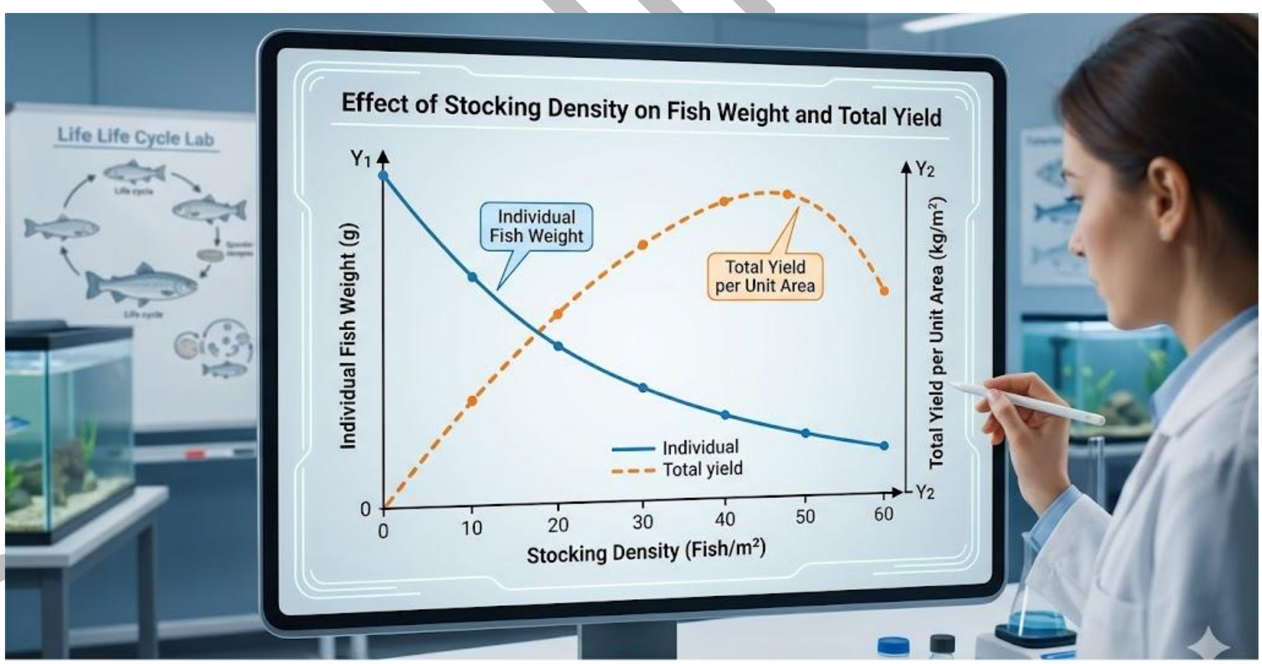

Figure 3.4: Graph showing the relationship between stocking density and individual fish growth rate and total yield per unit area

Figure 3.4: Graph showing the relationship between stocking density and individual fish growth rate and total yield per unit area

3.3.2 Feeding regimes and enhancement of fish growth

Feeding regime encompasses the type of feed used, the amount fed per day (feeding rate), and the frequency and timing of feeding. An appropriate feeding regime ensures that fish receive sufficient nutrients for maximum growth without generating excess waste that degrades water quality. Feed is the largest single cost in intensive aquaculture, typically accounting for 50 to 70 per cent of variable production costs, making feeding efficiency critical to farm profitability.

The daily feeding rate is expressed as a percentage of body weight per day (%BW/day); it decreases as fish grow larger (juveniles at 5 to 10 per cent, fingerlings at 3 to 5 per cent, grow-out fish at 1.5 to 3 per cent). Fish should be fed to satiation at each meal rather than a fixed ration, as appetite varies with temperature, fish condition, and dissolved oxygen level. Feed conversion ratio (FCR), the mass of feed required to produce one unit of fish body weight gain, is the primary measure of feeding efficiency; values below 1.5 are considered good for catfish and tilapia under Nigerian farm conditions.

Fill in the blank: Feed conversion ratio (FCR) is the mass of ________ required to produce one unit of fish body weight gain and is the primary measure of feeding efficiency.

Stage	Body Weight Range	Daily Feeding Rate (% of Body Weight)	Feeding Frequency (per day)
Juvenile	1–5 g	8–10%	3–4 times
Fingerling	5–50 g	5–7%	2–3 times
Grow-out	> 50 g	2–3%	1–2 times

Table 3.2: Recommended feeding rates and frequencies for African catfish at different body weight stages

3.3.3 Health management and disease prevention on the farm

Disease prevention is far more cost-effective than disease treatment in fish farming. The primary tool of disease prevention is **biosecurity**, which encompasses all practices designed to prevent the introduction and spread of pathogens on the farm. Key biosecurity measures include using disease-free seed stock, quarantining new fish before introducing them to production units, disinfecting equipment and vehicles between ponds, controlling access to the farm, and avoiding the introduction of wild fish or water from unknown sources.

Health management also involves maintaining water quality within optimal ranges (since most disease outbreaks are triggered or exacerbated by poor water quality), feeding fish to maintain good body condition and immune function, and monitoring fish daily for early signs of disease including abnormal behaviour, loss of appetite, surfacing or gathering at the inlet, skin lesions, haemorrhage, fin erosion, and abnormal posture. Early detection allows prompt treatment and containment. Common diseases of farmed catfish and tilapia in Nigeria include bacterial infections (Aeromonas, Pseudomonas), fungal infections (Saprolegnia), parasitic infestations (Trichodina, Ichthyophthirius), and viral diseases in tilapia.

Fill in the blank: ________ encompasses all practices designed to prevent the introduction and spread of pathogens on a fish farm, including disinfecting equipment and quarantining new fish.

Practice	Description / Purpose
Quarantine	Isolate new or sick fish before introduction to main stock to prevent disease spread.
Disinfection	Regular cleaning and sterilisation of tanks, nets, and equipment to reduce pathogen load.
Water quality management	Maintain optimal parameters (DO, pH, ammonia, nitrite) to minimise stress and disease risk.
Disease monitoring	Routine health checks, sampling, and observation for early detection of outbreaks.
Controlled access	Limit entry of personnel and equipment to reduce external contamination risks.
Proper waste management	Remove uneaten feed and organic waste to prevent pathogen build-up.
Vaccination / prophylaxis	Use vaccines or preventive treatments where available to reduce disease incidence.
Record keeping	Maintain logs of stock health, treatments, and mortalities for traceability and management.

Box 3.3: Key biosecurity and health management practices for fish farms

Pilot questions 3.3

Define stocking rate and explain how it influences individual fish growth.

What happens to fish growth and mortality when stocking density exceeds the optimum?

Define feed conversion ratio (FCR) and state what value is considered good for catfish.

Why is feeding fish to satiation preferred over a fixed daily ration?

State three biosecurity practices used to prevent disease introduction on a fish farm.

3.4 Record Keeping and Accounting in Fish Farms

3.4.1 Importance and types of farm records

Record keeping is the systematic documentation of all significant events, inputs, outputs, and observations on a fish farm. Accurate records are essential for farm management because they provide the information needed to make informed production decisions, diagnose the causes of poor performance, demonstrate compliance with regulatory requirements, support applications for credit or certification, and evaluate the profitability of the enterprise. Without records, a farm manager is forced to rely on memory and guesswork rather than evidence.

The main types of records maintained on a fish farm include production records (dates of stocking, species, source, number, and weight of fish stocked; periodic sampling data; harvest dates, quantities, and weights), feeding records (daily feed type, quantity fed, and water temperature), water quality records (daily measurements of key parameters), health records (disease events, treatments administered, mortality counts and causes), financial records (all purchases, sales, and expenses), and stock records (inventory of feed, chemicals, equipment, and supplies). Each record type serves a different purpose but together they provide a comprehensive management information system.

Fill in the blank: The main purpose of keeping farm records is to provide the ________ needed to make informed production decisions and evaluate farm profitability.

Figure 3.5: Example of a fish farm daily prooduction record sheet showing fields for water quality, feeding, and mortality data.

Figure 3.5: Example of a fish farm daily production record sheet showing fields for water quality, feeding, and mortality data

3.4.2 Accounting procedures and financial records

Farm accounting involves the systematic recording, classification, and summarisation of all financial transactions on the fish farm to determine its profitability and financial health. The two fundamental financial statements required for farm management are the income statement (profit and loss account), which shows total revenue minus total costs over a defined period, and the balance sheet, which shows the farm's assets, liabilities, and net worth at a point in time.

Key financial records include a cash book (recording all money received and paid), a purchase ledger (recording all supplies and services bought on credit), a sales ledger (recording all produce sold), a depreciation schedule (allocating the cost of capital assets such as tanks, pumps, and vehicles over their useful life), and an inventory record. Cost analysis separates fixed costs (costs that do not vary with output, such as land rental, loan repayments, and depreciation) from variable costs (costs that vary with production level, such as feed, fingerlings, and labour), enabling the farm manager to calculate the break-even production level and determine the minimum price at which the farm is viable.

Fill in the blank: The income statement shows total ________ minus total costs over a defined period, while the balance sheet shows assets, liabilities, and net worth at a point in time.

Item	Amount (₦)	Notes
Revenue	1,200,000	Sales of market-size catfish (e.g., 1,200 kg at ₦1,000/kg).
Variable Costs		
– Fingerlings	150,000	Purchase of 3,000 fingerlings at ₦50 each.
– Feed	500,000	Commercial feed over production cycle.
– Other variable costs	50,000	Includes medicines, fuel, and miscellaneous inputs.
Total Variable Costs	700,000	
Fixed Costs		
– Depreciation	100,000	Annual depreciation of pond infrastructure and equipment.
– Labour	150,000	Hired labour for pond management.
Total Fixed Costs	250,000	
Net Profit	250,000	Revenue – (Variable + Fixed Costs).

Table 3.3: Example partial income statement for a small-scale catfish pond farm showing revenue, variable costs, fixed costs, and net profit

3.4.3 Using records for farm performance evaluation

Farm performance evaluation uses production and financial records to calculate key performance indicators (KPIs) that reveal how efficiently the farm is operating and identify areas requiring improvement. Important production KPIs include survival rate (percentage of stocked fish surviving to harvest), specific growth rate (SGR), feed conversion ratio (FCR), yield per unit area or volume, and harvest weight relative to target weight. These indicators are compared against benchmarks for the species and production system to assess whether performance is acceptable.

Financial KPIs include gross margin (revenue minus variable costs), net profit margin (net profit as a percentage of revenue), return on investment (net profit as a percentage of total capital invested), and break-even analysis (the quantity of fish that must be sold to cover all costs). Trend analysis, comparing KPIs across successive production cycles, reveals whether the farm is improving or deteriorating over time. Record-based performance evaluation transforms a fish farm from a reactive operation responding to problems as they arise into a proactive, evidence-based enterprise continuously improving its efficiency and profitability.

Fill in the blank: Return on investment is calculated as net profit as a percentage of total ________ invested and is a key financial performance indicator for fish farms.

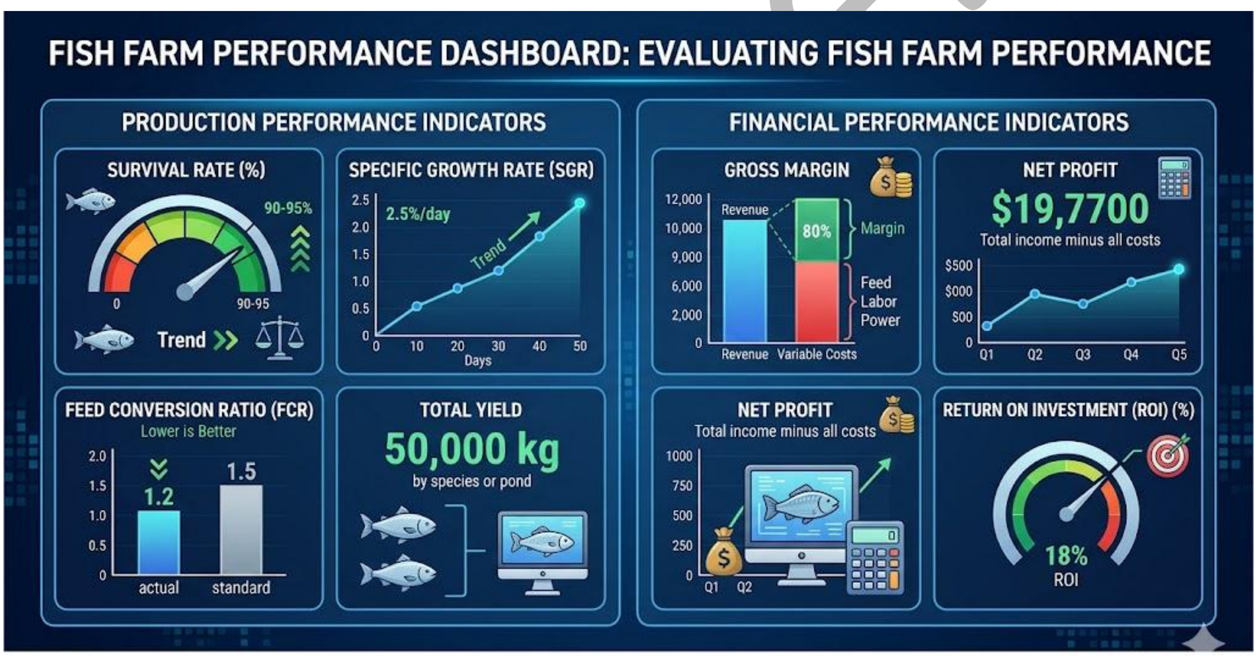

Figure 3.6: Dashboard diagram showing the key production and financial performance indicators used to evaluate fish farm performance

Figure 3.6: Dashboard diagram showing the key production and financial performance indicators used to evaluate fish farm performance

Pilot questions 3.4

State four types of records that should be maintained on a fish farm.

Why is record keeping important for a fish farm seeking access to credit?

Define fixed costs and variable costs in fish farm accounting and give one example of each.

What is break-even analysis and how is it used in fish farm management?

Name three production key performance indicators used to evaluate fish farm performance.

Series Summary

This Series has examined the management structures, policy frameworks, production management practices, and record-keeping systems that underpin well-managed fish farming operations. We began by describing the objectives and principles of fisheries management, the institutional structure in Nigeria, and the concept of rights-based fisheries management including ITQs and TURFs. We then critically evaluated management effectiveness using biological, economic, social, and compliance criteria, analysed the specific advantages and challenges of rights-based approaches in tropical fisheries, and described co-management as a practical governance alternative for Nigerian artisanal fisheries.

Following that, we studied fish farm production management, covering the relationship between stocking density and fish growth, the principles of feeding regimes and feed conversion efficiency, and the biosecurity and health management practices essential for disease prevention. Finally, we examined record keeping and accounting, distinguishing the types of records required, the financial statements and cost analysis methods used, and the key performance indicators that enable evidence-based farm management. By completing this Series, you should now be able to achieve all nine Series Learning Outcomes (SLO 3.1 to SLO 3.9).

Glossary of Terms

Biosecurity: all practices designed to prevent the introduction and spread of pathogens on a fish farm, including quarantine, disinfection, access control, and use of disease-free seed stock.

Break-even analysis: a financial calculation determining the quantity of product that must be sold to cover all costs (fixed plus variable), below which the farm incurs a loss.

Co-management: a fisheries governance arrangement in which responsibility for resource management is shared between government authorities and fishing communities or other resource users.

Depreciation: the systematic allocation of the cost of a capital asset over its useful life; recorded as a fixed cost in farm financial accounts.

Ecosystem approach to fisheries: a management framework that considers the broader aquatic ecosystem, including habitat, biodiversity, and trophic relationships, alongside the target stock.

Feed conversion ratio (FCR): the mass of feed required to produce one unit of fish body weight gain; a primary measure of feeding efficiency, with values below 1.5 considered good for catfish and tilapia.

Federal Department of Fisheries (FDF): the primary federal fisheries regulatory authority in Nigeria, responsible for policy formulation, vessel licensing, and national fisheries data coordination.

Fixed costs: production costs that do not vary with the level of output, such as land rental, loan repayments, and depreciation of capital equipment.

Individual transferable quota (ITQ): a rights-based management tool that allocates a specific share of the total allowable catch to individual fishers or companies, which can be bought and sold.

Key performance indicator (KPI): a quantitative measure used to evaluate how efficiently a farm or fishery is achieving its production or financial objectives.

NAFAN: the Nigerian Artisanal Fishermen Association of Nigeria; a national organisation of artisanal fishers that participates in fisheries co-management and advocacy.

NIOMR: the Nigerian Institute for Oceanography and Marine Research; the federal research institution providing scientific data to support marine and coastal fisheries management.

Precautionary approach: a fisheries management principle requiring cautious action to avoid irreversible harm when scientific information is uncertain or inadequate.

Production record: a farm document recording stocking details, periodic sampling data, harvest results, and other events related to the production of fish.

Rights-based fisheries management (RBFM): a management approach that allocates secure, exclusive, and transferable rights to fish or fishing opportunities to specific individuals or groups to internalise conservation incentives.

Return on investment (ROI): net profit expressed as a percentage of total capital invested; a measure of the financial efficiency of a farm enterprise.

Social equity: in fisheries management, the fair distribution of benefits and management burdens among different user groups including artisanal and industrial fishers and future generations.

Stocking density: the number of fish per unit area or volume of a production system; a key management variable determining competition intensity and the balance between individual growth rate and total yield.

Territorial use right in fisheries (TURF): a rights-based management tool that allocates exclusive access to a defined fishing area to a community or individual.

Total allowable catch (TAC): the maximum quantity of a fish species that may be harvested from a stock in a defined area over a defined period, set by management authority based on stock assessment advice.

Variable costs: production costs that vary directly with the level of output, such as feed, fingerlings, fuel, and labour.

Concept Check Questions [Series 3]

Objective Questions

Define fisheries management. (Linked to SLO 3.1)

The management approach that allocates secure, exclusive, and transferable rights to fishing opportunities is called ________ management. (Linked to SLO 3.2)

A fisheries governance arrangement sharing responsibility between government and fishing communities is called ________. (Linked to SLO 3.5)

Feed conversion ratio (FCR) is the mass of feed required to produce one unit of fish ________ gain. (Linked to SLO 3.6)

The systematic documentation of all significant events, inputs, and outputs on a fish farm is called ________ keeping. (Linked to SLO 3.8)

Short-Answer Questions

State three guiding principles of fisheries management and briefly explain each. (Linked to SLO 3.1)

Explain two challenges that limit the application of rights-based management in Nigerian artisanal fisheries. (Linked to SLO 3.4)

Explain the relationship between stocking density and individual fish growth rate. (Linked to SLO 3.6)

State four types of records that should be kept on a fish farm and explain the purpose of each. (Linked to SLO 3.8)

Explain the difference between fixed costs and variable costs in fish farm accounting and give one example of each. (Linked to SLO 3.9)

Long-Answer Questions

Analyse the rights-based approach to fisheries management, explaining its principles, the main types of fishing rights, the potential advantages in well-managed fisheries, and the challenges faced in applying it in tropical developing-country contexts such as Nigeria. (Linked to SLOs 3.2, 3.4)

Discuss the management of fish farm production, explaining how stocking rate and feeding regime influence fish growth, how feed conversion efficiency is measured and improved, and the biosecurity and health management practices needed to prevent disease on the farm. (Linked to SLOs 3.6, 3.7)

Evaluate the role of record keeping and accounting in fish farm management, explaining the types of records required, the key financial statements and cost analysis methods used, and how production and financial KPIs enable evidence-based performance evaluation and improvement. (Linked to SLOs 3.8, 3.9)

Answers to Concept Check Questions [Series 3]

Objective Questions

Fisheries management is the integrated process of collecting information, analysing it, planning, consulting, making decisions, allocating resources, and implementing and enforcing regulations to achieve the productive and sustainable use of fisheries resources.

Rights-based.

Co-management.

Body weight.

Record.

Short-Answer Questions

Any three: sustainability (maintaining stocks at levels that can be harvested indefinitely without reducing their long-term productivity); equity (ensuring fair access to fisheries resources among different user groups and generations); efficiency (maximising economic and social benefits per unit of resource used); precautionary approach (acting cautiously to avoid irreversible harm when information is uncertain); ecosystem approach (considering the broader aquatic ecosystem alongside target stock productivity).

Any two: defining reliable catch limits requires stock assessment data that are largely absent in artisanal fisheries; allocating initial quotas among thousands of small-scale subsistence fishers raises serious equity questions; enforcement capacity to prevent illegal fishing by non-rights-holders is very limited; quota concentration through market-driven transfers can exclude small-scale fishers over time.

At low stocking densities, resources are abundant, competition is minimal, and individual fish grow rapidly; as stocking density increases towards the optimum, total yield per unit area rises; beyond the optimum, competition for feed, oxygen, and space intensifies, crowding stress increases, disease pressure rises, and individual growth rates fall sharply while mortality increases.

Any four with purposes: production records (track stocking, growth, and harvest to evaluate production performance); feeding records (monitor feed consumption and calculate FCR); water quality records (document daily parameter values to identify deterioration triggering disease or poor growth); health records (document disease events and treatments to guide future prevention); financial records (record all costs and revenues to assess profitability and support credit applications).

Fixed costs do not vary with output level; example: land rental, depreciation of tanks. Variable costs vary directly with production level; example: feed, fingerlings, labour.

Long-Answer Questions

Basic response: RBFM allocates secure, exclusive, and transferable rights (ITQs, TURFs, licences) to fishing opportunities to internalise conservation incentives. In well-managed fisheries it eliminates the race to fish, reduces over-capitalisation, and increases fishing efficiency. In Nigerian artisanal fisheries it faces challenges of absent stock assessment data, equity in initial allocation, weak enforcement, and risk of concentration excluding small-scale fishers.

Value-added response: The principle that rights-holders will protect the resource whose long-term value they own is theoretically sound but requires institutional conditions rarely present in tropical developing-country fisheries: reliable data, administrative capacity, functioning markets, and clear legal frameworks. Co-management, allocating territorial use rights to fishing communities with local governance capacity, may offer a more practical entry point for introducing RBFM principles in Nigeria than the ITQ systems developed for large-scale industrial fisheries.

Basic response: Higher stocking density increases competition for resources, reducing individual growth rate beyond the optimum and increasing disease risk. Feeding rate as percentage of body weight declines as fish grow; FCR below 1.5 is the target for catfish and tilapia. Biosecurity prevents disease entry; key measures include quarantine, disinfection, disease-free fingerlings, and water quality maintenance.

Value-added response: The interactions between stocking density, feeding rate, and water quality are tightly coupled in intensive systems. Over-stocking amplifies the consequences of any feeding or aeration management error: excess feed at high density rapidly crashes dissolved oxygen and generates ammonia spikes. The most profitable production systems are those that optimise stocking density for the available aeration and feed management capacity rather than simply maximising density. Daily adjustment of feeding rate to actual fish appetite and water temperature, guided by FCR monitoring, produces the greatest economic return per unit of feed cost.

Basic response: Records include production, feeding, water quality, health, and financial records. Key financial statements are the income statement (revenue minus costs) and balance sheet (assets, liabilities, net worth). Fixed costs include depreciation; variable costs include feed and fingerlings. KPIs include survival rate, SGR, FCR, gross margin, net profit, and ROI.

Value-added response: The difference between farms that improve cycle-on-cycle and those that stagnate is almost always the quality of their record-keeping and their willingness to use records analytically rather than merely as regulatory compliance. Trend analysis of FCR, survival rate, and gross margin across production cycles reveals the impact of management changes, enabling a farm manager to quantify the return on investments such as improved feed quality, aeration upgrades, or disease prevention expenditure. Records also protect the farm manager by documenting due diligence in the event of disease outbreaks or disputes with buyers or lenders.

Answers to Pilot Questions [Series 3]

Part 3.1: Fisheries Management Policy and Structure

Fisheries management is the integrated process of collecting information, planning, and implementing regulations to achieve productive and sustainable use of fisheries resources; its fundamental objective is to ensure fish stocks remain productive over the long term while supporting livelihoods and food security.

Sustainability; equity; efficiency; precautionary approach (and ecosystem approach).

The Federal Department of Fisheries is responsible for fisheries policy formulation, licensing of industrial fishing vessels, setting mesh size regulations, and coordinating national fisheries data collection.

Rights-based fisheries management allocates secure, exclusive, and transferable rights to fishing opportunities to specific individuals, communities, or companies; its main purpose is to internalise conservation incentives by giving rights-holders a personal stake in the long-term health of the resource they own the right to exploit.

An ITQ allocates a specific share of the total allowable catch to an individual or company that can be bought and sold in a market; a TURF allocates exclusive access to a defined geographic fishing area to a community or individual, regardless of the quantity caught.

Part 3.2: Appraisal of Management Effectiveness

Biological effectiveness; economic efficiency; social equity; compliance and enforceability; adaptability.

Rights-based management eliminates the open-access race to fish by giving each rights-holder a secure share of the allowable catch, removing the incentive to maximise short-term catch before others do, which leads to more orderly and cost-efficient fishing.

Any two: reliable stock assessment data needed to set catch limits are largely absent; allocating initial quotas equitably among thousands of subsistence artisanal fishers is politically and practically very difficult; enforcement capacity to prevent illegal fishing by non-rights-holders is limited; quota concentration through transfers can marginalise small-scale fishers.

Co-management is a fisheries governance arrangement sharing responsibility between government authorities and fishing communities; one benefit over purely government-led management is that community participation increases the legitimacy of rules and draws on local ecological knowledge, improving compliance without depending solely on government enforcement.

The Nigerian Artisanal Fishermen Association of Nigeria (NAFAN).

Part 3.3: Fish Farm Production and Management

Stocking rate is the number of fish per unit area or volume; at low density, resources are abundant and individual growth is fast; as density increases, competition for feed, oxygen, and space intensifies, reducing individual growth rate and eventually increasing mortality and disease pressure.

When stocking density exceeds the optimum, individual growth rates decline sharply because of resource competition; crowding stress suppresses the immune system making fish more susceptible to disease; oxygen depletion and ammonia accumulation increase; and mortality rates rise.

FCR is the mass of feed required to produce one unit of fish body weight gain; an FCR value below 1.5 is considered good for catfish and tilapia under Nigerian farm conditions.

Feed intake varies with water temperature, fish condition, and dissolved oxygen; a fixed ration may overfeed fish when conditions suppress appetite (causing waste and water quality deterioration) or underfeed them when conditions improve (reducing growth); feeding to satiation ensures fish receive exactly the amount they can efficiently use under prevailing conditions.

Any three: quarantine new fish before introducing them to production units; use disease-free certified fingerlings; disinfect all equipment and nets between ponds; control access to the farm; avoid introducing wild fish or water from unknown sources.

Part 3.4: Record Keeping and Accounting in Fish Farms

Any four: production records; feeding records; water quality records; health records; financial records; stock and inventory records.

Financial records documenting all revenue, costs, assets, and liabilities provide the evidence that lenders need to assess the farm's creditworthiness, cash flow capacity, and ability to repay loans; without records, a farmer cannot make a credible case for credit.

Fixed costs do not vary with output level and must be paid regardless of how much fish is produced; example: land rental or depreciation of tanks. Variable costs vary directly with production level; example: feed, fingerlings, or fuel for pumps.

Break-even analysis calculates the quantity of fish that must be sold to cover all costs (fixed plus variable); below this quantity the farm makes a loss; it is used to set minimum production targets, evaluate the viability of the farm at current prices, and assess the impact of cost changes on farm profitability.

Any three: survival rate; specific growth rate (SGR); feed conversion ratio (FCR); yield per unit area or volume; harvest weight relative to target weight.

References and Attributions [Series 3]

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Figures, Plates, Tables, and Boxes

Figure 3.1: Fisheries management cycle flowchart Attribution: AI generated using prompt "Generate a circular flowchart showing the fisheries management cycle from data collection through stock assessment, policy formulation, consultation, regulation, implementation, and monitoring." Suggested OER search string: "fisheries management cycle flowchart OER diagram".

Figure 3.2: Nigerian fisheries management institutions organisational chart Attribution: AI generated using prompt "Generate an organisational chart showing the structure of Nigerian fisheries management institutions from the Federal Ministry of Agriculture through FDF, NIOMR, and NAQS to State Ministries." Suggested OER search string: "Nigeria fisheries management institutions organisational chart OER".

Box 3.1: Types of fishing rights in rights-based management Attribution: AI generated using prompt "Generate a text box listing the main types of fishing rights used in rights-based fisheries management." Suggested OER search string: "rights-based fisheries management types fishing rights OER".

Table 3.1: Criteria for evaluating fisheries management policy effectiveness Attribution: AI generated using prompt "Generate a table listing the criteria for evaluating fisheries management policies with example indicators." Suggested OER search string: "fisheries management policy evaluation criteria indicators table OER".

Box 3.2: Pros and cons of rights-based management in tropical fisheries Attribution: AI generated using prompt "Generate a text box listing the pros and cons of rights-based fisheries management in tropical developing-country fisheries." Suggested OER search string: "rights-based fisheries management pros cons tropical developing country OER".

Figure 3.3: Fisheries governance spectrum from state to community management Attribution: AI generated using prompt "Generate a diagram showing the spectrum of fisheries governance from centralised state management through co-management to full community management." Suggested OER search string: "fisheries governance spectrum co-management state community OER diagram".

Figure 3.4: Stocking density versus growth rate and yield graph Attribution: AI generated using prompt "Generate a graph showing the relationship between fish stocking density and individual growth rate and total yield per unit area." Suggested OER search string: "fish stocking density growth rate total yield relationship graph OER".

Table 3.2: African catfish feeding rates and frequencies by body weight stage Attribution: AI generated using prompt "Generate a table showing the recommended daily feeding rates

and feeding frequencies for African catfish at juvenile, fingerling, and grow-out stages." Suggested OER search string: "African catfish feeding rate frequency body weight stages table OER".

Box 3.3: Biosecurity and health management practices for fish farms Attribution: AI generated using prompt "Generate a text box listing the key biosecurity and health management practices for fish farms." Suggested OER search string: "fish farm biosecurity health management disease prevention OER".

Figure 3.5: Fish farm daily production record sheet template Attribution: AI generated using prompt "Generate an image of a structured daily fish farm record sheet with fields for date, pond number, water quality parameters, feed type, quantity fed, mortality count, and remarks." Suggested OER search string: "fish farm daily production record sheet template OER".

Table 3.3: Example income statement for a small-scale catfish pond farm Attribution: AI generated using prompt "Generate a simplified income statement table for a small-scale catfish pond farm showing revenue, variable costs, fixed costs, and net profit." Suggested OER search string: "fish farm income statement profit loss example table OER".

Figure 3.6: Fish farm performance indicators dashboard Attribution: AI generated using prompt "Generate a visual dashboard diagram showing the main production and financial key performance indicators used to evaluate fish farm performance." Suggested OER search string: "fish farm performance indicators KPI dashboard OER diagram".

Course code: FAA 404

Course title: Fish Fry and Fingerlings Production; Hatchery Management; Fish Production and Management and Fish Food Nutrition and Fish Food Technology

Course credit load: 2 Units

Series 4: Nutrient Requirements and Fish Feed Formulation

Series outline

Part 4.1: Nutrient Requirements of Fish

Sub Part 4.1.1: Proteins and amino acid requirements

Sub Part 4.1.2: Lipid, carbohydrate, and energy requirements

Introduction

Fish nutrition is the scientific foundation upon which all practical feeding decisions are built. Whether a farmer is purchasing commercially formulated feed, compounding feed on the farm, or making ingredient substitutions to reduce cost, an understanding of the nutrient requirements of the target species and the nutritive value of available ingredients is essential for producing a diet that supports maximum growth without generating unnecessary waste or cost. This Series brings together the nutritional science needed to formulate and evaluate fish feeds effectively.

The aim of this Series is to equip you with a thorough understanding of the nutrient requirements of fish, the factors that modify those requirements, the chemistry and nutritive value of feed ingredients used in aquaculture, and the practical methods of feed formulation including the Pearson square and algebraic approaches.

We shall commence this Series by examining the macronutrient and micronutrient requirements of fish. Next, we will study the factors that cause nutrient requirements to vary between species, life stages, and environments. Following that, we will survey the major feed ingredients used in aquaculture, their nutrient composition, and the anti-nutritional factors that limit their use. Finally, we will wrap up with the principles and practical methods of fish feed formulation.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 4.1 describe the protein and amino acid requirements of fish and explain their importance in diet formulation (Linked to Part 4.1),

SLO 4.2 describe the lipid, carbohydrate, and energy requirements of fish and explain how they interact in feed formulation (Linked to Part 4.1),

SLO 4.3 identify the vitamins and minerals required by fish and describe the consequences of their deficiency (Linked to Part 4.1),

SLO 4.4 explain how species, age, physiological state, and environmental factors affect nutrient requirements in fish (Linked to Part 4.2),

SLO 4.5 describe the major plant-based and animal-based feed ingredients used in aquaculture and their nutrient composition (Linked to Part 4.3),

SLO 4.6 explain the anti-nutritional factors present in feed ingredients and describe how ingredient substitution is managed (Linked to Part 4.3),

SLO 4.7 explain the principles of least-cost diet formulation (Linked to Part 4.4),

SLO 4.8 apply the Pearson square and algebraic methods to formulate a fish feed meeting specified nutrient targets (Linked to Part 4.4), and

SLO 4.9 describe the requirements for feed stability, palatability, and appropriate formulation for different fish life stages (Linked to Part 4.4).

4.1 Nutrient Requirements of Fish

4.1.1 Proteins and amino acid requirements

Protein is the most important and most costly nutrient in fish diets. Fish generally require higher dietary protein levels than terrestrial farm animals because they use protein not only for tissue synthesis and growth but also as a major energy source, particularly in carnivorous species. Recommended dietary protein levels range from 25 to 35 per cent for omnivorous species such as common carp and tilapia, and from 38 to 50 per cent for carnivorous marine species such as seabass and grouper. African catfish, a facultative carnivore, performs optimally on diets containing 35 to 45 per cent crude protein.

Protein quality is determined by its amino acid profile. Fish require ten essential amino acids (EAAs) that cannot be synthesised de novo in adequate amounts and must therefore be supplied in the diet: lysine, methionine, threonine, tryptophan, arginine, isoleucine, leucine, valine, histidine, and phenylalanine. Lysine and methionine are the most commonly limiting EAAs in plant-based fish diets. The concept of the ideal protein describes the amino acid profile that exactly matches the requirements of the target species with no excess or deficiency; diets formulated towards the ideal protein minimise nitrogen excretion and feed cost.

Fill in the blank: The ten ________ amino acids that fish cannot synthesise in adequate amounts must be supplied in the diet; lysine and methionine are most commonly limiting in plant-based feeds.

Species	Recommended Crude Protein (%)	Most Limiting Essential Amino Acids
Nile tilapia	28–35%	Methionine, lysine
African catfish	35–40%	Methionine, arginine
Common carp	30–35%	Lysine, methionine
Catfish hybrid	35–38%	Methionine, lysine

Table 4.1: Recommended dietary protein levels and essential amino acid requirements for selected tropical aquaculture species

4.1.2 Lipid, carbohydrate, and energy requirements

Dietary lipids serve multiple roles in fish nutrition: they are the most energy-dense macronutrient (approximately 9 kcal/g), supply essential fatty acids (EFAs) that cannot be synthesised endogenously, serve as carriers for fat-soluble vitamins (A, D, E, and K), and contribute to the palatability and physical quality of the diet. Recommended dietary lipid levels are 5 to 8 per cent for tilapia and carp and 10 to 20 per cent for carnivorous marine species. The most important EFAs for freshwater fish are the n-6 fatty acid linoleic acid (18:2n-6) and the n-3 fatty acid linolenic acid (18:3n-3); marine fish additionally require the long-chain n-3 EFAs EPA (20:5n-3) and DHA (22:6n-3).

Carbohydrates are the cheapest energy source in fish diets and are used to spare protein from catabolism. However, fish are generally less efficient at utilising dietary carbohydrates than terrestrial animals; carnivorous species have limited glucokinase activity and tolerate only low levels of starch (below 20 per cent) without impaired glucose metabolism and fat deposition. Omnivorous species such as tilapia and carp tolerate higher carbohydrate levels (up to 40 per cent). Digestible energy (DE), expressed in kcal/kg or MJ/kg of diet, must be matched to the maintenance and production energy requirements of the target species and life stage.

Fill in the blank: Lipids supply the fat-soluble vitamins A, D, E, and K and provide essential fatty acids; they yield approximately ________ kcal per gram, making them the most energy-dense macronutrient in fish diets.

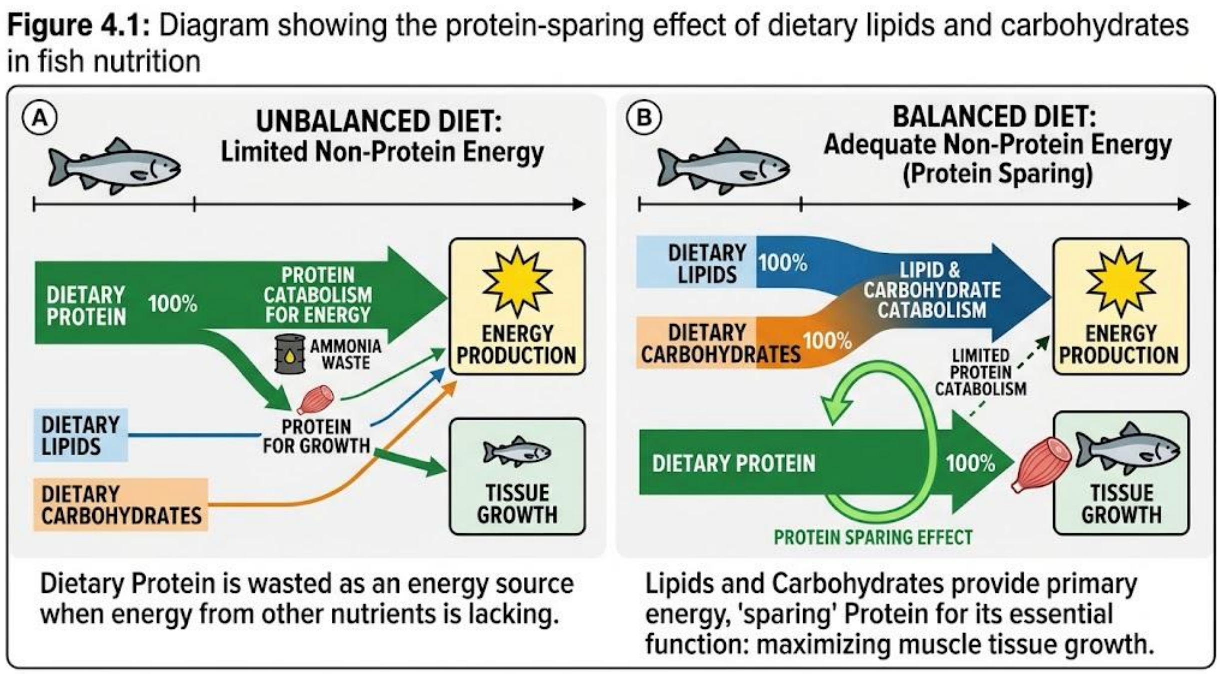

Figure 4.1: Diagram showing the protein-sparing effect of dietary lipids and carbohydrates in fish nutrition

4.1.3 Vitamins, minerals, and other micronutrients

Vitamins are organic micronutrients required in small amounts for normal metabolic function, immune competence, reproduction, and skeletal development. Fat-soluble vitamins (A, D, E, K) are stored in body lipid reserves and can cause toxicity if over-supplemented. Water-soluble vitamins (the B-complex vitamins and vitamin C) are not stored and must be supplied continuously in the diet. Vitamin C (ascorbic acid) is of particular importance in aquaculture because fish cannot synthesise it endogenously; deficiency causes scoliosis, haemorrhage, poor wound healing, and impaired immune function.

Minerals required by fish include macrominerals (calcium, phosphorus, magnesium, sodium, potassium, chloride, and sulphur) and trace minerals (iron, zinc, manganese, copper, iodine, selenium, and cobalt). Fish can absorb some minerals directly from the water across the gills and skin, but dietary supplementation is necessary particularly for phosphorus, which must be available in highly digestible form to avoid excess phosphorus excretion that contributes to eutrophication of water bodies. **Mineral premixes** are standard formulation tools that supply all required trace elements at guaranteed levels.

Fill in the blank: Vitamin ________ must be supplied continuously in fish diets because fish cannot synthesise it endogenously; its deficiency causes scoliosis, haemorrhage, and impaired immune function.

Nutrient	Main Functions	Deficiency Signs
Vitamin A	Supports vision, growth, and epithelial tissue integrity.	Poor growth, eye lesions, reduced resistance to infections.
Vitamin C	Antioxidant; collagen synthesis; immune support.	Skeletal deformities, poor wound healing, increased disease susceptibility.
Vitamin D	Regulates calcium and phosphorus metabolism; bone formation.	Skeletal deformities, soft bones, poor mineralisation.
Vitamin E	Antioxidant; protects cell membranes; reproductive health.	Muscular dystrophy, reduced fertility, increased oxidative stress.
Vitamin K	Essential for blood clotting and bone metabolism.	Hemorrhages, poor bone development.
B-complex vitamins	Coenzymes in metabolism; energy production; nervous system function.	Reduced growth, anemia, neurological disorders, poor feed conversion.
Calcium (Ca)	Bone and scale formation; muscle function.	Skeletal deformities, poor growth.
Phosphorus (P)	Energy metabolism (ATP); skeletal development.	Poor growth, bone deformities, reduced feed efficiency.
Zinc (Zn)	Enzyme activation; wound healing; immune function.	Skin lesions, poor growth, reduced immunity.
Iron (Fe)	Hemoglobin synthesis; oxygen transport.	Anemia, reduced growth, lethargy.
Selenium (Se)	Antioxidant enzyme function; thyroid hormone metabolism.	Reduced growth, muscle degeneration, increased susceptibility to oxidative damage.

Table 4.2: Selected vitamins and minerals required by fish, their functions, and the consequences of deficiency

Pilot questions 4.1

State the recommended dietary protein range for African catfish and explain why fish require more dietary protein than terrestrial livestock.

Name six of the ten essential amino acids required by fish.

What is the protein-sparing effect and why is it important in fish feed formulation?

Explain why carnivorous fish tolerate less dietary carbohydrate than omnivorous fish.

State two consequences of vitamin C deficiency in fish.

4.2 Factors Affecting Nutrient Requirements

4.2.1 Species, age, and physiological state

Species differences in nutrient requirements reflect the evolutionary dietary history of each fish. Carnivorous species evolved to consume protein-rich animal prey and have digestive systems and metabolic pathways optimised for protein and lipid catabolism; they require high dietary protein and long-chain polyunsaturated fatty acids but handle carbohydrate poorly. Herbivorous and omnivorous species evolved to consume plant material and have greater capacity for carbohydrate digestion and a lower protein requirement.

Age and body size significantly affect nutrient requirements because the ratio of maintenance requirement to productive requirement changes as fish grow. Larvae and juveniles have very high protein requirements (40 to 55 per cent) relative to their body weight because they are growing rapidly and have high metabolic rates per unit mass. As fish grow larger, their growth rate per unit body weight declines and their maintenance requirement becomes a larger fraction of total energy expenditure; dietary protein and energy density can therefore be reduced progressively. Broodstock have elevated requirements for vitamins E and C, essential fatty acids, and minerals to support gonadal development and egg quality.

Fill in the blank: As fish grow larger and older, their growth rate per unit body weight ________, allowing dietary protein and energy density to be progressively reduced.

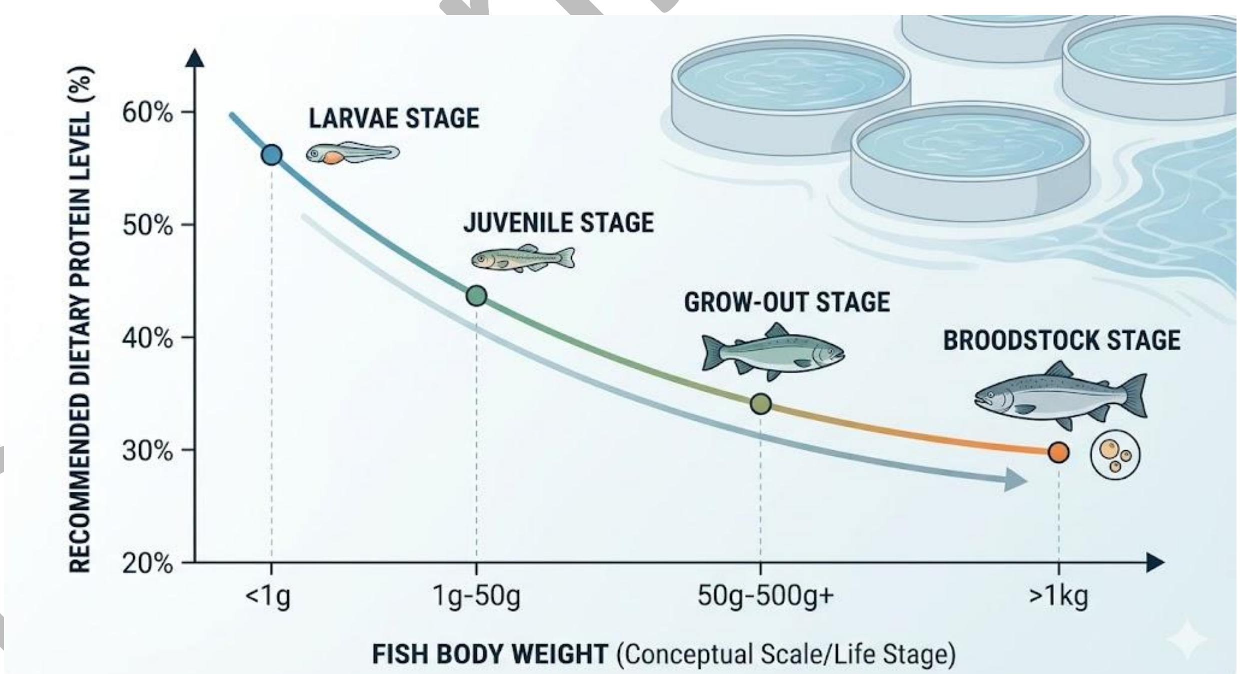

Figure 4.2: Graph showing how recommended dietary protein level changes with fish body weight from larvae through juvenile to grow-out and broodstock stages

4.2.2 Water temperature, salinity, and environmental factors

Water temperature is the most important environmental determinant of nutrient requirements in fish because it directly governs metabolic rate. At higher temperatures within the optimal range for a species, metabolic rate increases, fish eat more, digest feed faster, and grow more rapidly; their absolute requirements for all nutrients are therefore higher. At sub-optimal temperatures, appetite declines, digestion slows, and dietary adjustments may be needed to maintain growth, including increasing dietary lipid as an energy source to compensate for reduced feed intake.

Salinity affects the osmoregulatory energy cost of fish: euryhaline species moving between freshwater and saltwater must adjust ion exchange across the gills, which requires energy and may affect apparent protein utilisation. Oxygen availability interacts with feeding: at low dissolved oxygen, fish reduce feed intake and digestion, lowering nutrient uptake. Light intensity and photoperiod influence feeding behaviour and reproductive physiology, indirectly affecting nutritional requirements at different seasons. In Nigerian aquaculture, the high and relatively stable water temperatures (26 to 30 degrees Celsius) support high metabolic rates and rapid growth, favouring relatively high feeding rates year-round compared with temperate aquaculture systems.

Fill in the blank: At sub-optimal water temperatures, fish appetite ________ and digestion slows, potentially requiring increased dietary lipid to compensate for reduced energy intake.

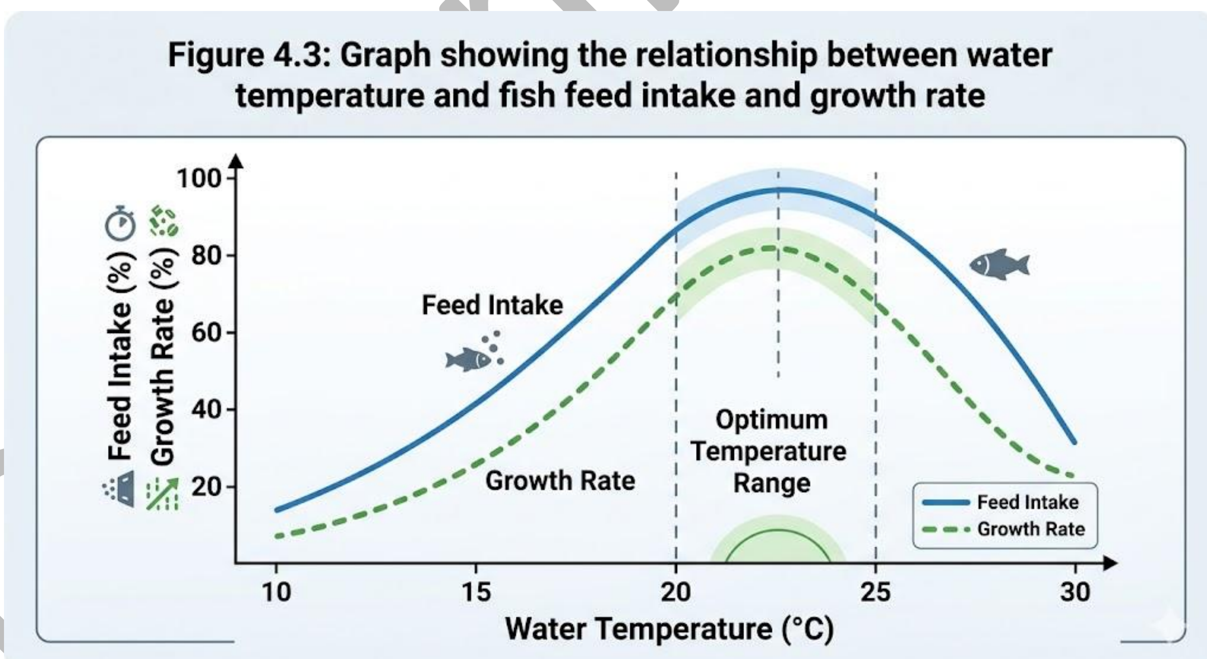

Figure 4.3: Graph showing the relationship between water temperature and fish feed intake and growth rate

4.2.3 Feeding method and feed type

The method and frequency of feeding affect the apparent nutrient requirements of fish by influencing feed intake, digestibility, and nutrient absorption. Fish fed continuously or at high frequency maintain more stable blood glucose levels, digest each meal more completely before the next is offered, and show higher apparent digestibility coefficients (ADCs) for protein, lipid, and energy than fish fed large infrequent meals that overwhelm their digestive capacity.

Feed type also influences nutrient requirements. Pelleted feeds that disintegrate rapidly in water leach nutrients before fish can consume them, effectively increasing the dietary requirement for leach-susceptible nutrients such as vitamin C and water-soluble minerals. Extruded (floating) pellets have greater water stability and also allow visual monitoring of feed consumption, reducing overfeeding. Natural live feeds such as Artemia and zooplankton provide highly available nutrients in forms that match larval digestive capacity, but their nutritional composition must be enriched (biofortified) with specific fatty acids and vitamins if they are to meet the full requirements of the larvae consuming them.

Fill in the blank: Extruded (floating) pellets have greater water ________ than compressed pellets, reducing nutrient leaching and allowing visual monitoring of feed consumption.

Factor	Influence on Nutrient Requirements
Species	Different species have varying metabolic rates and dietary needs.
Age	Younger fish require higher protein and energy for rapid growth; adults need balanced maintenance diets.
Physiological state	Reproductive, stressed, or diseased fish have elevated nutrient demands (e.g., protein, vitamins).
Water temperature	Higher temperatures increase metabolic activity and feed intake; lower temperatures reduce requirements.
Salinity	Osmoregulation in brackish or marine environments increases energy and mineral needs.
Dissolved oxygen	Low oxygen reduces feed intake and nutrient utilisation efficiency.
Feeding frequency	Frequent feeding improves nutrient absorption and reduces waste; infrequent feeding requires denser diets.
Feed type	Live feeds, formulated pellets, or natural diets differ in nutrient density and digestibility.

Box 4.1: Key factors that modify the nutrient requirements of fish in aquaculture

Pilot questions 4.2

Explain why juvenile fish require higher dietary protein than grow-out fish of the same species.

Describe the effect of increasing water temperature on fish feed intake and nutrient requirements.

How does sub-optimal dissolved oxygen affect nutrient uptake in fish?

Explain why extruded floating pellets are preferred over sinking pellets in many intensive aquaculture operations.

Why do broodstock have different nutrient requirements from grow-out fish of the same species?

4.3 Raw Materials and Feed Ingredient Chemistry

4.3.1 Plant-based ingredients and their nutrient composition

Plant-based ingredients form the energy and protein backbone of most practical aquaculture diets, particularly where fishmeal is restricted by cost or sustainability concerns. **Soybean meal (SBM)** is the most widely used plant protein source globally, containing 44 to 48 per cent crude protein with a good essential amino acid profile, although deficient in methionine. Full-fat soybean contains 36 per cent protein and 18 per cent lipid. **Groundnut cake** (peanut meal) is a common Nigerian alternative, containing 40 to 48 per cent crude protein but limited by its lysine content and susceptibility to aflatoxin contamination.

Energy-dense plant ingredients include yellow maize (8 to 9 per cent protein, 68 to 72 per cent starch), wheat and wheat bran, sorghum, cassava flour (a high-carbohydrate binder used in pellet manufacture), rice bran (12 to 14 per cent protein, 18 to 22 per cent lipid), and palm kernel cake (PKC, 16 to 18 per cent protein). In Nigeria, locally available plant ingredients including maize, soybean meal, groundnut cake, PKC, cottonseed cake, and blood meal form the basis of on-farm feed compounding for catfish and tilapia. Each ingredient must be evaluated for crude protein, digestible energy, amino acid profile, moisture content, and the presence of anti-nutritional factors before inclusion in a diet.

Fill in the blank: Soybean meal contains 44 to 48 per cent crude protein but is deficient in the essential amino acid ________, which must be supplemented when it is the primary protein source.

Ingredient	Crude Protein (%)	Crude Lipid (%)	Crude Fibre (%)	Digestible Energy (kcal/kg)
Soybean meal	40–45	18–20	5–7	~2,800–3,000
Groundnut cake	40–45	8–10	6–8	~2,500–2,700

Ingredient	Crude Protein (%)	Crude Lipid (%)	Crude Fibre (%)	Digestible Energy (kcal/kg)
Maize	8–10	3–4	2–3	~3,200–3,400
Wheat bran	12–16	3–4	10–12	~2,000–2,200
Palm kernel cake	15–20	8–10	12–15	~2,000–2,300
Cassava flour	2–4	0.5–1	1–2	~3,000–3,200

Table 4.3: Nutrient composition of major plant-based feed ingredients used in Nigerian aquaculture

4.3.2 Animal-based ingredients and supplements

Fishmeal is the gold standard animal protein source in aquaculture diets, containing 60 to 72 per cent crude protein with an excellent essential amino acid profile, high digestibility, and rich content of long-chain n-3 fatty acids (EPA and DHA). However, declining global supply and rising prices have made fishmeal increasingly expensive and have driven the search for alternatives. In Nigerian on-farm diets, fishmeal is often replaced partly or fully by **blood meal** (80 to 85 per cent crude protein, highly digestible), **poultry by-product meal** (55 to 65 per cent crude protein), and **livestock offal meal** (45 to 55 per cent crude protein).

Other important animal-based ingredients include dried shrimp meal and crayfish meal, which are locally available and rich in protein, minerals, and carotenoid pigments that enhance flesh colour. Mineral and vitamin premixes are essential supplements added at 0.5 to 2 per cent of the diet to ensure all micronutrient requirements are met regardless of variability in the main ingredients. Synthetic amino acid supplements, particularly lysine (L-lysine) and methionine (DL-methionine), are added to correct specific deficiencies when plant-based diets are used and to allow reduction of total dietary crude protein while maintaining adequate EAA supply.

Fill in the blank: Blood meal contains ________ to 85 per cent crude protein and is one of the richest protein supplements used in on-farm fish feed compounding in Nigeria.

Ingredient	Crude Protein (%)	Crude Lipid (%)	Key Essential Amino Acids
Fishmeal	55–65	8–12	Lysine, methionine, threonine
Blood meal	80–90	1–2	Lysine-rich, but deficient in methionine
Poultry by-product meal	50–60	12–15	Balanced profile; lysine and methionine
Shrimp meal	40–50	6–8	Arginine, lysine, methionine
Livestock offal meal	45–55	10–12	Variable; lysine and methionine often limiting

Table 4.4: Nutrient composition of major animal-based feed ingredients and supplements used in aquaculture

4.3.3 Anti-nutritional factors and ingredient substitution

Anti-nutritional factors (ANFs) are naturally occurring compounds in feed ingredients that interfere with nutrient digestion, absorption, or utilisation, reducing the effective nutritive value of the ingredient. Key ANFs in plant ingredients include trypsin inhibitors and phytic acid in raw soybeans (inactivated by heat processing), gossypol in cottonseed meal (toxic to fish at high levels), tannins in sorghum and cassava leaves (reduce protein digestibility), and aflatoxins produced by Aspergillus moulds in poorly stored groundnut meal (hepatotoxic and immunosuppressive).

Ingredient substitution involves replacing one ingredient with another of similar nutritive value when the original is unavailable, too expensive, or nutritionally limiting. Successful substitution requires knowledge of the nutritive value of both ingredients, adjustment of inclusion rates to maintain the target nutrient levels in the diet, and supplementation to compensate for any nutrient that the replacement ingredient provides at a lower level. For example, replacing fishmeal with soybean meal requires methionine supplementation and may require the use of a phytase enzyme supplement to improve phosphorus digestibility from the soy. Practical substitution guides based on empirical digestibility trials for Nigerian ingredients are an important resource for local feed compounders.

Fill in the blank: ________ inhibitors in raw soybeans interfere with protein digestion but are inactivated by heat processing such as toasting or extrusion.

Anti-nutritional Factor	Ingredient Source	Effect on Fish Nutrition	Management Strategy
Trypsin inhibitors	Soybean meal, legumes	Reduce protein digestion and growth.	Heat treatment (toasting/extrusion) to inactivate inhibitors.
Phytic acid	Oilseeds, cereals (soybean, maize)	Binds phosphorus and trace minerals, reducing bioavailability.	Supplementation with phytase enzyme; mineral fortification.
Gossypol	Cottonseed meal	Toxic to fish; reduces growth, damages liver and reproductive organs.	Limit inclusion levels; detoxification by heat or chemical treatment.
Tannins	Plant leaves, seed coats	Reduce palatability and protein digestibility.	Processing (soaking, fermentation); limit use of high-tannin ingredients.
Aflatoxins	Contaminated oilseeds, grains	Carcinogenic; cause liver damage, immunosuppression, and mortality.	Proper storage; use of binders (e.g., clay, activated charcoal); strict quality control.

Box 4.2: Common anti-nutritional factors in fish feed ingredients, their effects, and management strategies

Pilot questions 4.3

State the crude protein content of soybean meal and groundnut cake and name one limiting amino acid in each.

Explain why fishmeal is considered the gold standard protein source in aquaculture diets.

Name three animal-based protein ingredients used as fishmeal alternatives in Nigerian on-farm diets.

What are anti-nutritional factors and how do trypsin inhibitors in soybeans affect fish nutrition?

Explain one key consideration when substituting fishmeal with soybean meal in a fish diet.

4.4 Fish Feed Formulation

4.4.1 Principles of diet formulation and the least-cost approach

Feed formulation is the process of combining feed ingredients in proportions that meet the nutrient requirements of the target species at a particular life stage while satisfying constraints on ingredient cost, availability, palatability, and manufacturing properties. The goal is to produce a nutritionally complete diet at the lowest possible cost, since feed accounts for 50 to 70 per cent of variable production costs in intensive aquaculture.

The least-cost formulation approach uses linear programming software (such as UFFDA, WinFeed, or Format) to determine the combination of ingredients that satisfies all specified nutrient constraints (minimum protein, minimum EAAs, maximum fibre, maximum carbohydrate, energy level) at the minimum cost. The formulator specifies the nutritive value of each available ingredient, its cost per kg, and its minimum and maximum inclusion limits (based on palatability, anti-nutritional factors, or physical constraints on pellet quality). The computer then finds the least-cost combination satisfying all constraints simultaneously.

Fill in the blank: Least-cost formulation uses ________ programming to find the minimum-cost combination of ingredients that satisfies all specified nutrient constraints simultaneously.

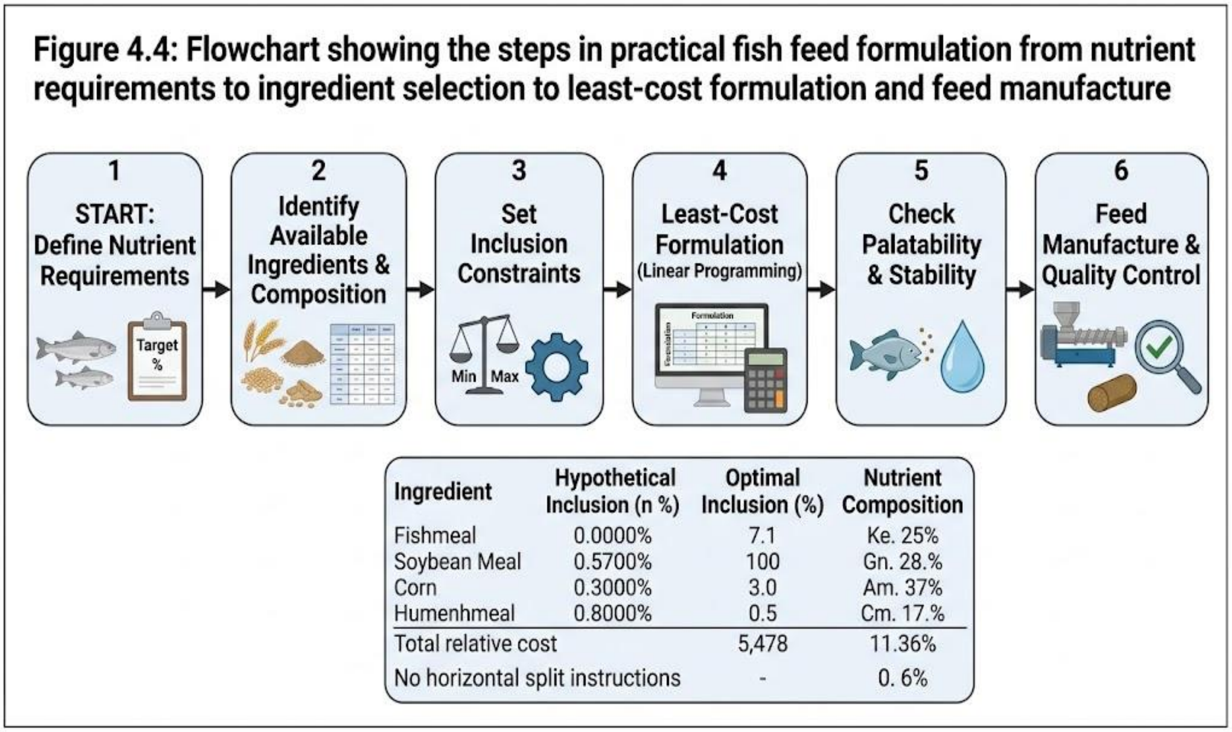

Figure 4.4: Flowchart showing the steps in practical fish feed formulation from nutrient requirements to ingredient selection to least-cost formulation and feed manufacture

4.4.2 Practical feed formulation using the Pearson square and algebraic methods

The Pearson square is a simple graphical method for calculating the proportions of two ingredients (or two ingredient groups) needed to achieve a target nutrient level, typically crude protein. The procedure is as follows: (1) draw a square with the target crude protein level in the centre; (2) place the crude protein content of the high-protein ingredient in the top left corner and that of the low-protein ingredient in the bottom left corner; (3) subtract diagonally (larger minus smaller), ignoring signs, and place the results in the opposite corners; (4) the right-hand values give the parts of each ingredient needed; (5) convert to percentages of the total mixture.

Example: to produce a feed with 35 per cent crude protein using soybean meal (44 per cent CP) and maize (9 per cent CP), place 44 in the top left, 9 in the bottom left, and 35 in the centre. Subtracting diagonally: 35 − 9 = 26 parts soybean meal; 44 − 35 = 9 parts maize. Total parts = 26 + 9 = 35. Soybean meal inclusion = 26/35 × 100 = 74.3 per cent; maize inclusion = 9/35 × 100 = 25.7 per cent. The algebraic method extends this to multiple ingredients by setting up simultaneous equations for two or more nutrient constraints (protein and energy, for example) and solving for the unknown ingredient proportions.

Fill in the blank: In the Pearson square method, the ingredient proportions are found by subtracting ________ across the square and placing the absolute differences in the opposite corners.

Figure 4.5: Illustrated example of the Pearson square method for formulating a 35 per cent crude protein fish diet from soybean meal and maize

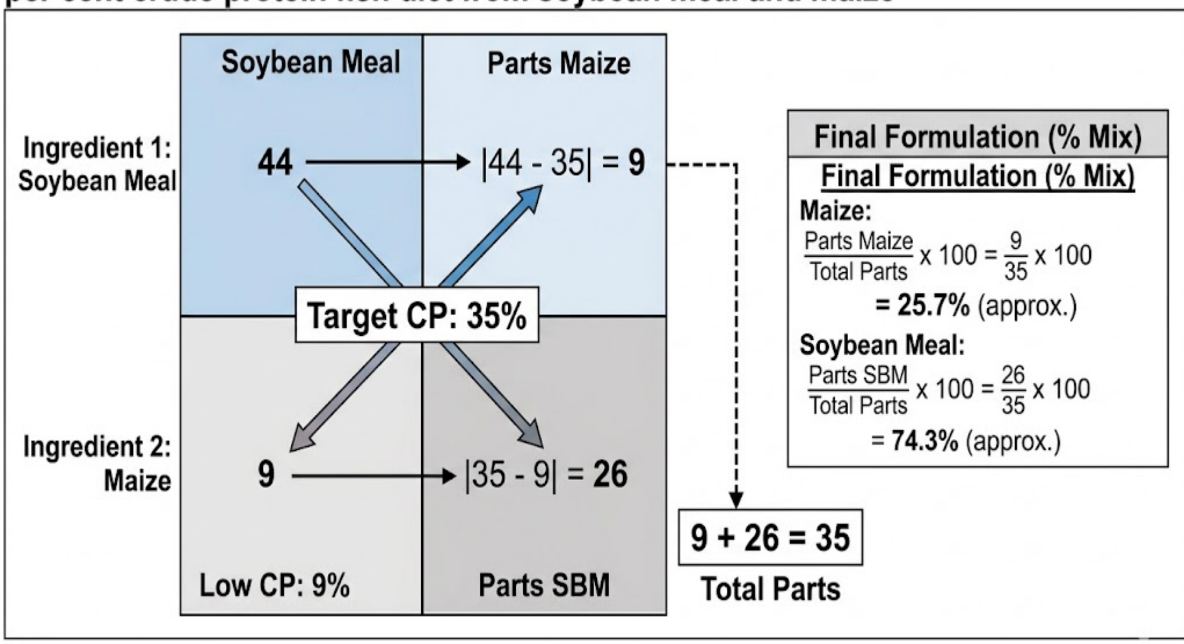

Figure 4.5: Illustrated example of the Pearson square method for formulating a 35 per cent crude protein fish diet from soybean meal and maize

4.4.3 Feed stability, palatability, and formulation for different life stages

Feed stability refers to the resistance of a pellet to physical disintegration and nutrient leaching when immersed in water. Poor water stability results in rapid nutrient loss and deterioration of water quality. Stability is enhanced by the inclusion of binders such as cassava starch, wheat flour, guar gum, or carboxymethylcellulose, and by the physical process of extrusion, which gelatinises starch to form a strong pellet matrix. Extruded pellets maintain integrity in water for 30 minutes or longer, compared with 5 to 15 minutes for compressed pellets.

Palatability is the attractiveness of a diet to fish, influencing voluntary feed intake. Ingredients that enhance palatability include fish-based products (fishmeal, fish oil, fish hydrolysate), fermented proteins, and amino acid-rich extracts. Ingredients that reduce palatability include high levels of plant oils (particularly palm oil in some species), poorly processed blood meal with a strong odour, and bitter-tasting tannins or saponins from plant sources. Diets for different life stages must be formulated to match particle size, nutrient density, digestibility, and palatability to the specific physiological capacity of larvae, fry, fingerlings, grow-out fish, and broodstock.

Fill in the blank: Extruded pellets maintain water ________ for 30 minutes or longer because extrusion gelatinises starch, forming a strong pellet matrix resistant to disintegration.

Life Stage	Target Crude Protein (%)	Target Dietary Lipid (%)	Pellet / Crumble Size	Key Palatability Considerations
Larvae	45–55	10–15	50–100 µm (microdiet)	High digestibility; attractants (e.g., amino acids) needed.
Fry	40–45	8–12	150–250 µm (crumbles)	Soft texture; gradual transition from live feed to pellets.
Fingerlings	35–40	8–10	0.5–1.0 mm pellets	Good water stability; moderate hardness for easy ingestion.
Grow-out fish	28–35	6–8	2–4 mm pellets	Balanced energy density; durable pellets to reduce waste.
Broodstock	35–40	10–12	4–6 mm pellets	Enhanced palatability; inclusion of essential fatty acids and vitamins for reproduction.

Table 4.5: Summary of key formulation targets for fish feeds at different life stages

Pilot questions 4.4

Define feed formulation and explain the objective of the least-cost approach.

Describe the five steps of the Pearson square method for feed formulation.

Using the Pearson square, calculate the proportions of fishmeal (65 per cent CP) and maize (9 per cent CP) needed to produce a diet with 40 per cent CP.

Explain what feed water stability means and name two binders used to improve it.

State two ingredients or factors that enhance feed palatability for fish.

Series Summary

This Series has provided a comprehensive treatment of the nutrient requirements of fish, the factors that modify those requirements, the chemistry and nutritive value of feed ingredients, and the practical methods of feed formulation used in aquaculture. We began by examining macronutrient requirements, covering the high protein and amino acid needs of fish (especially carnivorous species), the roles of dietary lipids including essential fatty acids and fat-soluble vitamin transport, and the limited but useful role of carbohydrates as energy-sparing nutrients. We then described the micronutrient requirements for vitamins and minerals, with particular emphasis on vitamin C, which fish cannot synthesise and must receive continuously in their diet.

Following that, we examined the factors that modify nutrient requirements, including species feeding strategy, life stage, physiological state, water temperature, salinity, dissolved oxygen, feeding frequency, and feed type. We then surveyed the major plant-based ingredients (soybean meal, groundnut cake, maize, palm kernel cake) and animal-based ingredients (fishmeal, blood meal, poultry by-product meal), their nutrient composition, and the anti-nutritional factors that limit their use and must be managed through processing or substitution. Finally, we covered feed formulation principles including the least-cost approach, the Pearson square and algebraic methods, and the requirements for water stability, palatability, and life-stage-appropriate formulation. By completing this Series, you should now be able to achieve all nine Series Learning Outcomes (SLO 4.1 to SLO 4.9).

Glossary of Terms

Aflatoxin: a hepatotoxic and immunosuppressive mycotoxin produced by Aspergillus moulds in poorly stored groundnut meal and other cereal ingredients; a major anti-nutritional and food safety concern in tropical feed compounding.

Anti-nutritional factor (ANF): a naturally occurring compound in a feed ingredient that interferes with nutrient digestion, absorption, or utilisation, reducing the effective nutritive value of the ingredient.

Apparent digestibility coefficient (ADC): the proportion of a nutrient in the feed that is absorbed by the fish, calculated from the difference between intake and faecal output; used to evaluate feed ingredient quality.

Binder: a feed additive such as cassava starch, wheat flour, or guar gum included in pellet formulations to improve water stability and pellet cohesion.

Blood meal: a dried animal protein ingredient containing 80 to 85 per cent crude protein, used as a fishmeal alternative in on-farm aquaculture diets.

Crude protein: the estimated total protein content of a feed ingredient or diet, calculated as total nitrogen multiplied by 6.25; includes both true protein and non-protein nitrogen.

Digestible energy (DE): the portion of gross energy in a feed that is actually absorbed by the fish after faecal losses; expressed in kcal/kg or MJ/kg and used to balance energy in diet formulation.

DHA (docosahexaenoic acid, 22:6n-3): a long-chain n-3 essential fatty acid critical for neural and retinal development in marine fish larvae and an important nutrient for broodstock reproductive performance.

Essential amino acids (EAAs): amino acids that fish cannot synthesise de novo in adequate quantities and must obtain from the diet; the ten EAAs for fish are lysine, methionine, threonine, tryptophan, arginine, isoleucine, leucine, valine, histidine, and phenylalanine.

Essential fatty acids (EFAs): fatty acids that fish cannot synthesise endogenously and must obtain from the diet; n-6 (linoleic acid) and n-3 (linolenic acid, EPA, DHA) fatty acids are most important in fish nutrition.

Extrusion: a high-temperature, high-pressure manufacturing process that cooks and shapes feed ingredients into pellets, gelatinising starch to improve water stability and digestibility and producing floating pellets.

Fishmeal: a high-quality animal protein ingredient (60 to 72 per cent crude protein) derived from whole fish or fish processing waste; the gold standard protein source in aquaculture diets.

Gossypol: a toxic polyphenol found in cottonseed meal that inhibits digestive enzymes and damages internal organs in fish at high dietary inclusion levels.

Groundnut cake (peanut meal): a plant protein ingredient containing 40 to 48 per cent crude protein, commonly used in Nigerian on-farm fish diets; susceptible to aflatoxin contamination if stored in humid conditions.

Ideal protein: the theoretical amino acid profile that exactly matches the requirements of the target species with no excess or deficiency; formulating towards the ideal protein minimises nitrogen excretion and feed cost.

Least-cost formulation: a computerised diet formulation approach using linear programming to find the minimum-cost combination of ingredients satisfying all specified nutrient constraints.

Linear programming: a mathematical optimisation technique used in least-cost feed formulation to find the optimal combination of ingredients that meets nutrient targets at minimum cost.

Palm kernel cake (PKC): a by-product of palm oil extraction containing 16 to 18 per cent crude protein; a locally available and economical energy and protein ingredient in Nigerian aquaculture diets.

Pearson square: a simple graphical method for calculating the proportions of two ingredients (or ingredient groups) needed to achieve a target nutrient level in a mixed diet.

Phytic acid: an anti-nutritional factor in plant ingredients that binds dietary minerals (especially phosphorus, zinc, and iron), reducing their availability; managed with phytase enzyme supplementation.

Protein-sparing effect: the use of dietary lipids and carbohydrates as energy sources, reducing the catabolism of dietary protein for energy and allowing more protein to be directed towards tissue growth.

Soybean meal (SBM): the most widely used plant protein source in aquaculture diets globally, containing 44 to 48 per cent crude protein; deficient in methionine and contains trypsin inhibitors that are inactivated by heat processing.

Trypsin inhibitor: an anti-nutritional factor in raw soybeans that inhibits the digestive enzyme trypsin, reducing protein digestion; inactivated by toasting, autoclaving, or extrusion.

Vitamin C (ascorbic acid): a water-soluble vitamin that fish cannot synthesise endogenously; essential for collagen synthesis, immune function, and antioxidant protection; deficiency causes scoliosis, haemorrhage, and poor wound healing.

Concept Check Questions [Series 4]

Objective Questions

African catfish performs optimally on diets containing ________ to 45 per cent crude protein. (Linked to SLO 4.1)

The most energy-dense macronutrient in fish diets, providing approximately 9 kcal per gram, is ________. (Linked to SLO 4.2)

Vitamin C deficiency in fish causes scoliosis, haemorrhage, and impaired ________ function. (Linked to SLO 4.3)

Soybean meal is the most widely used plant protein source in aquaculture but is deficient in the amino acid ________. (Linked to SLO 4.5)

The simple graphical method for calculating the proportions of two ingredients needed to achieve a target protein level is called the Pearson ________. (Linked to SLO 4.8)

Short-Answer Questions

Explain the protein-sparing effect and state why it is important in fish feed formulation. (Linked to SLO 4.2)

Explain how water temperature affects the nutrient requirements of fish. (Linked to SLO 4.4)

Describe trypsin inhibitors in soybean meal and explain how they are managed in feed processing. (Linked to SLO 4.6)

State the five steps of the Pearson square method and apply it to calculate the proportions of soybean meal (44 per cent CP) and maize (9 per cent CP) needed to produce a 35 per cent CP diet. (Linked to SLO 4.8)

Explain what feed water stability means and state two ways it can be improved. (Linked to SLO 4.9)

Long-Answer Questions

Analyse the macronutrient requirements of fish, explaining the roles of protein, lipids, and carbohydrates in fish nutrition, the concept of the ideal protein, and how the protein-sparing effect of lipids and carbohydrates is used in diet formulation. (Linked to SLOs 4.1, 4.2)

Discuss the major feed ingredients available for aquaculture in Nigeria, describing the nutrient composition of key plant-based and animal-based ingredients, the anti-nutritional factors that limit their use, and the considerations involved in successful ingredient substitution. (Linked to SLOs 4.5, 4.6)

Evaluate the principles and practical methods of fish feed formulation, explaining the least-cost approach, the Pearson square and algebraic methods, and the requirements for water stability, palatability, and appropriate formulation across different fish life stages. (Linked to SLOs 4.7, 4.8, 4.9)

Answers to Concept Check Questions [Series 4]

Objective Questions

35.

Lipid (dietary fat).

Immune.

Methionine.

Square.

Short-Answer Questions

The protein-sparing effect is the use of dietary lipids and carbohydrates as energy sources that reduce catabolism of dietary protein for energy, allowing more protein to be directed to tissue synthesis and growth; it is important because protein is the most expensive nutrient in aquaculture diets, and maximising its use for growth rather than energy production reduces diet cost and improves economic efficiency.

Higher water temperature within the optimal range increases metabolic rate, appetite, and growth rate, increasing the absolute daily requirements for all nutrients; fish eat more feed per day and therefore consume more total protein, energy, vitamins, and minerals. At sub-optimal temperatures, appetite declines and digestion slows, reducing nutrient uptake and often requiring an increase in dietary energy density (particularly lipid) to compensate for reduced feed intake.

Trypsin inhibitors in raw soybeans bind and inactivate the digestive enzyme trypsin, preventing normal protein digestion and reducing protein digestibility and utilisation; they are managed by heat processing including toasting, autoclaving, extrusion, or steam treatment, all of which denature the inhibitor protein and restore normal trypsin activity in the fish digestive tract.

Step 1: draw a square with the target protein level (35) in the centre; Step 2: place high-protein ingredient value (44, SBM) top left and low-protein value (9, maize) bottom left; Step 3: subtract diagonally ignoring signs: 35 − 9 = 26 (parts SBM); 44 − 35 = 9 (parts maize); Step 4: total parts = 26 + 9 = 35; Step 5: SBM = 26/35 × 100 = 74.3%; maize = 9/35 × 100 = 25.7%.

Feed water stability is the resistance of a pellet to physical disintegration and nutrient leaching when submerged in water; it is important because unstable pellets lose nutrients rapidly before fish consume them and deteriorate water quality. It can be improved by: (1) including binders such as cassava starch, wheat flour, or guar gum; (2) using the extrusion process, which gelatinises starch and forms a strong pellet matrix resistant to disintegration.

Long-Answer Questions

Basic response: Fish require high dietary protein (25 to 50 per cent depending on species) as the primary growth nutrient, with ten EAAs that must be supplied in the diet; lysine and methionine are most commonly limiting. Lipids supply energy (9 kcal/g), EFAs, and fat-soluble vitamins; recommended levels are 5 to 20 per cent. Carbohydrates are the cheapest energy source but are used less efficiently than by terrestrial animals; carnivorous species tolerate below 20 per cent. The ideal protein concept minimises nitrogen waste; the protein-sparing effect reduces feed cost.

Value-added response: Understanding the interaction between macronutrients is essential for efficient formulation. Feeding a high-protein diet without adequate non-protein energy forces fish to catabolise protein for energy, wasting the most expensive dietary component. Conversely, excess dietary carbohydrate in carnivorous species is deposited as visceral fat, reducing dressing percentage and market value. Balancing protein to digestible energy ratio (P:DE ratio) for each species and life stage is the central challenge of practical feed formulation.

Basic response: Key plant ingredients in Nigeria: soybean meal (44 to 48% CP, methionine-limiting), groundnut cake (40 to 48% CP, aflatoxin risk), maize (8 to 9% CP, high starch), palm kernel cake (16 to 18% CP). Key animal ingredients: fishmeal (60 to 72% CP, excellent EAA profile), blood meal (80 to 85% CP), poultry by-product meal (55 to 65% CP). ANFs include trypsin inhibitors (SBM, heat-labile), phytic acid (SBM, managed with phytase), gossypol (cottonseed, toxic at high levels), aflatoxins (groundnut, managed by proper storage).

Value-added response: Successful substitution requires knowledge of not just the crude protein content of the replacement ingredient but also its digestibility, EAA profile, energy content, and ANF load. Replacing fishmeal with soybean meal requires methionine supplementation, phytase addition, and often a vitamin C increase to compensate for reduced fishmeal-derived nucleotides and palatability enhancers. In Nigeria, the limited availability of digestibility data for locally produced ingredients means substitution often relies on published tables from other regions, introducing formulation uncertainty that can be reduced by conducting local digestibility trials.

Basic response: Least-cost formulation uses linear programming software to minimise ingredient cost while satisfying all nutrient constraints. The Pearson square calculates the proportions of two ingredients to achieve a target protein level by diagonal subtraction. The algebraic method extends this to multiple constraints. Extrusion and binders improve water stability. Palatability is enhanced by fish-based ingredients. Formulation targets (protein, lipid, particle size) differ for larvae, fry, fingerlings, grow-out, and broodstock.

Value-added response: While least-cost formulation is the most economically rational approach to diet design, the cost minimised is ingredient cost alone, not total production cost; a diet that appears cheaper per kg may produce a higher FCR, offsetting its lower ingredient cost. The most cost-effective diet is the one that minimises cost per kg of fish produced, not cost per kg of feed. Feed formulation decisions should therefore be evaluated against FCR data from feeding trials wherever possible, rather than from ingredient cost calculations alone.

Answers to Pilot Questions [Series 4]

Part 4.1: Nutrient Requirements of Fish

Recommended dietary protein for African catfish is 35 to 45 per cent crude protein; fish require more dietary protein than terrestrial livestock because they use protein not only for tissue synthesis but also as a major energy source, particularly carnivorous species, and because they have higher metabolic protein turnover rates.

Any six of the ten: lysine, methionine, threonine, tryptophan, arginine, isoleucine, leucine, valine, histidine, phenylalanine.

The protein-sparing effect is the reduction in protein catabolism for energy when dietary lipids and carbohydrates supply sufficient non-protein energy; it is important because it allows more of the dietary protein to be used for tissue growth rather than burnt for energy, improving the efficiency of the most expensive nutrient in the diet.

Carnivorous fish evolved to consume protein and lipid-rich animal prey and have limited glucokinase (hepatic glucose-metabolising enzyme) activity; they cannot efficiently regulate blood glucose at high dietary carbohydrate levels, leading to hyperglycaemia, fat deposition, and impaired growth when starch exceeds about 20 per cent of the diet.

Any two: scoliosis (spinal deformity); haemorrhage (internal bleeding); poor wound healing; impaired immune function; reduced growth rate.

Part 4.2: Factors Affecting Nutrient Requirements

Juvenile fish have very high growth rates per unit body weight and high metabolic rates per unit mass; a large fraction of their total energy budget is directed towards growth, requiring high protein density (40 to 55 per cent) in the diet; as fish grow larger, their growth rate per unit mass declines and their maintenance requirement becomes proportionally larger, allowing dietary protein to be progressively reduced.

Increasing water temperature within the optimal species range raises metabolic rate; fish eat more feed per day, digest it faster, and grow more rapidly, increasing absolute daily requirements for all nutrients; the dietary nutrient concentrations needed may not change much, but the daily intake of all nutrients increases because of higher voluntary feed consumption.

At low dissolved oxygen, fish reduce feed intake and digestive activity, lowering nutrient absorption; energy and nutrients that are consumed are partially redirected to the physiological stress of low-oxygen exposure; growth rates decline and feed conversion efficiency worsens because less of each nutrient consumed is directed to productive growth.

Extruded floating pellets have greater water stability (30+ minutes versus 5 to 15 minutes for compressed pellets), reducing nutrient leaching and water quality deterioration; floating pellets allow the farmer to observe feeding behaviour and adjust the amount fed, reducing overfeeding and improving FCR; they also reduce oxygen depletion caused by uneaten sinking pellets decomposing on the pond bottom.

Broodstock require elevated levels of vitamin E, vitamin C, essential fatty acids (especially arachidonic acid and DHA), and minerals such as zinc and selenium to support gonadal development, egg lipid composition, and larval viability; grow-out diets formulated for maximum muscle growth are insufficient in these specific micronutrients for supporting reproduction.

Part 4.3: Raw Materials and Feed Ingredient Chemistry

Soybean meal: 44 to 48 per cent crude protein, limiting amino acid methionine. Groundnut cake: 40 to 48 per cent crude protein, limiting amino acid lysine.

Fishmeal is the gold standard because it contains 60 to 72 per cent crude protein with an excellent essential amino acid profile including high lysine and methionine, is highly digestible (ADC above 85 per cent for most species), contains long-chain n-3 fatty acids (EPA and DHA) that are essential for marine fish and broodstock, and has high palatability that stimulates voluntary feed intake.

Any three: blood meal; poultry by-product meal; livestock offal meal; dried shrimp meal; crayfish meal.

Anti-nutritional factors are naturally occurring compounds that interfere with nutrient digestion or absorption; trypsin inhibitors in soybeans bind and inactivate the digestive enzyme trypsin, preventing normal protein breakdown in the fish gut and reducing apparent protein digestibility and growth.

When substituting fishmeal with soybean meal, methionine supplementation is required because soybean meal is methionine-deficient; phytase enzyme addition improves phosphorus digestibility from the soy (since phytic acid in soy binds dietary phosphorus); palatability may decline and may need to be offset by fish hydrolysate or other attractants.

Part 4.4: Fish Feed Formulation

Feed formulation is the process of combining ingredients in proportions that meet nutrient requirements at a particular life stage; the least-cost approach uses linear programming to find the minimum-cost combination of ingredients satisfying all specified nutrient constraints, minimising the largest single cost in intensive aquaculture production.

Step 1: draw a square with target CP in the centre; Step 2: place high-protein ingredient CP top left, low-protein CP bottom left; Step 3: subtract diagonally ignoring signs; Step 4: sum the two differences; Step 5: express each difference as a percentage of the total to give the inclusion rate of each ingredient.

Fishmeal (65% CP) and maize (9% CP), target 40% CP. Pearson square: 40 − 9 = 31 parts fishmeal; 65 − 40 = 25 parts maize; total = 56 parts. Fishmeal = 31/56 × 100 = 55.4%; maize = 25/56 × 100 = 44.6%.

Feed water stability is the resistance of a pellet to physical disintegration and nutrient leaching in water; two binders used to improve it: cassava starch and wheat flour (or guar gum, carboxymethylcellulose).

Any two: fish-based ingredients such as fishmeal, fish oil, or fish hydrolysate; fermented protein meals; amino acid-rich extracts; compounds with umami taste (such as betaine); avoiding strong-smelling poorly processed blood meal or bitter plant compounds.

References and Attributions [Series 4]

Textual References (Books and External Sources)

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Pillay, T. V. R., & Kutty, M. N. (2005). Aquaculture: Principles and practices (2nd ed.). Blackwell Publishing.

FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable aquaculture. FAO.

Figures, Plates, Tables, and Boxes

Table 4.1: Protein and amino acid requirements for selected tropical aquaculture species Attribution: AI generated using prompt "Generate a table listing recommended dietary protein levels and essential amino acid requirements for selected tropical aquaculture species." Suggested OER search string: "fish dietary protein requirements essential amino acids table OER".

Figure 4.1: Protein-sparing effect of lipids and carbohydrates in fish nutrition Attribution: AI generated using prompt "Generate a diagram showing how dietary lipids and carbohydrates provide energy that spares dietary protein for fish tissue growth." Suggested OER search string: "protein sparing effect lipids carbohydrates fish nutrition diagram OER".

Table 4.2: Vitamins and minerals required by fish with functions and deficiency signs Attribution: AI generated using prompt "Generate a table listing key vitamins and minerals required by fish, their main functions, and deficiency signs." Suggested OER search string: "fish vitamins minerals functions deficiency signs table OER".

Figure 4.2: Dietary protein requirement versus fish body weight at different life stages Attribution: AI generated using prompt "Generate a line graph showing how recommended dietary protein level declines with increasing fish body weight from larvae to grow-out." Suggested OER search string: "fish dietary protein requirement body weight life stage graph OER".

Figure 4.3: Water temperature versus fish feed intake and growth rate Attribution: AI generated using prompt "Generate a graph showing how fish feed intake and growth rate change with water temperature, peaking at the optimal temperature." Suggested OER search string: "water temperature fish feed intake growth rate relationship graph OER".

Box 4.1: Factors modifying fish nutrient requirements in aquaculture Attribution: AI generated using prompt "Generate a text box summarising the key factors that modify fish nutrient requirements in aquaculture." Suggested OER search string: "factors affecting fish nutrient requirements aquaculture OER".

Table 4.3: Nutrient composition of plant-based feed ingredients in Nigerian aquaculture Attribution: AI generated using prompt "Generate a table listing the nutrient composition of major plant-based feed ingredients used in Nigerian aquaculture." Suggested OER search string: "plant-based feed ingredients nutrient composition Nigerian aquaculture table OER".

Table 4.4: Nutrient composition of animal-based feed ingredients in aquaculture Attribution: AI generated using prompt "Generate a table listing the nutrient composition of major animal-based feed ingredients used in aquaculture." Suggested OER search string: "animal-based feed ingredients nutrient composition aquaculture table OER".

Box 4.2: Anti-nutritional factors in fish feed ingredients and management strategies Attribution: AI generated using prompt "Generate a text box listing common anti-nutritional factors in fish feed ingredients with their effects and management strategies." Suggested OER search string: "anti-nutritional factors fish feed ingredients effects management OER".

Figure 4.4: Fish feed formulation steps flowchart Attribution: AI generated using prompt "Generate a flowchart showing the steps in fish feed formulation from defining nutrient requirements through least-cost computation to feed manufacture." Suggested OER search string: "fish feed formulation steps flowchart OER diagram".

Figure 4.5: Pearson square method example for 35% CP diet from SBM and maize Attribution: AI generated using prompt "Generate a diagram illustrating the Pearson square method for formulating a 35 per cent crude protein fish feed using soybean meal and maize." Suggested OER search string: "Pearson square fish feed formulation crude protein example OER diagram".

Table 4.5: Feed formulation targets by fish life stage Attribution: AI generated using prompt "Generate a table summarising key formulation targets including crude protein, lipid level, particle size, and palatability requirements for fish feeds at each life stage." Suggested OER search string: "fish feed formulation targets life stages crude protein lipid particle size table OER".

Course code: FAA 404

Course title: Fish Fry and Fingerlings Production; Hatchery Management; Fish Production and Management and Fish Food Nutrition and Fish Food Technology

Course credit load: 2 Units

Series 5: Fish Food Technology and Product Development

Series outline

Introduction

The preceding Series have covered the biological and nutritional foundations of fish feeding in aquaculture. This final Series shifts focus to the technology and economics of turning those nutritional principles into manufactured feeds and marketable fish products. Understanding how feeds are made, how their quality is controlled, and how fish are processed into products with economic value completes the production chain from broodstock to consumer.

The aim of this Series is to equip you with knowledge of feed mill operations and pelleting and extrusion technology, feed quality control and storage, traditional and modern fish product development, and the food safety and sustainability considerations that govern fish food technology in Nigeria and globally.

We shall commence this Series by examining feed mill components and the operating principles of pelleting and extrusion machines. Next, we will study feed quality control procedures and storage requirements. Following that, we will explore fish product development from traditional processing methods through to modern value-added products and their economic importance. Finally, we will wrap up with food safety, quality standards, and the sustainability challenges facing fish food technology.

Series Learning Outcomes

Upon completing this Series, you should be able to:

SLO 5.1 identify the components of a feed mill and describe their functions in the feed manufacturing process (Linked to Part 5.1),

SLO 5.2 describe the types of pelleting machines and explain their operating principles (Linked to Part 5.1),

SLO 5.3 explain the extrusion process and describe how floating pellets are produced (Linked to Part 5.1),

SLO 5.4 identify the physical and chemical quality parameters of fish feed and describe quality control procedures during manufacture (Linked to Part 5.2),

SLO 5.5 explain the requirements for fish feed storage and describe how spoilage is prevented (Linked to Part 5.2),

SLO 5.6 describe traditional fish processing methods and explain their application in Nigerian fisheries (Linked to Part 5.3),

SLO 5.7 describe modern fish product development and explain the economic value and market implications of fish products (Linked to Part 5.3),

SLO 5.8 explain food safety and hygiene requirements in fish processing and describe the relevant quality standards (Linked to Part 5.4), and

SLO 5.9 discuss the sustainability considerations relevant to fish food technology and product development (Linked to Part 5.4).

5.1 Feed Manufacturing Technology

5.1.1 Feed mill components and operations

A feed mill is a processing facility that transforms raw feed ingredients into finished pelleted or extruded feeds of specified size, nutritional composition, and physical quality. The major components of a fish feed mill are: raw material intake and storage (silos, bins, or bags for dry ingredients; tanks for liquid ingredients such as fish oil); grinding equipment (hammer mills or roller mills) to reduce particle size to the target fineness; mixing equipment (horizontal or vertical ribbon mixers) to blend dry ingredients uniformly; liquid addition systems for oils and molasses; and the pellet press or extruder where the mixed mash is converted into pellets.

Post-processing equipment includes a dryer to reduce moisture content to below 10 per cent in extruded pellets, a cooler to bring pellets to ambient temperature before packaging (which prevents condensation and mould growth), a screener to remove fines and oversized pellets, a liquid coater or vacuum coater for post-pelleting oil addition, and a bagging and weighing station. Accurate batch management, regular equipment calibration, and strict sanitation of all surfaces in contact with feed ingredients are essential for producing feed of consistent nutritional and physical quality.

Fill in the blank: After extrusion, pellets pass through a ________ to reduce their moisture content below 10 per cent and then a cooler to prevent condensation and mould growth during storage.

Figure 5.1: Flowchart showing the sequence of operations in a fish feed mill from raw material intake to bagged finished feed

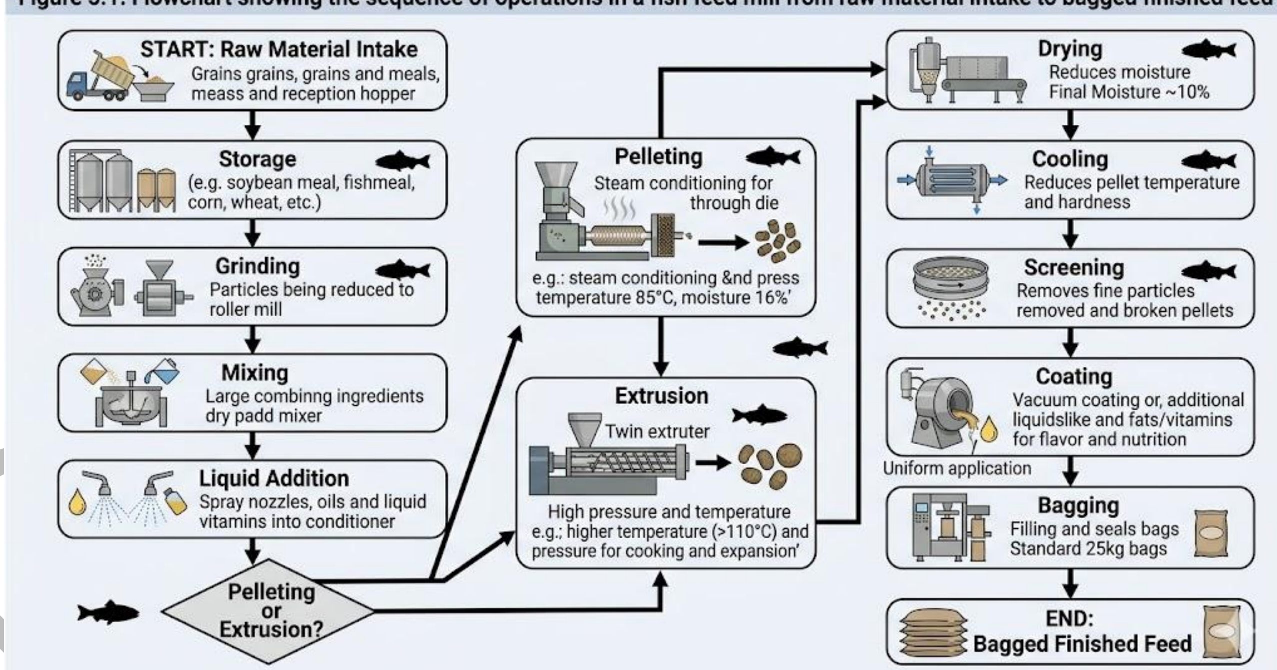

Figure 5.1: Flowchart showing the sequence of operations in a fish feed mill from raw material intake to bagged finished feed

5.1.2 Pelleting machines: types and operating principles

Pelleting is the process of compressing a moist, heated mash of mixed feed ingredients through a die to produce cylindrical pellets of defined diameter and length. The two main types of pellet press used in aquaculture feed production are the **flat-die pellet mill** and the **ring-die pellet mill**. In a flat-die mill, the feed mash is pressed through holes in a horizontal flat die by rotating rollers; in a ring-die mill, the mash is pressed outward through a cylindrical die by rollers inside the ring. Ring-die mills have higher throughput and more uniform pellet quality and are preferred for large-scale production.

Before pelleting, the mixed mash is conditioned with steam in a conditioner unit, which hydrates the starch and softens the material to improve compressibility and pellet durability. Steam conditioning at 75 to 85 degrees Celsius for 20 to 30 seconds partially gelatinises starch, binds particles together, and kills surface pathogens. After pressing through the die, pellets are cut to length by a knife, cooled, and screened. Pellet durability index (PDI) is the standard measure of pellet physical quality, expressed as the percentage of pellets surviving a standardised tumbling test; values above 90 per cent are considered acceptable for aquaculture feeds.

Fill in the blank: The ________ durability index (PDI) measures the percentage of pellets that survive a standardised tumbling test and values above 90 per cent are considered acceptable for aquaculture.

Plate 5.1: Ring-die pellet mill in a commercial fish feed factory showing the die and roller assembly

Plate 5.1: Ring-die pellet mill in a commercial fish feed factory showing the die and roller assembly

5.1.3 Extrusion technology and floating pellet production

Extrusion is a high-temperature, high-pressure, short-time (HTST) process in which a mixed feed mash is forced through a die under conditions that cook the starch, denature proteins, and reduce pathogens simultaneously. In an **extruder**, a rotating screw conveyor pushes the conditioned mash through a barrel under compression; frictional and external heating raises the temperature to 130 to 160 degrees Celsius. As the material exits the die at atmospheric pressure, the superheated moisture flashes to steam, causing the pellet to expand (puff), reducing its density and producing a floating pellet.

Floating pellets have significant advantages over sinking pellets for many aquaculture applications: they allow the farmer to observe feeding activity directly, making it easier to match feed quantity to actual appetite and avoid overfeeding; they have superior water stability (30 minutes or more compared with 5 to 15 minutes for compressed sinking pellets); and the cooking during extrusion improves starch digestibility and destroys anti-nutritional factors such as trypsin inhibitors. The main limitation of extrusion is its higher energy cost and capital investment compared with compression pelleting. In Nigeria, demand for extruded floating pellets has grown rapidly with the expansion of intensive catfish and tilapia farming.

Fill in the blank: During extrusion, superheated moisture in the pellet ________ to steam upon exit from the die, causing the pellet to expand and float.

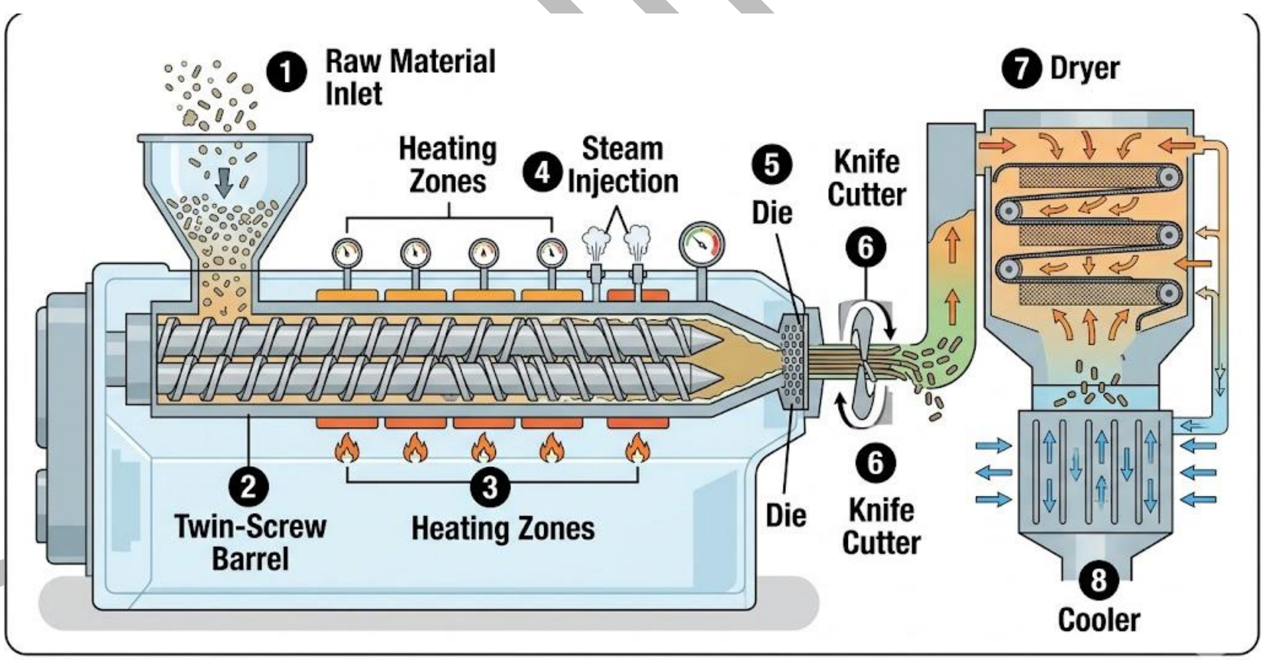

Figure 5.2: Diagram showing the components and process flow of a twin-screw fish feed extruder

Figure 5.2: Diagram showing the components and process flow of a twin-screw fish feed extruder

Pilot questions 5.1

Name four major components of a fish feed mill and state the function of each.

Distinguish between a flat-die and a ring-die pellet mill.

Explain the purpose of steam conditioning before pelleting.

Describe how floating pellets are produced in an extruder.

State two advantages of extruded floating pellets over sinking compressed pellets.

5.2 Feed Quality Control and Storage

5.2.1 Physical and chemical quality parameters of fish feed

Physical quality parameters of fish feed include pellet size (diameter and length, which must match the mouth gape of the target fish), pellet hardness (resistance to compression, important for sinking pellets that must not crumble during handling), pellet durability index (PDI, resistance to mechanical abrasion during transport), and water stability (time before the pellet disintegrates in water, target above 20 to 30 minutes for most aquaculture applications). For floating pellets, bulk density and sink rate are also measured.

Chemical quality parameters include crude protein (CP), crude lipid (ether extract), crude fibre, moisture content, ash, and nitrogen-free extract (NFE), collectively known as the proximate composition. These are measured by the standard Weende proximate analysis system. Additional chemical parameters include amino acid profile (determined by HPLC or ion exchange chromatography), digestible energy content (bomb calorimetry), peroxide value and acid value of lipids (to assess rancidity), and aflatoxin content (important when groundnut or maize is used). Comparing the analysed composition against the formulated targets allows quality control to verify that the manufactured feed meets its specification.

Fill in the blank: The standard ________ proximate analysis system measures crude protein, crude lipid, crude fibre, moisture, ash, and nitrogen-free extract in fish feeds.

Parameter	Category	Measurement Method
Pellet size	Physical	Sieve analysis; calipers or micrometer measurement.
Pellet Durability Index (PDI)	Physical	Standard tumbling test (e.g., Holmen durability tester).

Parameter	Category	Measurement Method
Water stability	Physical	Immersion test in water; measure disintegration time and nutrient leaching.
Hardness	Physical	Compression test using texture analyzer or penetrometer.
Crude protein	Chemical	Kjeldahl method or Dumas combustion method.
Crude lipid	Chemical	Soxhlet extraction or solvent extraction methods.
Moisture	Chemical	Oven drying at 105°C until constant weight.
Ash	Chemical	Combustion in muffle furnace at 550–600°C.
Aflatoxin	Chemical	ELISA test kits; High-Performance Liquid Chromatography (HPLC) for precise quantification.

Table 5.1: Key physical and chemical quality parameters of fish pellets and their measurement methods

5.2.2 Quality control procedures during manufacture

Quality control (QC) during feed manufacture involves systematic checks at each stage of the production process to detect and correct deviations before they result in a substandard batch reaching the customer. At the raw material intake stage, each delivery is sampled and checked for moisture content, crude protein (using a rapid NIR analyser), contamination with moulds or mycotoxins, and identity (species authenticity for fishmeal). Rejected materials are returned to the supplier; accepted materials are stored in designated bins.

During mixing, the mixing uniformity (coefficient of variation of a tracer compound between samples) is periodically checked to verify that ingredients are blended homogeneously throughout the batch. At the pelleting or extrusion stage, pellet size, PDI, and water stability are measured on samples from each production run. For finished feed lots, a representative composite sample is retained and analysed for proximate composition, amino acid profile, and mycotoxin content. Non-conforming batches are quarantined and either reworked (if the defect is correctable) or condemned. QC records form part of the traceability system required by modern food safety standards.

Fill in the blank: Mixing ________ is measured by the coefficient of variation of a tracer compound between samples taken from different positions in the mixer, and must be below 10 per cent for acceptable uniformity.

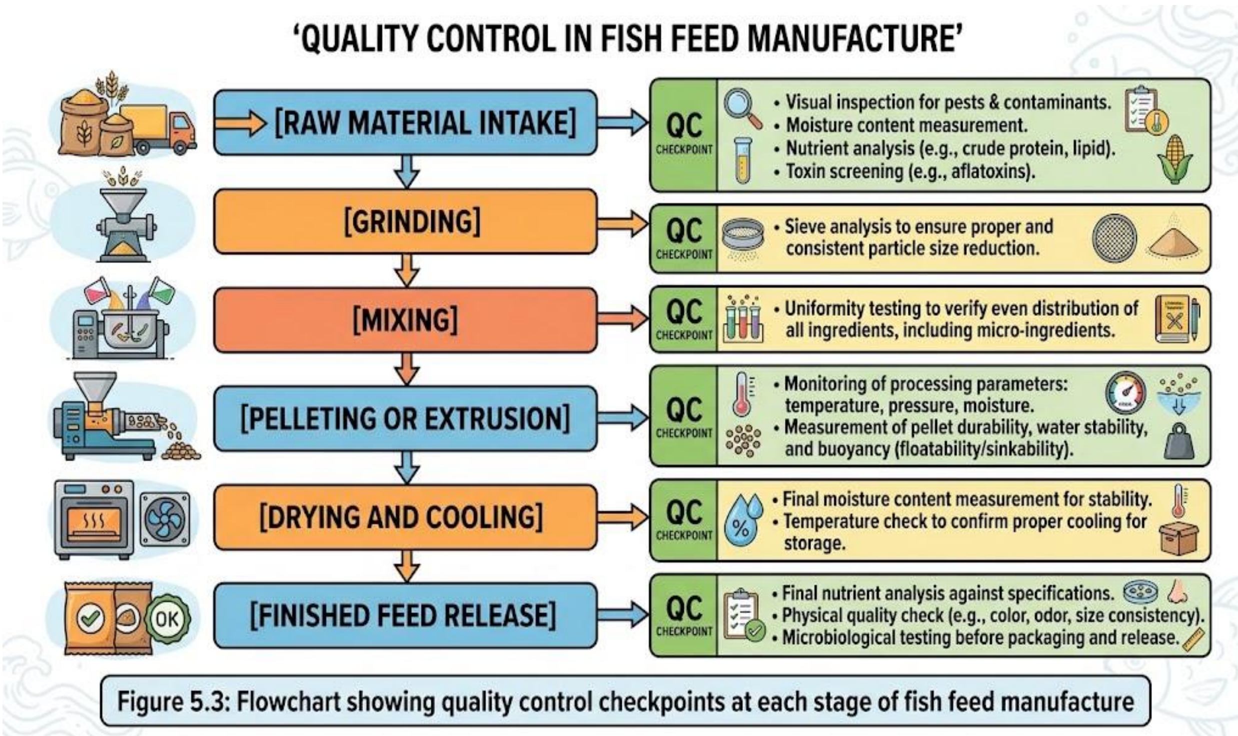

Figure 5.3: Flowchart showing quality control checkpoints at each stage of fish feed manufacture

5.2.3 Feed storage, shelf life, and spoilage prevention

Feed storage conditions are critical determinants of feed shelf life and nutritional value at the point of use. The primary spoilage mechanisms in stored fish feed are lipid oxidation (rancidity), mould growth and mycotoxin production, and insect or rodent infestation. Lipid oxidation occurs when unsaturated fatty acids react with atmospheric oxygen, producing peroxides and free radicals that reduce the energy value of the diet, destroy fat-soluble vitamins, and produce palatability-reducing rancid odours and flavours.

Feed should be stored in a cool (below 25 degrees Celsius), dry (below 65 per cent relative humidity), well-ventilated warehouse, away from direct sunlight, off the floor on pallets, and away from walls and ceilings to allow air circulation and pest inspection. Antioxidants such as ethoxyquin, butylated hydroxytoluene (BHT), or vitamin E are incorporated into feeds at manufacture to retard lipid oxidation. The recommended maximum storage time for complete pelleted fish feeds is three to four months at ambient tropical conditions; extruded feeds with higher lipid content (coated with fish oil post-pellet) are more susceptible to rancidity and should be used within six to eight weeks of manufacture.

Fill in the blank: Lipid ________ in stored fish feed is caused by the reaction of unsaturated fatty acids with atmospheric oxygen and destroys fat-soluble vitamins while producing rancid odours.

Practice	Description / Purpose
Temperature control	Store feed in cool, dry conditions (ideally below 25°C) to prevent nutrient degradation.
Humidity management	Keep relative humidity below 60% to avoid mold growth and aflatoxin contamination.
Ventilation	Ensure proper airflow in storage areas to reduce moisture buildup and maintain freshness.
Pest exclusion	Use sealed containers and rodent-proof storage to prevent contamination and feed loss.
Antioxidant inclusion	Add antioxidants (e.g., vitamin E, ethoxyquin) to reduce lipid oxidation and rancidity.
Maximum storage time	Use feed within 3–6 months of production; shorter if conditions are suboptimal.

Box 5.1: Best practices for fish feed storage to maximise shelf life and nutritional quality

Pilot questions 5.2

Name four physical quality parameters of fish feed pellets.

What is proximate analysis and what components does it measure?

Explain the purpose of quality control at the raw material intake stage of feed manufacturing.

Describe two main spoilage mechanisms in stored fish feed.

State three best practices for storing fish feed to maximise shelf life.

5.3 Development of Fish Products

5.3.1 Traditional fish processing methods

Traditional fish processing encompasses methods that have been practised for centuries to preserve fish and extend its shelf life beyond the short window between harvest and spoilage. **Sun drying** is the simplest and most widely practised method in Nigeria, involving spreading cleaned fish on raised racks or mats in direct sunlight to reduce moisture content to below 15 per cent. **Smoking** combines drying with the deposition of antimicrobial compounds from wood smoke; it is the dominant preservation method for high-value fish such as catfish (Clarias gariepinus) and bonga (Ethmalosa fimbriata) in southern Nigeria, producing a product with moisture below 10 per cent and shelf life of several weeks.

Salting involves treating fish with dry salt or immersion in brine to draw out moisture by osmosis and create an environment hostile to bacterial growth. Fermentation produces strongly flavoured fish condiments such as iru and dawadawa through microbial breakdown of proteins; fermented fish products are important flavour ingredients in Nigerian cuisine. Traditional smoking and drying are associated with significant post-harvest losses due to insect infestation, mould, and rehydration during storage in humid conditions. Improvements in smoking kiln design, such as the FAO-Thiaroye processing technique (FTT-Thiaroye), have substantially improved fuel efficiency, product quality, and the occupational health of processors.

Fill in the blank: Traditional ________ combines drying with antimicrobial compounds from wood smoke and is the dominant preservation method for catfish and bonga in southern Nigeria.

Plate 5.2: Traditional fish smoking kiln in Nigeria showing catfish being smoked over wood fuel

5.3.2 Modern fish product development and value addition

Modern fish product development encompasses a range of processing technologies and product forms that add value to fish beyond simple preservation. **Chilled and frozen fish** require reliable cold chain infrastructure but offer superior product quality and access to urban and export markets. **Fish fillets** (skinned, boneless portions) command premium prices in urban supermarkets and hotels. **Fish meal and fish oil** produced from processing waste or low-value whole fish are high-value industrial ingredients sold to poultry, pig, and aquaculture feed manufacturers.

Other value-added products include fish sausages, fish cakes, fish burgers, and fish-based snacks, which increase shelf life, convenience, and market appeal, particularly to urban consumers with changing dietary preferences. In Nigeria, the development of branded packaged smoked catfish (Clarias), packaged dried tilapia, and ready-to-cook frozen catfish portions represents a growing segment of the domestic fish product market. Fish by-products including fish skin (for gelatine and collagen), fish bones (for calcium supplements), and fish viscera (for fish silage or biogas) present additional opportunities for zero-waste processing that improve the overall economics of the value chain.

Fill in the blank: Fish ________ and fish oil produced from processing waste are high-value industrial ingredients sold to poultry, pig, and aquaculture feed manufacturers.

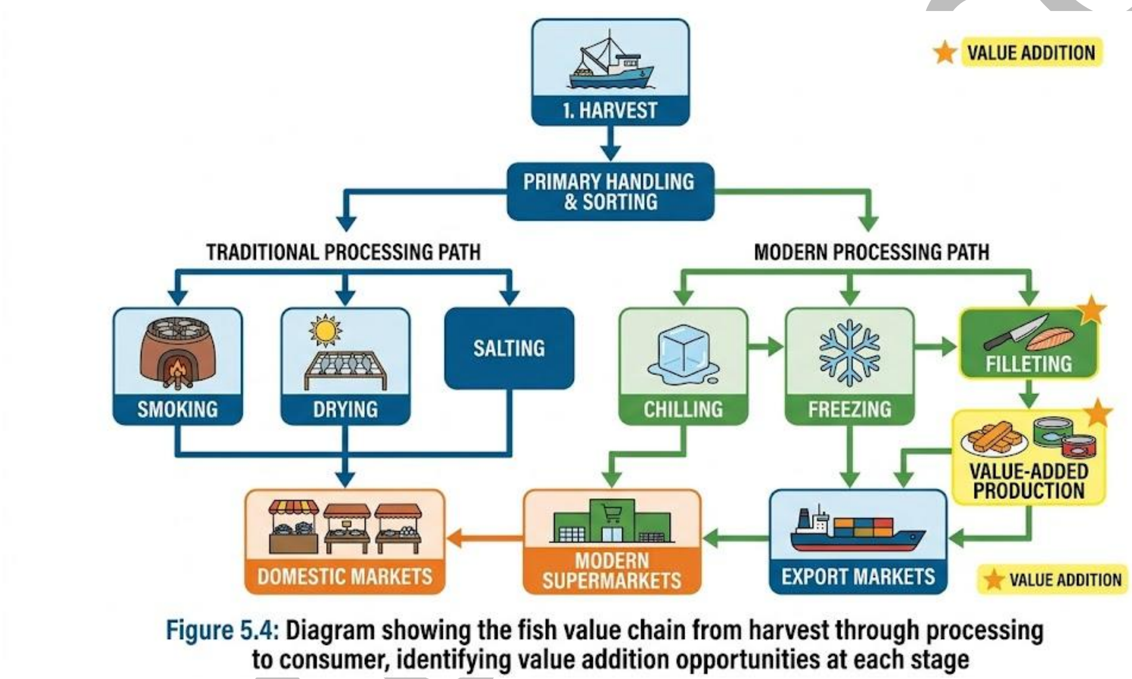

Figure 5.4: Diagram showing the fish value chain from harvest through processing to consumer, identifying value addition opportunities at each stage

Figure 5.4: Diagram showing the fish value chain from harvest through processing to consumer, identifying value addition opportunities at each stage

5.3.3 Economic value of fish products and market implications

Fish products are among the most economically important agricultural commodities in Nigeria. **Nigeria** is one of the largest fish-consuming nations in Africa, with per capita fish consumption among the highest on the continent. Domestic aquaculture production, dominated by catfish and tilapia, has grown substantially over the past two decades but still falls far short of demand, making Nigeria a net importer of fish. The annual fish import bill exceeds USD 1 billion, representing a major drain on foreign exchange that domestic aquaculture expansion is intended to reduce.

The economic value added through processing varies substantially by product type. A kilogram of live catfish sold at the farm gate commands the lowest price; the same kilogram processed into smoked catfish adds 50 to 100 per cent in value; packaged, branded smoked catfish targeted at urban supermarkets may command prices three to four times the farm-gate live weight price. Developing reliable cold chain infrastructure, modern processing facilities, and strong product branding are therefore national priorities for improving the economic returns from Nigerian aquaculture and fisheries. Access to urban and export markets also requires compliance with food safety and quality standards that are increasingly demanded by retailers and regulatory authorities.

Fill in the blank: Nigeria is a net ________ of fish, with annual imports exceeding USD 1 billion, creating a strong economic incentive for expanding domestic aquaculture production.

Figure 5.5: Bar chart showing the price of catfish at different points in the value chain from live farm-gate to branded packaged smoked product

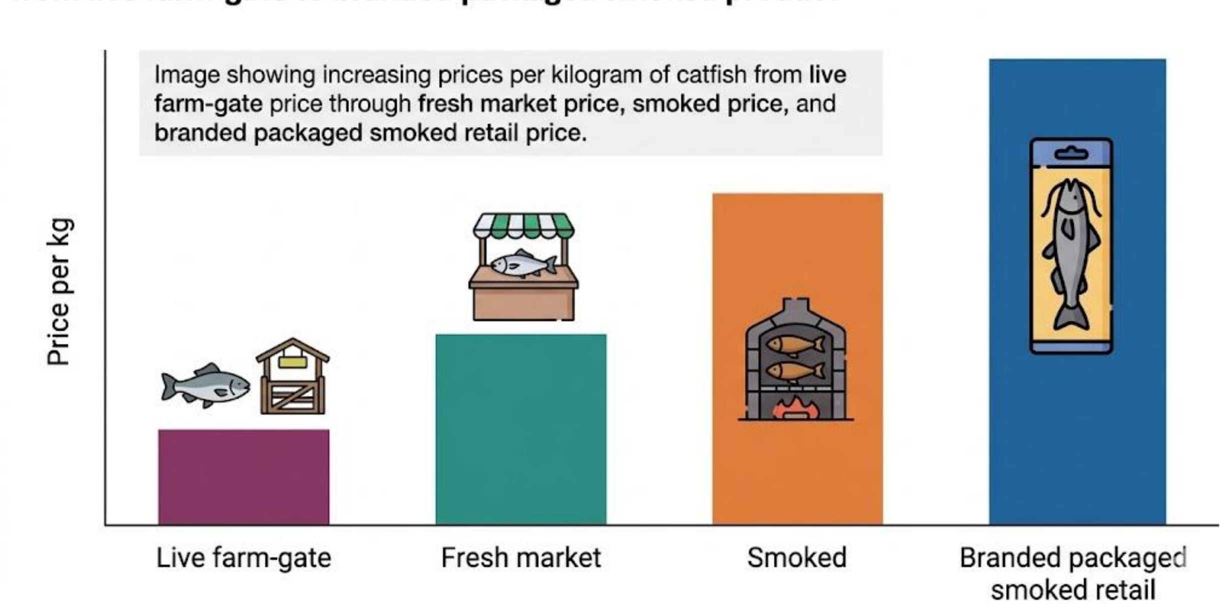

Figure 5.5: Bar chart showing the price of catfish at different points in the value chain from live farm-gate to branded packaged smoked product

Pilot questions 5.3

Name four traditional fish processing methods used in Nigeria.

Explain the principle of fish smoking and state the target moisture content of smoked fish.

Name three modern value-added fish products and explain the benefit of each.

Explain what fish meal and fish oil are and where they are used in the agricultural sector.

Explain why developing processing and cold chain infrastructure is an economic priority for Nigerian fisheries.

5.4 Food Safety, Standards, and Sustainability

5.4.1 Food safety and hygiene in fish processing

Fish is one of the most perishable of all food commodities and one of the most significant vehicles of foodborne illness. **Fish spoilage** begins immediately after death through autolytic enzyme activity and bacterial proliferation; at tropical ambient temperatures, ungutted fish becomes organoleptically unacceptable within 6 to 12 hours. Spoilage bacteria (primarily Pseudomonas, Acinetobacter, and Moraxella spp.) and foodborne pathogens (Salmonella, Listeria, Staphylococcus aureus, Vibrio parahaemolyticus, and Clostridium botulinum in smoked fish) present serious public health risks if fish is mishandled.

Hygiene in fish processing requires the application of Hazard Analysis and Critical Control Points (HACCP) principles, which identify the specific stages in the processing chain where hazards are most likely to occur and establish controls to prevent, eliminate, or reduce them to acceptable levels. Key hygiene practices include handling fish on clean, non-porous surfaces; maintaining the cold chain from catch to consumer; separating raw and processed product; ensuring personal hygiene of workers; and regular sanitation of all processing surfaces and equipment. In Nigeria, improving hygiene standards in artisanal fish processing is a major food safety challenge, particularly in smoked fish produced in rural areas where refrigeration and clean water are unavailable.

Fill in the blank: Hazard Analysis and Critical Control Points (HACCP) is a food safety management system that identifies the stages in processing where ________ are most likely to occur and establishes controls to prevent them.

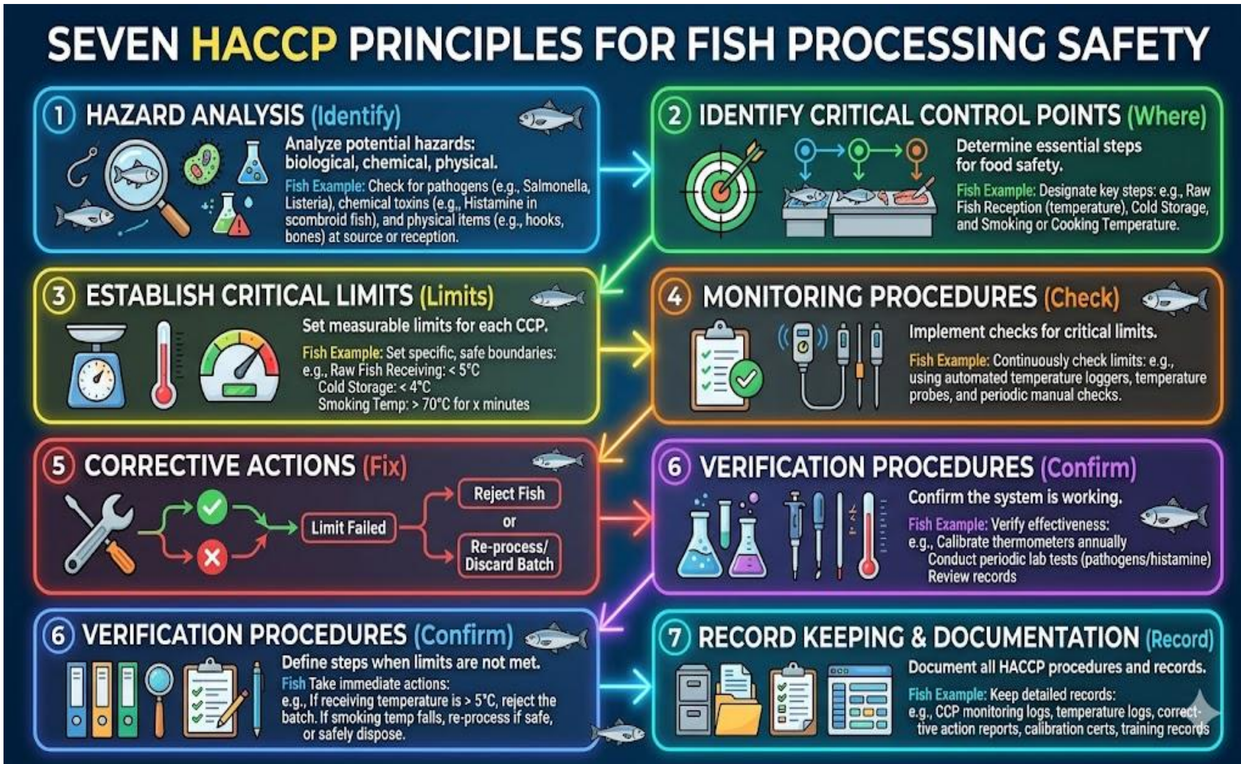

Figure 5.6: Diagram illustrating the seven principles of HACCP applied to a fish processing operation

5.4.2 Quality standards and regulatory frameworks

Quality standards for fish and fish products are established at international, regional, and national levels. At the international level, the **Codex Alimentarius Commission** (jointly administered by FAO and WHO) develops food standards, guidelines, and codes of practice for fish and fishery products that serve as the reference for international trade under the WTO Sanitary and Phytosanitary (SPS) Agreement. Codex standards cover maximum residue limits for veterinary drugs, maximum levels for environmental contaminants, and hygiene requirements for fish processing.

In Nigeria, the regulatory framework for fish and aquaculture products involves multiple agencies. The National Agency for Food and Drug Administration and Control (NAFDAC) sets and enforces standards for packaged fish products sold in the domestic market and regulates food additives and contaminants. The Standard Organisation of Nigeria (SON) maintains Nigerian Industrial Standards (NIS) for fish products including dried fish, smoked fish, and canned fish. The Nigerian Agricultural Quarantine Service (NAQS) manages the certification of fish and fish products for export, ensuring compliance with the importing country's standards. Compliance with these standards is a prerequisite for accessing premium markets at home and abroad.

Fill in the blank: The ________ Agency for Food and Drug Administration and Control (NAFDAC) sets and enforces standards for packaged fish products sold in the Nigerian domestic market.

Regulatory Body	Scope / Standards Applied
Codex Alimentarius (FAO/WHO)	International food standards, guidelines, and codes of practice for safety and quality of fish and fish products in global trade.
NAFDAC (National Agency for Food and Drug Administration and Control, Nigeria)	Regulates fish feed, fish products, and aquaculture inputs for safety, labeling, and compliance with Nigerian food laws.
SON (Standards Organisation of Nigeria)	Develops and enforces national standards for fish products, packaging, and quality assurance in domestic and export markets.
NAQS (Nigeria Agricultural Quarantine Service)	Oversees inspection and certification of fish and aquaculture products for export, ensuring compliance with international sanitary and phytosanitary measures.

Box 5.2: Key regulatory bodies and standards frameworks governing fish products in Nigeria and internationally

5.4.3 Sustainability considerations in fish food technology

Sustainability in fish food technology requires addressing the environmental footprint of feed manufacturing, fish processing, and product distribution. Feed production is the largest contributor to the environmental impact of aquaculture: the sourcing of fishmeal and fish oil from wild-capture fisheries creates a dependency link between aquaculture sustainability and the management of industrial pelagic fisheries. Replacing fishmeal with sustainable alternatives (insect meal, single-cell protein, algal meal, duckweed) reduces this dependency and is an active area of research and commercial development.

In fish processing, energy consumption (particularly for smoking, chilling, and freezing), water use, and the disposal of processing waste (blood water, offal, and scales) represent major environmental concerns. Improved kiln designs such as the FTT-Thiaroye reduce fuelwood consumption by 30 to 50 per cent and reduce emissions of polycyclic aromatic hydrocarbons (PAHs), which are carcinogenic compounds produced by traditional smoking at high temperatures. Zero-waste processing approaches that convert fish by-products into fishmeal, fish oil, gelatine, and fertiliser improve resource efficiency and reduce the environmental burden of fish processing. In Nigeria, the sustainability of both aquaculture feed supply chains and fish processing will be essential to the long-term growth and viability of the sector.

Fill in the blank: The FTT-Thiaroye improved kiln design reduces fuelwood consumption by 30 to 50 per cent and reduces emissions of ________ aromatic hydrocarbons, which are carcinogenic compounds produced during high-temperature smoking.

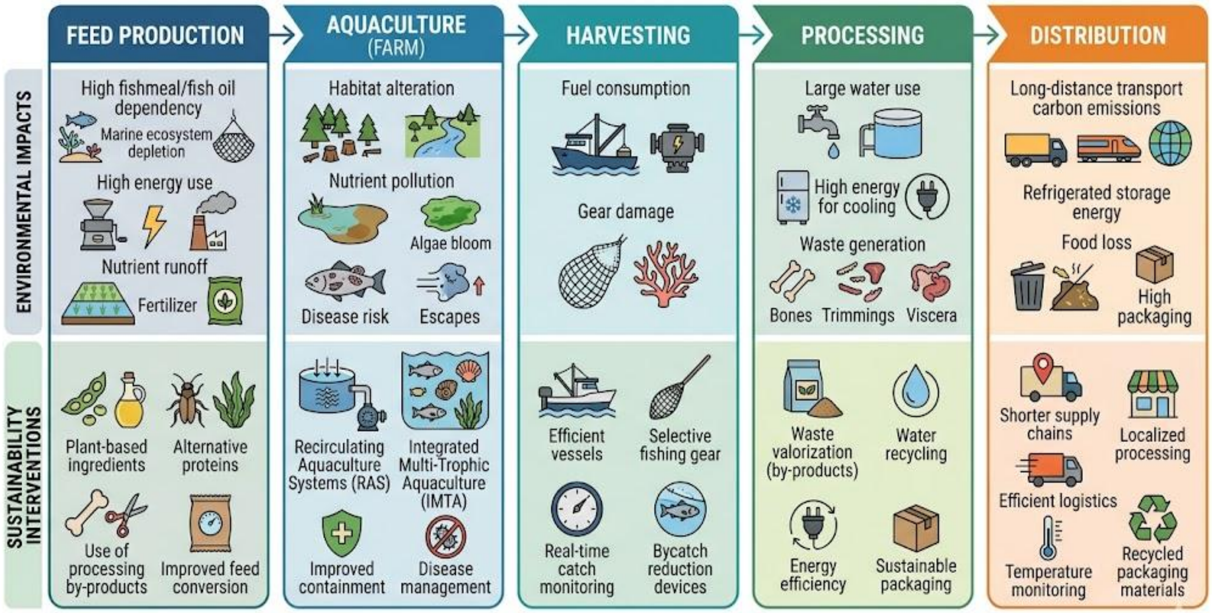

Figure 5.7: Diagram showing the environmental impacts and sustainability interventions along the fish food technology chain from feed production to fish processing and distribution

Figure 5.7: Diagram showing the environmental impacts and sustainability interventions along the fish food technology chain from feed production to fish processing and distribution

Pilot questions 5.4

Name three foodborne pathogens associated with fish and fish products.

Explain the HACCP approach to food safety in fish processing.

State the roles of NAFDAC and SON in regulating fish products in Nigeria.

Explain why the use of fishmeal in aquaculture feeds raises sustainability concerns.

Describe two sustainability improvements in fish processing technology.

Series Summary

This final Series has completed the course by examining the technology and economics of fish feed manufacture and fish product development. We began with feed manufacturing technology, describing the components and operations of a fish feed mill, the types and operating principles of pelleting machines, and the extrusion process that produces floating pellets with superior water stability, digestibility, and anti-nutritional factor destruction. We then studied feed quality control and storage, covering the physical and chemical parameters used to assess pellet quality, QC procedures at each stage of manufacture, and the best practices for feed storage to prevent rancidity, mould, and mycotoxin contamination.

Following that, we examined fish product development from traditional methods including smoking, drying, salting, and fermentation, through to modern value-added products including chilled, frozen, and packaged fillets, with an analysis of the economic value added through processing and the market implications for Nigerian fisheries. Finally, we addressed food safety and hygiene through the HACCP framework, the regulatory standards governing fish products in Nigeria and internationally (Codex Alimentarius, NAFDAC, SON, NAQS), and the sustainability challenges relating to fishmeal dependency in feed production, energy use in processing, and opportunities for zero-waste processing. By completing this Series, you should now be able to achieve all nine Series Learning Outcomes (SLO 5.1 to SLO 5.9), and the course as a whole will have equipped you with the full range of knowledge needed for professional practice in fish fry production, hatchery management, fish production and management, and fish food nutrition and technology.

Glossary of Terms

Antioxidant: a compound such as ethoxyquin, BHT, or vitamin E added to fish feeds to retard lipid oxidation (rancidity) during manufacture and storage.

Codex Alimentarius Commission: an international food standards body jointly administered by FAO and WHO that develops standards, guidelines, and codes of practice for fish and food products used as references in international trade.

Cold chain: a temperature-controlled supply chain infrastructure that maintains fish and fish products at optimal refrigerated or frozen temperatures from harvest to consumer.

Extrusion: a high-temperature, high-pressure, short-time (HTST) process that cooks, expands, and shapes feed ingredients into floating pellets with improved water stability, starch digestibility, and pathogen reduction.

FTT-Thiaroye: the FAO-Thiaroye processing technique; an improved fish smoking kiln design that reduces fuelwood consumption by 30 to 50 per cent and reduces PAH emissions compared with traditional kilns.

HACCP: Hazard Analysis and Critical Control Points; a systematic food safety management approach that identifies hazards at each stage of processing and establishes controls to prevent, eliminate, or reduce them to acceptable levels.

Hammer mill: a grinding machine that reduces feed ingredient particle size by impact of rotating hammers; used in feed mills to prepare ingredients for mixing and pelleting.

Lipid oxidation (rancidity): the reaction of unsaturated fatty acids in feed or fish products with atmospheric oxygen, producing peroxides, aldehydes, and ketones that reduce energy value, destroy vitamins, and create off-flavours.

NAFDAC: the National Agency for Food and Drug Administration and Control; the Nigerian regulatory authority for food safety, setting and enforcing standards for packaged fish products in the domestic market.

NAQS: the Nigerian Agricultural Quarantine Service; responsible for disease surveillance, live fish import and export regulation, and export certification of Nigerian fish and fish products.

Pellet durability index (PDI): a measure of the physical strength of a pellet, expressed as the percentage surviving a standardised tumbling test; values above 90 per cent are considered acceptable for aquaculture feeds.

Pelleting: the compression of a conditioned feed mash through a die using a flat-die or ring-die pellet mill to produce cylindrical pellets of defined diameter and length.

Polycyclic aromatic hydrocarbons (PAHs): carcinogenic organic compounds produced by incomplete combustion of wood during high-temperature fish smoking; reduced by improved kiln designs such as FTT-Thiaroye.

Proximate analysis: the standard Weende system for measuring the approximate nutritional composition of a feed or feedstuff: crude protein, crude lipid, crude fibre, moisture, ash, and nitrogen-free extract.

Ring-die pellet mill: a pelleting machine in which rollers inside a rotating cylindrical die press the conditioned mash outward through the die holes; preferred for high-throughput commercial feed production.

SON: the Standards Organisation of Nigeria; the national standards body that maintains Nigerian Industrial Standards (NIS) for fish and agricultural products.

Steam conditioning: the addition of steam to a feed mash in a conditioner before pelleting, hydrating starch for compressibility, softening the material, partially gelatinising starch, and destroying surface pathogens.

Value addition: the process of increasing the economic value of a raw material through processing, transformation, packaging, or branding; in fisheries, value is added at each stage from live fish to processed, packaged, and branded products.

Water stability: the resistance of a feed pellet to physical disintegration and nutrient leaching when submerged in water; a key quality parameter distinguishing extruded floating pellets (30+ minutes) from compressed sinking pellets (5 to 15 minutes).

Zero-waste processing: an approach to fish processing that utilises all fractions of the fish, including offal, bones, skin, and blood water, as inputs for fishmeal, oil, gelatine, collagen, fertiliser, or biogas production.

Concept Check Questions [Series 5]

Objective Questions

Name the processing equipment used after extrusion to reduce pellet moisture content below 10 per cent. (Linked to SLO 5.1)

The percentage of pellets surviving a standardised tumbling test is called the pellet ________ index (PDI). (Linked to SLO 5.2)

The standard system for measuring crude protein, crude lipid, crude fibre, moisture, ash, and NFE in feed is called ________ analysis. (Linked to SLO 5.4)

The dominant traditional fish preservation method for catfish and bonga in southern Nigeria is ________. (Linked to SLO 5.6)

The Nigerian regulatory authority that sets and enforces standards for packaged fish products is ________. (Linked to SLO 5.8)

Short-Answer Questions

Explain how the extrusion process produces floating pellets and state two advantages over compressed sinking pellets. (Linked to SLO 5.3)

Describe two spoilage mechanisms in stored fish feed and state one preventive measure for each. (Linked to SLO 5.5)

Explain how value is added to catfish at different stages of the processing chain. (Linked to SLO 5.7)

Explain the HACCP approach to food safety and state why it is important in fish processing. (Linked to SLO 5.8)

Explain why fishmeal dependency in aquaculture feeds is a sustainability concern and name two alternative protein sources. (Linked to SLO 5.9)

Long-Answer Questions

Analyse the fish feed manufacturing process, explaining the components and operations of a feed mill, the pelleting and extrusion technologies used, and the quality control procedures that ensure consistent feed quality. (Linked to SLOs 5.1, 5.2, 5.3, 5.4)

Discuss the development of fish products in Nigeria, comparing traditional processing methods with modern value-added approaches, explaining the economic significance of fish products, and identifying the opportunities for expanding value addition in the Nigerian fish value chain. (Linked to SLOs 5.6, 5.7)

Evaluate the food safety, quality standards, and sustainability challenges facing fish food technology in Nigeria, explaining the HACCP framework, the roles of NAFDAC, SON, NAQS, and the Codex Alimentarius, and the sustainability interventions needed to reduce the environmental footprint of feed production and fish processing. (Linked to SLOs 5.8, 5.9)

Answers to Concept Check Questions [Series 5]

Objective Questions

Dryer.

Durability.

Proximate.

Smoking.

NAFDAC (National Agency for Food and Drug Administration and Control).

Short-Answer Questions

In the extruder, the mash is heated under pressure to 130 to 160 degrees Celsius; as it exits the die at atmospheric pressure, the superheated moisture flashes to steam, causing the pellet to expand and lower its density to below that of water, making it float. Advantages: (1) superior water stability (30+ minutes versus 5 to 15 minutes for sinking pellets), reducing nutrient leaching; (2) visible feeding activity allowing the farmer to adjust feed quantity to actual appetite and avoid overfeeding.

Lipid oxidation: unsaturated fatty acids react with oxygen producing rancid off-flavours and destroying vitamins; prevented by incorporating antioxidants (ethoxyquin, BHT, vitamin E) at manufacture. Mould growth and mycotoxin production: occurs in humid storage conditions on poorly dried feed; prevented by ensuring pellet moisture content below 10 per cent before bagging and storing in cool, dry, well-ventilated conditions.

At farm-gate as live fish the price is lowest; processed into smoked catfish, value increases by 50 to 100 per cent; branded, packaged smoked catfish sold in urban supermarkets commands a price three to four times the farm-gate live weight price; further value is added through filleting, freezing, or incorporation into ready-to-cook products with convenience and market differentiation benefits.

HACCP identifies the specific stages in a processing chain where biological, chemical, or physical hazards are most likely to occur, establishes critical control points (CCPs) at those stages, sets critical limits for control parameters, and specifies monitoring and corrective action procedures; it is important in fish processing because fish is highly perishable and a vehicle for serious foodborne pathogens, and HACCP provides a systematic preventive approach rather than relying solely on end-product testing.

Fishmeal is produced from wild-capture industrial pelagic fisheries that are under pressure globally; using large quantities of wild fish to feed farmed fish undermines the net food production benefit of aquaculture and links its sustainability to the management of those fisheries. Two alternative protein sources: insect meal (e.g. black soldier fly larvae meal, Hermetia illucens) and single-cell protein (yeast or bacterial biomass grown on agricultural waste).

Long-Answer Questions

Basic response: A feed mill processes raw ingredients through grinding, mixing, pelleting or extrusion, drying, cooling, screening, and bagging. Pelleting uses flat-die or ring-die presses with steam conditioning to produce sinking pellets; PDI target above 90 per cent. Extrusion uses HTST processing producing floating pellets with superior stability. QC covers raw material intake, mixing uniformity, pellet size, PDI, water stability, and proximate analysis of finished batches.

Value-added response: The choice between pelleting and extrusion involves a trade-off between capital cost (extrusion is more expensive) and product benefits (floating pellets allow appetite monitoring, have better stability, and improve feed efficiency). For Nigerian small-scale farms where overfeeding is a major problem, the FCR improvement from switching to floating pellets often justifies the higher feed cost. Investing in on-farm or small-scale community feed mills using locally sourced ingredients can substantially reduce the feed cost per kg of fish produced compared with imported commercial feeds.

Basic response: Traditional methods include smoking, drying, salting, and fermentation; smoking is dominant in southern Nigeria for catfish and bonga. Modern products include chilled and frozen fish, fillets, sausages, fish cakes, and packaged smoked fish. Value addition increases price from farm-gate live weight to 3 to 4 times at branded retail level. Nigeria is a net fish importer with imports exceeding USD 1 billion annually, making domestic processing development a national priority.

Value-added response: The gap between farm-gate and retail price represents economic value currently captured largely by intermediaries rather than producers. Supporting fish farmer organisations to engage in primary processing (smoking, chilling, packaging) would transfer more value to the production stage, improving farm profitability and incentivising production expansion. Cold chain infrastructure investment is the single most important enabling condition for expanding modern fish product markets in Nigeria.

Basic response: HACCP identifies hazards at each processing stage and establishes CCPs with critical limits, monitoring, and corrective actions. NAFDAC enforces domestic food safety standards; SON maintains product standards (NIS); NAQS certifies exports; Codex Alimentarius sets international trade reference standards. Fishmeal dependency links aquaculture to wild fisheries; alternatives include insect meal, algal meal, single-cell protein. FTT-Thiaroye kiln reduces fuelwood use by 30 to 50 per cent and cuts PAH emissions.

Value-added response: The effective implementation of HACCP in artisanal processing contexts in Nigeria requires simplification and adaptation because the full HACCP system was designed for industrial settings with controlled inputs and infrastructure. Simplified approaches based on Good Manufacturing Practice (GMP) and Good Hygiene Practice (GHP) codes may be more immediately achievable for small-scale processors, with progressive upgrading to full HACCP as infrastructure improves. The sustainability of Nigerian aquaculture and fisheries in the long term will require integrating environmental performance alongside food safety and economic viability as equally weighted objectives in industry standards and regulatory frameworks.

Answers to Pilot Questions [Series 5]

Part 5.1: Feed Manufacturing Technology

Any four with functions: raw material intake and storage (receives and holds ingredients before processing); hammer mill (reduces ingredient particle size for thorough mixing); ribbon mixer (blends dry and liquid ingredients uniformly throughout the batch); pellet press or extruder (converts the mixed mash into pellets of defined size); dryer (reduces moisture in extruded pellets); cooler (brings pellets to ambient temperature before bagging).

A flat-die mill presses feed mash through holes in a horizontal flat die with rotating rollers above the die surface; a ring-die mill presses mash outward through holes in a rotating cylindrical die with rollers inside the ring; ring-die mills have higher throughput, more uniform pellet quality, and are preferred for large-scale production.

Steam conditioning adds moisture and heat (75 to 85 degrees Celsius for 20 to 30 seconds) to the mixed mash before it enters the pellet press; this softens the material, hydrates starch for better compressibility, partially gelatinises starch to improve pellet durability, and kills surface pathogens.

In the extruder, a rotating screw pushes the conditioned mash through a heated barrel under high pressure; frictional and applied heat raises the temperature to 130 to 160 degrees Celsius; as the cooked mash exits the die at atmospheric pressure, the superheated moisture flashes to steam, causing the pellet to expand and reducing its density below that of water, producing a floating pellet.

Any two: superior water stability (30+ minutes versus 5 to 15 minutes for compressed pellets); visible floating pellets allow the farmer to monitor feeding activity and adjust ration to appetite; improved starch digestibility from cooking during extrusion; destruction of anti-nutritional factors such as trypsin inhibitors.

Part 5.2: Feed Quality Control and Storage

Any four: pellet size (diameter and length); pellet hardness; pellet durability index (PDI); water stability; bulk density (for floating pellets).

Proximate analysis is the standard Weende system for measuring the approximate nutritional composition of a feed ingredient or complete diet; it measures crude protein (total N x 6.25), crude lipid (ether extract), crude fibre (acid and alkali digestion residue), moisture (drying to constant weight), ash (incineration), and nitrogen-free extract (calculated by difference).

Raw material intake QC prevents substandard or contaminated ingredients from entering the production batch; poor-quality raw materials cannot be corrected during manufacture and will produce a substandard finished feed; checking moisture, crude protein, mycotoxin contamination, and ingredient identity at intake allows rejection of non-conforming deliveries before they incur processing costs.

Any two: lipid oxidation (rancidity): unsaturated fatty acids react with oxygen to produce peroxides and aldehydes, reducing energy value and destroying vitamins; mould growth and mycotoxin production: moulds colonise inadequately dried or humid feed, producing toxins (aflatoxins) that are immunosuppressive and hepatotoxic; insect or rodent infestation: physical contamination and feed consumption, destroying nutritional integrity.

Any three: store below 25 degrees Celsius; maintain relative humidity below 65 per cent; ensure good ventilation; store on pallets off the floor and away from walls; use feed within the recommended shelf life (three to four months for standard pellets; six to eight weeks for high-lipid extruded feeds); include antioxidants at manufacture.

Part 5.3: Development of Fish Products

Sun drying; smoking; salting; fermentation.

Fish smoking combines moisture removal with the deposition of antimicrobial phenolic compounds, organic acids, and formaldehyde from wood smoke onto the fish surface, inhibiting bacterial and mould growth; the target moisture content of smoked fish is below 10 per cent, which prevents microbial spoilage and extends shelf life to several weeks at ambient temperature.

Any three: chilled and frozen fish (extends shelf life, provides access to urban and export markets, maintains fresh product quality); fish fillets (skinless, boneless portions command premium prices in supermarkets and hotels); fish sausages or fish cakes (convenient, longer shelf life, appeal to urban consumers); branded packaged smoked fish (consistent quality, market differentiation, higher retail price).

Fish meal is a high-protein (60 to 72 per cent CP) ingredient produced from whole fish or processing waste by cooking, pressing, drying, and grinding; fish oil is the lipid-rich fraction recovered from the pressing step; both are sold to poultry, pig, and aquaculture feed manufacturers as high-quality protein and energy supplements.

Most of the value addition from fish occurs after the farm gate and is captured by processors, traders, and retailers rather than producers; developing cold chain infrastructure enables access to fresh and frozen product markets where margins are higher; modern processing facilities enable production of branded value-added products commanding premium prices; improving processing infrastructure and cold chain reduces post-harvest losses and increases the economic return from each kilogram of fish produced.

Part 5.4: Food Safety, Standards, and Sustainability

Any three: Salmonella spp.; Listeria monocytogenes; Staphylococcus aureus; Vibrio parahaemolyticus; Clostridium botulinum.

HACCP is a systematic preventive food safety management approach; it involves seven principles: conducting a hazard analysis; identifying critical control points (CCPs); establishing critical limits at each CCP; implementing monitoring procedures; specifying corrective actions; verifying the system is working; and maintaining records; it is important in fish processing because fish is highly perishable and a common vehicle for serious foodborne pathogens that cause illness and death if not controlled.

NAFDAC sets and enforces food safety and labelling standards for packaged fish products sold in the domestic Nigerian market, including maximum limits for contaminants, additives, and residues. SON maintains Nigerian Industrial Standards (NIS) for fish products including dried, smoked, and canned fish, specifying quality parameters such as moisture content, protein content, and microbiological limits.

Most fishmeal is produced from small pelagic fish (anchovies, herrings, sardines) caught from wild fisheries that are at or near their maximum sustainable yield; using large quantities of wild fish to produce feed for farmed fish means that for every kilogram of wild fish used, only a fraction of a kilogram of farmed fish is produced, raising the question of whether aquaculture is a net consumer or producer of fish protein; over-reliance on fishmeal also exposes aquaculture to price volatility and supply disruption from wild fishery fluctuations.

Any two: adoption of improved kiln designs such as FTT-Thiaroye, which reduces fuelwood consumption by 30 to 50 per cent and reduces emissions of carcinogenic PAHs; zero-waste processing that converts fish offal, bones, skin, and blood water into fishmeal, oil, gelatine, fertiliser, or biogas; replacing fishmeal with sustainable alternatives (insect meal, algal meal, single-cell protein) in aquaculture feed formulations.

References and Attributions [Series 5]

Textual References (Books and External Sources)

Lovell, R. T. (1998). Nutrition and feeding of fish. Springer Science and Business Media.

Hardy, R. W., & Gatlin, D. M. (2002). Nutritional strategies to reduce phosphorus excretion by trout. In K. Fitzsimmons & J. Filho (Eds.), Tilapia aquaculture in the 21st century. American Tilapia Association.

Connell, J. J. (1995). Control of fish quality (4th ed.). Blackwell Science.

FAO (Food and Agriculture Organization of the United Nations). (2020). The state of world fisheries and aquaculture. FAO.

Pillay, T. V. R., & Kutty, M. N. (2005). Aquaculture: Principles and practices (2nd ed.). Blackwell Publishing.

FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable aquaculture. FAO.

Figures, Plates, Tables, and Boxes

Figure 5.1: Fish feed mill operations flowchart Attribution: AI generated using prompt "Generate a flowchart showing the sequence of operations in a fish feed mill from raw material intake through grinding, mixing, pelleting or extrusion, drying, cooling, and bagging." Suggested OER search string: "fish feed mill operations flowchart OER diagram".

Plate 5.1: Ring-die pellet mill in a fish feed factory Attribution: AI generated using prompt "Generate an image of a ring-die pellet mill in a commercial fish feed factory showing the cylindrical die, rollers, and pellet output." Suggested OER search string: "ring-die pellet mill commercial fish feed factory OER image".

Figure 5.2: Fish feed extruder components and process flow Attribution: AI generated using prompt "Generate a diagram showing the components and process flow of a fish feed extruder including raw material inlet, screw barrel, heating zone, die, knife cutter, dryer, and cooler." Suggested OER search string: "fish feed extruder components process flow diagram OER".

Table 5.1: Physical and chemical quality parameters of fish feed Attribution: AI generated using prompt "Generate a table listing the key physical and chemical quality parameters of fish feed pellets and the methods used to measure each." Suggested OER search string: "fish feed quality parameters measurement methods table OER".

Figure 5.3: Fish feed manufacture quality control checkpoints flowchart Attribution: AI generated using prompt "Generate a flowchart showing the quality control checkpoints at each stage of fish feed manufacture from raw material intake to finished feed release." Suggested OER search string: "fish feed manufacture quality control checkpoints flowchart OER".

Box 5.1: Best practices for fish feed storage Attribution: AI generated using prompt "Generate a text box listing best practices for fish feed storage including temperature control, humidity management, ventilation, and antioxidant use." Suggested OER search string: "fish feed storage best practices shelf life OER".

Plate 5.2: Traditional fish smoking kiln in Nigeria Attribution: AI generated using prompt "Generate an image of a traditional fish smoking kiln in Nigeria with catfish on wire racks above smouldering wood fuel." Suggested OER search string: "traditional fish smoking kiln Nigeria catfish OER image".

Figure 5.4: Fish value chain from harvest to consumer Attribution: AI generated using prompt "Generate a diagram showing the fish value chain from harvest through traditional and modern processing to value-added products and final markets." Suggested OER search string: "fish value chain processing value addition consumer market OER diagram".

Figure 5.5: Catfish price at different value chain stages Attribution: AI generated using prompt "Generate a bar chart showing the increasing price per kilogram of catfish at different points in the value chain: live farm-gate, fresh market, smoked, and branded packaged retail." Suggested OER search string: "catfish value chain price premium farm gate smoked retail OER chart".

Figure 5.6: HACCP seven principles applied to fish processing Attribution: AI generated using prompt "Generate a diagram illustrating the seven HACCP principles applied to a fish processing operation." Suggested OER search string: "HACCP seven principles fish processing food safety OER diagram".

Box 5.2: Regulatory bodies and standards for fish products in Nigeria Attribution: AI generated using prompt "Generate a text box listing the key regulatory bodies and standards frameworks governing fish products in Nigeria and internationally." Suggested OER search string: "fish products regulatory bodies standards NAFDAC SON NAQS Codex OER".

Figure 5.7: Fish food technology sustainability chain diagram Attribution: AI generated using prompt "Generate a diagram showing the fish food technology chain with environmental impacts and sustainability interventions at each stage." Suggested OER search string: "fish food technology sustainability environmental impact interventions OER diagram".